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Interesting lines in the infrared solar spectrum between λ 1.49 and λ 1.8 μm

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Abstract. — Lists are presented of two groups of spectral lines interesting for the study of solar and stellar magnetic fields, convection and atmospheric structure and appearing in the infrared solar spectrum between 1.49 and 1.8 μm. The first group contains 130 spectral lines judged to be relatively unblended from a visual inspection of the spectra, while the second is composed of 30 lines exhibiting large Stokes *V* amplitudes in a quiet network region. Some interesting aspects of these lines are discussed. In particular, it is pointed out that blending due to magnetically unsplit spectral lines, such as telluric lines, can seriously affect all four Stokes parameters.

Key words: the sun: spectrum — lines: unblended — lines: identification — atomic data — Stokes *V* — infrared.

1. Introduction.

In the visible part of the solar spectrum, the availability of comprehensive lists of unblended lines (e.g. Moore *et al.*, 1966; Holweger, 1967; Stenflo and Lindegren, 1977; Rutten and Van der Zalm, 1984) has led to spectral studies based on a large number of lines (e.g. Holweger, 1967; Stenflo and Lindegren, 1977; Dravins *et al.*, 1981, 1986; Balthasar, 1984; Solanki, 1986; Solanki and Steenbock, 1988) which have considerably enhanced our knowledge of the structure of the quiet photosphere, solar granulation, turbulent magnetic fields and small scale magnetic features. In addition, lists of unblended lines or of lines with no Zeeman splitting (e.g., Sistla and Harvey, 1970), large Zeeman splitting (e.g., Harvey, 1973), or large Stokes *V* amplitudes (Solanki *et al.*, 1986) greatly simplify the search for a small number of special lines required for particular investigations.

Spectral studies in the infrared H band, which approximately covers the wavelength range 1.49-1.80 μm and is bounded at both ends by deep terrestrial absorption features, are in many respects complementary to analyses of visible spectra. The lines in the infrared H band are formed deeper in the atmosphere due to a minimum in the continuum opacity at these wavelengths. They generally have a higher excitation potential and exhibit a considerably larger sensitivity to the magnetic field. Also, due to the reduced continuum contrast in the infrared, H band spectral lines sample the warm and cool regions on the solar or stellar surface in a different way than their visible counterparts. Finally, the maximum brightness of the spectral energy distribution of many cool stars occurs at or near the H band, making it the wavelength region of choice for high signal-to-noise observations of such stars.

Preliminary solar applications of H-band spectra have been presented by e.g. Harvey (1977), Van Ballegooijen (1984), Sun *et al.* (1986), Nadeau (1988) and Zayer *et al.* (1989). More extensive use of such data would be of great value, but requires that interesting spectral lines be identified and listed together with their main atomic parameters. Consequently, we present a list of unblended lines in the H-band and also identify the 30 lines with the largest Stokes *V* amplitudes in a network region at the centre of the solar disk. Lines with large Stokes *V* amplitudes (Stokes *V* is the difference between left and right circularly polarized light) are of particular interest for magnetic field studies. They are ideal for making magnetograms and quite generally for investigations requiring large signal to noise ratios in Stokes *V*.

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2. Unblended lines.

Table I lists the lines which appear to be unblended upon visual inspection of a spectrum covering the wavelength range 1.468 – 1.804 μm, obtained in a solar quiet network region at cos $\theta = 0.99$ (θ is the heliocentric angle) with the McMath telescope on Kitt Peak and the Fourier transform spectrometer (FTS) used as a polarimeter (spectra of Stokes *I, V* and *Q* were obtained). The observations are described in detail by Stenflo *et al.* (1987) and Solanki (1987). The magnetic filling factor of the observed region is approximately 4% (Solanki *et al.*, 1989; Zayer *et al.*, 1989), sufficiently small for Stokes *I* to be relatively unaffected by the magnetic field. A comparison to the Kitt Peak FTS infrared spectral atlas (Delbouille *et al.*, 1981) shows that the spectrum used by us has lower telluric H_2O absorption. Consequently, some of the lines listed in table I may be blended in the Delbouille *et al.* (1981) atlas or in other spectra obtained under less dry conditions. On the other hand, observations made from drier sites (e.g. Jungfraujoch station, space) may well reveal additional unblended lines.

Classifying a particular spectral line as "unblended" in the presence of the ubiquitous haze of weak absorption features is generally a subjective decision, so that the term "unblended" can only be used in a relative sense. A given spectral line may be sufficiently pure for a certain type of analysis, but not for a more sensitive one. So as not to be too restrictive, we have therefore included lines which are not totally free of blends. Thus table I should contain almost all lines which are relatively unblended in the H-band, but for some analyses a more rigorous selection will have to be made from among these lines. To help with such a selection we have added a "blending index" to table I, which mirrors our subjective impression of the amount of blending.

Column 1 of table I gives the solar wavelengths (in air), $\lambda_\odot$, of the lines, while the second column lists the corresponding vacuum wavenumbers, $\sigma_\odot$. For almost all lines these values have been derived from the spectral atlas of Delbouille *et al.* (1981) whose wavenumber scale is corrected for sun-observer relative motion and solar rotation (cf. Biémont *et al.*, 1985a, b, 1986). The conversion from wavenumber to wavelength is made using Edlén's (1953) formula. The blending index, an estimate of the blending of the chosen lines, is tabulated in column 3. The following scale is used: 0 = no detectable blend, 1 = minor blending, 2 = significant blending, 3 = severe blending. It is calibrated by comparing with lines in the visible, listed and similary classified by Harvey (1973) and Solanki *et al.* (1986). When judging the blending we have also included the Stokes *V* profiles, which are rather sensitive to blends (cf. Stenflo *et al.*, 1984). The lines marked by a * in this column were suspected of being blended by Biémont *et al.* (1985a) from an inspection of the Delbouille *et al.* (1981) atlas and should be considered with caution.

Columns 4 and 5 list the ions and their laboratory wavelengths identified with the solar spectral lines, generally from a comparison of the laboratory wavelengths $\lambda_{\rm lab}$, with $\lambda_\odot$ (from e.g. Outred, 1978; Biémont *et al.*, 1985a, b, 1986; Biémont and Brault, 1987a, b). The correspondence between $\lambda_\odot$ and $\lambda_{\rm lab}$ is generally (but not always) better than 0.03 Å and a sizeable fraction of this difference is probably of solar origin (cf. Nadeau, 1988). In some cases no direct laboratory measurement of the wavelength is available and wavelength values calculated from the difference between measured or calculated energy levels have been listed under $\lambda_{\rm lab}$ (taken e.g. from Biémont and Grevesse, 1973; Biémont, 1976). All the lines found in the literature with $\lambda_{\rm lab}$ sufficiently close to $\lambda_\odot$ are listed, with the exception of the lines found to be too weak when calculated using *gf* values taken from Kurucz and Peytremann (1975). More details of these calculations are provided in section 4. Whenever more than one identification of a given solar line is possible we have listed them in what we think is the order of decreasing probability, based on their calculated equivalent widths (where possible), proximity of wavelengths and Landé factors.

Column 6 lists the responsible transitions, where known, and column 7 gives their sources. The notation of the terms in the identified transitions follows the National Bureau of Standards (NBS) atomic energy levels (Martin and Zalubas, 1979, 1980; Corliss and Sugar, 1979, 1981, 1982; Sugar and Corliss, 1977, 1985), as well the recent work by Johansson and Learner (1989) and may in some cases differ from older notations. The final digits of the wavelengths corresponding to the listed transitions (calculated on the basis of available energy levels) are presented in the last column of the table, marked $\lambda_{\rm calc}$. A small $|\lambda_{\rm calc} - \lambda_{\rm lab}|$ is a necessary (but not sufficient) condition for the identification of a particular transition with an observed spectral line. Only transitions with $|\lambda_{\rm calc} - \lambda_{\rm lab}| \leq 0.5.$ Å have been retained. The reason for the often larger discrepancy between $\lambda_{\rm calc}$ and $\lambda_\odot$ than between $\lambda_{\rm lab}$ and $\lambda_\odot$ is the much lower precision with which the energy of some atomic levels is known, particularly of highly excited states. Unfortunately, the latest high precision measurements of laboratory wavelengths have so far been only partly used to extend and improve the term systems of some key elements (e.g. iron). All the transitions due to iron group elements have been checked with the newest atomic energy levels available in the literature. This has led to the rejection of numerous previous identifications, either due to the fact that one of the levels is no longer present in the NBS tables, or to the fact that $\lambda_{\rm lab} - \lambda_{\rm calc} > 0.5$ Å. Lines which had previously been wrongly attributed to a particular atomic transition have been marked by an [f] is column 7. Of course, the direct comparison of all the possible wavelengths calculated from the atomic energy levels with $\lambda_{\rm lab}$ has also led to numerous new identifications, marked by an [n] in column 7. Note that gaps in the $\lambda_{\rm calc}$ column signify that the wavelength listed under $\lambda_{\rm lab}$ has been calculated from the energy levels of the transitions. Column 8 contains the excitation potential of the lower level of the transition, χ_e in eV, generally taken from the NBS atomic energy level tables.

1990A&AS...83..307S

The effective Landé factor calculated from the listed transitions, $g_{\rm eff}^{\rm calc}$, is presented in column 9, while the effective Landé factor derived empirically from laboratory measurements, $g_{\rm eff}^{\rm emp}$, is listed in column 10 for those lines for which such data are available. The importance of empirical Landé factors has been pointed out by, e.g., Landi Degl'Innocenti (1982) and Mathys (1989). The $g_{\rm eff}$ values have been calculated using the equation

$$g_{\rm eff} = \frac{1}{2}(g_{\rm l}+g_{\rm u}) + \frac{1}{4}(g_{\rm l}-g_{\rm u})(J_{\rm l}(J_{\rm l}+1)-J_{\rm u}(J_{\rm u}+1)) \quad (1)$$

(Shenstone and Blair, 1929). $J_{\rm u}$ and $J_{\rm l}$ are the total angular momentum quantum numbers, while $g_{\rm u}$ and $g_{\rm l}$ are the Landé factors of the upper and lower levels involved in the transition, respectively. The validity of equation (1) for cases of departure from LS-coupling or the contribution of multiple terms to a given energy level has been discussed by Landi Degl'Innocenti (1982). It has been extensively applied to Fe I and II lines in the visible by Solanki and Stenflo (1985). For $g_{\rm eff}^{\rm calc}$, $g_{\rm u}$ and $g_{\rm l}$ are calculated using the standard LS-coupling formula for all transitions, except those taken from Johansson and Learner (1989). For $g_{\rm eff}^{\rm emp}$, $g_{\rm u}$ and $g_{\rm l}$ are, wherever possible, taken from the measured values listed in the NBS atomic energy levels. Often only either $g_{\rm l}$ or $g_{\rm u}$ is available from laboratory measurements. In such cases the missing atomic level Landé factor is assumed to be represented by its calculated value. A question mark has been placed behind such $g_{\rm eff}^{\rm emp}$ values. However, we feel that even in such cases the $g_{\rm eff}^{\rm emp}$ should be preferred to the $g_{\rm eff}^{\rm LS}$ values. Finally, columns 11, 12 and 13 of table I contain, X_π, X_σ and Y_σ, the second and third order coefficients of the expansion of a spectral line according to its Zeeman moments (cf. Mathys and Stenflo, 1987). The X_π and X_σ coefficients represent, respectively, the scatter of the π- and σ- components about their centres of gravity and were first introduced by Landi Degl'Innocenti (1982, 1985). They are defined as follows:

$$\begin{aligned} X_\pi &= (g_{\rm l}-g_{\rm u})^2(3s-d^2-2)/10 \\ X_\sigma &= (g_{\rm l}-g_{\rm u})^2(8s-d^2-12)/80 \end{aligned} \quad (2)$$

where

$$\begin{aligned} s &= J_{\rm l}(J_{\rm l}+1)+J_{\rm u}(J_{\rm u}+1) \\ d &= J_{\rm l}(J_{\rm l}+1)-J_{\rm u}(J_{\rm u}+1) \end{aligned} \quad (3)$$

Although for most transitions in the visible X_π and X_σ play a minor role outside of sunspots, they attain considerable importance in the infrared for all solar magnetic features due to the larger Zeeman sensitivity of the lines. Still higher order moments may be obtained from the tables published by Mathys and Stenflo (1987).

3. Lines with large Stokes V amplitudes.

Tables II lists the 30 lines in the H band with the largest Stokes V amplitudes outside sunspots at solar disk centre. Columns 1 and 2 list the solar wavelength and wavenumber, respectively. These values have again been determined from the Delbouille *et al.* (1981) atlas. We have included lines with blending index 2 and even 3 in this table for the sake of consistency with similar previous lists (e.g. Harvey, 1973; Solanki *et al.*, 1986). Also, many of these lines are blended only in one wing, so that the other Stokes V wing can still be used for making magnetograms. Note that the accuracy of $\lambda_\odot$ and $\sigma_\odot$ is considerably lower for blended lines.

The third and fourth columns contain the amplitudes of the blue, $a_{\rm b}$, and red, $a_{\rm r}$, Stokes V wings, respectively. Stokes V has been normalised to the local continuum intensity and the actual $a_{\rm b}$ and $a_{\rm r}$ values recorded in the spectrum are tabulated (in % polarization). As pointed out by Solanki *et al.* (1986), who produced a corresponding list for the visible part of the solar spectrum, the relative Stokes V amplitudes of the lines in such lists may vary slightly for different solar regions due to variations in the temperature of magnetic elements from one region to another. Solanki *et al.* then compared two regions known to have different temperatures within the magnetic elements and found that the same lines had the strongest Stokes V signals in both regions. Such variations should be even smaller in the infrared due to the rather similar $\chi_{\rm e}$ values of all the lines (cf. Tab. II). We therefore expect this table to be valid for all non-spot, non-pore solar magnetic features. The rest of the columns in table II corresponds to their counterparts in table I and the relevant remarks made in section 2 also apply here.

4. Discussion.

Some of the identifications made in table I and II may be due to the chance coincidence of $\lambda_{\rm calc}$ and $\lambda_{\rm lab}$. For those transitions for which oscillator strengths are available (e.g. from Kurucz and Peytremann, 1975), it is possible to compare the equivalent width calculated using a solar atmospheric model (Holweger and Müller, 1974) with the observed equivalent width (cf. Biémont, 1976). We have applied this procedure to those lines for which more than one identification appeared possible and have been able to rule out some transitions giving a negligible contribution to the observed line, i.e. whose equivalent width $\lesssim$ 1 mÅ. These rejected identifications are listed in table III. In addition, for three lines $\lambda_\odot$ = 16680.809 Å, 16718.977 Å and 17448.585 Å the calculated W_λ of the primary identifications (Si I, Al I and C I, respectively) is so large that it is highly improbable that the secondary identification (Fe I in all three cases) contributes significantly to the observed line on the sun. Note, however, that for other temperatures and abundance ratio, as found on some other stars, contributions from the rejected transitions cannot be ruled out.

In some cases theoretical or empirical Landé factors may help to rule out identifications or decide between two possible identifications. As an illustrative example consider Fe I 15611.151 Å. Its observed Stokes V profile is weak and has a sign opposite to the other lines in our sample, suggestive of a small negative Landé factor. However, $g_{\rm eff}$ determined from the transition given in table I is large and positive, thus making this identification highly unlikely. The case is not so clear cut for all lines, but the Landé factors have allowed us in some cases to prefer one identification to another.

Since telluric lines are one of the main sources of blending in the infrared, we feel it is important to point out again that, in contrast to statements in the literature (e.g. Stenflo *et al.*, 1984), *telluric blends can seriously distort all four Stokes parameters*, as demonstrated by Solanki (1990). For more details we refer to that paper.

Due to the larger Zeeman spliting in the infrared, large a_b and a_r are much more strongly indicative of a large line strength than in the visible. Thus 5 out of the 7 strongest lines in the considered wavelength range are present in table II (Mg I 15025.015 Å, Mg I 15765.854 Å, Si I 15888.435 Å, Si I 15960.080 Å and Mg I 17108.660 Å).

While searching for possible transitions corresponding to the observed lines in the process of creating table I and II, it became clear how incomplete the current knowledge of the atomic structure relevant to the line identifications is. In particular, we have been unable to find any atomic transitions corresponding to a number of Fe I lines. Iron is a key element, since at least 92 out of the 130 lines in table I may be attributed to it, mainly to Fe I. Although line identifications and laboratory measurements in the infrared have progressed considerably over the past 15 years (e.g. Litzén and Vergés, 1976; Litzén, 1976; Biémont, 1976; Biémont *et al.*, 1985a, b, 1986; Biémont and Brault, 1987a, b; Johansson and Learner, 1989), the lack of reliable identifications still constitutes one of the main obstacles to progress in studies of the infrared spectrum of the sun and other late type stars. Improvements in the term structure of the high lying states of Fe I and other iron group elements should, therefore, be given a very high priority.

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References

BALTHASAR H.: 1984, *Solar Phys.* **93**, 219.

BIEMONT E.: 1976, *Astron. Astrophys. Suppl. Ser.* **26**, 89.

BIEMONT E., BRAULT J.W.: 1987a, *Physica Scr.* **34**, 751.

BIEMONT E., BRAULT J.W.: 1987b, *Physica Scr.* **35**, 286.

BIEMONT E., BRAULT J.W., DELBOUILLE L., ROLAND G.: 1985a, *Astron. Astrophys. Suppl. Ser.* **61**, 107.

BIEMONT E., BRAULT J.W., DELBOUILLE L., ROLAND G.: 1985b, *Astron. Astrophys. Suppl. Ser.* **61**, 185.

BIEMONT E., BRAULT J.W., DELBOUILLE L., ROLAND G.: 1986, *Astron. Astrophys. Suppl. Ser.* **65**, 21.

BIEMONT E., GREVESSE N.: 1973, *Atomic Data Nuclear Data Tables* **12**, 217.

CORLISS C., SUGAR J.: 1979, *J. Phys. Chem. Ref. Data* **1**, 1

CORLISS C., SUGAR J.: 1981, *J. Phys. Chem. Ref. Data* **10**, 197.

CORLISS C., SUGAR J.: 1982, *J. Phys. Chem. Ref. Data* **11**, 135.

DELBOUILLE L., ROLAND G., BRAULT J.W., TESTERMAN L.: 1981, Photometric Atlas of the Solar Spectrum from 1850 to 10 000 $\rm cm^{-1}$,NOAO, Tucson, Az.

DRAVINS D., LARSSON B., NORDLUND Å.: 1986, *Astron. Astrophys.* **158**, 83.

DRAVINS D., LINDEGREN L., NORDLUND Å.: 1981, *Astron. Astrophys.* **96**, 345.

EDLEN B.: 1953, *J. Opt. Soc. America* **43**, 339.

HALL D.N.B.: 1974, An Atlas of Infrared Spectra of the Solar Photosphere and of Sunspot Umbrae, Kitt Peak National Observatory, Contribution No. 556, Tucson, Az.

HARVEY J.W.: 1973, *Solar Phys.* **28**, 9.

HARVEY J.W.: 1977, in Highlights of Astronomy, E.A. Müller Ed., Vol. **4**, Part II, p. 223.

HOLWEGER H.: 1967, *Z. Astrophys.* **65**, 365.

HOLWEGER H., MÜLLER E.A.: 1974, *Solar Phys.* **39**, 19.

JOHANSSON S., LEANER R.C.M: 1989, *Astrophys. J.* submitted.

KURUCZ R.L., PEYTREMANN E.: 1975, Smithson. Inst. Astrophys. Obs. Special Report No. 362.

LANDI DEGL'INNOCENTI E.: 1982, *Solar Phys.* **77**, 285.

LANDI DEGL'INNOCENTI E.: 1985, *Solar Phys.* **99**, 1.

LITZEN U.: 1976, *Physica Scr.* **14**, 165.

LITZEN U., VERGES J.: 1976, *Physica Scr.* **13**, 240.

MARTIN W.C., ZALUBAS R.: 1979, *J. Phys. Chem. Ref. Data* **8**, 817

MARTIN W.C., ZALUBAS R.: 1980, *J. Phys. Chem. Ref. Data* **9**, 1.

MATHYS G.: 1989, *Fundamentals Cosmic Phys.* in press.

MATHYS G., STENFLO J.O: 1987, *Astron. Astrophys. Suppl. Ser.* **67**, 557.

MOORE C.E., MINNEART M.G.J. and HOUTGAST J.: 1966, The Solar Spectrum 2935 Å to 8770 Å, National Bureau of Standards, Monograph 61, Washington, D.C.

NADEAU D.: 1988, *Astrophys. J.* **325**, 480.

OUTRED M.: 1978, *J. Phys. Chem. Ref. Data* **7**, 1.

RUTTEN R.J., VAN DER ZALM. E.B.J.: 1984, *Astron. Asytrophys. Suppl. Ser.* **55**, 143.

SHENSTONE A.G., BLAIR H.A.: 1929, *Philos. Mag.* **8**, 765.

SISTLA G., HARVEY J.W.: 1970, *Solar Phys.* **12**, 66.

SOLANKI S.K.: 1986, *Astron. Astrophys.* **168**, 311.

SOLANKI S.K.: 1987, Ph.D. Thesis, No. 8309; E.T.H., Zürich.

SOLANKI S.K.: 1990, in preparation.

SOLANKI S.K., PANTELLINI F.G.E., STENFLO J.O.: 1986, *Solar Phys.* **107**, 57.

SOLANKI S.K., STEENBOCK W.: 1988, *Astron. Astrophys.* **189**, 243.

SOLANKI S.K., STENFLO J.O.: 1985, *Astron. Astrophys.* **148**, 123.

SOLANKI S.K., ZAYER I., STENFLO J.O.: 1989, in Proc. 10th Sacramento Peak Workshop, O. von der Lühe (Ed.), in press.

STENFLO J.O., HARVEY J.W., BRAULT J.W., SOLANKI S.K.: 1984, *Astron. Astrophys.* **131**, 333.

STENFLO J.O., LINDEGREN L.: 1977, *Astron. Astrophys.* **59**, 367.

STENFLO J.O., SOLANKI S.K., HARVEY J.W.: 1987, *Astron. Astrophys.* **173**, 167.

SUGAR J., CORLISS C.: 1977, *J. Phys. Chem. Ref. Data* **6**, 317.

SUGAR J., CORLISS C.: 1985, *J. Phys. Chem. Ref. Data* **14**, Supplement No. 2.

SUN W.-H., GIAMPAPA M.S., WORDEN S.P.: 1987, *Astrophys. J.* **312**, 930.

VAN BALLEGOOIJEN A.A.: 1984, *Solar Phys.* **91**, 195.

ZAYER I., SOLANKI S.K., STENFLO J.O.: 1989, *Astron. Astrophys.* **211**, 463.

TABLE I. — *Lines judged to be relatively unblended from a visual examination.*

$\lambda_\odot$ (Å)	$\sigma_\odot$ (cm^{-1})	Blend	Ion	$\lambda_{\rm lab}$ † (Å)	Transition	Ref.	χ_e (eV)	$g_{\rm eff}^{\rm calc}$ ¶	$g_{\rm eff}^{\rm emp}$	X_π	X_σ	Y_σ	$\lambda_{\rm calc}$ (Å)
14982.819	6672.488	1	Fe I	14982.801	$e\ {}^7P_4 - (7/2)[9/2]^\circ_5$	[8]	6.26	0.736	1.066?	0.548	0.411	0.232	.801
15017.716	6656.983	0–1	Fe I	15017.699	$3d^6 4s5p\ {}^7P^\circ_4 - 3d^6 4s5d\ 3_4$	[n]	6.22						.745
15067.021	6635.199	1–2	Fe I	15066.956	$e\ {}^5D_2 - u\ {}^3D^\circ_3$	[n]	5.62	1.167	1.109	0.044	0.033	0.006	7.007
			Ca I	15067.041	$4s4d\ {}^1D_2 - 3d4p\ {}^1P_1$	[n]	4.62	1.000		0.000	0.000	0.000	
15122.392	6610.904	1	Fe I	15122.379	$e\ {}^5D_2 - u\ {}^5P^\circ_2$	[7]	5.62	1.667	1.668?	0.378	0.117	0.000	.378
15168.352	6590.873	1	K I	15168.40	$3d\ {}^2D_{3/2} - 4f\ {}^2F^\circ_{5/2}$	[4]	2.67	0.900		0.003	0.003	0.000	
15176.720	6587.239	0–1	Fe I	15176.713	$e\ {}^5F_3 - 3d^7 5p\ {}^3D^\circ_2$	[5]	5.92	1.333	1.305?	0.011	0.008	−0.001	.757
15178.254	6586.573	1	Fe I	15178.252									
15201.574	6576.469	1–2	Fe I	15201.563	$3d^6 4s4p\ {}^5F^\circ_2 - f\ {}^7D_3$	[5]	5.49	2.500	2.383?	0.900	0.675	−0.506	.796
15207.545	6573.887	0	Fe I	15207.527	$e\ {}^7D_3 - 3d^6 4s5p\ {}^7D^\circ_2$	[6]	5.38	1.500	1.510?	0.100	0.075	0.019	.547
15219.637	6568.664	1	Fe I	15219.619	$e\ {}^5D_3 - t\ {}^5D^\circ_2$	[1,7]	5.59	1.500	1.516?	0.000	0.000	0.000	.621
15224.741	6566.462	1	Fe I	15224.728									
15243.562	6558.354	1–2	Si I	15243.59	$3d\ {}^3D^\circ_3 - 6p\ {}^3P_2$	[4]	6.73	1.167		0.044	0.033	0.006	
15301.562	6533.495	1	Fe I	15301.559	$e\ {}^5F_3 - 54289.09\ {\rm cm}^{-1}$	[7]	5.92						.43
15361.164	6508.145	1–2	Si I	15361.16	$4p\ {}^3D_1 - 5s\ {}^3P^\circ_2$	[4,5]	5.95	2.000		0.600	0.450	−0.300	.59
15376.850	6501.506	1 *	Si I	15376.831	$3d\ {}^3D^\circ_2 - 6p\ {}^3P_1$	[4]	6.72	1.000		0.067	0.050	0.011	.94
			Fe I	15376.926									
15459.331	6466.818	1	Fe I	15459.311									
15499.408	6450.097	0–1	Fe I	15499.392	$e\ {}^7F_4 - (3/2)[7/2]^\circ_3$	[8]	6.35	2.150	2.442?	0.562	0.422	−0.244	.386
					$w\ {}^5D^\circ_1 - e\ {}^7P_2$	[n]	5.51	2.750	2.843?	0.417	0.313	−0.174	.232
15524.326	6439.744	0–1	Fe I	15524.307	$3d^7 4p\ {}^5D^\circ_4 - f\ {}^5P_3$	[5]	5.79	1.250	0.852?	0.083	0.063	0.014	.543
15531.769	6436.658	1–2	Fe I	15531.756	$e\ {}^5D_1 - u\ {}^5F^\circ_1$	[n]	5.64	0.750	0.759?	2.250	0.563	0.000	.742
					$e\ {}^7F_6 - (9/2)[15/2]^\circ_7$	[8]	6.24	0.668	0.698?	0.415	0.312	0.151	.812
15534.257	6435.627	1	Fe I	15534.244	$e\ {}^5D_1 - u\ {}^5P^\circ_2$	[1,7]	5.64	2.000	1.991?	0.067	0.050	−0.011	.240
15540.591	6433.004	1	Ni I	15540.596									
15542.089	6432.384	0	Fe I	15542.079	$e\ {}^5D_1 - t\ {}^5D^\circ_0$	[1,6]	5.64	1.500	1.518?	0.000	0.000	0.000	.096
			Mg I	15542.16	$5p\ {}^3P^\circ_2 - 11d\ {}^3D_2$	[n]	6.73	1.333		0.378	0.117	0.000	
					$5p\ {}^3P^\circ_2 - 11d\ {}^3D_3$	[n]	6.73	1.167		0.044	0.033	0.006	
					$5p\ {}^3P^\circ_2 - 11d\ {}^3D_1$	[n]	6.73	2.000		0.600	0.450	−0.300	
			Si I	15542.016	$3p4d\ {}^1D_2 - 3p6f\,(7/2)_3$	[n]	6.73						
15543.780	6431.684	1	Ti I	15543.68	$a\ {}^3G_4 - z\ {}^3G^\circ_4$	[1]	1.88	1.050	1.06	0.000	0.000	0.000	.720
15557.784	6425.895	0	Si I	15557.81	$4p\ {}^3D_2 - 5s\ {}^3P^\circ_2$	[4,5]	5.96	1.333		0.378	0.117	0.000	.78
15565.251	6422.812	1	Fe II	15565.228	$3d^5 4s4p\ {}^4S^\circ_{3/2} - 104761.10\ {\rm cm}^{-1}$	[n]	12.19						.23
15566.749	6422.194	0–1	Fe I	15566.726	$e\ {}^5G_3 - (3/2)[7/2]^\circ_4$	[f,8]	6.35	1.832	1.266?	0.403	0.302	−0.147	.732
15588.264	6413.330	0–1	Fe I	15588.259	$3d^6 4s4p\ {}^5F^\circ_2 - f\ {}^5D_2$	[5]	5.49	1.250	1.366	0.850	0.263	0.000	.627
15591.520	6411.991	0–1	Fe I	15591.493	$e\ {}^7F_6 - (9/2)[13/2]^\circ_7$	[f,8]	6.24	1.104	1.134?	0.094	0.071	0.016	.500
					$e\ {}^7F_2 - (1/2)[7/2]^\circ_3$	[f,8]	6.36	0.608		0.318	0.239	0.106	.500
15593.743	6411.077	1	Fe I	15593.747	$x\ {}^5F^\circ_4 - e\ {}^5F_5$	[1]	5.03	1.500	1.607	0.012	0.009	−0.001	.738
15598.889	6408.962	1	Fe I	15598.871	$e\ {}^7F_6 - (9/2)[11/2]^\circ_5$	[8]	6.24	1.665	1.630?	0.030	0.023	−0.003	.879
15604.240	6406.764	0–1	Fe I	15604.221	$e\ {}^7F_6 - (9/2)[11/2]^\circ_6$	[f,8]	6.24	1.467	1.462?	0.112	0.037	0.000	.226
15605.687	6406.170	1–2	Ni I	15605.657									
15611.151	6403.928	0	Fe I	15611.133	$a\ {}^1P_1 - z\ {}^3P^\circ_2$	[1] **	3.41	1.750	1.831	0.150	0.113	−0.038	.158
15621.679	6399.612	1	Fe I	15621.655	$e\ {}^5D_4 - t\ {}^5D^\circ_4$	[1,7]	5.54	1.500	1.494	0.000	0.000	0.000	.664
15648.518	6388.636	0–1	Fe I	15648.511	$e\ {}^7D_1 - 3d^6 4s5p\ {}^7D^\circ_1$	[6]	5.43	3.000	3.001?	0.000	0.000	0.000	.535
15652.889	6386.852	0	Fe I	15652.869	$f\ {}^7D_5 - (9/2)[7/2]^\circ_4$	[f,8]	6.25	1.802	1.532?	0.049	0.037	−0.006	.877
15662.031	6383.124	1–2	Fe II	15662.013	$3d^5 4s4p\ {}^2G^\circ_{7/2} - 3d^6 4d\ {}^2H_{9/2}$	[n]	12.35	0.944		0.002	0.001	0.000	.033
15682.533	6374.779	1–2	Fe I	15682.514	$e\ {}^5G_2 - (1/2)[5/2]^\circ_3$	[f,8]	6.35	1.855	1.235?	0.926	0.694	−0.528	.514
15723.609	6358.126	1	Fe I	15723.588	$e\ {}^5D_2 - u\ {}^5P^\circ_3$	[1,5,6]	5.62	1.833	1.830?	0.044	0.033	−0.006	.591
15789.018	6331.786	1	Fe I	15788.997	$f\ {}^5D_4 - (9/2)[9/2]^\circ_4$	[8]	6.25	1.461	1.468?	0.072	0.023	0.000	.997
15821.720	6318.699	1–2	Fe I	15821.709	$e\ {}^5D_1 - t\ {}^5D^\circ_1$	[6]	5.64	1.500	1.509?	0.000	0.000	0.000	.707
			Cr I	15821.736									
15822.834	6318.254	1	Fe I	15822.817	$e\ {}^5D_1 - u\ {}^5F^\circ_2$	[1,7]	5.64	0.750	0.741?	0.150	0.113	0.038	.812
15837.659	6312.340	1	Fe I	15837.639	$e\ {}^7F_5 - (7/2)[11/2]^\circ_5$	[8]	6.30	1.38	1.39?	0.94	0.31	0.00	.639
			Si I	15837.659	$3p4d\ {}^3F_3 - 3p7f\,(7/2)_4$	[n]	7.12						
15840.211	6311.323	0–1	Fe I	15840.191	$e\ {}^7F_2 - (3/2)[7/2]^\circ_3$	[8]	6.36	0.634		0.300	0.225	0.097	.203
15860.233	6303.355	0	Cr I	15860.214	$e\ {}^5S_2 - w\ {}^5P^\circ_2$	[1]	4.70	1.917	1.90?	0.094	0.029	0.000	
15868.542	6300.055	1–2	Fe I	15868.522	$e\ {}^5D_3 - t\ {}^5D^\circ_3$	[1,6]	5.59	1.500	1.504?	0.000	0.000	0.000	.522
15871.459	6298.897	0–1	Fe I	15871.452									
15873.852	6297.947	1	Fe I	?									
15901.526	6286.987	0–1	Fe I	15901.516	$e\ {}^5F_3 - 3d^7 5p\ {}^5D^\circ_2$	[6]	5.92	1.000	0.972?	0.100	0.075	0.019	.551
15904.397	6285.852	1	Fe I	15904.345	$v\ {}^5P^\circ_2 - f\ {}^3D_1$	[5]	5.97	2.500	2.360?	1.067	0.800	−0.711	.397
15906.060	6285.195	1	Fe I	15906.041	$e\ {}^5D_2 - u\ {}^5F^\circ_3$	[1,5,6,7]	5.62	1.000	0.997?	0.100	0.075	0.019	.037
			Mg I	15905.90	$5p\ {}^3P^\circ_1 - 10d\ {}^3D_2$	[4]	6.73	1.000		0.067	0.050	0.011	.91

TABLE I (*continued*)

$\lambda_\odot$ (Å)	$\sigma_\odot$ (cm^{-1})	Blend	Ion	$\lambda_{\rm lab}$ † (Å)	Transition	Ref.	χ_e (eV)	$g_{\rm eff}^{\rm calc}$ ¶	$g_{\rm eff}^{\rm emp}$	X_π	X_σ	Y_σ	$\lambda_{\rm calc}$ (Å)
					$5p\ ^3P^\circ_1 - 10d\ ^3D_1$	[4]	6.73	1.000		1.000	0.250	0.000	.91
15911.318	6283.118	0–1	Fe I	15911.300	$e\ ^5F_4 - 3d^6 4s4p\ ^5F^\circ_3$	[7]	5.87	1.500	1.51	0.030	0.023	−0.003	.292
15912.581	6282.619	1–2	Mg I	15912.60	$5p\ ^3P^\circ_2 - 10d\ ^3D_1$	[4]	6.73	2.000		0.600	0.450	−0.300	.59
					$5p\ ^3P^\circ_2 - 10d\ ^3D_2$	[4]	6.73	1.333		0.378	0.117	0.000	.59
					$5p\ ^3P^\circ_2 - 10d\ ^3D_3$	[4]	6.73	1.167		0.044	0.033	0.006	.59
			Fe I	15912.588	$e\ ^7G_3 - (1/2)[7/2]^\circ_4$	[f,8]	6.38	1.835	1.719?	0.214	0.161	−0.057	.599
15928.176	6276.468	0–1	Fe I	15928.163	$e\ ^3F_4 - t\ ^3G^\circ_4$	[5]	5.95	1.150	1.236	0.472	0.154	0.000	.161
15934.035	6274.160	1	Fe I	15934.017	$f\ ^5D_1 - (7/2)[3/2]^\circ_2$	[8]	6.31	1.257	1.176?	0.016	0.012	0.001	.017
15941.854	6271.083	1	Fe I	15941.846		[f]							
15943.867	6270.291	1	Fe I	15943.846									
15960.080	6263.921	1	Si I	15960.04	$4p\ ^3D_3 - 5s\ ^3P^\circ_2$	[4,5]	5.98	1.167		0.044	0.033	0.006	.06
15964.878	6262.039	0–1	Fe I	15964.865	$e\ ^5F_3 - 3d^7 5p\ ^3G^\circ_4$	[6]	5.92	0.750	0.771?	0.120	0.090	0.024	.891
15971.254	6259.539	1–2	Fe I	15971.248									
16051.757	6228.146	1	Fe I	16051.737	$e\ ^5G_6 - (9/2)[11/2]^\circ_5$	[8]	6.26	1.082	1.143?	0.071	0.053	0.011	.747
16070.216	6220.992	1–2	Fe I	16070.182		[f]							
16075.930	6218.781	1–2	Fe I	16075.918	$e\ ^5G_3 - (5/2)[9/2]^\circ_4$	[8]	6.35	1.665	1.099?	0.269	0.202	−0.080	.927
16088.754	6213.824	1	Fe I	16088.731	$e\ ^5G_3 - (5/2)[5/2]^\circ_3$	[8]	6.35	1.142	1.331?	1.426	0.458	0.000	.739
16150.763	6189.967	1	Ca I	16150.77	$5p\ ^3P^\circ_1 - 5d\ ^3D_2$	[4]	4.53	1.000		0.067	0.050	0.011	.76
16195.078	6173.029	1	Fe I	16195.058	$e\ ^7S_3 - (1/2)[7/2]^\circ_4$	[8]	6.39	0.585	0.70?	0.961	0.721	0.544	.065
16207.768	6168.196	0–1	Fe I	16207.744	$e\ ^5G_4 - (7/2)[9/2]^\circ_5$	[8]	6.32	1.936	1.760?	0.329	0.247	−0.108	.744
16215.712	6165.174	0–1	Si I	16215.68	$4p\ ^3D_1 - 3d\ ^3D^\circ_1$	[4,5]	5.95	0.500		0.000	0.000	0.000	.67
16225.640	6161.402	0	Fe I	16225.619	$a\ ^5P_3 - z\ ^7P^\circ_4$	[7]	2.18	1.875	1.869	0.021	0.016	−0.002	.956
16227.130	6160.836	1	Fe I	16227.087	$z\ ^3H^\circ_5 - f\ ^5G_6$	[n]	5.83	2.083	1.981	0.630	0.473	−0.284	.215
16231.673	6159.112	0	Fe I	16231.650	$f\ ^5F_4 - (3/2)[9/2]^\circ_5$	[8]	6.38	1.356	1.346?	0.000	0.000	0.000	.654
16235.980	6157.478	0–1	Fe I	16235.966	$w\ ^5G^\circ_4 - f\ ^3D_3$	[n] *	5.90	0.875	0.976	0.101	0.076	0.018	6.019
16241.869	6155.245	1–2	Si I	16241.84	$4p\ ^3D_2 - 3d\ ^3D^\circ_3$	[4]	5.96	1.500		0.044	0.033	−0.006	.83
16284.794	6139.021	1 *	Fe I	16284.768	$f\ ^5F_3 - (1/2)[7/2]^\circ_4$	[8]	6.40	1.710		0.102	0.076	−0.019	.768
16292.851	6135.985	0–1	Fe I	16292.843	$e\ ^5F_3 - 3d^6 4s4p\ ^5D^\circ_3$	[7]	5.92	1.375	1.356	0.438	0.141	0.000	.862
16310.507	6129.343	0–1	Ni I	16310.497	$e\ ^3D_3 - w\ ^3P^\circ_2$	[1]	5.28	1.167	1.18?	0.044	0.033	0.006	.504
16316.347	6127.149	0–1	Fe I	16316.322	$e\ ^7G_7 - (9/2)[15/2]^\circ_8$	[f,8]	6.28	1.192		0.035	0.026	0.004	.342
16318.715	6126.260	1	Fe I	16318.697	$3d^6 4s4p\ ^1D^\circ_2 - h\ ^5D_3$	[n] *	5.88	2.000	1.863?	0.400	0.300	−0.150	.947
16324.463	6124.103	1	Fe I	16324.453	$e\ ^7D_3 - 3d^6 4s5p\ ^7D^\circ_4$	[5,6]	5.38	1.500	1.492?	0.030	0.023	0.003	.484
16384.158	6101.790	0–1	Fe I	16384.140	$e\ ^7F_2 - (5/2)[5/2]^\circ_3$	[f,8]	6.36	1.236		0.028	0.021	0.003	.140
16394.400	6097.978	0	Fe I	16394.387		[f]							
16404.620	6094.179	0–1	Fe I	16404.597	$e\ ^7G_4 - (5/2)[11/2]^\circ_5$	[f,8]	6.36	1.129	1.053?	0.016	0.012	0.001	.609
16436.632	6082.310	0–1	Fe I	16436.621	$e\ ^5F_3 - 3d^7 5p\ ^3D^\circ_3$	[6]	5.92	1.292	1.285?	0.049	0.016	0.000	.637
16440.421	6080.908	0–1	Fe I	16440.398	$f\ ^5D_2 - (9/2)[5/2]^\circ_2$	[8]	6.29	1.611	1.668?	0.168	0.052	0.000	.411
16444.840	6079.274	0	Fe I	16444.816	$e\ ^5F_5 - 3d^7 5p\ ^5F^\circ_5$	[6]	5.83	1.400	1.410?	0.000	0.000	0.000	.816
16468.519	6070.533	1–2	Fe II	16468.509	$z\ ^6D^\circ_{5/2} - c\ ^2F_{5/2}$	[n] *	4.82	1.257	1.255?	3.232	1.024	0.000	.359
16474.094	6068.479	0–1	Fe I	16474.080	$e\ ^3F_3 - t\ ^3G^\circ_3$	[5]	6.02	0.917	1.014	0.778	0.250	0.000	.085
16486.686	6063.844	0–1	Fe I	16486.664	$e\ ^5F_5 - 3d^7 5p\ ^5G^\circ_6$	[6]	5.83	1.167	1.114?	0.031	0.023	0.003	.691
16517.251	6052.623	0–1	Fe I	16517.225	$e\ ^5G_5 - (9/2)[13/2]^\circ_6$	[8]	6.29	1.401	1.167?	0.010	0.008	−0.001	.229
					$e\ ^3F_4 - 3d^6 4s4p\ ^5F^\circ_5$	[1]	5.95	1.700	1.492	0.108	0.081	−0.020	6.751
			Fe II	16517.225	$d\ ^2F_{7/2} - z\ ^4G^\circ_{7/2}$	[n]	6.81	1.063	1.056?	0.233	0.076	0.000	.425
16524.494	6049.970	1	Fe I	16524.467	$f\ ^5F_5 - (7/2)[13/2]^\circ_6$	[f,8]	6.34	0.924	0.964?	0.129	0.097	0.026	.477
16539.212	6044.586	1–2	Fe I	16539.192	$f\ ^5F_5 - (7/2)[9/2]^\circ_5$	[8]	6.34	1.406	1.398?	0.003	0.001	0.000	.199
16584.475	6028.089	1	Ni I	16584.438	$e\ ^3D_2 - 3d^8 4s4p\ ^1P^\circ_1$	[n]	5.31	1.250	1.128?	0.017	0.012	−0.001	.8
16586.057	6027.514	1	Fe I	16586.049	$e\ ^5D_2 - t\ ^5D^\circ_3$	[5]	5.62	1.500	1.497?	0.000	0.000	0.000	.052
16612.786	6017.816	1–2	Fe I	16612.763	$f\ ^5F_3 - (3/2)[9/2]^\circ_4$	[8]	6.40	1.170		0.003	0.002	0.000	.773
16645.883	6005.851	0–1	Fe I	16645.872	$e\ ^5F_2 - 3d^7 5p\ ^5D^\circ_2$	[6]	5.96	1.250	1.245?	0.850	0.263	0.000	.886
16661.393	6000.260	1	Fe I	16661.372	$e\ ^7F_3 - (7/2)[7/2]^\circ_4$	[8]	6.34	0.965	0.967?	0.137	0.103	0.029	.391
16665.490	5998.785	0–1	Fe I	16665.480	$3d^8\ ^3P_1 - 3d^7 4p\ ^5D^\circ_1$	[n]	5.11	1.500	1.455?	0.000	0.000	0.000	.396
16673.715	5995.826	1	Ni I	16673.702	$3d^9 5p\ ^1F^\circ_3 - f\ ^3G_4$	[f] ††	6.03	1.125	1.08?	0.007	0.006	0.000	.2
			Co I	16673.4	$x\ ^4G^\circ_{11/2} - f\ ^4F_{9/2}$	[1]	5.15	1.136		0.021	0.016	0.002	
16680.809	5993.276	0–1 *	Si I	16680.77	$4p\ ^3D_3 - 3d\ ^3D^\circ_3$	[4]‡	5.98	1.333		0.000	0.000	0.000	
			Fe I	16680.831									
16693.106	5988.861	0–1	Fe I	16693.077	$f\ ^5F_1 - (1/2)[5/2]^\circ_2$	[8]	6.42	0.586		0.092	0.069	−0.018	.081
16718.977	5979.594	1 *	Al I	16718.957	$4p\ ^2P^\circ_{1/2} - 4d\ ^2D_{3/2}$	[4]‡	4.09	0.833		0.004	0.003	0.000	.957
			Fe I	16719.072	$e\ ^5F_4 - 3d^7 5p\ ^5F^\circ_3$	[6]	5.87	1.500	1.453?	0.030	0.023	−0.003	.111
16723.284	5978.054	0–1	Fe I	16723.276	$e\ ^5F_3 - 3d^7 5p\ ^5D^\circ_3$	[6]	5.92	1.375	1.368?	0.438	0.141	0.000	.312
16753.088	5967.419	0–1	Fe I	16753.066	$f\ ^5F_4 - (5/2)[11/2]^\circ_5$	[8]	6.38	1.029	1.019?	0.055	0.041	0.007	.076
16760.134	5964.910	0	Fe I	16760.094									

TABLE I (*continued*)

$\lambda_{\odot}$ (Å)	$\sigma_{\odot}$ (cm^{-1})	Blend	Ion	$\lambda_{\rm lab}$ † (Å)	Transition	Ref.	χ_e (eV)	$g_{\rm eff}^{\rm calc}$ ¶	$g_{\rm eff}^{\rm emp}$	X_{π}	X_{σ}	Y_{σ}	$\lambda_{\rm calc}$ (Å)
			Mg II	16760.306	$5p\ {}^2P^{\circ}_{1/2}$ — $5d\ {}^2D_{3/2}$	[2,4]	12.08	0.833		0.004	0.003	0.000	.22
16799.660	5950.876	0–1	Fe I	16799.646	$e\ {}^5F_4$ — $3d^7 5p\ {}^5D^{\circ}_4$	[6]	5.87	1.425	1.416?	0.265	0.087	0.000	.691
16815.475	5945.279	0	Ni I	16815.465	$e\ {}^3D_2$ — $w\ {}^3P^{\circ}_2$	[1]	5.31	1.333	1.293?	0.378	0.117	0.000	.470
16818.763	5944.117	0–1	Ni I	16818.747		[f]							
16820.540	5943.489	0	Fe I	16820.515	$v\ {}^5F^{\circ}_3$ — $e\ {}^3G_4$	[1]	5.97	0.750	0.886	0.120	0.090	0.024	.220
16867.298	5927.013	0–1 *	Ni I	16867.264	$e\ {}^3D_1$ — $3d^9 5p\ {}^3F^{\circ}_2$	[1]	5.47	0.750		0.017	0.012	−0.001	.40
			Fe I	16867.292									
16874.145	5924.608	0–1	Fe I	16874.117	$e\ {}^7G_5$ — $(7/2)[13/2]^{\circ}_6$	[8]	6.35	1.007	0.977?	0.074	0.055	0.011	.128
16945.297	5899.731	1	Ni I	16945.307	$3d^8 4s4p\ {}^3F^{\circ}_4$ — $e\ {}^3G_5$	[1]	5.36	1.100	1.11	0.012	0.009	0.001	.280
16957.809	5895.378	0–1	Si I	16957.794	$5p\ {}^3D_3$ — $8s\ {}^3P^{\circ}_2$	[4]	7.09	1.167		0.044	0.033	0.006	.80
16996.274	5882.036	0–1	Ni I	16996.246	$e\ {}^3D_2$ — $3d^9 5p\ {}^1F^{\circ}_3$	[n] ††	5.31	0.833	0.915?	0.044	0.033	0.006	.7
17001.037	5880.388	0	Ni I	17001.026	$e\ {}^1D_2$ — $3d^9 5p\ {}^{\circ}_3$	[n]	5.49						.6
17009.023	5877.627	0–1	Fe I	17008.975		[f]							
17011.107	5876.907	0–1	Fe I	17011.096	$e\ {}^3F_4$ — $3d^7 5p\ {}^3D^{\circ}_3$	[6]	5.95	1.125	1.220?	0.021	0.016	0.002	.110
17088.867	5850.165	1	Ni II	?									
17108.660	5843.397	1	Mg I	17108.632	$4s\ {}^1S_0$ — $4p\ {}^1P^{\circ}_1$	[4,5]	5.39	1.000		0.000	0.000	0.000	.663
17131.003	5835.776	0–1	Fe I	17130.952									
17161.115	5825.536	0–1	Fe I	17161.106	$e\ {}^3F_3$ — $3d^7 5p\ {}^3G^{\circ}_3$	[6]	6.02	0.917	0.929?	0.778	0.250	0.000	.121
17204.304	5810.912	1	Fe I	17204.299	$e\ {}^3F_3$ — $3d^7 5p\ {}^3D^{\circ}_2$	[6]	6.02	1.000	1.047?	0.011	0.008	0.001	.345
			Cr I	17204.379									
17282.318	5784.681	0–1 *	Fe I	17282.294	$e\ {}^5P_3$ — $(3/2)[9/2]^{\circ}_4$	[8]	6.43	0.545	0.549?	0.604	0.453	0.271	.315
17327.378	5769.638	1–2	Si I	17327.29	$3p3d\ {}^1F_3$ — $3p4f\,(9/2)_4$	[n]	6.62						
17433.666	5734.462	0–1	Fe I	17433.641	$f\ {}^5F_2$ — $(5/2)[7/2]^{\circ}_3$	[8]	6.41	1.302	1.335?	0.036	0.027	−0.004	.657
17448.585	5729.559	1 *	C I	17448.58	$3p\ {}^1D_2$ — $4s\ {}^1P^{\circ}_1$	[4]‡	9.00	1.000		0.000	0.000	0.000	
			Fe I	17448.582									
17538.645	5700.138	1–2	Fe I	17538.632	$w\ {}^5P^{\circ}_3$ — $e\ {}^5P_3$	[7]	5.72	1.667	1.661	0.000	0.000	0.000	.639
17712.720	5644.119	1	Fe I	17712.731									
17747.352	5633.105	1–2	Fe I	17747.371		[f]							
17889.372	5588.385	0–1	Fe I	17889.342									
17982.325	5559.498	1	Fe I	17982.299	$x\ {}^3G^{\circ}_3$ — $g\ {}^5F_4$	[n]	5.93	2.250	2.373?	1.080	0.810	−0.648	.441

TABLE II. — *Lines with large Stokes V amplitudes.*

$\lambda_{\odot}$ (Å)	$\sigma_{\odot}$ (cm^{-1})	a_b (%)	a_r (%)	Blend	Ion	$\lambda_{\rm lab}$ † (Å)	Transition	Ref.	χ_e (eV)	$g_{\rm eff}^{\rm calc}$ ¶	$g_{\rm eff}^{\rm emp}$	X_{π}	X_{σ}	Y_{σ}	$\lambda_{\rm calc}$ (Å)
15025.015	6653.749	2.70	2.56	2–3	Mg I	15024.996	$4s\ {}^3S_1$ — $4p\ {}^3P^{\circ}_2$	[2,4]	5.11	1.250		0.150	0.113	0.038	4.993
15040.201	6647.031	2.29	2.77	3	Mg I	15040.245	$4s\ {}^3S_1$ — $4p\ {}^3P^{\circ}_1$	[2,4]	5.11	1.750		0.250	0.063	0.000	.245
15047.644	6643.743	3.26	1.96	3	Mg I	15047.715	$4s\ {}^3S_1$ — $4p\ {}^3P^{\circ}_0$	[2,4]	5.11	2.000		0.000	0.000	0.000	.705
15051.765	6641.924	2.73	2.23	2	Fe I	15051.745	$e\ {}^7D_4$ — $3d^6 4s5p\ {}^7D^{\circ}_3$	[6]	5.35	1.500	1.513?	0.030	0.023	0.003	.770
15207.545	6573.887	2.57	2.12	0	Fe I	15207.527	$e\ {}^7D_3$ — $3d^6 4s5p\ {}^7D^{\circ}_2$	[6]	5.38	1.500	1.510?	0.100	0.075	0.019	.547
15294.584	6536.476	3.39	2.37	3	Fe I	15294.559	$e\ {}^7D_5$ — $3d^6 4s5p\ {}^7D^{\circ}_5$	[6]	5.31	1.600	1.593?	0.000	0.000	0.000	.582
15621.679	6399.612	2.47	2.09	1	Fe I	15621.655	$e\ {}^5D_4$ — $t\ {}^5D^{\circ}_4$	[1,7]	5.54	1.500	1.494	0.000	0.000	0.000	.664
15631.960	6395.403	2.44	1.95	2–3	Fe I	15631.946	$e\ {}^7D_4$ — $3d^6 4s5p\ {}^7D^{\circ}_4$	[6]	5.35	1.650	1.653?	0.000	0.000	0.000	.975
15723.609	6358.126	2.02	1.73	1	Fe I	15723.588	$e\ {}^5D_2$ — $u\ {}^5P^{\circ}_3$	[1,5,6]	5.62	1.833	1.830?	0.044	0.033	−0.006	.591
15765.854	6341.089	1.62	1.94	3	Mg I	15765.839	$4p\ {}^3P^{\circ}_2$ — $4d\ {}^3D_3$	[2,4]	5.93	1.167		0.044	0.033	0.006	.842
							$4p\ {}^3P^{\circ}_2$ — $4d\ {}^3D_2$	[2]	5.93	1.333		0.378	0.117	0.000	.747
							$4p\ {}^3P^{\circ}_2$ — $4d\ {}^3D_1$	[2]	5.93	2.000		0.600	0.450	−0.300	.646
15818.165	6320.119	2.24	1.82	2	Fe I	15818.139	$e\ {}^5D_3$ — $u\ {}^5F^{\circ}_4$	[1]	5.59	1.125	1.113?	0.067	0.051	0.010	.130
15833.622	6313.949	2.11	1.62	2	Si I	15833.58	$4p\ {}^1D_2$ — $4d\ {}^1D^{\circ}_2$	[4]	6.22	1.000		0.000	0.000	0.000	.60
15888.435	6292.167	3.04	2.71	2–3	Si I	15888.39	$4s\ {}^1P^{\circ}_1$ — $4p\ {}^1P_1$	[4]	5.08	1.000		0.000	0.000	0.000	.41
15960.080	6263.921	2.65	2.32	1	Si I	15960.04	$4p\ {}^3D_3$ — $5s\ {}^3P^{\circ}_2$	[4,5]	5.98	1.167		0.044	0.033	0.006	.06
15980.754	6255.818	2.02	1.63	2	Fe I	15980.724	$e\ {}^5G_6$ — $(9/2)[15/2]^{\circ}_7$	[8]	6.26	1.168	1.115?	0.016	0.012	0.001	.738
							$z\ {}^1F^{\circ}_3$ — 56842.70 cm^{-1}	[n]	6.27						.73

TABLE II (*continued*)

$\lambda_\odot$ (Å)	$\sigma_\odot$ (cm^{-1})	a_b (%)	a_r (%)	Blend	Ion	$\lambda_{\rm lab}$ † (Å)	Transition	Ref.	χ_e (eV)	$g_{\rm eff}^{\rm calc}$ ¶	$g_{\rm eff}^{\rm emp}$	X_π	X_σ	Y_σ	$\lambda_{\rm calc}$ (Å)
16094.801	6211.489	2.40	2.00	2	Si I	16094.80	$4p\ {}^3D_2 - 5s\ {}^3P^\circ_1$	[4]	5.96	1.000		0.067	0.050	0.011	
16125.904	6199.509	2.15	1.69	3	Fe I	16125.902	$g\ {}^5D_4 - t\ {}^3F^\circ_4$	[7]	6.37	1.375	1.361	0.738	0.241	0.000	.904
							$e\ {}^7G_5 - (5/2)[11/2]^\circ_6$	[8]	6.35	1.315	1.285?	0.002	0.001	0.000	.907
16165.055	6184.494	2.01	1.64	3	Fe I	16165.027	$e\ {}^7G_6 - (7/2)[13/2]^\circ_7$	[8]	6.32	1.238	1.207?	0.017	0.013	0.001	.037
16241.869	6155.245	2.00	1.69	1–2	Si I	16241.84	$4p\ {}^3D_2 - 3d\ {}^3D^\circ_3$	[4]	5.96	1.500		0.044	0.033	−0.006	.83
16316.347	6127.149	2.10	1.66	0–1	Fe I	16316.322	$e\ {}^7G_7 - (9/2)[15/2]^\circ_8$	[f,8]	6.28	1.192		0.035	0.026	0.004	.342
16381.579	6102.750	2.12	1.54	2–3	Si I	16381.55	$4p\ {}^3D_2 - 3d\ {}^3D^\circ_2$	[4]	5.96	1.167		0.000	0.000	0.000	
16444.840	6079.274	2.29	1.96	0	Fe I	16444.816	$e\ {}^5F_5 - 3d^7 5p\ {}^5F^\circ_5$	[6]	5.83	1.400	1.410?	0.000	0.000	0.000	.816
16486.686	6063.844	2.33	1.89	0–1	Fe I	16486.664	$e\ {}^5F_5 - 3d^7 5p\ {}^5G^\circ_6$	[6]	5.83	1.167	1.114?	0.031	0.023	0.003	.691
16680.809	5993.276	2.84	2.36	0–1 *	Si I	16680.77	$4p\ {}^3D_3 - 3d\ {}^3D^\circ_3$	[4]‡	5.98	1.333		0.000	0.000	0.000	
					Fe I	16680.831									
16718.977	5979.594	2.25	1.80	1 *	Al I	16718.957	$4p\ {}^2P^\circ_{1/2} - 4d\ {}^2D_{3/2}$	[4]‡	4.09	0.833		0.004	0.003	0.000	.957
					Fe I	16719.072	$e\ {}^5F_4 - 3d^7 5p\ {}^5F^\circ_3$	[6]	5.87	1.500	1.453?	0.030	0.023	−0.003	.111
16750.486	5968.346	2.20	2.12	3	Al I	16750.533	$4p\ {}^2P^\circ_{3/2} - 4d\ {}^2D_{5/2}$	[3,4] #	4.08	1.100		0.019	0.014	0.002	.564
17108.660	5843.397	2.42	2.21	1	Mg I	17108.632	$4s\ {}^1S_0 - 4p\ {}^1P^\circ_1$	[4,5]	5.39	1.000		0.000	0.000	0.000	.663
17225.639	5803.715	1.94	1.67	2	Si I	17225.570	$3p3d\ {}^1P_1 - 3p4f\,(3/2)_2$	[n]	6.62						
17327.378	5769.638	2.57	2.16	1–2	Si I	17327.276	$3p3d\ {}^1F_3 - 3p4f\,(9/2)_4$	[n]	6.62						
17617.027	5674.777	2.02	1.47	3	Si I	17617.027	$3p3d\ {}^1F_3 - 3p4f\,(7/2)_4$	[n]	6.62						
					Fe I	17617.107	$y\ {}^3G^\circ_4 - f\ {}^5F_5$	[n]	5.63	2.100	2.046	0.588	0.441	−0.257	6.986

TABLE III. — *Possible blends rejected as too weak.*

$\lambda_\odot$ (Å)	Ion	$\lambda_{\rm lab}$ † (Å)	χ_e (eV)	log(gf)
15168.352	Ni II	15168.359	14.25	−1.54
15178.254	Cr I	15178.594	5.98	−3.91
15207.545	Cr I	15207.607	5.47	−3.20
15219.637	Cr I	15219.669	6.03	−3.55
15224.741	Ni II	15224.768	14.09	−4.98
15598.889	Ti I	15599.035	4.69	0.37
15906.060	Co I	15906.072	5.79	−4.41
16404.620	Ti I	16404.563	5.13	−4.64
16444.840	Ni I	16444.800	13.24	−2.96
16584.475	P I	16584.500	8.25	−0.42

References:

[1] = Biémont (1976)
[2] = Biémont and Brault (1987a)
[3] = Biémont and Brault (1987b)
[4] = Biémont and Grevesse (1973)
[5] = Hall (1974)
[6] = Litzén (1976)
[7] = Litzén and Vergés (1976)
[8] = Johansson and Learner (1989). In accordance with this reference JK notation is used for the levels of the $3d^6\,4s\,(^6D)\,4f$ configuration.
[f] = The line was previously assigned a transition which is incompatible with the latest NBS tables.
[n] = A new transition is assigned to this line.

Notes to the tables

* (in column: Blend) = Line is blended according to Biémont et al. (1985a).

* (in column: Ref.): This transition involves a change in total spin $\Delta S > 1$ or in orbital angular momentum $\Delta L > 1$, making the identification somewhat uncertain. Such identifications are listed only where no other possible identification is known.

† In those cases where no laboratory wavelength is available in the above references the calculated wavelength has been written instead.

‡ Due to the huge equivalent width of the primary identification, the secondary identification (blend) probably contributes only a very minute amount to the line.

¶ For most transitions the LS coupling Landé factors of the upper and lower levels are used to determine $g_{\rm eff}$. For the levels of the $3d^6\,4s\,(^6D)\,4f$ configuration g values have been taken from [8].

Al I 16750.486 is probably unblended by other lines, but distorted by the large hyperfine splitting of the given transition (see [3]).

†† Ni I 16673.715 and Ni I 16996.274: The laboratory wavelengths of both lines can be matched much better by the calculated wavelengths of the transitions identified by [3] if the $3d^9 5p\ {}^1F^\circ_3$ level common to both lies at 48672.085 ± 0.015 cm^{-1} (instead of 48671.9 cm^{1-} listed in Corliss and Sugar, 1981).

** The sign of the Landé factor of Fe I 15611.151 is opposite to that expected from the observed Stokes V profile, so that the identification is probably wrong.