Critically Evaluated Energy Levels and Spectral Lines of Singly Ionized Indium (In II)

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A comprehensive list of the best measured wavelengths in the In II spectrum has been compiled. Uncertainties of the wavelength measurements have been analyzed, and existing inconsistencies have been resolved. An optimized set of fine-structure energy levels that fits all observed wavelengths has been derived. Uncertainties of the energy level values have been reduced by an order of magnitude. An improved value of the ionization limit of In II has been determined by fitting quantum-defect and polarization formulas for several series of levels. Intensities of lines observed by different authors have been analyzed and converted to a uniform scale. A set of recommended values of radiative transition rates has been critically compiled, and uncertainties of these rates have been estimated. The hyperfine structure interval in the 5s 1S ground state of In III has been determined from the measurements of the 5s5p and 5s5h series in In II.

Key words: atomic energy levels; hyperfine structure; ionization potentials; singly ionized indium; spectral lines; transition probabilities.

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1. Introduction

Singly ionized indium, isoelectronic with Cd I, has a ground state [Kr]4d105s21S0. Its photon emission spectrum has been investigated by a number of researchers since the beginning of the 20th century (see the current bibliography on this spectrum in the Atomic Energy Levels and Spectra Bibliographic Database [1] of the National Institute of Standards and Technology (NIST)). The most important of the early contributions is the work of Paschen and Campbell [2]. They presented a list of about 500 spectral lines of In II, 325 of which had partially resolved and analyzed hyperfine structure (hfs) patterns. From those observed spectral lines they derived a list of 180 fine-structure energy levels and derived the first ionization limit at 152195 cm⁻¹. Paschen and Campbell observed the spectrum from 2078 Å to 9246 Å, but adopted a value of 43349 cm⁻¹ for the 5s21S0 – 5s5p 3P°1 separation, as determined earlier by Lang and Sawyer [3] whose observations covered a wider range from 680 Å to 7277 Å. The energy levels given in the Atomic Energy Levels compilation (AEL) by Moore [4] were quoted from Paschen and Campbell [1]. The spectrum from 680 Å to 5122 Å was re-observed in 1969 by Bhatia [5] who identified many transitions previously unknown. Sansonetti and Martin [6] re-analyzed the fine-structure data of Paschen and Campbell together with Bhatia’s observations and found that the positions of all excited levels above and including the 5s6s 3S1 level, as well as the ionization limit, have to be shifted upwards by 4.37(30) cm⁻¹ from the values given by Paschen and Campbell.

Interest in the In II spectrum greatly increased in the early 1980s, when it was realized that the strongly forbidden 5s21S0 – 5s5p 3P°0 transition can be exploited in single-ion traps to construct a high-precision atomic clock [7]. This transition, strictly forbidden in unperturbed atomic spectra, is induced by the
hyperfine interaction. With the clock application in mind, Larkins and Hannaford [8] have measured the absolute frequencies of hyperfine components of several transitions in $^{115}$In, from which they derived the corresponding energy levels and $\text{f}$-structure constants. In particular, the wave number of the above-mentioned clock transition was found to be $42275.986(7) \text{ cm}^{-1}$. This result was confirmed two years later by Peik et al. [9]. In 2001, von Zanthier et al. [10] refined this wave number by many orders of magnitude. Their result, $42275.99525348(8) \text{ cm}^{-1}$, agrees with both previous measurements.

In the same year 2001, Karlsson and Litzén [11] accurately measured wavelengths of 53 In II lines using a Fourier transform spectrometer. From these measurements, they derived values for 38 energy levels of In II, much improved compared to Moore’s AEL [4]. For the $5\text{s}5\text{p}^2 \, ^3\text{P}_0$ level, Karlsson and Litzén obtained $42275.997 \text{ cm}^{-1}$. They did not specify the uncertainty of this value, but mentioned that all their energy level values have uncertainties ranging from $\pm0.001 \text{ cm}^{-1}$ to $\pm0.020 \text{ cm}^{-1}$. Their result for the forbidden $5\text{s} \, ^1\text{S}_0 - 5\text{s}5\text{p} \, ^3\text{P}_0$ transition is in good agreement with all previously mentioned data. The agreement is not so good for other transitions. In particular, for the four other transitions measured by Larkins and Hannaford [8], the wave numbers measured by Karlsson and Litzén disagree by amounts far exceeding the combined measurement uncertainties. For the energy levels above 90000 $\text{ cm}^{-1}$, Karlsson and Litzén arrived at conclusions similar to those of Sansonetti and Martin [6]. Namely, they concluded that all these levels and the ionization limit determined by Paschen and Campbell [2] should be shifted upwards by $5.16 \text{ cm}^{-1}$. This shift value is greater than that determined by Sansonetti and Martin by $0.79 \text{ cm}^{-1}$. Since the lines observed by Karlsson and Litzén represent a small subset of all lines observed by Paschen and Campbell and by Bhatia, this indicates that the level shifts are not the same for all levels. The individual level shifts should be determined by re-analyzing all observed data accounting for measurement uncertainties. It was noted by Smirnov [12] that, by combining the highly accurate levels values from Karlsson and Litzén [11] with wavenumbers measured by Paschen and Campbell [2], it is possible to determine many of the levels not included in [11] with uncertainties as small as $\pm0.01 \text{ cm}^{-1}$.

Karlsson and Litzén [11] pointed out that the levels $5\text{s}5\text{d} \, ^1\text{D}_2$ and $5\text{p}^2 \, ^1\text{D}_2$ are strongly mixed, and their designations as given in Moore’s AEL [4] should be reversed. This revision was not reflected in Sansonetti and Martin [6].

Another problem not addressed previously is related to relative intensities of observed lines. In the selection of In II lines included in the NIST publications [13,14], the line intensities were determined by summing up the intensities of the hyperfine components, as given by Paschen and Campbell [2]. However, the latter authors used several different spectrographs, some with prisms and some with gratings, and, in the case of gratings, observed lines in different orders of diffraction. Intensities of lines registered by different methods were actually on different scales. According to my analysis, the sensitivity of different registration methods used by Paschen and Campbell varies greatly (often by orders of magnitude), and the corresponding intensity scales have different wavelength dependences. In addition to that, other observers (e.g., Lang and Sawyer [3], Bhatia [5], Karlsson and Litzén [11], and Wagatsuma [15]) report vastly different relative intensities, which are due to the different light sources and spectral registration equipment used. In order to make a comprehensive list of observed lines, the various intensity scales have to be analyzed, and the differences have to be removed to place all intensities on a uniform scale.

One problem with interpreting the In II spectrum is due to wide $\text{f}$-structure patterns in most lines observed in the visible range. Indium has two naturally occurring isotopes, $^{114}$In and $^{115}$In, with abundances of 4.3 % and 95.7 %, respectively [6]. Both isotopes have the same nuclear spin of 9/2 and similar values of the nuclear magnetic moment, $+5.5289 \mu_N$ and $+5.5408 \mu_N$ [16]. Thus, the hyperfine structures are very similar for both isotopes. The lines from the rare isotope $^{115}$In are very hard to observe with samples of natural indium due to their low intensity. In this paper, most of the discussion refers to $^{115}$In. The hyperfine structure and isotope shifts will be addressed only insofar as they concern the accuracy of the derived center-of-gravity values of energy levels and observed wave numbers of fine-structure transitions.

The aims of the present study are: 1) analyze the measurement uncertainties of different studies, explain and remove inconsistencies, and build a comprehensive list of the best measured wavelengths; 2) from this line list, determine the optimized set of energy levels that fit all observed wavelengths; 3) determine an improved value of the ionization limit; 4) analyze line intensities observed by different authors and convert them to a uniform scale; 5) compile a list of recommended values of radiative transition rates. These objectives are addressed in the following sections.
2. Evaluation of Measured Wavelengths

The total list of observed lines compiled in Table 1 includes 680 lines selected from Karlsson and Litzén [11], Larkins and Hannaford [8], von Zanthier et al. [10], Paschen and Campbell [2], Bhatia [5], Lang and Sawyer [3], and Wagatsuma [15]. The first four of these sources provide data that are sufficiently accurate to determine all energy levels involved in other observations. Measurements of Bhatia [5], Lang and Sawyer [3], and Wagatsuma [15] were not included in the level optimization procedure because they were found to possess significant systematic and statistical errors and do not improve the level values.

In Table 1, the wavelengths below 2000 Å are given in vacuum, and above that in standard air. Conversion from vacuum to air and vice versa was made using the five-parameter formula from Peck and Readerr [28]. The uncertainties in the units of the least significant digit of the value are given in parentheses after the value. These uncertainties do not account for the uncertainties of the vacuum-air conversion formula. All uncertainties are meant to be on the level of one standard deviation. Where the systematic uncertainties are significant, they are given in addition to the statistical ones.

A detailed analysis of all observations follows.

2.1 Measurements of Karlsson and Litzén [11]

Karlsson and Litzén [11] recorded spectra of indium in the region (12500–55500) cm⁻¹ (i.e., from 8000 Å to 1800 Å) using a vacuum ultraviolet (VUV) Fourier transform spectrometer. The light source was a hollow cathode discharge with the carrier gas consisting of neon at 170 Pa (1.3 Torr) or an argon–neon 1:1 mixture at 160 Pa (1.2 Torr). Small pieces of metallic indium were placed inside the water-cooled iron cathode.

The wavenumber scale was calibrated by means of Ar II lines [17] in the ultraviolet (UV) region, whereas Ne I and Ne II lines were used at longer wavelengths. The neon lines had been measured with high accuracy relative to Fe I and Fe II lines [18,19] during previous experiments using an iron cathode and neon as the carrier gas. Since the above-mentioned Fe I–II measurements were calibrated against Ar II wave numbers of Norlén [17], all In II wave numbers measured by Karlsson and Litzén [11] can be ultimately traced to the Ar II reference data of Norlén. It was recently found by Nave and Sansonetti [20] that the wavenumber scale used by Norlén has a calibration error, and all wave numbers from his paper have to be increased by 6.7 parts in 10⁸. I applied this correction factor to all In II wave numbers reported in Ref. [11].

To analyze the measurement uncertainties, one has to take into account the hfs of the observed lines, as well as statistical and systematic uncertainties. Karlsson and Litzén noted that most In II lines exhibit wide hfs extending over several reciprocal centimeters. One line at 2941.0375 Å corresponding to the 5s5p⁠ ¹P₀ → 5s6s⁠ ¹S₀ transition was observed as a symmetric feature with no discernible hfs. This line was denoted as a category ‘a’ in Table 1 of Ref. [11] and was fitted with a Voigt profile. Some of the lines have well-resolved hfs with up to 16 distinct components. For these lines, denoted as a category ‘c’ in [11], Karlsson and Litzén modeled the hfs with an account for the linear and quadratic magnetic hfs and determined the center-of-gravity wave number from this fitting procedure. For lines where the hfs was noticeable but the fitting procedure did not give an unambiguous result due to a lack of resolution or a too low signal-to-noise ratio (S/N), the center of gravity of the observed hfs pattern was derived by fitting the observed feature using an empirical procedure. These lines were denoted as a category ‘b’ in Ref. [11].

In the presence of such a large hfs splitting, the positions of centers of gravity of observed features do not necessarily coincide with the differences between centers of gravity of the hfs components of the upper and lower levels, because they depend on the distribution of intensities within the hfs multiplets. This is true even if the population of the hfs sublevels follows the Boltzmann distribution (see the discussion of this effect in relation to the fine structure in the hydrogen spectrum [21]). In such a case, the energy levels derived from the centers of gravity of observed features are only approximate and depend on the observational conditions, which may distort the distribution of intensities and thus shift the centers of gravities of the features. Such approximate energy levels were called distinctive energy levels in [21]. In the case of the In II spectrum, where the hfs is not completely resolved in most lines, only such distinctive energy levels can be determined. They have an intrinsic uncertainty, which is a sizable fraction of the total uncertainty, which is a sizable fraction of the total.
Table 1. Observed and predicted spectral lines of In II

| $\lambda_{\text{obs}}$ (Å) | $\sigma_{\text{obs}}$ (cm$^{-1}$) | $\lambda_{\text{Ref.}}$ (Å) | $\Delta\lambda_{\text{obs-Ref.}}$ (Å) | $I_{\text{obs}}$ (arb.u.) | $A$ (s$^{-1}$) | Type | Transition | Notes | Line Ref. | TP Ref. |
|-------------------------|--------------------------|-------------------------|---------------------------------|----------------------|-----------------|-------|------------------------|------|-----------|---------|
| 680.28(3)(1) | 146998 | 680.20(5) | 0.08 | 170 | 5s$^2$ | $^1S_0$ | 5s12p | $^1P_1$ | B69 |
| 686.54(3)(1) | 145658 | 686.4185(7) | 0.12 | 170 | 5s$^2$ | $^1S_0$ | 5s11p | $^1P_1$ | B69 |
| 695.83(11)(24) | 143710 | 695.5888(4) | 0.24 | 180 | 6e+5 | E | 5s$^2$ | $^1S_0$ | 5s10p | $^1P_1$ | 1 | L31 | TW |
| 695.86(3)(0) | 143707 | 695.8266(4) | 0.00 | 70 | 1.0e+5 | E | 5s$^2$ | $^1S_0$ | 5s10p | $^3P_1$ | 1 | B69 | TW |
| 710.09(11)(24) | 140830 | 710.00036(18) | 0.09 | 95 | 1.5e+6 | E | 5s$^2$ | $^1S_0$ | 5s9p | $^3P_1$ | 1 | L31 | TW |
| 710.55(3)(0) | 140736 | 710.55737(21) | -0.01 | 47 | 3.1e+5 | E | 5s$^2$ | $^1S_0$ | 5s9p | $^3P_1$ | 1 | B69 | TW |
| 734.78(3)(0) | 136095 | 734.7704(5) | 0.01 | 230 | 3.6e+7 | E | 5s$^2$ | $^1S_0$ | 5s8p | $^1P_1$ | B69 | B99 |
| 736.04(3)(0) | 135862 | 736.0430(3) | 0.00 | 210 | 8e+5 | E | 5s$^2$ | $^1S_0$ | 5s8p | $^3P_1$ | 1 | B69 | TW |
| 783.98(3)(0) | 127554 | 783.86296(6) | 0.12 | 440 | | | | | | |
| 787.45(3)(0) | 126992 | 787.43326(7) | 0.02 | 1100 | 1.7e+6 | E | 5s$^2$ | $^1S_0$ | 5s7p | $^3P_1$ | 1 | B69 | TW |
| 910.90(3)(1) | 109782 | 910.91090(7) | -0.01 | 2700 | 7e+6 | E | 5s$^2$ | $^1S_0$ | 5s6p | $^1P_1$ | B69 | B99 |
| 927.27(3)(1) | 107843 | 927.28257(5) | -0.01 | 2500 | 4.9e+6 | D+ | 5s$^2$ | $^1S_0$ | 5s6p | $^3P_1$ | B69 | TW |
| 933.7684(19) | | | | | 1.5e+6 | D+ | 5s5p | $^3P_0$ | 5s19s | $^3S_1$ | TW |
| 935.9123(19) | | | | | 1.9e+6 | D+ | 5s5p | $^3P_0$ | 5s18s | $^3S_1$ | TW |
| 936.5492(6) | | | | | 1.5e+6 | D+ | 5s5p | $^3P_0$ | 5s15s | $^3S_1$ | TW |
| 937.87(3)(1) | 106625 | 937.9023(23) | -0.03 | 610* | 5s5p | $^3P_1$ | 5s16d | $^3D_2$ | B69 |
| 937.87(3)(1) | 106625 | 937.9269(21) | -0.06 | 610* | 5s5p | $^3P_1$ | 5s16d | $^3D_1$ | B69 |
| 938.5571(14) | | | | | 2.5e+6 | D+ | 5s5p | $^3P_0$ | 5s17s | $^3S_1$ | TW |
| 940.60(3)(1) | 106315 | 940.6123(18) | -0.01 | 970 | | | | | | |
| 941.87(3)(1) | 106172 | 941.8556(15) | 0.01 | 760* | 3.2e+6 | D+ | 5s5p | $^3P_1$ | 5s16s | $^3S_1$ | B69 | TW |
| 941.87(3)(1) | 106172 | 941.9310(6) | -0.06 | 760* | 2.0e+6 | D+ | 5s5p | $^3P_0$ | 5s14s | $^3S_1$ | B69 | TW |
| 944.81(3)(1) | 105841 | 944.7713(20) | 0.04 | 1200 | | | | | | |
| 946.0705(6) | | | | | 4.2e+6 | D+ | 5s5p | $^3P_1$ | 5s14d | $^3D_2$ | B69 |
| 947.41(3)(1) | 105551 | 947.3507(7) | 0.06 | 390 | | | | | | |
| 949.17(3)(1) | 105355 | 949.1393(5) | 0.03 | 910 | 2.9e+6 | D+ | 5s5p | $^3P_0$ | 5s13s | $^3S_1$ | TW |
| 950.19(3)(1) | 105242 | 950.1936(16) | 0.00 | 660 | | | | | | |
| 950.32(3)(1) | 105228 | 950.2168(18) | 0.10 | 670 | | | | | | |
| 951.27(3)(1) | 105123 | 951.2487(20) | 0.02 | 1200 | | | | | | |

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| $\lambda_{\text{obs}}$ \(^a\) (Å) | $\sigma_{\text{obs}}$ \(^b\) (cm\(^{-1}\)) | $\lambda_{\text{Ritz}}$ \(^c\) (Å) | $\Delta \lambda_{\text{obs-Ritz}}$ \(^c\) (Å) | $I_{\text{obs}}$ \(^d\) (arb.u.) | $A$ \(^e\) (s\(^{-1}\)) | Type \(^f\) | Transition | Notes \(^g\) | Line Ref. \(^h\) | TP Ref. \(^i\) |
|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 951.59(3)(1) | 105087          | 951.5626(6)     | 0.03            | 480            | 5.8e+6          | D+              | 5s5p \(3^p\) \(3s\) \(1^s\)   | B69             | TW              |
| 956.62(3)(1) | 104535          | 956.5864(13)    | 0.03            | 750*           | 2.4e+6          | D+              | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             | TW              |
| 956.62(3)(1) | 104535          | 956.6036(7)     | 0.02            | 750*           | 2.4e+6          | D+              | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             | TW              |
| 957.28(11)(16) | 104463 | 957.0687(15)    | 0.21            | 780*           |                |                 | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | L31             |
| 957.28(11)(16) | 104463 | 957.0941(7)     | 0.19            | 780*           |                |                 | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | L31             |
| 957.55(3)(1) | 104433          | 957.5845(18)    | -0.03           | 580*           |                |                 | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 957.55(3)(1) | 104433          | 957.591(4)      | -0.04           | 580*           |                |                 | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 957.55(3)(1) | 104433          | 957.591(4)      | -0.04           | 580*           |                |                 | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 959.06(11)(15) | 104269 | 958.9196(6)     | 0.14            | 790            | 9e+6           | D+              | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | L31             |
| 959.06(11)(15) | 104269 | 959.1299(3)     | 0.14            | 790            | 9e+6           | D+              | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | L31             |
| 960.30(3)(1) | 104134          | 960.2178(18)    | 0.08            | 780*           |                |                 | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 960.30(3)(1) | 104134          | 960.2251(24)    | 0.07            | 780*           |                |                 | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 960.30(3)(1) | 104134          | 960.2509(22)    | 0.05            | 780*           |                |                 | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 960.98(3)(1) | 104060          | 960.9115(14)    | 0.07            | 310            | 3.9e+6         | D+              | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 964.33(3)(1) | 103699          | 964.3693(16)    | -0.04           | 1100           | 5.0e+6         | D+              | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 966.64(3)(1) | 103451          | 966.5136(8)     | 0.13            | 1700*          |                |                 | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 966.64(3)(1) | 103451          | 966.5392(7)     | 0.10            | 1700*          |                |                 | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 966.64(3)(1) | 103451          | 968.7886(7)     | 0.10            | 1700*          |                |                 | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 969.07(3)(1) | 103192          | 969.1183(3)     | -0.05           | 1100           | 1.4e+7         | D+              | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 969.93(3)(1) | 103100          | 969.8663(3)     | 0.06            | 1600           | 4.6e+7         | D+              | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 972.93(3)(1) | 102782          | 973.0797(19)    | -0.15           | 850*           |                |                 | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 972.93(3)(1) | 102782          | 973.1126(17)    | -0.18           | 850*           |                |                 | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 973.48(6)(1) | 102724          | 973.5772(3)     | -0.10           | 14000n        | 1.6e+7         | D+              | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 974.54(3)(1) | 102613          | 974.5485(7)     | -0.01           | 390            | 9e+6           | D+              | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 978.99(3)(1) | 102146          | 978.9623(6)     | 0.03            | 810            |                |                 | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 980.21(3)(1) | 102019          | 980.0355(5)     | 0.17            | 2800*          | 6e+7           | D+              | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| 980.21(3)(1) | 102019          | 980.0808(3)     | 0.13            | 2800*          | 3.3e+7         | D+              | 5s5p \(3^p\) \(3s\) \(1^s\) \(1^D\) | B69             |
| \(^{2}\lambda_{\text{obs}} \text{ (Å)}| \quad | \sigma_{\text{obs}} \text{ (cm}^{-1})| \quad | \lambda_{\text{Ritz}} \text{ (Å)}| \quad | \Delta \lambda_{\text{obs-Ritz}} \text{ (Å)}| \quad | L_{\text{obs}} \text{ (arb.u.)}| \quad | A \text{ (s}^{-1})| \quad | \text{Transition}| \quad | \text{Notes}| \quad | \text{Line Ref.}| \quad | \text{TP Ref.}| |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 980.21(3)(1) | 102019 | 980.2863(18) | -0.08 | 7200* | 5s5p | \(^{3}\)P\(^{+}\)\(^{2}\) S\(1/2\) | TW | 669 | |
| 980.43(3)(1) | 101996 | 980.3246(16) | 0.11 | 1900 | 5s5p | \(^{3}\)P\(^{+}\)\(^{2}\) S\(1/2\) | B69 | |
| 982.31(3)(1) | 101801 | 982.2666(6) | 0.04 | 800 | 1.3e+7 | D+ | B69 | |
| 983.05(3)(1) | 101724 | 982.9394(4) | 0.11 | 700 | 8e+5 | E | B69 | |
| 984.05(3)(1) | 101621 | 983.8703(3) | 0.18 | 1200 | 4.5e+7 | D+ | B69 | |
| 990.19(3)(1) | 100991 | 989.87874(24) | 0.31 | 2900* | 2.0e+7 | C | B69 | |
| 990.19(3)(1) | 100991 | 990.1839(13) | 0.01 | 2900* | 5s5p | \(^{3}\)P\(^{+}\)\(^{2}\) S\(1/2\) | B69 | |
| 992.97(3)(1) | 100708 | 992.9707(3) | 0.00 | 770 | 2.2e+7 | D+ | B69 | |
| 1000.45(3)(1) | 99955 | 1000.4539(3) | 0.00 | 2700 | 2.8e+7 | C | B69 | |
| 1000.54(3)(1) | 99946 | 1000.52139(25) | 0.02 | 2700 | 1.3e+7 | C | B69 | |
| 1004.35(3)(1) | 99567 | 1004.3621(4) | -0.01 | 2000* | 8e+7 | D+ | B69 | |
| 1004.35(3)(1) | 99567 | 1004.4351(5) | -0.09 | 2000* | 1.9e+7 | D+ | B69 | |
| 1004.95(3)(1) | 99507 | 1004.9617(3) | -0.01 | 860 | 5s5p | \(^{3}\)P\(^{+}\)\(^{2}\) S\(1/2\) | B69 | |
| 1006.48(3)(1) | 99356 | 1006.46409(21) | 0.02 | 1200 | 1.3e+7 | C | B69 | |
| 1008.41(3)(1) | 99166 | 1008.4637(3) | -0.05 | 1200 | 7e+7 | D+ | B69 | |
| 1022.44(3)(1) | 97805 | 1022.4297(3) | 0.01 | 2300 | 3.4e+7 | C | B69 | |
| 1032.21(3)(1) | 96880 | 1032.21472(22) | 0.00 | 2100* | 2.1e+7 | C | B69 | |
| 1032.21(3)(1) | 96880 | 1032.40663(23) | -0.20 | 2100* | 6.3e+6 | C | B69 | |
| 1033.69(3)(1) | 96741 | 1033.6766(3) | 0.01 | 3100 | 4.5e+7 | C | B69 | |
| 1043.89(3)(1) | 95796 | 1043.98874(23) | -0.10 | 3300 | 1.8e+7 | C | B69 | |
| 1060.68(3)(1) | 94279 | 1060.6727(6) | 0.01 | 3700 | 5.5e+7 | C | B69 | |
| 1060.92(3)(1) | 94258 | 1060.8573(3) | 0.06 | 1700 | 1.2e+7 | C | B69 | |
| 1062.75(3)(1) | 94096 | 1062.7839(8) | -0.03 | 990i | 5s5p | \(^{3}\)P\(^{+}\)\(^{2}\) S\(1/2,3/2,5/2\) | B69 | |
| 1071.93(11)(13) | 93290 | 1071.72178(24) | 0.21 | 3100 | 2.9e+7 | C | B69 | |

\(^{2}\lambda_{\text{obs}}, \sigma_{\text{obs}}, \lambda_{\text{Ritz}}, \Delta \lambda_{\text{obs-Ritz}}, L_{\text{obs}}\) are observed wavelengths, standard deviations, Ritz wavelengths, wavelength shifts, and observed intensities, respectively. \(A\) is the transition probability. Notes include details about the transition, such as spin-orbit coupling and parity restrictions. Line Ref. and TP Ref. are references for detailed line properties and transition probabilities.
| \( \lambda_{\text{obs}} \) (Å) | \( \sigma_{\text{obs}} \) (cm\(^{-1}\)) | \( \lambda_{\text{Ritz}} \) (Å) | \( \Delta \lambda_{\text{obs-Ritz}} \) (Å) | \( I_{\text{obs}} \) (arb.u.) | \( A \) (s\(^{-1}\)) | Type | Transition | Notes | Line Ref. | TP Ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1081.66(11)(13) | 92450 | 1081.66000(12) | 0.00 | 5000 | 4.6e+7 | C | 5s5p | \( ^3P^0 \) 5s7d | \( ^3D_1 \) | L31 | J07 |
| 1094.18(3)(1) | 91393 | 1094.17047(11) | 0.01 | 6200 | 6.0e+7 | C | 5s5p | \( ^3P^1 \) 5s7d | \( ^3D_2 \) | B69 | J07 |
| 1094.38(3)(1) | 91376 | 1094.38039(12) | 0.00 | 2500 | 3.3e+7 | C | 5s5p | \( ^3P^0 \) 5s7d | \( ^3S_1 \) | B69 | J07 |
| 1101.38(3)(1) | 90795.2 | 1101.36385(9) | 0.02 | 2200 | 1.3e+7 | C | 5s5p | \( ^3P^0 \) 5s8s | \( ^3P^1 \) 5s7d | \( ^3D_1 \) | B69 | J07 |
| 1114.55(11)(12) | 89722 | 1114.55472(9) | 0.00 | 1900 | 3.8e+7 | C | 5s5p | \( ^1P^1 \) 5s8s | \( ^3S_1 \) | L31 | J07 |
| 1116.42(3)(1) | 89572.0 | 1116.43191(11) | -0.01 | 2600 | 1.5e+5 | D+ | 5s5p | \( ^3P^2 \) 5s7d | \( ^3D_2 \) | B69 | TW |
| 1124.39(11)(12) | 88937 | 1124.32011(10) | 0.07 | 4000 | 7.3e+7 | C | 5s5p | \( ^3P^2 \) 5s7d | \( ^3D_3 \) | L31 | J07 |
| 1124.70(11)(12) | 88913 | 1124.67263(10) | 0.03 | 2000 | 1.8e+7 | C | 5s5p | \( ^3P^2 \) 5s7d | \( ^3D_2 \) | L31 | J07 |
| 1146.14(11)(11) | 87249 | 1146.22042(8) | -0.08 | 1100 | 6.4e+7 | C | 5s5p | \( ^3P^2 \) 5s8s | \( ^3S_1 \) | L31 | J07 |
| 1161.06(3)(1) | 86128.2 | 1161.043(3) | 0.02 | 1200* | 1200* | 5s5p | \( ^3P^0 \) 5s14d | \( ^3D_2 \) | B69 |
| 1161.06(3)(1) | 86128.2 | 1161.0790(22) | -0.02 | 1200* | 1200* | 5s5p | \( ^3P^0 \) 5s14d | \( ^3D_1 \) | B69 |
| 1162.32(3)(1) | 86034.8 | 1162.267(4) | 0.05 | 1800 | 1200* | 1200* | 5s5p | \( ^3P^0 \) 5s14d | \( ^3D_1 \) | B69 |
| 1162.59(3)(1) | 86014.8 | 1162.6230(10) | -0.03 | 1300 | 1200* | 1200* | 5s5p | \( ^3P^0 \) 5s14d | \( ^3D_1 \) | B69 |
| 1179.24(3)(1) | 84800.4 | 1179.2767(23) | -0.04 | 1500 | 1200* | 1200* | 5s5p | \( ^3P^0 \) 5s14d | \( ^3D_1 \) | B69 |
| 1193.68(3)(1) | 83774.5 | 1193.6494(12) | 0.03 | 2100 | 2.0e+6 | C | 5s5p | \( ^3P^2 \) 5s7d | \( ^3D_1 \) | J07 |
| 1200.18680(11) | 82480 | 1200.18680(11) | 0.03 | 2100 | 2.3e+6 | D | 5s5p | \( ^3P^2 \) 5s6d | \( ^3D_2 \) | B69 |
| 1212.63(3)(1) | 82465.4 | 1212.61017(9) | 0.02 | 8100 | 1.3e+8 | C | 5s5p | \( ^3P^0 \) 5s6d | \( ^3D_1 \) | B69 |
| 1214.44(3)(1) | 82342.5 | 1214.3416(8) | 0.10 | 1900* | 1900* | 5s5p | \( ^3P^0 \) 5s10d | \( ^3D_2 \) | B69 |
| 1214.44(3)(1) | 82342.5 | 1214.4110(5) | 0.03 | 1900* | 1900* | 5s5p | \( ^3P^0 \) 5s10d | \( ^3D_1 \) | B69 |
| 1218.76(3)(1) | 82050.6 | 1218.8031(5) | -0.04 | 1600 | 1.5e+8 | D+ | 5s5p | \( ^3P^1 \) 5s11s | \( ^3S_0 \) | B69 |
| 1228.24(11)(10) | 81417 | 1228.10697(9) | 0.13 | 8300 | 1.7e+8 | C | 5s5p | \( ^3P^1 \) 5s6d | \( ^3D_2 \) | L31 |
| 1228.62(11)(10) | 81392 | 1228.61975(9) | 0.00 | 5500 | 9.4e+7 | C | 5s5p | \( ^3P^1 \) 5s6d | \( ^3D_1 \) | L31 |
| 1236.99(3)(1) | 80841.4 | 1236.98554(10) | 0.00 | 1700 | 5e+5 | E | 5s5p | \( ^3P^2 \) 5s6d | \( ^3D_2 \) | B69 |
| 1243.10(3)(1) | 80444.1 | 1243.0800(10) | 0.02 | 2600 | 1.3e+8 | D+ | 5s5p | \( ^3P^2 \) 5s6d | \( ^3D_2 \) | B69 |
| 1245.91(3)(1) | 80262.6 | 1245.9518(4) | -0.04 | 1400 | 8e+4 | D+ | 5s5p | \( ^3P^1 \) 5s6d | \( ^3D_1 \) | B69 |
| 1249.67(3)(1) | 80021.1 | 1249.6522(3) | 0.02 | 2800 | 5e+6 | E | 5s5p | \( ^3P^2 \) 5s7s | \( ^3S_0 \) | B69 |
| 1263.16(3)(1) | 79166.5 | 1263.15982(19) | 0.00 | 3700 | 3.0e+7 | C | 5s5p | \( ^3P^0 \) 5s7s | \( ^3S_1 \) | B69 |
| 1265.96(11)(10) | 78991 | 1265.80804(11) | 0.15 | 5600 | 2.1e+8 | C+ | 5s5p | \( ^3P^2 \) 5s6d | \( ^3D_3 \) | L31 | J07 |
| $\lambda_{\text{obs}}$ (Å) | $\sigma_{\text{obs}}$ (cm$^{-1}$) | $\lambda_{\text{Ritz}}$ (Å) | $\Delta \lambda_{\text{obs,Ritz}}$ (Å) | $I_{\text{obs}}$ (arb.u.) | $A$ (s$^{-1}$) | Type | Transition | Notes$^b$ | Line Ref.$^b$ | TP Ref.$^b$ |
|----------------|----------------|----------------|----------------|----------------|-------------|-------|------------|---------|------------|----------|
| 1266.67(3)(1) | 78947.2 | 1266.66524(7) | 0.00 | 4900 | 5.2e+7 | C | 5s5p | $^3P^o_2$ | 5s6d | $^3D_2$ | B69 | J07 |
| 1267.19(11)(9) | 78915 | 1267.21073(8) | -0.02 | 1400 | 5.8e+6 | C | 5s5p | $^3P^o_2$ | 5s6d | $^3D_1$ | L31 | J07 |
| 1280.49(11)(9) | 78095 | 1280.54157(20) | -0.05 | 28000 | 8.9e+7 | C | 5s5p | $^3P^o_1$ | 5s7s | $^3S_1$ | L31 | J07 |
| 1292.50(3)(1) | 77369.4 | 1292.4937(7) | 0.01 | 2000 | 1.7e+8 | D+ | 5s5p | $^1P^o_1$ | 5p$^2$ | $^1S_0$ | B69 | TW |
| 1297.78(3)(1) | 77054.7 | 1297.7896(5) | -0.01 | 1000 | 2.4e+7 | E | 5s5p | $^1P^o_1$ | 5s8d | $^1D_2$ | B69 | |
| 1309.82(3)(1) | 76346.4 | 1309.7791(5) | 0.04 | 2200 | 1.1e+5 | D+ | 5s5p | $^1P^o_1$ | 5s9s | $^1S_0$ | B69 | TW |
| 1314.12(3)(1) | 76096.6 | 1314.0862(4) | 0.03 | 3 | 1.5e+8 | C | 5s5p | $^3P^o_2$ | 5s7s | $^3S_1$ | B69 | J07 |
| 1322.51(3)(1) | 75613.8 | 1322.51892(20) | -0.01 | 4200 | 1.8e+8 | D | 5s5p | $^3P^o_1$ | 5s7d | $^3D_2$ | B69 | J07 |
| 1394.92(3)(0) | 71688.7 | 1394.93473(23) | -0.01 | 190 | 2.4e+5 | D+ | 5s5p | $^1P^o_1$ | 5s7d | $^1D_1$ | B69 | TW |
| 1407.53(3)(0) | 70534.3 | 1407.74920(22) | 0.00 | 410 | 3.6e+6 | E | 5s5p | $^3P^o_1$ | 5p$^2$ | $^3D_2$ | B69 | B99 |
| 1418.13(3)(0) | 70515.4 | 1418.1212(3) | 0.01 | 2000 | 1.2e+8 | D | 5s5p | $^3P^o_2$ | 5s8 | $^3S_0$ | B69 | J07 |
| 1469.49(11)(8) | 68051 | 1469.38544(22) | 0.10 | 2300 | 2.5e+7 | D+ | 5s5p | $^3P^o_2$ | 5p$^2$ | $^3D_2$ | L31 | J07 |
| 1571.53(3)(0) | 63632.3 | 1571.5264(23) | 0.00 | 260000 | 5.2e+8 | B | 5s5p | $^3P^o_1$ | 5s6d | $^3D_2$ | B69 | J07 |
| 1586.37(11)(7) | 63037 | 1586.33100(24) | 0.04 | 850000 | 1.2e+9 | B+ | 5s$^2$ | $^1S_0$ | 5s5p | $^3P^o_1$ | L31 | CMEF00 |
| 1607.32(3)(1) | 62215.4 | 1607.3371(3) | -0.02 | 260000 | 3.2e+8 | B | 5s5p | $^3P^o_1$ | 5p$^2$ | $^3P_2$ | B69 | J07 |
| 1619.80(3)(1) | 61736.0 | 1619.74357(23) | 0.06 | 17 | 2.7e+5 | E | 5s5p | $^3P^o_1$ | 5s6d | $^3D_2$ | B69 | TW |
| 1620.60(3)(1) | 61705.5 | 1620.63567(23) | -0.04 | 15 | 5.2e+5 | D+ | 5s5p | $^1P^o_1$ | 5s6d | $^3D_1$ | B69 | TW |
| 1640.05(3)(1) | 60973.8 | 1640.060(4) | -0.01 | 180000 | 3.7e+8 | C | 5s5p | $^3P^o_0$ | 5p$^2$ | $^3P_1$ | B69 | J07 |
| 1669.46(3)(1) | 59899.6 | 1669.482(4) | -0.02 | 110000 | 3.5e+8 | C | 5s5p | $^3P^o_1$ | 5p$^2$ | $^3P_1$ | B69 | J07 |
| 1671.87(3)(1) | 59183.3 | 1671.8850(11) | -0.02 | 120000 | 7.3e+8 | B | 5s5p | $^3P^o_0$ | 5s5d | $^3D_1$ | B69 | A86c |
| 1674.02(3)(1) | 59736.4 | 1674.0317(3) | -0.01 | 130000 | 9.5e+8 | B | 5s5p | $^3P^o_2$ | 5p$^2$ | $^3P_2$ | B69 | A86c, J07 |
| 1699.97(3)(1) | 58824.6 | 1699.9835(7) | -0.01 | 200000 | 8.6e+8 | B | 5s5p | $^1P^o_1$ | 5s5d | $^3D_2$ | B69 | A86c |
| 1702.45(3)(1) | 58738.9 | 1702.4714(12) | -0.02 | 120000 | 4.1e+8 | B | 5s5p | $^3P^o_1$ | 5s5d | $^3D_1$ | B69 | J07 |
| 1716.53(3)(1) | 58257.1 | 1716.5186(6) | 0.01 | 110000 | 1.1e+9 | C | 5s5p | $^3P^o_1$ | 5p$^2$ | $^3P_0$ | B69 | J07 |
| 1716.70(3)(1) | 58251.3 | 1716.7092(9) | -0.01 | 190000 | 1.0e+9 | C+ | 5s5p | $^1P^o_1$ | 5p$^2$ | $^1S_0$ | B69 | A86c |
| 1741.53(3)(1) | 57420.8 | 1741.5494(4) | -0.02 | 95000 | 4.9e+8 | B | 5s5p | $^3P^o_2$ | 5p$^2$ | $^3P_1$ | B69 | J07 |
| 1770.56(3)(1) | 56479.3 | 1770.5652(4) | -0.01 | 140000 | 1.0e+9 | A | 5s5p | $^3P^o_2$ | 5s5d | $^1D_3$ | B69 | A86 |
\begin{table}
\centering
\begin{tabular}{cccccccc}
\hline
$\lambda_{obs}^a$ (Å) & $\sigma_{obs}$ (cm$^{-1}$) & $\lambda_{Ritz}^b$ (Å) & $\Delta \lambda_{obs-Ritz}$ (Å) & $I_{obs}$ (arb. u.) & $A^c$ (s$^{-1}$) & Type$^d$ & Transition & Notes$^e$ & Line Ref.$^h$ & TP Ref.$^i$ \\
\hline
1774.75(3)(1) & 56346.0 & 1774.7667(8) & -0.02 & 58000 & 2.34e+8 & B & 5s5p $^3P^o_2$ & 5s5d $^3D_2$ & B69 & J07 \\
1777.46(3)(1) & 56260.1 & 1777.4787(13) & -0.02 & 27000 & 1.6e+7 & C & 5s5p $^3P^o_2$ & 5s5d $^3D_1$ & B69 & J07 \\
1842.36(3)(1) & 54278.2 & 1842.3720(3) & -0.01 & 26000 & 3.7e+6 & D & 5s5p $^3P^o_1$ & 5s5d & B69 & J07 \\
1862.89(3)(1) & 53680.0 & 1862.9040(4) & -0.01 & 4900 & 4.7e+6 & D & 5s5p $^3P^o_1$ & 5s6s & B69 & J07 \\
1930.5331(4) & 51799.164 & 1930.5325(3) & 0.0006 & 25000 & 1.1e+7 & D+ & 5s5p $^3P^o_1$ & 5s5d & B69 & J07 \\
1932.14(9)(1) & 51756.1 & 1932.0000(5) & 0.14 & 590 & 5s6s $^3S_1$ & 5s11p & $^3P^o_1$ & B69 \\
1936.1876(3) & 51647.888 & 1936.18758(18) & 0.0000 & 20000 & 9.6e+7 & C & 5s5p $^3P^o_0$ & 5s6s & $^3S_1$ & B69 & J07 \\
1953.34(9)(1) & 51194.4 & 1953.4345(5) & -0.09 & 300 & 5s6s $^3S_1$ & 5s8f & $^3P^o_2$ & B69 \\
1965.98(9)(1) & 50865.2 & 1966.0635(5) & -0.08 & 720 & 5s5d $^3D_2$ & 5s11f & $^3F^o_3$ & 2 & B69 \\
1966.7087(3) & 50846.372 & 1966.708624(24) & 0.0001 & 92000 & 1.27e+9 & B+ & 5s5p $^3P^o_1$ & 5p & $^3D_2$ & B69 & A86c \\
1977.3278(23) & 50573.302 & 1977.32789(19) & -0.00001 & 32000 & 2.7e+8 & B & 5s5p $^3P^o_1$ & 5s6s & $^3S_1$ & K01c & J07 \\
1997.03(9)(1) & 50074.4 & 1996.9685(8) & 0.06 & 240 & 1.5e+7 & D+ & 5s5d $^3D_2$ & 5s10f & $^3F^o_3$ & B69 & TW \\
1998.04(9)(1) & 50049.0 & 1997.9215(5) & 0.12 & 140 & 5s6s $^3S_1$ & 5s10p & $^3P^o_1$ & B69 \\
2008.12(9)(1) & 49781.7 & 2008.0823(3) & 0.04 & 140 & 5s5d $^3S_1$ & 5s10p & $^3F^o_3$ & B69 \\
2039.79(9)(1) & 49008.9 & 2039.7485(5) & 0.04 & 330 & 4.0e+7 & D+ & 5s5d $^3D_2$ & 5s9f & $^3F^o_3$ & B69 & TW \\
2040.81(9)(1) & 48984.4 & 2040.753216(16) & 0.06 & 210* & 5s5d $^3D_2$ & 5s9f & $^3F^o_3$ & B69 \\
2040.81(9)(1) & 48984.4 & 2040.8345(3) & -0.02 & 210* & 5s5d $^3D_2$ & 5s9f & $^3F^o_3$ & B69 \\
2054.76(9)(1) & 48651.9 & 2054.6926(4) & 0.07 & 210 & 5s6s $^3S_1$ & 5s11p & $^3P^o_1$ & B69 \\
2055.72(9)(1) & 48629.2 & 2055.8727(7) & -0.15 & 400 & 5s6s $^3S_0$ & 5s11p & $^3P^o_1$ & 2 & B69 \\
2078.5718(13) & 48094.629 & 2078.571813(3) & -0.00004 & 76000 & 4.2e+8 & B & 5s5p $^3P^o_2$ & 5s6s & $^3S_1$ & K01c & A86c, J07 \\
2080.30(9)(1) & 48054.7 & 2080.2746(3) & 0.03 & 330 & 5s5d $^3D_2$ & 5s11p & $^3P^o_1$ & B69 \\
2081.51(9)(1) & 48026.7 & 2081.4837(3) & 0.03 & 300 & 5s5d $^3D_2$ & 5s11p & $^3P^o_1$ & B69 \\
2103.89(18) & 47515.9 & 2103.8865(5) & 0.005 & 1700 & 1.0e+7 & E & 5s5d $^3D_2$ & 5s8f & $^3F^o_3$ & 1 & P38P & TW \\
2105.10(9)(1) & 47488.6 & 2105.0764(5) & 0.02 & 190* & 5s5d $^3D_2$ & 5s8f & $^3F^o_3$ & B69 \\
2105.10(9)(1) & 47488.6 & 2105.1566(6) & -0.06 & 190* & 5s5d $^3D_2$ & 5s8f & $^3F^o_3$ & B69 \\
2135.64(9)(1) & 46809.6 & 2135.589819(8) & 0.05 & 160 & 3.5e+5 & E & 5s6s $^3S_1$ & 5s9p & $^3P^o_1$ & 1 & B69 & TW \\
2139.15(18) & 46732.8 & 2139.1464(4) & 0.004 & 540 & 5s6s $^3S_0$ & 5s10p & $^3P^o_1$ & P38P & TW \\
2141.68(9)(1) & 46677.6 & 2141.7394(6) & -0.06 & 170 & 5s6s $^3S_0$ & 5s10p & $^3P^o_1$ & B69 \\
2166.876(9) & 46134.9 & 2166.8884(4) & -0.012 & 990 & 1.2e+7 & D+ & 5s5d $^3D_2$ & 5s10p & $^3P^o_1$ & P38P & TW \\
2169.548(19) & 46078.1 & 2169.5484(4) & 0.000 & 560 & 1.7e+6 & D+ & 5s5d $^3D_2$ & 5s10p & $^3P^o_1$ & P38P & TW \\
\hline
\end{tabular}
\end{table}
| \( \lambda_{\text{obs}} \) & \( \sigma_{\text{obs}} \) & \( \lambda_{\text{Ritz}} \) & \( \Delta \lambda_{\text{Ritz}} \) & \( I_{\text{obs}} \) & \( A \) & Transition & Notes & Line Ref. & TP Ref. |
|---|---|---|---|---|---|---|---|---|
| 2192.65(9)(0) & 45592.7 & 2192.591(7) & 0.06 & 70 & 3.8e+6 & D+ & 5s5d & \( ^1D_1 \) & 5s10f & \( ^3P_2 \) & B69 & TW |
| 2195.668(19) & 45530.0 & 2195.684(6) & -0.016 & 450 & 7e+5 & D+ & 5s5d & \( ^1D_2 \) & 5s10f & \( ^3F_2 \) & P38P & |
| 2196.734(7) & 2196.837(7) & 0.06 & 70 & 3.8e+6 & D+ & 5s5d & \( ^1D_2 \) & 5s10f & \( ^3F_3 \) & TW |
| 2197.27(9)(0) & 45496.8 & 2197.441(10) & -0.17 & 971 & 0.04 & 130 & 5s5d & \( ^1D_3 \) & 5s10f & \( ^3F_2 \) & B69 |
| 2202.19(9)(0) & 45395.2 & 2202.152(6) & 0.04 & 74 & 4.4e+6 & D+ & 5s5d & \( ^1D_3 \) & 5s10f & \( ^3F_3 \) & B69 |
| 2202.67(9)(0) & 45385.3 & 2202.756(7) & -0.09 & 80 & 4.9e+5 & D+ & 5s5d & \( ^1D_3 \) & 5s10f & \( ^3F_3 \) & B69 |
| 2203.27(9)(0) & 45372.9 & 2003.311(7) & -0.04 & 80 & 4.9e+5 & D+ & 5s5d & \( ^1D_3 \) & 5s10f & \( ^3F_3 \) & B69 |
| 2205.279(19) & 45331.6 & 2205.292(4) & -0.013 & 1000 & 1.8e+7 & D+ & 5s5d & \( ^1D_2 \) & 5s7f & \( ^1F_3 \) & P38P & |
| 2206.720(19) & 45302.0 & 2206.7303(23) & -0.010 & 440 & 0.04 & 130 & 5s5d & \( ^1D_2 \) & 5s7f & \( ^1F_3 \) & P38P & |
| 2245.31(9)(0) & 44523.5 & 2245.208(3) & 0.10 & 170 & 8e+6 & D+ & 5s5d & \( ^1D_1 \) & 5s9f & \( ^3F_2 \) & B69 |
| 2248.318(0) & 44463.9 & 2248.330(7) & -0.012 & 110 & 0.04 & 130 & 5s5d & \( ^1D_2 \) & 5s9f & \( ^3F_3 \) & B69 |
| 2249.61(7) & 44438.3 & 2249.5515(23) & 0.06 & 150h & 1.5e+6 & D+ & 5s5d & \( ^1D_2 \) & 5s9f & \( ^3F_2 \) & P38P & |
| 2249.61(7) & 44438.3 & 2249.650(6) & -0.04 & 150h & 8e+6 & D+ & 5s5d & \( ^1D_2 \) & 5s9f & \( ^3F_3 \) & P38P & |
| 2255.78(7)(15) & 44316.7 & 2255.805(7) & -0.018 & 300 & 9e+6 & D+ & 5s5d & \( ^1D_3 \) & 5s9f & \( ^3F_2 \) & P38P & |
| 2256.14(9)(0) & 44309.8 & 2256.440(6) & -0.30 & 43 & 1.0e+6 & D+ & 5s5d & \( ^1D_3 \) & 5s9f & \( ^3F_2 \) & P38P & |
| 2269.29(9)(0) & 44072.4 & 2268.125(13) & 0.16 & 48 & 0.04 & 130 & 5s6s & \( ^1S_0 \) & 5s9p & \( ^P_1 \) & B69 |
| 2269.68(9)(0) & 44045.5 & 2269.562(14) & 0.12 & 100 & 0.04 & 130 & 5s6s & \( ^1S_0 \) & 5s9p & \( ^P_1 \) & P38P |
| 2281.64(16) & 43814.6 & 2281.6301(19) & 0.010 & 330 & 0.04 & 130 & 5s6s & \( ^1S_0 \) & 5s9p & \( ^P_1 \) & P38P |
| 2287.395(10) & 43704.37 & 2287.3947(22) & 0.000 & 130 & 0.04 & 130 & 5s6s & \( ^1S_0 \) & 5s9p & \( ^P_1 \) & P38P |
| 2293.15(9)(1) & 43594.7 & 2293.134(8) & 0.02 & 35 & 0.04 & 130 & 5s6s & \( ^1S_0 \) & 5s9p & \( ^P_1 \) & P38P |
| 2294.85(9)(1) & 43562.4 & 2294.603(9) & 0.25 & 25 & 0.04 & 130 & 5s6s & \( ^1S_0 \) & 5s9p & \( ^P_1 \) & P38P |
| 2297.72(9)(1) & 43508.8 & 2297.666(8) & 0.05 & 48 & 0.04 & 130 & 5s6s & \( ^1S_0 \) & 5s9p & \( ^P_1 \) & P38P |
| 2305.29(9)(1) & 43365.1 & 2305.307(8) & -0.02 & 360 & 0.04 & 130 & 5s6s & \( ^1S_0 \) & 5s9p & \( ^P_1 \) & P38P |
| 2306.06448(8) & 43350.5817 & 2306.06448(8) & 0.00000 & 19000 & 2.10e+6 & B+ & 5s6s & \( ^1S_0 \) & 5s9p & \( ^P_1 \) & L93c |
| 2313.217(11) & 43216.55 & 2313.2164(19) & 0.001 & 540 & 8e+6 & E & 5s5d & \( ^1D_2 \) & 5s9p & \( ^3P_1 \) & 1 |
| 2314.42(9)(1) & 43194.1 & 2314.422(9) & 0.00 & 65 & 0.04 & 130 & 5s5d & \( ^1D_2 \) & 5s9p & \( ^3P_2 \) & B69 |
| 2319.154(11) & 43105.93 & 2319.1418(22) & 0.012 & 290 & 1.5e+6 & E & 5s5d & \( ^1D_2 \) & 5s9p & \( ^3P_1 \) & 1 |
| 2323.306(16) & 43028.9 & 2323.308(5) & -0.002 & 83 & 0.04 & 130 & 5s5d & \( ^1D_2 \) & 5s9p & \( ^3P_2 \) & P38P |
| 2323.870(16) & 43027.4 & 2323.405(7) & -0.018 & 150 & 5.8e+6 & D+ & 5s5d & \( ^1D_1 \) & 5s9p & \( ^3P_3 \) & P38P |
| \(\lambda_{\text{obs}}\) (Å) | \(\sigma_{\text{obs}}\) (cm\(^{-1}\)) | \(\lambda_{\text{Ritz}}\) (Å) | \(\Delta \lambda_{\text{obs-Ritz}}\) (Å) | \(I_{\text{obs}}\) (arb. u.) | \(A^c\) (s\(^{-1}\)) | Type | Transition | Notes | Line Ref. | TP Ref. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-------|-------------|--------|-----------|---------|
| 2326.4910(16)  | 42970.0         | 2326.504(6)    | -0.013          | 67              | 5s5d 1^D_2 5s8f 1^F_3  | P38P  |
| 2327.949(11)   | 42943.08        | 2327.959(5)    | -0.010          | 290             | 5s5d 1^D_2 5s8f 1^F_3  | P38P  |
|                 |                 | 2328.057(7)    | 1.1e+6          | D+              | 5s5d 1^D_2 5s8f 1^F_3  | TW    |
| 2334.570(16)   | 42821.3         | 2334.584(9)    | -0.014          | 320             | 5s5d 1^D_3 5s8f 1^F_3  | P38P  |
|                 |                 | 2335.231(6)    | 8e+5            | D+              | 5s5d 1^D_3 5s8f 1^F_3  | TW    |
| 2343.49(9)(1)  | 42658.3         | 2343.298(12)   | 0.19            | 310             | 5s6p 1^p_1 5s18d 1^D_2  | B69   |
| 2343.87(3)     | 42651.5         | 2343.865(16)   | 0.01            | 89*             | E2    |
| 2343.87(3)     | 42651.5         | 2343.865(23)   | 89*             |                  |       |
| 2343.997(16)   | 42649.1         | 2343.997(19)   | 28              | 5s6p 1^p_1 5s18d 1^D_1  | 3 P38P|
| 2350.7432(22)  | 42526.72        | 2350.7423(4)   | 0.0009          | 2800            | 5s5p 1^p_1 5p^2 3^P_2  | K01c  |
| 2355.67(9)(1)  | 42437.8         | 2355.862(11)   | -0.19           | 110             | 5p^2 3^P_1 5s11p 1^P_1  | B69   |
| 2356.108(17)   | 42429.9         | 2356.107(19)   | 230             | 5s6p 1^P_1 5s17d 1^D_2  | 3 P38P|
| 2356.88(3)     | 42416.0         | 2356.88(3)     | 150*            |                  |       |
| 2356.88(3)     | 42416.0         | 2356.88(3)     | 150*            |                  |       |
| 2362.863(17)   | 42308.6         | 2362.853(14)   | 0.010           | 37              | 5s6p 3^P_0 5s16d 1^D_2  | P38P  |
| 2363.037(17)   | 42305.5         | 2363.009(13)   | 0.028           | 34              | 5s6p 3^P_0 5s16d 1^D_1  | P38P  |
| 2364.6858699778(4) | 42275.995245348 | 2364.6858699778(4) | 0e-10          | 220             | 5s^2 1^S_0 5s5p 3^P_0  | Z01   |
| 2365.721(17)   | 42257.5         | 2365.723(19)   | 54              | 5s6p 3^P_2 5s19d 1^D_1  | P38P  |
| 2367.009(17)   | 42234.5         | 2367.015(9)    | -0.006          | 31              | 5s6p 3^P_0 5s17s 3^S_1  | P38P  |
| 2370.59(9)(2)  | 42170.7         | 2370.459(5)    | 0.13            | 580             | 5s6s 3^S_1 5s8p 1^P_1   | 1 B69 |
| 2372.63(9)(2)  | 42134.5         | 2372.370(7)    | 0.26            | 43              | 5p^2 3^P_2 5s10f 1^F_3  | 1 B69 |
| 2372.904(17)   | 42129.6         | 2372.909(15)   | -0.005          | 76              | 5s6p 3^P_1 5s16d 1^D_2  | P38P  |
| 2373.039(17)   | 42127.2         | 2373.066(14)   | -0.027          | 76              | 5s6p 3^P_1 5s16d 1^D_1  | P38P  |
| 2373.73(9)(2)  | 42114.9         | 2373.716(8)    | 0.01            | 220             | 5p^2 3^P_2 5s10f 3^F_3  | B69   |
| 2374.80(9)(2)  | 42096.0         | 2374.658(12)   | 0.14            | 100             | 5p^2 3^P_0 5s10p 3^P_1   | B69   |
| 2375.960(17)   | 42075.4         | 2375.956(13)   | 0.004           | 130             | 5s6s 3^S_1 5s8p 3^P_2   | P38P  |
| 2376.655(17)   | 42063.1         | 2376.652(17)   | 0.003           | 100             | 5s6p 3^P_2 5s18d 1^D_1  | P38P  |
| 2377.085(17)   | 42055.5         | 2377.106(9)    | -0.021          | 64              | 5.4e+5 D+ 5s6p 3^P_1 5s17s 3^S_1  | P38P  |
| 2378.630(11)   | 41957.63        | 2382.626(5)    | 0.004           | 4800            | 5s5d 1^D_2 5s6f 1^F_3  | 2 P38G4|
| 2383.76(9)(2)  | 41937.7         | 2383.760(3)    | 0.00            | 300             | 5s6s 3^S_1 5s8p 3^P_1   | B69   |

http://dx.doi.org/10.6028/jres.118.004
| $\lambda_{\text{obs}}$ (Å) | $\sigma_{\text{obs}}$ (cm$^{-1}$) | $\lambda_{\text{ref}}$ (Å) | $\Delta \lambda_{\text{obs-ref}}$ (Å) | $I_{\text{obs}}$ (arb. u.) | $A$ (s$^{-1}$) | Type | Transition | Notes | Line Ref. | TP Ref. |
|-----------------|-----------------|------------------|------------------|----------------|---------|-------|-------------|-------|-----------|---------|
| 2384.526(11)   | 41924.27        | 2384.524(4)      | 0.002            | 1500           | 5s5d    | $^1D_2$ | 5s6f       | $^3F_{3}^0$ | P38G4     |         |
| 2387.689(9)    | 41868.9         | 2387.822(11)     | -0.14            | 500            | 5p$^2$  | $^3P_1$ | 5s8f       | $^3F_{2}^0$ | B99       |         |
| 2389.989(11)   | 41828.45        | 2389.995(11)     | -0.006           | m              | 2.5e+5  | D$^+$  | 5s6p       | $^3P_{0,2}$ | 2         | B69     |
| 2393.017(11)   | 41775.52        | 2393.019(10)     | -0.002           | 91             | E2      | 5s6p    | $^3P_{1,2}$ | 5s15d  | P38      |
| 2393.179(11)   | 41772.69        | 2393.180(11)     | 110              | 5s6p           | $^3P_{1,2}$ | 5s15d | $^3D_3$    | P38P  |         |
| 2393.456(13)   | 41704.0         | 2397.225(12)     | -0.11            | 76             | 7e+5    | D$^+$  | 5s6p       | $^3P_{0,2}$ | B69       |         |
| 2398.381(17)   | 41682.1         | 2398.388(10)     | -0.007           | 22             | 7e+5    | D$^+$  | 5s6p       | $^3P_{1,2}$ | B69       |         |
| 2402.086(5)    | 41323.5         | 2403.8(10)       | 1.0e+6           | D$^+$          | 5s6p    | $^3P_{1,2}$ | 5s15d  | P38      |
| 2405.069(17)   | 41556.5         | 2405.551(13)     | 0.08             | 120            | 5s6p    | $^3P_{0,2}$ | 5s16d | $^1D_2$ | B69     |
| 2405.639(9)    | 41541.96        | 2406.472(12)     | 0.004            | 110            | 5s6p    | $^3P_{0,2}$ | 5s14d | $^3D_3$ | P38P  |
| 2408.566(12)   | 41505.86        | 2408.597(14)     | -0.031           | 96             | E2      | 5s6p    | $^3P_{0,2}$ | 5s14d  | P38P     |
| 2408.758(12)   | 41502.55        | 2408.754(10)     | 0.004            | 110            | 5s6p    | $^3P_{0,2}$ | 5s14d | $^3D_1$ | P38P  |
| 2410.846(12)   | 41466.60        | 2410.836(9)      | 0.010            | 93             | E2      | 5s6p    | $^3P_{0,2}$ | 5s17s  | P38P     |
| 2412.831(17)   | 41432.5         | 2412.831(17)     | 3e+5            | 83             | E2      | 5s6p    | $^3P_{0,2}$ | 5s10p  | P38P     |
| 2415.409(5)    | 41388.27        | 2415.411(4)      | -0.002           | 110            | 3.2e+5  | D$^+$  | 5s6p       | $^3P_{0,2}$ | P38P     |
| 2417.219(9)    | 41357.4         | 2417.393(13)     | -0.18            | 84             | E2      | 5s6p    | $^3P_{1,2}$ | 5s14d  | P38P     |
| 2418.932(18)   | 41328.0         | 2418.923(10)     | 0.009            | 69             | E2      | 5s6p    | $^3P_{1,2}$ | 5s14d  | P38P     |
| 2419.067(18)   | 41325.7         | 2419.047(14)     | 0.020            | 100            | 5s6p    | $^3P_{1,2}$ | 5s14d | $^3D_2$ | P38P  |
| 2419.196(18)   | 41323.5         | 2419.205(10)     | -0.009           | 78             | 5s6p    | $^3P_{1,2}$ | 5s14d | P38P     |
| 2424.429(2)    | 41234.5         | 2424.370(18)     | 0.05             | 120            | 5s6p    | $^3P_{1,2}$ | 5s15s | $^3S_0$ | B69     |
| 2425.924(18)   | 41208.9         | 2425.920(4)      | 0.004            | 110            | 9e+5    | D$^+$  | 5s6p       | $^3P_{1,2}$ | P38P     |
| 2426.059(9)    | 41206.8         | 2425.991(18)     | 0.06             | 54             | 5s6p    | $^3P_{2}$ | 5s15d | $^3D_2$ | B69     |
| 2427.206(12)   | 41187.13        | 2427.205(11)     | 0.001            | 98             | 5s6p    | $^3P_{2}$ | 5s15d | P38P     |
| 2428.539(9)    | 41164.7         | 2428.778(7)      | -0.25            | 370i           | 5s6p    | $^3P_{2}$ | 5s1/2,3P=413g | B69 |         |
| \( \lambda_{\text{obs}} \) \(^a\) (Å) | \( \sigma_{\text{obs}} \) (cm\(^{-1}\)) | \( \lambda_{\text{Ritz}} \) \(^b\) (Å) | \( \Delta \lambda_{\text{obs-Ritz}} \) \(^c\) (Å) | \( I_{\text{obs}} \) \(^d\) (arb. u.) | \( A \) \(^e\) (s\(^{-1}\)) | Type\(^f\) | Transition | Notes\(^g\) | Line Ref.\(^h\) | TP Ref.\(^i\) |
|---|---|---|---|---|---|---|---|---|---|---|
| 2432.731(12) | 41093.59 | 2432.729(10) | 0.002 | 50 | 1.2e+6 | D+ | 5s6p \( ^3P^o_2 \) 5s16s \( ^3S_1 \) | P38P | TW |
| 2442.471(12) | 40929.74 | 2442.480(11) | -0.009 | 67 | 7e+5 | D+ | 5p\(^2\) \( ^3P^o_2 \) 5s9f \( ^1F^o_3 \) | P38P | TW |
| 2442.634(12) | 40927.01 | 2442.634(12) | 0.000 | 110 | 1.0e+7 | D+ | 5s6p \( ^3P^o_0 \) 5s13d \( ^1D_2 \) | P38P |
| 2447.886(12) | 40839.21 | 2447.893(3) | -0.007 | 220 | 4.4e+5 | D+ | 5s5d \( ^3D_1 \) 5s7f \( ^3F^o_2 \) | P38P | TW |
| 2451.121(12) | 40785.30 | 2451.135(5) | -0.014 | 2000 | 1.1e+7 | D+ | 5s5d \( ^3D_2 \) 5s7f \( ^3F^o_3 \) | P38G4 |
| 2451.549(5) | 40778.19 | 2451.550(4) | -0.001 | 36 | 1.9e+6 | D+ | 5s5d \( ^3D_2 \) 5s7f \( ^3F^o_2 \) | P38P | TW |
| 2452.910(12) | 40755.57 | 2452.912(3) | -0.002 | 1400 | 1.2e+7 | D+ | 5s5d \( ^3D_3 \) 5s7f \( ^3F^o_3 \) | P38P | TW |
| 2453.229(12) | 40750.26 | 2453.227(11) | 0.002 | 89 | 1.3e+6 | D+ | 5s5d \( ^3D_3 \) 5s7f \( ^3F^o_3 \) | P38P |
| 2453.856(12) | 40739.85 | 2453.858(11) | -0.002 | 92 | 1.5e+6 | D+ | 5s5d \( ^3D_3 \) 5s15s \( ^3S_1 \) | P38P | TW |
| 2460.188(18) | 40635.0 | 2460.198(9) | -0.010 | 2500 | 1.2e+7 | D+ | 5s5d \( ^3P^o_2 \) 5s14s \( ^3S_1 \) | P38G4 | TW |
| 2460.986(3) | 4060.42 | 2460.986(3) | 0.010 | 33 | 1.2e+6 | D+ | 5s5d \( ^3D_3 \) 5s14d \( ^3D_3 \) | P38P | TW |
| 2461.070(12) | 40620.44 | 2461.060(4) | 0.001 | 17 | 2.1e+6 | D+ | 5s5p \( ^1P_1 \) 5s14s \( ^3S_1 \) | P38G4 | TW |
| 2462.378(12) | 40598.87 | 2462.377(4) | 0.001 | 160 | 5e+5 | D+ | 5s5p \( ^1P_1 \) 5s7f \( ^1F^o_3 \) | P38P | J07 |
| 2486.152(12) | 40210.66 | 2486.141(9) | 0.011 | 120 | 1.2e+7 | D+ | 5s5p \( ^1P_1 \) 5s12d \( ^1D_2 \) | P38P |
| 2488.618(5) | 40170.82 | 2488.619(5) | -0.001 | 110 | 1.3e+6 | D+ | 5s5p \( ^1P_1 \) 5s13d \( ^1D_2 \) | P38P |
| 2498.591(12) | 40046.92 | 2496.315(9) | 0.003 | 81 | 2.1e+6 | D+ | 5s5p \( ^1P_1 \) 5s12d \( ^1D_2 \) | P38P |
| 2498.588(4) | 40010.49 | 2498.588(4) | 0.003 | 93 | 1.7e+6 | D+ | 5s5p \( ^1P_1 \) 5s13s \( ^3S_1 \) | P38P | TW |
| 2499.353(12) | 39998.29 | 2499.354(12) | -0.001 | 32 | 6e+5 | D+ | 5s5p \( ^1P_1 \) 5s13s \( ^3S_1 \) | P38P | TW |
| 2499.600(12) | 39960.34 | 2499.603(10) | -0.003 | 110 | 8e+5 | E+ | 5s5p \( ^1P_1 \) 5s13s \( ^3S_1 \) | P38P | TW |
| 2501.002(5) | 39971.93 | 2501.003(4) | -0.001 | 67 | 8e+5 | E+ | 5s5p \( ^1P_1 \) 5s13s \( ^3S_1 \) | P38P | TW |
| 2508.157(19) | 39857.9 | 2508.159(19) | 0.000 | 53 | 1.7e+6 | D+ | 5s6p \( ^1P_1 \) 5s15d \( ^1D_2 \) | P38P |
| 2509.320(5) | 39839.44 | 2509.320(4) | 0.000 | 13 | 1.7e+6 | D+ | 5s6p \( ^1P_1 \) 5s13s \( ^3S_0 \) | P38P |
| 2512.274(9) | 39792.60 | 2512.272(4) | 0.002 | 96 | 8e+5 | E+ | 5s6p \( ^1P_1 \) 5s13s \( ^3S_1 \) | P38P | TW |
| 2514.082(13) | 39763.98 | 2514.082(13) | 0.002 | 2800 | 8e+5 | E+ | 5s6p \( ^1P_1 \) 5s16s \( ^3S_0 \) | P38G2 | TW |
| 2536.670(19) | 39409.9 | 2536.669(12) | 0.002 | 4000 | 8e+5 | E+ | 5s6p \( ^1P_1 \) 5s16s \( ^3S_0 \) | P38G2 | TW |
| 2543.953(19) | 39297.1 | 2543.955(19) | 0.002 | 100 | 9e+5 | E+ | 5s6p \( ^1P_1 \) 5s15s \( ^3S_0 \) | P38G2 | TW |
| 2545.747(13) | 39269.41 | 2545.7185(10) | 0.028 | 490 | 1.2e+6 | D+ | 5s5p \( ^1P_1 \) 5s5d \( ^3D_3 \) | P38G2 | TW |
| $\lambda_{\text{obs}}$ (Å) | $\sigma_{\text{obs}}$ (cm$^{-1}$) | $\lambda_{\text{Ritz}}$ (Å) | $\Delta\lambda_{\text{obs}}$ (Å) | $I_{\text{obs}}$ (arb.u.) | $A^e$ (s$^{-1}$) | Type | Transition | Notes | Line Ref. | TP Ref. |
|----------------|----------------|----------------|----------------|----------------|----------------|-------|------------|-------|-----------|--------|
| 2549.978(13)  | 39204.26      | 2549.977(4)   | 0.001          | 0.001         | 300            | 2.9e+6 | D+        | $^3P^o_2$ | $^3S_1$   | P38G2   | TW     |
| 2553.345(8)   | 39152.57      | 2553.347(6)   | -0.002         | 0.002         | 15             | E2     |           | $^3P^o_0$ | $^1D_2$   | P38P    |        |
| 2553.525(20)  | 39149.8       | 2553.526(5)   | -0.001         | 0.001         | 51             | E2     |           | $^3P^o_0$ | $^3D_1$   | P38P    |        |
| 2554.436(13)  | 39135.85      | 2554.416(16)  | 0.020          | 0.020         | 1100           | 1.5e+6 | D+        | $^1P^o_1$ | $^3D_2$   | P38G2   | J07    |
| 2558.956(6)   |              | 2558.956(6)   |              |              | m              | 3.6e+6 | E          | $^1S_0$  | $^3P^o_1$ | P38     | B99    |
| 2560.040(3)   |              | 2560.040(3)   |              |              | m              | 1.2e+6 | D+        | $^1P^o_1$ | $^3D_1$   | L31     | J07    |
| 2564.738(13)  | 38978.66      | 2564.741(9)   | -0.003         | 0.003         | 19             | E2     |           | $^3P^o_1$ | $^3D_3$   | P38P    |        |
| 2565.098(13)  | 38973.19      | 2565.094(6)   | 0.004          | 0.004         | 47             | E2     |           | $^3P^o_1$ | $^3D_2$   | P38P    |        |
| 2565.265(13)  | 38970.65      | 2565.274(5)   | -0.009         | 0.009         | 14             | E2     |           | $^3P^o_1$ | $^3D_1$   | P38P    |        |
| 2571.603(8)   | 38874.60      | 2571.613(23)  | -0.010         | 0.010         | 150            | 9e+5   | D+        | $^3P^o_0$ | $^3S_1$   | P38G2   | TW     |
| 2573.200(13)  | 38850.48      | 2573.191(9)   | 0.009          | 0.009         | 95             | E2     |           | $^3P^o_1$ | $^3D_2$   | P38G2   | TW     |
| 2574.464(5)   | 38831.40      | 2574.464(3)   | 0.000          | 0.000         | 28             | 4.0e+5 | E          | $^3S_0$  | $^3P^o_1$ | P38P    | B99    |
| 2583.523(13)  | 38695.26      | 2583.528(23)  | -0.006         | 0.006         | 220            | 2.7e+6 | D+        | $^3P^o_1$ | $^3S_1$   | P38G2   | TW     |
| 2586.696(12)  |              | 2586.825(4)   | 1.3e+5         | 1.3e+5       | 560            | 5.5d   | D+        | $^3D_2$  | $^3P^o_2$ | P38G2   | TW     |
| 2588.1(11)    |              | 2588.1(11)    | 9e+5           | 9e+5         | 560            | 5.5d   | D+        | $^3D_1$  | $^3P^o_1$ | P38G2   | TW     |
| 2591.946(13)  | 38569.51      | 2591.946(13)  | 220            | 2.2e+6       | 560            | 5.5d   | D+        | $^3P^o_1$ | $^3P^o_2$ | P38G2   | J07    |
| 2598.754(14)  | 38468.48      | 2598.753(6)   | 0.001          | 0.001        | 700            | 1.8e+7 | D          | $^3D_2$  | $^1P^o_1$ | P38G2   | B99    |
| 2604.040(14)  | 38390.31      | 2604.049(9)   | -0.003         | 0.003        | 540            | E2     |           | $^3P^o_2$ | $^3D_3$   | P38G2   |        |
| 2604.413(14)  | 38384.90      | 2604.413(6)   | 0.000          | 0.000        | 160            | E2     |           | $^3P^o_2$ | $^3D_2$   | P38G2   |        |
| 2604.596(14)  | 38382.21      | 2604.599(5)   | -0.003         | 0.003        | 45             | E2     |           | $^3P^o_2$ | $^3D_1$   | P38G2   |        |
| 2614.755(14)  | 38233.09      | 2614.748(3)   | 0.007          | 0.007        | 160            | 2.2e+6 | E          | $^3D_2$  | $^3P^o_1$ | P38G2   | B99    |
| 2623.282(14)  | 38108.82      | 2623.287(10)  | -0.005         | 0.005        | 430            | E2     |           | $^3P^o_1$ | $^1D_2$   | P38G2   |        |
| 2623.435(14)  | 38106.60      | 2623.419(24)  | 0.016          | 0.016        | 440            | 4.5e+6 | D+        | $^3P^o_2$ | $^3S_1$   | P38G2   | TW     |
| 2637.647(14)  | 37901.29      | 2637.652(5)   | -0.005         | 0.005        | 9              | 8e+5   | E          | $^3P^o_1$ | $^1S_0$   | 1       | P38G2,P  | TW     |
| 2640.920(14)  | 37854.32      | 2640.915(4)   | 0.005          | 0.005        | 4              | 7e+4   | D+        | $^3P^o_1$ | $^1S_0$   | P38P    |        |
| 2649.960(14)  | 37725.19      | 2649.974(4)   | -0.014         | 0.014        | 42             | E2     |           | $^3P^o_0$ | $^3D_2$   | P38G2   |        |
| 2650.296(11)  | 37720.41      | 2650.304(3)   | -0.008         | 0.008        | 500            | 8e+6   | D+        | $^3P^o_0$ | $^3D_1$   | P38G2   | TW     |
| 2654.708(14)  | 37657.72      | 2654.719(5)   | -0.011         | 0.011        | 36             |       |           | $^3P^o_1$ | $^1D_2$   | P38P    |        |
| \(\lambda_{\text{obs}}\) (Å) | \(\sigma_{\text{obs}}\) (cm\(^{-1}\)) | \(\lambda_{\text{Ritz}}\) (Å) | \(\Delta \lambda_{\text{obs-Ritz}}\) (Å) | \(I_{\text{obs}}\) (arb.u.) | \(A\) (s\(^{-1}\)) | Type | Transition | Notes | Line Ref. | TP Ref.
|---|---|---|---|---|---|---|---|---|---|---|
| 2662.636(14) | 37545.60 | 2662.628(4) | 0.008 | 1100 | 1.0e+7 | D+ | 5s6p \(^3p^0\) 5s10d \(^3D_2\) | P38G2 | TW |
| 2668.421(14) | 37464.20 | 2668.434(5) | -0.013 | 150 | 5.4e+6 | D+ | 5s6p \(^3p^0\) 5s10d \(^3D_1\) | P38G2 | TW |
| 2668.658(14) | 37460.88 | 2668.671(6) | -0.013 | 690 | 1.8e+7 | D | 5s5d \(^3D_1\) 5s6f \(^3F_3\) | P38G2 | B99 |
| 2672.175(14) | 37411.58 | 2672.184(6) | -0.009 | 360 | E2 | 5s5d \(^3D_2\) 5s6f \(^3F_3\) | P38G2 | TW |
| 2673.508(14) | 37392.93 | 2673.526(10) | -0.018 | 85 | 3.4e+6 | D+ | 5s5d \(^3D_3\) 5s6f \(^3F_3\) | P38G2 | B99 |
| 2674.565(14) | 37378.15 | 2674.571(5) | -0.006 | 770 | 1.9e+7 | C+ | 5s5d \(^3p^0\) 5s11s \(^3S_1\) | P38G2 | TW |
| 2674.797(14) | 37374.91 | 2674.810(6) | -0.013 | 85 | 2.2e+6 | D+ | 5s6p \(^3p^0\) 5s11s \(^3S_1\) | P38G2 | B99 |
| 2681.744(22) | 37278.1 | 2681.769(6) | -0.025 | 4 | 5s5d \(^3D_3\) 5s6f \(^3F_3\) | P38P | |
| 2683.118(14) | 37259.01 | 2683.120(10) | -0.002 | 3400 | 2.2e+7 | C+ | 5s5d \(^3D_3\) 5s6f \(^3F_3\) | P38G2 | B99 |
| 2684.158(14) | 37244.57 | 2684.174(5) | -0.016 | 200 | 2.4e+6 | D+ | 5s5d \(^3D_3\) 5s6f \(^3F_3\) | P38G2 | B99 |
| 2691.332(14) | 37148.05 | 2691.1362(20) | -0.004 | 580 | 6e+6 | D+ | 5s6p \(^3p^0\) 5s11s \(^3S_1\) | P38G2 | TW |
| 2693.883(15) | 37110.12 | 2693.8987(7) | -0.015 | 570 | 6e+6 | D+ | 5s6p \(^3p^0\) 5s11d \(^3D_2\) | P38G2 | |
| 2699.336(15) | 37035.16 | 2699.346(6) | -0.010 | 4 | 5s5d \(^3p^0\) 5s11s \(^3S_1\) | P38G2 | |
| 2704.484(15) | 36964.67 | 2704.489(3) | -0.005 | 570 | 1.3e+7 | D+ | 5s5d \(^3p^0\) 5s10d \(^3D_1\) | P38G2 | TW |
| 2705.011(15) | 36957.47 | 2705.019(4) | -0.008 | 140 | 3.6e+6 | D+ | 5s6p \(^3p^0\) 5s10d \(^3D_1\) | P38G2 | TW |
| 2714.900(15) | 36822.85 | 2714.908(4) | -0.008 | 130 | 3.6e+6 | D+ | 5s6p \(^3p^0\) 5s12s \(^3S_0\) | P38G2 | |
| 2734.450(15) | 36559.60 | 2734.464(20) | 0.004 | 130 | 1.1e+7 | D+ | 5s6p \(^3p^0\) 5s11s \(^3S_1\) | P38G2 | TW |
| 2749.746(15) | 36356.24 | 2749.733(4) | 0.013 | 6300 | 5.9e+7 | B | 5s5d \(^3D_2\) 5s5f \(^3F_3\) | P38G3 | J07 |
| 2752.793(15) | 36316.01 | 2752.772(4) | 0.021 | 340 | 3.1e+6 | D | 5s5d \(^3D_2\) 5s5f \(^3F_3\) | P38G6-2 | J07 |
| 2798.780(16) | 35719.32 | 2798.779(5) | 0.001 | 500 | E2 | 5s6p \(^3p^0\) 5s10d \(^3D_2\) | P38G2 | |
| 2804.813(24) | 35642.5 | 2804.813(3) | 0.000 | 61 | 5.6e+6 | D+ | 5s6p \(^3p^0\) 5s9d \(^3D_2\) | P38P | |
| 2805.337(3) | 35635.84 | 2805.3432(19) | -0.006 | 500 | 7e+6 | D+ | 5s6p \(^3p^0\) 5s9d \(^3D_1\) | P38G3.2 | TW |
| 2807.572(4) | 35558.04 | 2807.572(4) | 3.9e+5 | D+ | 5s6p \(^3p^0\) 5s10d \(^3D_2\) | P38G2 | |
| 2807.943(3) | 35536.82 | 2807.943(3) | 2.3e+5 | D+ | 5s6p \(^3p^0\) 5s10d \(^3D_1\) | P38G2 | |
| 2818.991(16) | 35463.24 | 2818.993(3) | -0.002 | 860 | 9e+6 | D+ | 5s6p \(^3p^0\) 5s9d \(^3D_2\) | P38G2 | TW |
| 2819.527(5) | 35456.50 | 2819.5291(19) | -0.002 | 350 | 4.9e+6 | D+ | 5s6p \(^3p^0\) 5s9d \(^3D_1\) | P38G2 | TW |
| \(\lambda_{\text{obs}}\) (Å) | \(\sigma_{\text{obs}}\) (cm\(^{-1}\)) | \(\lambda_{R\text{ex}}\) (Å) | \(\Delta \lambda_{\text{obs}-R\text{ex}}\) (Å) | \(I_{\text{obs}}\) (arb.u.) | \(A\) (s\(^{-1}\)) | Type | Transition | Notes | Line Ref. | TP Ref. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-------|-----------|-------|----------|--------|
| 2831.539(16)   | 3530.10         | 2831.544(3)    | -0.005          | 330             | 5\(e+6\)        | E     | 5\(^1\)P\(^1\) 5s11s \(^1\)S\(_0\) | 1     | P38G3.2  | TW     |
| 2839.53(13)(5)  | 3520.67         | 2839.2860(22)  | 0.24            | 190             | 2.7e+5          | D+    | 5\(^1\)P\(^1\) 5s11s \(^1\)S\(_1\) | B69   | TW       |
| 2852.579(3)    | 3504.50         | 2852.5857(17)  | -0.007          | 190             | 1.6e+6          | D+    | 5\(^1\)P\(^0\) 5s10s \(^3\)S\(_1\) | P38G3.2 | TW      |
| 2865.682(16)   | 3488.546        | 2865.684(12)   | -0.002          | 450             | 1.2e+7          | D+    | 5\(^3\)p\(^2\) 5s9d \(^3\)D\(_3\) | 2     | P38G3.2  | TW     |
| 2866.543(16)   | 3487.499        | 2866.552(3)    | -0.009          | 380             | 2.9e+6          | D+    | 5\(^3\)p\(^2\) 5s9d \(^3\)D\(_2\) | P38G3.2 | TW      |
| 2867.251(3)    | 3486.638        | 2867.2546(17)  | -0.004          | 740             | 4.6e+6          | D+    | 5\(^3\)p\(^2\) 5s10s \(^3\)S\(_1\) | P38G3.2 | TW      |
| 2890.1708(3)   | 3458.889        | 2890.17075(24) | 0.0000          | 10000           | 2.0e+7          | D+    | 5\(^3\)p\(^1\) 5s5d \(^3\)D\(_2\) | K01c  | A86c     |
| 2916.466(17)   | 3427.804        | 2916.4703(18)  | -0.004          | 1100            | 8e+6            | D+    | 5\(^3\)p\(^2\) 5s10s \(^3\)S\(_1\) | P38G3   | TW      |
| 2938.514(7)    |                 |                 |                 |                 |                 |       |                       |       |          |        |
| 2941.0373(10)  | 3399.1669       | 2941.0376(8)   | -0.0003         | 9600            | 3.4e+8          | B     | 5\(^3\)p\(^2\) 5s6f \(^3\)F\(_3\) | B99   |          |
| 2955.558(20)   |                 |                 |                 |                 |                 |       |                       |       |          |        |
| 2960.016(12)   |                 |                 |                 |                 |                 |       |                       |       |          |        |
| 2960.089(5)    |                 |                 |                 |                 |                 |       |                       |       |          |        |
| 2963.5(10)     |                 |                 |                 |                 |                 |       |                       |       |          |        |
| 2966.175(18)   | 33703.61        | 2966.170(6)    | 0.005           | 4300            | 1.9e+7          | D+    | 5\(^3\)p\(^1\) 5s9d \(^3\)D\(_2\) | P38G4  | TW      |
| 2970.950(7)    |                 |                 |                 |                 |                 |       |                       |       |          |        |
| 2981.979(3)    |                 |                 |                 |                 |                 |       |                       |       |          |        |
| 2999.4092(4)   | 3333.182        | 2999.4090(4)   | 0.0002          | 1400            | 2.1e+6          | D     | 5\(^3\)p\(^1\) 5s7p \(^3\)P\(_2\) | K01c  | J07      |
| 3022.403(5)    | 3307.62         | 3022.402(3)    | 0.001           | 170             | 1.2e+7          | E     | 5\(^3\)p\(^1\) 5s10s \(^3\)S\(_0\) | 1     | P38G2    | TW     |
| 3022.904(18)   | 3307.14         | 3022.9163(9)   | -0.012          | 84              | 8e+5            | D     | 5\(^3\)S\(_1\) 5s7p \(^3\)P\(_1\) | P38G2  | J07      |
| 3028.595(6)    | 3309.00         | 3028.5958(19)  | -0.011          | 67              | 3.1e+6          | D+    | 5\(^3\)S\(_1\) 5s7p \(^3\)P\(_0\) | P38G2  | B99      |
| 3052.228(19)   | 3275.43         | 3052.2226(12)  | 0.002           | 240             | 7.2e+7          | C     | 5\(^3\)S\(_1\) 5s9f \(^3\)F\(_3\) | 2     | P38G3.2  | TW     |
| 3069.757(19)   | 3256.60         | 3069.760(4)    | -0.003          | 170             | 1.2e+6          | D+    | 5\(^3\)p\(^1\) 5s8d \(^3\)D\(_2\) | P38P   | TW       |
| 3083.663(4)    | 3241.55         | 3083.6656(24)  | -0.003          | 1000            | 1.2e+7          | D+    | 5\(^3\)p\(^0\) 5s8d \(^3\)D\(_1\) | P38G3  | TW       |
| 3099.809(19)   | 3225.69         | 3099.813(3)    | -0.004          | 3800            | 1.6e+7          | D+    | 5\(^3\)p\(^1\) 5s8d \(^3\)D\(_2\) | 2     | P38G4    | TW     |
| 3108.814(6)    | 3224.24         | 3108.8142(24)  | 0.000           | 700             | 9e+6            | D+    | 5\(^3\)p\(^1\) 5s8d \(^3\)D\(_1\) | P38G2  | TW       |
| 3138.212(20)   | 3185.05         | 3138.217(6)    | -0.005          | 51              |                 | E2    | 5\(^3\)d\(_1\) 5s5f \(^3\)F\(_3\) | P38G4.2 | TW       |
| $\lambda_{\text{obs}}$ (Å) | $\sigma_{\text{obs}}$ (cm$^{-1}$) | $\lambda_{\text{Ritz}}$ (Å) | $\Delta \lambda_{\text{obs-Ritz}}$ (Å) | $I_{\text{obs}}$ (arb.u.) | $A^\ast$ (s$^{-1}$) | Type | Transition | Notes$^b$ | Line Ref.$^a$ | TP Ref.$^c$ |
|------------------|-------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| 3438.417(24)    | 29074.82          | 3438.413(9)      | 0.004            | 800              | 1.6e+6           | E                | $^1D_2$          | $^1S_0$          | 1               | P38G4,3          | TW               |
| 3441.911(24)    | 29045.30          | 3441.911(6)      | 0.000            | 230              |                  |                  |                  |                  |                  |                  |
| 3517.686(25)    | 28419.65          | 3517.697(6)      | -0.011           | 210              | 6e+5             | D                | $^3P_2$          | $^3P_0$          | 5               | P38G3            | J07              |
| 3522.671(25)    | 28379.44          | 3522.671(7)      | 0.000            | 340              |                  |                  |                  |                  |                  |                  |
| 3627.612(11)    | 27558.49          | 3627.632(10)     | -0.020           | 140              | 1.3e+6           | D                | $^3P_1$          | $^1S_0$          | 5               | P38G3,2          | J07              |
| 3693.9239(14)   | 27063.781         | 3693.9239(11)    | 0.00000          | 430              | 2.5e+7           | C+               | $^3P_0$          | $^1S_0$          | 5               | K01c             | J07              |
| 3708.133(11)    | 26960.08          | 3708.133(5)      | 0.000            | 290              | 1.0e+7           | E                | $^1D_2$          | $^1S_0$          | 1.2             | P38G3            | TW               |
| 3716.1350(11)   | 26902.026         | 3716.1349(10)    | 0.0001           | 760              | 3.3e+7           | C+               | $^3P_1$          | $^1S_0$          | 5               | K01c             | J07              |
| 3718.5578(21)   | 26884.499         | 3718.5582(12)    | -0.0004          | 370              | 1.8e+7           | C+               | $^3P_1$          | $^1S_0$          | 5               | K01c             | J07              |
| 3723.389(11)    | 26849.62          | 3723.381(6)      | 0.008            | 540              | 1.8e+6           | E                | $^3P_2$          | $^1S_0$          | 1               | P38G3,2          | TW               |
| 3795.2048(10)   | 26341.560         | 3795.2048(10)    | 0.00000          | 1100             | 4.2e+7           | C+               | $^3P_2$          | $^1S_0$          | 5               | K01c             | J07              |
| 3799.2255(22)   | 26313.683         | 3799.2257(11)    | -0.0002          | 300              | 1.04e+7          | C+               | $^3P_2$          | $^1S_0$          | 5               | K01c             | J07              |
| 3801.760(6)     | 26296.14          | 3801.7586(13)    | 0.001            | 390              | 1.2e+6           | D+               | $^3P_0$          | $^1S_0$          | 1               | P38G3            | J07              |
| 3802.757(12)    | 26289.25          | 3802.758(9)      | -0.001           | 19b*             |                  |                  |                  |                  |                  |                  |
| 3803.260(12)    | 26285.77          | 3803.261(11)     | -0.001           | 19b*             |                  |                  |                  |                  |                  |                  |
| 3807.731(15)    | 26254.91          | 3807.729(9)      | 0.002            | 9                |                  |                  |                  |                  |                  |                  |
| 3808.24(3)      | 26251.40          | 3808.234(11)     | 0.01             | 9                |                  |                  |                  |                  |                  |                  |
| 3834.6306(4)    | 26070.735         | 3834.6307(4)     | -0.0001          | 32000            | 2.20e+8          | B                | $^1D_2$          | $^3P_0$          | 2               | K01c             | M96              |
| 3842.189(15)    | 26019.45          | 3842.158(3)      | 0.031            | 900              | 2.1e+7           | C                | $^3S_1$          | $^3P_0$          | 2               | P38G4            | M96              |
| 3853.04(3)      | 25946.18          | 3853.034(17)     | 0.01             | 15               |                  |                  |                  |                  |                  |                  |
| 3853.55(3)      | 25942.71          | 3853.553(17)     | 0.00             | 44               |                  |                  |                  |                  |                  |                  |
| 3855.52(3)      | 25929.49          | 3855.524(17)     | 0.00             | 69               |                  |                  |                  |                  |                  |                  |
| 3856.04(3)      | 25926.02          | 3856.043(17)     | 0.00             | 7                |                  |                  |                  |                  |                  |                  |
| 3860.63(3)      | 25895.16          | 3860.634(17)     | 0.00             | 46               |                  |                  |                  |                  |                  |                  |
| 3861.16(3)      | 25891.61          | 3861.154(17)     | 0.01             | 21               |                  |                  |                  |                  |                  |                  |
| 3888.0738(19)   | 0.00000           | 3888.0738(19)    | 1.8e+6           | D+               |                  |                  |                  |                  |                  |                  |
| 3889.78(3)      | 25701.13          | 3889.764(12)     | 0.02             | 470              | 3.4e+6           | D                | $^3P_2$          | $^3P_0$          | 5               | P38G2,1          | B99              |
| 3894.82(3)      | 25667.86          | 3894.824(10)     | 0.00             | 65               |                  |                  |                  |                  |                  |                  |
| 3902.079(8)     | 25620.103         | 3902.0794(8)     | 0.0001           | 910              | 4.0e+7           | B                | $^1D_2$          | $^3P_0$          | 2               | K01c             | J07              |
| $\lambda_{obs}$ (Å) | $\sigma_{obs}$ (cm⁻¹) | $\lambda_{R(2)}$ (Å) | $\Delta \lambda_{obs-R(2)}$ (Å) | $I_{obs}$ (arb. u.) | $A$ (s⁻¹) | Type | Transition | Notes | Line Ref. | TP Ref. |
|------------------|------------------|------------------|------------------|------------------|-----------|-------|-----------|-------|-----------|--------|
| 3921.32(3)      | 25949.38         | 3921.318(16)     | 0.00             | 19               | 5s4f      | $^3F^0_2$ | $5s1/2,p=12g$ |      | P38TP     |        |
| 3921.57(3)      | 2592.76          | 3921.567(18)     | 0.00             | 19               | 5s4f      | $^3F^0_3$ | $5s1/2,p=12g$ |      | P38TP     |        |
| 3922.12(3)      | 25892.21         | 3922.110(16)     | 0.01             | 80               | 5s4f      | $^3F^0_3$ | $5s1/2,p=12g$ |      | P38TP     |        |
| 3924.14(3)      | 25476.07         | 3924.146(18)     | -0.01            | 45               | 5s4f      | $^3F^0_4$ | $5s1/2,p=12g$ |      | P38TP     |        |
| 3924.68(3)      | 25472.57         | 3924.689(16)     | -0.01            | 11               | 5s4f      | $^3F^0_4$ | $5s1/2,p=12g$ |      | P38TP     |        |
| 3929.44(3)      | 25441.73         | 3929.439(18)     | 0.00             | 52               | 5s4f      | $^3F^0_3$ | $5s1/2,p=12g$ |      | P38TP     |        |
| 3929.98(3)      | 25438.24         | 3929.985(16)     | -0.01            | 36               | 5s4f      | $^1F^0_3$ | $5s1/2,p=12g$ |      | P38TP     |        |
| 3934.3742(19)   | 25099.809        | 3934.3750(9)     | -0.0008          | 240              | 5s6p      | $^3P^0_0$ | $5s8s$ | $^3S^0_1$ | K01c   | J07     |
| 3962.3330(14)   | 25230.518        | 3962.3328(8)     | 0.0002           | 490              | 5s6p      | $^3P^0_1$ | $5s7p$ | $^3S^0_1$ | K01c   | J07     |
| 4004.6688(13)   | 24963.80         | 4004.6685(15)    | -0.001           | 79               | 5s6p      | $^3P^0_1$ | $5s7d$ | $^3D^2$ | P38G2,TP | J07     |
| 4007.5830(24)   | 24945.644        | 4007.5788(21)    | 0.0042           | 110              | 5s5d      | $^3D^3$ | $5s7p$ | $^3P^2_0$ | K01c   | J07     |
| 4012.52(3)      | 24914.97         | 4012.521(13)     | 0.00             | 12               | 5s4f      | $^3F^0_2$ | $5s1/2,p=11g$ |      | P38TP     |        |
| 4013.10(3)      | 24911.36         | 4013.090(12)     | 0.01             | 28               | 5s4f      | $^3F^0_2$ | $5s1/2,p=11g$ |      | P38TP     |        |
| 4013.35(3)      | 24909.77         | 4013.351(13)     | 0.00             | 42               | 5s4f      | $^3F^0_3$ | $5s1/2,p=11g$ |      | P38TP     |        |
| 4013.92(3)      | 24906.26         | 4013.920(12)     | 0.00             | 96               | 5s4f      | $^3P^0_3$ | $5s1/2,p=11g$ |      | P38TP     |        |
| 4016.04(3)      | 24893.14         | 4016.052(13)     | -0.01            | 61               | 5s5d      | $^3D^1$ | $5s7p$ | $^3P^0_1$ |       | B99     |
| 4021.58(3)      | 24858.84         | 4021.597(12)     | -0.02            | 67               | 5s4f      | $^3F^0_4$ | $5s1/2,p=11g$ |      | P38TP     |        |
| 4022.17(3)      | 24855.17         | 4022.168(12)     | 0.00             | 34               | 5s4f      | $^3F^0_3$ | $5s1/2,p=11g$ |      | P38TP     |        |
| 4023.88(5)      | 24844.6          | 4023.954(7)      | -0.07            | 388f             | 5s5d      | $^3D^1$ | $5s7p$ | $^3P^0_0$ | P38TP   | B99     |
| 4027.79(3)      | 24820.51         | 4027.838(4)      | -0.05            | 54               | 5s5d      | $^3D^2$ | $5s7p$ | $^3P^0_1$ | P38TP   | B99     |
| 4056.9378(12)   | 24642.173        | 4056.9377(9)     | 0.0001           | 1300             | 5s6p      | $^3P^2_0$ | $5s8s$ | $^3S^0_1$ | K01c   | J07     |
| 4109.34(3)      | 24327.96         | 4109.34(3)       | 13               | 5s6d             | $^3D^1$ | $5s12f$ | $^3F^0_2$ |      | P38TP     |        |
| 4109.87(3)      | 24324.78         | 4109.86(4)       | 0.01             | 8                | 5s6d      | $^3D^1$ | $5s12f$ | $^3F^0_3$ | P38TP   |        |
| 4112.01(3)      | 24312.17         | 4112.01(3)       | 5                | 5s6d             | $^3D^2$ | $5s12f$ | $^3F^0_3$ |      | P38TP     |        |
| 4115.61(5)      | 24290.9          | 4115.61(4)       | 0.00             | 10               | 5s6d      | $^3D^2$ | $5s12f$ | $^3F^0_3$ | P38TP   |        |
| $\lambda_{\text{obs}}$ | $\sigma_{\text{obs}}$ | $\lambda_{\text{Ritz}}$ | $\Delta \lambda_{\text{obs>Ritz}}$ | $I_{\text{obs}}$ | $A$ | Type | Transition | Notes | Line Ref. | TP Ref. |
|-----------------|-----------------|-----------------|-------------------|-------|-----|-------|-----------|-------|-----------|--------|
| 4122.79(3)     | 24248.58        | 4122.79(3)      | 0.00               | 25    | 5s6d | $^1$D$_3$ | $^1$S$_1$ | P38TP |
| 4139.97(3)     | 24147.93        | 4139.974(11)    | 0.00               | 38    | 5s4f | $^3$F$_2$ | $^3$F$_2$ | P38TP |
| 4140.588(14)   | 24144.35        | 4140.579(9)     | 0.009              | 110   | 5s4f | $^3$F$_2$ | $^3$F$_2$ | P38G1 |
| 4140.854(17)   | 24142.80        | 4140.857(11)    | -0.003             | 110   | 5s4f | $^3$F$_3$ | $^3$F$_3$ | P38G1 |
| 4141.458(17)   | 24139.28        | 4141.462(9)     | -0.004             | 190   | 5s4f | $^3$F$_3$ | $^3$F$_3$ | P38G1 |
| 4143.73(3)     | 24126.03        | 4143.732(11)    | 0.0              | 38    | 5s4f | $^3$F$_4$ | $^3$F$_4$ | P38G1 |
| 4144.33(3)     | 24122.55        | 4144.339(10)    | -0.01             | 19    | 5s4f | $^3$F$_4$ | $^3$F$_4$ | P38G1 |
| 4149.63(3)     | 24091.72        | 4149.635(11)    | -0.01             | 550   | 5s4f | $^3$F$_4$ | $^3$F$_4$ | P38G4 |
| 4150.23(3)     | 24088.22        | 4150.243(9)     | 0.00               | 100   | 5s4f | $^3$F$_3$ | $^3$F$_3$ | P38G1 |
| 4205.0626(19)  | 23774.161       | 4205.0626(19)   | 290               | 3.9e+7 | C+ | 5s6p | $^1$P$_1$ | $^1$S$_0$ | K01c  |
| 4213.01(5)     | 23729.3         | 4213.007(23)    | 0.00               | 450   | 5s6d | $^1$D$_1$ | $^3$F$_2$ | P38G1,TP |
| 4213.66(4)     | 23725.65        | 4213.659(24)    | 0.00               | 330   | 5s6d | $^1$D$_1$ | $^3$F$_3$ | P38G1,TP |
| 4215.59(4)     | 23714.78        | 4215.593(3)     | 0.00               | 57    | 5s6d | $^1$D$_2$ | $^3$F$_3$ | P38G1,TP |
| 4219.08(5)     | 23695.2         | 4219.050(23)    | 0.03               | 170   | 5s6d | $^1$D$_2$ | $^3$F$_3$ | P38G1,TP |
| 4219.70(5)     | 23691.7         | 4219.703(24)    | 0.00               | 450   | 5s6d | $^1$D$_3$ | $^3$F$_3$ | P38G1,TP |
| 4227.16(4)     | 23649.89        | 4227.17(3)      | -0.01              | 240   | 5s6d | $^1$D$_3$ | $^3$F$_3$ | P38G1,TP |
| 4228.55(5)     | 23642.1         | 4228.590(23)    | -0.04              | 240   | 5s6d | $^1$D$_3$ | $^3$F$_3$ | P38G1,TP |
| 4229.23(5)     | 23638.3         | 4229.247(24)    | -0.02              | 190   | 5s6d | $^1$D$_3$ | $^3$F$_3$ | P38G1,TP |
| 4292.064(11)   | 23292.26        | 4292.0586(15)   | 0.005              | 100   | 4.8e+5 | 5s6p | $^1$P$_1$ | $^3$S$_1$ | P38G3  |
| 4325.684(7)    | 23111.23        | 4325.688(6)     | -0.004             | 440   | 5s4f | $^1$F$_2$ | $^5$P$_2$ | P38G3  |
| 4326.375(15)   | 23107.54        | 4326.367(9)     | 0.008              | 330   | 5s4f | $^1$F$_2$ | $^5$P$_2$ | P38G3  |
| 4326.645(15)   | 23106.10        | 4326.652(7)     | -0.007             | 330   | 5s4f | $^1$F$_3$ | $^5$P$_2$ | P38G3  |
| 4327.332(15)   | 23102.43        | 4327.331(9)     | 0.001              | 390   | 5s4f | $^1$F$_3$ | $^5$P$_2$ | P38G3  |
| 4329.80(4)     | 23089.24        | 4329.791(8)     | 0.01               | 290   | 5s4f | $^3$F$_4$ | $^5$P$_2$ | P38G3  |
| 4330.46(4)     | 23085.77        | 4330.472(9)     | -0.01              | 290   | 5s4f | $^3$F$_4$ | $^5$P$_2$ | P38G3  |
| 4336.26(4)     | 23054.89        | 4336.237(7)     | 0.02               | 200   | 5s4f | $^3$F$_3$ | $^5$P$_2$ | P38G3  |
| 4336.93(4)     | 23051.33        | 4336.920(9)     | 0.01               | 58    | 5s4f | $^3$F$_3$ | $^5$P$_2$ | P38G3  |
| 4358.00(4)     | 22939.85        | 4358.000(3)     | 0.00               | 110   | 2.2e+6 | 5s6d | $^1$D$_1$ | $^3$F$_2$ | P38G2, TW |
| 4358.39(4)     | 22937.78        | 4358.40(3)      | -0.01              | 48    | E2  | 5s6d | $^1$D$_1$ | $^3$F$_3$ | P38G2  |
| 4360.31(4)     | 22927.69        | 4360.32(3)      | -0.01              | 110   | 5s6d | $^1$D$_2$ | $^3$F$_3$ | P38G2,1 |
| $\lambda_{ob}$ (Å) | $\sigma_{ob}$ (cm$^{-1}$) | $\lambda_{Rzz}$ (Å) | $\Delta \lambda_{ob,Rzz}$ (Å) | $L_{ob}$ (arb.u.) | $A$ (s$^{-1}$) | Type $^c$ | Transition | Notes $^d$ | Line Ref. $^h$ | TP Ref. $^l$ |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 4364.46(4) | 22905.92 | 4364.46(3) | 0.00 | 170 | 4.0e+5 | D+ | 5s6d $^1D_2$ | 5p10f | 3F$^2$ | P38G2 | TW |
| 4364.87(4) | 22903.74 | 4364.87(3) | 0.00 | 230 | 2.3e+6 | D+ | 5s6d $^1D_2$ | 5p10f | 3F$^3$ | P38G2 | TW |
| 4372.90(4) | 22861.69 | 4372.89(3) | 0.01 | 360 | 2.6e+6 | D+ | 5s6d $^1D_1$ | 5p10f | 3F$^4$ | P38G3,2,1 | TW |
| 4375.08(4) | 22850.30 | 4375.08(3) | 0.00 | 27 | 2.9e+5 | D+ | 5s6d $^1D_1$ | 5p10f | 3F$^3$ | P38G1 | TW |
| 4484.423(16) | 4489.11(4) | 4500.806(18) | -0.002 | 360 | 9.7e+6 | C+ | 5p$^2$ $^1S_0$ | 5p10p | 3P$^1$ | P38G3,2 | B99 |
| 4571.320(8) | 21869.39 | 4571.286(23) | 0.034 | 510 | E2 | 5s6d $^1D_1$ | 5s9f | 3F$^2$ | P38G3 | TW |
| 4572.95(4) | 21861.61 | 4572.94(3) | 0.01 | 170 | 1.1e+6 | E | 5p$^2$ $^1D_2$ | 5s9p | 3P$^1$ | P38G3,2 | B99 |
| 4578.02(4) | 21837.40 | 4577.995(8) | 0.03 | 530bl* | 7e+5 | D+ | 5s6d $^1D_1$ | 5s9f | 3F$^2$ | P38G3 | TW |
| 4578.40(4) | 21835.58 | 4578.401(23) | 0.00 | 530bl* | 4.2e+6 | D+ | 5s6d $^1D_2$ | 5s9f | 3F$^3$ | P38G3 | TW |
| 4587.03(4) | 21794.51 | 4587.01(3) | 0.02 | 520 | 4.7e+6 | D+ | 5s7p $^3P_{2,2}$ | 5s15p | 3S$^1$ | P38G3 | TW |
| 4589.28(6) | 21783.8 | 4589.230(8) | 0.05 | 57bl | 57bl | | | | |
| 4589.64(4) | 21782.09 | 4589.639(23) | 0.00 | 54bl | 5.2e+5 | D+ | 5s6d $^1D_1$ | 5s9f | 3F$^3$ | P38G1 | TW |
| 4615.310(21) | 21660.95 | 4615.307(9) | 0.003 | 200 | 5s$^4f$ | 3F$^2$ | 5s12p,5s8g | P38G3 | |
| 4616.083(17) | 21657.32 | 4616.068(9) | 0.015 | 540 | 5s$^4f$ | 3F$^2$ | 5s12p,5s4g | P38G3 | |
| 4616.405(17) | 21655.81 | 4616.405(9) | 0.000 | 140 | 5s$^4f$ | 3F$^2$ | 5s12p,5s4g | P38G3 | |
| 4617.175(21) | 21652.20 | 4617.166(9) | 0.009 | 350 | 5s$^4f$ | 3F$^2$ | 5s12p,5s4g | P38G3 | |
| 4619.987(21) | 21639.02 | 4619.979(10) | 0.008 | 410 | 5s$^4f$ | 3F$^2$ | 5s12p,5s4g | P38G3 | |
| 4620.728(13) | 21635.55 | 4620.741(8) | -0.013 | 350 | 5s$^4f$ | 3F$^2$ | 5s12p,5s4g | P38G3 | |
| 4627.312(17) | 21604.77 | 4627.318(9) | -0.006 | 320 | 5s$^4f$ | 3F$^2$ | 5s12p,5s4g | P38G3 | |
| 4628.074(17) | 21601.21 | 4628.083(8) | -0.009 | 510 | 5s$^4f$ | 3F$^2$ | 5s12p,5s4g | P38G3 | |
| 4637.047(9) | 21559.41 | 4637.055(9) | -0.008 | 610 | E2 | 5s5d $^3D_1$ | 5s4f | 3F$^3$ | P38G3 | |
| 4638.168(9) | 21554.20 | 4638.162(7) | 0.006 | 8800 | 1.77e+8 | B | 5s5d $^3D_1$ | 5s4f | 3F$^2$ | P38G3, J07,M96 | |
| 4644.581(9) | 21524.44 | 4644.572(5) | 0.009 | 5900 | 1.4e+7 | C | 5s5d $^3D_2$ | 5s4f | 3F$^3$ | 2 | P38G3 | M96 |
| 4652.00(4) | 21490.13 | 4651.990(7) | 0.01 | 240 | E2 | 5s5d $^3D_2$ | 5s4f | 3F$^4$ | P38G3 | |
| 4655.621(9) | 21473.40 | 4655.620(6) | 0.001 | 7800 | 1.84e+8 | B | 5s5d $^3D_2$ | 5s4f | 3F$^3$ | P38G3 | M96 |
| \( \lambda_{\text{obs}} \) (Å) | 0.004 | \( \lambda_{\text{rec}} \) (Å) | \( \Delta \lambda_{\text{obs-rec}} \) (Å) | 0.004 | \( A \) (s\(^{-1}\)) | Type | Transition | Notes | Line Ref. | TP Ref. |
|------------------|--------|------------------|------------------|--------|------------------|-------|----------|--------|----------|--------|
| 4656.740(9) | 21468.24 | 4656.736(6) | 0.004 | 1700 | 3.0e+7 | B | 5s5d | 1^{1}D_{2} | 5s4f | 3^{1}P_{2} | P38G3 | J07,M96 |
| 4637.590(9) | 21390.80 | 4637.605(3) | -0.006 | 390 | 1.8e+6 | D- | 5s5d | 1^{1}D_{1} | 5s4f | 3^{1}F_{3} | P38G3 | M96 |
| 4681.105(9) | 21356.50 | 4681.115(6) | -0.010 | 16000 | 2.00e+8 | B | 5s5d | 1^{1}D_{2} | 5s4f | 3^{1}F_{3} | 2 | P38G3 | A86,M96 |
| 4664.779(9) | 21339.75 | 4664.791(5) | -0.012 | 2500 | 1.80e+7 | B | 5s5d | 1^{1}D_{2} | 5s4f | 3^{1}F_{3} | P38G3 | M96 |
| 4747.54(5) | 21057.64 | 4747.57(3) | -0.03 | 83 | 7e+5 | D+ | 5s5d | 1^{1}P_{1} | 5s13d | 1^{1}D_{2} | P38G1 |
| 4783.24(7) | 20900.5 | 4783.204(18) | 0.04 | 27 | 5s7p | 3^{1}P_{0} | 5s12d | 1^{1}D_{1} | P38G1 |
| 4796.82(7) | 20841.3 | 4796.80(4) | 0.02 | 79 | 5s5d | 1^{1}D_{2} | 5s4f | 3^{1}P_{2} | P38G1 |
| 4843.674(14) | 4843.67(4) | 0.00 | 88 | 5s7p | 3^{1}P_{1} | 5s13d | 3^{1}S_{1} | P38G1 | TW |
| 4856.27(7) | 20586.2 | 4856.27(4) | 0.00 | 56 | 6e+5 | D | 5s7p | 1^{1}P_{2} | 5s12d | 1^{1}D_{1} | P38G1 |
| 4902.18(5) | 20393.38 | 4902.14(3) | 0.04 | 56 | 6e+5 | D | 5s7p | 3^{1}P_{1} | 5s13d | 3^{1}S_{1} | P38G1 | TW |
| 4905.29(5) | 20380.47 | 4905.271(15) | 0.02 | 14 | 1.8e+6 | D+ | 5s6d | 1^{1}D_{1} | 5s8f | 3^{1}F_{3} | P38G1 | J07 |
| 4906.64(5) | 20374.85 | 4906.639(23) | 0.00 | 42 | 1.8e+6 | D+ | 5s6d | 1^{1}D_{1} | 5s8f | 3^{1}F_{3} | P38G1 | TW |
| 4907.07(5) | 20373.08 | 4907.07(3) | 0.00 | 180 | 4.2e+6 | D+ | 5s6d | 1^{1}D_{1} | 5s8f | 3^{1}F_{3} | P38G1 | TW |
| 4908.36(5) | 20367.70 | 4908.36(3) | 0.00 | 85 | 1.8e+6 | D+ | 5s6d | 1^{1}D_{1} | 5s8f | 3^{1}F_{3} | P38G1 | TW |
| 4914.85(5) | 20340.83 | 4914.837(23) | 0.01 | 83 | 4.5e+6 | D+ | 5s6d | 1^{1}D_{2} | 5s8f | 3^{1}F_{3} | P38G1 | TW |
| 4915.30(5) | 20338.96 | 4915.27(3) | 0.03 | 14 | 8e+5 | D+ | 5s6d | 1^{1}D_{2} | 5s8f | 3^{1}F_{3} | P38G1 | TW |
| 4924.93(5) | 20299.17 | 4924.91(4) | 0.02 | 140 | 5.0e+6 | C | 5s6d | 1^{3}D_{2} | 5s8f | 3^{1}F_{2} | P38G1 | TW |
| 4927.82(5) | 20287.30 | 4927.789(23) | 0.03 | 57 | 5.5e+5 | D+ | 5s6d | 1^{3}D_{3} | 5s8f | 3^{1}F_{3} | P38G1 | TW |
| 4971.75(5) | 20108.05 | 4971.730(17) | 0.02 | 47 | 1.0e+6 | E | 5s7p | 1^{1}P_{1} | 5s13s | 1^{3}S_{0} | 1 | P38G1 | TW |
| 4973.776(20) | 20099.84 | 4973.754(12) | 0.022 | 460 | 2.8e+6 | D | 5s7p | 1^{1}D_{2} | 5s5f | 3^{1}F_{3} | P38G3 | J07 |
| 4983.76(5) | 20059.56 | 4983.704(13) | 0.06 | 74 | 1.9e+5 | D+ | 5s7p | 1^{1}D_{2} | 5s5f | 3^{1}F_{3} | P38G3 | J07 |
| 5006.76(3) | 5028.874(21) | 3.8e+6 | D+ | 5s6d | 1^{3}D_{2} | 5s9f | 3^{1}F_{3} | P38G3 | J07 |
| 5043.93(5) | 19820.27 | 5043.913(22) | 0.02 | 170bl | 5s7p | 1^{3}P_{1} | 5s11d | 1^{3}D_{2} | P38G1 | TW |
| 5044.623(25) | 19817.56 | 5044.611(20) | 0.012 | 100bl | 5s7p | 1^{3}P_{1} | 5s11d | 1^{3}D_{2} | P38G1 | TW |
| 5099.509(13) | 19604.30 | 5099.504(9) | -0.004 | 33 | 4.1e+5 | D+ | 5s7p | 1^{3}P_{0} | 5s12s | 3^{1}S_{1} | P38G1 | TW |
| 5109.36(5) | 19566.47 | 5109.34(4) | 0.02 | 140 | 5s7p | 1^{3}P_{2} | 5s11d | 3^{1}D_{3} | P38G1 | TW |
| $\lambda_{\text{obs}}$ (Å) | $\sigma_{\text{obs}}$ (cm$^{-1}$) | $\lambda_{\text{Rex}}$ (Å) | $\Delta \lambda_{\text{obs-Rex}}$ (Å) | $I_{\text{obs}}$ (arb.u.) | $A$ (s$^{-1}$) | Type | Notes | Line Ref. | TP Ref. |
|--------------------------|-------------------------------|-----------------------------|--------------------------------|--------------------------|----------------|-------|--------|----------|---------|
| 5110.75(5)              | 19561.14                      | 5110.744(23)               | 0.01                            | 30                       | 5s7p $^3P^o_{2}$ 5s11d $^3D^o_2$ | P38G1 |
| 5112.234(13)            | 19555.47                      | 5112.234(10)               | 0.00                            | 31                       | 4.6e+5 D+      | P38G1 |
| 5115.10(3)              | 19544.51                      | 5115.108(14)               | -0.01                           | 800                      | 5s4f $^3P^o_{2}$ 5s1/2,5p=57g | P38G3,1|
| 5116.06(3)              | 19540.85                      | 5116.040(14)               | 0.02                            | 590                      | 1.1e+6 D+      | P38G1 |
| 5116.47(3)              | 19539.28                      | 5116.456(14)               | 0.01                            | 350                      | 5s7p $^3P^o_{2}$ 5s11d $^3S^o_1$ | P38G3 |
| 5117.392(21)            | 19535.76                      | 5117.388(13)               | 0.004                           | 810                      | 5s4f $^3P^o_{3}$ 5s1/2,5p=57g | P38G3 |
| 5120.839(21)            | 19522.61                      | 5120.847(14)               | -0.008                          | 960                      | 5s4f $^3P^o_{4}$ 5s1/2,5p=57g | P38G3 |
| 5121.768(21)            | 19510.07                      | 5121.781(13)               | -0.013                          | 880                      | 5s4f $^3P^o_{3}$ 5s1/2,5p=57g | P38G3,1|
| 5129.86(5)              | 19488.28                      | 5129.865(14)               | -0.01                           | 710                      | 5s4f $^3P^o_{3}$ 5s1/2,5p=57g | P38G3 |
| 5130.78(5)              | 19484.78                      | 5130.802(13)               | -0.02                           | 240                      | 5s4f $^3P^o_{3}$ 5s1/2,5p=57g | P38G3,1|
| 5158.54(5)              |                               |                             | 3.0e+5                          | D+                       | 5s7p $^3P^o_{2}$ 5s11d $^3D^o_2$ | P38G1 |
| 5175.41(3)              | 19316.77                      | 5175.394(24)               | 0.02                            | 200                      | 5s7p $^3P^o_{2}$ 5s11d $^3D^o_2$ | P38G1 |
| 5184.455(13)            | 19283.06                      | 5184.446(9)                | 0.009                           | 160                      | 2.0e+6 D+      | P38G1 |
| 5253.498(14)            | 19029.64                      | 5253.495(13)               | 0.003                           | 48                       | 9e+5 E         | P38G1 |
| 5258.16(6)              | 19012.84                      | 5258.16(4)                 | 0.00                            | 26                       | 5s7p $^3P^o_{2}$ 5s11d $^3S^o_1$ | P38G1 |
| 5309.492(17)            | 18828.953                     | 5309.492(16)               | 0.0000                          | 550                      | 2.6e+6 D      | J07   |
| 5402.54(3)              | 18504.68                      | 5402.539(19)               | 0.00                            | 110                      | 5s7p $^3P^o_{1}$ 5s10d $^1D^o_2$ | P38G1 |
| 5411.65(6)              | 18473.51                      | 5411.65(3)                 | 0.00                            | 130                      | 2.4e+6 E       | P38G1 |
| 5417.09(6)              | 18454.97                      | 5417.131(17)               | -0.04                           | 18                       | E2              | P38G1 |
| 5418.513(15)            | 18450.12                      | 5418.514(11)               | -0.001                          | 140                      | 3.2e+6 D+      | P38G1 |
| 5433.29(6)              | 18399.95                      | 5433.258(12)               | 0.03                            | 18                       | E2              | P38G1 |
| 5435.38(3)              | 18392.88                      | 5435.396(16)               | -0.02                           | 440                      | 3.9e+6 D+      | P38G1 |
| 5436.792(15)            | 18388.09                      | 5436.789(11)               | 0.003                           | 160                      | 2.2e+6 D+      | P38G1 |
| 5496.74(3)              | 18187.55                      | 5496.757(14)               | -0.02                           | 110                      | E2              | P38G1 |
| 5497.492(12)            | 18185.16                      | 5497.486(8)                | 0.006                           | 1000                     | 7.5e+6 C       | P38G1 |
| 5498.111(3)             | 18163.01                      | 5498.098(22)               | 0.01                            | 390                      | E2              | P38G1 |
| 5503.111(6)             | 18166.49                      | 5503.105(5)                | 0.01                            | 64                       | E2              | P38G1 |
| 5507.053(18)            | 18153.49                      | 5507.048(14)               | 0.005                           | 1000                     | 7.8e+6 C       | P38G1 |
| 5507.772(12)            | 18151.12                      | 5507.779(9)                | -0.007                          | 570                      | 1.4e+6 D+      | P38G1 |

Notes:
- $^a$ 
- $^b$ 
- $^c$ 
- $^d$ 
- $^e$ 
- $^f$ 

TYPICAL TABLE
| $\lambda_{\text{obs}}$ (Å) | $\sigma_{\text{obs}}$ (cm$^{-1}$) | $\lambda_{\text{Ritz}}$ (Å) | $\Delta \lambda_{\text{obs-Ritz}}$ (Å) | $I_{\text{obs}}$ (arb.u.) | $A$ (s$^{-1}$) | Type$^f$ | Transition | Notes$^g$ | Line Ref.$^h$ | TP Ref.$^l$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 5510.884(12) | 18140.87 | 5510.883(12) | 0.001 | 1000 | 5.5e+6 | C | 5s7p $^3p^0_2$ 5s10d $^1D_3$ | P38G3 | TW |
| 5513.0057(21) | 18133.888 | 5513.0060(21) | -0.0003 | 1500 | 4.9e+6 | C | 5s7p $^3p^0_2$ 5s4f $^3F_3$ | K01c | J07 |
| 5513.10(3) | 18133.58 | 5513.083(16) | 0.02 | 350 | 1.4e+6 | D+ | 5s7p $^3p^0_2$ 5s10d $^1D_3$ | P38G3 | TW |
| 5514.53(6) | 18128.88 | 5514.516(11) | 0.01 | 23 | 1.5e+5 | D+ | 5s7p $^3p^0_2$ 5s10d $^1D_1$ | P38G1 | TW |
| 5519.36(6) | 18113.01 | 5519.35(5) | 0.01 | 1100 | 8.8e+6 | C | 5s6d $^1D_3$ 5s7f $^3F_4$ | P38G3 | TW |
| 5523.31(3) | 18100.07 | 5523.314(15) | 0.00 | 180 | 1.0e+6 | D+ | 5s6d $^1D_3$ 5s7f $^3F_3$ | P38G1 | TW |
| 5525.965(15) | 18091.36 | 5525.965(11) | 0.000 | 43 | 5s7p $^3p^0_1$ 5s11s $^1S_0$ | P38G1 | |
| 5528.600(21) | 18082.74 | 5528.577(7) | 0.023 | 290 | 7e+5 | D | 5p$^2_1$ 5s4f $^3F_3$ | K01c | J07 |
| 5530.16(5) | 18077.65 | 5530.151(9) | 0.01 | 33 | 5p$^2_1$ 5s4f $^3F_2$ | P38G1 | |
| 5536.438(15) | 18057.14 | 5536.445(9) | -0.007 | 130 | 8e+5 | D+ | 5s7p $^3p^0_0$ 5s11s $^3S_1$ | P38G1 | TW |
| 5555.529(15) | 17995.09 | 5555.525(9) | 0.004 | 140 | 2.3e+6 | D+ | 5s7p $^3p^0_1$ 5s11s $^3S_1$ | P38G1 | TW |
| 5576.88(3) | 17926.19 | 5576.866(20) | 0.01 | 1200 | 5s7p $^3p^0_1$ 5s10d | P38G3 | |
| 5611.89(3) | 17814.36 | 5611.884(17) | 0.01 | 28 | 3.2e+5 | D+ | 5s7p $^3p^0_1$ 5s10d | P38G1 | TW |
| 5636.733(16) | 17735.85 | 5636.710(9) | 0.023 | 140 | 4.0e+6 | D+ | 5s7p $^3p^0_2$ 5s11s $^3S_1$ | P38G1 | TW |
| 5708.486(16) | 17512.92 | 5708.483(11) | 0.003 | 270 | 5s7p $^3p^0_1$ 5s11s $^3S_0$ | P38G1 | |
| 5721.807(16) | 17472.15 | 5721.806(12) | 0.001 | 130 | 5s7s $^1S_0$ 5s9p $^3P_1$ | P38G1 | |
| 5758.184(17) | 17361.77 | 5758.194(13) | -0.010 | 32 | 5s7s $^1S_0$ 5s9p $^3P_1$ | P38G1 | |
| 5853.1713(10) | 17080.021 | 5853.1709(9) | 0.0004 | 3400 | 6.3e+7 | B | 5s6p $^3p^0_0$ 5s6d $^3D_1$ | K01c | J07 |
| 5903.3920(10) | 16934.721 | 5903.3916(9) | 0.0004 | 9000 | 8.1e+7 | B | 5s6p $^3p^0_1$ 5s6d $^3D_2$ | K01c | J07 |
| 5915.2623(14) | 16900.738 | 5915.2627(12) | -0.0004 | 1300 | 4.5e+7 | B | 5s6p $^3P_1$ 5s6d $^3D_1$ | K01c | J07 |
| 5918.7693(11) | 16890.724 | 5918.7693(10) | 0.0000 | 5100 | 8.4e+7 | B | 5s6p $^3P_1$ 5s6d $^3D_2$ | K01c | J07 |
| 6062.96(4) | 16489.02 | 6062.970(25) | -0.010 | 130 | 8e+5 | D+ | 5s7p $^3P_1$ 5s9d | P38G1 | TW |
| 6095.9333(19) | 16399.839 | 6095.9334(19) | -0.0001 | 3300 | 1.09e+8 | B | 5s6p $^3P_2$ 5s6d $^3D_1$ | K01c | J07 |
| 6108.706(19) | 16365.55 | 6108.689(11) | 0.017 | 140 | 3.7e+6 | D+ | 5s7p $^3p^0_0$ 5s9d $^3D_1$ | P38G1 | TW |
| 6115.8707(15) | 16346.377 | 6115.8707(12) | 0.0000 | 830 | 2.7e+7 | B | 5s6p $^3P_2$ 5s6d $^3D_2$ | K01c | J07 |
| 6128.62(4) | 16312.38 | 6128.6126(17) | 0.01 | 130/ | 3.0e+6 | D+ | 5s6p $^3P_2$ 5s6d $^3D_1$ | P38G1 | J07 |
| 6129.391(19) | 16310.32 | 6129.391(12) | 0.000 | 160 | 4.6e+6 | C | 5s7p $^3P_1$ 5s9d $^3D_2$ | P38G1 | TW |
| 6131.959(19) | 16303.49 | 6131.925(9) | 0.034 | 280 | 2.5e+6 | D+ | 5s7p $^3P_1$ 5s9d $^3D_1$ | P38G1 | TW |
| 6137.51(8) | 16288.75 | 6137.483(3) | 0.03 | 110 | 3.7e+6 | D | 5s6d $^1D_2$ 5s7f $^3F_3$ | P38G1 | |
| 6139.88(4) | 16282.46 | 6139.863(3) | 0.02 | 2100 | 5s4f $^3P_2$ 5s11/2,5p=56g | P38G2,1 | |
| $\lambda_{\text{obs}}$ (Å) | $\sigma_{\text{obs}}$ (cm$^{-1}$) | $\lambda_{\text{Ritz}}$ (Å) | $\Delta \lambda_{\text{obs,Ritz}}$ (Å) | $I_{\text{obs}}$ (arb. u.) | $A$ (s$^{-1}$) | Type | Transition | Notes | Line Ref. | TP Ref. |
|--------------------------|--------------------------|--------------------------|--------------------------|------------------|-------------------|--------|----------------|---------------|-------------|------------|
| 6141.27(4) | 16278.76 | 6141.25(3) | 0.02 | 1500 | 5s4f $^3F^2_2$ & 5s$^2$P$_{3/2}$=5g | P38G2,1 |
| 6141.78(6) | 16277.41 | 6141.80(3) | -0.02 | 160 | 5s4f $^3F^2_3$ & 5s$^2$P$_{3/2}$=5g | P38G2,1 |
| 6143.20(6) | 16273.67 | 6143.20(3) | 0.00 | 2100 | 5s4f $^3F^2_3$ & 5s$^2$P$_{3/2}$=5g | P38G2,1 |
| 6148.10(6) | 16260.68 | 6148.13(3) | -0.03 | 2100 | 5s4f $^3F^2_4$ & 5s$^2$P$_{3/2}$=5g | P38G2,1 |
| 6149.49(6) | 16257.00 | 6149.53(3) | -0.04 | 2200 | 5s4f $^3F^2_4$ & 5s$^2$P$_{3/2}$=5g | P38G2,1 |
| 6161.09(8) | 16226.41 | 6161.13(3) | -0.04 | 2000 | 5s4f $^3F^2_3$ & 5s$^2$P$_{3/2}$=5g | P38G2,1 |
| 6162.53(6) | 16222.63 | 6162.54(3) | -0.02 | 4100 | 5s4f $^3F^2_3$ & 5s$^2$P$_{3/2}$=5g | |
| 6224.27(8) | 16061.69 | 6224.26(5) | 0.01 | 120 | 6.3e+6 | C | 5s7p $^3P^0_2$ & 5s9d $^3D^1_1$ | 1 | P38GI | TW |
| 6228.368(19) | 16051.13 | 6228.363(13) | 0.005 | 200 | 1.6e+6 | D+ | 5s7p $^3P^0_2$ & 5s9d $^3D^1_2$ | 1 | P38GI | TW |
| 6231.00(4) | 16044.34 | 6230.979(10) | 0.02 | 130b | 1.8e+5 | D+ | 5s7p $^3P^0_2$ & 5s9d $^3D^1_2$ | 1 | P38GI | TW |
| 6283.40(4) | 15910.56 | 6283.39(3) | 0.01 | 69 | 8.5e+6 | C | 5s7p $^3P^0_2$ & 5s9d $^3D^1_2$ | 1 | P38GI | TW |
| 6302.636(20) | 15861.99 | 6302.644(12) | -0.008 | 57 | 7.5e+6 | E | 5s7p $^3P^0_2$ & 5s10s $^3S^0_1$ | 1 | P38GI | TW |
| 6304.874(16) | 15856.36 | 6304.883(3) | -0.009 | 230 | 2.9e+6 | D+ | 5s6s $^3P^1_3$ & 5s6p $^3P^1_1$ | P38GI,1 | J07 |
| 6337.215(20) | 15775.44 | 6337.212(11) | 0.003 | 120 | 8.5e+5 | D+ | 5s7p $^3P^0_0$ & 5s10s $^3S^1_1$ | P38GI | TW |
| 6354.74(4) | 15731.93 | 6354.758(13) | -0.02 | 110 | 3.2e+5 | D+ | 5s7p $^3P^0_1$ & 5s9d $^3D^1_2$ | P38GI | TW |
| 6362.252(20) | 15713.36 | 6362.222(9) | 0.030 | 230 | 2.2e+6 | D+ | 5s7p $^3P^0_1$ & 5s10s $^3S^1_1$ | P38GI | TW |
| 6437.006(21) | 15530.88 | 6437.016(7) | -0.010 | 95 | 1.6e+6 | D+ | 5s6p $^3P^1_2$ & 5s7$^3P^1_1$ | P38GI,1 | J07 |
| 6468.975(21) | 15454.13 | 6468.921(9) | 0.054 | 270 | 3.9e+6 | D+ | 5s7p $^3P^0_2$ & 5s10s $^3S^1_1$ | P38GI | TW |
| 6473.23(4) | 15443.98 | 6473.23(4) | 24h$^1$ | 5s$^2$P$_{1/2}$=4g & 5s$^2$P$_{1/2}$=4h | P38P |
| 6473.35(4) | 15443.69 | 6473.35(4) | 24h$^1$ | 5s$^2$P$_{1/2}$=5g & 5s$^2$P$_{1/2}$=5h | P38P |
| 6541.180(21) | 15283.54 | 6541.179(13) | 0.001 | 150 | 7e+6 | E | 5s7p $^3P^0_1$ & 5s10s $^3S^0_1$ | 1 | P38GI | TW |
| 6627.03(4) | 15085.54 | 6627.03(4) | 25h$^1$ | 5s$^2$P$_{3/2}$=4g & 5s$^2$P$_{3/2}$=4h | P38P |
| 6627.16(4) | 15085.24 | 6627.16(4) | 25h$^1$ | 5s$^2$P$_{3/2}$=5g & 5s$^2$P$_{3/2}$=5h | P38P |
| 6666.43(13) | 14996.4 | 6666.385(3) | 0.05 | 35 | 2.1e+6 | C | 5s6p $^3P^1_1$ & 5s6d $^3D^2_2$ | P38GI,1 | J07 |
| 6750.63(9) | 14809.35 | 6750.59(4) | 0.04 | 67 | 1.5e+6 | D+ | 5s6p $^3P^1_1$ & 5s6d $^3D^2_1$ | 1 | P38GI | J07 |
| 6751.88(5) | 14806.60 | 6751.84(3) | 0.04 | 160 | 1.5e+7 | C+ | 5s6d $^3D^2_1$ & 5s6f $^3P^2_2$ | P38GI | B99 |
| 6765.91(9) | 14775.89 | 6765.85(3) | 0.06 | 160 | 1.5e+7 | C+ | 5s6d $^3D^2_1$ & 5s6f $^3P^2_2$ | P38GI | B99 |
| 6767.36(9) | 14772.74 | 6767.37(3) | -0.01 | 66 | 2.7e+6 | C+ | 5s6d $^3D^2_1$ & 5s6f $^3P^2_2$ | P38GI | B99 |
| $\lambda_{obs}$ | $\sigma_{obs}$ | $\lambda_{Rex}$ | $\Delta_{obs,Rex}$ | $I_{obs}$ | $A_e$ | Type | Transition | Notes | Line Ref. | TP Ref. |
|-------------|------------|-------------|----------------|----------|-------|------|------------|-------|-----------|---------|
| (Å)        | (cm$^{-1}$) | (Å)         | (Å)           | (arb.u.) | (s$^{-1}$) |      |            |       |           |         |
| 6783.72(9) | 14737.11   | 6783.68(6)  | 0.04          | 150      | 1.7e+7   | C$^+$| 5s6d $^3$D$_3$ | P38G1 | B99       |
| 6790.42(5) | 14722.56   | 6790.42(3)  | 0.00          | 45       | 1.9e+6   | C$^+$| 5s6d $^1$D$_3$ | P38G1 | B99       |
| 6831.65(7) | 14633.72   | 6831.65(7)  | -0.01         | 7273.07  | 5.1e+6   |     | 5s5f $^3$F$_2$ | P38G1 |           |
| 6831.78(7) | 14633.43   | 6831.78(7)  | -0.01         | 7272.05  | 5.1e+6   |     | 5s5f $^3$F$_3$ | P38G1 |           |
| 6841.03(7) | 14615.64   | 6841.04(4)  | -0.01         | 7254.98  | 5.1e+6   |     | 5s5f $^3$F$_4$ | P38G1 |           |
| 6841.28(7) | 14613.11   | 6841.25(4)  | -0.01         | 7273.07  | 5.1e+6   |     | 5s5f $^3$F$_5$ | P38G1 |           |
| 6842.90(9) | 14609.65   | 6842.91(4)  | -0.01         | 7273.07  | 5.1e+6   |     | 5s5f $^3$F$_6$ | P38G1 |           |
| 6848.79(14)| 14597.1    | 6848.82(4)  | -0.01         | 7273.07  | 5.1e+6   |     | 5s5f $^3$F$_7$ | P38G1 |           |
| 6850.45(9) | 14593.56   | 6850.48(4)  | -0.01         | 7273.07  | 5.1e+6   |     | 5s5f $^3$F$_8$ | P38G1 |           |
| 6860.16(9) | 14572.90   | 6860.09(4)  | 0.00          | 15.59    | 1.5e+6   |     | 5s5f $^1$F$_3$ | P38G1 |           |
| 6861.85(14)| 14569.3    | 6861.76(4)  | 0.00          | 15.59    | 1.5e+6   |     | 5s5f $^3$F$_3$ | P38G1 |           |
| 6867.70(14)| 14556.9    | 6867.73(11) | -0.03         | 6790    | 6.5e+7   | B   | 5s6s $^3$S$_1$ | K01c | J07      |
| 6891.5821(19)| 14506.454 | 6891.582(15)| -0.0005      | 3900    | 6.5e+7   | B   | 5s6s $^1$S$_{1/2}$ | P38G1 |           |
| 6933.32(4) | 14419.13   | 6933.343(23)| -0.02         | 34.5    | 1.3e+6   | D   | 5s7s $^3$S$_1$ | P38G1 | B99      |
| 6952.5     | 14419.13   | 6952.5      | -0.02         | 34.5    | 1.3e+6   | D   | 5s7s $^3$S$_1$ | P38G1 | B99      |
| 7108.57(8) | 14063.64   | 7108.572(21)| 0.00          | 92.5    | 1.3e+6   | D   | 5s6d $^1$D$_2$ | P38G1 |           |
| 7113.99(10)| 14052.93   | 7113.99(10) | 0.00          | 92.5    | 1.3e+6   | D   | 5s6d $^3$S$_1$ | P38G1 |           |
| 7114.14(10)| 14052.93   | 7114.14(10) | 0.00          | 92.5    | 1.3e+6   | D   | 5s6d $^3$S$_1$ | P38G1 |           |
| 7182.9038(21)| 13918.110 | 7182.9048(15)| -0.0010      | 5800    | 5.6e+7   | B   | 5s6s $^3$S$_1$ | K01c | J07      |
| 7218.22(10)| 13850.02   | 7218.15(4)  | 0.07          | 14.5    | 1.3e+6   | D   | 5s6f $^1$F$_2$ | P38G1 |           |
| 7219.96(10)| 13846.67   | 7219.99(3)  | 0.07          | 14.5    | 1.3e+6   | D   | 5s6f $^3$F$_2$ | P38G1 |           |
| 7220.22(10)| 13846.87   | 7220.23(4)  | 0.07          | 14.5    | 1.3e+6   | D   | 5s6f $^3$F$_3$ | P38G1 |           |
| 7222.05(10)| 13846.27   | 7222.07(4)  | 0.07          | 14.5    | 1.3e+6   | D   | 5s6f $^3$F$_4$ | P38G1 |           |
| 7228.63(10)| 13830.07   | 7228.66(4)  | 0.07          | 14.5    | 1.3e+6   | D   | 5s6f $^3$F$_5$ | P38G1 |           |
| 7230.44(10)| 13826.61   | 7230.51(3)  | 0.07          | 14.5    | 1.3e+6   | D   | 5s6f $^3$F$_6$ | P38G1 |           |
| 7241.23(10)| 13806.00   | 7241.22(4)  | 0.07          | 14.5    | 1.3e+6   | D   | 5s6f $^3$F$_7$ | P38G1 |           |
| 7243.06(10)| 13802.51   | 7243.07(4)  | 0.07          | 14.5    | 1.3e+6   | D   | 5s6f $^3$F$_8$ | P38G1 |           |
| 7254.9811(11)| 13779.836 | 7254.982(6) | -0.001        | 30.0    | 5.6e+7   | B   | 5s6p $^3$P$_0$ | K01c | J07      |
| 7272.04(11)| 13747.51   | 7272.05(7)  | -0.01         | 30.0    | 5.6e+7   | B   | 5s6d $^3$D$_2$ | P38G1 |           |
| 7273.07(11)| 13745.56   | 7273.07(7)  | 0.00          | 30.0    | 5.6e+7   | B   | 5s6d $^3$D$_1$ | P38G1 |           |
| $\lambda_{\text{obs}}$ (Å) | $\sigma_{\text{obs}}$ (cm$^{-1}$) | $\lambda_{\text{Ritz}}$ (Å) | $\Delta \lambda_{\text{obs-Ritz}}$ (Å) | $I_{\text{obs}}$ (arb.u.) | $A$ (s$^{-1}$) | Type | Transition | Notes | Line Ref. | TP Ref. |
|----------------------------|-------------------------------|-----------------------------|---------------------------------|--------------------------|-------------|-------|------------|--------|-----------|---------|
| 7276.637(3)                | 13738.827                     | 7276.6388(21)               | -0.002                          | 2400                     | 5.6e+7      | B     | 5s6s $^3S_1$ 5s6p $^3P_0$ | K01c   | J07       |
|                           |                               | 7282.35(7)                  |                                 |                          |              |       | 5s7d $^1D_2$ 5s11f $^3F_2$ | P38    |           |
|                           |                               | 7284.30(7)                  |                                 |                          |              |       | 5s7d $^1D_3$ 5s11f $^3F_3$ | P38    |           |
| 7293.00(11)                | 13708.00                      | 7292.96(8)                  | 0.04                            | 60                      | 3.4e+7      | B     | 5s6p $^3P_1$ 5s7s $^3S_1$ | K01c   | J07       |
|                           |                               | 7350.619(8)                 |                                 |                          |              |       | 5s6p $^3P_1$ 5s7s $^3S_0$ | K01c   | J07       |
| 7354.903(10)               | 13592.628                     | 7354.903(9)                 |                                 |                          |              |       | 5s7p $^3P_{1/2}$ 5s8d $^1D_2$ | P38GI  |           |
| 7434.27(3)                 | 13447.51                      | 7434.258(17)                | 0.01                            | 47                      | 1.9e+6      | D     | 5s6p $^3P_{1/2}$ 5s8d $^1D_2$ | P38GI  |           |
| 7453.12(6)                 | 13413.51                      | 7453.140(23)                | -0.02                           | 230                     | 1.2e+6      | D+    | 5s7p $^3P_{1/2}$ 5s8d $^1D_2$ | P38GI  | TW        |
| 7520.79(11)                | 13292.82                      | 7520.82(11)                 | -0.03                           | 18                      |              |       | 5s_{1/2}P_{1/2} 5s_{1/2}P_{1/2} | P38GI  |           |
| 7522.4(3)                  | 13290.0                       | 7522.70(11)                 | -0.3                            | 27bl*                   |              |       | 5s_{1/2}P_{1/2} 5s_{1/2}P_{1/2} | P38GI  |           |
| 7523.3(3)                  | 13288.3                       | 7523.03(11)                 | 0.3                             | 27bl*                   |              |       | 5s_{1/2}P_{1/2} 5s_{1/2}P_{1/2} | P38GI  |           |
| 7524.95(11)                | 13285.46                      | 7524.91(11)                 | 0.04                            | 18                      |              |       | 5s_{1/2}P_{1/2} 5s_{1/2}P_{1/2} | P38GI  |           |
| 7602.86(3)                 | 13149.33                      | 7602.843(17)                | 0.02                            | 220                     | 6.8e+6      | C     | 5s7p $^3P_{0}$ 5s8d $^3D_1$ | P38GI  | TW        |
| 7625.65(3)                 | 13110.03                      | 7625.683(6)                 | -0.03                           | 51                      | 9e+5        | D     | 5s7p $^3P_{1/2}$ 5s8d $^3P_{1/2}$ | P38GI  | J07       |
| 7632.80(3)                 | 13097.74                      | 7632.798(16)                |                                 |                          |              |       | 5s7p $^3P_{1/2}$ 5s8d $^3P_{1/2}$ | P38GI  | TW        |
| 7638.88(3)                 | 13087.32                      | 7638.869(15)                |                                 |                          |              |       | 5s7p $^3P_{1/2}$ 5s8d $^3P_{1/2}$ | P38GI  | TW        |
| 7682.978(18)               | 13102.21                      | 7682.979(7)                 | -0.001                          | 1500                    | 5.6e+7      | B     | 5s6p $^3P_{1/2}$ 5s7s $^3S_1$ | K01c   | J07       |
| 7716.24(8)                 |                               | 7716.248                    |                                 |                          |              |       | 1.4e+6 D+ 1s10f $^3F_2$ | TW     |           |
| 7726.69(8)                 |                               | 7726.698                    |                                 |                          |              |       | 2.6e+5 D+ 1s10f $^3F_2$ | TW     |           |
| 7727.97(8)                 |                               | 7727.978                    |                                 |                          |              |       | 1.5e+6 D+ 1s10f $^3F_2$ | TW     |           |
| 7737.77(12)                | 12920.06                      | 7737.80(8)                  | -0.03                           | 37                      | 1.7e+6      | C     | 5s7d $^1D_3$ 5s10f $^3F_4$ | P38GI,2| TW        |
| 7740.70(9)                 | 12915.17                      | 7740.69(5)                  | 0.01                            | 310                     | 8.5e+6      | C+    | 5s6d $^1D_2$ 5s6f $^1F_3$ | P38GI,2| B99       |
| 7744.66(8)                 |                               | 7744.668                    |                                 |                          |              |       | 1.8e+5 D+ 1s10f $^3F_3$ | TW     |           |
| 7760.81(12)                | 12881.71                      | 7760.75(4)                  | 0.06                            | 42                      |              |       | 5s6d $^1D_2$ 5s6f $^3F_3$ | P38GI  |           |
| 7776.95(3)                 | 12854.98                      | 7776.94(3)                  | 0.01                            | 320                     | 1.2e+7      | C     | 5s7p $^3P_{1/2}$ 5s8d $^3D_1$ | P38GI  | TW        |
| 7786.93(3)                 | 12838.50                      | 7786.885(17)                | 0.05                            | 100                     | 2.9e+6      | C     | 5s7p $^3P_{1/2}$ 5s8d $^3D_2$ | P38GI  | TW        |
| 7788.99(6)                 | 12835.10                      | 7789.028(25)                | -0.04                           | 320                     | 1.3e+7      | C     | 5s7p $^3P_{1/2}$ 5s8d $^3D_2$ | P38GI  | TW        |
| 7793.204(15)               |                               | 7793.204                    |                                 |                          |              |       | 3.2e+5 D+ 5s8d $^3D_1$ | TW     |           |
| $\lambda_{\text{obs}}$ (Å) | $\sigma_{\text{obs}}$ (cm$^{-1}$) | $\lambda_{\text{Rtx}}$ (Å) | $\Delta \lambda_{\text{obs-Rtx}}$ (Å) | $I_{\text{obs}}$ (arb. u.) | $A_e$ ($s^{-1}$) | Type | Transition | Notes | Line Ref. | TP Ref. |
|--------------------------|-------------------------------|--------------------------|-----------------------------|------------------------|----------------|-------|--------------|--------|---------|---------|
| 7802.22(6)               | 12813.34                      | 7802.17(13)              | 0.05                        | 64                     | 5s5f          | $^{3}P_{2}$ | $^{3}S_{1/2}$ | P38G1  |          |         |
| 7804.31(6)               | 12809.91                      | 7804.38(3)               | -0.07                       | 62                     | 5s5f          | $^{1}P_{1}$ | $^{3}S_{1/2}$ | P38G1  |          |         |
| 7806.87(9)               | 12808.39                      | 7806.81(4)               | 0.03                        | 39                     | 5s5f          | $^{3}P_{1}$ | $^{3}S_{1/2}$ | P38G1  |          |         |
| 7814.49(9)               | 12793.22                      | 7814.45(3)               | 0.04                        | 230                    | 5s5f          | $^{3}P_{1}$ | $^{3}S_{1/2}$ | P38G1  |          |         |
| 7816.62(12)              | 12789.74                      | 7816.67(3)               | -0.05                       | 120                    | 5s5f          | $^{3}F_{4}$ | $^{3}S_{1/2}$ | P38G1  |          |         |
| 7829.18(12)              | 12769.21                      | 7829.12(4)               | 0.06                        | 93                     | 5s5f          | $^{3}P_{1}$ | $^{3}S_{1/2}$ | P38G1  |          |         |
| 7831.36(12)              | 12765.66                      | 7831.35(4)               | 0.01                        | 40                     | 5s5f          | $^{3}P_{1}$ | $^{3}S_{1/2}$ | P38G1  |          |         |
| 7840.96(13)              | 12750.031                     | 7840.97(4)               | -0.013                      | 2900                   | 4.4e+7        | B                | $^{1}S_{0}$ | K01c    | J07     |
| 7985.46(6)               | 12519.31                      | 7985.47(18)              | 0.00                        | 75                     | 5.8e+5        | D+               | $^{1}P_{1}$ | P38G1   | TW      |
| 7992.10(16)              | 8035.40(15)                   | 7992.103(15)             | 5.5e+5                      | D+                     | 5s7p          | $^{3}P_{1}$ | $^{3}D_{2}$   | TW     |          |         |
| 8067.26(3)               | 12392.38                      | 8067.23(18)              | 0.02                        | 75                     | 1.3e+6        | D+               | $^{1}S_{0}$ | P38G1   | TW      |
| 8125.29(13)              | 12303.87                      | 8125.19(9)               | 0.10                        | 40                     | 2.2e+5        | E                | $^{1}D_{2}$ | P38G1   | TW      |
| 8153.74(13)              | 12260.94                      | 8153.70(10)              | 0.04                        | 32                     | 5s7p          | $^{3}P_{1}$ | $^{3}D_{2}$   | P38G1  |          |         |
| 8156.07(13)              | 12257.43                      | 8156.05(10)              | 0.02                        | 50h*                   | 5s7p          | $^{3}P_{1}$ | $^{3}D_{2}$   | P38G1  |          |         |
| 8156.27(13)              | 12257.14                      | 8156.30(10)              | -0.03                       | 50h*                   | 5s7p          | $^{3}P_{1}$ | $^{3}D_{2}$   | P38G1  |          |         |
| 8158.64(13)              | 12255.58                      | 8158.66(10)              | -0.02                       | 32                     | 5s7p          | $^{3}P_{1}$ | $^{3}D_{2}$   | P38G1  |          |         |
| 8191.63(3)               | 12204.23                      | 8191.662(18)             | -0.03                       | 190                    | 1.4e+6        | D+               | $^{3}P_{0}$ | P38G1   | TW      |
| 8227.01(13)              | 12151.75                      | 8226.982(6)              | 0.03                        | 2100                   | 2.4e+7        | B                | $^{1}D_{2}$ | P38G2   | J07     |
| 8233.48(3)               | 12142.19                      | 8233.500(15)             | -0.02                       | 480                    | 3.9e+6        | C                | $^{1}P_{1}$ | P38G1   | TW      |
| 8413.11(4)               | 11882.95                      | 8413.080(15)             | 0.03                        | 520                    | 6.6e+6        | C                | $^{3}S_{1}$ | P38G1   | TW      |
| 8422.23(14)              | 11870.08                      | 8422.14(3)               | 0.09                        | 71                     | 4.5e+5        | D+               | $^{3}F_{2}$ | P38G1   | TW      |
| 8423.51(14)              | 11868.28                      | 8423.52(8)               | -0.01                       | 92                     | 2.6e+6        | C                | $^{3}F_{2}$ | P38G1   | TW      |
| 8434.53(14)              | 11852.77                      | 8434.47(9)               | 0.06                        | 250                    | 2.9e+6        | C                | $^{3}F_{2}$ | P38G1   | TW      |
| 8443.35(8)               | 11843.35                      | 8443.35(8)               | 3.2e+5                      | D+                     | 5s7p          | $^{1}P_{1}$ | $^{3}S_{1}$  | P38G1  |          |         |
| 8462.27(4)               | 11813.91                      | 8462.222(19)             | 0.05                        | 240                    | 1.2e+7        | C                | $^{3}P_{1}$ | P38G1   | TW      |
| 8572.25(15)              | 11662.35                      | 8572.268(9)              | -0.02                       | 72                     | 1.1e+6        | D+               | $^{3}P_{1}$ | P38G1   | J07     |
| 8592.22(17)              |                                |                          |                             |                        | 8e+5          | D+               | $^{3}P_{1}$ | P38G1   | TW      |
| \( \lambda_{\text{obs}} \) (Å) | \( \sigma_{\text{obs}} \) (cm\(^{-1}\)) | \( \lambda_{\text{Ritz}} \) (Å) | \( \Delta \lambda_{\text{obs-Ritz}} \) (Å) | \( I_{\text{obs}} \) (arb.u.) | \( A \) (s\(^{-1}\)) | Type | Transition | Notes | Line Ref. | TP Ref. |
|---|---|---|---|---|---|---|---|---|---|---|
| 8686.21(4) | 11509.34 | 8686.233(24) | -0.02 | 340 | 4.4e+7 | B | 5s6p | \( ^1P^0 \) | \( ^1P^2 \) | \( ^1S^0 \) | P38G1 | J07 |
| 8797.96(12) | 11363.15 | 8797.95(4) | 0.01 | 110 | | | 5s5f | \( ^3F^2 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 8800.69(15) | 11359.63 | 8800.71(4) | -0.02 | 110 | | | 5s5f | \( ^3F^2 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 8801.04(15) | 11359.18 | 8801.03(5) | 0.01 | 89 | | | 5s5f | \( ^3P^3 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 8803.86(12) | 11355.53 | 8803.79(5) | 0.07 | 360 | | | 5s5f | \( ^3P^3 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 8813.51(12) | 11343.10 | 8813.56(4) | -0.05 | 820 | | | 5s5f | \( ^3P^4 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 8816.29(16) | 11339.52 | 8816.33(4) | -0.04 | 82 | | | 5s5f | \( ^3P^4 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 8832.25(12) | 11319.03 | 8832.23(5) | 0.02 | 790 | | | 5s5f | \( ^3P^3 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 8835.12(16) | 11315.36 | 8835.02(5) | 0.10 | 110 | | | 5s5f | \( ^3P^3 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 9194.38(8) | 10873.23 | 9194.41(5) | -0.03 | 340 | | | 5s4f | \( ^3P^2 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 9197.73(13) | 10869.26 | 9197.71(5) | 0.02 | 1300 | | | 5s4f | \( ^3P^2 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 9198.87(17) | 10867.92 | 9198.76(5) | 0.11 | 100 | | | 5s4f | \( ^3P^3 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 9202.06(17) | 10864.15 | 9202.07(5) | -0.01 | 1400 | | | 5s4f | \( ^3P^3 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 9212.98(8) | 10851.27 | 9212.97(5) | 0.01 | 1500 | | | 5s4f | \( ^3P^4 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 9216.31(8) | 10847.35 | 9216.29(5) | 0.02 | 530 | | | 5s4f | \( ^3P^4 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 9242.13(17) | 10817.05 | 9242.20(5) | -0.07 | 1400 | | | 5s4f | \( ^1P^3 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 9244.46(17) | 10814.32 | 9244.46(17) | 45 | \( 5s_{1/2},5p_{3/2} \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 9244.70(17) | 10814.04 | 9244.70(17) | 45 | \( 5s_{1/2},5p_{3/2} \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 9245.49(9) | 10813.12 | 9245.54(5) | -0.05 | 450 | | | 5s4f | \( ^1P^3 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 |
| 9246.633(10) | 10239.76(3) | 1.0e+6 | D+ | 1s6s | \( ^1S^0 \) | 5s6p | \( ^3P^0 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 | J07 |
| 9247.81(18) | 10239.76(3) | 1.0e+6 | D+ | 1s6s | \( ^1S^0 \) | 5s6p | \( ^3P^0 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 | J07 |
| 9487.05(21) | 1.1e+6 | D+ | 5s8p | \( ^3P^2 \) | 5s12s | \( ^3S^1 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 | J07 |
| 9622.65(12) | 3.0e+6 | C | 5s7d | \( ^1D^1 \) | 5s8f | \( ^3F^2 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 | J07 |
| 9637.24(9) | 3.2e+6 | C | 5s7d | \( ^3D^2 \) | 5s8f | \( ^3P^3 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 | J07 |
| 9638.91(12) | 5.6e+5 | D+ | 5s7d | \( ^1D^2 \) | 5s8f | \( ^3F^2 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 | J07 |
| 9652.15(16) | 3.6e+6 | C | 5s7d | \( ^3D^3 \) | 5s8f | \( ^3P^3 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 | J07 |
| 9663.21(9) | 3.9e+5 | D+ | 5s7d | \( ^1D^3 \) | 5s8f | \( ^3P^3 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 | J07 |
| 9788.225(8) | 6e+5 | D+ | 5s5d | \( ^1D^2 \) | 5s6p | \( ^3P^2 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 | J07 |
| 10186.473(8) | 1.92e+7 | B | 5p2 | \( ^1D^2 \) | 5s4f | \( ^3P^3 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 | J07 |
| 10239.76(3) | 8.6e+5 | B | 5p2 | \( ^1D^2 \) | 5s4f | \( ^3P^3 \) | \( 5s_{1/2},5p_{3/2} \) | P38G1 | J07 |
| $\lambda_{\text{obs}}$ (Å) | $\sigma_{\text{obs}}$ (cm$^{-1}$) | $\lambda_{\text{Ritz}}$ (Å) | $\Delta\lambda_{\text{obs-Ritz}}$ (Å) | $I_{\text{obs}}$ (arb.u.) | $A^e$ (s$^{-1}$) | Type | Transition | Notes | Line Ref. | TP Ref. |
|--------------------------|--------------------------------|----------------------------|--------------------------------|--------------------------|----------------|-------|------------|--------|-----------|---------|
| 10259.78(11)            |                                |                            |                                |                          | 2.7e+6         | C     | 1$^1$D$_2$ 5$^1$Sf  | TW     |           |         |
| 10457(12)               |                                |                            |                                |                          | 1.8e+6         | C     | 1$^3$P$_0$ 5$^1$S10d | TW     |           |         |
| 10494.62(8)             |                                |                            |                                |                          | 2.1e+6         | C     | 1$^3$P$_1$ 5$^1$S10d | TW     |           |         |
| 10499.81(7)             |                                |                            |                                |                          | 1.2e+6         | D$^+$ | 1$^3$P$_1$ 5$^1$S10d | TW     |           |         |
| 10632.41(12)            |                                |                            |                                |                          | 1.3e+6         | D     | 1$^3$P$_1$ 5$^1$S10d | TW     |           |         |
| 10640.4(3)              |                                |                            |                                |                          | 3.1e+6         | C     | 1$^3$P$_2$ 5$^1$S10d | TW     |           |         |
| 10648.6(3)              |                                |                            |                                |                          | 8e+5           | D$^+$ | 1$^3$P$_2$ 5$^1$S10d | TW     |           |         |
| 10815.89(7)             |                                |                            |                                |                          |                |       |                        |        |           |         |
| 10820.54(8)             |                                |                            |                                |                          |                |       |                        |        |           |         |
| 10835.30(7)             |                                |                            |                                |                          |                |       |                        |        |           |         |
| 10839.49(7)             |                                |                            |                                |                          |                |       |                        |        |           |         |
| 10856.99(6)             |                                |                            |                                |                          | 2.27e+6         | B     | 1$^1$D$_2$ 5$^1$Sf  | J07    |           |         |
| 10863.54(8)             |                                |                            |                                |                          |                |       |                        |        |           |         |
| 10868.94(5)             |                                |                            |                                |                          | 3.7e+7         | B     | 1$^3$D$_1$ 5$^1$Sf  | J07    |           |         |
| 10904.51(6)             |                                |                            |                                |                          | 3.6e+7         | B     | 1$^3$D$_2$ 5$^1$Sf  | J07    |           |         |
| 10909.25(5)             |                                |                            |                                |                          | 6.8e+6         | B     | 1$^3$D$_2$ 5$^1$Sf  | J07    |           |         |
| 10949.07(4)             |                                |                            |                                |                          | 4.3e+7         | B     | 1$^3$D$_3$ 5$^1$Sf  | J07    |           |         |
| 10968.47(7)             |                                |                            |                                |                          | 4.6e+6         | B     | 1$^3$D$_3$ 5$^1$Sf  | J07    |           |         |
| 11477.2(13)             |                                |                            |                                |                          |                |       |                        |        |           |         |
| 11477.7(13)             |                                |                            |                                |                          |                |       |                        |        |           |         |
| 11893.809(17)           |                                |                            |                                |                          | 1.39e+6         | B     | 1$^3$P$_1$ 5$^1$S7d | J07    |           |         |
| 12135.65(14)            |                                |                            |                                |                          |                |       |                        |        |           |         |
| 12140.56(12)            |                                |                            |                                |                          |                |       |                        |        |           |         |
| 12156.93(22)            |                                |                            |                                |                          |                |       |                        |        |           |         |
| 12184.74(15)            |                                |                            |                                |                          |                |       |                        |        |           |         |
| 12189.82(4)             |                                |                            |                                |                          | 5.4e+6         | C     | 1$^3$D$_1$ 5$^1$S7f | TW     |           |         |
| 12212.34(7)             |                                |                            |                                |                          | 5.7e+6         | C     | 1$^3$D$_2$ 5$^1$S7f | TW     |           |         |
| 12215.93(4)             |                                |                            |                                |                          | 9.9e+5         | C     | 1$^3$D$_2$ 5$^1$S7f | TW     |           |         |
| 12234.56(23)            |                                |                            |                                |                          | 6.4e+6         | C     | 1$^3$D$_3$ 5$^1$S7f | TW     |           |         |
| 12254.07(7)             |                                |                            |                                |                          | 7.0e+5         | C     | 1$^3$D$_3$ 5$^1$S7f | TW     |           |         |
| $\lambda_{\text{obs}}$ (Å) | $\sigma_{\text{obs}}$ (cm$^{-1}$) | $\lambda_{\text{Ritz}}$ (Å) | $\Delta \lambda_{\text{obs-Ritz}}$ (Å) | $I_{\text{obs}}$ (arb.u.) | $A$ (s$^{-1}$) | Type | Transition | Notes | Line Ref. | TP Ref. |
|----------------------|-------------------|-------------------|-------------------------|-------------------|------------------|-------|------------|-------|-----------|--------|
| 12687.0(3)          |                   |                   |                         |                   |                  |       |             |       |           |        |
| 12687.7(3)          |                   |                   |                         |                   |                  |       |             |       |           |        |
| 12693.0(3)          |                   |                   |                         |                   |                  |       |             |       |           |        |
| 12772.783(18)       | 2.38e+7 B         | 5s7p $^{1}P_{1}$  | 5s7d $^{1}D_{2}$       | J07              |
| 12827.51(4)         | 1.6e+7 C+         | 5s7p $^{3}P_{0}$  | 5s7d $^{3}D_{1}$       | J07              |
| 12901.147(21)       | 2.11e+7 B         | 5s7p $^{1}P_{1}$  | 5s7d $^{1}D_{2}$       | J07              |
| 12930.400(22)       | 1.15e+7 C+        | 5s7p $^{3}P_{1}$  | 5s7d $^{3}D_{1}$       | J07              |
| 13115.86(14)        | 7.8e+5 C          | 5s8p $^{1}P_{1}$  | 5s9d $^{1}D_{2}$       | TW               |
| 13144.73(4)         | 2.9e+5 D          | 5s5d $^{3}D_{2}$  | 5s6p $^{3}P_{1}$       | J07              |
| 13153.64(25)        | 9.8e+5 C          | 5s8d $^{1}D_{1}$  | 5s10f $^{3}F_{2}$      | TW               |
| 13175.40(24)        | 1.0e+6 C          | 5s8d $^{3}D_{2}$  | 5s10f $^{3}F_{3}$      | TW               |
| 13184.0(3)          | 1.2e+6 C          | 5s8d $^{1}D_{3}$  | 5s10f $^{3}F_{4}$      | TW               |
| 13224.87(13)        | 4.9e+6 C          | 5s7d $^{1}D_{2}$  | 5s7f $^{3}F_{3}$       | TW               |
| 13298.074(16)       | 2.9e+7 B          | 5s7p $^{3}P_{2}$  | 5s7d $^{3}D_{3}$       | J07              |
| 13347.570(16)       | 7.3e+6 C+         | 5s7p $^{3}P_{2}$  | 5s7d $^{3}D_{2}$       | J07              |
| 13373(20)           | 2.5e+6 C          | 5s8p $^{3}P_{0}$  | 5s9d $^{3}D_{1}$       | J07              |
| 13378.885(18)       | 8.1e+5 C          | 5s7p $^{3}P_{2}$  | 5s7d $^{3}D_{1}$       | J07              |
| 13430.71(10)        | 3.0e+6 C          | 5s8p $^{3}P_{1}$  | 5s9d $^{3}D_{2}$       | J07              |
| 13442.88(10)        | 1.6e+6 C          | 5s8p $^{3}P_{1}$  | 5s9d $^{3}D_{1}$       | J07              |
| 13533.67(20)        | 4.8e+6 C          | 5s8p $^{3}P_{1}$  | 5s9d $^{3}D_{2}$       | J07              |
| 13664.2(5)          | 4.3e+6 C          | 5s8p $^{3}P_{2}$  | 5s9d $^{3}D_{3}$       | J07              |
| 13668.85(9)         | 3.0e+7 B          | 5s6d $^{1}D_{2}$  | 5s5f $^{3}F_{3}$       | J07              |
| 13683.9(4)          | 1.1e+6 C          | 5s8p $^{3}P_{2}$  | 5s9d $^{3}D_{2}$       | J07              |
| 13744.26(10)        | 1.81e+6 B         | 5s6d $^{1}D_{2}$  | 5s5f $^{3}F_{3}$       | J07              |
| 13882.94(17)        | 5s6f $^{1}F_{2}$  | 5s1/2,p=4g        |                       |                   |
| 13889.37(15)        | 5s6f $^{1}F_{3}$  | 5s1/2,p=4g        |                       |                   |
| 13910.6(3)          | 5s6f $^{1}F_{4}$  | 5s1/2,p=4g        |                       |                   |
| 13941.828(22)       | 1.15e+6 C+        | 5s7p $^{3}P_{1}$  | 5s7d $^{3}D_{2}$       | J07              |
| 13947.05(17)        | 5s6f $^{1}F_{3}$  | 5s1/2,p=5g        |                       |                   |
| 13975.997(23)       | 8.3e+5 C+         | 5s7p $^{3}P_{1}$  | 5s7d $^{3}D_{1}$       | J07              |
| \( \lambda_{\text{obs}}^a \) (Å) | \( \sigma_{\text{obs}} \) (cm\(^{-1}\)) | \( \lambda_{\text{ref}}^b \) (Å) | \( \Delta \lambda_{\text{obs},\text{ref}}^c \) (Å) | \( \lambda_{\text{obs}}^d \) (arb.u.) | \( A_t^e \) (s\(^{-1}\)) | Type\(^f\) | Transition | Notes\(^g\) | Line Ref.\(^h\) | TP Ref.\(^i\) |
|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|----------------|----------------|----------------|----------------|----------------|
| 14599.0(4) | 14599.3(4) | 14601.58(11) | 1.5e+6 C | 5s8p | \(^3\)P\(_1^1\) | 5s10s | \(^3\)S\(_1^1\) | TW | | |
| 14789.01(21) | 14901.4(5) | 15240.92(4) | 2.24e+6 B | 5s7p | \(^3\)P\(_1^1\) | 5s8s | \(^3\)S\(_1^1\) | TW | | |
| 15354.09(11) | 15334.1(3) | 15343.4(3) | 1.9e+6 C | 5s8d | \(^3\)D\(_1^1\) | 5s9f | \(^3\)F\(_2^2\) | TW | | |
| 15909.62(8) | 15981.19(7) | 16283.16(6) | 3.8e+6 C | 5s7p | \(^3\)P\(_0^1\) | 5s8s | \(^3\)S\(_1^1\) | J07 | | |
| 16330.23(4) | 16449.31(3) | 16714.87(4) | 2.8e+7 B | 5s7p | \(^3\)P\(_1^1\) | 5s8s | \(^3\)S\(_0^1\) | J07 | | |
| 17182.033(22) | 17202.49(4) | 17376.67(12) | 1.31e+6 B | 5s5d | \(^3\)D\(_1^1\) | 5s6p | \(^3\)P\(_2^1\) | J07 | | |
| 17383.8(3) | 17393.84(22) | 17427.4(4) | 1.44e+7 B | 5s7s | \(^3\)S\(_1^1\) | 5s7p | \(^3\)P\(_2^1\) | J07 | | |
| 17484.6(3) | 17640.26(8) | 17935.58(13) | 5.0e+6 B | 5s5d | \(^3\)D\(_1^1\) | 5s6p | \(^3\)P\(_0^1\) | J07 | | |

\(^a\) Observed wavelength.

\(^b\) Reference wavelength.

\(^c\) Observed wavelength minus reference wavelength.

\(^d\) Observed intensity in arbitrary units.

\(^e\) Transition probability.

\(^f\) Type of transition.

\(^g\) Notes on the line.

\(^h\) Reference for line.

\(^i\) Reference for transition probability.
| $\lambda_{obs}$ (Å) | $\sigma_{obs}$ (cm$^{-1}$) | $\lambda_{Ritz}$ (Å) | $\Delta\lambda_{obs,Ritz}$ (Å) | $I_{obs}$ (arb.u.) | $A$ (s$^{-1}$) | Type | Transition | Notes | Line Ref. | TP Ref. |
|---------------------|--------------------------|----------------------|-------------------------------|-------------------|-------------|-------|------------|--------|-----------|---------|
| 18005.48(5)        |                          |                      |                               |                   |             | B     | 5s7s $^3$S$_1$ 5s7p $^3$P$_0$ | J07    |           |         |
| 18208.86(8)        |                          |                      |                               |                   |             | B     | 5s7s $^3$S$_1$ 5s7p $^3$P$_0$ | J07    |           |         |
| 18271(10)          |                          |                      |                               |                   |             |      | 5s1/2,f=45g 5s1/2,f=46h | TW     |           |         |
| 18284(10)          |                          |                      |                               |                   |             |      | 5s1/2,f=55g 5s1/2,f=56h | TW     |           |         |
| 18284(10)          |                          |                      |                               |                   |             |      | 5s1/2,f=45g 5s1/2,f=46h | TW     |           |         |
| 18297(10)          |                          |                      |                               |                   |             |      | 5s1/2,f=55g 5s1/2,f=46h | TW     |           |         |
| 18497.1(8)         |                          |                      |                               |                   |             |      | 5s1/2,f=45g 5s1/2,f=46h | TW     |           |         |
| 18497.3(8)         |                          |                      |                               |                   |             |      | 5s1/2,f=55g 5s1/2,f=46h | TW     |           |         |
| 19861.2(5)         | 2.3e+6                   | C                    |                               |                   |             |       | 5s8d $^3$D$_1$ 5s8f $^3$F$_2$ | TW     |           |         |
| 19895.3(4)         | 2.4e+6                   | C                    |                               |                   |             |       | 5s8d $^3$D$_2$ 5s8f $^3$F$_3$ | TW     |           |         |
| 19913.3(7)         | 2.7e+6                   | B                    |                               |                   |             |       | 5s8d $^3$D$_3$ 5s8f $^3$F$_4$ | TW     |           |         |
| 20578.1(3)         |                          |                      |                               |                   |             |       | 5s7f $^3$P$_2$ 5s1/2,f=410g |         |           |         |
| 20588.2(3)         |                          |                      |                               |                   |             |       | 5s7f $^3$P$_3$ 5s1/2,f=410g |         |           |         |
| 20628.6(7)         |                          |                      |                               |                   |             |       | 5s7f $^3$P$_4$ 5s1/2,f=410g |         |           |         |
| 20699.2(4)         |                          |                      |                               |                   |             |       | 5s7f $^3$P$_5$ 5s1/2,f=410g |         |           |         |
| 20734.3(3)         | 1.16e+7                  | B                    |                               |                   |             |       | 5s7d $^3$D$_1$ 5s6f $^3$F$_2$ | TW     |           |         |
| 20795.5(3)         | 1.21e+7                  | B                    |                               |                   |             |       | 5s7d $^3$D$_2$ 5s6f $^3$F$_3$ | TW     |           |         |
| 20809.9(3)         | 2.1e+6                   | C                    |                               |                   |             |       | 5s7d $^3$D$_2$ 5s6f $^3$F$_2$ | TW     |           |         |
| 20853.0(6)         | 1.35e+7                  | B                    |                               |                   |             |       | 5s7d $^3$D$_3$ 5s6f $^3$F$_4$ | TW     |           |         |
| 20916.8(3)         | 1.5e+6                   | C                    |                               |                   |             |       | 5s7d $^3$D$_3$ 5s6f $^3$F$_3$ | TW     |           |         |
| 21114.5(5)         | 2.4e+6                   | C                    |                               |                   |             |       | 5s8d $^3$D$_2$ 5s8f $^3$F$_3$ | TW     |           |         |
| 21394.2(5)         | 8.7e+6                   | B                    |                               |                   |             |       | 5s8p $^3$P$_1$ 5s8d $^3$D$_2$ | TW     |           |         |
| 23635.0(3)         | 6.2e+6                   | B                    |                               |                   |             |       | 5s8p $^3$P$_1$ 5s8d $^3$D$_2$ | TW     |           |         |
| 23890.2(5)         | 1.27e+7                  | B                    |                               |                   |             |       | 5s7d $^3$D$_2$ 5s6f $^3$F$_3$ | TW     |           |         |
| 24332.8(14)        | 8.7e+6                   | B                    |                               |                   |             |       | 5s8p $^3$P$_2$ 5s8d $^3$D$_3$ | TW     |           |         |
| 27514.5(7)         |                          |                      |                               |                   |             |       | 5s6f $^3$F$_2$ 5s1/2,f=47g |         |           |         |
| 27539.7(6)         |                          |                      |                               |                   |             |       | 5s6f $^3$F$_3$ 5s1/2,f=47g |         |           |         |
| 27623.8(11)        |                          |                      |                               |                   |             |       | 5s6f $^3$F$_4$ 5s1/2,f=57g |         |           |         |
| 27767.8(7)         |                          |                      |                               |                   |             |       | 5s6f $^3$F$_3$ 5s1/2,f=57g |         |           |         |
| 30293(9)           |                          |                      |                               |                   |             |       | 5s1/2,f=46g 5s1/2,f=47h |         |           |         |
| $\lambda_{\text{obs}}$<sup>a</sup> (Å) | $\sigma_{\text{obs}}$<sup>a</sup> (cm<sup>-1</sup>) | $\lambda_{\text{Ritz}}$<sup>b</sup> (Å) | $\Delta \lambda_{\text{obs-Ritz}}$<sup>c</sup> (Å) | $I_{\text{obs}}$<sup>d</sup> (arb. u.) | $A$<sup>e</sup><sup>f</sup> (s<sup>-1</sup>) | Transition | Notes<sup>g</sup> | Line Ref.<sup>h</sup> | TP Ref.<sup>i</sup> |
|-----------------|--------------|-----------------|-----------------|----------------|--------------|-------------|--------------|-------------|-------------|
| 30295(9)        |              |                 |                 |                |              | Type        | Transition   | Notes       | Line Ref.   |
|                 |              |                 |                 |                |              | Reference   | Description  | Description  | Description  |

<sup>a</sup>Observed wavelengths below 2000 Å are given in vacuum, above that in standard air. Conversion from vacuum to air wavelengths was made using the five-parameter formula from Peck and Reeder [28].

<sup>b</sup>Ritz wavelengths and their uncertainties were determined in the level optimization procedure using the LOPT code [23].

<sup>c</sup>Deviation of the observed wavelength from the Ritz value. This column is blank for lines that alone determine one of the two energy levels involved in the transition.

<sup>d</sup>Observed relative intensities have been converted to a uniform scale corresponding to emission from a plasma with an effective excitation temperature of about 3 eV (see Sec. 6.6).

<sup>e</sup>Transition probability values are followed by a letter code denoting the estimated uncertainty (see Table 3).

<sup>f</sup>Designations of transition types are as follows: E2 – electric quadrupole transition (enabled by an external electric field; see Sec. 2.3); HF – transition induced by hyperfine interaction.

<sup>g</sup>Notes: 1 – Transition probability value determined in the present work is uncertain because of strong cancellation effects (see Sec. 7); 2 – Observed intensity value is unreliable (see Sec. 6.6); 3 – Observed intensity was marked as questionable in Paschen and Campbell [2].

<sup>h</sup>Codes for references to observed wavelengths and line identifications: B69 – Bhatia [5]; K01c – Karlsson and Litzén [11] (observed wavelengths have been corrected to account for a minor systematic error in the calibration of the wave number scale; see Sec. 2.1); L31 – Lang and Sawyer [3]; L93c – Larkins and Hannaford [8] (re-calibrated using the measurement of Wang et al. [27]; see Sec. 2.2); P38 – Paschen and Campbell [2]; this code followed by “P”, “TP”, “G1”, “G2”, etc. means the measurements made with a one-prism spectrograph, three-prism spectrograph, and a grating spectrograph in various orders of diffraction (see Sec. 2.3); W96 – lines identified by Wagatsuma [15] (no wavelength measurement was given, but the intensities were measured; see Sec. 2.6); Z01 – von Zanthier et al. [10].

<sup>i</sup>Codes for references to transition probability values: A86 – Ansbach et al. [38]; A86c – The $A$-value was derived from the radiative lifetime measured by Ansbach et al. [38] using transition rates for weaker decay branches calculated by Jönsson and Andersson [43] (see Sec. 7); B99 – Biémont and Zeippen [35]; B01 – Becker et al. [37]; CMEF00 – Curtis et al. [39]; J07 – Jönsson and Andersson [43]; L94 – Lavin and Martin [44]; M96 – Martinez et al. [41]; TW – This work.
breadth of the hfs. Thus, even if the centers of gravity of the observed hfs are determined precisely, we can expect them to deviate from the Ritz values due to the intrinsic inaccuracy of the distinctive energy levels.

We can also expect the lines from the category b of Karlsson and Litzén to have the largest uncertainties due to inaccuracies of the measurement of centers of gravity of the hfs.

To estimate the wave number uncertainties, as a zero approximation, I neglected the hfs considerations and assumed that the measurement uncertainties \( \delta \sigma \) are entirely due to statistical and systematic uncertainties (\( \delta \sigma_{\text{stat}} \) and \( \delta \sigma_{\text{syst}} \), respectively) in the wave number measurements of symmetric well-resolved features (see, for example, Kramida and Nave [22]):

\[
\delta \sigma \approx (\delta \sigma_{\text{stat}}^2 + \delta \sigma_{\text{syst}}^2)^{1/2};
\]

\[
\delta \sigma_{\text{stat}} \approx W/(2S/N),
\]

where \( W \) is the full width at half-maximum. The \( S/N \) values are given in Table 1 of Karlsson and Litzén [11] in the column of line intensities. The values of \( W \) and \( \delta \sigma_{\text{syst}} \) can be estimated as 0.02 cm\(^{-1}\) and 0.003 cm\(^{-1}\), respectively, from the statement that the uncertainty of the wave numbers varies from \( \pm 0.003 \) cm\(^{-1}\) for strong unblended lines to \( \pm 0.02 \) cm\(^{-1}\) for weak, unresolved, or blended lines [11]. However, I found that setting

\[
W = 0.03 \text{ cm}^{-1}
\]

results in better statistical consistency of the energy levels with the measured wave numbers. The value of 0.003 cm\(^{-1}\) for the systematic uncertainty corresponds to the maximum value of the wavenumber scale correction described above. With these assumed wavenumber uncertainty values, using the level-optimization code LOPT [23], I have derived a set of optimized energy levels from the observed wave numbers given in Table 1 of Karlsson and Litzén [11]. The resulting values agreed with those given in Ref. [11] with an average deviation of 0.003 cm\(^{-1}\), the maximum deviation being 0.006 cm\(^{-1}\). This close agreement indicates that the assumed wavenumber uncertainties are close to those used by Karlsson and Litzén in their level-optimization procedure.

The final assignment of wavenumber uncertainties was made when all measured lines from different sets of measurements were brought together in a comprehensive line list and checked for internal consistency (see Sec. 3). At that stage, it was found that the lines from the categories a and b of Karlsson and Litzén [11] deviate from the Ritz values by much greater amounts than those of the category c, which is consistent with the expectations noted above. Therefore, the uncertainties of these categories of lines have been increased by a factor of 3.7 as compared to Eq. (3). Only then can the measurements of Karlsson and Litzén [11] be considered consistent with those of Paschen and Campbell [2] and with other observations.

### 2.2 Measurements of Larkins and Hannaford [8]

Larkins and Hannaford [8] measured the absolute frequencies of hyperfine components of the four lines at 1936 Å (5s5p \( ^3P_0 - 5s6s \; ^3S_1 \)), 1977 Å (5s5p \( ^3P_2 - 5s6s \; ^3S_1 \)), 2079 Å (5s5p \( ^3P_1 - 5s6s \; ^3S_1 \)), and 2306 Å (5s \( ^1S_0 - 5s5p \; ^3P_1 \)) emitted by a hollow-cathode lamp by using a 2.5 m scanning monochromator. The monochromator was fitted with a 316 lines/mm échelle grating having a blaze angle of 65° and mounted in a Czerny-Turner configuration. The four In II lines listed above were measured in different orders of diffraction (29\(^{th}\) for the first two lines, 27\(^{th}\) for the third one, and 24\(^{th}\) for the fourth). The absolute frequency scale was calibrated separately for each of the four lines using different sets of Fe I and Fe II reference lines, for which the Ritz wavelengths from Nave et al. [19] and O’Brian et al. [24] were used. The orders of diffraction for the reference lines were different for different Fe lines and, most importantly, for different In II lines. Larkins and Hannaford assumed the calibration uncertainty to be equal to the quadrature sum of the quoted uncertainties in the energies of the upper and lower Fe levels of the reference lines [19,24]. However, as noted by Reader [25], this method of calibration that uses reference lines in an order of diffraction different from that of the measured line can cause a significant systematic error in a Czerny-Turner spectrometer. These systematic errors are the most probable cause of the discrepancies between the
wave numbers measured by Larkins and Hannaford [8] and by Karlsson and Litzén [11] mentioned in the previous section. The suspected culprit of these systematic errors is the variation of the refraction index of air with pressure. Larkins and Hannaford made all measurements in air and used a formula for conversion from air wavelengths to vacuum wave numbers that does not account for the air pressure, temperature, and composition. They did not mention anything about the air conditions in their setting. If the grating is assumed to be ideal, the observed wavelength of any line in any order of diffraction is equal to the wavelength in the first order multiplied by the order number. However, the refraction index of air is different at different first-order wavelengths. Thus, if the reference and investigated lines are observed in different orders of diffraction, the variation of the refraction index of air has to be taken into account in the derivation of the measured wavelength. My numerical experiments showed that possible variations of the atmospheric air pressure between 101.2 kPa and 104.8 kPa in the experiment of Larkins and Hannaford [8] can explain all discrepancies between their measurements and those of Karlsson and Litzén [11] (the average air pressure at the site of measurements in Clayton, Australia, is 101.11 kPa).

It should be noted that the Fe I and Fe II wave numbers given in Refs. [19,24] were calibrated against the Ar II reference lines from Norlén [17] and thus have to be increased by 6.7 parts in 10^9 (see the discussion in the previous section). The difference between the reference Fe wavenumbers as given by Larkins and Hannaford from the corrected ones given in the current version of the NIST Atomic Spectra Database [26] amounts to 0.004 cm^{-1}, which is much smaller than the discrepancies in the measured In II wave numbers.

In the absence of reliable means to correct the calibration errors of Larkins and Hannaford [8], the measurements of Karlsson and Litzén [11] should be preferred, despite the fact that they [11] possess significantly greater statistical uncertainties. However, for one transition, 5s^2 1S_0 – 5s5p 3P_1, the measurement of Larkins and Hannaford [8] can be re-calibrated using a recent independent high-precision measurement of an hfs component of this line. Namely, Wang et al. [27] measured the absolute frequency of the 5s^2 1S_0 (F=9/2) – 5s5p 3P_1 (F=11/2) transition in a single^{115}In^+ ion cooled in a radio-frequency trap by using a frequency comb referenced to a Cs atomic clock. Converted to wave number units, their result is 43351.62276 cm^{-1}. The wave number of this transition, as measured by Larkins and Hannaford [8], is 43351.614(2) cm^{-1}. The difference is 0.009 cm^{-1}, which is almost twice as large as the systematic uncertainty assumed by Larkins and Hannaford. By utilizing the air wavelengths of the three hfs components of the 5s^2 1S_0 – 5s5p 3P_1 transition, which are given by Larkins and Hannaford with relatively greater precision, I obtained 43350.5817(15) cm^{-1} for the corrected wave number of the centroid of this transition.

2.3 Measurements of Paschen and Campbell [2]

Paschen and Campbell [2] observed the In II spectrum excited in the negative glow of a hollow carbon cathode discharge filled with helium. The spectrum was dispersed in the region 2350 Å through 9217 Å using a 4 m concave grating spectrograph in various orders of diffraction (first through eighth) and recorded on photographic plates. Additional measurements of weaker lines were made with a higher-throughput single-prism spectrograph in the region 2078 Å through 6627 Å and a three-prism spectrograph in the region 3802 Å through 4229 Å. The wavelength scale was calibrated against known lines of helium, neon, and iron. Paschen and Campbell listed about 1400 measured wave numbers of lines belonging to about 500 transitions of In II. Many of the lines had completely resolved hfs patterns, but most of them were resolved only partially. For all lines, Paschen and Campbell gave an estimated center-of-gravity wave number (averaged over the hyperfine structure) without an uncertainty estimate. Thus, in order to obtain an optimized set of energy levels, it is necessary to estimate the uncertainty for each line.

The number of decimal places in the wave numbers listed by Paschen and Campbell can serve as a guide to their uncertainties. Most of the wave numbers of hfs components in the red region of the spectrum measured with the grating spectrograph were given with three digits after the decimal point. However, the center-of-gravity wave numbers were given with only two digits after the point, which indicates a reasonable loss of accuracy in the averaging. The nominal resolution of the grating spectrograph was \( R \equiv \lambda/\Delta\lambda \approx 82500 \) in the first order of diffraction [2], so one can expect the uncertainty of the wave numbers \( \sigma \) of individual hfs components to be greater than approximately 0.1 \( \sigma/R \approx 0.013 \) cm^{-1} at the longest
wavelength 9217 Å. The finite entrance slit width and uncertainties of reference lines should further increase the uncertainty. For far-ultraviolet lines measured with the prism spectrograph, the wave numbers are given with only one digit after the decimal point, indicating a much greater uncertainty.

As a zero approximation, I assumed that the measurement uncertainties of unblended lines are equal to 20 units of the last given decimal place and twice that for blended or perturbed lines. With these uncertainties, a set of optimized energy levels was obtained with the LOPT code [23]. The resulting level values agreed with those given by Paschen and Campbell [2] with a standard deviation of 0.04 cm⁻¹. However, the too small residuals (i.e., deviations of observed wave numbers from the Ritz values) indicated that the wavenumber uncertainties should be decreased in order to achieve statistical consistency. The latter requirement means that the root of sum of squares (RSS) of the residuals should be approximately equal to degrees of freedom (DF) of the problem (in this case, DF = 320). With the initial estimate of uncertainties described above, RSS/DF = 0.12, which means that the assumed uncertainties were too large on average. Better estimates can be obtained by analyzing mean values of residuals (observed minus Ritz wave number) separately for each category of lines. Division of the lines into categories is naturally defined by the different observation methods (with the single-prism, three-prism, or grating spectrograph in different orders of diffraction) and by the character of the lines (well-resolved or blended). The finally adopted uncertainty values are listed in Table 1. They vary from 0.02 cm⁻¹ for a few red lines to 1.0 cm⁻¹ for the blended line at 2249.6 Å. With these final uncertainty values, the level optimization procedure yields RSS/DF = 1.15, which indicates a good statistical consistency. Agreement of the optimized levels with the original values from Paschen and Campbell remained the same (on average) after the uncertainty adjustments.

The line list of Paschen and Campbell [2] includes 28 forbidden transitions. One of them is the hyperfine-induced clock transition 5s2 1S0 − 5s5p 3P0 at 2364.686 Å, and all the others are electric-quadrupole (E2) transitions between opposite-parity levels with the change in the angular momentum ΔJ = 2. In the absence of external fields, these transitions are highly forbidden. However, an electric field present in the discharge mixes the hyperfine components of the levels having the same total angular momentum F but J values differing by one. For example, an external electric field mixes the F = 15/2 component of the 5s7f 3F° 3 level with the F = 15/2 component of the 5s7f 3F° 1 level, thus enabling the normally forbidden 5s6d 3D 2 − 5s7f 3F° 4 transition. For such an electric-field induced transition, only a certain part of the hfs components of both levels become allowed. Thus, its observed center of gravity will be shifted from the difference between the centers of gravity of the two levels. This may cause systematic shifts in the level values derived with the level optimization procedure. To avoid such shifts, for the purpose of level optimization I have decreased the weight of these forbidden transitions by a factor of four by increasing their uncertainties with a factor of two. However, the uncertainties given in Table 1 are given without these adjustment factors.

A small inconsistency was found in the tables of Paschen and Campbell [2]. Namely, the 5s17s 3S1 level was given in [2] as 149892.67 cm⁻¹. This level takes part in three observed transitions, 5s6p 3P0,1,2 − 5s17s 3S1 at 2367.0 Å, 2377.1 Å, and 2410.8 Å, all measured with the single-prism spectrograph. The Ritz wave number given in the line list of [2] for the 5s17s 3S1 transition agrees with the listed energy levels. However, the Ritz values given for the other two transitions imply a different value of the 5s17s 3S1 level, 149891.99 cm⁻¹.

2.4 Measurements of Bhatia [5]

The thesis of Bhatia [5] was mainly focused on the spectra of doubly and triply ionized indium. However, it also includes new energy-level classifications for about a hundred of In II lines. For another several tens of lines, Bhatia’s measurements are the most accurate available. Emission spectra of indium were photographed over the spectral range from 340 Å to 9500 Å using a disruptive electrodeless discharge and a spark in helium. About 4000 lines of indium were measured, and 36 % of these lines were classified as belonging to the In I–V spectra. The spectrum from 340 Å to 2440 Å was obtained using a 3 m grazing incidence vacuum spectrograph with a 1200 lines/mm grating giving a reciprocal dispersion of 2.775 Å/mm. The grating was blazed for 1300 Å. In the region 2300 Å to 9500 Å, a prism spectrograph was used. Different types of photographic plates were used in three spectral ranges: 340 Å to 3000 Å,
3000 Å to 6500 Å, and 4500 Å to 9500 Å. For the wavelength scale calibration in the vacuum range, C, N, and O standards were used below 1760 Å and Si standards between 1930 Å and 2297 Å. For the prism spectra, iron and neon standards were used.

Bhatia noted that the prism measurements have uncertainties greater than ±0.05 Å. This corresponds to a wavenumber uncertainty of ±0.8 cm⁻¹ at 2440 Å and ±0.05 cm⁻¹ at 9600 Å. For the grating measurements, I estimated uncertainties by comparing the measured wavenumbers with much more accurate Ritz values derived from the measurements described in the previous sections. In the region below 1900 Å, the statistical uncertainty of well-resolved lines is ±0.03 Å; between 1900 Å and 2440 Å, it is ±0.09 Å; and above 2440 Å, it is ±0.13 Å.

All newly classified or re-measured In II lines in Bhatia’s thesis correspond to transitions between known levels determined from other, more accurate measurements. Therefore, these lines were not included in the level optimization procedure. However, for the sake of completeness, I include them in the line list and give their original observed wavelengths. They were found to contain noticeable systematic shifts, which are responsible for the difference between the values of the correction to the energy levels of Paschen and Campbell derived by different authors [6,11]. These systematic shifts were estimated by fitting deviations of Bhatia’s original wavelengths from the Ritz values with cubic polynomials. This was done separately for the prism and grating measurements. For the grating measurements, systematic shifts vary from −0.02 Å at 2430 Å to +0.01 Å at 1900 Å, −0.01 Å at 1000 Å, and +0.005 Å at 680 Å. For the prism measurements, they vary from −0.44 Å at 5123 Å to +0.10 Å at 2460 Å.

In Table 1, the observed wavelengths selected from Bhatia [5] are given with two uncertainty values in parentheses after the value. The first uncertainty is a statistical one, and the second is a systematic one.

2.5 Measurements of Lang and Sawyer [3]

Lang and Sawyer [3] observed the In II spectrum emitted by a hollow cathode discharge in helium or in neon. As cathodes, they used a carbon tube with indium placed inside or a tungsten tube coated with indium. The spectrum between 500 Å and 8000 Å was photographed with a 1 m vacuum grating spectrograph and with two prism spectrographs. Lang and Sawyer did not specify their measurement uncertainties, but indicated that the higher terms deduced from the vacuum ultraviolet measurements should be accurate to less than 5 cm⁻¹, which corresponds to ±0.05 Å at 1000 Å.

Lang and Sawyer listed 144 observed and classified lines of In II between 680 Å and 7183 Å. All their measurements above 3273 Å have been superseded by other observers. However, in the shorter wavelength region there remain 18 lines for which their observations are the only available ones. All of the levels associated with these lines are accurately established by other observations, so I did not use the lines from [3] in the level optimization procedure. Nevertheless, I include them in Table I with their original wavelengths. They were found to contain significant systematic shifts. These shifts were estimated by fitting deviations of the original wavelengths from the Ritz values with a cubic polynomial. The systematic shifts vary from −0.25 Å at 680 Å to −0.07 Å at 1586 Å and −0.14 Å at 3273 Å, while the average statistical uncertainty is ±0.11 Å below 2300 Å and ±0.09 Å above that.

Similar to Bhatia’s measurements, the observed wavelengths selected from Lang and Sawyer [3] are given in Table 1 with two uncertainties, statistical and systematic, given in parentheses after the value.

Five lines listed by Lang and Sawyer [3] at 1133.15 Å, 1625.36 Å, 1681.72 Å, 2446.02 Å, and 3274.11 Å do not match any combination between the known energy levels. For the line at 1133.15 Å, I found that Lang and Sawyer made an error in conversion from the correctly given wavenumber 87249 cm⁻¹. The correct wavelength is 1146.14 Å. The line at 1625.36 was classified by Bhatia [5] as belonging to In III. For the line at 3274.11 Å, the wave number was misprinted in Lang and Sawyer as 30534, while the correct value is 30543 cm⁻¹. Thus, the correct wavelength is 3273.13 Å. Paschen and Campbell [2] noted that this line was expected to occur in their spectra, but they could not detect it. The origins of the other two lines are unknown. Thus, they are omitted from Table 1.
2.6 Measurements of Wagatsuma [15]

Wagatsuma [15] observed emission spectra of several elements, including indium, from Grimm glow discharge plasmas with argon, neon, and mixtures of argon with helium and neon with helium as buffer gases. The main purpose was to investigate relative intensities of spectral lines in different buffer gases. The Grimm-type discharge features a hollow anode, and a plain sample is placed close to the anode opening. A Fastie-Ebert mounting spectrograph with a focal length of 3.4 m equipped with a photomultiplier detector was employed to measure the spectra in the wavelength region from 2300 Å to 8000 Å. The grating had 1200 lines/mm and was blazed at 3000 Å. Emission spectra in the shorter wavelength region, 1600 Å to 2450 Å, were recorded on a 2.0 m Eagle-mounting vacuum spectrometer with a 1200 lines/mm grating blazed at 1700 Å, equipped with a CaF₂ window and a photomultiplier tube.

Wagatsuma reported intensity measurements for 43 lines of In II between 1571 Å and 6116 Å. He did not give his measured wavelengths; instead, he listed the Ritz wavelengths calculated from the energy levels given by Moore [4]. Most of the lines were observed and classified elsewhere. However, two lines were newly classified. These are the lines at 1657.43 Å (5s5p 3P°₁ − 5s7s 3S₀) and 3842.92 Å (5p−1 D₂ − 5s4f 3F°₂). Since no wavelength measurements are available, I give the Ritz wavelengths for these two lines in Table 1.

3. Optimized Energy Levels and the Ionization Limit

After the wavelength measurement uncertainties have been assessed, the level optimization is a straightforward procedure. For that I used the least-squares level optimization code LOPT [23]. As noted above, only the measurements of Karlsson and Litzén [11], Larkins and Hannaford [8], von Zanthier et al. [10], and Paschen and Campbell [2] were included in the level optimization procedure, which makes a total of 495 lines. Although high-precision measurements constitute only about 10% of all included lines, they have a dramatic effect on the accuracy of the derived excitation energies, decreasing the uncertainties from a few reciprocal centimeters for the level list of Paschen and Campbell [2] to 0.2 cm⁻¹ on average. More than half of the levels have uncertainties below 0.1 cm⁻¹, and 75 of them are accurate to better than ±0.05 cm⁻¹.

The average shift of the newly optimized levels above 63000 cm⁻¹ from those given by Paschen and Campbell [2] is 4.88 cm⁻¹ with a standard deviation of 0.18 cm⁻¹. For two levels from the list of Paschen and Campbell, 5s9p 3P°₁ and 5s11p 3P°₁, there are no observed lines in their list. Transitions from these levels were observed by Bhatia [5] (one from 5s9p 3P°₂ and four from 5s11p 3P°₁). Their measurement uncertainties are between 1.6 cm⁻¹ and 1.9 cm⁻¹, which is much greater than uncertainties in the measurements of Paschen and Campbell. I assumed that those lines were actually observed by Paschen and Campbell but omitted from their line list. Therefore, the values given for these levels in Table 2 are derived from those of Paschen and Campbell by adding the average shift mentioned above.

As can be seen in Table 2, there are several Rydberg series accurately measured up to high values of principal quantum number n, such as 5snD₁ (n = 5−19), 5snD₂ and 5s₁D₁ (n = 5−18), 5snsS₁ (n = 5−17), 5sng (n = 5−14), and 5snh (n = 8−14). These series are unperturbed and thus can be used to determine the ionization limit. I used computer codes written by Sansonetti [29] to fit Ritz-type quantum-defect formulas for the 5sns and 5snD series and the polarization formula for the 5sng and 5snh series. Thus, I have obtained five values for the ionization limit derived with different methods, one with the polarization formula and four with quantum-defect formulas. The weighted average of these five values is 152200.10 cm⁻¹ with ±0.22 cm⁻¹ adopted as a conservative estimate of uncertainty.

From the same or similar series formulas, several unobserved levels, such as 5s6h, 5s7h, 5s₁5d 3D₁, 5s₁9D₁, 5s₁9D₂, 5s₁8S₁, 5s₁9S₁, and 5sns 3S₀ (n = 17−19), could be accurately determined. For two levels, 5s₁2p 1P°₁ and 5s₁7d 3D₃, the values derived from the series formulas are significantly more accurate than the measured ones. These interpolated or extrapolated values are included in Table 2.

The only two high-precision energy values in Table 2, i.e., those for the 5s5p 1P°₀ and 5s5p 1P°₁ levels, are pertinent to the isotope ¹¹₅In, while the rest of the level values were determined from wavelengths of lines observed in a natural mixture of isotopes. The only available experimental measurement of the isotope...
Table 2. Optimized energy levels of In II

| Configuration | Term   | $J$ | Level * (cm⁻¹) | Leading percentages b | Comments c |
|---------------|--------|-----|----------------|------------------------|------------|
| 5s           | 1S     | 0   | 0.000000000    | 98                     |            |
| 5s5p         | 1P°    | 0   | 42275.995245348(8) | 100                        |            |
| 5s5p         | 1P°    | 1   | 43350.5817(15)  | 99                     |            |
| 5s5p         | 1S     | 2   | 45829.256(6)    | 100                   |            |
| 5s5p         | 1P°    | 1   | 63038.546(10)   | 98                     |            |
| 5s6s         | 1S     | 1   | 93923.884(5)    | 100                   |            |
| 5s6s         | 1S     | 0   | 97030.212(12)   | 99                     |            |
| 5s5p         | 1D     | 2   | 97628.436(9)    | 67  31  5p²  1D        |            |
| 5s5p         | 1P°    | 0   | 101608.06(20)   | 97                     |            |
| 5s5d         | 1D     | 1   | 102088.72(4)    | 100                  |            |
| 5s5d         | 1D     | 2   | 102174.69(3)    | 100                   |            |
| 5s5d         | 3D     | 3   | 102308.397(20)  | 100                  |            |
| 5s5p         | 1P°    | 1   | 10249.39(19)    | 100                   |            |
| 5s5p         | 2P°    | 2   | 105565.283(12)  | 96                     |            |
| 5s6p         | 1P°    | 0   | 107662.707(6)   | 100                   |            |
| 5s6p         | 1P°    | 1   | 107841.992(6)   | 96  4  1P°            |            |
| 5s6p         | 2P°    | 2   | 108430.337(6)   | 100                   |            |
| 5s6p         | 1P°    | 1   | 109780.221(8)   | 94  4  3P°            |            |
| 5s5d         | 1D     | 2   | 113884.919(11)  | 58  27  5s5d  1D      |            |
| 5s7s         | 1S     | 0   | 121289.53(3)    | 56  42  5s7s  1S      |            |
| 5s7s         | 1S     | 1   | 121442.541(12)  | 100                   |            |
| 5s7s         | 1S     | 0   | 123372.848(18)  | 57  39  5p²  1S       |            |
| 5s4f         | 1F°    | 2   | 123642.95(3)    | 100                   |            |
| 5s4f         | 1F°    | 3   | 123648.096(24)  | 100                   |            |
| 5s4f         | 2F°    | 4   | 123664.85(3)    | 100                   |            |
| 5s4f         | 3F°    | 3   | 123699.170(10)  | 100                   |            |
| 5s6d         | 1D     | 1   | 124742.729(6)   | 100                   |            |
| 5s6d         | 1D     | 2   | 124776.714(6)   | 100                   |            |
| 5s6d         | 3D     | 3   | 124830.176(8)   | 100                   |            |
| 5s6d         | 1D     | 2   | 126670.945(8)   | 88  7  5p²  1D        |            |
| 5s7p         | 1P°    | 0   | 126932.875(22)  | 100                   |            |
| 5s7p         | 1P°    | 1   | 126994.890(11)  | 91  9  1P°            |            |
| 5s7p         | 2P°    | 2   | 127254.067(7)   | 100                   |            |
| 5s7p         | 1P°    | 1   | 127573.319(10)  | 90  9  3P°            |            |
| 5s8s         | 1S     | 1   | 133072.511(7)   | 100                   |            |
| 5s8s         | 1S     | 0   | 133554.382(14)  | 98                     |            |
| 5s5f         | 1F°    | 2   | 133940.74(4)    | 100                   |            |
| 5s5f         | 3F°    | 3   | 133944.72(6)    | 100                   |            |
| 5s5f         | 1F°    | 4   | 133960.87(3)    | 100                   |            |
| 5s5f         | 1F°    | 3   | 133984.85(6)    | 100                   |            |
| 5s1/2,1/2<5g |       |     | 134512.23(6)    |                       |            |
| 5s1/2,1/2<5g |       |     | 134516.14(6)    |                       |            |
| 5s7d         | 1D     | 1   | 134726.488(10)  | 100                   |            |
| 5s7d         | 1D     | 2   | 134744.019(9)   | 100                   |            |
| Configuration | Term | J | Level \(^a\) (cm\(^{-1}\)) | Leading percentages \(^b\) | Comments \(^c\) |
|---------------|------|---|-----------------|-----------------|----------------|
| 5s7d          | \(^1\)D  | 3  | 134771.897(9)  | 100             |                |
| 5s7d          | \(^1\)D  | 2  | 135400.325(10) | 95              |                |
| 5s8p          | \(^3\)p\(^a\) | 0  | [135823(11)]   | 100             | LSF            |
| 5s8p          | \(^3\)p\(^a\) | 1  | 135861.62(5)   | 86              | \(^1\)p\(^a\) |
| 5s8p          | \(^3\)p\(^a\) | 2  | 135999.37(23)  | 100             |                |
| 5s8p          | \(^1\)p\(^a\) | 1  | 136096.93(9)   | 85              | \(^3\)p\(^a\) |
| 5s9s          | \(^3\)S  | 1  | 139137.055(23) | 100             |                |
| 5s9s          | \(^1\)S  | 0  | 139387.30(5)   | 99              |                |
| 5s6f          | \(^3\)F\(^a\) | 2  | 139549.42(10)  | 100             |                |
| 5s6f          | \(^1\)F\(^a\) | 3  | 139552.75(7)   | 100             |                |
| 5s6f          | \(^3\)F\(^a\) | 4  | 139567.37(14)  | 100             |                |
| 5s6f          | \(^1\)F\(^a\) | 3  | 139586.14(8)   | 100             |                |
| 5s8d          | \(^3\)D  | 1  | 140082.23(3)   | 100             |                |
| 5s8d          | \(^3\)D  | 2  | 140092.64(4)   | 100             |                |
| 5s8d          | \(^3\)D  | 3  | 140109.05(5)   | 100             |                |
| 5s8d          | \(^3\)D  | 2  | 140408.36(5)   | 97              |                |
| 5s9p          | \(^3\)p\(^a\) | 0  | [140716(17)]   | 100             | LSF            |
| 5s9p          | \(^1\)p\(^a\) | 1  | 140734.59(5)   | 85              | \(^1\)p\(^a\) |
| 5s9p          | \(^1\)p\(^a\) | 2  | 140822.48(18)  | 100             |                |
| 5s9p          | \(^3\)p\(^a\) | 1  | 140845.00(4)   | 84              | \(^3\)p\(^a\) |
| 5s9p          | \(^1\)p\(^a\) | 1  | 140927.81(3)   | 100             |                |
| 5s7f          | \(^3\)F\(^a\) | 3  | 142930.22(5)   | 100             |                |
| 5s7f          | \(^3\)F\(^a\) | 4  | 142943.23(16)  | 100             |                |
| 5s7f          | \(^1\)F\(^a\) | 3  | 142959.77(9)   | 100             |                |
| 5s10s         | \(^3\)S  | 1  | 142708.324(25) | 100             |                |
| 5s10s         | \(^1\)S  | 0  | 142856.86(3)   | 99              |                |
| 5s7f          | \(^1\)F\(^a\) | 2  | 144989.99(4)   | 100             |                |
| 5s7f          | \(^3\)F\(^a\) | 3  | 145086.25(4)   | 99              |                |
| 5s8f          | \(^3\)F\(^a\) | 2  | 145115.79(15)  | 100             |                |
| Configuration | Term | J | Level (cm\(^{-1}\)) | Leading percentages | Comments |
|---------------|------|---|---------------------|--------------------|----------|
| 5s8f          | \(^3\)F\(^\dagger\) | 3 | 145117.59(11)      | 100                |          |
| 5s8f          | \(^3\)F\(^\dagger\) | 4 | 145129.44(20)      | 100                |          |
| 5s8f          | \(^1\)F\(^\dagger\) | 3 | 145144.45(11)      | 100                |          |
| 5s_{1/2},p_{4}g |     |   | 145300.34(4)       |                    |          |
| 5s_{1/2},p_{5}g |     |   | 145303.91(4)       |                    |          |
| 5s_{1/2},p_{4}h |     |   | 145326.55(21)      |                    |          |
| 5s_{1/2},p_{5}h |     |   | 145330.18(21)      |                    |          |
| 5s10d         | \(^3\)D | 1 | 145382.99(4)       | 100                |          |
| 5s10d         | \(^3\)D | 2 | 145387.70(6)       | 100                |          |
| 5s10d         | \(^3\)D | 3 | 145394.94(4)       | 100                |          |
| 5s10d         | \(^1\)D | 2 | 145499.56(7)       | 98                 |          |
| 5s11p         | \(^3\)P | 1 | 145655.81(18)      |                    |          |
| 5s11p         | \(^1\)P | 1 | 145683.72(14)      |                    |          |
| 5s12s         | \(^3\)S | 1 | 145637.16(4)       | 100                |          |
| 5s12s         | \(^1\)S | 0 | 146602.97(5)       | 99                 |          |
| 5s9f          | \(^3\)F | 3 | 146612.28(11)      | 100                |          |
| 5s9f          | \(^3\)F | 2 | 146614.22(4)       | 100                |          |
| 5s9f          | \(^3\)F | 4 | 146624.75(15)      | 100                |          |
| 5s9f          | \(^1\)F | 3 | 146638.37(13)      | 100                |          |
| 5s_{1/2},p_{4}g |     |   | 146750.53(5)       |                    |          |
| 5s_{1/2},p_{5}g |     |   | 146754.16(4)       |                    |          |
| 5s_{1/2},p_{5}h |     |   | 146769.69(15)      |                    |          |
| 5s_{1/2},p_{5}h |     |   | 146773.23(15)      |                    |          |
| 5s11d         | \(^3\)D | 1 | 146812.50(9)       |                    |          |
| 5s11d         | \(^3\)D | 2 | 146815.24(9)       |                    |          |
| 5s11d         | \(^3\)D | 3 | 146820.60(14)      |                    |          |
| 5s11d         | \(^1\)D | 2 | 146890.14(11)      |                    |          |
| 5s12p         | \(^1\)P | 1 | [147016(10)]       |                    | RITZPL   |
| 5s13s         | \(^3\)S | 1 | 147634.61(6)       | 100                |          |
| 5s10f         | \(^3\)F | 3 | 147680.47(13)      | 100                |          |
| 5s13s         | \(^1\)S | 0 | 147681.43(7)       | 99                 |          |
| 5s10f         | \(^3\)F | 2 | 147682.61(14)      | 100                |          |
| 5s10f         | \(^3\)F | 4 | 147691.91(15)      | 100                |          |
| 5s10f         | \(^1\)F | 3 | 147704.35(16)      | 100                |          |
| 5s_{1/2},p_{4}g |     |   | 147787.35(5)       |                    |          |
| 5s_{1/2},p_{5}g |     |   | 147790.88(6)       |                    |          |
| 5s_{1/2},p_{5}h |     |   | 147800.67(20)      |                    |          |
| 5s_{1/2},p_{5}h |     |   | 147804.99(20)      |                    |          |
| 5s12d         | \(^3\)D | 1 | 147833.52(8)       |                    |          |
| 5s12d         | \(^3\)D | 2 | 147836.29(17)      |                    |          |
| 5s12d         | \(^3\)D | 3 | 147840.27(19)      |                    |          |
| 5s12d         | \(^1\)D | 2 | 147888.97(15)      |                    |          |
| 5s14s         | \(^3\)S | 1 | 148440.88(7)       | 100                |          |
| 5s11f         | \(^1\)P | 3 | 148468.39(14)      |                    |          |
| 5s11f         | \(^3\)P | 2 | 148472.06(14)      |                    |          |
| Configuration | Term | $J$ | Level (cm$^{-1}$) | Leading percentages | Comments |
|---------------|------|-----|------------------|---------------------|----------|
| 5s14s         | 1/2S| 0   | [148475.56(22)]  | 99                  | RITZPL   |
| 5s11f         | 3F   | 4   | 148479.98(15)    |                     |          |
| 5s11f         | 1F   | 3   | 148491.51(14)    |                     |          |
| 5s1/2,p=411g |      |     | 148554.36(7)     |                     |          |
| 5s1/2,p=511g |      |     | 148557.89(8)     |                     |          |
| 5s1/2,p=411h |      |     | 148565.16(21)    |                     |          |
| 5s1/2,p=511h |      |     | 148568.78(21)    |                     |          |
| 5s13d         | 3D   | 1   | 148589.72(20)    |                     |          |
| 5s13d         | 3D   | 2   | 148592.29(18)    |                     |          |
| 5s13d         | 3D   | 3   | 148595.76(20)    |                     |          |
| 5s15s         | 1S   | 1   | 149050.95(8)     | 100                 |          |
| 5s12f         | 3F   | 3   | 149067.58(24)    |                     |          |
| 5s12f         | 1F   | 2   | 149070.69(20)    |                     |          |
| 5s15s         | 1S   | 0   | 149077.3(3)      | 99                  |          |
| 5s12f         | 1F   | 4   | 149078.76(20)    |                     |          |
| 5s12f         | 1F   | 3   | 149088.88(20)    |                     |          |
| 5s1/2,p=12g   |      |     | 149137.36(10)    |                     |          |
| 5s1/2,p=512g |      |     | 149140.89(12)    |                     |          |
| 5s1/2,p=412h |      |     | 149145.95(16)    |                     |          |
| 5s1/2,p=512h |      |     | 149149.57(16)    |                     |          |
| 5s14d         | 3D   | 1   | 149165.33(18)    |                     |          |
| 5s14d         | 3D   | 2   | 149168.03(25)    |                     |          |
| 5s14d         | 3D   | 3   | 149170.15(18)    |                     |          |
| 5s14d         | 1D   | 2   | [149196.30(22)]  | RITZPL              |          |
| 5s16s         | 1S   | 1   | 149523.97(18)    | 100                 |          |
| 5s16s         | 1S   | 0   | 149544.20(20)    | 99                  |          |
| 5s1/2,p=13g   |      |     | 149590.82(12)    |                     |          |
| 5s1/2,p=513g |      |     | 149594.31(12)    |                     |          |
| 5s1/2,p=13h  |      |     | 149597.77(12)    |                     |          |
| 5s1/2,p=513h |      |     | 149601.39(12)    |                     |          |
| 5s15d         | 3D   | 1   | [149614.22(22)]  | RITZPL              |          |
| 5s15d         | 3D   | 2   | 149614.68(20)    |                     |          |
| 5s15d         | 3D   | 3   | 149617.48(18)    |                     |          |
| 5s15d         | 1D   | 2   | 149638.13(3)     |                     |          |
| 5s17s         | 1S   | 1   | 149897.11(20)    | 100                 |          |
| 5s17s         | 1S   | 0   | [149913.51(22)]  | 99                  | RITZPL   |
| 5s1/2,p=14g   |      |     | 149950.61(8)     |                     |          |
| 5s1/2,p=514g |      |     | 149954.09(7)     |                     |          |
| 5s1/2,p=414h |      |     | 149956.21(12)    |                     |          |
| 5s1/2,p=514h |      |     | 149959.83(12)    |                     |          |
| 5s16d         | 3D   | 1   | 149968.70(25)    |                     |          |
| 5s16d         | 3D   | 2   | 149971.53(3)     |                     |          |
| 5s16d         | 3D   | 3   | 149972.30(20)    |                     |          |
| 5s16d         | 1D   | 2   | [149988.21(22)]  | RITZPL              |          |
Excitation energies and their uncertainties have been determined from observed wavelengths using the least-squares level optimization code LOPT [23]. Uncertainties in terms of one standard deviation are given in parentheses after the value in the units of the least significant figure of the value. Values enclosed in square brackets correspond to unobserved or poorly measured levels. They were determined semi-empirically using series formulas or a parametric fitting; the method used is specified in the last column.

The leading percentages have been determined in the present work by means of a parametric least-squares fitting using Cowan’s codes [30] (see Sec. 4). Methods used in semi-empirical determination of unobserved or poorly measured levels: RITZPL and POLAR – Ritz-type quantum-defect and polarization formulas fitted with Sansonetti’s computer codes [29]; LSF – Parametric least-squares fitting with Cowan’s codes [30].

**4. Theoretical Interpretation of the Energy Levels**

To find eigenvector compositions of the levels and calculate transition probabilities, I used a parametric fitting with Cowan’s computer codes [30]. The following configurations were included in the calculations: 5s², 5sn (n = 6–19), 5snl (n = 5–10), 5snl (n = 5–10), and 5sp² for even parity, and 5snp (n = 5–10), 5snl (n = 4–10), and 5snl (n = 6–10) for odd parity. In the even parity set, 79 known levels were fitted with 35 free parameters with an average deviation of 16 cm⁻¹. In the odd parity set, 60 known levels were fitted with 25 free parameters with an average deviation of 13 cm⁻¹. Percentage compositions of the levels included in Table 2 are from these calculations. The fitted parameters were used to calculate the transition probabilities.

The percentage compositions of the levels given in Table 2 result from the parametric fitting described above. In this table, the energies of the 5snp³P°₀ levels with n = 8–10, which were not observed experimentally, are from the same parametric fitting. The value for 5s8p³P°₀, 135823(10) cm⁻¹, is in fair agreement with the result of the parametric fitting by Biémont and Zeippen [35], 135833 cm⁻¹.
5. Interpretation of the 5sng and 5snh Series

Paschen and Campbell [2] found that the 5sng and 5snh configurations are split into pairs of closely located level groups, which they designated as n–G, n+G, n–H, and n+H. The 5sng series was observed for n = 5–14, and the 5snh series for n = 8–14. The separations within the pairs (e.g., between n–G and n+G) are almost constant along the series and are equal to 3.56(3) cm\(^{-1}\) for the 5sng (n = 7–14) series and 3.58(8) cm\(^{-1}\) for the 5snh (n = 8–14). The separations within the 5s5g and 5s6g level pairs are slightly greater, 3.91(8) cm\(^{-1}\) and 3.71(10) cm\(^{-1}\), respectively. The almost constant separations for n ≥ 7 imply that their probable cause is the hyperfine splitting of the In III 5s core. Indeed, the predicted hfs interval in the 115In III 5s ground state is 3.56 cm\(^{-1}\) [31]. There are no measurements of this interval in In III. However, it was measured in the isoelectronic spectra of 109Ag I [32] and 111Cd II [33]. These measurements agree with the calculations of Beck and Datta [31] within 3 %, which suggests that their result for \(^{115}\)In III quoted above is similarly accurate. The close agreement between the theoretical hfs interval of \(^{115}\)In III 5s and the observed separations in the In II 5sng and 5snh series suggests that these observed separations represent the first measurement of the hfs interval in \(^{115}\)In III 5s. The weighted mean of this interval, averaged over the high members of both the 5sng and 5snh series (n ≥ 7) is 3.56(3) cm\(^{-1}\).

Thus, these two series represent the first observation of an unusual coupling between the fine-structure and hfs interactions in an atomic system where the hfs interaction dominates over the fine-structure effects such as the spin-orbit splitting and electrostatic exchange. According to my Cowan code calculations (see the previous section), the average fine-structure splittings caused by the spin-orbit splitting and electrostatic exchange are the largest for the 5s5g configuration and amount to about 2 cm\(^{-1}\). They rapidly decrease with increasing n along the 5sng series and are smaller than 1 cm\(^{-1}\) for n ≥ 9. For all members of the 5sng series, the fine-structure splittings are smaller than 0.0002 cm\(^{-1}\). These splittings are indeed much smaller than the hfs interval in \(^{115}\)In III 5s, which may explain the observed constant intervals within the pairs along the series, as well as the increased intervals in 5s5g and 5s6g. A similar behavior of the level intervals along the 1sng, 1sng, 1snh, 1sn, and 1snk series was predicted by Morton et al. [34] for \(^3\)He I, where the hfs interval in the \(^3\)He II 1s core, ~8666 MHz, is much greater (in absolute value) than the fine-structure splittings. The latter are smaller than 400 MHz for all members of these series.

Because of this unusual coupling, no LS term designations can be assigned to the 5sng and 5sng series. Instead, I designate Paschen and Campbell’s n–G, n+G, n–H, and n+H levels as 5s1/2,F=gH, 5s1/2,F=gH, 5s1/2,F=gH, 5s1/2,F=gH, respectively. Each of these levels is comprised of multiple sublevels arising from the coupling of the angular momentum F of the core with the angular momentum J of the outer electron. For the lower members of the 5sng series, the intervals between the sublevels are comparable to the interval between the F = 4 and F = 5 hyperfine components of the core, while for the higher members of this series, as well as for the entire 5sng series, they are much smaller.

6. Relative Intensities of Observed Lines

As noted in the Introduction, relative intensities of lines observed with different light sources and with different registration equipment are vastly different. In order to give a consistent set of relative intensities, they must be converted to the same scale. To account for the different excitation conditions in various light sources, the observed line intensities can be approximated by local thermodynamic equilibrium (LTE) with certain excitation temperature pertinent to each light source, and then scaled to the same excitation temperature. In reality, the LTE approximation describes the observed intensities only qualitatively, with deviations in both directions up to an order of magnitude. However, this method results in much better qualitative agreement between relative intensities observed by different authors. Besides the different effective temperatures in the light sources, the observed intensities are strongly affected by different behaviors of spectral response functions of the registration equipment at different wavelengths. These variations can also be accounted for and removed. These procedures are described below. The general method relies on radiative transition rates \(A_{ij}\) calculated with Cowan’s codes (see Sec. 4), and on the LTE relation between these transition rates and the observed intensities \(I_{obs}\). 

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\[ I_{\text{obs}} \propto (g_k A_k / \lambda) \exp(-E_k / k T_{\text{eff}}), \] \hspace{1cm} (4)

where \( g_k \) and \( E_k \) are the statistical weight and energy of the upper level, \( \lambda \) is the central wavelength of the line, \( k \) is the Boltzmann constant, and \( T_{\text{eff}} \) is the effective temperature.

### 6.1 Line Intensities in the Spectra Observed by Karlsson and Litzén [11]

As noted in Sec. 2.1, the intensities given by Karlsson and Litzén [11] for their FTS measurements are roughly the signal-to-noise ratios. The effective temperature can be easily found from the Boltzmann plot, i.e., from the linear slope of \( I_{\text{obs}} \lambda / (g_k A_k) \) versus the energy of the upper level \( E_k \). Intensities reported by Karlsson and Litzén [11] are well described by effective temperature of \( T_{\text{eff}} \approx 1.1 \) eV. No wavelength dependence of the registration sensitivity was found for their observations.

### 6.2 Line Intensities in the Spectra Observed by Paschen and Campbell [2]

The analysis of line intensities reported by Paschen and Campbell [2] is complicated due to the large number of different registration methods used. The analysis is simplest for the observations made with the single-prism spectrograph. These observations span the wavelength region between 2100 Å and 6630 Å, but most of them are below 2700 Å. The intensities reported by Paschen and Campbell are visual estimates of blackening of photographic plates; hence, they are non-linear in response to exposure. This non-linearity should be removed together with the wavelength dependence of the sensitivity. This was done in an iterative procedure, which resulted in an effective temperature \( T_{\text{eff}} \approx 3.4 \) eV. The spectral variation of the sensitivity can be visualized by plotting the logarithm of the ratio of calculated and observed intensities \( I_{\text{obs}} / I_{\text{calc}} \), where \( I_{\text{calc}} \) is set to equal the right side of Eq. (4), against wavelength. This plot for the single-prism observations is presented in Fig. 1.

As seen from this figure, the sensitivity of the single-prism observations exponentially drops by three orders of magnitude when the wavelength decreases from 2700 Å to 2100 Å.

![Fig. 1. A logarithmic plot of the spectral sensitivity of single-prism observations of Paschen and Campbell [2] against wavelength. The solid line is a linear least-squares fit to the data points.](http://dx.doi.org/10.6028/jres.118.004)
Similar plots were built for observations made with the three-prism spectrograph and with the grating spectra in various orders of diffraction. As a sample, the plot of the spectral sensitivity of the grating observations in the first order of diffraction is given in Fig. 2.

![Fig. 2](image)

Fig. 2. A logarithmic plot of the spectral sensitivity of grating observations of Paschen and Campbell [2] in the first order of diffraction against wavelength. The solid line is a quadratic least-squares fit to the data points.

To verify that the non-linearity was correctly removed from the intensity values, the logarithm of the calculated intensities is plotted against the corrected observed intensities in Fig. 3. In this plot, the wavelength dependence was removed from all observations.

![Fig. 3](image)

Fig. 3. Verification of linearity of the corrected intensity scale for the observations of Paschen and Campbell [2]. The solid curve is a linear fit to the data points. Its slope is close to one, and it nearly crosses the (0, 0) point.
Removal of the wavelength dependence of sensitivity and non-linearity of the intensity scale has a dramatic effect on the values of relative intensities. For example, the ratio of relative intensities of the allowed $5s^2 \, ^1S_0 - 5s5p \, ^3P^\circ_1$ transition at 2306 Å and the highly forbidden hyperfine-induced $5s^2 \, ^1S_0 - 5s5p \, ^3P^\circ_0$ transition at 2365 Å, as given by Paschen and Campbell [2], is 3.3, while the ratio of the corrected intensities is 75.

### 6.3 Line Intensities in the Spectra Observed by Bhatia [5]

Analysis of intensities observed by Bhatia [5] presented the greatest difficulties for several reasons. First, as noted in Sec. 2.4, the great majority of the lines observed in this work belong to higher ionization stages. Out of the total 4000 lines, only about 300 could be ascribed to In II. Thus, blending with lines of other ionization stages can be expected to distort intensities of many In II lines. Second, a significant number of the lines were overexposed. Due to a strong non-linearity of the response of photographic plates at high exposures, intensities of strong lines are greatly underestimated. Therefore, when analyzing the intensities from Bhatia [5], overexposed lines and lines suspected to be perturbed by other ionization stages were excluded from consideration.

The analysis was made using an approach similar to the one described above. Namely, the intensities of the lines in different spectral regions were treated separately, assuming that the response of the registration equipment has a different dependence on wavelength in those regions.

The effective excitation temperature describing the line intensities observed by Bhatia was found to be about 8 eV. This is much higher than the temperature found for all other observations, which is consistent with the fact that most of the lines observed in Bhatia’s experiment belong to higher ionization stages.

### 6.4 Line Intensities in the Spectra Observed by Lang and Sawyer [3]

As noted in Sec. 2.5, Lang and Sawyer [3] used three different spectrographs, a 1 m vacuum grating spectrograph and two prism spectrographs, to photograph the spectrum between 500 Å and 8000 Å. They did not specify the spectral regions in which each of these spectrographs was used. However, by making Boltzmann plots similar to those described in the previous section it was possible to determine the effective temperature of their light source, $T_{\text{eff}} \approx 2.5$ eV, and divide the entire spectral range of their observations into three separate regions with distinctly different variation of spectral sensitivity. This division is illustrated in Fig. 4, which depicts the dependence of the logarithm of the ratio of observed and calculated intensities.

![Fig. 4. A logarithmic plot of the spectral sensitivity of experimental set-up of Lang and Sawyer [3] in three wavelength regions, 500 Å to 1500 Å, 1500 Å to 3200 Å, and 3200 Å to 7000 Å. The solid lines are polynomial least-squares fits to the data points (cubic for the first two regions, and quadratic for the last one).](http://dx.doi.org/10.6028/jres.118.004)
6.5 Line Intensities in the Spectra Observed by Wagatsuma [15]

By using a similar method as described above, I determined the effective excitation temperatures for the three sets of measurements presented by Wagatsuma. For the spectrum obtained with neon buffer gas, the effective temperature was $T_{\text{eff}} \approx 2.1$ eV; for the Ar-He mixture, $T_{\text{eff}} \approx 2.0$ eV; and for pure argon, $T_{\text{eff}} \approx 1.2$ eV. Since the greatest number of lines was observed with neon buffer gas, I reduced all intensity measurements to $T_{\text{eff}} = 2.1$ eV and averaged all intensities observed in more than one set-up.

6.6 Reduction of Intensities to a Uniform Scale

After the intensities reported by different observers were corrected for variations of the response functions, as described above, they were reduced to a uniform scale by scaling them to the same effective excitation temperature $T^*$. This temperature was chosen to be about 3 eV, since the most extensive line list given by Paschen and Campbell is described by a temperature close to that value (see Sec. 6.2). The scaling was made by multiplying the intensity values by a factor $f_a \exp[-E_a/(1/kT^*-1/kT_{\text{eff}})]$, where the scaling coefficient $f_a$ was determined by adjusting the scale so that the mean ratio of intensities to those of Paschen and Campbell is equal to one. After that, intensities from multiple observations were averaged. The resulting values are reported in Table 1. About 70% of the lines have only one intensity measurement. Most of them are from Paschen and Campbell [2], while about 90 are from Bhatia [5], 22 from Lang and Sawyer [3], two from Wagatsuma [15], and one from Karlsson and Litzén [11]. For 181 lines, intensities have been determined by averaging two or more measurements. For 17 lines, relative intensities resulting from measurements of different authors differ by more than an order of magnitude. These highly volatile values, as well as five other intensities that may have been affected by blending with other lines, have been marked as unreliable in Table 1.

7. Transition Probabilities

Calculated or measured transition probabilities and radiative lifetimes of In II are given in more than 30 published articles. The complete list of these articles can be obtained from the NIST Atomic Transition Probability Bibliographic Database [36]. Here I will discuss only the articles that provide the most dependable data.

Becker et al. [37] measured the radiative lifetime of the metastable 5s5p $^3P_0$ level of a single laser-cooled $^{115}$In$^+$ ion in a radiofrequency trap. The value they obtained, 0.195(8) s, corresponds to the probability of 5.13(21) s$^{-1}$ for the hyperfine-induced transition to the ground state. These authors also measured the Landé factor of the 5s5p $^3P_0$ level, $g = 0.000987(5)$. As well as the non-zero decay probability, the non-zero value of the Landé factor is caused by perturbations induced by the hyperfine interactions.

Ansbacher et al. [38] measured radiative lifetimes for 13 levels of In II using the beam-foil method with an account for cascade corrections. These measurements provided a base for the most accurate transition probability values of transitions originating from those levels. For two levels, 5s5d $^3D_1$ and 5s4f $^3P_0$, there is only one branch of radiative decay to the 5s5p $^1P_2$ and 5s5d $^3D_3$ levels, respectively, so the measured lifetimes directly yield the transition probabilities. For each of the other eight levels (5s6s $^1S_0$, 5s5s $^3S_1$, 5s5d $^3D_2$, 5s5d $^1D_1$, 5s5d $^1D_2$, 5p$^2$ $^3P_2$, 5p$^2$ $^1D_2$, and 5p$^2$ $^1S_0$) radiative decay is dominated by one transition. For these levels, the transition probability of the dominant decay branch could be accurately determined by subtracting from the total decay rate (i.e., inverse of the measured lifetime) the sum of the contributions of the other weak decay branches, which were accurately calculated by other authors. Uncertainties of thus determined transition probabilities vary between 3% and 40%.

Curtis et al. [39] made an isoelectronic comparison of measured and calculated radiative lifetimes of the 5s5p $^1P_1$ and 5s5p $^3P_0$ levels for Cd-like spectra of elements between Cd and Ho. Their semi-empirically corrected values for In II are probably accurate to within a few percent. They agree well with the best available measurements [38,40].

Martinez et al. [41] measured the branching fractions of transitions from the four 5s4f levels using an optically thin laser-produced plasma. From these data, they derived transition probabilities ($A$-values) for
10 transitions by normalizing them to the lifetimes measured by Ansbacher et al. [38] (for 5s4f \(^1\)F\(_0\) and 5s4f \(^3\)F\(_{5,4}\)) and by Blagoev et al. [42] (for 5s4p \(^3\)P\(_0\)). For these \(A\)-values, they gave uncertainty values ranging from 10% to 35%. I have adopted their \(A\)-values that were normalized to the lifetimes measured by Ansbacher et al. Comparison of different measurements and accurate calculations shows that the lifetimes measured by Blagoev et al. [42] cannot be trusted. In most cases, they are too low by up to a factor of 2.

Jönsson and Andersson [43] made extensive relativistic multiconfiguration Dirac–Hartree–Fock calculations of oscillator strengths for electric-dipole transitions in In II. They gave weighted oscillator strengths (\(gf\)) calculated in both Babushkin and Coulomb gauges, and provided for each transition their calculated wave number. Comparison of the values in the two gauges provides a rough estimate of average uncertainty of their \(gf\) values, which is about 15%. The given wave numbers allowed me to adjust their \(gf\) values by re-scaling them to the accurate Ritz wave numbers and convert to the \(A\)-values. Comparison of the resulting \(A\)-values with the accurate data discussed above shows that there is a strong dependence of the accuracy of the calculated \(A\)-values on the line strength \(S\). It turned out that the \(A\)-values for \(S > 3\), as calculated by Jönsson and Andersson, are accurate to within 8%, while for weaker transitions the accuracy is much worse, 33% on average. The agreement between the \(gf\) values in Babushkin and Coulomb gauges was used as an additional indicator of accuracy. I have decreased the assumed accuracy for transitions for which the \(gf\) values in the two gauges differ by more than 15%.

Biémont and Zeippen [35] calculated the oscillator strengths for a large number of electric dipole transitions in In II using Cowan’s Hartree-Fock Relativistic method [30] modified to account for core-polarization effects by including a semi-empirically determined model potential. The radial parameters of the wave functions were determined in a least-squares fitting of the experimentally known energy levels. I have compared their results with an extended base of accurately determined \(A\)-values that included the accurate results from Jönsson and Andersson [43] in addition to other results discussed above. For strong transitions with \(S > 1.25\), calculations of Biémont and Zeippen agree with other accurate results with an average deviation of 18%. For transitions with \(S\) between 0.2 and 1.25, the average deviation is about 30%. For weaker transitions, the agreement is much worse, often only to an order of magnitude.

Lavin and Martin [44] employed the relativistic quantum defect orbital (RQDO) approach with an account for core polarization to calculate the oscillator strengths of the 5s5p \(^3\)P – 5snd \(^3\)D (\(n = 5–9\)) and 5s5p \(^1\)P – 5sns \(^3\)S (\(n = 6–10\)) transitions in In II and similar transitions in a few neighboring isoelectronic spectra. Where the scope of their calculations intersects the scope of the other works considered above [38,35,43], their results agree to about 25% with those references with no discernible correlation with the line strength.

The works discussed above provided an extensive database for comparison with my semi-empirical Cowan-code calculations. It is well known that Cowan-code calculations of transition rates suffer from cancellation effects. To check whether these effects are significant, the Cowan code provides the value of the cancellation factor in the output for each transition. The cancellation factor is computed as follows. The line strength is computed as an expansion over contributions from each basis state. The sum of positive contributions \(S^+\) and the sum of negative contributions \(S^-\) are computed separately, and the cancellation factor is calculated as \(CF = (S^+ + S^-)/(S^+ + |S^-|)\). Since each of \(S^+\) and \(S^-\) are calculated with a finite accuracy, the values of \(CF\) close to zero indicate a significant loss of accuracy in the final line strength. Of course, this is only a qualitative criterion. Different researchers adopt different threshold values of \(CF\) below which they consider the results to be adversely affected by cancellations. In the case of the In II calculations, my comparisons show that there is no correlation between the accuracy of line-strength calculations and \(CF\) for \(|CF| > 0.1\) generally indicate that the resulting line strength can be in error by an order of magnitude or more.

Considering only transitions unaffected by cancellations, I found that, similar to several other calculation methods discussed above, the accuracy of Cowan-code calculations strongly depends on the line strength. For strongest transitions with \(S > 80\), the results of Cowan’s code agree with other, more accurate calculations or measurements within 9% on average. For strong transitions with \(S\) between 2.5 and 80, the accuracy is about 23% on average. For weaker transitions with \(S < 2.5\), the average accuracy is about 30%. I have discarded most of the \(A\)-values from the Cowan code calculations that were adversely affected by cancellation effects (i.e., those that have \(CF < 0.1\)). Only a few of such unreliable \(A\)-values are
included in Table 1 for transitions that have observed intensities roughly agreeing with those calculated using these \( A \)-values in the assumption of LTE.

Comparisons of radiative lifetimes measured by different authors with calculations were given in many papers; see, for example, Biémont and Zeippen [35]. These comparisons show that the various measurements strongly disagree with each other for many energy levels. It can be seen that the lifetimes measured by Ansbacher et al. [38] with an account for multi-exponential decay are in much better agreement with theory than the other measurements. Some of the lifetimes measured by other authors may be significantly affected by cascades from higher levels. For example, there is a large disagreement between theory and measurements for the 5s5f \( 3^{3}F_{4} \) level. For this level, Blagoev et al. [42] measured a lifetime of 19(1) ns, in agreement with an earlier beam-foil measurement by Andersen and Sørensen [45], 21(2) ns. Different calculations yield consistently lower values, 11.8 ns [43], 10.0 ns [35], or 9.5 ns (this work). As follows from my calculations, the measured lifetime probably corresponds to the cascade from 5s6g, for which my calculations yield a lifetime of 21.3 ns. Similarly, for the 5s5f \( 3^{3}F_{3} \) level, Andersen and Sørensen [45] reported a lifetime of 21(2) ns, while three different calculations yield 11.7 ns [43], 9.9 ns [35], and 9.4 ns (this work). Similar to the 5s5f \( 3^{3}F_{4} \) level, the measured 5s5f \( 3^{3}F_{3} \) lifetime appears to correspond to the cascade from 5s6g.

The critically evaluated transition probabilities with assessed uncertainties are compiled in Table 1. The uncertainties are denoted by a letter code explained in Table 3.

| Letter | Uncertainty in \( A \)-value | Uncertainty in log(\( gf \)) |
|--------|-----------------------------|-----------------------------|
| A      | \( \leq 3 \% \)             | \( \leq 0.013 \)             |
| B+     | \( \leq 7 \% \)             | \( \leq 0.03 \)             |
| B      | \( \leq 10 \% \)            | \( \leq 0.04 \)             |
| C+     | \( \leq 18 \% \)            | \( \leq 0.08 \)             |
| C      | \( \leq 25 \% \)            | \( \leq 0.11 \)             |
| D+     | \( \leq 40 \% \)            | \( \leq 0.18 \)             |
| D      | \( \leq 50 \% \)            | \( \leq 0.24 \)             |
| E      | \( > 50 \% \)               | \( > 0.24 \)               |

It should be noted that the transition probability values resulting from theoretical calculations do not follow a normal statistical distribution. For example, for normal statistics the uncertainty of ±10 % (at the one standard deviation level) would imply that the true value should be within 20 % of the measured or calculated one with a probability of 95 %, and a deviation of 30 % has an extremely small probability. However, in quantum mechanics calculations it is often observed that the bulk of results for \( A \)-values lie within certain limits from true values, but there are some \( A \)-values (usually for weak transitions) that deviate grossly (by an order of magnitude or more) from the true values. This is the reason for using the above letter codes rather than the usual numerical specification of uncertainties. The numerical uncertainty values given in Table 3 should be used with caution, since there may be a significant number of outliers one would not expect to have in normal statistics. The logarithms of the \( A \)-values, as well as the values of log(\( gf \)), have statistical distributions much closer to normal.

8. Conclusions

In the present study, a comprehensive list of the best measured wavelengths of 650 observed lines has been compiled. Uncertainties of all available wavelength measurements in the In II spectrum have been analyzed, and the existing inconsistencies have been resolved. From this line list with assigned uncertainties, a set of 173 optimized energy levels that fits all observed wavelengths has been derived. An additional 21 levels have been determined semi-empirically from series formulas and from parametric
fitting. Percentage compositions of the levels and radiative transition rates have been calculated in the parametric fitting procedure. An improved value of the ionization limit of In II has been determined by fitting quantum-defect and polarization formulas for several series of levels. The fine structures observed by different authors have been analyzed and converted to a uniform scale. A set of 528 recommended values of radiative transition rates has been critically compiled, and uncertainties of these rates have been estimated. Of these transition rates, 353 are associated with observed lines. From the observed separations of levels in the 5s2g and 5s2n series of In II, the hfs splitting of the ground state of 113In III has been found to be 3.56(3) cm\(^{-1}\).

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