

# Atomic data from the IRON Project.

## XIX. Radiative transition probabilities for forbidden lines in Fe II\*

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**Abstract.** — Radiative transition probabilities have been calculated for the magnetic dipole (M1) and electric quadrupole (E2) transitions connecting the 63 metastable levels in the  $3d^64s$ ,  $3d^7$  and  $3d^54s^2$  configurations in Fe II. The most important configuration interaction (CI) and relativistic effects have been taken into account in the computations carried out with the help of two independent computer programs, SUPERSTRUCTURE (SST) and RELATIVISTIC HARTREE-FOCK (HFR). The results obtained in the present work are compared with previous theoretical studies and with some astrophysical observations. The new data presented here are probably the most reliable to date.

**Key words:** atomic data — Fe II — transition probabilities

### 1. Introduction

Singly ionized iron is one of the most important atomic ions in astrophysics because of its high relative abundance in many sources, its comparatively low ionization potential and the sheer density of its energy structure. Hence, the calculation of oscillator strengths for lines in Fe II is of considerable practical interest (see, for example, Viotti et al. 1988). The most extensive studies were performed by Kurucz (1981, 1990), Fawcett (1987, 1988) and Nahar & Pradhan (1994). Critical compilations of oscillator strengths for Fe II lines were published by Fuhr et al. (1988) and by Giridhar & Ferro (1995). However, most of previous work concerns only allowed electric dipole (E1) radiation without consideration of forbidden transitions.

The present calculations were performed within the framework of the IRON Project (IP), an international collaboration whose aim is to produce accurate collisional and radiative atomic data for ions of astrophysical interest, with a particular attention to members of the Fe group. The goals and methods of the Project are presented in Paper I of this series (Hummer et al. 1993). A considerable amount of IP work has already been devoted to Fe II: collision strengths and rate coefficients can be found in Paper VI (Zhang & Pradhan 1995), E1 transition proba-

bilities are reported in Paper VII (Nahar 1995) while electron excitation rates and emissivity ratios for forbidden lines are presented in Paper XIII (Bautista & Pradhan 1996).

Forbidden lines of Fe II were first identified by Merril (1928) in the spectrum of  $\eta$  Carinae and they have since been observed in many other astrophysical objects like novae, nebulae and peculiar stars. To mention but recent studies in which IP collisional atomic data were used, Bautista et al. (1994), Bautista & Pradhan (1995) and Bautista et al. (1995) have considered [Fe II] lines in the Orion Nebula and in Supernova 1987A.

In this context, it must be noted that a very limited number of transition probability calculations have been performed for [Fe II] lines. Smith & Wiese (1973) and Fuhr et al. (1988) have published compilations of forbidden lines in iron group elements. The transition probabilities reported in these tabulations for [Fe II] lines are essentially taken from the extensive work of Garstang (1962) who used an intermediate coupling method. Radiative data for a small number of forbidden lines in Fe II were also published by Nussbaumer & Swings (1970), Johansson (1977) and Nussbaumer & Storey (1980). However, CI effects were considered to a very limited extent in all these computations. More recently, Nussbaumer & Storey (1988) used a twelve-configuration basis set in the program SUPERSTRUCTURE (SST) of Eissner et al. (1974) as modified by Nussbaumer & Storey (1978) for calculating transition probabilities for forbidden lines

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\*Table 4 is also available in electronic form from the CDS via anonymous ftp 130.79.128.5 or on www at <http://cdsweb.u-strasbg.fr/abstract.html>

connecting the lowest four terms of Fe II. The results of Garstang and Nussbaumer & Storey were used by Bautista and his colleagues in their work on the Orion Nebula and SN 1987A.

The aim of the present attempt is to describe Fe II with a more elaborate physical model in order to provide a firmer basis to astrophysical studies. Together, the three low even configurations  $3d^64s$ ,  $3d^7$  and  $3d^54s^2$  in Fe II have 63 metastable levels. In this paper, radiative transition probabilities for forbidden lines between these metastable levels are reported. The new data were calculated using the SST and RELATIVISTIC HARTREE-FOCK (HFR) codes. Indeed, it was felt that thorough comparisons between sets of radiative data obtained with two independent methods would help to assess more clearly the reliability of the present transition probabilities. The most important CI and relativistic effects were included in the calculations. This study can be seen as an extension of the recent investigations of forbidden transitions in iron group elements carried out in the cases of Fe III (Quinet 1996), Ni I and Ni II (Quinet & Le Dourneuf 1996).

## 2. Methods and physical models

### 2.1. SUPERSTRUCTURE (SST)

First, the calculations were performed using the SST code due to Eissner et al. (1974) as modified by Nussbaumer & Storey (1978). In this formalism, the wavefunctions are expressed as linear combinations of the type

$$\Psi = \sum_i \Theta_i C_i \quad (1)$$

where the basis functions  $\Theta_i$  are constructed using one-electron orbitals  $\psi$  calculated in a scaled Thomas-Fermi statistical model potential (Eissner & Nussbaumer 1969).

The configurations selected for the present physical model were  $3d^64s$ ,  $3d^7$ ,  $3d^54s^2$ ,  $3d^6\overline{4d}$ ,  $3d^5\overline{4p}^2$ ,  $3d^54s\overline{4d}$ ,  $3d^6\overline{5s}$ ,  $3d^6\overline{5d}$ ,  $3s3p^63d^74s$  and  $3s3p^63d^8$ . The only terms retained in this calculation are those whose symmetry matches one of the spectroscopic symmetries.

In order to optimize the radial orbitals, each radial potential was scaled using  $n$ - and  $l$ -dependent parameters  $\lambda_{nl}$  which were determined by minimizing the sum of the 24 lowest term energies of Fe II, i.e. all the terms which lie below the lowest level of odd parity. The resulting scaling parameters are:

$$\begin{aligned} \lambda_{1s} &= 1.43173, \lambda_{2s} = 1.13593, \lambda_{2p} = 1.07935, \lambda_{3s} = \\ &1.06537, \lambda_{3p} = 1.05402, \lambda_{3d} = 1.06000, \lambda_{4s} = 1.06888, \\ \lambda_{\overline{4p}} &= 1.22203, \lambda_{\overline{4d}} = 1.46551, \lambda_{\overline{5s}} = 1.43837, \lambda_{\overline{5d}} = \\ &2.26965. \end{aligned}$$

Relativistic corrections such as the spin-orbit, the spin-spin and the spin-other-orbit interactions, which are important for fine-structure splittings, were introduced in the framework of the Breit-Pauli approximation. The quality

of the wavefunctions can be improved by means of semi-empirical term energy corrections (TECs) following the procedure described by Zeippen et al. (1977). In practice, the TEC for a given term is simply taken to be the difference between the measured and calculated energy of the lowest level in the multiplet. Experience has shown that this type of "fine-tuning" is both justified and efficient when the corrections are sufficiently small as compared to observed energies (see, for example, Biémont et al. 1992, 1994).

The TECs used in the present calculations are reported in Table 1 together with the calculated fine-structure splittings (FS). Observed energies taken from the compilation of Sugar & Corliss (1985) are also given for comparison. It appears that most of the TECs are small (5–15%) as compared to the observed energies, that is taking into account the complexity of the ion treated here. One can see also that the fine-structure splittings are in very good agreement with experiment for all multiplets, which gives some confidence in the quality of the present wavefunctions.

Finally, it is important to note that the radiative transition probabilities were calculated with experimental level energies.

### 2.2. Relativistic Hartree-Fock (HFR)

An independent set of calculations was carried out with the relativistic Hartree-Fock method (HFR) originally introduced by Cowan & Griffin (1976). The computer codes written by Cowan (1981) were used. The same set of configurations selected for the SST calculations was chosen for this part of the work. In order to reduce as much as possible the discrepancies between computed and observed energy levels, the average energies ( $E_{av}$ ), the single-configuration direct ( $F^k$ ) and exchange ( $G^k$ ) Coulomb interaction integrals and the effective interaction parameters ( $\alpha, \beta, T$ ) associated with the  $3d^64s$ ,  $3d^7$  and  $3d^54s^2$  configurations were adjusted using a least-squares optimization program. The energy level data required for the fitting procedure were taken from the compilation of Sugar & Corliss (1985).

The HFR values for the  $F^k$  and  $G^k$  electrostatic parameters within other configurations than those included in the fitting procedure and for the CI integrals,  $R^k$ , were reduced by 20% as recommended by Cowan (1994) to simulate CI effects while the ab initio values of all the spin-orbit parameters,  $\zeta$ , computed by the Blume-Watson method, were used without scaling.

The radial parameters adopted in the present work for the  $3d^64s$ ,  $3d^7$  and  $3d^54s^2$  configurations are reported in Table 2 while our calculated energy levels are compared with experiment in Table 3. In all cases, the agreement between observed and computed values is very good. The standard deviation of the fit is defined by Cowan (1981)

**Table 1.** Observed energy levels,  $E_{\text{obs}}$ , and fine-structure splittings,  $FS_{\text{obs}}$ , for the 24 lowest terms of Fe II. The present fine-structure splittings,  $FS_{\text{calc}}$ , obtained with SST and the semi-empirical corrections to calculated non-relativistic energies, TEC, are also given. All values are in  $\text{cm}^{-1}$

Configuration	Term	$J$	$E_{\text{obs}}^a$	$FS_{\text{obs}}$	$FS_{\text{calc}}$	TEC
3d <sup>6</sup> ( <sup>3</sup> D)4s	a <sup>6</sup> D	9/2	0.	0.	0.	0.
		7/2	385.	385.	380.	
		5/2	668.	668.	659.	
		3/2	863.	863.	850.	
		1/2	977.	977.	963.	
3d <sup>7</sup>	a <sup>4</sup> F	9/2	1873.	0.	0.	-86.
		7/2	2430.	557.	565.	
		5/2	2838.	965.	978.	
		3/2	3117.	1244.	1262.	
3d <sup>6</sup> ( <sup>5</sup> D)4s	a <sup>4</sup> D	7/2	7955.	0.	0.	-293.
		5/2	8292.	437.	436.	
		3/2	8680.	725.	724.	
		1/2	8847.	892.	890.	
3d <sup>7</sup>	a <sup>4</sup> P	5/2	13474.	0.	0.	-1548.
		3/2	13673.	199.	202.	
		1/2	13905.	431.	438.	
3d <sup>7</sup>	a <sup>2</sup> G	9/2	15845.	0.	0.	-2023.
		7/2	16369.	524.	529.	
3d <sup>7</sup>	a <sup>2</sup> P	3/2	18361.	0.	0.	-2580.
		1/2	18887.	526.	540.	
3d <sup>7</sup>	a <sup>2</sup> H	11/2	20340.	0.	0.	-2341.
		9/2	20806.	466.	469.	
3d <sup>7</sup>	a <sup>2</sup> D	5/2	20517.	0.	0.	-3158.
		3/2	21308.	791.	781.	
3d <sup>6</sup> ( <sup>3</sup> P)4s	b <sup>4</sup> P	5/2	20831.	0.	0.	-3829.
		3/2	21812.	981.	959.	
		1/2	22410.	1579.	1547.	
3d <sup>6</sup> ( <sup>3</sup> H)4s	a <sup>4</sup> H	13/2	21252.	0.	0.	-2682.
		11/2	21430.	178.	176.	
		9/2	21582.	330.	324.	
		7/2	21712.	460.	453.	
3d <sup>6</sup> ( <sup>3</sup> F)4s	b <sup>4</sup> F	9/2	22637.	0.	0.	-3691.
		7/2	22810.	173.	163.	
		5/2	22939.	302.	285.	
		3/2	23031.	394.	372.	
3d <sup>5</sup> 4s <sup>2</sup>	a <sup>6</sup> S	5/2	23318.	0.	0.	3388.
		3d <sup>6</sup> ( <sup>3</sup> G)4s	a <sup>4</sup> G	11/2	25429.	0.
		9/2	25805.	376.	353.	-3914.
		7/2	25982.	553.	523.	
		5/2	26055.	626.	597.	
3d <sup>6</sup> ( <sup>3</sup> P)4s	b <sup>2</sup> P	3/2	25788.	0.	0.	-4077.
		1/2	26933.	1145.	1127.	
3d <sup>6</sup> ( <sup>3</sup> H)4s	b <sup>2</sup> H	11/2	26170.	0.	0.	-2766.
		9/2	26353.	183.	201.	
3d <sup>6</sup> ( <sup>3</sup> F)4s	a <sup>2</sup> F	7/2	27315.	0.	0.	-3735.
		5/2	27620.	305.	274.	
3d <sup>6</sup> ( <sup>3</sup> G)4s	b <sup>2</sup> G	9/2	30388.	0.	0.	-4084.
		7/2	30764.	376.	369.	
3d <sup>6</sup> ( <sup>3</sup> D)4s	b <sup>4</sup> D	3/2	31364.	0.	0.	-5427.
		1/2	31368.	4.	0.	
		5/2	31388.	24.	28.	
		7/2	31483.	119.	125.	
3d <sup>7</sup>	b <sup>2</sup> F	5/2	31812.	0.	0.	-4505.
		7/2	31999.	187.	168.	
3d <sup>6</sup> ( <sup>1</sup> I)4s	a <sup>2</sup> I	13/2	32876.	0.	0.	-4079.
		11/2	32910.	34.	34.	
3d <sup>6</sup> ( <sup>1</sup> G)4s	c <sup>2</sup> G	9/2	33466.	0.	0.	-5340.
		7/2	33501.	35.	36.	
3d <sup>6</sup> ( <sup>3</sup> D)4s	b <sup>2</sup> D	3/2	36126.	0.	0.	-5696.
		5/2	36253.	127.	120.	
3d <sup>6</sup> ( <sup>1</sup> S)4s	a <sup>2</sup> S	1/2	37227.	0.	0.	-7176.
		5/2	38164.	0.	0.	-6035.
	c <sup>2</sup> D	3/2	38214.	50.	49.	

<sup>a</sup> Sugar & Corliss (1985).

as

$$s = \sqrt{\sum_k \frac{(E_k - T_k)^2}{N_k - N_p}} \quad (2)$$

where  $N_k$  is the number of levels involved in the fit,  $N_p$  is the number of parameters,  $E_k$  is a computed eigenvalue and  $T_k$  the corresponding observed energy level. In the present work (100 levels, 19 fitted parameters), we found  $s = 72 \text{ cm}^{-1}$ .

**Table 2.** Values of the parameters (in  $\text{cm}^{-1}$ ) adopted in the HFR calculations for the 3d<sup>6</sup>4s, 3d<sup>7</sup> and 3d<sup>5</sup>4s<sup>2</sup> configurations of Fe II. The ratios between fitted and ab initio HFR values are also indicated

Configuration	Parameter	Fitted value	Ratio
3d <sup>6</sup> 4s	$E_{\text{av}}$	33168.	
	$F^2(3d,3d)$	70863.	0.8160
	$F^4(3d,3d)$	44277.	0.8215
	$G^2(3d,4s)$	8546.	0.8666
	$\alpha$	35.	
	$\beta$	781.	
	$T(3d^6)$	0.2	
	$\zeta_{3d}$	412. <sup>a</sup>	1.0000
	$E_{\text{av}}$	21168.	
	$F^2(3d,3d)$	64426.	0.8183
3d <sup>7</sup>	$F^4(3d,3d)$	41255.	0.8501
	$\alpha$	28.	
	$\beta$	608.	
	$T(3d^7)$	0.6	
	$\zeta_{3d}$	367. <sup>a</sup>	1.0000
3d <sup>5</sup> 4s <sup>2</sup>	$E_{\text{av}}$	78584.	
	$F^2(3d,3d)$	76661.	0.8122
	$F^4(3d,3d)$	48333.	0.8204
	$\alpha$	27.	
	$\beta$	1015.	
$T(3d^5)$	$T(3d^5)$	-7.3	
	$\zeta_{3d}$	460. <sup>a</sup>	1.0000

<sup>a</sup> Fixed to the ab initio value.

### 3. Results and discussion

The transition probabilities,  $A_{ki}$ , were calculated for M1 and E2 lines connecting the 63 metastable levels of the 3d<sup>6</sup>4s, 3d<sup>7</sup> and 3d<sup>5</sup>4s<sup>2</sup> configurations in Fe II. The SST and HFR probabilities obtained in the present work are compared in Table 4. If the two types of radiation contribute significantly to the total intensity of a line, the sum of both components is given. The exclusion criterion of one particular type of radiation for a given transition is that the corresponding  $A$ -value should be less than 1% of the sum of M1 and E2 contributions. Owing to the extensive nature of the results, only transitions for which  $A_{ki}$  is greater than  $0.001 \text{ s}^{-1}$  are reported in the table. For some of the transitions reported in the present paper, the cancellation factor (CF) as defined by Cowan (1970) is very small (typically  $CF \leq 0.01$ ) indicating that the corresponding HFR probabilities must be considered with some care.

It can be seen from Table 4 that there is general agreement between our SST and HFR transition probabilities. In particular, for the strongest lines ( $A_{ki} \geq 0.01 \text{ s}^{-1}$ ), both sets of results are in very good agreement (within 15%) if we except the  $a^6D_{7/2}-a^2D_{5/2}$ ,  $a^4F_{7/2,9/2}-b^2H_{11/2}$ ,  $a^4F_{5/2}-b^2H_{9/2}$ ,  $a^4F_{5/2}-a^2F_{7/2}$ ,  $a^4F_{3/2}-a^2F_{5/2}$ ,  $a^4F_{3/2}-b^2D_{3/2}$ ,  $a^4P_{3/2}-a^2S_{1/2}$ ,  $a^4P_{3/2}-c^2D_{3/2,5/2}$  and  $a^2D_{5/2}-b^2F_{7/2}$  transitions for which the discrepancies reach 20, 27, 28, 37, 32, 30, 32, 22, 28, 28 and 22% respectively. Exceptions occur also for  $a^4D_{7/2}-b^2F_{7/2}$  and  $a^4P_{5/2}-c^2D_{5/2}$  where cancellation effects are present in the HFR calculations and where consequently the SST results are probably more reliable. For weaker lines, our SST and HFR  $A$ -values generally agree to within 15–40% except for some very weak transitions and again for some transitions affected by cancellation effects.

The transition probabilities published for [Fe II] lines by Garstang (1962), Nussbaumer & Swings (1970), Johansson (1977) and Nussbaumer & Storey (1980) were obtained with the help of configuration basis sets including only the  $3d^64s$ ,  $3d^7$  and, occasionally,  $3d^54s^2$  configurations. In general, for the magnetic dipole transitions within a configuration, the results obtained by Garstang agree well with the SST and HFR transition probabilities reported in the present work. For the E2 contributions and for the M1 transitions arising through CI effects, large discrepancies are observed for a number of lines and they can reach a factor of two in many cases. However, these transitions are very sensitive to correlation effects and our results were obtained with more CI effects taken into account than in Garstang's calculations. Therefore, our data are expected to be more accurate. More significant is the comparison between the more extended computations of Nussbaumer & Storey (1988) and the present work. Table 5 shows such a comparison for the forbidden lines involving the levels of the four terms  $3d^64s$   $a^6D$ ,  $3d^7$   $a^4F$ ,  $3d^64s$   $a^4D$  and  $3d^7$   $a^4P$ . Nussbaumer & Storey also used the SST code but with only a twelve-configuration basis set. They obtained the potential scaling parameters by minimizing the sum of the energies of the lowest four terms. The agreement between the three sets of results in Table 5 is excellent (within a few percent) for the  $a^6D-a^6D$ ,  $a^4F-a^4F$  and  $a^4D-a^4D$  transitions. Good agreement (within 10–30%) is also observed for the  $a^6D-a^4F$ ,  $a^6D-a^4D$ ,  $a^4F-a^4D$ ,  $a^4F-a^4P$  and  $a^4D-a^4P$  transitions if we except some very weak lines ( $A_{ki} \leq 0.0001 \text{ s}^{-1}$ ). For the  $a^6D-a^4P$  transitions, both our SST and HFR values are systematically larger by about a factor of two than the transition probabilities reported by Nussbaumer & Storey (1988). For this multiplet, magnetic dipole transitions arise through a combination of CI and spin-orbit interaction and are therefore particularly sensitive to the choice of eigenfunctions. More precisely,  $3d^64s$   $a^6D$  is connected to  $3d^64s$   $b^4P$  by spin-orbit interaction while  $3d^7$   $a^4P$  and  $3d^64s$   $b^4P$  are connected by CI.

The magnitudes of the coefficients due to spin-orbit and CI depend on the  $a^6D-b^4P$  and  $a^4P-b^4P$  term separations. These term separations calculated in our work using two methods, SST (21020 and  $7826 \text{ cm}^{-1}$ ) and HFR (21105 and  $7886 \text{ cm}^{-1}$ ), are in very good agreement with the observations (21005 and  $7809 \text{ cm}^{-1}$ ) while the values obtained by Nussbaumer & Storey (1988), i.e. 27122 and  $13158 \text{ cm}^{-1}$ , are too large.

Preliminary values of HFR transition probabilities for some forbidden lines in Fe II have already been published (Quinet et al. 1996). These  $A$ -coefficients differ slightly from the present HFR results due to the fact that the set of configurations included explicitly in the model has been extended in the present calculation.

Some limited comparisons between our calculated transition probabilities and astrophysical observations can be made. For example, intensity ratios for some [Fe II] lines have been measured in supernova remnants by Dennefeld (1982, 1986), in two LMC supernova remnants by Oliva (1987) and in the Orion Nebula by Bautista et al. (1994). The ratios of intensities deduced from the transition probabilities calculated in the present work,  $R_1 = I(a^4F_{9/2}-a^4P_{5/2})/I(a^4F_{7/2}-a^4P_{5/2}) = 4.47$  (SST) and 4.55 (HFR) and  $R_2 = I(a^4F_{7/2}-a^4P_{3/2})/I(a^4F_{5/2}-a^4P_{3/2}) = 1.78$  (SST) and 1.81 (HFR) are in good agreement with the observations of Dennefeld (1982) for the Kepler supernova remnant ( $R_1 = 4.1$  and  $R_2 = 2.3$  respectively) while larger discrepancies are observed when comparing our results with the measurements of Dennefeld (1986) in four other remnants in the galaxy and in the LMC ( $R_1 = 3.6$  and  $R_2 = 0.8$ ). For these ratios, the results of Nussbaumer & Storey (1988) are  $R_1 = 4.40$  and  $R_2 = 1.82$  in very good agreement with our values. The ratio of the intensities deduced from the observations of Oliva (1987) in two LMC supernova remnants is  $R = I(a^4F_{9/2}-a^4D_{7/2})/I(a^6D_{9/2}-a^4D_{7/2}) = 0.77$ . Our SST and HFR results ( $R = 0.96$  and  $0.84$  respectively) as well as Nussbaumer & Storey's estimate ( $R = 0.74$ ) are in nice agreement with the observation. Good agreement (within the experimental errors) is also observed when comparing our values with the intensity ratios within the  $a^6D-a^4D$ ,  $a^4F-a^4G$  and  $a^4F-a^4H$  multiplets deduced from the recent observations in the Orion Nebula by Bautista et al. (1994) while larger discrepancies are observed within the  $a^4F-a^4H$  and  $a^4F-a^4P$  multiplets.

In view of this discussion and also from previous experience, it is our opinion that the present SST results should be recommended to the user, pending even more elaborate computations which will become possible with the future evolution of codes and computers.

#### 4. Conclusion

Using a rather sophisticated physical model and two independent computer codes, radiative transition probabilities have been estimated for all forbidden lines connecting 63

low-lying even-parity levels in Fe II. The analysis of the present data shows that their accuracy should be satisfactory. Thus a more extended and reliable physical basis has been provided for astrophysical studies where Fe II plays an important rôle. Of course, the quality of our results is likely to increase with even better optimization of the codes and mainly with further developments of modern computers. At this stage however the new SST data presented in this paper are probably the best available.

*Note added in proof:* The effect of some configurations not included explicitly in our physical models due to computer memory limitations was estimated in separate ab initio HFR calculations. More precisely, the configurations  $3d^54d^2$  and  $3d^54f^2$  were investigated separately. By comparing a three-configuration calculation (including  $3d^64s$ ,  $3d^7$  and  $3d^54s^2$ ) with a four-configuration calculation (adding  $3d^54d^2$ ), the effect of the latter configuration on  $A$ -values was estimated for the transitions reported in Table 4. In general, both calculations agree within a few percent if we except some transitions affected by cancellation effects and the  $a^4F-a^4P$ ,  $a^4F-a^2P$ ,  $a^2D-a^2S$ ,  $b^4P-b^2P$ ,  $b^4P-b^4D$ ,  $b^4P-c^2D$ ,  $b^2P-b^4D$ ,  $b^2P-a^2S$  M1 transitions and  $a^4P-b^4D$ ,  $a^2G-a^2F$ ,  $a^2G-b^2G$ ,  $a^2G-a^2I$ ,  $a^2D-b^2D$  and  $a^2D-a^2S$  E2 transitions for which the  $A$ -values were about 25–30% larger when calculated with the four-configuration expansion. Exceptions occur also for the  $a^4F-a^4D$  and  $a^2P-b^2P$  E2 lines for which the transition probabilities were reduced by 30% when adding the  $3d^54d^2$  configuration. The inclusion of  $3d^54f^2$  was found to affect the  $A$ -values for all the transitions by less than 1%.

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**Table 3.** Calculated HFR energy levels (in cm<sup>-1</sup>) and comparison with experiment for the 3d<sup>6</sup>4s, 3d<sup>7</sup> and 3d<sup>5</sup>4s<sup>2</sup> configurations of Fe II

Configuration	Term	<i>J</i>	<i>E</i> <sub>obs</sub> <sup>a</sup>	<i>E</i> <sub>calc</sub>	$\Delta E^b$
3d <sup>6</sup> ( <sup>5</sup> D)4s	a <sup>6</sup> D	9/2	0.	0.	0.
		7/2	385.	379.	6.
		5/2	668.	661.	7.
		3/2	863.	857.	6.
3d <sup>7</sup>	a <sup>4</sup> F	1/2	977.	972.	5.
		9/2	1873.	1898.	-25.
		7/2	2430.	2460.	-30.
		5/2	2838.	2876.	-38.
3d <sup>6</sup> ( <sup>5</sup> D)4s	a <sup>4</sup> D	3/2	3117.	3163.	-46.
		7/2	7955.	7961.	-6.
		5/2	8392.	8402.	-10.
		3/2	8680.	8697.	-17.
3d <sup>7</sup>	a <sup>4</sup> P	1/2	8847.	8869.	-22.
		5/2	13474.	13471.	3.
		3/2	13673.	13705.	-32.
		1/2	13905.	13963.	-58.
3d <sup>7</sup>	a <sup>2</sup> G	9/2	15845.	15871.	-26.
		7/2	16369.	16404.	-35.
3d <sup>7</sup>	a <sup>2</sup> P	3/2	18361.	18380.	-19.
		1/2	18887.	18911.	-24.
3d <sup>7</sup>	a <sup>2</sup> H	11/2	20340.	20367.	-27.
		9/2	20806.	20835.	-29.
3d <sup>7</sup>	a <sup>2</sup> D	5/2	20517.	20588.	-71.
		3/2	21308.	21356.	-48.
3d <sup>6</sup> ( <sup>3</sup> P)4s	b <sup>4</sup> P	5/2	20831.	20942.	-111.
		3/2	21812.	21893.	-81.
		1/2	22410.	22490.	-80.
		13/2	21252.	21332.	-80.
3d <sup>6</sup> ( <sup>3</sup> H)4s	a <sup>4</sup> H	11/2	21430.	21479.	-49.
		9/2	21582.	21606.	-24.
		7/2	21712.	21718.	-6.
		9/2	22637.	22687.	-50.
3d <sup>6</sup> ( <sup>3</sup> F)4s	b <sup>4</sup> F	7/2	22810.	22849.	-39.
		5/2	22939.	22974.	-35.
		3/2	23031.	23067.	-36.
		5/2	23318.	23246.	72.
3d <sup>5</sup> 4s <sup>2</sup>	a <sup>6</sup> S	11/2	25429.	25424.	5.
		9/2	25805.	25777.	28.
		7/2	25982.	25934.	48.
		5/2	26055.	25991.	64.
3d <sup>6</sup> ( <sup>3</sup> P)4s	b <sup>2</sup> P	3/2	25788.	25920.	-132.
		1/2	26933.	27060.	-127.
3d <sup>6</sup> ( <sup>3</sup> H)4s	b <sup>2</sup> H	11/2	26170.	26317.	-147.
		9/2	26353.	26486.	-133.
3d <sup>6</sup> ( <sup>3</sup> F)4s	a <sup>2</sup> F	7/2	27315.	27175.	140.
		5/2	27620.	27453.	167.
3d <sup>6</sup> ( <sup>3</sup> G)4s	b <sup>2</sup> G	9/2	30388.	30443.	-55.
		7/2	30764.	30802.	-38.
3d <sup>6</sup> ( <sup>3</sup> D)4s	b <sup>4</sup> D	3/2	31364.	31407.	-43.
		1/2	31368.	31401.	-33.
		5/2	31388.	31442.	-54.
		7/2	31483.	31540.	-57.
3d <sup>7</sup>	b <sup>2</sup> F	5/2	31812.	31823.	-11.
		7/2	31999.	32021.	-22.
3d <sup>6</sup> ( <sup>1</sup> I)4s	a <sup>2</sup> I	13/2	32876.	33038.	-162.
		11/2	32910.	33048.	-138.
3d <sup>6</sup> ( <sup>1</sup> G)4s	c <sup>2</sup> G	9/2	33466.	33486.	-20.
		7/2	33501.	33507.	-6.
3d <sup>6</sup> ( <sup>3</sup> D)4s	b <sup>2</sup> D	3/2	36126.	36158.	-32.
		5/2	36253.	36262.	-9.
3d <sup>6</sup> ( <sup>1</sup> S)4s	a <sup>2</sup> S	1/2	37227.	37226.	1.
		3/2	38164.	38093.	71.
3d <sup>6</sup> ( <sup>1</sup> D)4s	c <sup>2</sup> D	3/2	38214.	38126.	88.
		5/2	44915.	44892.	23.
3d <sup>6</sup> ( <sup>1</sup> F)4s	c <sup>2</sup> F	5/2	44929.	44903.	26.
		7/2	47675.	47724.	-49.
3d <sup>7</sup>	d <sup>2</sup> D	3/2	48039.	48025.	14.
		5/2	50157.	50137.	20.
3d <sup>6</sup> ( <sup>3</sup> P)4s	c <sup>4</sup> P	1/2	49101.	49260.	-159.
		3/2	49507.	49649.	-142.
		5/2	50213.	50353.	-140.
		7/2	50076.	50090.	-14.
3d <sup>6</sup> ( <sup>3</sup> F)4s	c <sup>4</sup> F	5/2	50143.	50146.	-3.
		9/2	50157.	50137.	20.
		7/2	50188.	50177.	11.

**Table 3.** continued

Configuration	Term	<i>J</i>	<i>E</i> <sub>obs</sub> <sup>a</sup>	<i>E</i> <sub>calc</sub>	$\Delta E^b$
3d <sup>6</sup> ( <sup>3</sup> P)4s	c <sup>2</sup> P	1/2	54063.	54163.	-100.
		3/2	54902.	54992.	-90.
		9/2	54232.	54350.	-118.
		5/2	54274.	54358.	-84.
3d <sup>5</sup> 4s <sup>2</sup>	b <sup>4</sup> G	7/2	54276.	54308.	-32.
		7/2	54283.	54339.	-56.
		5/2	54870.	54842.	28.
		7/2	54904.	54855.	49.
3d <sup>6</sup> ( <sup>3</sup> F)4s	c <sup>2</sup> F	5/2	57411.	57445.	-34.
		3/2	57493.	57522.	-29.
		1/2	57578.	57612.	-34.
		7/2	57612.	57644.	-58.
3d <sup>5</sup> 4s <sup>2</sup>	d <sup>4</sup> P	9/2	58631.	58557.	74.
		7/2	58666.	58568.	98.
		5/2	60270.	60327.	-57.
		1/2	60384.	60415.	-31.
3d <sup>6</sup> ( <sup>1</sup> G)4s	d <sup>2</sup> G	9/2	73394.	73448.	-54.
		5/2	73396.	73415.	-19.
		7/2	73492.	73534.	-42.
		3/2	73637.	73686.	-40.
3d <sup>5</sup> 4s <sup>2</sup>	c <sup>4</sup> D	7/2	72967.	72960.	7.
		5/2	73960.	73960.	0.
		3/2	77019.	77019.	0.
		5/2	77019.	77195.	36.
3d <sup>5</sup> 4s <sup>2</sup>	2I	11/2	77231.	77195.	36.
		13/2	77231.	77608.	41.
		5/2	78185.	78208.	-23.
		9/2	78577.	78564.	13.
3d <sup>5</sup> 4s <sup>2</sup>	2D	9/2	81639.	81628.	11.
		7/2	81735.	81779.	-44.
		5/2	81735.	81779.	-44.
		3/2	86661.	86661.	0.
3d <sup>5</sup> 4s <sup>2</sup>	2S	1/2	93882.	93882.	0.
		5/2	93954.	93954.	0.
		3/2	97723.	97723.	0.
		7/2	101928.	101964.	-16.
3d <sup>5</sup> 4s <sup>2</sup>	2G	9/2	117646.	117646.	0.
		7/2	117646.	117699.	-53.
		5/2	125601.	125601.	0.
		3/2	125651.	125651.	0.

<sup>a</sup> Sugar & Corliss (1985).<sup>b</sup>  $\Delta E = E_{\text{obs}} - E_{\text{calc}}$ .

**Table 4.** Radiative transition probabilities,  $A_{ki}$  in  $s^{-1}$ , as obtained with SST and HFR for forbidden lines of Fe II.  $A(B)$  stands for  $A \cdot 10^B$ 

Multiplet	$2J-2J'$	$\lambda(\text{\AA})^a$	Type	$A_{ki}(\text{SST})$	$A_{ki}(\text{HFR})$
$a^6D-a^6D$	9-7	259811.18	M1	2.13(-3)	2.05(-3)
	7-5	353397.94	M1	1.57(-3)	1.56(-3)
$a^6D-a^4D$	9-7	12566.80	M1	4.74(-3)	5.18(-3)
	7-7	13205.54	M1	1.31(-3)	1.44(-3)
	5-5	12942.68	M1	1.98(-3)	2.23(-3)*
	3-5	13277.76	M1	1.17(-3)	1.30(-3)
	3-3	12787.76	M1	2.45(-3)	2.80(-3)
	1-3	12977.73	M1	1.08(-3)	1.23(-3)
$a^6D-a^4P$	1-1	12703.46	M1	3.32(-3)	3.82(-3)
	7-5	7637.54	M1	6.64(-3)	7.30(-3)
	5-3	7686.93	M1	6.81(-3)	7.53(-3)
	3-1	7665.30	M1	6.23(-3)	6.95(-3)
	1-1	7733.16	M1	1.93(-3)	2.14(-3)
	7-5	4965.79	M1	1.16(-2)	1.42(-2)
$a^6D-b^4P$	7-5	4889.62	M1	3.41(-1)	3.47(-1)
	5-5	4958.22	M1	5.00(-3)	5.13(-3)*
	5-3	4728.07	M1	4.53(-1)	4.78(-1)
	3-5	5006.62	M1	2.70(-2)	2.60(-2)
	3-3	4772.06	M1	2.30(-2)	2.41(-2)*
	3-1	4639.67	M1	4.67(-1)	4.99(-1)
$a^6D-a^4H$	1-3	4798.27	M1	6.75(-2)	6.85(-2)
	1-1	4664.44	M1	1.47(-1)	1.56(-1)
	9-9	4632.27	M1	2.01(-3)	2.14(-3)*
	9-9	4416.27	M1	4.19(-1)	4.54(-1)*
	9-7	4382.74	M1	5.14(-2)	5.43(-2)
	7-9	4492.63	M1	5.61(-2)	5.97(-2)
$a^6D-a^6S$	7-7	4457.94	M1	2.55(-1)	2.79(-1)
	7-5	4432.45	M1	4.88(-2)	5.27(-2)
	5-7	4514.90	M1	6.00(-2)	6.51(-2)
	5-5	4488.75	M1	1.35(-1)	1.50(-1)
	5-3	4470.29	M1	2.51(-2)	2.75(-2)
	3-5	4528.38	M1	3.98(-2)	4.38(-2)
$a^6D-a^4G$	3-3	4509.60	M1	5.19(-2)	5.80(-2)
	1-3	4533.00	M1	1.45(-2)	1.62(-2)
	9-5	4287.39	E2	1.37(+0)	1.65(+0)
	7-5	4359.33	E2	1.02(+0)	1.22(+0)
	5-5	4413.78	E2	7.25(-1)	8.58(-1)
	3-5	4452.10	E2	4.65(-1)	5.48(-1)
$a^6D-b^2P$	1-5	4474.90	E2	2.27(-1)	2.67(-1)
	9-9	3874.07	M1	6.81(-3)	9.08(-3)*
	7-9	3932.71	M1	1.53(-3)	1.77(-3)
	7-7	3905.63	M1	4.01(-3)	5.51(-3)*
	5-7	3949.27	M1	1.18(-3)	1.51(-3)
	5-5	3937.79	M1	1.18(-3)	1.67(-3)
$a^6D-b^4D$	5-3	3979.78	M1	4.05(-3)	4.33(-3)
	3-1	3834.72	M1	1.45(-3)	1.66(-3)
	9-7	3175.38	M1	1.90(-1)	2.08(-1)
	7-7	3214.67	M1	5.95(-2)	6.36(-2)*
	7-5	3224.55	M1	2.94(-2)	3.20(-2)
	5-7	3244.18	M1	2.53(-2)	2.71(-2)
$a^4F-a^4F$	5-5	3254.24	M1	1.01(-1)	1.09(-1)*
	5-3	3256.73	M1	1.05(-3)	1.17(-3)*
	3-5	3275.02	M1	4.91(-2)	5.28(-2)
	3-3	3277.55	M1	1.34(-1)	1.45(-1)
	3-1	3277.12	M1	3.52(-2)	3.83(-2)
	1-3	3289.89	M1	5.40(-2)	5.80(-2)
$a^4F-a^4D$	1-1	3289.46	M1	1.89(-1)	2.04(-1)
	9-7	179313.66	M1	5.84(-3)	6.01(-3)
	7-5	245121.35	M1	3.92(-3)	4.17(-3)
	5-3	357671.44	M1	1.41(-3)	1.53(-3)
	9-7	16435.50	E2	5.98(-3)	5.73(-3)
	9-5	15334.71	E2	3.12(-3)	3.00(-3)
$a^4F-a^4P$	7-7	18093.95	E2	1.32(-3)	1.25(-3)
	7-5	16768.76	E2	2.49(-3)	2.38(-3)
	7-3	15994.73	E2	4.18(-3)	4.03(-3)
	5-5	18000.16	E2	1.82(-3)	1.72(-3)
	5-3	17111.29	E2	1.18(-3)	1.13(-3)
	5-1	16637.66	E2	4.75(-3)	4.56(-3)
$a^4F-b^2H$	3-3	17971.04	E2	2.12(-3)	2.00(-3)
	3-1	17449.34	E2	2.47(-3)	2.35(-3)
	9-5	8616.96	E2	3.56(-2)	3.12(-2)
	7-5	9051.95	M1,E2	8.83(-3)	7.53(-3)
	7-3	8891.91	E2	2.21(-2)	1.98(-2)
	5-5	9399.05	M1,E2	1.68(-3)	1.38(-3)

**Table 4. continued**

Multiplet	$2J-2J'$	$\lambda(\text{\AA})^a$	Type	$A_{ki}(\text{SST})$	$A_{ki}(\text{HFR})$
$a^4F-a^2G$	3-3	9470.93	E2	3.65(-3)	3.18(-3)
	3-1	9267.57	E2	2.13(-2)	1.91(-2)
	9-9	7155.16	M1	1.46(-1)	1.53(-1)*
	9-7	6896.18	M1	5.31(-3)	5.28(-3)
	7-9	7452.54	M1	4.77(-2)	4.92(-2)
	7-7	7172.00	M1	5.51(-2)	5.88(-2)
$a^4F-a^2P$	5-7	7388.18	M1	4.21(-2)	4.48(-2)
	7-3	6275.51	E2	3.16(-3)	2.60(-3)
	5-3	6440.40	M1,E2	2.33(-2)	2.13(-2)
	5-1	6229.26	E2	1.74(-3)	1.47(-3)
	3-3	6558.49	M1	1.61(-2)	1.42(-2)
	9-9	5280.26	M1,E2	1.19(-3)	1.38(-3)*
$a^4F-a^2D$	9-5	5362.05	E2	9.06(-3)	1.40(-2)
	7-5	5527.34	M1	2.78(-1)	2.73(-1)
	5-5	5654.86	M1,E2	3.14(-2)	3.11(-2)*
	5-3	5412.65	M1	2.74(-1)	2.83(-1)
	3-5	5745.70	M1	1.40(-2)	1.29(-2)
	9-5	5495.82	M1	1.47(-1)	1.51(-1)
$a^4F-b^4P$	9-5	5273.35	E2	4.80(-1)	5.50(-1)
	7-5	5433.13	M1,E2	1.51(-1)	1.74(-1)
	7-3	5158.00	E2	3.84(-1)	4.40(-1)
	5-5	5556.29	M1,E2	3.01(-2)	3.45(-2)*
	5-3	5268.87	E2	2.50(-1)	2.88(-1)
	5-1	5107.94	E2	3.13(-1)	3.60(-1)
$a^4F-b^4F$	3-5	5643.97	M1,E2	3.42(-3)	3.91(-3)
	3-3	5347.65	E2	7.57(-2)	8.70(-2)
	3-1	5181.95	E2	4.37(-1)	5.00(-1)
	9-13	5158.78	E2	5.56(-1)	6.05(-1)
	9-11	5111.63	E2	1.20(-1)	1.31(-1)
	9-9	5072.39	E2	2.53(-2)	2.80(-2)
$a^4F-b^2P$	9-7	5039.08	E2	1.86(-3)	2.04(-3)
	7-11	5261.62	E2	4.01(-1)	4.29(-1)
	7-9	5220.06	E2	1.34(-1)	1.44(-1)
	7-7	5184.79	E2	2.39(-2)	2.59(-2)
	5-9	5333.65	E2	3.32(-1)	3.51(-1)
	5-7	5296.83	E2	1.11(-1)	1.18(-1)
$a^4F-b^4F$	3-7	5376.45	E2	3.31(-1)	3.48(-1)
	9-9	4814.53	E2	4.57(-1)	5.21(-1)
	9-7	4774.72	E2	1.45(-1)	1.63(-1)
	9-5	4745.48	E2	1.45(-2)	1.62(-2)
	7-9	4947.37	E2	6.62(-2)	7.47(-2)
	7-7	4905.34	E2	2.51(-1)	2.85(-1)
$a^4F-a^4G$	7-5	4874.48	E2	1.99(-1)	2.23(-1)
	7-3	4852.73	E2	2.55(-2)	2.85(-2)
	5-7	5005.51	E2	9.34(-2)	1.05(-1)
	5-5	4973.39	E2	1.61(-1)	1.83(-1)
	5-3	4950.74	E2	2.01(-1)	2.25(-1)
	3-5	5043.52	E2	8.48(-2)	9.42(-2)
$a^4F-b^2H$	3-3	5020.23	E2	2.10(-1)	2.36(-1)
	7-3	4280.08	E2	2.29(-3)	2.78(-3)
	5-3	4356.14	E2	9.26(-3)	1.12(-2)
	5-1	4149.10	E2	1.38(-3)	1.65(-3)
	3-1	4197.80	E2	9.85(-3)	1.23(-2)
	9-11	4243.97	E2	1.02(+0)	1.12(+0)
$a^4F-a^2G$	9-9	4177.20	E2	1.84(-1)	1.94(-1)
	9-7	4146.65	E2	1.33(-2)	1.31(-2)
	7-11	4346.85	E2	2.27(-1)	2.50(-1)
	7-9	4276.83	E2	7.50(-1)	8.19(-1)
	7-7	4244.81	E2	3.18(-1)	3.36(-1)
	7-5	4231.56	E2	3.11(-2)	3.18(-2)
$a^4F-a^2F$	5-9	4352.78	E2	3.45(-1)	3.80(-1)
	5-7	4319.62	E2	6.05(-1)	6.58(-1)
	5-5	4305.89	E2	3.67(-1)	3.88(-1)
	3-7	4372.43	E2	3.10(-1)	3.40(-1)
	3-5	4358.36	E2	8.10(-1)	8.75(-1)
	9-9	4083.78	E2	4.74(-3)	6.82(-3)
$a^4F-b^2H$	7-11	4211.10	E2	3.37(-2)	4.44(-2)
	7-9	4178.96	E2	9.95(-3)	1.56(-2)
	5-9	4251.44	E2	1.28(-2)	1.87(-2)
	9-7	3929.34	M1,E2	4.54(-3)	6.42(-3)
	7-7	4017.38	M1,E2	5.09(-3)	7.88(-3)*
	5-5	4084.32	M1,E2	1.47(-2)	2.04(-2)
$a^4F-a^2P$	3-7	4131.50	E2	4.27(-3)	6.45(-3)
	3-5	4079.99	M1,E2	2.64(-2)	3.59(-2)

**Table 4.** continued

Multiplet	$2J-2J'$	$\lambda(\text{\AA})^a$	Type	$A_{ki}(\text{SST})$	$A_{ki}(\text{HFR})$
$a^4F-b^2G$	9-9	3505.80	M1,E2	4.56(-3)	5.79(-3)
	7-9	3575.72	M1,E2	2.67(-3)	3.19(-3)
	7-7	3528.27	M1,E2	2.67(-3)	3.15(-3)*
	5-9	3628.65	E2	1.30(-3)	1.62(-3)
	5-7	3579.80	E2	1.51(-3)	1.94(-3)
	9-7	3376.20	E2	8.46(-1)	9.81(-1)
	9-5	3387.09	E2	2.49(-1)	2.82(-1)
$a^4F-b^4D$	7-7	3440.99	E2	2.89(-1)	3.26(-1)
	7-5	3452.31	E2	4.24(-1)	4.97(-1)
	7-3	3455.11	E2	4.38(-1)	5.00(-1)
	5-7	3489.98	E2	4.23(-2)	4.71(-2)
	5-5	3501.63	E2	3.97(-1)	4.52(-1)
	5-3	3504.51	E2	2.31(-1)	2.73(-1)
	5-1	3504.02	E2	6.35(-1)	7.20(-1)
	3-7	3524.37	E2	1.94(-3)	2.14(-3)
	3-5	3536.25	E2	7.67(-2)	8.57(-2)
	3-3	3539.19	E2	4.54(-1)	5.15(-1)
$a^4F-c^2G$	3-1	3538.69	E2	4.73(-1)	5.40(-1)
	9-9	3164.25	M1,E2	2.73(-3)	2.67(-3)*
	7-7	3217.49	M1,E2	1.39(-3)	1.42(-3)*
	5-7	3260.29	M1,E2	1.66(-3)	1.81(-3)
	3-7	3290.28	E2	2.24(-3)	2.85(-3)
$a^4F-b^2F$	9-7	3318.38	M1	3.60(-2)	4.25(-2)
	7-7	3380.96	M1	5.97(-3)	7.05(-3)*
	7-5	3402.50	M1,E2	9.04(-3)	1.00(-2)*
	5-7	3428.24	M1,E2	1.57(-2)	1.87(-2)
	5-5	3450.40	M1,E2	7.16(-3)	8.09(-3)*
$a^4F-b^2D$	3-5	3484.01	M1,E2	4.11(-2)	4.72(-2)
	9-5	2907.79	E2	2.07(-3)	2.32(-3)
	7-5	2955.72	M1,E2	4.44(-3)	5.91(-3)
	5-5	2991.80	M1,E2	1.06(-3)	1.29(-3)*
	5-3	3003.17	M1,E2	8.55(-3)	1.23(-2)
$a^4F-c^2D$	3-3	3028.60	M1,E2	1.12(-2)	1.55(-2)
	7-5	2797.62	M1,E2	2.28(-3)	3.14(-3)
	5-5	2829.92	M1,E2	5.90(-3)	8.50(-3)*
	5-3	2825.90	M1,E2	1.48(-3)	2.61(-3)
	3-5	2852.50	M1,E2	2.83(-3)	4.68(-3)
$a^4D-a^4D$	3-3	2848.41	M1,E2	7.47(-3)	1.18(-2)*
	7-5	228959.20	M1	2.56(-3)	2.67(-3)
	5-3	346513.96	M1	1.36(-3)	1.46(-3)
	5-3	18113.92	M1,E2	2.23(-3)	2.30(-3)
	7-3	17484.19	E2	2.25(-3)	2.23(-3)
$a^4D-a^2P$	5-1	18134.39	E2	2.76(-3)	2.79(-3)
	5-3	10028.64	M1	6.84(-3)	6.60(-3)
	3-1	9795.15	M1,E2	6.67(-3)	6.72(-3)
	1-1	9957.42	M1	1.98(-3)	2.07(-3)
	7-5	7764.68	M1,E2	3.08(-2)	3.35(-2)
$a^4D-b^4P$	7-3	7214.71	E2	2.95(-3)	5.33(-3)
	5-5	8037.25	M1,E2	1.02(-2)	1.15(-2)
	5-1	7131.76	E2	4.05(-3)	7.35(-3)
	3-5	8228.10	M1,E2	8.47(-3)	8.73(-3)
	3-3	7613.12	M1,E2	1.27(-2)	1.43(-2)
	3-1	7281.63	M1,E2	6.27(-3)	7.84(-3)
	1-3	7710.78	M1,E2	6.22(-3)	7.49(-3)
	1-1	7370.93	M1	1.71(-2)	1.85(-2)
	7-9	6809.22	M1	2.29(-2)	2.47(-2)
	7-7	6729.85	M1	1.43(-2)	1.56(-2)
$a^4D-a^4G$	7-5	6671.92	M1	4.46(-3)	4.55(-3)
	5-7	6933.66	M1,E2	1.75(-3)	2.06(-3)
	5-5	6872.17	M1	2.12(-2)	2.35(-2)
	5-3	6829.02	M1	5.52(-3)	5.98(-3)
	3-5	7011.23	M1,E2	1.88(-3)	2.07(-3)
$a^4D-b^2P$	3-3	6966.31	M1	2.26(-2)	2.53(-2)
	1-3	7047.99	M1	1.41(-2)	1.57(-2)
	7-7	5545.90	M1	4.80(-3)	6.11(-3)
	5-7	5683.57	M1,E2	2.19(-3)	2.78(-3)
	5-5	5659.83	M1	3.06(-3)	3.65(-3)
$a^4D-a^2F$	3-5	5753.81	M1,E2	2.30(-3)	2.68(-3)
	5-3	5746.97	M1	3.62(-1)	3.73(-1)
	3-3	5843.89	M1	1.41(-2)	1.46(-2)*
	3-1	5477.24	M1	4.23(-1)	4.48(-1)
	1-3	5901.26	M1	4.11(-2)	4.10(-2)
$a^4D-a^2F$	1-1	5527.61	M1	1.19(-1)	1.25(-1)
	7-7	5163.95	M1	2.98(-1)	3.09(-1)
	7-5	5083.73	M1	1.59(-2)	1.57(-2)
	5-7	5283.11	M1	8.25(-2)	8.46(-2)

**Table 4.** continued

Multiplet	$2J-2J'$	$\lambda(\text{\AA})^a$	Type	$A_{ki}(\text{SST})$	$A_{ki}(\text{HFR})$
$a^4D-b^2G$	5-5	5199.17	M1	1.13(-1)	1.18(-1)
	3-5	5278.37	M1	6.48(-2)	6.75(-2)
	5-7	4382.97	M1	2.44(-3)	2.21(-3)*
	5-5	4468.51	M1,E2	1.07(-3)	9.99(-4)
	7-7	4249.08	M1,E2	4.00(-3)	4.50(-4)*
	7-5	4266.35	M1,E2	2.04(-2)	1.98(-2)
	5-7	4329.43	M1,E2	1.63(-2)	1.51(-2)
$a^4D-b^4D$	5-3	4351.81	M1,E2	1.56(-2)	1.38(-2)
	5-1	4351.05	E2	1.39(-3)	3.63(-6)*
	3-5	4402.59	M1,E2	1.47(-2)	1.35(-2)
	3-1	4406.38	M1,E2	6.10(-3)	2.76(-3)*
	1-3	4439.71	M1,E2	7.85(-3)	6.58(-3)*
	7-7	4157.91	M1,E2	1.65(-2)	2.65(-2)*
	5-7	4234.82	M1	4.03(-3)	6.96(-3)
$a^4D-b^2F$	5-5	4268.68	M1	7.25(-3)	1.20(-2)
	3-5	4321.92	M1	3.77(-3)	6.37(-3)
	7-7	3913.41	M1	2.02(-3)	3.43(-3)*
	5-5	3532.86	M1	1.52(-1)	1.63(-1)
	5-5	3588.23	M1	3.91(-2)	4.12(-2)
$a^4D-c^2G$	5-3	3604.60	M1	1.26(-2)	1.32(-2)
	3-5	3625.77	M1	5.39(-2)	5.67(-2)
	3-3	3642.49	M1	5.83(-2)	6.23(-2)
	1-3	3664.70	M1	1.18(-1)	1.26(-1)
	5-5	3357.87	M1	1.02(-3)	1.38(-3)*
$a^4D-c^2D$	3-5	3390.73	M1,E2	1.31(-3)	2.00(-3)
	3-3	3384.95	M1,E2	2.12(-3)	2.77(-3)
	1-1	20066.94	M1	8.30(-2)	8.15(-2)
	5-5	14195.52	M1	1.99(-2)	1.83(-2)
	3-5	14607.84	M1	7.09(-3)	6.12(-3)
$a^4P-a^2P$	3-3	13094.25	M1	9.69(-3)	9.28(-3)
	1-3	13503.94	M1	4.83(-3)	4.45(-3)
	5-5	11990.51	M1,E2	3.13(-3)	3.93(-3)*
	3-5	13967.75	M1,E2	2.53(-3)	3.33(-3)*
	3-1	11442.89	M1	1.18(-3)	1.59(-3)*
$a^4P-b^4F$	5-9	10910.71	E2	4.99(-3)	5.37(-3)
	5-7	10708.35	E2	1.93(-3)	2.05(-3)
	3-7	10941.31	E2	3.21(-3)	4.63(-3)
	3-5	10788.99	E2	3.07(-3)	3.22(-3)
	3-3	10682.99	E2	1.54(-3)	1.61(-3)
$a^4P-a^6S$	1-5	11065.60	E2	1.68(-3)	1.73(-3)
	1-3	10954.13	E2	3.84(-3)	4.00(-3)
	5-5	10156.49	M1	2.93(-3)	1.40(-3)*
	3-5	10365.83	M1	1.14(-3)	5.43(-4)
	5-7	8252.36	M1,E2	1.60(-3)	1.67(-3)
$a^4P-b^2P$	3-1	7539.65	M1,E2	3.21(-3)	3.43(-3)
	5-7	7328.43	E2	1.73(-3)	1.64(-3)
	5-5	5551.31	M1,E2	1.49(-1)	1.76(-1)
	5-5	5580.82	M1,E2	1.38(-1)	1.63(-1)
	5-3	5588.15	M1,E2	7.85(-2)	9.22(-2)
$a^4D-b^4F$	5-1	5586.90	E2	2.17(-2)	2.56(-2)
	3-7	5613.27	E2	8.08(-2)	9.34(-2)
	3-5	5643.44	M1,E2	3.89(-3)	4.40(-3)
	3-3	5650.94	M1,E2	8.49(-2)	9.71(-2)
	3-1	5649.66	M1,E2	1.77(-1)	2.03(-1)
$a^4D-a^4G$	1-5	5718.21	E2	7.29(-2)	8.23(-2)
	1-3	5725.91	E2	4.36(-2)	4.90(-2)
	1-1	5724.60	M1	3.76(-3)	3.47(-3)
	5-5	4388.87	E2	1.54(-3)	1.58(-3)
	5-3	4413.39	M1,E2	1.35(-3)	1.48(-3)
$a^4P-b^2D$	3-5	4427.51	E2	7.13(-3)	7.68(-3)
	3-3	4452.46	M1,E2	8.21(-3)	9.56(-3)*
	1-3	4498.87	M1,E2	6.28(-3)	7.86(-3)
	5-1	4208.82	E2	6.93(-3)	1.06(-2)
	3-1	4244.34	M1,E2	1.82(-2)	2.28(-2)
$a^4P-b^2P$	1-1	4286.50	M1	4.51(-3)	5.60(-3)*
	5-5	4049.11	M1,E2	1.59(-2)	2.26(-2)*
	5-3	4040.88	M1,E2	1.88(-3)	2.89(-3)
	3-5	4081.98	M1,E2	3.56(-2)	4.71(-2)
	1-3	4073.61	M1,E2	1.03(-2)	1.36(-2)
$a^4D-a^2F$	1-5	4120.96	E2	2.04(-3)	2.72(-3)
	1-3	4112.43	M1,E2	7.14(-3)	9.40(-3)

**Table 4.** continued

Multiplet	$2J-2J'$	$\lambda(\text{\AA})^a$	Type	$A_{ki}(\text{SST})$	$A_{ki}(\text{HFR})$
$a^2G-a^2G$	9-7	190529.52	M1	2.14(-3)	2.26(-3)
$a^2G-a^2H$	9-11	22237.65	M1	1.48(-2)	1.58(-2)
	9-9	20151.24	M1	4.37(-2)	4.65(-2)
	7-9	22534.60	M1	1.39(-2)	1.48(-2)
$a^2G-a^4G$	7-5	10321.29	M1,E2	1.62(-3)	1.87(-3)
$a^2G-b^2H$	9-11	9682.08	M1,E2	2.07(-2)	2.16(-2)
	9-9	9513.84	M1,E2	1.40(-2)	1.52(-2)
	7-11	102004.43	E2	1.18(-3)	1.24(-3)
	7-9	10013.87	M1,E2	1.74(-2)	1.80(-2)
$a^2G-a^2F$	9-7	8715.80	M1,E2	7.47(-2)	6.97(-2)
	9-5	8489.69	E2	6.92(-3)	6.10(-3)
	7-7	9133.62	M1,E2	1.00(-2)	9.74(-3)*
	7-5	8885.62	M1,E2	6.70(-2)	6.02(-2)
$a^2G-b^2G$	9-9	6873.84	E2	1.40(-1)	1.51(-1)
	9-7	6700.63	E2	1.26(-2)	1.07(-2)
	7-9	7131.12	M1,E2	1.50(-2)	1.61(-2)
	7-7	6944.88	E2	1.26(-1)	1.35(-1)
$a^2G-b^2F$	9-7	6188.55	M1,E2	1.94(-1)	2.19(-1)
	9-5	6261.12	E2	3.52(-2)	3.97(-2)
	7-7	6396.31	M1,E2	4.86(-2)	4.63(-2)*
	7-5	6473.86	M1,E2	1.65(-1)	1.83(-1)
$a^2G-a^2I$	9-13	5870.02	E2	1.95(-1)	2.14(-1)
	9-11	5858.23	E2	1.61(-3)	1.43(-3)
	7-11	6044.07	E2	1.51(-1)	1.63(-1)
$a^2G-c^2G$	9-9	5673.21	E2	3.77(-1)	4.02(-1)
	9-7	5662.03	M1,E2	9.93(-3)	9.31(-3)*
	7-9	5847.32	E2	4.07(-2)	4.44(-2)
	7-7	5835.45	E2	4.07(-1)	4.38(-1)
$a^2G-b^2D$	9-5	4898.61	E2	1.22(+0)	1.33(+0)
	7-5	5027.88	E2	8.89(-2)	9.72(-2)
	7-3	5060.08	E2	8.23(-1)	8.85(-1)
$a^2G-c^2D$	9-5	4479.12	E2	1.75(-1)	1.55(-1)
	7-5	4586.96	E2	2.96(-2)	2.90(-2)
	7-3	4576.39	E2	6.69(-1)	6.90(-1)
$a^2P-a^2P$	3-1	190015.29	M1	2.46(-3)	2.54(-3)
$a^2P-a^2D$	3-5	46362.88	M1	7.17(-3)	7.30(-3)
	3-3	33919.07	M1	5.10(-2)	5.08(-2)
	1-3	41289.55	M1	9.29(-3)	9.20(-3)
$a^2P-b^2P$	3-3	13460.80	M1,E2	6.80(-3)	7.42(-3)*
	3-1	11662.56	M1,E2	1.20(-2)	1.27(-2)*
	1-3	14487.07	M1,E2	3.90(-3)	4.04(-3)*
$a^2P-a^2F$	3-7	11164.80	E2	1.06(-2)	9.94(-3)
	3-5	10796.46	E2	7.64(-3)	7.03(-3)
	1-5	11446.86	E2	8.25(-3)	7.57(-3)
$a^2P-b^4D$	3-1	7685.58	M1,E2	2.18(-3)	2.29(-3)
$a^2P-b^2F$	3-7	7330.22	E2	1.21(-3)	1.15(-3)
	3-5	7432.25	M1,E2	3.03(-3)	2.28(-3)
	1-5	7734.79	E2	1.07(-3)	8.53(-4)
$a^2P-c^2G$	3-7	6602.93	E2	1.45(-3)	1.56(-3)
$a^2P-b^2D$	3-5	5587.45	E2	3.84(-2)	3.55(-2)
	3-3	5627.25	E2	2.21(-1)	2.30(-1)
	1-5	5756.74	E2	2.74(-2)	2.78(-2)
	1-3	5798.99	E2	1.32(-1)	1.38(-1)
$a^2P-a^2S$	3-1	5298.88	M1,E2	2.32(-2)	2.63(-2)
	1-1	5450.88	M1	5.20(-3)	6.35(-3)
$a^2P-c^2D$	3-5	5048.19	E2	5.20(-1)	5.77(-1)
	3-3	5035.40	E2	1.15(-1)	1.27(-1)
	1-5	5185.97	E2	1.68(-1)	1.87(-1)
	1-3	5172.47	E2	2.25(-1)	2.50(-1)
$a^2H-a^2H$	11-9	214778.06	M1	1.46(-3)	1.50(-3)
$a^2H-b^2H$	11-11	17148.33	E2	4.28(-3)	4.77(-3)
	9-9	18022.84	E2	3.30(-3)	3.65(-3)
$a^2H-b^2G$	11-9	9949.26	M1,E2	3.25(-2)	3.51(-2)
	11-7	9590.44	E2	2.73(-3)	3.44(-3)
	9-9	10432.54	M1	2.56(-3)	2.41(-3)*
	9-7	10038.70	M1,E2	3.00(-2)	3.12(-2)
$a^2H-b^2F$	11-7	8574.89	E2	6.30(-2)	6.15(-2)
	9-7	8931.48	E2	6.45(-3)	7.20(-3)
	9-5	9083.42	E2	4.95(-2)	4.85(-2)
$a^2H-a^2I$	11-13	7975.25	E2	9.26(-2)	1.05(-1)
	11-11	7953.51	M1,E2	2.90(-3)	2.57(-3)*
	9-11	8259.37	E2	8.14(-2)	9.08(-2)
$a^2H-c^2G$	11-9	7616.28	M1,E2	5.90(-3)	7.67(-3)
	9-9	7896.29	M1,E2	7.26(-3)	8.53(-3)*
	9-7	7874.65	M1,E2	5.54(-3)	7.53(-3)
$a^2H-b^2D$	9-5	6471.90	E2	2.55(-3)	1.83(-3)
$a^2D-a^2D$	5-3	126375.01	M1	7.36(-3)	6.80(-3)
$a^2D-b^4P$	5-3	77193.07	M1	1.02(-3)	1.18(-3)

**Table 4.** continued

Multiplet	$2J-2J'$	$\lambda(\text{\AA})^a$	Type	$A_{ki}(\text{SST})$	$A_{ki}(\text{HFR})$
$a^2D-b^2P$	5-3	18967.85	M1,E2	1.70(-3)	1.96(-3)
	5-1	15582.29	E2	2.70(-3)	2.94(-3)
	3-1	17773.84	M1,E2	3.83(-3)	4.08(-3)
$a^2D-a^2F$	5-7	14706.28	E2	2.49(-3)	2.20(-3)
$a^2D-b^2G$	5-9	10127.31	E2	1.16(-2)	1.14(-2)
	3-7	10571.90	E2	1.04(-2)	1.04(-2)
$a^2D-b^4D$	5-7	9116.41	M1	2.52(-3)	2.98(-3)
$a^2D-b^2F$	5-7	8706.82	M1,E2	1.06(-2)	8.46(-3)
	5-5	8851.15	M1,E2	9.92(-3)	9.18(-3)*
	3-5	9517.77	M1,E2	6.03(-3)	5.19(-3)
$a^2D-c^2G$	5-9	7720.18	E2	3.67(-2)	3.97(-2)
	5-7	7699.50	M1,E2	2.45(-3)	2.59(-3)
	3-7	8199.03	E2	2.42(-2)	2.59(-2)
$a^2D-b^2D$	5-5	6353.11	E2	2.34(-1)	2.45(-1)
	5-3	6404.61	M1,E2	8.33(-2)	8.64(-2)*
	3-5	6689.41	M1,E2	6.70(-2)	6.47(-2)*
	3-3	6746.53	E2	7.03(-2)	7.45(-2)
$a^2D-a^2S$	5-1	5982.65	E2	3.01(-1)	3.32(-1)
	3-1	6279.95	M1,E2	2.05(-1)	2.31(-1)
$a^2D-c^2D$	5-5	5665.04	M1,E2	2.69(-2)	2.69(-2)*
	5-3	5648.93	M1,E2	4.20(-2)	4.42(-2)*
	3-5	5930.91	M1,E2	1.05(-2)	1.12(-2)*
	3-3	5913.26	E2	1.32(-1)	1.39(-1)
$b^4P-b^4P$	5-3	101859.17	M1	2.22(-2)	2.03(-2)
	3-1	167237.23	M1	9.49(-3)	9.50(-3)
$b^4P-b^2P$	5-3	20167.90	M1	4.20(-2)	4.35(-2)
	3-3	25146.95	M1	1.42(-2)	1.51(-2)
	3-1	19523.29	M1	4.17(-3)	3.99(-3)
$b^4P-b^4D$	5-7	9384.80	M1,E2	3.98(-2)	3.97(-2)
	5-5	9469.46	M1,E2	2.40(-2)	2.43(-2)*
	5-3	9490.59	M1,E2	1.58(-2)	1.57(-2)
	3-5	10440.03	M1	5.77(-3)	5.92(-3)
$b^4P-b^2D$	5-5	6482.31	M1,E2	4.29(-2)	4.61(-2)*
	5-3	6535.93	M1,E2	2.07(-3)	2.45(-3)*
	3-5	6922.89	M1	9.35(-3)	9.50(-3)
	3-3	6984.08	M1,E2	2.19(-3)	2.28(-3)
$b^4P-a^2S$	5-1	6097.08	E2	5.24(-3)	6.80(-3)
	3-1	6485.28	M1	5.54(-1)	5.70(-1)
	1-1	6746.92	M1	1.45(-1)	1.52(-1)
$b^4P-c^2D$	5-5	5767.54	M1,E2	6.42(-2)	6.92(-2)*
	5-3	5750.84	M1,E2	1.22(-2)	1.42(-2)
	3-5	6113.72	M1,E2	1.00(-2)	1.10(-2)
	3-3	6094.96	M1	3.97(-2)	4.35(-2)
	1-3	6325.50	M1	9.50(-3)	1.04(-2)
$a^4H-a^4G$	13-11	23933.12	M1	2.11(-2)	2.10(-2)
	11-11	25003.06	M1	1.14(-2)	1.17(-2)*
	11-9	22851.06	M1,E2	2.50(-3)	2.57(-3)
	9-9	23669.52	M1	1.73(-2)	1.79(-2)*
	9-7	22721.12	M1,E2	2.78(-3)	2.69(-3)
$a^4H-b^2H$	13-11	20325.56	M1	1.01(-2)	1.18(-2)
	9-11	21787.48	M1	1.30(-3)	1.44(-3)
	7-9	21541.90	M1	1.26(-3)	1.40(-3)
$a^4H-a^2F$	9-7	17437.26	M1	5.51(-3)	5.58(-3)
	7-7	17842.71	M1	1.47(-3)	1.04(-3)*
$a^4H-b^2G$	11-9	11159.93	M1	1.74(-2)	1.77(-2)
	9-9	11351.62	M1	4.20(-3)	4.25(-3)*
	9-7	10886.88	M1	1.69(-2)	1.88(-2)
	7-7	11043.56	M1	1.24(-2)	1.36(-2)
$a^4H-b^2F$	9-7	9596.68	M1,E2	1.07(-3)	1.53(-3)
$a^4H-a^2I$	13-13	8600.50	M1	8.38(-2)	9.29(-2)*
	13-11	8575.22	M1	1.24(-3)	1.37(-3)*
	11-13	8734.82	M1	3.37(-2)	3.77(-2)
	11-11	8708.75	M1	3.25(-2)	3.60(-2)
$a^4H-c^2G$	11-9	8825.05	M1	3.31(-2)	3.69(-2)
	9-9	8411.78	M1	1.60(-2)	1.77(-2)*
	9-7	8387.23	M1	1.25(-1)	1.36(-1)
	7-9	8505.01	M1	3.88(-3)	4.28(-3)
	7-7	8479.92	M1	8.73(-2)	9.55(-2)
$b^4F-a^4G$	9-11	35812.37	M1	1.32(-2)	1.32(-2)

**Table 4.** continued

Multiplet	$2J-2J'$	$\lambda(\text{\AA})^a$	Type	$A_{ki}(\text{SST})$	$A_{ki}(\text{HFR})$
	9-9	31555.85	M1	1.41(-2)	1.42(-2)*
	9-7	29892.40	M1	1.68(-3)	1.50(-3)
	7-9	33380.21	M1	1.45(-3)	1.46(-3)
	7-7	31524.51	M1	2.02(-2)	2.00(-2)
	7-5	30807.67	M1	1.89(-3)	1.70(-3)
	5-7	32861.23	M1	1.79(-3)	1.75(-3)
	5-5	32083.06	M1	1.81(-2)	1.78(-2)
	3-5	33058.45	M1	1.50(-2)	1.49(-2)
$b^4F-b^2H$	9-11	28297.08	M1	1.43(-3)	1.97(-3)
	9-9	26906.50	M1	1.30(-3)	1.24(-3)
	7-9	28221.67	M1	1.36(-3)	1.68(-3)
$b^4F-a^2F$	9-7	21372.15	M1	1.95(-3)	2.43(-3)
	5-5	21356.90	M1	1.15(-3)	1.28(-3)
$b^4F-b^2G$	9-9	12897.48	M1	1.64(-2)	1.84(-2)
	7-9	13192.17	M1	5.85(-3)	6.55(-3)
	7-7	12568.65	M1	5.34(-3)	5.85(-3)
	5-7	12775.85	M1	4.77(-3)	5.21(-3)
$b^4F-b^4D$	9-7	11301.49	M1,E2	7.90(-3)	7.53(-3)
	7-7	11527.12	M1,E2	2.77(-3)	2.15(-3)*
	5-7	11701.16	M1,E2	1.26(-3)	1.11(-3)
	5-5	11833.06	M1,E2	3.29(-3)	3.25(-3)*
	5-3	11866.08	M1,E2	1.52(-3)	1.50(-3)
	5-1	11860.43	E2	1.22(-3)	1.84(-3)
	3-3	11996.99	M1,E2	2.75(-3)	2.81(-3)
	3-1	11991.22	M1,E2	4.33(-3)	4.25(-3)
$b^4F-b^2F$	7-7	10879.96	M1	1.10(-3)	1.28(-3)*
	5-7	11034.88	M1	1.31(-3)	1.68(-3)
$b^4F-c^2G$	9-9	9231.72	M1	1.75(-1)	1.84(-1)*
	9-7	9202.15	M1	1.08(-2)	1.15(-2)
	7-9	9381.72	M1	5.84(-2)	6.15(-2)
	7-7	9351.19	M1	8.15(-2)	8.68(-2)
	5-7	9465.41	M1	5.75(-2)	6.13(-2)
$b^4F-b^2D$	7-5	7437.01	M1	1.20(-2)	1.23(-2)
	5-5	7509.07	M1	1.61(-3)	1.64(-3)*
	3-5	7561.29	M1	1.37(-3)	1.36(-3)
$b^4F-c^2D$	7-5	6511.23	M1	1.57(-1)	1.56(-1)
	5-5	6566.40	M1	2.00(-2)	1.93(-2)*
	5-3	6544.77	M1	1.94(-1)	1.95(-1)
	3-5	6606.30	M1	7.72(-3)	7.55(-3)
	3-3	6584.40	M1	1.13(-1)	1.13(-1)
$a^4G-a^4G$	11-9	265496.60	M1	1.75(-3)	1.44(-3)
$a^4G-b^2H$	11-11	134843.19	M1	1.04(-3)	2.04(-3)*
$a^4G-a^2F$	9-7	66225.09	M1	3.60(-3)	3.74(-3)
	7-5	61004.37	M1	3.04(-3)	2.87(-3)
	5-5	63880.75	M1	2.30(-3)	2.32(-3)
$a^4G-b^2G$	9-9	21812.81	M1	2.87(-3)	3.81(-3)*
	7-7	20902.29	M1	2.73(-3)	3.36(-3)
	5-7	21229.82	M1	4.89(-3)	5.78(-3)
$a^4G-b^2F$	7-5	17147.42	M1	1.02(-3)	1.72(-3)
$a^4G-a^2I$	11-11	13363.31	M1	4.00(-3)	5.10(-3)*
$a^4G-c^2G$	11-9	12438.00	M1	8.07(-3)	1.02(-2)
	9-9	13049.34	M1	3.14(-3)	4.01(-3)*
	7-7	13294.91	M1	2.34(-3)	3.38(-3)*
	5-7	13426.66	M1	3.75(-3)	4.99(-3)
$a^4G-c^2D$	7-5	8206.20	M1	5.48(-3)	6.48(-3)
	5-5	8256.21	M1	4.99(-3)	6.23(-3)
$b^2P-b^2P$	3-1	87301.00	M1	2.70(-2)	2.68(-2)
$b^2P-b^4D$	3-5	17851.15	M1	6.61(-3)	6.83(-3)
	1-3	22558.60	M1	6.42(-3)	6.65(-3)
	1-1	22538.20	M1	2.35(-3)	2.41(-3)
$b^2P-b^2D$	3-5	9552.75	M1,E2	1.68(-2)	1.61(-2)
	3-3	9669.66	M1,E2	6.16(-2)	6.26(-2)
	1-3	10874.11	M1,E2	1.36(-2)	1.39(-2)
$b^2P-a^2S$	3-1	8739.06	M1	1.56(-1)	1.62(-1)
	1-1	9711.19	M1	1.55(-1)	1.60(-1)
$b^2P-c^2D$	3-5	8077.55	M1,E2	2.25(-2)	2.67(-2)
	3-3	8044.84	M1,E2	2.09(-2)	2.46(-2)
	1-3	8861.43	M1,E2	9.16(-3)	1.08(-2)
$b^2H-b^2G$	11-9	23699.43	M1	1.50(-2)	1.53(-2)
	9-9	24771.66	M1	2.00(-2)	2.01(-2)*
	9-7	22660.71	M1	1.44(-2)	1.44(-2)
$b^2H-a^2I$	11-13	14909.12	M1	1.35(-2)	1.44(-2)
	11-11	14833.34	M1	2.66(-2)	2.79(-2)*
	9-11	15246.38	M1	1.16(-2)	1.23(-2)
$b^2H-c^2G$	11-9	13701.87	M1	2.64(-2)	2.57(-2)
	9-9	14053.56	M1	5.27(-2)	5.28(-2)*
	9-7	13985.16	M1	2.93(-2)	2.94(-2)

**Table 4.** continued

Multiplet	$2J-2J'$	$\lambda(\text{\AA})^a$	Type	$A_{ki}(\text{SST})$	$A_{ki}(\text{HFR})$
$a^2F-b^2G$	7-9	32526.05	M1	6.37(-3)	7.19(-3)
	7-7	28981.21	M1	1.88(-2)	2.01(-2)
	5-7	31797.13	M1	5.67(-3)	6.31(-3)
$a^2F-b^4D$	7-7	23984.28	M1	1.21(-3)	1.12(-3)*
$a^2F-b^2F$	7-5	22231.47	M1,E2	1.11(-3)	1.86(-3)*
$a^2F-c^2G$	7-9	16251.65	M1	2.75(-2)	3.03(-2)
	7-7	16160.26	M1	5.63(-2)	6.01(-2)*
	5-7	16999.73	M1	1.85(-2)	1.93(-2)
$a^2F-b^2D$	7-5	11185.12	M1,E2	1.76(-3)	1.08(-3)
	5-5	11580.95	M1,E2	1.40(-3)	7.82(-4)*
	5-3	11753.22	M1,E2	5.25(-3)	4.66(-3)*
$a^2F-c^2D$	7-5	9214.68	M1,E2	4.17(-2)	4.26(-2)
	5-5	9481.66	M1	7.28(-2)	7.32(-2)
	5-3	9436.63	M1,E2	3.81(-2)	3.90(-2)
$b^4D-b^2D$	7-5	20959.78	M1	1.44(-3)	1.44(-3)
$b^4D-c^2D$	7-5	14963.71	M1	4.22(-2)	3.98(-2)
	5-5	14753.41	M1	8.88(-3)	8.83(-3)*
	5-3	14644.66	M1	4.86(-3)	4.68(-3)
	3-5	14702.40	M1	1.75(-2)	1.70(-2)
	3-3	14594.40	M1	1.40(-2)	1.38(-2)
	1-3	14602.95	M1	3.61(-2)	3.53(-2)
$b^2D-c^2D$	5-3	50965.15	M1	1.07(-2)	1.01(-2)
	3-5	49059.15	M1	7.85(-3)	7.45(-3)

<sup>a</sup> The wavelengths, given in air, are deduced from the observed energy levels compiled by Sugar & Corliss (1985).

\* Cancellation effects (see text).

**Table 5.** Comparison of the transition probabilities,  $A_{ki}$  in  $\text{s}^{-1}$ , calculated in the present work using SST and HFR with those obtained by Nussbaumer & Storey (1988) (NS) for the forbidden lines connecting the lowest four terms in Fe II.  $A(B)$  stands for  $A \cdot 10^B$

Multiplet	$2J - 2J'$	Type	NS	SST	HFR
$a^6D - a^6D$	9-7	M1	2.13(-3)	2.13(-3)	2.05(-3)
	7-5	M1	1.57(-3)	1.57(-3)	1.56(-3)
	5-3	M1	7.18(-4)	7.18(-4)	7.28(-4)
	3-1	M1	1.88(-4)	1.89(-4)	1.94(-4)
	9-9	M1	4.17(-5)	9.15(-5)	5.35(-5)
	7-9	M1	2.72(-6)	8.36(-6)	4.77(-6)
	9-7	M1	8.89(-6)	3.04(-5)	1.66(-5)
	7-7	M1	3.71(-5)	6.39(-5)	3.93(-5)
	5-7	M1	5.80(-6)	1.14(-5)	6.93(-6)
	7-5	M1	1.10(-5)	2.31(-5)	1.36(-5)
$a^6D - a^4F$	5-5	M1	2.47(-5)	3.69(-5)	2.37(-5)
	3-5	M1	5.73(-6)	8.89(-6)	5.67(-6)
	5-3	M1	6.14(-6)	9.87(-6)	6.18(-6)
	3-3	M1	1.09(-5)	1.51(-5)	9.90(-6)
	1-3	M1	2.71(-6)	3.74(-6)	2.46(-6)
	9-7	M1	5.84(-3)	5.84(-3)	6.01(-3)
	7-5	M1	3.92(-3)	3.92(-3)	4.17(-3)
	5-3	M1	1.41(-3)	1.41(-3)	1.53(-3)
	9-7	M1	4.83(-3)	4.74(-3)	5.18(-3)
	7-7	M1	1.33(-3)	1.31(-3)	1.44(-3)
$a^4F - a^4D$	5-7	M1	9.03(-4)	8.42(-4)	8.93(-4)
	9-5	E2	2.67(-6)	5.84(-6)	3.50(-6)
	7-5	M1	3.19(-4)	3.78(-4)	4.62(-4)
	5-5	M1	1.94(-3)	1.98(-3)	2.23(-3)
	3-5	M1	1.21(-3)	1.17(-3)	1.30(-3)
	7-3	E2	1.14(-6)	2.62(-6)	1.44(-6)
	5-3	M1	8.51(-5)	4.64(-5)	4.70(-5)
	3-3	M1	2.25(-3)	2.45(-3)	2.80(-3)
	1-3	M1	1.00(-3)	1.08(-3)	1.23(-3)
	3-1	M1	6.48(-4)	6.46(-4)	7.30(-4)
$a^4F - a^4D$	1-1	M1	2.91(-3)	3.32(-3)	3.82(-3)
	9-7	E2	4.65(-3)	5.98(-3)	5.73(-3)
	7-7	E2	1.03(-3)	1.32(-3)	1.25(-3)
	5-7	E2	1.13(-4)	1.46(-4)	1.35(-4)
	9-5	E2	2.44(-3)	3.12(-3)	3.00(-3)
	7-5	E2	1.94(-3)	2.49(-3)	2.38(-3)
	5-5	E2	1.43(-3)	1.82(-3)	1.72(-3)
	3-5	E2	2.32(-4)	2.98(-4)	2.78(-4)
	7-3	E2	3.28(-3)	4.18(-3)	4.03(-3)
	5-3	E2	9.20(-4)	1.18(-3)	1.13(-3)
$a^4D - a^4D$	3-3	E2	1.67(-3)	2.12(-3)	2.00(-3)
	5-1	E2	3.73(-3)	4.75(-3)	4.56(-3)
	3-1	E2	1.95(-3)	2.47(-3)	2.35(-3)
	7-5	M1	2.57(-3)	2.56(-3)	2.67(-3)
	5-3	M1	1.36(-3)	1.36(-3)	1.46(-3)
	3-1	M1	3.72(-4)	3.71(-4)	4.07(-4)
	7-5	M1	3.49(-3)	6.64(-3)	7.30(-3)
	5-5	M1,E2	6.94(-5)	1.20(-4)	1.38(-4)
	3-5	M1	2.73(-4)	5.02(-4)	5.40(-4)
	1-5	E2	7.13(-7)	6.69(-6)	5.10(-6)
$a^6D - a^4P$	7-3	E2	3.86(-5)	9.25(-5)	7.73(-5)
	5-3	M1	3.24(-3)	6.81(-3)	7.53(-3)
	3-3	M1,E2	1.73(-4)	3.76(-4)	4.09(-4)
	1-3	M1	4.94(-4)	9.80(-4)	1.07(-3)
	5-1	E2	8.18(-5)	2.03(-4)	1.87(-4)
	3-1	M1	2.84(-3)	6.23(-3)	6.95(-3)
	1-1	M1	8.82(-4)	1.93(-3)	2.14(-3)
	9-5	E2	2.73(-2)	3.56(-2)	3.12(-2)
	7-5	E2	6.51(-3)	8.37(-3)	7.20(-3)
	5-5	E2	1.17(-3)	1.47(-3)	1.25(-3)
$a^4F - a^4P$	3-5	E2	1.11(-4)	1.37(-4)	1.15(-4)
	7-3	E2	1.74(-2)	2.21(-2)	1.98(-2)
	5-3	E2	9.95(-3)	1.29(-2)	1.14(-2)
	3-3	E2	2.80(-3)	3.65(-3)	3.18(-3)
	5-1	E2	1.26(-2)	1.61(-2)	1.46(-2)
	3-1	E2	1.63(-2)	2.13(-2)	1.91(-2)

**Table 5.** continued

Multiplet	$2J - 2J'$	Type	NS	SST	HFR
$a^4D - a^4P$	7-5	M1,E2	1.84(-3)	2.23(-3)	2.30(-3)
	5-5	M1,E2	8.83(-4)	1.06(-3)	1.06(-3)
	3-5	M1,E2	2.76(-4)	3.67(-4)	3.82(-4)
	1-5	E2	2.89(-5)	3.36(-5)	3.22(-5)
	7-3	E2	1.92(-3)	2.25(-3)	2.23(-3)
	5-3	M1,E2	3.56(-5)	6.28(-5)	4.86(-5)
	3-3	M1,E2	5.79(-4)	6.35(-4)	6.74(-4)
	1-3	M1,E2	5.12(-4)	5.77(-4)	5.93(-4)
	5-1	E2	2.34(-3)	2.76(-3)	2.79(-3)
	3-1	E2	7.81(-4)	9.09(-4)	9.20(-4)
$a^4P - a^4P$	1-1	M1	1.13(-4)	4.04(-5)	9.90(-5)
	5-3	M1	1.91(-4)	1.86(-4)	3.05(-4)
	3-1	M1	5.59(-4)	5.51(-4)	7.65(-4)