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# A critical compilation and extended analysis of the Ne V spectrum

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**Abstract.** Previous works devoted to the Ne V spectrum are very fragmentary and yield a rather controversial picture of this ion. A lot of unidentified lines are still reported in these multiple studies. In the present paper, Hartree-Fock calculations and least-squares fits over the whole set of the available data (including the most recent ones) have been performed. As a result, a comprehensive view of the Ne V spectrum is presented. 10 new energy levels and 40 newly classified lines are proposed. An improved value of the ionisation potential of Ne V is also proposed.

**PACS.** 32.30.-r Atomic spectra – 32.10.Hq Ionization potentials, electron affinities

## 1 Introduction

Ne V belongs to the carbon-like sequence whose ground state is $1s^2 2s^2 2p^2\ {}^3\mathrm{P}_0$. The observed Ne V spectrum breaks into several separated wavelength regions: the short-wavelength grazing-incidence region 100−230 Å where the lines connecting the $n = 2$ configurations with the $n \geq 3$ configurations are located; the longer-wavelength VUV region 350−1200 Å containing mostly the $n = 3$ to $n = 4$ transitions; the UV and visible regions where most of the $\Delta n = 0$ transitions and transitions between highly excited configurations occur; and the infrared region where the transitions within the ground-state ${}^3\mathrm{P}$ term (which are very important for astrophysics) are observed. Thus, it is not surprising that the multiple studies of this spectrum have been very fragmentary and yielded a rather controversial picture.

The most recent investigations [1,2] accomplished by means of the beam-foil technique include an analysis of the previously made identifications. Several revisions made to the old identifications lead to a more consistent description of the spectrum, making the total number of known levels close to 150, and the number of classified lines about 260.

A further analysis employing extended calculations with use of additional tools has been undertaken in the present study. A more comprehensive analysis has led to some corrections to the previous identifications and has resulted in an additional 10 new energy levels and 40 newly classified lines. All available wavelength data have been fitted by means of a least-squares procedure yielding a complete level scheme together with computed wavelengths for observed lines which are in most cases more accurate than the measured ones. New identifications of the $5g$ and $6h$ configurations have permitted the derivation of a new, greatly improved, ionisation potential of Ne V.

## 2 History

The earliest available data on Ne V were obtained by Bowen [3]. In spectra emitted by planetary nebulae, he observed and identified the two parity-forbidden transitions (${}^3\mathrm{P}_{1,2}$−${}^1\mathrm{D}_2$) within the lowest configuration $2s^2 2p^2$. These observations were superseded by his later work [4] which supplies the wavelengths 3345.83 and 3425.87 (± 0.02) Å for these two lines. In [5], Bowen also observed the violet ${}^1\mathrm{D}_2$−${}^1\mathrm{S}_0$ and infrared ${}^3\mathrm{P}_1$−${}^3\mathrm{P}_2$ transitions. The ${}^1\mathrm{D}_2$−${}^1\mathrm{S}_0$ line was later re-measured by Penston *et al.* [6] at 2973.13 ± 0.05 Å in the emission spectrum of a slow nova. Observations of the other forbidden UV transition ${}^3\mathrm{P}_1$−${}^1\mathrm{S}_0$ at 1574.9 Å [7], 1574.82 ± 0.05 Å [8], and 1574.68 ± 0.05 Å [6] are less accurate in terms of the wavenumber uncertainty. The infrared ${}^3\mathrm{P}_1$−${}^3\mathrm{P}_2$ line, observed first by Pottash *et al.* [9], and the ${}^3\mathrm{P}_0$−${}^3\mathrm{P}_1$ line, first reported by Forrest *et al.* [10], have recently been precisely measured by Feuchtgruber *et al.* [11]. From these astrophysical observations, all five levels of the $2s^2 2p^2$ ground configuration can now be determined with a very

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good accuracy: 0.005 cm$^{-1}$ for the $^3$P$_1$, 0.011 cm$^{-1}$ for the $^3$P$_2$, 0.12 cm$^{-1}$ for the $^1$D$_2$, and 0.6 cm$^{-1}$ for the $^1$S$_0$ level.

The first laboratory observation of the Ne V spectrum was made by Paul and Polster [12] with use of gas discharge tubes as light sources. This work remains one of the best sources of experimental data on multiply-ionised neon in the VUV and EUV regions. A total of 57 lines and 38 levels of Ne V were found therein, but several assignments have been rejected by later investigators.

Nine energy levels of the second excited configuration $2s2p^3$ (all, except for the lowest quintet level $^5\mathrm{S}^o_2$), first found by Paul and Polster [12], have been re-measured with higher accuracy by Lindeberg [13] who has used a theta-pinch device to excite the spectra of multiply-ionised neon. The structure of this configuration was completed when the two intercombination lines connecting the $^5\mathrm{S}^o_2$ level with the ground $^3$P term were observed in the spectrum of the solar corona [14]. Later Sandlin *et al.* [7] re-measured these two lines more accurately at 1136.51 ± 0.02 Å ($^3\mathrm{P}_1$–$^5\mathrm{S}^o_2$) and at 1145.61 ± 0.02 Å ($^3\mathrm{P}_2$–$^5\mathrm{S}^o_2$).

The highest configuration of the $n = 2$ complex is $2p^4$. Despite its doubly-excited character, it is located well below the lowest excited configuration with $n = 3$. It is connected with the $2s2p^3$ configuration by several lines, while no connection with the higher-lying configurations has been observed. The $^3$P term was found by Paul and Polster [12], and the $^1$D and $^1$S terms were found by Lindeberg [13] who also improved the accuracy of the $^3$P levels.

From the available observations, all energy levels of the $2s2p^3$ and $2p^4$ configurations can now be derived with an uncertainty of 2 to 4 cm$^{-1}$.

The excitation energies of the $n \geq 3$ configurations are determined presently from the lines connecting these configurations with the ground ($2s^22p^2$) and the $2s2p^3$ configurations. Thus the uncertainties of these excitation energies depend entirely on the accuracy of EUV line wavelengths measured by Paul and Polster [12]. In their work the neon spectra produced by an electrical discharge in gas were recorded by means of a 3-meter grazing incidence (84°) spectrograph with a dispersion approximately equal to 1 Å/mm at 500 Å. The good dispersion, the use of high-quality photographic plates and the large number of internal reference lines (mostly from oxygen, nitrogen, carbon and silicon impurities) have provided accurate measured wavelengths. On the basis of a comparison of Paul and Polster's measured wavelengths with more accurate wavelengths derived from the known energy levels of Ne III [15] and Ne IV [16], we believe that their measurement uncertainty is not worse than ± 0.010 Å, except for weak and blended lines.

In a later work of Hermansdorfer [17], using a theta-pinch apparatus as a light source, a rather good 1-meter grazing-incidence spectrograph with a 3600 lines/mm grating had been employed. The image of the entrance slit on the photographic film had a spectral width of 0.03 Å. Nevertheless, the lack of proper reference lines and the use of photographic films instead of plates restricted the absolute wavelength-measurement accuracy in Hermansdorfer's work to 0.05 Å. In [18] we have reduced in some cases this uncertainty down to 0.02 Å on the basis of comparison of wavelengths measured independently by Hermansdorfer and some other authors (see discussion therein). Although Hermansdorfer did not improve Paul and Polster's measurements, he was able to identify many new Ne V lines that were not observed elsewhere. He also revised some line assignments made by Paul and Polster. The hotter plasma used in his study allowed him to exclude contamination of the spectrum by lines emitted by less ionised species of neon.

Based on the lines measured in the works of Paul and Polster [12] and Hermansdorfer [17], the excitation energies of all presently identified energy levels of the $n \geq 3$ configurations can be established with an uncertainty of 30 to 50 cm$^{-1}$ with a few exceptions for the levels determined from a single line observed only in Hermansdorfer's spectra (these may have an uncertainty as large as 400 cm$^{-1}$).

The ultraviolet transitions within the $n = 3$ configuration complex have been studied by Kaufman *et al.* [19] and Goldsmith and Kaufman [20] using a high-temperature toroidal discharge as a light source. They have succeeded in identifying a few $\left[2s^22p\right]3s$–$3p$ and $\left[2s2p^2(^4\mathrm{P})\right]3s$–$3p$ lines, all belonging to two multiplets. Another work of Lindeberg [21], in which a theta-pinch light source was employed, added two more multiplets in the UV range within these transition arrays, and two multiplets of the $\left[2s^22p\right]3p$–$3d$ and $\left[2s2p^2(^4\mathrm{P})\right]3p$–$3d$ transition arrays.

The development of the beam-foil technique has brought some more progress into the studies of the Ne V spectrum. Denis *et al.* [22,23] have registered a large number of lines in the UV and visible ranges and measured lifetimes for some of them. Spectral resolution was low in these studies, so Denis *et al.* have succeeded in identifying only one new line ($2s^22p3s\ ^1\mathrm{P}^o_1$–$2s^22p3p\ ^1\mathrm{D}_2$) in excess of the multiplets observed by Lindeberg [21] whose work was known to them. The lifetimes measured by Denis *et al.* [23] support their own assignments and those of Lindeberg [21].

Buchet and Druetta [24] have identified unresolved multiplets belonging to the $2s2p^3$–$2s^22p3p$ two-electron transition array at 210–230 Å, but their measurements do not contribute to the determination of the excitation energies of the $n = 3$ configurations because of the low spectral resolution.

Vach *et al.* [25] have observed several $3s$–$3p$ and $3p$–$3d$ transitions at much better resolution (0.5 Å) than Denis *et al.* [23]. They have identified some new lines around 2 000 Å. Although they have declared the measurement uncertainty as small as 0.2 Å, this can be valid only for the known lines they have recorded in the region above 2 000 Å. It is seen from Table 2 in [25] that the difference of their measured wavelengths from the more accurate Lindeberg's measurements is as large as 0.55 Å for the wavelengths shorter than 1 900 Å. We have scanned the spectrogram presented in Figure 2 of [25] by means of a desktop scanner and re-measured the lines on this spectrogram using image-processing computer software. The known lines of Ne IV, V and VI have been used as internal wavelength references to transform the coordinate space to wavenumbers by means of a linear interpolation. The resulting scatter of the reference lines is within ± 0.2 Å, while the 1999.0 Å wavelength presented by Vach *et al.* differs from our result (1999.5 Å) by $-0.5$ Å. The average systematic shift of the $\lambda = 1819-1865$ Å lines in Table 2 of [25] from Lindeberg's measurements is also negative ($-0.23$ Å) which evokes a suspicion that Vach *et al.* may have erroneously used air wavelengths in this range. But this can not be entirely true since the line at 1992.1 Å is close to our result. Finally, we have concluded that the vacuum wavelengths from [25] can be trusted only to ±0.5 Å. As for the 1999 Å line, we have preferred to use our value $1999.5 \pm 0.5$ Å (in vacuum).

Some of the lines observed by Denis *et al.* [22,23] around 2970 Å have also been reported by Lembo *et al.* [26] with somewhat lower wavelength uncertainty. However, Lembo *et al.* could only identify these lines as belonging to the $n = 5 \rightarrow n = 6$ transitions without detailed term assignments.

The majority of the other beam-foil studies were focused on lifetime measurements. The interested reader can find more information on this subject in the review of these studies presented by Bastin in his thesis [1].

The recent work of Bastin *et al.* [2], although applying the same beam-foil technique to excite the spectrum, has the advantage of a greatly improved spectral resolution which was about 0.1 Å in the region 400−1100 Å. This improvement, combined with almost certain assignments of the ionisation stages using spectra obtained at different beam energies, and with careful examination of the previously made classifications, has permitted the identification of a large number (65) of new VUV lines between the states belonging to the $2s^22pnl$ and $2s2p^2nl$ ($n = 3, 4$; $l = s$, $p$, $d$, $f$) configurations. These identifications have permitted Bastin *et al.* to propose 50 new energy levels within these configurations. This work has also revealed some errors in the old assignments of EUV lines [17].

## 3 New calculations

In order to verify the revisions made by the different authors and to find possible assignments for the large number of remaining unclassified lines, we have performed a parametric fitting of the energy levels derived from the whole set of observed spectral lines. In the fitting procedure we have included the following configurations: $2s^22p^2$, $2p^4$, $2s2p^2ns$, $2s2p^2nd$, $2s2p^2ng$, $(2s^22p+2p^3)np$, $(2s^22p+2p^3)nf$ ($n \leq 6$) – even parity; $2s2p^3$, $2s2p^2np$, $2s2p^2nf$, $(2s^22p+2p^3)n's$, $(2s^22p+2p^3)n'd$, $(2s^22p+2p^3)ng$ ($n \leq 6$, $n' \leq 7$) – odd parity. Cowan's computer codes [27] have been used for the calculations.

It should be noted that the inclusion of the highly excited unknown $2p^3nl$ configurations must be done simultaneously with the $2s^22pnl$ ones because of the very large configuration-interaction parameters between them. In the Hartree-Fock calculations, the repulsion from the $2p^3nl$ configurations brings the calculated levels of the $2s^22pnl$ configurations 10 000 cm$^{-1}$ lower than those calculated without accounting for the $2p^3nl$ configurations. This effect is actually responsible for the 10 000 cm$^{-1}$ downwards correction that had been applied to the Hartree-Fock average energies of the $2s^22pnl$ configurations in the previous analysis [1,2], as the $2p^3nl$ configurations had not been included in that analysis. This lowering of the energies is not the only effect of the configuration interaction. It also results in a significant change of the eigenvectors (which is most pronounced for the $2s^22p4f$ configuration) and, consequently, to a change of calculated transition rates. As a result, we had to revise 3 assignments made in [1,2]. Another consequence is that the $jK$ coupling is not confirmed to be the best description of the $2s^22p4f$ configuration as suggested previously [1,2]. When the $2p^3nl$ configurations were accounted for, the $LS$-coupling average purity of the $2s^22p4f$ configuration increased to 77% while the $jK$-coupling purity decreased to 71%. Also, the lowest leading $jK$ percentage became 46%, to be compared with 65% as calculated without the $2p^3nl$ configurations [1]. The newly calculated lowest $LS$ percentage is 59%, so that unique $LS$ designations can be given to the levels unambiguously.

Parametric calculations with the inclusion of multiple overlapping configurations have been made easier by the modifications made to Cowan's parametric-fitting code RCE [27] in Kramida's version of Cowan's package (this program may be obtained upon request to the author A.E. Kramida). In particular, the vector-input file permits the user to explicitly attribute the experimental energies to the states having known leading contributions to their wavefunctions. The new eigenvector-recognition algorithm introduced in this new version of RCE makes the iterative fitting much more stable.

As a result of our extended calculations, we have predicted the positions and relative intensities of the emitted lines more confidently than was previously possible. We have been able to find unambiguous assignments for a number of previously unclassified Ne V lines observed in [1,17,23–25] and to identify 10 new energy levels.

A separate calculation has been done in order to identify the $n = 5$ to $n = 6$ lines observed by Lembo *et al.* [26]. These lines have also been observed by Denis *et al.* [22,23] who have measured the lifetimes for the most intense ones of them. In this calculation, a larger configuration set was used, including all the $2s^22pnl$, $2s2p^2nl$, and $2p^3nl$ ($n \leq 6$, $l \leq 5$), and some of the $n = 7$, $l \leq 6$ configurations. The usual 85% scaling has been applied to the Coulomb, exchange and CI integrals, while all the other parameters have been fixed at the Hartree-Fock values.

## 4 Wavelengths and classification

The total list of observed and classified spectral lines of Ne V is presented in Table 1. The line intensities reported by different authors have been converted to a uniform scale

**Table 1.** Observed and classified lines of Ne V.

| Observed | | | Calculated$^b$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Intens.$^a$ | $\lambda$ Å | unc. Å | $\lambda$ Å | unc. Å | Classification$^c$ | | | | Ref.$^d$ |
| 18 | 107.96 | 0.05 | 107.961 | 0.005 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})4p$ | $^3\mathrm{D}^o_3$ | | [17] |
| 13 | 108.89 | 0.02 | – | – | $2s2p^3$ | $^5\mathrm{S}^o_2$–$2s2p^2(^4\mathrm{P})5d$ | $^5\mathrm{P}_3$ | | [17] |
| 18 | 109.57 | 0.02 | – | – | $2s^22p^2$ | $^1\mathrm{D}_2$–$2s^22p6d$ | $^1\mathrm{F}^o_3$ | | [17] |
| 23 | 110.36 | 0.02 | – | – | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s^22p5d$ | $^3\mathrm{P}^o_2$ | | [17] |
| 23 | 110.410 | 0.010 | – | – | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s^22p5d$ | $^3\mathrm{D}^o_3$ | | [12,17] |
| 30 | 113.870 | 0.010 | – | – | $2s^22p^2$ | $^1\mathrm{D}_2$–$2s^22p5d$ | $^1\mathrm{F}^o_3$ | | [12,17] |
| 27 | 117.23 | 0.05 | – | – | $2s2p^3$ | $^5\mathrm{S}^o_2$–$2s2p^2(^4\mathrm{P})4d$ | $^5\mathrm{P}_2$ | | [17] |
| 27 | 117.27 | 0.05 | – | – | $2s2p^3$ | $^5\mathrm{S}^o_2$–$2s2p^2(^4\mathrm{P})4d$ | $^5\mathrm{P}_3$ | | [17] |
| 12bl | 118.74 | 0.05 | – | – | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s^22p4d$ | $^3\mathrm{P}^o_0$ | | [17] |
| | | | – | – | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s^22p4d$ | $^3\mathrm{P}^o_1$ | | [17,12] |
| 37 | 118.89 | 0.05 | – | – | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s^22p4d$ | $^3\mathrm{P}^o_2$ | | [17,12] |
| 66bl | 119.01 | 0.05 | 118.964 | 0.006 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s^22p4d$ | $^3\mathrm{D}^o_2$ | | [17] |
| | | | 119.012 | 0.005 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s^22p4d$ | $^3\mathrm{D}^o_3$ | | [17] |
| 400c | 122.520 | 0.020 | 122.525 | 0.008 | $2s^22p^2$ | $^1\mathrm{D}_2$–$2s^22p4d$ | $^1\mathrm{F}^o_3$ | | [12] |
| 60 | 123.712 | 0.010 | – | – | $2s^22p^2$ | $^1\mathrm{D}_2$–$2s^22p4d$ | $^1\mathrm{D}^o_2$ | | [12] |
| 23 | 124.33 | 0.05 | – | – | $2s^22p^2$ | $^1\mathrm{D}_2$–$2s2p^2(^2\mathrm{D})3p$ | $^1\mathrm{P}^o_1$ | | [17]c [2] |
| 23 | 124.77 | 0.05 | 124.788 | 0.005 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s^22p4s$ | $^3\mathrm{P}^o_2$ | | [17,2] |
| 66 | 125.12 | 0.05 | – | – | $2s^22p^2$ | $^1\mathrm{D}_2$–$2s2p^2(^2\mathrm{D})3p$ | $^1\mathrm{F}^o_3$ | | [17]c |
| 37 | 125.830 | 0.010 | – | – | $2s^22p^2$ | $^1\mathrm{D}_2$–$2s2p^2(^2\mathrm{D})3p$ | $^1\mathrm{D}^o_2$ | | [12]c [17]c |
| 50 | 127.84 | 0.05 | – | – | $2s^22p^2$ | $^1\mathrm{S}_0$–$2s^22p4d$ | $^1\mathrm{P}^o_1$ | ? | [17]n |
| 100 | 129.034 | 0.010 | 129.038 | 0.006 | $2s^22p^2$ | $^1\mathrm{D}_2$–$2s^22p4s$ | $^1\mathrm{P}^o_1$ | | [12] |
| 18 | 130.61 | 0.05 | 130.60 | 0.04 | $2s^22p^2$ | $^3\mathrm{P}_0$–$2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{P}^o_1$ | | [17] |
| | | | 130.62 | 0.04 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{P}^o_2$ | ? | [17] |
| 16 | 130.68 | 0.05 | 130.67 | 0.04 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{P}^o_1$ | | [17] |
| 30 | 130.74 | 0.05 | 130.74 | 0.04 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{P}^o_2$ | ? | [17] |
| 16 | 130.77 | 0.05 | 130.79 | 0.04 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{P}^o_1$ | | [17] |
| 45 | 131.99 | 0.05 | 132.010 | 0.012 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{D}^o_2$ | | [17] |
| 50 | 132.04 | 0.05 | 132.051 | 0.011 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{D}^o_3$ | | [17] |
| 18 | 132.11 | 0.05 | 132.132 | 0.012 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{D}^o_2$ | | [17] |
| 27 | 134.84 | 0.05 | 134.891 | 0.007 | $2s^22p^2$ | $^1\mathrm{S}_0$–$2s^22p4s$ | $^1\mathrm{P}^o_1$ | | [17] |
| 14 | 135.66 | 0.05 | 135.658 | 0.017 | $2s^22p^2$ | $^3\mathrm{P}_0$–$2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{S}^o_1$ | | [17] |
| 22 | 135.73 | 0.05 | 135.733 | 0.017 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{S}^o_1$ | | [17] |
| 24 | 135.86 | 0.05 | 135.862 | 0.016 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{S}^o_1$ | | [17] |
| 100 | 140.716 | 0.010 | – | – | $2s2p^3$ | $^5\mathrm{S}^o_2$–$2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{P}_1$ | | [12] |
| 300 | 140.757 | 0.010 | 140.757 | 0.009 | $2s2p^3$ | $^5\mathrm{S}^o_2$–$2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{P}_2$ | | [12] |
| 300 | 140.791 | 0.010 | 140.794 | 0.008 | $2s2p^3$ | $^5\mathrm{S}^o_2$–$2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{P}_3$ | | [12] |
| 27 | 141.45 | 0.05 | 141.423 | 0.008 | $2s2p^3$ | $^5\mathrm{S}^o_2$–$2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}_3$ | | [17] |
| 37bl | 142.441 | 0.020 | 142.426 | 0.007 | $2s^22p^2$ | $^3\mathrm{P}_0$–$2s^22p3d$ | $^3\mathrm{P}^o_1$ | | [12,17] |
| 27 | 142.48 | 0.02 | 142.473 | 0.011 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s^22p3d$ | $^3\mathrm{P}^o_0$ | | [17] |
| 200bl | 142.51 | 0.020 | 142.510 | 0.006 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s^22p3d$ | $^3\mathrm{P}^o_1$ | | [12,17] |
| 18 | 142.58 | 0.02 | 142.582 | 0.006 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s^22p3d$ | $^3\mathrm{P}^o_2$ | | [17] |
| 80 | 142.661 | 0.010 | 142.652 | 0.006 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s^22p3d$ | $^3\mathrm{P}^o_1$ | | [12] |
| 300bl | 142.724 | 0.010 | 142.690 | 0.011 | $2s2p^3$ | $^3\mathrm{D}^o_3$–$2s2p^2(^2\mathrm{D})3d$ | $^3\mathrm{D}_3$ | ? | [12,17] |
| | | | 142.724 | 0.006 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s^22p3d$ | $^3\mathrm{P}^o_2$ | | [12] |
| 100 | 143.219 | 0.010 | 143.220 | 0.006 | $2s^22p^2$ | $^3\mathrm{P}_0$–$2s^22p3d$ | $^3\mathrm{D}^o_1$ | | [12] |
| 200 | 143.273 | 0.010 | 143.264 | 0.007 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s^22p3d$ | $^3\mathrm{D}^o_2$ | | [12] |

**Table 1.** *Continued.*

| Observed | | | Calculated$^b$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Intens.$^a$ | $\lambda$ Å | unc. Å | $\lambda$ Å | unc. Å | Classification$^c$ | | | | Ref.$^d$ |
| 300 | 143.344 | 0.010 | 143.346 | 0.006 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s^22p3d$ | $^3\mathrm{D}^o_3$ | | [12] |
| 36 | 143.41 | 0.05 | 143.408 | 0.006 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s^22p3d$ | $^3\mathrm{D}^o_2$ | | [17] |
| 45 | 144.019 | 0.010 | – | – | $2s2p^3$ | $^3\mathrm{D}^o_3$–$2s2p^2(^2\mathrm{D})3d$ | $^3\mathrm{F}_4$ | | [12,17] |
| 18 | 146.86 | 0.05 | 146.888 | 0.007 | $2s^22p^2$ | $^1\mathrm{D}_2$–$2s^22p3d$ | $^1\mathrm{P}^o_1$ | | [17] |
| 300 | 147.132 | 0.010 | 147.138 | 0.007 | $2s^22p^2$ | $^1\mathrm{D}_2$–$2s^22p3d$ | $^1\mathrm{F}^o_3$ | | [12] |
| 18 | 148.15 | 0.05 | 148.16 | 0.05 | $2s2p^3$ | $^3\mathrm{P}^o_2$–$2s2p^2(^2\mathrm{D})3d$ | $^3\mathrm{S}_1$ | | [17] |
| | | | 148.16 | 0.05 | $2s2p^3$ | $^3\mathrm{P}^o_1$–$2s2p^2(^2\mathrm{D})3d$ | $^3\mathrm{S}_1$ | | [17] |
| 18 | 149.589 | 0.010 | – | – | $2s2p^3$ | $^3\mathrm{P}^o_2$–$2s2p^2(^2\mathrm{D})3d$ | $^3\mathrm{D}_3$ | ? | [12,17,2] |
| 66 | 151.23 | 0.02 | 151.237 | 0.007 | $2s^22p^2$ | $^1\mathrm{D}_2$–$2s^22p3d$ | $^1\mathrm{D}^o_2$ | | [17,2] |
| 66 | 151.42 | 0.02 | 151.424 | 0.007 | $2s^22p^2$ | $^1\mathrm{D}_2$–$2s^22p3d$ | $^3\mathrm{F}^o_2$ | | [17,12,2] |
| 45 | 154.50 | 0.02 | 154.520 | 0.007 | $2s^22p^2$ | $^1\mathrm{S}_0$–$2s^22p3d$ | $^1\mathrm{P}^o_1$ | | [17,12,2] |
| 18 | 156.14 | 0.05 | 156.145 | 0.011 | $2s2p^3$ | $^3\mathrm{D}^o_3$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{D}_3$ | | [17] |
| 18 | 156.20 | 0.05 | 156.202 | 0.014 | $2s2p^3$ | $^3\mathrm{D}^o_2$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{D}_2$ | | [17] |
| | | 0.05 | 156.217 | 0.015 | $2s2p^3$ | $^3\mathrm{D}^o_1$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{D}_1$ | | [17] |
| 30 | 158.59 | 0.05 | 158.601 | 0.010 | $2s2p^3$ | $^3\mathrm{D}^o_3$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}_4$ | | [17] |
| 25 | 158.72 | 0.05 | 158.734 | 0.012 | $2s2p^3$ | $^3\mathrm{D}^o_2$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}_3$ | | [17] |
| 23 | 158.822 | 0.010 | 158.812 | 0.010 | $2s2p^3$ | $^3\mathrm{D}^o_1$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}_2$ | | [12,17] |
| 15 | 162.15 | 0.05 | – | – | $2s2p^3$ | $^1\mathrm{D}^o_2$–$2s2p^2(^2\mathrm{D})3d$ | $^1\mathrm{D}_2$ | | [17]c |
| 200 | 164.023 | 0.010 | 164.027 | 0.009 | $2s2p^3$ | $^5\mathrm{S}^o_2$–$2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_3$ | | [12] |
| 200bl | 164.145 | 0.030 | 164.180 | 0.009 | $2s2p^3$ | $^5\mathrm{S}^o_2$–$2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_2$ | | [12] |
| 160 | 164.294 | 0.010 | 164.296 | 0.010 | $2s2p^3$ | $^5\mathrm{S}^o_2$–$2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_1$ | | [12] |
| 18 | 164.43 | 0.05 | 164.444 | 0.013 | $2s2p^3$ | $^3\mathrm{P}^o_2$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{D}_3$ | | [17] |
| 18 | 164.48 | 0.05 | 164.488 | 0.016 | $2s2p^3$ | $^3\mathrm{P}^o_2$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{D}_2$ | | [17] |
| | | | 164.488 | 0.016 | $2s2p^3$ | $^3\mathrm{P}^o_1$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{D}_2$ | | [17] |
| | | | 164.499 | 0.016 | $2s2p^3$ | $^3\mathrm{P}^o_1$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{D}_1$ | | [17] |
| | | | 164.508 | 0.017 | $2s2p^3$ | $^3\mathrm{P}^o_0$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{D}_1$ | | [17] |
| 30 | 166.05 | 0.05 | 166.06 | 0.05 | $2s2p^3$ | $^3\mathrm{D}^o_3$–$2s2p^2(^2\mathrm{D})3s$ | $^3\mathrm{D}_3$ | | [17] |
| 300 | 167.483 | 0.010 | 167.475 | 0.008 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s^22p3s$ | $^3\mathrm{P}^o_2$ | | [12] |
| 60 | 167.610 | 0.010 | 167.611 | 0.008 | $2s^22p^2$ | $^3\mathrm{P}_0$–$2s^22p3s$ | $^3\mathrm{P}^o_1$ | | [12] |
| 500 | 167.670 | 0.010 | 167.671 | 0.008 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s^22p3s$ | $^3\mathrm{P}^o_2$ | | [12] |
| 23 | 167.72 | 0.05 | 167.727 | 0.008 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s^22p3s$ | $^3\mathrm{P}^o_1$ | | [17] |
| 100 | 167.837 | 0.010 | 167.833 | 0.008 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s^22p3s$ | $^3\mathrm{P}^o_0$ | | [12] |
| 100 | 167.921 | 0.010 | 167.924 | 0.008 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s^22p3s$ | $^3\mathrm{P}^o_1$ | | [12] |
| 14 | 168.60 | 0.05 | 168.595 | 0.018 | $2s2p^3$ | $^3\mathrm{P}^o_2$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{P}_1$ | | [17] |
| | | | 168.595 | 0.018 | $2s2p^3$ | $^3\mathrm{P}^o_1$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{P}_1$ | | [17] |
| | | | 168.604 | 0.018 | $2s2p^3$ | $^3\mathrm{P}^o_0$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{P}_1$ | | [17] |
| 40bl | 168.73 | 0.05 | 168.711 | 0.015 | $2s2p^3$ | $^3\mathrm{P}^o_2$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{P}_2$ | | [17] |
| | | | 168.712 | 0.015 | $2s2p^3$ | $^3\mathrm{P}^o_1$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{P}_2$ | | [17] |
| 1000 | 173.932 | 0.010 | 173.928 | 0.010 | $2s^22p^2$ | $^1\mathrm{D}_2$–$2s^22p3s$ | $^1\mathrm{P}^o_1$ | | [12] |
| 18 | 175.48 | 0.05 | 175.47 | 0.05 | $2s2p^3$ | $^3\mathrm{P}^o_2$–$2s2p^2(^2\mathrm{D})3s$ | $^3\mathrm{D}_3$ | | [17] |
| 18 | 183.72 | 0.05 | 183.758 | 0.012 | $2s2p^3$ | $^3\mathrm{D}^o_3$–$2s2p^2(^4\mathrm{P})3s$ | $^3\mathrm{P}_2$ | | [17] |
| 200 | 184.730 | 0.010 | 184.732 | 0.010 | $2s^22p^2$ | $^1\mathrm{S}_0$–$2s^22p3s$ | $^1\mathrm{P}^o_1$ | | [12] |
| 10 | 192.0 | 0.2 | 191.60 | 0.02 | $2s2p^3$ | $^3\mathrm{S}^o_1$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{P}_1$ | | [24]n |
| | | | 191.751 | 0.019 | $2s2p^3$ | $^3\mathrm{S}^o_1$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{P}_2$ | | [24]n |
| 100 | 195.368 | 0.010 | 195.360 | 0.012 | $2s2p^3$ | $^3\mathrm{P}^o_2$–$2s2p^2(^4\mathrm{P})3s$ | $^3\mathrm{P}_2$ | | [12] |
| | | | 195.361 | 0.013 | $2s2p^3$ | $^3\mathrm{P}^o_1$–$2s2p^2(^4\mathrm{P})3s$ | $^3\mathrm{P}_2$ | | [12] |

**Table 1.** *Continued.*

| Observed | | | Calculated[b] | | | | | |
|---|---|---|---|---|---|---|---|---|
| Intens.[a] | λ Å | unc. Å | λ Å | unc. Å | Classification[c] | | | Ref.[d] |
| 60 | 195.553 | 0.010 | 195.560 | 0.012 | $2s2p^3$ | $^3\mathrm{P}^o_2$–$2s2p^2(^4\mathrm{P})3s$ | $^3\mathrm{P}_1$ | [12] |
| | | | 195.561 | 0.012 | $2s2p^3$ | $^3\mathrm{P}^o_1$–$2s2p^2(^4\mathrm{P})3s$ | $^3\mathrm{P}_1$ | [12] |
| | | | 195.573 | 0.011 | $2s2p^3$ | $^3\mathrm{P}^o_0$–$2s2p^2(^4\mathrm{P})3s$ | $^3\mathrm{P}_1$ | [12] |
| 40 | 195.621 | 0.010 | – | – | $2s2p^3$ | $^3\mathrm{P}^o_1$–$2s2p^2(^4\mathrm{P})3s$ | $^3\mathrm{P}_0$ | [12] |
| 130 | 210.3 | 0.4 | 210.196 | 0.012 | $2s2p^3$ | $^3\mathrm{D}^o_3$–$2s^22p3p$ | $^3\mathrm{P}_2$ | [24] |
| | | | 210.227 | 0.012 | $2s2p^3$ | $^3\mathrm{D}^o_2$–$2s^22p3p$ | $^3\mathrm{P}_2$ | [24] |
| | | | 210.422 | 0.013 | $2s2p^3$ | $^3\mathrm{D}^o_2$–$2s^22p3p$ | $^3\mathrm{P}_1$ | [24] |
| | | | 210.432 | 0.012 | $2s2p^3$ | $^3\mathrm{D}^o_1$–$2s^22p3p$ | $^3\mathrm{P}_1$ | [24] |
| | | | 210.574 | 0.012 | $2s2p^3$ | $^3\mathrm{D}^o_1$–$2s^22p3p$ | $^3\mathrm{P}_0$ | [24] |
| 60 | 214.8 | 0.4 | 214.682 | 0.013 | $2s2p^3$ | $^3\mathrm{D}^o_3$–$2s^22p3p$ | $^3\mathrm{D}_3$ | [24] |
| 25 | 225.5 | 0.4 | 225.516 | 0.014 | $2s2p^3$ | $^3\mathrm{P}^o_2$–$2s^22p3p$ | $^3\mathrm{P}_2$ | [24] |
| | | | 225.517 | 0.014 | $2s2p^3$ | $^3\mathrm{P}^o_1$–$2s^22p3p$ | $^3\mathrm{P}_2$ | [24] |
| | | | 225.742 | 0.014 | $2s2p^3$ | $^3\mathrm{P}^o_1$–$2s^22p3p$ | $^3\mathrm{P}_1$ | [24] |
| | | | 225.758 | 0.014 | $2s2p^3$ | $^3\mathrm{P}^o_0$–$2s^22p3p$ | $^3\mathrm{P}_1$ | [24] |
| 80 | 228.2 | 0.4 | 228.262 | 0.015 | $2s2p^3$ | $^3\mathrm{P}^o_2$–$2s^22p3p$ | $^3\mathrm{S}_1$ | [24] |
| | | | 228.263 | 0.015 | $2s2p^3$ | $^3\mathrm{P}^o_1$–$2s^22p3p$ | $^3\mathrm{S}_1$ | [24] |
| 60 | 231.2 | 0.4 | 230.687 | 0.015 | $2s2p^3$ | $^3\mathrm{P}^o_2$–$2s^22p3p$ | $^3\mathrm{D}_3$ | [24] |
| | | | 231.103 | 0.015 | $2s2p^3$ | $^3\mathrm{P}^o_1$–$2s^22p3p$ | $^3\mathrm{D}_2$ | [24] |
| | | | 231.360 | 0.015 | $2s2p^3$ | $^3\mathrm{P}^o_0$–$2s^22p3p$ | $^3\mathrm{D}_1$ | [24] |
| 800 | 357.944 | 0.005 | 357.947 | 0.004 | $2s^22p^2$ | $^3\mathrm{P}_0$–$2s2p^3$ | $^3\mathrm{S}^o_1$ | [13, 12] |
| 1000bl | 358.474 | 0.005 | 358.474 | 0.004 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s2p^3$ | $^3\mathrm{S}^o_1$ | [13, 12] |
| 1000bl | 359.375 | 0.005 | 359.374 | 0.004 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s2p^3$ | $^3\mathrm{S}^o_1$ | [13, 12] |
| 2000 | 365.591 | 0.005 | 365.593 | 0.004 | $2s^22p^2$ | $^1\mathrm{D}_2$–$2s2p^3$ | $^1\mathrm{P}^o_1$ | [13, 12] |
| 1600 | 416.209 | 0.005 | 416.212 | 0.004 | $2s^22p^2$ | $^1\mathrm{D}_2$–$2s2p^3$ | $^1\mathrm{D}^o_2$ | [13, 12] |
| 500 | 416.838 | 0.005 | 416.834 | 0.005 | $2s^22p^2$ | $^1\mathrm{S}_0$–$2s2p^3$ | $^1\mathrm{P}^o_1$ | [13, 12] |
| 200 | 420.370 | 0.005 | 420.369 | 0.005 | $2s2p^3$ | $^3\mathrm{D}^o_1$–$2p^4$ | $^3\mathrm{P}_0$ | [13, 12] |
| 300 | 420.944 | 0.005 | 420.937 | 0.003 | $2s2p^3$ | $^3\mathrm{D}^o_2$–$2p^4$ | $^3\mathrm{P}_1$ | [13, 12] |
| m | – | – | 420.977 | 0.004 | $2s2p^3$ | $^3\mathrm{D}^o_1$–$2p^4$ | $^3\mathrm{P}_1$ | [13, 12] |
| 300 | 422.219 | 0.005 | 422.216 | 0.004 | $2s2p^3$ | $^3\mathrm{D}^o_3$–$2p^4$ | $^3\mathrm{P}_2$ | [13, 12] |
| 100 | 422.335 | 0.005 | 422.341 | 0.004 | $2s2p^3$ | $^3\mathrm{D}^o_2$–$2p^4$ | $^3\mathrm{P}_2$ | [13, 12] |
| 30 | 472.89 | 0.10 | 472.92 | 0.06 | $2s^22p3s$ | $^1\mathrm{P}^o_1$–$2s^22p4p$ | $^1\mathrm{P}_1$ | [1]n |
| 500 | 480.412 | 0.005 | 480.415 | 0.005 | $2s^22p^2$ | $^3\mathrm{P}_0$–$2s2p^3$ | $^3\mathrm{P}^o_1$ | [13, 12, 2] |
| 300 | 481.290 | 0.005 | 481.293 | 0.005 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s2p^3$ | $^3\mathrm{P}^o_0$ | [13, 12, 2] |
| 500 | 481.373 | 0.005 | 481.366 | 0.005 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s2p^3$ | $^3\mathrm{P}^o_1$ | [13, 12, 2] |
| | | | 481.371 | 0.005 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s2p^3$ | $^3\mathrm{P}^o_2$ | [13, 12, 2] |
| 1000 | 482.993 | 0.005 | 482.990 | 0.005 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s2p^3$ | $^3\mathrm{P}^o_1$ | [13, 12, 2] |
| | | | 482.994 | 0.005 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s2p^3$ | $^3\mathrm{P}^o_2$ | [13, 12, 2] |
| 30 | 486.249 | 0.010 | 486.245 | 0.007 | $2s2p^3$ | $^3\mathrm{P}^o_1$–$2p^4$ | $^3\mathrm{P}_0$ | [13, 12] |
| 60w | 487.055 | 0.010 | 487.053 | 0.006 | $2s2p^3$ | $^3\mathrm{P}^o_2$–$2p^4$ | $^3\mathrm{P}_1$ | [13, 12, 2] |
| | | | 487.057 | 0.006 | $2s2p^3$ | $^3\mathrm{P}^o_1$–$2p^4$ | $^3\mathrm{P}_1$ | [13, 12, 2] |
| 60 | 487.12 | 0.010 | 487.133 | 0.006 | $2s2p^3$ | $^3\mathrm{P}^o_0$–$2p^4$ | $^3\mathrm{P}_1$ | [13, 12, 2] |
| m | – | – | 488.933 | 0.006 | $2s2p^3$ | $^3\mathrm{P}^o_2$–$2p^4$ | $^3\mathrm{P}_2$ | [13, 12, 2] |
| m | – | – | 488.938 | 0.006 | $2s2p^3$ | $^3\mathrm{P}^o_1$–$2p^4$ | $^3\mathrm{P}_2$ | [13, 12, 2] |
| 60 | 506.89 | 0.10 | – | – | $2s^22p3p$ | $^3\mathrm{D}_2$–$2s^22p4d$ | $^3\mathrm{F}^o_3$ | [2] |
| 260 | 507.11 | 0.10 | – | – | $2s^22p3p$ | $^3\mathrm{D}_1$–$2s^22p4d$ | $^3\mathrm{F}^o_2$ | [2] |
| | | | – | – | $2s^22p3p$ | $^3\mathrm{D}_3$–$2s^22p4d$ | $^3\mathrm{F}^o_4$ | [2] |

**Table 1.** *Continued.*

| Observed | | | Calculated[b] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Intens.[a] | $\lambda$ Å | unc. Å | $\lambda$ Å | unc. Å | Classification[c] | | | | Ref.[d] |
| 180 | 508.485 | 0.005 | – | – | $2s2p^3$ | $^1P^o_1$–$2p^4$ | $^1S_0$ | | [13,2] |
| 80 | 526.78 | 0.10 | 526.70 | 0.09 | $2s^22p3p$ | $^3P_1$–$2s^22p4d$ | $^3D^o_2$ | | [2] |
| | | | 526.92 | 0.08 | $2s^22p3p$ | $^3P_2$–$2s^22p4d$ | $^3D^o_3$ | | [2] |
| 130 | 546.41 | 0.10 | 546.41 | 0.10 | $2s^22p3p$ | $^1D_2$–$2s^22p4d$ | $^1F^o_3$ | | [2] |
| m | – | – | 553.94 | 0.63 | $2s^22p3s$ | $^3P^o_2$–$2s2p^2(^2D)3s$ | $^3D_3$ | | [13] |
| 800 | 568.420 | 0.005 | 568.424 | 0.005 | $2s^22p^2$ | $^3P_0$–$2s2p^3$ | $^3D^o_1$ | | [13,12,2] |
| 500 | 569.760 | 0.005 | 569.756 | 0.005 | $2s^22p^2$ | $^3P_1$–$2s2p^3$ | $^3D^o_1$ | | [13,12,2] |
| 1000 | 569.830 | 0.005 | 569.828 | 0.005 | $2s^22p^2$ | $^3P_1$–$2s2p^3$ | $^3D^o_2$ | | [13,12,2] |
| 500 | 572.103 | 0.005 | 572.105 | 0.005 | $2s^22p^2$ | $^3P_2$–$2s2p^3$ | $^3D^o_2$ | | [13,12,2] |
| 1600 | 572.337 | 0.005 | 572.335 | 0.005 | $2s^22p^2$ | $^3P_2$–$2s2p^3$ | $^3D^o_3$ | | [13,12,2] |
| 160bl | 586.91 | 0.10 | 586.90 | 0.09 | $2s^22p3p$ | $^1P_1$–$2s^22p4s$ | $^1P^o_1$ | | [2] |
| m | – | – | 602.18 | 1.22 | $2s^22p3p$ | $^1D_2$–$2s2p^2(^2D)3p$ | $^1F^o_3$ | – | |
| 1400 | 602.300 | 0.005 | 602.302 | 0.005 | $2s2p^3$ | $^1D^o_2$–$2p^4$ | $^1D_2$ | | [13,2] |
| 180 | 618.79 | 0.10 | 618.79 | 0.07 | $2s^22p3p$ | $^3D_2$–$2s^22p4s$ | $^3P^o_2$ | | [2] |
| 330 | 620.64 | 0.10 | 620.67 | 0.06 | $2s^22p3p$ | $^3D_1$–$2s^22p4s$ | $^3P^o_1$ | | [2] |
| 580 | 621.80 | 0.10 | 621.78 | 0.07 | $2s^22p3p$ | $^3D_3$–$2s^22p4s$ | $^3P^o_2$ | | [2] |
| | | | 621.82 | 0.09 | $2s^22p3p$ | $^3D_1$–$2s^22p4s$ | $^3P^o_0$ | | [2] |
| 290 | 622.40 | 0.10 | 622.41 | 0.06 | $2s^22p3p$ | $^3D_2$–$2s^22p4s$ | $^3P^o_1$ | | [2] |
| 60 | 626.54 | 0.10 | 626.55 | 0.10 | $2s2p^2(^4P)3d$ | $^5F_3$–$2s2p^2(^4P)4f$ | $^5F^o_3$ | | [2] |
| 100 | 627.28 | 0.10 | 627.26 | 0.09 | $2s2p^2(^4P)3d$ | $^5F_4$–$2s2p^2(^4P)4f$ | $^5F^o_4$ | | [2] |
| 90 | 628.29 | 0.10 | 628.31 | 0.09 | $2s2p^2(^4P)3d$ | $^5F_5$–$2s2p^2(^4P)4f$ | $^5F^o_5$ | | [2] |
| 70 | 631.35 | 0.10 | 631.30 | 0.08 | $2s2p^2(^4P)3d$ | $^5F_4$–$2s2p^2(^4P)4f$ | $^3G^o_5$ | | [1]n |
| 60 | 632.04 | 0.10 | 632.02 | 0.12 | $2s2p^2(^4P)3d$ | $^5F_3$–$2s2p^2(^4P)4f$ | $^3G^o_4$ | | [1]n |
| | | | 632.18 | 0.14 | $2s2p^2(^4P)3d$ | $^5F_2$–$2s2p^2(^4P)4f$ | $^3G^o_3$ | ? | [1]n |
| 100 | 632.66 | 0.10 | 632.64 | 0.08 | $2s2p^2(^4P)3d$ | $^5F_5$–$2s2p^2(^4P)4f$ | $^3G^o_5$ | | [1]n |
| 1500 | 633.74 | 0.10 | – | – | $2s2p^2(^4P)3d$ | $^5F_5$–$2s2p^2(^4P)4f$ | $^5G^o_6$ | | [2] |
| | | | 633.85 | 0.10 | $2s2p^2(^4P)3d$ | $^5F_4$–$2s2p^2(^4P)4f$ | $^5G^o_5$ | | [2] |
| | | | 633.90 | 0.14 | $2s2p^2(^4P)3d$ | $^5F_3$–$2s2p^2(^4P)4f$ | $^5G^o_4$ | | [2] |
| 100bl | 634.01 | 0.10 | 634.10 | 0.11 | $2s2p^2(^4P)3d$ | $^5F_2$–$2s2p^2(^4P)4f$ | $^5G^o_3$ | ? | [2] |
| | | | – | – | $2s2p^2(^4P)3d$ | $^5F_1$–$2s2p^2(^4P)4f$ | $^5G^o_2$ | ? | [2] |
| 170 | 635.05 | 0.10 | 634.91 | 0.11 | $2s2p^2(^4P)3d$ | $^5F_3$–$2s2p^2(^4P)4f$ | $^5G^o_3$ | ? | [2] |
| | | | 634.97 | 0.14 | $2s2p^2(^4P)3d$ | $^5F_4$–$2s2p^2(^4P)4f$ | $^5G^o_4$ | | [2] |
| | | | 635.19 | 0.11 | $2s2p^2(^4P)3d$ | $^5F_5$–$2s2p^2(^4P)4f$ | $^5G^o_5$ | | [2] |
| 130 | 642.93 | 0.10 | 642.87 | 0.10 | $2s^22p3d$ | $^3F^o_3$–$2s^22p4f$ | $^1G_4$ | | [2] |
| 70 | 645.78 | 0.10 | 645.80 | 0.09 | $2s^22p3d$ | $^3F^o_2$–$2s^22p4f$ | $^3G_3$ | | [1]n |
| 570 | 648.48 | 0.10 | 648.49 | 0.08 | $2s^22p3d$ | $^3F^o_3$–$2s^22p4f$ | $^3G_4$ | | [2] |
| 630 | 649.21 | 0.10 | 649.22 | 0.09 | $2s^22p3d$ | $^1D^o_2$–$2s^22p4f$ | $^3G_3$ | | [2] |
| | | | 649.11 | 0.09 | $2s^22p3d$ | $^3F^o_3$–$2s^22p4f$ | $^3G_3$ | | [2] |
| 1300 | 649.64 | 0.10 | 649.62 | 0.10 | $2s^22p3d$ | $^3F^o_4$–$2s^22p4f$ | $^3G_5$ | | [2] |
| 190 | 650.15 | 0.10 | 650.22 | 0.09 | $2s^22p3d$ | $^3F^o_2$–$2s^22p4f$ | $^3F_3$ | | [1]n |
| 730 | 650.72 | 0.10 | 650.70 | 0.07 | $2s^22p3d$ | $^3F^o_2$–$2s^22p4f$ | $^1F_3$ | | [2] |
| 180 | 651.08 | 0.10 | 651.08 | 0.08 | $2s^22p3d$ | $^3F^o_4$–$2s^22p4f$ | $^3G_4$ | | [2] |
| 660 | 653.24 | 0.10 | 653.34 | 0.29 | $2s2p^2(^4P)3d$ | $^5D_1$–$2s2p^2(^4P)4f$ | $^5F^o_2$ | | [2] |
| | | | 653.21 | 0.19 | $2s2p^2(^4P)3d$ | $^5D_2$–$2s2p^2(^4P)4f$ | $^5F^o_3$ | | [2] |
| | | | 653.22 | 0.09 | $2s^22p3d$ | $^3F^o_3$–$2s^22p4f$ | $^3F_4$ | | [2] |
| | | | 653.40 | 0.13 | $2s2p^2(^4P)3d$ | $^5D_3$–$2s2p^2(^4P)4f$ | $^5F^o_4$ | | [2] |

**Table 1.** *Continued.*

| Observed | | | Calculated$^b$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Intens.$^a$ | $\lambda$ Å | unc. Å | $\lambda$ Å | unc. Å | Classification$^c$ | | | | Ref.$^d$ |
| 630 | 653.69 | 0.10 | 653.77 | 0.15 | $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}_3$–$2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{F}^o_3$ | | [2] |
| | | | 653.59 | 0.25 | $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}_2$–$2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{F}^o_2$ | | [2] |
| | | | 653.77 | 0.11 | $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}_4$–$2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{F}^o_5$ | | [2] |
| | | | 653.68 | 0.10 | $2s^22p3d$ | $^1\mathrm{D}^o_2$–$2s^22p4f$ | $^3\mathrm{F}_3$ | | [2] |
| 230 | 654.10 | 0.10 | 654.06 | 0.11 | $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}_4$–$2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{F}^o_4$ | | [2] |
| | | | 654.16 | 0.08 | $2s^22p3d$ | $^1\mathrm{D}^o_2$–$2s^22p4f$ | $^1\mathrm{F}_3$ | | [2] |
| 210 | 660.79 | 0.10 | 660.80 | 0.08 | $2s^22p3p$ | $^3\mathrm{P}_1$–$2s^22p4s$ | $^3\mathrm{P}^o_2$ | | [2] |
| 180 | 661.27 | 0.10 | 661.22 | 0.10 | $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}_4$–$2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{G}^o_5$ | | [1]n |
| 470 | 662.73 | 0.10 | 662.74 | 0.07 | $2s^22p3p$ | $^3\mathrm{P}_2$–$2s^22p4s$ | $^3\mathrm{P}^o_2$ | | [2] |
| 170 | 663.51 | 0.10 | 663.52 | 0.07 | $2s^22p3p$ | $^3\mathrm{P}_0$–$2s^22p4s$ | $^3\mathrm{P}^o_1$ | | [2] |
| 140 | 664.93 | 0.10 | 664.93 | 0.07 | $2s^22p3p$ | $^3\mathrm{P}_1$–$2s^22p4s$ | $^3\mathrm{P}^o_1$ | | [2] |
| 180 | 666.28 | 0.10 | 666.25 | 0.10 | $2s^22p3p$ | $^3\mathrm{P}_1$–$2s^22p4s$ | $^3\mathrm{P}^o_0$ | | [2] |
| 190 | 666.95 | 0.10 | 666.89 | 0.07 | $2s^22p3p$ | $^3\mathrm{P}_2$–$2s^22p4s$ | $^3\mathrm{P}^o_1$ | | [2] |
| 130 | 667.86 | 0.10 | 667.88 | 0.10 | $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}_3$–$2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{D}^o_4$ | | [1]n |
| 90 | 670.63 | 0.10 | 670.58 | 0.10 | $2s^22p3d$ | $^3\mathrm{D}^o_1$–$2s^22p4f$ | $^3\mathrm{D}_1$ | | [1]n |
| 110 | 671.45 | 0.10 | 671.46 | 0.09 | $2s^22p3d$ | $^3\mathrm{D}^o_2$–$2s^22p4f$ | $^3\mathrm{D}_1$ | | [1]n |
| 140 | 673.34 | 0.10 | 673.31 | 0.09 | $2s^22p3d$ | $^3\mathrm{D}^o_2$–$2s^22p4f$ | $^3\mathrm{D}_2$ | | [2] |
| 280 | 675.18 | 0.10 | 675.24 | 0.10 | $2s^22p3d$ | $^3\mathrm{D}^o_3$–$2s^22p4f$ | $^3\mathrm{D}_3$ | | [2] |
| 240 | 679.77 | 0.10 | 679.74 | 0.10 | $2s^22p3d$ | $^3\mathrm{D}^o_2$–$2s^22p4f$ | $^3\mathrm{G}_3$ | | [2] |
| | | | 679.79 | 0.16 | $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{D}^o_2$ | ? | [2]n |
| 250 | 680.47 | 0.10 | 680.46 | 0.09 | $2s^22p3d$ | $^3\mathrm{D}^o_3$–$2s^22p4f$ | $^3\mathrm{G}_4$ | | [2] |
| 360bl | 680.77 | 0.10 | 680.80 | 0.14 | $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{P}_3$–$2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{D}^o_3$ | | [1]n |
| | | | – | – | $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{P}_1$–$2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{D}^o_1$ | | [1]n |
| 260 | 681.67 | 0.10 | 681.67 | 0.10 | $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{D}^o_3$ | | [2] |
| 610 | 682.26 | 0.10 | 682.26 | 0.10 | $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{P}_3$–$2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{D}^o_4$ | | [2] |
| 700 | 683.93 | 0.10 | – | – | $2s^22p3d$ | $^3\mathrm{D}^o_1$–$2s^22p4f$ | $^3\mathrm{F}_2$ | | [2] |
| 830bl | 684.76 | 0.20 | 684.64 | 0.10 | $2s^22p3d$ | $^3\mathrm{D}^o_2$–$2s^22p4f$ | $^3\mathrm{F}_3$ | | [2] |
| 800 | 685.64 | 0.10 | 685.67 | 0.10 | $2s^22p3d$ | $^3\mathrm{D}^o_3$–$2s^22p4f$ | $^3\mathrm{F}_4$ | | [2] |
| 190 | 686.10 | 0.10 | 686.09 | 0.10 | $2s^22p3d$ | $^3\mathrm{P}^o_2$–$2s^22p4f$ | $^1\mathrm{D}_2$ | | [2] |
| | | | 686.05 | 0.10 | $2s^22p3d$ | $^3\mathrm{D}^o_3$–$2s^22p4f$ | $^3\mathrm{F}_3$ | | [2]n |
| 200 | 687.82 | 0.10 | 687.77 | 0.09 | $2s^22p3d$ | $^3\mathrm{P}^o_1$–$2s^22p4f$ | $^1\mathrm{D}_2$ | | [2] |
| 210 | 688.49 | 0.10 | 688.54 | 0.10 | $2s^22p3d$ | $^3\mathrm{P}^o_1$–$2s^22p4f$ | $^3\mathrm{D}_1$ | | [2] |
| 210 | 688.79 | 0.10 | 688.80 | 0.09 | $2s^22p3d$ | $^3\mathrm{P}^o_2$–$2s^22p4f$ | $^3\mathrm{D}_2$ | | [1]n |
| 1200 | 689.45 | 0.10 | 689.38 | 0.11 | $2s^22p3d$ | $^3\mathrm{P}^o_2$–$2s^22p4f$ | $^3\mathrm{D}_3$ | | [2] |
| | | | 689.41 | 0.23 | $2s^22p3d$ | $^3\mathrm{P}^o_0$–$2s^22p4f$ | $^3\mathrm{D}_1$ | | [2] |
| 680 | 690.55 | 0.10 | 690.49 | 0.09 | $2s^22p3d$ | $^3\mathrm{P}^o_1$–$2s^22p4f$ | $^3\mathrm{D}_2$ | | [2] |
| 230 | 691.27 | 0.10 | 691.26 | 0.14 | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{D}^o_3$ | | [2] |
| | | | 691.28 | 0.15 | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{P}_1$–$2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{D}^o_2$ | ? | [2]n |
| 390 | 691.84 | 0.10 | – | – | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{D}^o_3$ | ? | [1]n |
| 180 | 692.26 | 0.15 | – | – | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{P}_1$–$2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{D}^o_2$ | | [1]n |
| 80 | 698.23 | 0.10 | 698.23 | 0.10 | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}_2$–$2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{F}^o_2$ | | [2] |
| 110 | 699.44 | 0.10 | 699.43 | 0.10 | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}_3$–$2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{F}^o_3$ | | [2] |
| 120 | 701.29 | 0.10 | 701.29 | 0.10 | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}_4$–$2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{F}^o_4$ | | [2] |
| 210 | 702.95 | 0.10 | 702.90 | 0.10 | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}_4$–$2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{F}^o_5$ | | [1]n |
| 530 | 705.15 | 0.10 | 705.13 | 0.10 | $2s^22p3p$ | $^1\mathrm{D}_2$–$2s^22p4s$ | $^1\mathrm{P}^o_1$ | | [2] |

**Table 1.** *Continued.*

| Observed | | | Calculated$^b$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Intens.$^a$ | $\lambda$ Å | unc. Å | $\lambda$ Å | unc. Å | Classification$^c$ | | | | Ref.$^d$ |
| 1400 | 708.19 | 0.10 | 708.01 | 0.18 | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}_2$–$2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{G}^o_3$ | ? | [2] |
| | | | 708.32 | 0.13 | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}_4$–$2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{G}^o_5$ | | [2] |
| | | | 708.25 | 0.16 | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}_3$–$2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{G}^o_4$ | | [2] |
| 1500 | 729.33 | 0.10 | 729.38 | 0.10 | $2s^22p3d$ | $^1\mathrm{F}^o_3$–$2s^22p4f$ | $^1\mathrm{G}_4$ | | [2] |
| 650 | 732.90 | 0.10 | 732.95 | 0.10 | $2s^22p3d$ | $^1\mathrm{P}^o_1$–$2s^22p4f$ | $^1\mathrm{D}_2$ | | [2] |
| 280 | 735.97 | 0.10 | 736.04 | 0.10 | $2s^22p3d$ | $^1\mathrm{P}^o_1$–$2s^22p4f$ | $^3\mathrm{D}_2$ | | [2] |
| 80 | 742.75 | 0.10 | 742.73 | 0.10 | $2s^22p3d$ | $^1\mathrm{F}^o_3$–$2s^22p4f$ | $^3\mathrm{F}_4$ | | [2] |
| 260 | 743.81 | 0.03 | 743.827 | 0.017 | $2s2p^3$ | $^3\mathrm{S}^o_1$–$2p^4$ | $^3\mathrm{P}_0$ | | [13,2] |
| | | | 743.81 | 0.05 | $2s^22p3d$ | $^1\mathrm{F}^o_3$–$2s^22p4f$ | $^1\mathrm{F}_3$ | | [13,2] |
| 480 | 745.730 | 0.005 | 745.731 | 0.005 | $2s2p^3$ | $^3\mathrm{S}^o_1$–$2p^4$ | $^3\mathrm{P}_1$ | | [13,2] |
| 680 | 750.150 | 0.005 | 750.149 | 0.005 | $2s2p^3$ | $^3\mathrm{S}^o_1$–$2p^4$ | $^3\mathrm{P}_2$ | | [13,2] |
| m | 753.221 | 0.10 | 753.24 | 0.18 | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{D}_2$–$2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{F}^o_3$ | | [13,2] |
| 830 | 753.221 | 0.005 | 753.219 | 0.008 | $2s2p^3$ | $^1\mathrm{P}^o_1$–$2p^4$ | $^1\mathrm{D}_2$ | | [13,2] |
| m | 753.221 | 0.10 | 753.24 | 0.25 | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{D}_1$–$2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{F}^o_2$ | | [13,2] |
| 590 | 753.70 | 0.10 | 753.70 | 0.10 | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{D}_3$–$2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{F}^o_4$ | | [2] |
| 70 | 754.16 | 0.10 | 754.16 | 0.10 | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{D}_3$–$2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{F}^o_3$ | | [2] |
| 120 | 772.43 | 0.10 | 772.42 | 0.10 | $2s^22p3d$ | $^3\mathrm{F}^o_2$–$2s^22p4p$ | $^3\mathrm{D}_1$ | | [2] |
| 460 | 774.23 | 0.10 | 774.23 | 0.10 | $2s^22p3d$ | $^3\mathrm{F}^o_4$–$2s^22p4p$ | $^3\mathrm{D}_3$ | | [2] |
| 240 | 775.03 | 0.10 | – | – | $2s^22p3d$ | $^3\mathrm{F}^o_3$–$2s^22p4p$ | $^3\mathrm{D}_2$ | | [2] |
| 150 | 777.33 | 0.10 | 777.30 | 0.10 | $2s^22p3d$ | $^1\mathrm{D}^o_2$–$2s^22p4p$ | $^3\mathrm{D}_1$ | | [2] |
| 60 | 792.69 | 0.10 | 792.71 | 0.10 | $2s^22p3d$ | $^3\mathrm{D}^o_2$–$2s^22p4p$ | $^3\mathrm{P}_2$ | | [1]n |
| 140 | 793.56 | 0.10 | 793.62 | 0.10 | $2s^22p3d$ | $^3\mathrm{F}^o_2$–$2s^22p4p$ | $^1\mathrm{P}_1$ | | [1]n |
| 180 | 794.64 | 0.10 | 794.62 | 0.10 | $2s^22p3d$ | $^3\mathrm{D}^o_3$–$2s^22p4p$ | $^3\mathrm{P}_2$ | | [2] |
| 160 | 795.37 | 0.10 | – | – | $2s^22p3d$ | $^3\mathrm{D}^o_2$–$2s^22p4p$ | $^3\mathrm{P}_1$ | ? | [2] |
| 100 | 798.77 | 0.10 | 798.78 | 0.10 | $2s^22p3d$ | $^1\mathrm{D}^o_2$–$2s^22p4p$ | $^1\mathrm{P}_1$ | | [1]n |
| 60 | 811.27 | 0.10 | 811.29 | 0.10 | $2s^22p3s$ | $^3\mathrm{P}^o_0$–$2s2p^2(^4\mathrm{P})3s$ | $^3\mathrm{P}_1$ | | [1]n |
| 60 | 813.85 | 0.10 | 813.77 | 0.09 | $2s^22p3s$ | $^3\mathrm{P}^o_1$–$2s2p^2(^4\mathrm{P})3s$ | $^3\mathrm{P}_1$ | | [1]n |
| 100 | 816.13 | 0.10 | 816.13 | 0.10 | $2s^22p3d$ | $^3\mathrm{D}^o_3$–$2s^22p4p$ | $^3\mathrm{D}_3$ | | [2] |
| 80 | 820.12 | 0.10 | 820.16 | 0.10 | $2s^22p3d$ | $^3\mathrm{D}^o_1$–$2s^22p4p$ | $^3\mathrm{D}_1$ | | [1]n |
| 50 | 823.02 | 0.15 | 823.07 | 0.15 | $2s2p^2(^4\mathrm{P})3s$ | $^3\mathrm{P}_1$–$2s^22p4d$ | $^3\mathrm{D}^o_2$ | | [1]n |
| 60 | 824.21 | 0.10 | 824.18 | 0.10 | $2s2p^2(^4\mathrm{P})3s$ | $^3\mathrm{P}_2$–$2s^22p4d$ | $^3\mathrm{D}^o_3$ | | [2] |
| 70 | 826.28 | 0.15 | 826.28 | 0.15 | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}_4$–$2s2p^2(^4\mathrm{P})4p$ | $^3\mathrm{D}^o_3$ | | [2]c |
| 60 | 826.81 | 0.10 | – | – | $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}_3$–$2s2p^2(^4\mathrm{P})4p$ | $^3\mathrm{D}^o_2$ | | [1]n |
| 40 | 946.90 | 0.10 | 946.84 | 0.10 | $2s^22p3d$ | $^1\mathrm{P}^o_1$–$2s^22p4p$ | $^1\mathrm{P}_1$ | | [1]n |
| | 1136.51 | 0.02 | 1136.515 | 0.014 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s2p^3$ | $^5\mathrm{S}^o_2$ | | [7,14] |
| | 1145.61 | 0.02 | 1145.606 | 0.014 | $2s^22p^2$ | $^3\mathrm{P}_2$–$2s2p^3$ | $^5\mathrm{S}^o_2$ | | [7,14] |
| 5 | 1569.1 | 1.5 | 1569.1 | 2.0 | $2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{S}^o_1$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{P}_2$ | | [23]n |
| | | | 1569.5 | 1.6 | $2s^22p4f$ | $^3\mathrm{F}_3$–$2s^22p5g$ | $1/2[9/2]^o$ | | [23]n |
| 20 | 1571.8 | 1.5 | 1571.5 | 1.6 | $2s^22p4f$ | $^3\mathrm{F}_4$–$2s^22p5g$ | $1/2[9/2]^o$ | | [23]n |
| | | | 1571.6 | 1.3 | $2s^22p4f$ | $^3\mathrm{G}_5$–$2s^22p5g$ | $3/2[11/2]^o$ | | [23]n |
| | 1574.75 | 0.05 | 1574.700 | 0.014 | $2s^22p^2$ | $^3\mathrm{P}_1$–$2s^22p^2$ | $^1\mathrm{S}_0$ | | [6,8,7] |
| 20 | 1594.4 | 1.5 | 1593.8 | 0.9 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_1$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{S}^o_2$ | | [23]n |
| 20 | 1596.5 | 1.5 | 1596.7 | 1.3 | $2s^22p4f$ | $^1\mathrm{G}_4$–$2s^22p5g$ | $3/2[11/2]^o$ | | [23]n |
| 5 | 1603.7 | 1.5 | 1604.8 | 0.9 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{S}^o_2$ | | [23]n |
| 20 | 1620.3 | 1.5 | 1619.6 | 0.9 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_3$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{S}^o_2$ | | [23]n |
| 20 | 1719.0 | 1.5 | 1718.3 | 1.0 | $2s^22p3s$ | $^1\mathrm{P}^o_1$–$2s^22p3p$ | $^1\mathrm{D}_2$ | | [23] |

**Table 1.** *Continued.*

| Observed | | | Calculated$^b$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| Intens.$^a$ | $\lambda$ Å | unc. Å | $\lambda$ Å | unc. Å | Classification$^c$ | | | Ref.$^d$ |
| m | – | – | 1789.8 | 0.6 | $2s^22p3p$ | $^3\mathrm{S}_1$–$2s^22p3d$ | $^3\mathrm{P}^o_1$ | [25] |
| 2 | 1791.4 | 0.5 | 1791.4 | 0.5 | $2s^22p3p$ | $^1\mathrm{P}_1$–$2s^22p3d$ | $^3\mathrm{F}^o_2$ | [25] |
| 5 | 1801.4 | 0.5 | 1801.2 | 0.4 | $2s^22p3p$ | $^3\mathrm{S}_1$–$2s^22p3d$ | $^3\mathrm{P}^o_2$ | [25] |
| 10 | 1819.45 | 0.03 | 1819.48 | 0.03 | $2s^22p3s$ | $^3\mathrm{P}^o_1$–$2s^22p3p$ | $^3\mathrm{P}_2$ | [21,25] |
| 5 | 1821.61 | 0.03 | 1821.69 | 0.03 | $2s^22p3s$ | $^3\mathrm{P}^o_0$–$2s^22p3p$ | $^3\mathrm{P}_1$ | [21,25] |
| 5 | 1834.25 | 0.03 | 1834.23 | 0.03 | $2s^22p3s$ | $^3\mathrm{P}^o_1$–$2s^22p3p$ | $^3\mathrm{P}_1$ | [21,25] |
| 10 | 1845.06 | 0.03 | 1845.06 | 0.03 | $2s^22p3s$ | $^3\mathrm{P}^o_1$–$2s^22p3p$ | $^3\mathrm{P}_0$ | [21,25] |
| 50 | 1849.72 | 0.03 | 1849.69 | 0.03 | $2s^22p3s$ | $^3\mathrm{P}^o_2$–$2s^22p3p$ | $^3\mathrm{P}_2$ | [21,25] |
| 10 | 1864.99 | 0.03 | 1864.93 | 0.03 | $2s^22p3s$ | $^3\mathrm{P}^o_2$–$2s^22p3p$ | $^3\mathrm{P}_1$ | [21,25,23] |
| 5 | 1893.3 | 1.5 | 1893.3 | 0.6 | $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o_4$–$2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}_4$ | [23]n |
| 20 | 1975.62 | 0.03 | 1975.62 | 0.03 | $2s^22p3p$ | $^3\mathrm{D}_2$–$2s^22p3d$ | $^3\mathrm{F}^o_3$ | [21,23] |
| 100 | 1981.98 | 0.03 | 1981.98 | 0.03 | $2s^22p3p$ | $^3\mathrm{D}_3$–$2s^22p3d$ | $^3\mathrm{F}^o_4$ | [21,23] |
| 20bl | 1987.7 | 1.5 | 1989.0 | 0.5 | $2s^22p3p$ | $^3\mathrm{D}_1$–$2s^22p3d$ | $^3\mathrm{F}^o_2$ | [23]n |
| m | – | – | 1992.7 | 0.6 | $2s^22p3p$ | $^3\mathrm{P}_2$–$2s^22p3d$ | $^3\mathrm{P}^o_2$ | [25] |
| 1 | 1998.9 | 0.5 | 1999.4 | 0.5 | $2s^22p3s$ | $^3\mathrm{P}^o_0$–$2s^22p3p$ | $^3\mathrm{S}_1$ | [25] |
| 9 | 2000.6 | 0.5 | 2000.52 | 0.05 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_1$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{P}^o_2$ | [25]n [23] |
| 10 | 2003.16 | 0.03 | 2003.16 | 0.03 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{P}^o_3$ | [21,23] |
| 5 | 2005.9 | 0.5 | 2005.78 | 0.07 | $2s^22p3p$ | $^3\mathrm{D}_3$–$2s^22p3d$ | $^3\mathrm{F}^o_3$ | [25]n |
| | | | 2006.3 | 0.5 | $2s^22p3p$ | $^3\mathrm{D}_2$–$2s^22p3d$ | $^3\mathrm{F}^o_2$ | [25]n |
| 4 | 2009.1 | 0.5 | 2008.87 | 0.06 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_1$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{P}^o_1$ | [25]n |
| 4 | 2014.6 | 0.5 | 2014.4 | 0.5 | $2ls^22p3s$ | $^3\mathrm{P}^o_1$–$2s^22p3p$ | $^3\mathrm{S}_1$ | [25] |
| 40 | 2026.27 | 0.03 | 2026.27 | 0.06 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{P}^o_1$ | [21,23] |
| | | | 2026.28 | 0.04 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_3$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{P}^o_3$ | [21,23] |
| 22 | 2041.24 | 0.03 | 2041.24 | 0.03 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_3$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{P}^o_2$ | [21,23] |
| 2 | 2060.7 | 1.5 | 2059.1 | 1.8 | $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{P}^o_1$–$2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}_2$ | [23]n |
| | | | 2061.7 | 2.4 | $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{P}^o_1$–$2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}_1$ | [23]n |
| 2 | | | 2062.4 | 1.2 | $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{P}^o_2$–$2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}_3$ | [23]n |
| 20bl | 2072.2 | 1.5 | 2071.3 | 0.8 | $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{P}^o_3$–$2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}_4$ | [23]n |
| 1 | 2084.4 | 1.5 | 2084.6 | 2.0 | $2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{D}^o_3$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}_4$ | [23]n |
| | | | 2084.6 | 2.7 | $2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{D}^o_2$–$2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}_3$ | [23]n |
| 5 | 2131.77 | 0.03 | 2131.77 | 0.03 | $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o_1$–$2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{F}_2$ | [21] |
| 2 | 2132.05 | 0.03 | – | – | $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o_0$–$2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{F}_1$ | [21] |
| 10 | 2133.76 | 0.03 | 2133.76 | 0.03 | $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o_2$–$2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{F}_3$ | [21,23] |
| 20 | 2138.07 | 0.03 | 2138.07 | 0.03 | $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o_3$–$2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{F}_4$ | [21,23] |
| 50 | 2144.25 | 0.03 | 2144.25 | 0.03 | $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o_4$–$2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{F}_5$ | [21,23] |
| 30 | 2224.12 | 0.02 | 2224.12 | 0.02 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_1$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o_2$ | [20,22] |
| 80 | 2227.42 | 0.02 | 2227.43 | 0.02 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o_3$ | [20,22] |
| 300 | 2232.41 | 0.02 | 2232.41 | 0.02 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_3$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o_4$ | [19,22,23] |
| 50 | 2236.29 | 0.02 | 2236.29 | 0.02 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_1$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o_1$ | [20,19,23] |
| 70 | 2245.48 | 0.02 | 2245.47 | 0.02 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o_2$ | [20,22] |
| 30 | 2256.05 | 0.02 | 2256.05 | 0.02 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_3$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o_3$ | [20,22] |
| 200 | 2259.57 | 0.02 | 2259.55 | 0.02 | $2s^22p3s$ | $^3\mathrm{P}^o_1$–$2s^22p3p$ | $^3\mathrm{D}_2$ | [19,22] |
| 70 | 2263.39 | 0.02 | 2263.37 | 0.02 | $2s^22p3s$ | $^3\mathrm{P}^o_0$–$2s^22p3p$ | $^3\mathrm{D}_1$ | [20,22] |
| 400bl | 2265.71 | 0.05 | 2265.71 | 0.05 | $2s^22p3s$ | $^3\mathrm{P}^o_2$–$2s^22p3p$ | $^3\mathrm{D}_3$ | [19,22,25] |
| 10 | 2274.54 | 0.05 | 2274.56 | 0.04 | $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}_3$–$2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o_2$ | [20,22] |

**Table 1.** *Continued.*

| Observed | | | Calculated[b] | | | | | |
|---|---|---|---|---|---|---|---|---|
| Intens.[a] | $\lambda$ Å | unc. Å | $\lambda$ Å | unc. Å | Classification[c] | | | Ref.[d] |
| 100 | 2282.61 | 0.05 | 2282.76 | 0.05 | $2s^22p3s$ | $^3P^o_1$–$2s^22p3p$ | $^3D_1$ | [19] |
| 50 | 2306.31 | 0.02 | 2306.33 | 0.02 | $2s^22p3s$ | $^3P^o_2$–$2s^22p3p$ | $^3D_2$ | [20,19,22] |
| 110 | 2961.9 | 0.8 | – | – | $2s^22p5g$ | $1/2[9/2]^o$–$2s^22p6h$ | $1/2[11/2]$ | [26]n [22] |
| 250 | 2967.1 | 0.8 | – | – | $2s^22p5g$ | $3/2[11/2]^o$–$2s^22p6h$ | $3/2[13/2]$ | [26]n [22,23] |
| | 2973.13 | 0.05 | 2973.13 | 0.05 | $2s^22p^2$ | $^1D_2$–$2s^22p^2$ | $^1S_0$ | [6,5] |
| | 3345.83 | 0.02 | 3345.821 | 0.014 | $2s^22p^2$ | $^3P_1$–$2s^22p^2$ | $^1D_2$ | [4,7,6] |
| | 3425.87 | 0.02 | 3425.881 | 0.015 | $2s^22p^2$ | $^3P_2$–$2s^22p^2$ | $^1D_2$ | [4,7] |
| | 143217 | 2 | 143217 | 2 | $2s^22p^2$ | $^3P_1$–$2s^22p^2$ | $^3P_2$ | [11,6,5] |
| | 243175 | 3 | 243175 | 3 | $2s^22p^2$ | $^3P_0$–$2s^22p^2$ | $^3P_1$ | [11,10] |

[a] Intensity legends: w – wide or diffuse or hazy; bl – blended with another line that may affect the wavelength and/or intensity; (includes "shoulder", "affected" etc.); m – masked (no wavelength measured). Intensity values, converted to a uniform scale (see the text), are given in arbitrary units.

[b] If no calculated wavelength is given, this means that one of the levels involved in the transition is determined from this single line.

[c] The lines for which the classification is uncertain are marked with a question mark. Some of them are discussed in the text. In most of the other cases one of the levels involved is determined by this single line.

[d] References are given for the papers from which the wavelength was taken or derived. Symbol "n" after the reference indicates that a new identification is proposed here for this previously unclassified line; Symbol "c" is to show that the identification is changed compared to the cited papers.

using different conversion procedures. The linear intensity scale reported by Hermansdorfer [17] was adopted as the reference one. The intensities given in [2,12,19,20] were converted using a linear function since they appear to be on a linear scale, while the intensities from Lindeberg's tables [13,21,28] were converted with a fitted logarithmic function. The intensities of the lines from [24,25] were estimated from the pictures of spectra presented in these papers. No account for the registration efficiency has been made, so the relative intensities are valid only for comparison of closely located lines. In Table 1, all wavelengths below 2000 Å are in vacuum, above that in air. For computed wavelengths above 2000 Å, the calculated wavenumbers have been converted to air using the five-parameter formula of Peck and Reeder [29]. In the following section we discuss the lines for which the classification was changed compared to the previous one.

The lines at 110.410 and 113.87 Å (respectively assigned by Hermansdorfer [17] to the $2s^22p^2$ $^3P_2$–$2s^22p5d$ $^3D^o_3$ and $2s^22p^2$ $^1D_2$–$2s^22p5d$ $^1F^o_3$ transitions) had been previously ascribed to Ne VI by Paul and Polster [12]. Our calculations support Hermansdorfer's assignments.

In Paul and Polster [12], the 118.715 Å (intensity = 5) and 118.841 Å (intensity = 1) lines assigned to the $2s^22p^2$ $^3P$–$2s^22p(^2P)4d$ $^3P^o$ and $^3D^o$ transitions are rather close to Hermansdorfer's measurements at 118.74 Å (intensity = "12bl") and 118.89 Å (intensity = 37) [17], but the relative intensities are reversed. Hermansdorfer's hotter spectrum was much less contaminated by impurities, and his relative line intensities are in better agreement with the predicted transition rates. Thus we suppose that the lines observed in [12] had been affected by some impurities or other ionisation stages, and retain Hermansdorfer's measurements despite their lower wavelength accuracy.

The 124.33 Å line observed by Hermansdorfer [17] has been rejected by Bastin *et al.* [2]. Kelly's [30] assignment of this line to the $2s^22p^2$ $^3P_2$–$2s^22p4s$ $^1P^o_1$ transition is not realistic because of the negligible predicted rate for this transition. We have assigned it to the $2s^22p^2$ $^1D_2$–$2s2p^2(^2D)3p$ $^1P^o_1$ transition which places the previously unknown upper $^1P^o_1$ level at 834 600 ± 300 cm$^{-1}$, in good agreement with our parametric calculations.

The 124.77 Å line assigned to Ne VI [17] had been reassigned to Ne V by Bastin *et al.* [2]. This feature is probably a blend, since the $2s^22p4s$ $^3P^o$ lifetime determined from the 619 Å line is $0.127 \pm 0.006$ ns [31] while the lifetime measured for the 125.0 Å line is $0.082 \pm 0.006$ ns [24].

The original classifications of the lines at 125.12 and 125.830 Å ($2s^22p^2$ $^1D_2$–$2s2p^2(^2D)3p$ $^1D^o_2$, $^1F^o_3$) have been interchanged, as suggested by Ryabtsev [32] for F IV and other isoelectronic ions. This also complies with the observed and calculated relative line intensities.

The Paul and Polster [12] suggested assignment of the 128.793 Å line to the $2s2p^3$ $^5S^o_2$–$2s2p^2(^4P)4d$ $^5P$ transition in Ne V has been rejected by Hermansdorfer [17] who identified two other lines at 117.23 and 117.27 Å for this transition array. Bastin *et al.* [2] have confirmed the new assignments. The 128.793 Å line remains unclassified.

The line at 136.215 Å, assigned by Paul and Polster [12] to the $2s2p^3$ $^5S^o_2$–$2s2p^2(^4P)4s$ $^5P$ transition in Ne V, has been identified by Hermansdorfer [17] as the $2s2p^2\ ^4\mathrm{P}_{3/2}$–$2s2p(^3\mathrm{P}^o)3s\ ^4\mathrm{P}^o_{5/2}$ transition in Ne VI. In accordance with the work of Bastin *et al.* [2], we have rejected this line and the corresponding $2s2p^2(^4\mathrm{P})4s\ ^5\mathrm{P}$ level value.

The line at 142.51 Å has been observed both by Paul and Polster [12] and by Hermansdorfer [17]. Both authors have noted that this line is an unresolved blend, but Hermansdorfer has classified it as a Ne VI line. Due to the blending, the wavelength accuracy is comparable for these two measurements, and we accepted the mean of the two values as the best one.

The line at 144.01 Å assigned by Hermansdorfer [17] to the $2s2p^3\ ^3\mathrm{D}^o_3$–$2s2p^2(^2\mathrm{D})3d\ ^3\mathrm{F}_4$ transition had been previously ascribed to Ne IV by Paul and Polster [12]. The hotter character of the spectra observed by Hermansdorfer has excluded the Ne IV assignment of this line. Still we use Paul and Polster's wavelength 144.019 Å as more accurate.

The line at 148.787 Å has been assigned by Paul and Polster [12] both to Ne IV and Ne V transitions. The Ne V assignment was later rejected by Hermansdorfer [17]. This revision has been further confirmed by Bastin *et al.* [2].

The difference in the classifications of the two lines at 151.23 and 151.42 Å from [17] compared to [12] is not fundamental. It is just a question of the convention for naming of the upper $2s^22p3d\ ^3\mathrm{F}^o_2$ and $^1\mathrm{D}^o_2$ levels which are almost equally mixed. Bastin *et al.* [2] have chosen to keep the Paul and Polster [12] designations. Our extended calculations have yielded the leading percentages of the states, as denoted by Hermansdorfer [17], 57%. Thus we have retained Hermansdorfer's designations. We have adopted the wavelength 151.42 Å measured by Hermansdorfer rather than Paul and Poster's value 151.424 Å, since the line observed in [12] was marked as "blended by O V and Ne IV". These impurities were absent in Hermansdorfer's spectra.

The line at 154.488 Å assigned by Paul and Polster [12] to Ne IV is probably a different one from the line at 154.50 Å assigned by Hermansdorfer to Ne V [17]. Although the two wavelengths are within the measurement uncertainties, the predicted wavelength of the $2s^22p^2\ ^1\mathrm{S}_0$–$2s^22p3d\ ^1\mathrm{P}^o_1$ transition in Ne V is $154.520 \pm 0.007$ Å which is too far from Paul and Polster's measurement. We have discarded Paul and Polster's classification of the 154.488 Å line in [16]. Nevertheless their assignment to Ne IV, rather than to Ne V, seems reasonable since their plasma source was apparently not as hot as Hermansdorfer's.

The 158.82 Å line [17] had been previously assigned to Ne IV by Paul and Polster [12]. We believe that Hermansdorfer's assignment is correct since Ne IV was very weak in his spectra. Still we prefer to use Paul and Polster's wavelength 158.822 Å as more accurate.

Hermansdorfer's assignment [17] of the 162.15 Å line to the $2s2p^3\ ^1\mathrm{D}^o_2$–$2s2p^2(^2\mathrm{D})3d\ ^1\mathrm{F}_3$ transition must definitely be rejected, since the $^1\mathrm{F}_3$ level is predicted to be approximately 12 000 $\mathrm{cm}^{-1}$ lower. The parametric fitting results in identification of this line with the $2s2p^3\ ^1\mathrm{D}^o_2$–$2s2p^2(^2\mathrm{D})3d\ ^1\mathrm{D}_2$ level which is in good agreement with the isoelectronic F IV data [32].

The line at 618.79 Å [2] was originally interpreted as a blend of the $2s^22p3p\ ^3\mathrm{D}_2$–$2s^22p4s\ ^3\mathrm{P}^o_2$ and $2s^22p3p\ ^1\mathrm{D}_2$–$2s2p^2(^2\mathrm{D})3p\ ^1\mathrm{F}^o_3$ transitions. The second assignment has now been rejected, as the upper level $^1\mathrm{F}^o_3$ has been interchanged with the $^1\mathrm{D}^o_2$ level on the basis of the isoelectronic comparison made by Ryabtsev [32].

The $2s2p^2(^4\mathrm{P})3d\ ^5\mathrm{F}_2$–$2s2p^2(^4\mathrm{P})4f\ ^3\mathrm{D}^o_3$ assignment of the 635.05 Å line [2] has been omitted because, according to our new calculations, the corresponding transition rate is negligible. Thus, the position of the upper $^3\mathrm{D}^o_3$ level, suggested in [2], relies on just one blended line at 688.48 Å, while the position of the $2s2p^2(^4\mathrm{P})4f\ ^3\mathrm{D}^o_2$ level is determined by another blended line at 687.82 Å. The resulting position of the $^3\mathrm{D}^o$ term deviates by about +500 $\mathrm{cm}^{-1}$ from the energies calculated by means of parametric fitting. For these reasons we have reevaluated the $2s2p^2(^4\mathrm{P})4f\ ^3\mathrm{D}^o$ term using the following lines: 691.84 Å ($2s2p^2(^4\mathrm{P})3d\ ^3\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})4f\ ^3\mathrm{D}^o_3$) [1], 691.27 Å ($2s2p^2(^4\mathrm{P})3d\ ^3\mathrm{P}_1$–$2s2p^2(^4\mathrm{P})4f\ ^3\mathrm{D}^o_2$, blended with the $2s2p^2(^4\mathrm{P})3d\ ^3\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})4f\ ^5\mathrm{D}^o_3$ transition), and 679.77 Å ($2s2p^2(^4\mathrm{P})3d\ ^5\mathrm{P}_2$–$2s2p^2(^4\mathrm{P})4f\ ^3\mathrm{D}^o_2$, blended with the $2s^22p3d\ ^3\mathrm{D}^o_2$–$2s^22p4f\ ^3\mathrm{G}_3$ transition). These assignments comply with the observed relative line intensities and make the parametric fitting errors much smaller.

The previous assignment of the 826.28 Å line to the $2s2p^2(^4\mathrm{P})3s\ ^3\mathrm{P}_2$–$2s^22p4d\ ^3\mathrm{D}^o_2$ transition [2] has been revised, since the newly calculated transition rate is negligible for this transition. The line is re-classified as the $2s2p^2(^4\mathrm{P})3d\ ^3\mathrm{F}_4$–$2s2p^2(^4\mathrm{P})4p\ ^3\mathrm{D}^o_3$ transition.

We have discarded the weak line at 1779.1 Å assigned to the $2s^22p3p\ ^3\mathrm{S}_1$–$2s^22p3d\ ^3\mathrm{P}^o_0$ transition [25] since its predicted position is at $1783.9 \pm 1.6$ Å. In the same manner, we have omitted the weak 1963.6 Å line reported by the same authors since the predicted position of the $2s^22p3p\ ^3\mathrm{P}_1$–$2s^22p3d\ ^3\mathrm{P}^o_1$ transition attributed to it is $1961.6 \pm 0.7$ Å.

The $2s^22p3p\ ^3\mathrm{S}_1$–$2s^22p3d\ ^3\mathrm{P}^o_1$ transition is probably masked by the moderately strong Ne IV line at 1789.988 Å [28] since its predicted position is at $1789.8 \pm 0.6$ Å. The 1791.4 Å line observed by Vach *et al.* [25] which they have identified as this transition is more likely due to the $2s^22p3p\ ^1\mathrm{P}_1$–$2s^22p3d\ ^3\mathrm{F}^o_2$ transition as it perfectly fits the level scheme.

The intense line at $1981.98 \pm 0.03$ Å [21] had previously been assigned to Ne VII by Bockasten *et al.* [33] who have noted that this line is somewhat too intense compared to the other two observed lines of the Ne VII multiplet to which it belongs, and that some blending by another ionisation stage is possible. This line has also been observed in the beam-foil spectrum [23] where it was identified as the Ne V line. Presence of the other two strongest lines of the $2s^22p3p\ ^3\mathrm{D}$–$2s^22p3d\ ^3\mathrm{F}$ multiplet at 1975.6 and (newly classified) 1987.7 Å in the beam-foil spectrum [23] is an additional argument in favor of the Ne V assignment of the 1981.98 Å line. We give more weight to Lindeberg's measurement [21] of this wavelength, although it is less accurate than that of Bockasten *et al.* [33], since the feature observed in [33] was mostly due to Ne VII.

The line observed at 1992.1 Å by Vach *et al.* [25] is actually the Ne VII line ($\lambda = 1992.060$ Å) identified by Bockasten *et al.* [33]. Ne VII could well be visible in the spectra of Vach *et al.* [25], since the most intense line within the 1990−2060 Å range in their spectrum belongs to Ne VI. The Ne VII origin of this line is verified by the presence of another Ne VII line at 1997.345 Å, belonging to the same multiplet as the 1992.060 Å line [33], in the spectrum presented in Figure 2 of [25]. The intensity ratio of the 1992.1 and 1997.3 Å lines is close to that observed by Bockasten *et al.* [33]. Thus we conclude that the $2s^22p3p\ ^3\mathrm{P}_2–2s^22p3d\ ^3\mathrm{P}^o_2$ transition, whose predicted wavelength is $1992.7 \pm 0.6$ Å, is masked by the Ne VII line or by the Ne IV line at 1992.643 Å [28].

We have changed the classification of the 2001.8 Å line observed in [23] from $2s2p^2(^4\mathrm{P})3s\ ^5\mathrm{P}_1–2s2p^2(^4\mathrm{P})3p\ ^5\mathrm{P}^o_1$ to $2s2p^2(^4\mathrm{P})3s\ ^5\mathrm{P}_1–2s2p^2(^4\mathrm{P})3p\ ^5\mathrm{P}^o_2$, as it better fits to the energy difference known from other transitions. This line is also seen quite distinctly on the fragment of spectrum presented by Vach *et al.* (see Fig. 2 in Ref. [25]). From this picture, we have estimated the wavelength of this line as $2000.6 \pm 0.5$ Å which is in good agreement with the wavelength derived from the level scheme. The $2s2p^2(^4\mathrm{P})3s\ ^5\mathrm{P}_1–2s2p^2(^4\mathrm{P})3p\ ^5\mathrm{P}^o_1$ transition is predicted to occur at $2008.87 \pm 0.06$ Å. That line is also present on the spectrogram in [25], with an estimated wavelength of $2009.1 \pm 0.5$ Å.

The 2050.2 Å line observed by Vach *et al.* [25] is omitted since it does not fit to the energy level scheme as the proposed $2s^22p3s\ ^3\mathrm{P}^o_2–2s^22p3p\ ^3\mathrm{S}_1$ transition. Another line observed at $2052.4 \pm 0.5$ Å on the spectrogram presented in [25] is a better candidate for this transition from the point of view of its wavelength and intensity, but there is no information available about its charge state assignment, so we do not list this line in Table 1. The predicted wavelength of the $2s^22p3s\ ^3\mathrm{P}^o_2–2s^22p3p\ ^3\mathrm{S}_1$ transition is $2051.5 \pm 0.5$ Å.

Based on our new parametric calculations, we have identified a number of previously unclassified lines in the range 470−950 Å which have been measured in the work of Bastin *et al.* [2] and listed in [1]. All of these lines exhibit behavior analogous to the other Ne V lines with variation of the ion beam energy. The computer code IDEN [34] was used to facilitate the search for possible combinations.

Most of the previously unclassified Ne V lines listed in [23] have also been unambiguously identified. In particular, the previously unknown $2s2p^2(^4\mathrm{P})3p\ ^5\mathrm{S}^o_2$ level is now established based on three observed combinations with the $2s2p^2(^4\mathrm{P})3s\ ^5\mathrm{P}$ term. A group of Ne V lines around 1570 Å has been attributed to the $2s^22p4f–2s^22p5g$ transition array. It provides a connection of the $2s^22p6h$ configuration observed in beam-foil spectra [22,23,26] with the ground state, which can be used in the determination of the ionisation potential of Ne V (see Sect. 6).

In Table 1, we have converted the wavelengths presented by Lembo *et al.* [26] from vacuum to air, since our calculation of the hydrogenic wavelengths showed that the values listed in Table 1 of [26] are vacuum ones.

## 5 Energy levels

The energy levels of Ne V, as derived from the observed spectral lines listed in Table 1, are presented in Table 2. The least-squares optimization code LOPT [15] has been used to obtain the energies.

The usual practice for the uncertainties estimation of the optimized energy levels is to assume that these uncertainties are determined by dispersion (defined as a square root of mean square deviation from a mean of a distribution) which can be calculated by some statistical method, *i.e.* error propagation from the lowest state. However, this approach has an important flaw: it produces wrong results in the case where systematic shifts in the measured wavelengths are present. These shifts can lead to a shift in the level value which actually does not decrease with increasing number of observed combinations, as would be the case in absence of systematic errors.

The present version of the LOPT code has been modified so that now it is possible to estimate the possible effects of systematic errors in the measured wavelengths on the derived energies and wavenumbers. Thus the uncertainties of the excitation energies, as well as the calculated-wavelength uncertainties in Table 1, are somewhat more than mean dispersions. To derive these values, the following procedure has been used. In the input file of the observed wavelengths, the lines have been divided into several groups. In each group (denoted by $K$), all lines were supposed to be correlated, *i.e.* it was assumed that the measured wavenumber between any states $E_i$ and $E_j$ in the group was affected by the same value of systematic shift $\delta_K$:

$$s_{ijK} = s^*_{ijK} + \delta_K \tag{1}$$

where $s^*_{ijK}$ is the unshifted wavenumber.

The smallest uncertainty of any measured wavelength in the group has been adopted as the upper bound of the possible systematic shift $\Delta_K$. The effect of this shift on the level energy $E_j$ resulting from the solution of the least-squares problem can be estimated by differentiating equation (3) of [15]:

$$E_j = \sum_i (W^{-1}_{ij} S_i) \tag{2}$$

by the group-shift variable $\delta_K$. The derivative is very simple since the inverse matrix $W^{-1}$ does not depend on wavenumbers (it is a combination of reciprocal squared uncertainties), and the variables $S_i$ depend on the measured wavenumbers linearly. The resulting derivative multiplied by the estimated upper bound of systematic shift $\Delta_K$ is an estimate of the possible error in level energy due to this systematic shift.

Thus, apart from the usual dispersion of the calculated energy, we have a set of additional possible errors

**Table 2.** The optimised energy levels of Ne V.

| Designation$^a$ | | $J$ | Energy cm$^{-1}$ | Unc. $D^b$ cm$^{-1}$ | Num. lines$^c$ | Leading percentages$^d$ | |
|---|---|---|---|---|---|---|---|
| $2s^22p^2$ | $^3\mathrm{P}$ | 0 | 0.000 | – | 9, 1B, 1D | 98% | |
| $2s^22p^2$ | $^3\mathrm{P}$ | 1 | 411.227 | 0.005 | 23, 2B, 4D | 98% | |
| $2s^22p^2$ | $^3\mathrm{P}$ | 2 | 1109.467 | 0.011 | 22, 3B, 4D | 98% | |
| $2s^22p^2$ | $^1\mathrm{D}$ | 2 | 30290.67 | 0.12 | 12, 1B | 98% | |
| $2s^22p^2$ | $^1\mathrm{S}$ | 0 | 63915.4 | 0.6 | 6, 1Q | 94% | + 6% $2p^4$ $^1\mathrm{S}$ |
| $2s2p^3$ | $^5\mathrm{S}^o$ | 2 | 88399.5 | 1.5 | 8, 1Q | 100% | |
| $2s2p^3$ | $^3\mathrm{D}^o$ | 3 | 175832.3 | 1.5 | 8, 1D | 100% | |
| $2s2p^3$ | $^3\mathrm{D}^o$ | 2 | 175902.7 | 1.5 | 8, 2L, 3D | 99% | |
| $2s2p^3$ | $^3\mathrm{D}^o$ | 1 | 175925.0 | 1.5 | 7, 3D | 99% | |
| $2s2p^3$ | $^3\mathrm{P}^o$ | 2 | 208151.3 | 2 | 14, 1B, 12D | 100% | |
| $2s2p^3$ | $^3\mathrm{P}^o$ | 1 | 208153.3 | 2 | 16, 1B, 14D | 100% | |
| $2s2p^3$ | $^3\mathrm{P}^o$ | 0 | 208185 | 2 | 7, 1B, 5D | 100% | |
| $2s2p^3$ | $^1\mathrm{D}^o$ | 2 | 270552.9 | 2 | 2 | 99% | |
| $2s2p^3$ | $^3\mathrm{S}^o$ | 1 | 279371.2 | 2 | 7, 2B, 1L, 2D | 99% | |
| $2s2p^3$ | $^1\mathrm{P}^o$ | 1 | 303819.2 | 2 | 3, 1D | 99% | |
| $2p^4$ | $^3\mathrm{P}$ | 2 | 412678.1 | 2 | 3, 1L | 97% | |
| $2p^4$ | $^3\mathrm{P}$ | 1 | 413467.9 | 2 | 5, 3B, 1L, 2D | 97% | |
| $2p^4$ | $^3\mathrm{P}$ | 0 | 413811 | 3 | 3, 1D | 97% | |
| $2p^4$ | $^1\mathrm{D}$ | 2 | 436582.7 | 3 | 2, 1D | 97% | |
| $2p^4$ | $^1\mathrm{S}$ | 0 | 500481.8 | 4 | 1 | 93% | + 6% $2s^22p^2$ $^1\mathrm{S}$ |
| $2s^22p3s$ | $^3\mathrm{P}^o$ | 0 | 596243.2 | 30 | 4, 1L | 96% | |
| $2s^22p3s$ | $^3\mathrm{P}^o$ | 1 | 596618.4 | 30 | 10, 2L | 95% | |
| $2s^22p3s$ | $^3\mathrm{P}^o$ | 2 | 597515.9 | 30 | 6, 1B, 2L | 96% | |
| $2s^22p3s$ | $^1\mathrm{P}^o$ | 1 | 605240 | 30 | 4 | 96% | |
| $2s^22p3p$ | $^1\mathrm{P}$ | 1 | 634867 | 30 | 2, 1B, 1D | 95% | |
| $2s^22p3p$ | $^3\mathrm{D}$ | 1 | 640411.5 | 30 | 6, 1L, 2D | 95% | |
| $2s^22p3p$ | $^3\mathrm{D}$ | 2 | 640861.4 | 30 | 7, 2L, 2D | 96% | |
| $2s^22p3p$ | $^3\mathrm{D}$ | 3 | 641638.6 | 30 | 6, 1B, 3D | 96% | |
| $2s^22p3p$ | $^3\mathrm{S}$ | 1 | 646244 | 30 | 4, 2D | 96% | |
| $2s^22p3p$ | $^3\mathrm{P}$ | 0 | 650817.2 | 30 | 3, 1D | 91% | + 5% $2s2p^2(^4\mathrm{P})3s$ $^3\mathrm{P}$ |
| $2s^22p3p$ | $^3\mathrm{P}$ | 1 | 651137.2 | 30 | 11, 2L, 5D | 91% | + 5% $2s2p^2(^4\mathrm{P})3s$ $^3\mathrm{P}$ |
| $2s^22p3p$ | $^3\mathrm{P}$ | 2 | 651579.1 | 30 | 9, 5D | 91% | + 5% $2s2p^2(^4\mathrm{P})3s$ $^3\mathrm{P}$ |
| $2s^22p3p$ | $^1\mathrm{D}$ | 2 | 663437 | 40 | 3 | 96% | |
| $2s^22p3d$ | $^3\mathrm{F}^o$ | 2 | 690689 | 30 | 9, 2D | 57% | + 40% $^1\mathrm{D}^o$ |
| $2s^22p3d$ | $^3\mathrm{F}^o$ | 3 | 691478.5 | 30 | 6, 3D | 96% | |
| $2s^22p3d$ | $^1\mathrm{D}^o$ | 2 | 691503 | 30 | 6, 3D | 56% | + 40% $^3\mathrm{F}^o$ |
| $2s^22p3d$ | $^3\mathrm{F}^o$ | 4 | 692093.2 | 30 | 3 | 97% | |
| $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}$ | 1 | 697058.6 | 30 | 6 | 99% | |
| $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}$ | 2 | 697486.0 | 30 | 5, 1D | 99% | |
| $2s2p^2(^4\mathrm{P})3s$ | $^5\mathrm{P}$ | 3 | 698055.3 | 30 | 7, 1D | 99% | |
| $2s^22p3d$ | $^3\mathrm{D}^o$ | 1 | 698226 | 30 | 3 | 95% | |
| $2s^22p3d$ | $^3\mathrm{D}^o$ | 2 | 698421 | 30 | 7, 1B, 1D | 93% | |
| $2s^22p3d$ | $^3\mathrm{D}^o$ | 3 | 698723 | 30 | 7, 1D | 96% | |
| $2s^22p3d$ | $^3\mathrm{P}^o$ | 2 | 701762 | 30 | 6, 3D | 93% | |
| $2s^22p3d$ | $^3\mathrm{P}^o$ | 1 | 702117 | 30 | 6, 1B | 95% | |
| $2s^22p3d$ | $^3\mathrm{P}^o$ | 0 | 702300 | 50 | 2, 1D | 96% | |
| $2s^22p3d$ | $^1\mathrm{F}^o$ | 3 | 709927 | 30 | 4, 1D | 96% | |

**Table 2.** *Continued.*

| Designation[a] | | $J$ | Energy cm$^{-1}$ | | Unc. $D$[b] cm$^{-1}$ | Num. lines[c] | Leading percentages[d] | |
|---|---|---|---|---|---|---|---|---|
| $2s^22p3d$ | $^1\mathrm{P}^o$ | 1 | 711080 | | 30 | 5, 1Q | 96% | |
| $2s2p^2(^4\mathrm{P})3s$ | $^3\mathrm{P}$ | 0 | 719350 | | 30 | 1 | 93% | + 5% $2s^22p3p$ $^3\mathrm{P}$ |
| $2s2p^2(^4\mathrm{P})3s$ | $^3\mathrm{P}$ | 1 | 719503 | | 30 | 6, 3D | 93% | + 5% $2s^22p3p$ $^3\mathrm{P}$ |
| $2s2p^2(^4\mathrm{P})3s$ | $^3\mathrm{P}$ | 2 | 720027 | | 30 | 5, 1Q, 2D | 93% | + 5% $2s^22p3p$ $^3\mathrm{P}$ |
| $2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{S}^o$ | 1 | 737150 | | 80 | 4, 1Q | 97% | |
| $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o$ | 0 | 741623.2 | $+x$? | 100 | 1, 1Q | 100% | |
| $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o$ | 1 | 741761.6 | | 30 | 2 | 100% | |
| $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o$ | 2 | 742006.2 | | 30 | 4 | 99% | |
| $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o$ | 3 | 742366.9 | | 30 | 3 | 99% | |
| $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{D}^o$ | 4 | 742836.0 | | 30 | 3 | 100% | |
| $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{P}^o$ | 1 | 746821.8 | | 30 | 4, 3D | 100% | |
| $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{P}^o$ | 2 | 747029.4 | | 30 | 3, 1D | 100% | |
| $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{P}^o$ | 3 | 747391.0 | | 30 | 4, 1Q, 1D | 100% | |
| $2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{D}^o$ | 2 | 757930 | | 70 | 3, 1D | 96% | |
| $2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{D}^o$ | 3 | 758390 | | 70 | 2, 1D | 96% | |
| $2s2p^2(^4\mathrm{P})3p$ | $^5\mathrm{S}^o$ | 2 | 759800 | | 50 | 3 | 99% | |
| $2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{P}^o$ | 1 | 765710 | | 200 | 3, 1D | 95% | |
| $2s2p^2(^4\mathrm{P})3p$ | $^3\mathrm{P}^o$ | 2 | 766000 | ? | 200 | 3, 1Q, 1D | 95% | |
| $2s2p^2(^2\mathrm{D})3s$ | $^3\mathrm{D}$ | 3 | 778040 | | 150 | 2 | 97% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{F}$ | 1 | 788510 | $+x$ | 100 | 1 | 100% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{F}$ | 2 | 788656.1 | | 30 | 3, 2Q, 2D | 99% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{F}$ | 3 | 788857.0 | | 30 | 5, 2Q, 3D | 99% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{F}$ | 4 | 789123.3 | | 30 | 5, 2D | 99% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{F}$ | 5 | 789457.7 | | 30 | 4, 1Q, 1D | 100% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}$ | 1 | 795310 | | 50 | 3, 2D | 99% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}$ | 2 | 795370 | | 50 | 4, 3D | 99% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}$ | 3 | 795500 | | 40 | 6, 2Q, 3D | 98% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{D}$ | 4 | 795654 | | 40 | 5, 2D | 100% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{P}$ | 3 | 798657 | | 40 | 3, 2D | 98% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{P}$ | 2 | 798845 | | 40 | 3, 1Q, 1D | 98% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^5\mathrm{P}$ | 1 | 799050 | | 50 | 1 | 99% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{P}$ | 2 | 800880 | | 50 | 5, 1Q, 1L, 4D | 98% | |
| $2s^22p4s$ | $^3\mathrm{P}^o$ | 0 | 801230 | | 30 | 2, 1D | 96% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{P}$ | 1 | 801290 | | 60 | 4, 1Q, 4D | 98% | |
| $2s^22p4s$ | $^3\mathrm{P}^o$ | 1 | 801528 | | 30 | 5 | 93% | |
| $2s^22p4s$ | $^3\mathrm{P}^o$ | 2 | 802468 | | 30 | 5, 1B, 1D | 96% | |
| $2s^22p4s$ | $^1\mathrm{P}^o$ | 1 | 805254 | | 40 | 4, 1B | 94% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}$ | 2 | 805599 | | 40 | 3, 1D | 97% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}$ | 3 | 805886 | | 50 | 4, 2D | 97% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{F}$ | 4 | 806346 | | 40 | 6, 1Q, 2D | 97% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{D}$ | 1 | 816060 | | 60 | 4, 4D | 98% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{D}$ | 2 | 816100 | | 60 | 4, 4D | 98% | |
| $2s2p^2(^4\mathrm{P})3d$ | $^3\mathrm{D}$ | 3 | 816262 | | 40 | 4 | 98% | |
| $2s^22p4p$ | $^1\mathrm{P}$ | 1 | 816694 | | 30 | 4 | 92% | |
| $2s^22p4p$ | $^3\mathrm{D}$ | 1 | 820153 | | 30 | 3 | 92% | |
| $2s^22p4p$ | $^3\mathrm{D}$ | 2 | 820506 | | 30 | 1 | 94% | |
| $2s^22p4p$ | $^3\mathrm{D}$ | 3 | 821253 | | 30 | 2 | 95% | |

**Table 2.** *Continued.*

| Designation[a] | | $J$ | Energy cm$^{-1}$ | | Unc. $D$[b] cm$^{-1}$ | Num. lines[c] | Leading percentages[d] | |
|---|---|---|---|---|---|---|---|---|
| $2s^22p4p$ | $^3$P | 1 | 824149 | ? | 30 | 1, 1Q | 77% | + 14% $2s^22p4p$ $^3$S |
| $2s^22p4p$ | $^3$P | 2 | 824570 | | 30 | 2 | 94% | |
| $2s2p^2(^2\mathrm{D})3p$ | $^1\mathrm{D}^o$ | 2 | 825010 | | 60 | 1 | 85% | + 6% $^3\mathrm{F}^o$ |
| $2s2p^2(^2\mathrm{D})3p$ | $^1\mathrm{F}^o$ | 3 | 829500 | | 300 | 1 | 93% | |
| $2s2p^2(^2\mathrm{D})3p$ | $^1\mathrm{P}^o$ | 1 | 834600 | | 300 | 1 | 91% | |
| $2s^22p4d$ | $^3\mathrm{F}^o$ | 2 | 837600 | | 80 | 1, 1D | 76% | + 16% $^1\mathrm{D}^o$ |
| $2s^22p4d$ | $^3\mathrm{F}^o$ | 3 | 838140 | | 40 | 1 | 94% | |
| $2s^22p4d$ | $^1\mathrm{D}^o$ | 2 | 838620 | | 70 | 1 | 76% | + 14% $^3\mathrm{F}^o$ |
| $2s^22p4d$ | $^3\mathrm{F}^o$ | 4 | 838830 | | 50 | 1, 1D | 97% | |
| $2s^22p4d$ | $^3\mathrm{D}^o$ | 2 | 841000 | | 30 | 3, 1B, 2D | 77% | + 13% $^3\mathrm{P}^o$ |
| $2s^22p4d$ | $^3\mathrm{D}^o$ | 3 | 841360 | | 40 | 3, 1B, 2D | 94% | |
| $2s^22p4d$ | $^3\mathrm{P}^o$ | 2 | 842200 | | 400 | 1 | 76% | + 16% $^3\mathrm{D}^o$ |
| $2s^22p4d$ | $^3\mathrm{P}^o$ | 1 | 842600 | | 400 | 1, 1B, 1D | 86% | + 7% $^3\mathrm{D}^o$ |
| $2s^22p4d$ | $^3\mathrm{P}^o$ | 0 | 842600 | | 600 | 1, 1B, 1D | 93% | |
| $2s^22p4f$ | $^1$F | 3 | 844370 | | 30 | 3, 2D | 71% | + 10% $^3$G + 8% $^3$F |
| | | | | | | | (46% | 1/2[5/2] + 26% 1/2[7/2]<br>+ 18% 3/2[5/2]) |
| $2s^22p4f$ | $^3$F | 2 | 844440 | | 40 | 1 | 89% | |
| | | | | | | | (66% | 1/2[5/2] + 29% 3/2[5/2]) |
| $2s^22p4f$ | $^3$F | 3 | 844484 | | 30 | 4, 1B, 2D | 68% | + 22% $^3$G |
| | | | | | | | (53% | 1/2[7/2] + 22% 1/2[5/2]<br>+ 10% 3/2[7/2]) |
| $2s^22p4f$ | $^3$F | 4 | 844566 | | 30 | 3, 1D | 71% | + 18% $^3$G + 5% $^1$G |
| | | | | | | | (68% | 1/2[7/2] + 25% 3/2[7/2]) |
| $2s^22p4f$ | $^3$G | 3 | 845535 | | 30 | 4, 3D | 59% | + 19% $^1$F + 15% $^3$F |
| | | | | | | | (79% | 3/2[7/2] + 14% 1/2[7/2]) |
| $2s^22p4f$ | $^3$G | 4 | 845683 | | 30 | 3 | 67% | + 22% $^3$F |
| | | | | | | | (60% | 3/2[7/2] + 17% 3/2[9/2]<br>+ 15% 1/2[7/2]) |
| $2s^22p4f$ | $^3$G | 5 | 846030 | | 40 | 1 | 91% | + 6% $2s2p^2(^2\mathrm{D})3d$ $^3$G |
| | | | | | | | (91% | 3/2[9/2]) |
| $2s^22p4d$ | $^1\mathrm{P}^o$ | 1 | 846100 | ? | 300 | 1, 1Q | 94% | |
| $2s^22p4d$ | $^1\mathrm{F}^o$ | 3 | 846450 | | 50 | 2, 1B | 93% | |
| $2s^22p4f$ | $^3$D | 3 | 846819 | | 30 | 2, 1D | 88% | |
| | | | | | | | (68% | 3/2[5/2] + 27% 1/2[5/2]) |
| $2s^22p4f$ | $^3$D | 2 | 846942 | | 30 | 4 | 64% | + 26% $^1$D + 6% $^3$F |
| | | | | | | | (61% | 3/2[5/2] + 26% 1/2[5/2]<br>+ 9% $2p4f$ 3/2[3/2]) |
| $2s^22p4f$ | $^1$G | 4 | 847030 | | 30 | 2 | 87% | + 7% $^3$G |
| | | | | | | | (75% | 3/2[9/2] + 10% 1/2[7/2]<br>+ 10% $2p4f$ 3/2[7/2]) |
| $2s^22p4f$ | $^3$D | 1 | 847351 | | 30 | 4, 1D | 96% | |
| | | | | | | | (96% | 3/2[3/2]) |
| $2s^22p4f$ | $^1$D | 2 | 847515 | | 30 | 3, 1D | 67% | + 29% $^3$D |
| | | | | | | | (87% | 3/2[3/2] + 6% 3/2[5/2]) |
| $2s2p^2(^2\mathrm{D})3d$ | $^3$F | 4 | 870180 | | 50 | 1 | 94% | |

**Table 2.** *Continued.*

| Designation$^a$ | | $J$ | Energy cm$^{-1}$ | | Unc. $D^b$ cm$^{-1}$ | Num. lines$^c$ | Leading percentages$^d$ | |
|---|---|---|---|---|---|---|---|---|
| $2s2p^2(^2\mathrm{D})3d$ | $^3\mathrm{D}$ | 3 | 876650 | ? | 40 | 1, 1Q | 96% | |
| $2s2p^2(^2\mathrm{D})3d$ | $^3\mathrm{S}$ | 1 | 883100 | | 200 | 1 | 95% | |
| $2s2p^2(^2\mathrm{D})3d$ | $^1\mathrm{D}$ | 2 | 887270 | | 200 | 1 | 96% | |
| $2s^22p5d$ | $^3\mathrm{D}^o$ | 3 | 906830 | | 80 | 1 | 89% | + 7% $^3\mathrm{F}^o$ |
| $2s^22p5d$ | $^3\mathrm{P}^o$ | 2 | 907230 | | 160 | 1 | 59% | + 36% $^3\mathrm{D}^o$ |
| $2s^22p5g$ | $1/2[9/2]^o$ | | 908200 | | 70 | 2, 2D | 97% | |
| $2s^22p5d$ | $^1\mathrm{F}^o$ | 3 | 908480 | | 80 | 1 | 93% | |
| $2s^22p5g$ | $3/2[11/2]^o$ | | 909660 | | 60 | 2, 2D | 97% | |
| $2s2p^2(^4\mathrm{P})4p$ | $^3\mathrm{D}^o$ | 2 | 926833 | | 50 | 1 | 95% | |
| $2s2p^2(^4\mathrm{P})4p$ | $^3\mathrm{D}^o$ | 3 | 927370 | | 50 | 2 | 96% | |
| $2s2p^2(^4\mathrm{P})4d$ | $^5\mathrm{P}$ | 3 | 941100 | | 400 | 1 | 94% | + 5% $2s2p^2(^4\mathrm{P})4d$ $^5\mathrm{D}$ |
| $2s2p^2(^4\mathrm{P})4d$ | $^5\mathrm{P}$ | 2 | 941400 | | 400 | 1 | 94% | |
| $2s^22p6h$ | $1/2[11/2]$ | | 941952 | | 70 | 1 | 97% | |
| $2s^22p6d$ | $^1\mathrm{F}^o$ | 3 | 942950 | | 170 | 1 | 90% | |
| $2s^22p6h$ | $3/2[13/2]$ | | 943353 | | 60 | 1 | 97% | |
| $2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{D}^o$ | 4 | 945228 | | 40 | 2 | 95% | |
| $2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{D}^o$ | 3 | 945420 | ? | 50 | 1, 1Q | 70% | + 26% $^5\mathrm{D}^o$ |
| $2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{D}^o$ | 3 | 945544 | | 40 | 3, 2D | 69% | + 26% $^3\mathrm{D}^o$ |
| $2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{D}^o$ | 2 | 945740 | | 60 | 1 | 46% | + 47% $^3\mathrm{D}^o$ |
| $2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{D}^o$ | 1 | 945940 | | 70 | 1, 1D | 71% | + 25% $^3\mathrm{D}^o$ |
| $2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{D}^o$ | 2 | 945950 | ? | 60 | 2, 2Q, 2D | 47% | + 49% $^5\mathrm{D}^o$ |
| $2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{G}^o$ | 2 | 946230 | ? | 110 | 1, 1Q, 1D | 96% | |
| $2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{G}^o$ | 3 | 946360 | ? | 40 | 2, 2Q, 2D | 85% | + 11% $^3\mathrm{G}^o$ |
| $2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{G}^o$ | 4 | 946610 | | 50 | 2, 2D | 84% | + 10% $^3\mathrm{G}^o$ + 5% $^5\mathrm{F}^o$ |
| $2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{G}^o$ | 3 | 946840 | ? | 40 | 2, 1Q, 2D | 86% | + 10% $^5\mathrm{G}^o$ |
| $2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{G}^o$ | 5 | 946890 | | 40 | 3, 2D | 86% | + 7% $^5\mathrm{F}^o$ + 6% $^3\mathrm{G}^o$ |
| $2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{G}^o$ | 4 | 947080 | | 40 | 2, 1Q, 2D | 84% | + 10% $^5\mathrm{G}^o$ + 6% $^3\mathrm{F}^o$ |
| $2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{G}^o$ | 6 | 947250 | | 40 | 1, 1D | 100% | |
| $2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{G}^o$ | 5 | 947526 | | 40 | 3, 1Q, 1D | 91% | + 8% $^5\mathrm{G}^o$ |
| $2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{F}^o$ | 2 | 948370 | | 70 | 2, 2D | 93% | |
| $2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{F}^o$ | 3 | 948460 | | 40 | 3, 2D | 92% | |
| $2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{F}^o$ | 4 | 948546 | | 40 | 3, 2D | 92% | + 5% $^5\mathrm{G}^o$ |
| $2s2p^2(^4\mathrm{P})4f$ | $^5\mathrm{F}^o$ | 5 | 948614 | | 40 | 3, 1D | 92% | + 5% $^5\mathrm{G}^o$ |
| $2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{F}^o$ | 2 | 948819 | | 50 | 2, 1D | 94% | |
| $2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{F}^o$ | 3 | 948859 | | 50 | 3, 1D | 94% | |
| $2s2p^2(^4\mathrm{P})4f$ | $^3\mathrm{F}^o$ | 4 | 948940 | | 40 | 2 | 94% | + 5% $^3\mathrm{G}^o$ |
| $2s2p^2(^4\mathrm{P})5d$ | $^5\mathrm{P}$ | 3 | 1006760 | | 170 | 1 | 83% | + 16% $2s2p^2(^4\mathrm{P})5d$ $^5\mathrm{D}$ |

[a] The level designations are based on the leading percentage in the appropriate coupling scheme (see text). Uncertain levels are quoted with a question mark.

[b] The meaning of the uncertainties is explained in the text. The unknown $x$ reflects the fact that the $2s2p^2(^4\mathrm{P})3d$ $^5\mathrm{F}$ ($J = 1-2$) splitting was fixed at the calculated value of 146 cm$^{-1}$, resulting from the parametric fitting.

[c] "Num. lines" is the number of observed combinations determining the level. The details of the records are best explained by an example: "6, 1B, 1Q, 1L, 1D" would mean: total 6 combinations, including 1 blended line, 1 questionable line, 1 line with large deviation of the observed wavelength from the calculated one (greater than 1.2 times uncertainty), and 1 doubly (or multiply) classified line.

[d] The leading percentages in excess of 5% are given. They have been computed in the parametric fitting procedure (see Sect. 3). An alternative designation in $jK$ coupling scheme is given in parentheses for some of the levels.

due to systematic shifts of each group $K$ of correlated lines. If the level is determined from several lines, these shifts must be added to the dispersion in order to obtain a more confident estimate of the possible error. The program LOPT does this by computing the square root of the sum of squares of the dispersion and all error bounds which are due to systematic line-shifts. The only exception is the case of a level determined from a single line. In this case the estimated dispersion of the level coincides with the wavenumber-measurement uncertainty which already includes the possible systematic error.

The effect of the possible systematic error of a certain group of lines on the calculated wavenumbers is estimated in the same manner, by computing the derivative of each calculated wavenumber with respect to the group-shift variable and multiplying of this derivative by the upper-bound estimate of the group shift. The squares of the contributions from each line group are added to the square of the dispersion to get the square of the estimated uncertainty of the calculated wavenumber, except for the case when this line alone determines one of the two levels involved.

Most of the energy levels listed in Table 2 were previously known from the works of Paul and Polster [12], Kaufman *et al.* [19], Goldsmith and Kaufman [20], Hermansdorfer [17], Lindeberg [13,21], and Bastin *et al.* [1,2]. The energies of these known levels have been only slightly corrected in the optimization procedure.

In the $2s^22p4p$ $^3$P, $^3$D, $2s^22p4d$ $^3$D$^o$, $2s^22p4f$ $^3$G$_3$, $^3$F$_3$, $2s2p^2(^4$P$)3s$ $^3$P$_1$, $2s2p^2(^4$P$)3p$ $^5$P$^o$, $2s2p^2(^4$P$)3d$ $^3$P, $^5$D, $^3$F, $2s2p^2(^4$P$)4p$ $^3$D$^o$, $2s2p^2(^4$P$)4f$ $^5$D$^o$, $^5$G$^o$, $^5$F$^o$, and $2s2p^2(^4$P$)4f$ $^3$G$^o$ terms there is an improvement in accuracy because of the identification of new combinations in the observed spectra.

The $2s2p^2(^2$D$)3p$ $^1$F$^o_3$ and $^1$D$^o_2$ levels have been significantly corrected because their old identification was erroneous.

The previously unknown $2s2p^2(^2$D$)3p$ $^1$P$^o_1$, $2s2p^2(^2$D$)3d$ $^1$D$_2$, $2s^22p4p$ $^1$P$_1$, $2s^22p4d$ $^1$P$^o_1$, $2s2p^2(^4$P$)4p$ $^3$D$^o_2$, $2s2p^2(^4$P$)3p$ $^5$S$^o_2$ levels are now firmly established due to our new identifications.

The $2s^22p5g$ 1/2[9/2]$^o$ and 3/2[11/2]$^o$, as well as the $2s^22p6h$ 1/2[11/2] and 3/2[13/2] terms are identified in the beam-foil spectra. Their identification is verified by the known $^2$P (1/2–3/2) interval in the ground term of Ne VI 1306.81 cm$^{-1}$ [35]. The observed intervals $2s^22p5g$ 1/2[9/2]$^o$–3/2[11/2] and $2s^22p6h$ 1/2[11/2]–3/2[13/2], 1460 and 1401 cm$^{-1}$, are rather close to the splitting of the parent term.

Our calculations have shown that there exists a few-percent admixture of the $2s^22p^2$ character to the $2p^4$ states. This would make the transitions connecting these states with the singly-excited $2s2p^2nl$ configurations observable. Such an observation, unavailable so far, would improve significantly the accuracy of their energies.

The $LS$ coupling scheme has been found to be the best description of the structure and character of most configurations, including the $2s^22p4f$ one, in contrast to findings of the previous investigation [2] where the $jK$ coupling scheme was suggested for this configuration. Our extended calculations have revealed that, despite the fact that the $jK$ coupling is the best one for the $2s^22p4f$ configuration in the previous members of the isoelectronic sequence, in Ne V this is no longer true, and so we have chosen $LS$ coupling for the notation of the levels of this configuration. Although many of the levels are significantly mixed, still we have found that a unique $LS$-coupling notation can be given to all of them.

$jK$ coupling has been found to be a very good description of the previously unknown $2s^22p5g$ and $2s^22p6h$ configurations.

As already noted, the unknown doubly excited $2p^3nl$ configurations interact strongly with the normal $2s^22pnl$ configurations, and this interaction results not only in a large downward shift of the normal configurations, but also in a significant redistribution in their wavefunctions.

## 6 Ionisation potential

The previously reported value of the ionisation potential, $1\,018\,000 \pm 1\,000$ cm$^{-1}$ [36], was a result of Edlén's extrapolation along the carbon isoelectronic sequence (see [37] and references therein). The new identification of the $2p5g$ and $2p6h$ configurations permits us to improve this value. Fitting the centres of gravity of the $2p(^2$P$_{1/2})nl$ and $2p(^2$P$_{3/2})nl$ ($nl = 4f$, $5g$ and $6h$) configurations by means of the polarisation formula [37] yields a consistent value of IP $= 1\,018\,250$ cm$^{-1}$ with a scatter of less than 40 cm$^{-1}$. This confirms the identification of the $2p5g$ and $2p6h$ levels. These levels are established with an uncertainty of 60 to 70 cm$^{-1}$, thus the uncertainty of IP is probably less than 100 cm$^{-1}$.

In a recent work of Biémont *et al.* [38], the ionisation potential of ions in several isoelectronic sequences have been determined using interpolation/extrapolation of differences between NIST compiled data and results of relativistic MCDF calculations. For Ne V they obtained $1\,018\,500 \pm 290$ cm$^{-1}$ which agrees very well with our result.

## 7 Summary

As a result of the present analysis, a consistent linelist with energy-level classifications has been built for Ne V, and the most complete set of optimized energy levels has been derived. The previous knowledge of the Ne V spectrum has been substantially extended. In total, some 10 new energy levels have been found, and more than 40 new spectral lines classified. An improved value of the ionisation potential has been obtained.

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