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Solar log *gf* values for the spectral lines in the range λλ 6209 - 6273 Å

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Abstract. Utilizing Liège solar atlas and solar photospheric models, we derived log *gf* values for the spectral lines in the wavelength range λλ 6209 – 6273 Å. These values, intended for use in a future study of a high resolution reticon spectrum of the star γ Draconis, are presented along with some recent results available in the literature.

Key words : log *gf* – oscillator strengths – photospheric models – solar spectrum

1. Introduction

The determination of abundances from stellar spectra needs precise scales of oscillator strengths. The product of statistical weight and oscillator strength i.e., *gf,* is independent of the physical environs of the atom in which it gives rise to an emission or absorption spectrum. Reliable *gf* values for many lines, particularly the weak ones are still missing in the literature.

Oscillator strengths are determined either by theoretical means or by experimental techinques. For an excellent review on the subject we refer to Aller (1963), Führ (1987) and Blackwell (1990). Recent critically compiled data on log *gf* include Führ et al. (1988), Martin et al. (1988), Giridhar & Arellano Ferro (1989; 1995), the databases VALD (Pishkunov et al. 1995) and those referred to in the ASP Conferences Series vol. 77, 78 and 81. The CD-ROMs by Kurucz too contain valuable data and so does the database 61 of the National Institute of Standards and Technology (Martin et al. 1995a). In the literature we do come across several excellent laboratory studies, for example those by the Oxford, Kiel and Hannover groups, but their complete description is outside the scope of this paper.

The solar spectrum has successfully been used to derive oscillator strengths for molecular lines (Grevesse & Sauval 1992; Sinha 1993; Sauval & Grevesse 1994). It has also been used for atomic lines by several groups as mentioned below.

The use of equivalent widths or central line depths taken from the Liège solar atlas in combination with the HM photospheric model (Holweger & Müller 1974; abbreviated as HM) provides *gf* values which are accurate to within 50% (Führ 1987; Blackwell 1990). Such an effort initiated by Gurtovenko & Kostik (1981, abbreviated as GK; 1982) resulted in a compilation for 1958 lines from 40 chemical elements (Gurtovenko & Kostik 1989). These authors were aware of the uncertainties caused by any deficiencies in the knowledge of solar abundances, solar atmospheric structure, equivalent widths, damping constants, hyperfine structure, micro and macro-turbulence, blending, non - LTE effects etc. (Gurtovenko et. al. 1990). Though this technique is not suitable for nearly saturated strong lines it has found a wide use by several investigators (Rutten & van der Zalm 1984; Thévenin 1989, 1990; Erdelyi - Mendes & Barbuy 1989; Shchukina & Perkhod 1994; Johansson et al. 1994; Ryabchikova et al. 1994; Ryabchikova 1995). These solar values are important because sometimes they are the only available values, especially for weak lines and are often more reliable than the measured values (Blackwell 1990).

Thévenin's (1989; 1990) is the largest single source of solar log *gf*. They utilized the Liège atlas (Delbouille et al. 1973) for the entire λλ 4006 - 7950 Å region of the spectrum and presented values for more than 6000 lines of about 35 chemical elements. However, he preferred to use a solar model due to Bell et al. (1976) in place of the well accepted HM model for some reasons. Further, the elemental abundances have been taken from Holweger (1979) which have since been revised. The equivalent widths of iron lines from Rutten & van der Zalm (1984) in combination with these log *gf* yield solar iron abundance significantly lower than what Rutten & van der Zalm (1984) themselves obtained. The remarks by Giridhar & Arellano Ferro (1995) on the Fe II oscillator strengths regarding systematic and random errors in the work by Thévenin (1989; 1990) make it less dependable. This uncertainty coupled with the lack of oscillator strengths for some lines in the λλ 6209 - 6273 Å region prompted us to derive an internally consistent set of log *gf* values which we intend to use in a future investigation of the star γ Draconis. We have obtained a high resolution reticon spectrum for this star.

2. Formulation of the problem

2.1 *The astrophysical method*

Closely following GK and Kostik et al. (1996), we believe that the central line depths defined by $D = (I_{cont} - I_{line}) / I_{cont}$ and taken from the Liège atlas of the solar spectrum when matched with the calculated spectrum based on the photospheric model HM should yield fairly accurate log *gf* values. Besides the simplicity and the short computer time needed for calculations, the advantage of the method is that the D values are considerably less blended in comparison with line profiles. The corrections for the instrumental profile of the Liège atlas can be neglected as they are negligibly small (≈0.1%). However, considering that there should not be an error exceeding 1% in measurements of the central depths of the lines, utilizing the Fe lines of different intensities, GK analysed the differences Δ log *gf* arising from this uncertainty and concluded that these differences depend only slightly upon the excitation potential and the wavelength and that they do depend upon line intensities. The faint and strong lines are affected inappreciably. The observational errors for the saturated lines are large (cf. Figure 8 of GK).

Therefore all lines with central depths in excess of 0.85 have not been included in the study. Also Gurtovenko & Kostik (1989) have shown that errors remain small as long as the central line depths do not exceed 0.8. The precedure is, however, sensitive to the choice of macroturbulence and departures from LTE. GK further state that the influence of the errors of damping constant appear to be almost negligible (±0.015 dex) when we change γ within (2.5 ± 1.0) γ_6.

2.2 *Computer programmes*

The computer programmes for the generation of the synthetic spectrum were written and provided to us by Dr. Y. Chmielewski and we have tested them on our machines (Sinha & Sanwal, 1992). Aimed at the analysis of a given spectrum, the programme consists of three parts. Programme ATM prepares a complete model atmosphere and puts it in the structure and format required for use in the spectrum synthesis programme ADRSL. In ATM, we have a provision for changing the default abundances of 21 principal elements. ADRSL computes synthetic stellar spectra of K to late F stars in the framework of LTE formalism. It is derived from a programme originally written in ALGOL by Baschek et al. (1966) and translated into FORTRAN by Peytremann et al. (1967). Programme TCONV performs the convolutions on the synthetic spectrum.

2.3 *Our approach*

The Liège atlas of the solar spectrum and an atlas of the solar spectrum wavelengths due to Moore et al. (1966, abbreviated as MMH) helped us to identify the lines in the spectral range of our interest. Iterations were performed on log *gf* values till the absorption peaks in the synthetic spectra matched with the observed solar spectra. This leads us to a set of solar log *gf* values. The results obtained with the use of two solar models are listed below in different tables. For the HM model we used a depth independent microturbulence = 1.0 km s^{-1}, whereas for the MACKKL model due to Maltby et al. (1986), the depth dependent values, as given in the model were utilized. Macroturbulence of 1.52 km s^{-1} was assumed.

3. Results and discussions

In Table 1 the elemental abundances utilized or given by different authors are presented. The present work closely follows Anders & Grevesse (1989) except where revised by Grevesse & Noels (1993). An inter-comparison between the different columns shows the changes in the recommended values of abundances over the years. It may be pointed out that Thévenin (1989; 1990) utilized the abundances given by Holweger (1979) and a solar model based upon the abundances given by Gustafsson et al. (1975). In our preliminary study, we depended upon Anders & Grevesse (1989), Lambert (1978) and Lambert & Luck (1978). The Ne and Ar abundances are the default abundances utilized in the computer code. We recalculated the electron and the gas pressures for the model following Neuforge (1993), used the new set of abundances and the code ATM (cf. section 2.2.). In Table 2, we show that the effects of such changes can be considered inappreciable on the calculations of log *gf*.

Table 1. The different sets of elemental abundances.

Atomic Number	Element	Holweger (1979)	Gustafsson et al. (1975)	In a Preliminary study	Grevesse (1984)	Anders & Grevesse (1989) Grevesse & Noels (1993)
01	Hydrogen	12.00	12.00	12.00	12.00	12.00
02	Helium	11.00	11.00	10.99	11.00	10.99
06	Carbon	8.67	8.55	8.67	8.69	8.55
07	Nitrogen	7.99	7.93	7.99	7.99	7.97
08	Oxygen	8.92	8.77	8.92	8.91	8.87
10	Neon	7.73	8.51	7.70	8.00	8.07
11	Sodium	6.28	6.18	6.32	6.33	6.33
12	Magnesium	7.53	7.48	7.62	7.58	7.58
13	Aluminium	6.43	6.40	6.49	6.47	6.47
14	Silicon	7.50	7.55	7.63	7.55	7.55
15	Phosphorous	5.35	5.51	5.45	5.45	5.45
16	Sulphur	7.20	7.21	7.23	7.21	7.21
18	Argon	6.83	6.62	6.00	6.58	6.56
19	Potassium	5.05	5.05	5.12	5.12	5.12
20	Calcium	6.36	6.33	6.34	6.36	6.36
21	*Scandium	2.99	3.20	3.10	3.10	3.10
22	Titanium	4.88	4.28	4.99	5.02	5.03
23	*Vanadium	3.91	3.66	4.00	4.00	4.00
24	Chromium	5.61	5.47	5.67	5.67	5.67
25	Manganese	5.47	4.88	5.39	5.45	5.39
26	Iron	7.46	7.50	7.51	7.67	7.51
27	Cobalt	4.85	4.30	4.92	4.92	4.92
28	Nickel	6.18	5.08	6.25	6.25	6.25

* Not included while calculating gas pressure and electron pressure of the model atmosphere (cf. section 3).

Table 2. Derivation of log *gf* for the lines of Fe with the help of HM model atmosphere and the Liège atlas.

Wavelength (Å)			Log *gf*						Differences	
			Solar							
MMH Fe	Liège	Central Depths	1	2	3	T	GK	Others	(1-2)	(2-3)
6209.754	.724	.0070	-3.75	-3.75	-3.90	-3.63			0.00	0.15
6212.067	.020	.0289	-2.81	-2.77	-2.93	-2.75			-0.04	0.16
6213.437	.438	.6683	-2.61	-2.62	-2.78	-2.61	-2.66	-2.48 (NJLBT) -2.60 (NIST)	-0.01	0.16
6219.287	.290	.6968	-2.44	-2.44	-2.60	-2.42	-2.46	-2.43 (NJLBT) -2.422 (BK) -2.43 (NIST)	-0.01	0.16

Table 2. Continued.

Wavelength (Å)			Log *gf*						Differences	
			Solar							
MMH	Liège	Central Depths	1	2	3	T	GK	Others	(1-2)	(2-3)
Fe										
6220.791	.780	.1768	-2.40	-2.39	-2.55	-2.48	-2.46	-2.46 (NJLBT) -2.50 (NIST) -2.20 (NIST)	-0.01	0.16
6221.643	.678	.0150	-6.45	-6.45	-6.60	-6.19			0.00	0.15
6226.740	.740	.2701	-2.15	-2.14	-2.30	-2.21	-2.22	-2.22 (NJLBT) -2.20 (NIST)	-0.01	0.16
6229.232	.232	.3636	-2.94	-2.93	-3.09	-3.02	-3.02	-2.97 (NJLBT) -2.805 (BKK) -3.00 (NIST)	-0.01	0.16
6232.648	.650	.6405	-1.29	-1.29	-1.45	-1.33		-0.96 (NJLBT) -1.223 (BK)	0.00	0.16
6240.318	.312	.1534	-2.23	-2.22	-2.37	-2.29	-2.28		-0.01	0.15
6240.653	.652	.4864	-3.29	-3.27	-3.44	-3.41	-3.36	-3.17 (NJLBT) -3.233 (BKK) -3.40 (NIST)	-0.02	0.17
6246.327	.328	.7166	-0.72	-0.72	-0.88	-0.70	-0.68	-0.88 (NJLBT) -0.733 (BKK)	0.00	0.16
6249.643	.636	.0684	-3.35	-3.34	-3.50	-3.38			-0.01	0.16
6251.286	.224	.0118	-3.00	-2.97	-3.13	-2.71			-0.03	0.16
6252.565	.564	.7412	-1.69	-1.70	-1.86	-1.72	-1.67	-1.69 (NJLBT) -1.69 (NIST)	-0.01	0.16
6253.834	.832	.1704	-1.62	-1.59	-1.75	-1.62	-1.66	-1.66 (NJLBT) -1.70 (NIST)	-0.03	0.16
6265.141	.142	.6778	-2.58	-2.58	-2.74	-2.64		-2.55 (NJLBT) -2.55 (NIST)	0.00	0.16
6270.231	.232	.5016	-2.61	-2.60	-2.76	-2.71	-2.69	-2.61 (NJLBT) -2.464 (BKK) -2.70 (NIST)	-0.01	0.16
6271.283	.284	.2318	-2.78	-2.77	-2.93	-2.85	-2.84	-2.703 (BK)	-0.01	0.16
6271.495	.472	.0270	-2.61	-2.61	-2.77	-2.56			0.00	0.16
Fe^+										
6233.498	.498	.0266	-2.95	-2.94	-3.08	-2.70		-2.51 (GAF)	-0.01	0.14
6239.948	.940	.1177	-3.60	-3.60	-3.74	-3.59		-3.68 (FMW) -3.40 (GAF) -3.70 (NIST)	0.00	0.14
6247.562	.564	.4729	-2.52	-2.52	-2.66	-2.55		-2.51 (FMW) -2.41 (GAF) -2.50 (NIST)	0.00	0.14
6248.910	.896	.0377	-2.74	-2.76	-2.92	-2.62		-2.43 (GAF)	0.02	0.16
6269.962	.962	.0557	-4.55	-4.56	-4.71				0.01	0.15

Codes :

1 : Preliminary study with microturbulence = 1.00 km/sec and Unsöld's (1955) formula for van der Waals coefficient C_6.

2 : Present study with microturbulence = 1.00 km/sec and enhancement factors for C_6 as recommended by Holweger et al. (1990) and Holweger et al. (1991) and abundances from Anders & Grevesse (1989) and Grevesse & Noels (1993).

3 : Same as 2 but with abundances from Grevesse (1984) which gives N (Fe) = 7.67.

BK	: Bard & Kock (1994)
BKK	: Bard et al. (1991).
FMW	: Führ et al. (1988).
GAF	: Giridhar & Arellano Ferro (1995).
GK	: Gurtovenko & Kostik (1981).
Liège	: Delbouille et al. (1973).
MMH	: Moore et al. (1966).
NIST	: Martin et al. (1995b).
NJLBT	: Nave et al. (1994).
T	: Thévenin (1990).

3.1 *The solar iron abundance*

Since a lot of iron lines are found in the present work, it may not be out of place here to mention the current controversy regarding solar abundance of iron. The key question is whether the solar abundance of iron is *equal to or higher than* the iron abundance 7.51 ± 0.01 obtained from the carbonaceous chondrites. Figure 1 in Holweger (1995) shows that all the elements except C,N, O and Li have same abundances in the sun and meteorites. There are reasons for the C, N, O and Li abundances to be dissimilar. No such reasons have been put forth for iron. However, the rapidly changing scenario on iron can be followed in excellent reviews by Grevesse and his group and in the papers cited by them. In all fairness, it must be said that all data and all ideas have been given due considerations in order to derive the solar abundance of iron. For a brief recap we quote :

> Grevesse (1984) : "*The reported solar abundance of iron is 7.67 ± 0.03 "Also very puzzling are the small differences observed for Fe and Ti, which could well be significant, because the uncertainties of the solar results are probably smaller than the observed differences. If the differences betweem the solar and the meteoritic abundances are confirmed, even small differences would have important consequences as far as the thermal and the chemical history of the early phases of the formation of the solar system is concerned".*

> Anders & Grevesse (1989) : *"Thus the question of the solar iron abundance remains in a state of flux, but there is hope that full agreement will soon be reached by joint efforts of atomic physicists and astronomers".*

> Grevesse (1992) : *"In summary we believe the solar abundance to be higher than the meteoritic value by 25 to 40%. We nevertheless urgently need very accurate gf-values for the numerous very good Fe II lines that are present in the solar spectrum in order to settle definitely the question".*

Grevesse & Noels (1993) : *"Since then, new accurate transition probabilities have been obtained for higher excitation lines in Fe I as well as for Fe II lines of solar interest. With these data, the photospheric abundance of iron has been revisited by different groups. These analyses show that the photospheric abundance of iron now agrees with the meteoritic value. The high value obtained from the low excitation Fe I lines still remains to be explained. A possible explanation of this discrepancy could come from a slight overestimation of the temperature distribution in the layers where those lines are formed, which could hardly affect higher excitation Fe I lines and Fe II lines".*

Kostik et al (1996) : *"The results seem to confirm the "high" value rather than the "low" one. However, they do not have much significance if the trend differences between the remaining lines are not explained. We, therefore see no compelling reason to reject equality between the solar and the meteoritic line abundance at present. The moral of this paper is that it won't be proven as long as the input oscillator strengths remain disputable and classical abundance determination is not validated by more realistic modeling. The last word on the photospheric iron abundance is* **not** *in"*

Thus, inspite of many very active groups working the world over, the scenario remains far from satisfactory with claims and counter - claims being incessantly put up by the different groups (Biemont et al. 1991; Holweger et al. 1995; Blackwell et al. 1995; Kostik et al. 1996). In the absence of a physical cause in support of a difference in the meteoritic and the solar abundance of iron, we are inclined to accept the meteoritic value and hope that the solution may perhaps lie in the analysis. In this context we refer to yet another important paper by Bikmaev (1995).

3.2 *Our results*

In Table 2 the results of calculations for the iron lines in the spectral region of our interest are presented. Data from current literature are also culled for comparison of our results with some of the latest values. We would like to point out that in agreement with Thévenin (1989) a realistic continuum energy level which is 1.25% lower than that of the Liège atlas was used. The two last columns of the table clearly demonstrate that (i) the selection of the damping constant is inconsequential in the method of fits for the central line depths (cf. section 2.1) and (ii) the differences in the input elemental abundances are reproducible. We have tabulated results from Thévenin (1989) for the sake of a comparison only. The reader is free to draw conclusions from comparisons between columns 5 and 9.

3.3 *Gurtovenko and Kostik's (1981) results*

GK used almost the same parameters as we have used in this study for iron abundance, micro and macroturbulence velocities and the photospheric model. As a consequence of this, the log *gf* values reported in Table 2 for the 12 lines, common to both the studies, should have been similar, if not the same. It may, however, be recalled that GK normalised the log *gf* values to the scale by Blackwell et al. (1976) and Blackwell et al. (1979) and they revised their own input abundance from 7.525 ± 0.007 to 7.57± 0.01 for the sake of internal consistency. Adopting the same procedure for the common lines and using the same symbols., we get

Table 3. Derivation of log *gf* for the lines of Ni, Sc, Si, Ti and V with the help of HM model atmosphere and the Liège atlas.

Wavelength (Å)			Log *gf* Solar					Differences	
MMH	Liège	Central Depths	1	2	3	T	Others	(1-2)	(2-3)
Ni									
6223.990	.988	.2574	-1.01	-1.01	-1.01	-1.08	-0.98(NIST)	0.00	0.00
6230.098	.098	.1827	-1.22	-1.23	-1.23	-1.28	-1.30 (NIST)	0.01	0.00
6259.594	.598	.1439	-1.34	-1.34	-1.34	-1.38		0.00	0.00
6271.767	.772	.0390	-2.70	-2.70	-2.70	-2.66	-2.62 (FMW) -2.60 (NIST)	0.00	0.00
Sc									
6210.671	.668	.0221	-1.66	-1.67	-1.67	-1.67	-1.57 (MFW) -1.53 (NIST)	0.01	0.00
6239.361	.360	.0632	-1.21	-1.21	-1.21	-1.23		0.00	0.00
6239.771	.792	.0253	-1.62	-1.62	-1.63	-1.70	-1.82 (MFW) -1.80 (NIST)	0.00	0.01
6258.936	.968	.0086	-2.09	-2.10	-2.09	-1.58	-1.84 (MFW) -1.80 (NIST)	0.01	-0.01
Sc^+									
6245.620	.620	.3022	-1.13	-1.14	-1.13	-1.15		0.01	-0.01
Si									
6220.211	.222	.0804	-2.00	-1.92	-1.92			-0.08	0.00
6237.328	.326	.3986	-1.28	-1.20	-1.19	-1.22	-1.138 (L)	-0.08	-0.01
6243.823	.818	.3441	-1.41	-1.33	-1.32	-1.34		-0.08	-0.01
6244.118	.112	.0496	-2.50	-2.42	-2.42	-2.33		-0.08	0.00
6244.476	.474	.3302	-1.44	-1.36	-1.36	-1.38	-1.363(L)	-0.08	0.00
6253.550	.598	.0107	-3.80	-3.72	-3.71	-3.23		-0.08	-0.01
6254.845	.844	.0270	-2.80	-2.70	-2.69	-2.45	-2.561 (L)	-0.10	-0.01
Ti									
6220.488	.476	.0879	-0.26	-0.30	-0.29	-0.30	-0.084 (L) -0.14 (MFW) -0.14 (NIST)	0.04	-0.01
6258.110	.110	.4933	-0.37	-0.41	-0.40	-0.46	-0.299 (L) -0.355 (MFW) -0.355(NIST)	0.04	-0.01
6258.713	.716	.5322	-0.25	-0.29	-0.28	-0.30	-0.184 (L) -0.24 (MFW) -0.24 (NIST)	0.04	-0.01
6266.015	.014	.0082	-2.25	-2.26	-2.25	-2.10		0.01	-0.01
V									
6213.866	.868	.0431	-1.90	-1.91	-1.91	-2.01	-2.05 (MFW) -2.10 (NIST)	0.01	0.00
6216.358	.360	.2932	-0.98	-0.99	-0.99	-1.09	-1.29 (MFW) -1.30 (NIST)	0.01	0.00
6224.506	.508	.0505	-1.84	-1.83	-1.83	-1.85	-2.01 (MFW) -2.00 (NIST)	-0.01	-0.00
6233.201	.198	.0372	-2.00	-2.00	-2.00	-1.94	-2.07 (MFW) -2.10 (NIST)	0.00	0.00

Table 3. Continued.

Wavelength (Å)					Log *gf*			Differences	
					Solar				
MMH	Liège	Central Depths	1	2	3	T	Others	(1-2)	(2-3)
V									
6242.838	.826	.0737	-1.70	-1.70	-1.70	-1.72	-1.55 (MFW) -1.60 (NIST)	0.00	0.00
6243.114	.112	.2416	-1.08	-1.07	-1.08	-1.18	-0.98 (MFW) -0.98 (NIST)	-0.01	0.01
6251.825	.822	.1109	-1.49	-1.50	-1.50	-1.55	-1.34 (MFW) -1.30 (NIST)	0.01	0.01
6256.887	.887	.0227	-2.21	-2.22	-2.22	-2.14	-2.01 (MFW) -2.00 (NIST)	0.01	0.00
6258.573	.588	.1491	-1.38	-1.38	-1.38	-1.47	-2.04 (MFW) -2.00 (NIST)	0.00	0.00
6266.326	.324	.0220	-2.22	-2.22	-2.22	-2.12	-2.29 (MFW) -2.30 (NIST)	0.00	0.00
V^+									
6226.320	.298	.0090	-2.46	-2.46	-2.45	-1.92		0.00	-0.01

Codes :

1 : Preliminary study with microturbulence = 1.00 km/sec and Unsöld's (1955) formula for van der Waals coefficient C_6.

2 : Present study as at 1 and abundances from Anders & Grevesse (1989) and Grevesse & Noels (1993).

3 : Same as at 1 but with abundances from Grevesse (1984).

BK : Bard & Kock (1994).
BKK : Bard et al. (1991).
FMW : Führ et al. (1988).
GAF : Giridhar & Arellano Ferro (1995).
GK : Gurtovenko & Kostik (1981).
L : Luck (1995, Private communication).
Liège : Delbouille et al. (1973).
MFW : Martin et al. (1988).
MMH : Moore et al. (1966).
NIST : Martin et al. (1995b).
NJLBT : Nave et al. (1994).
T : Thévenin (1990).

Table 4. Comparision of log gf values derived using HM and MACKKL models for the lines of Fe, Ni, Sc, Si, Ti, and V(cf. Section 3.5).

Wavelength (Å)		Log *gf*		
MMH	Liège	HM	MACKKL	Differences
Fe				
6209.754	6209.724	-3.75	-3.80	0.05
6212.067	6212.020	-2.77	-2.81	0.04
6213.437	6213.438	-2.62	-2.75	0.13
6219.287	6219.290	-2.44	-2.60	0.16
6220.791	6220.780	-2.39	-2.43	0.04
6221.643	6221.678	-6.45	-6.55	0.10
6226.740	6226.740	-2.14	-2.18	0.04
6229.232	6229.232	-2.93	-2.99	0.06
6232.648	6232.650	-1.29	-1.40	0.11
6240.318	6240.312	-2.22	-2.25	0.03
6240.653	6240.652	-3.27	-3.35	0.08
6246.327	6246.328	-0.72	-0.91	0.19
6249.643	6249.636	-3.34	-3.39	0.05
6251.286	6251.224	-2.97	-3.00	0.03
6252.565	6252.564	-1.70	-1.96	0.26
6253.834	6253.832	-1.59	-1.63	-0.04
6265.141	6265.142	-2.58	-2.72	0.14
6270.231	6270.232	-2.60	-2.67	0.07
6271.283	6271.284	-2.77	-2.81	0.04
6271.495	6271.472	-2.61	-2.65	0.04
Fe^+				
6233.498	6233.498	-2.94	-2.90	-0.04
6239.948	6239.940	-3.60	-3.60	0.00
6247.562	6247.564	-2.52	-2.54	0.02
6248.910	6248.896	-2.76	-2.73	-0.03
6269.962	6269.962	-4.56	-4.55	-0.01
Ni				
6223.990	6223.988	-1.01	-1.04	0.03
6230.098	6230.094	-1.23	-1.25	-0.02
6259.594	6259.598	-1.34	-1.38	0.04
6271.767	6271.772	-2.70	-2.75	0.05
Sc				
6210.671	6210.668	-1.67	-1.77	0.10
6239.361	6239.360	-1.21	-1.30	0.09
6239.771	6239.792	-1.62	-1.73	0.11
6258.966	6258.968	-2.10	-2.20	0.10
6245.620	6245.620	-1.14	-1.16	0.02
Si				
6220.211	6220.222	-1.92	-1.94	0.02
6237.328	6237.326	-1.20	-1.22	0.02
6243.823	6243.818	-1.33	-1.35	0.02
6244.118	6244.112	-2.42	-2.44	0.02
6244.476	6244.474	-1.36	-1.38	0.02

Table 4. Continued.

Wavelength (Å)		Log *gf*		
MMH	Liège	HM	MACKKL	Differences
Fe				
6244.476	6244.474	-1.36	-1.38	0.02
6253.550	6253.598	-3.72	-3.71	-0.01
6254.845	6254.844	-2.70	-2.71	0.01
Ti				
6220.488	6220.476	-0.30	-0.35	0.05
6258.110	6258.110	-0.41	-0.48	0.07
6258.713	6258.716	-0.29	-0.37	0.08
6266.015	6266.014	-2.26	-2.33	0.07
V				
6213.866	6213.868	-1.91	-2.00	0.09
6216.358	6216.360	-0.99	-1.06	0.07
6224.506	6224.508	-1.83	-1.93	0.10
6233.201	6233.198	-2.00	-2.10	0.10
6242.838	6242.826	-1.70	-1.79	0.09
6243.114	6243.112	-1.07	-1.14	0.07
6251.825	6251.822	-1.50	-1.57	0.07
6256.887	6256.887	-2.22	-2.32	0.10
6258.573	6258.588	-1.38	-1.45	0.07
6266.326	6266.324	-2.22	-2.32	0.10
V+				
6226.320	6266.298	-2.46	-2.46	0.00

Codes:

MMH : Moore et al. (1966).
Liège : Delbouille et al. (1973).
HM : Holweger & Müller (1974).
MACKKL : Maltby et al. (1986).

ϵ = 0.02 and abundance of iron as 7.57 ± 0.02 consistent with GK. However the lines at 6246.328 Å and 6252.564 Å with central depths between 0.701 and 0.800 were not included by us in this calculation; GK utilized a different macroturbulence velocity for these lines to account for the non-LTE effects. The differences in damping constants are inconsequential for the calculation of log *gf* (cf. section 2.1).

3.4 *The elements Ni, Sc, Si, Ti and V*

The HM based results for these elements are given in Table 3. The presentation of the results is the same as that for the iron lines in Table 2. The differences given in the last column strengthen the conclusions related to the damping constants and input abundances reached above with the iron lines.

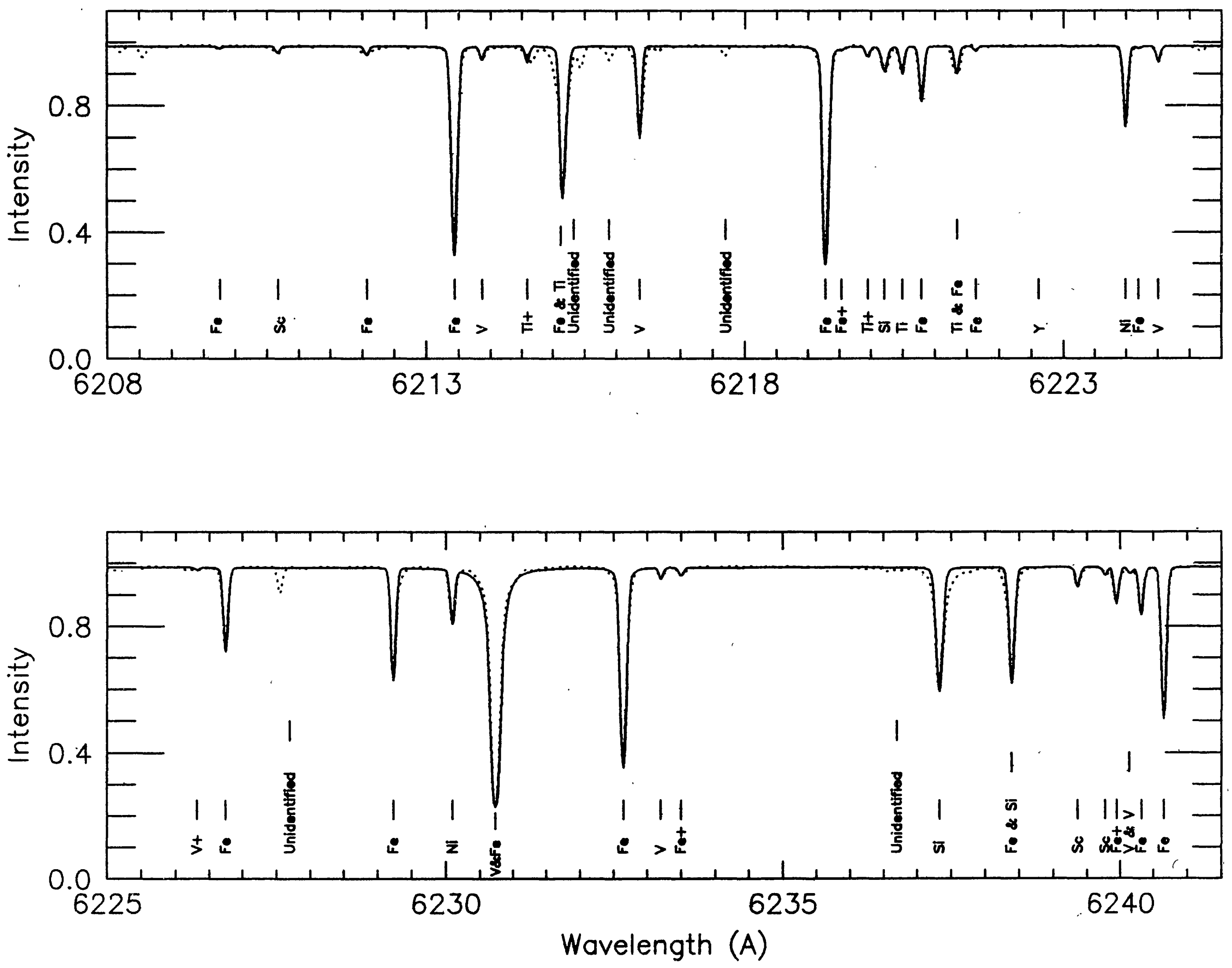

Figure 1. The computed (continous line) and the observed (dotted line) solar spectra in the wavelength region λλ 6208 - 6241 Å. For details see sections 3.2 and 3.4.

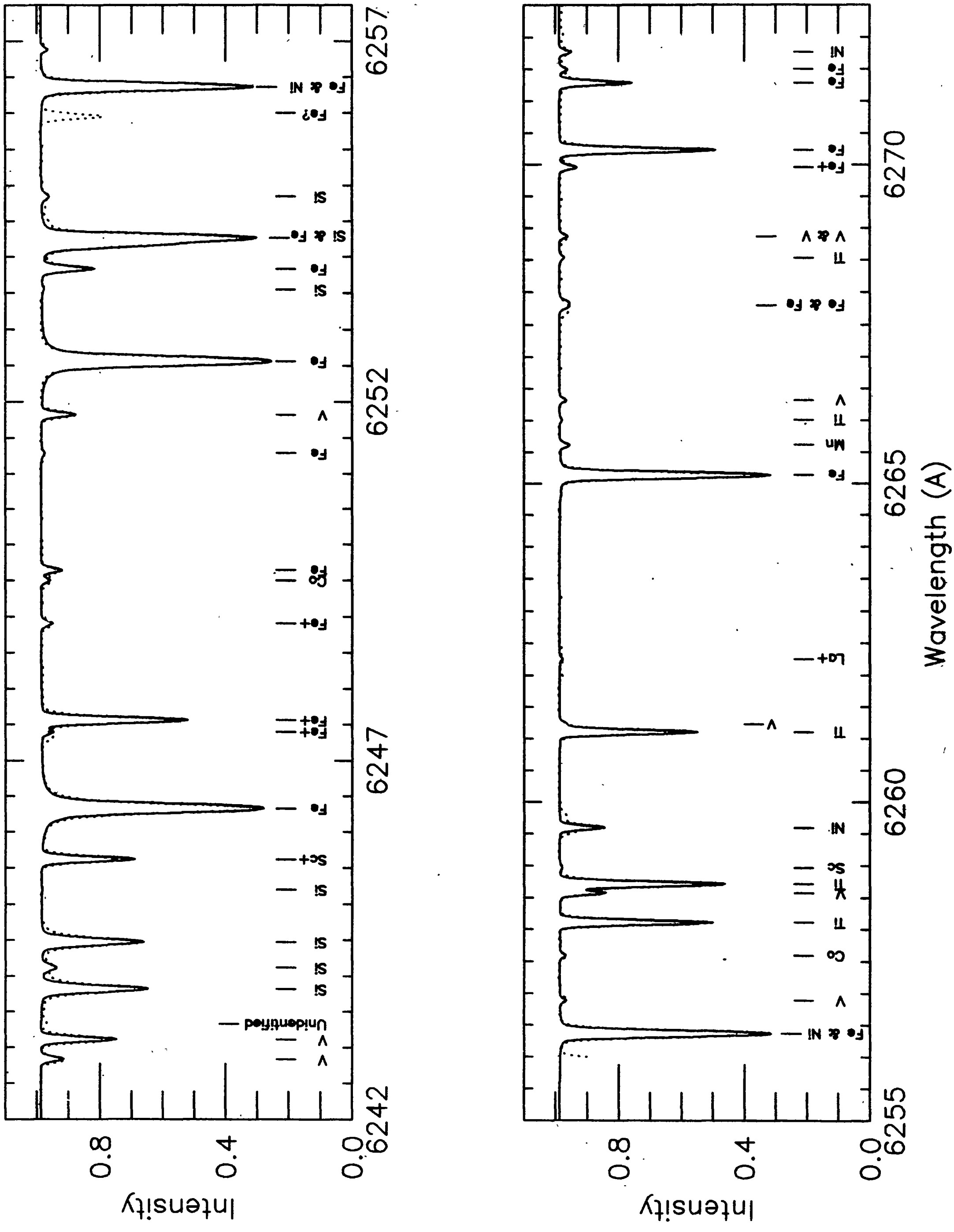

Figure 2. Same as Figure 1 but for the λλ 6242 - 6217 Å region of the solar spectrum.

3.5 *Effect of choice of model atmospheres*

In Table 4 we show that the log *gf* values derived here are dependent upon the chosen model atmosphere. The HM results are compared with the MACKKL results and we note that iron lines seem to be more sensitive than the lines due to other atoms. The elemental abundances are from Anders & Grevesse (1989) and Grevesse & Noels (1993). The van der Waals coefficients for the iron lines are enhanced following Holweger et al. (1990) and Holweger et al. (1991). Considering little or no effect of this parameter on the derived log *gf* or abundances in the method used here (cf. section 2.1), these were calculated following Unsöld (1995) for atomic lines other than those of iron.

However, the HM photospheric model atmosphere continues to enjoy the confidence of many solar physicists.

3.6 *Synthetic spectrum*

In Figures 1 and 2 we attempt to show the fit of the central depths to the computations. The van der Waals coefficients for iron lines have been used as per the recommendations by Holweger et al. (1990) and Holweger et al. (1991). No enhancement factors were used for this coefficient for other lines.

4. Conclusions

In Tables 2 and 3 and Figures 1 and 2 we have been able to present the results of our calculatons for log *gf* for several lines of interest to us. The central line intensity method described by GK was used. We hope to use the reported log *gf* in our study of the spectrum of the star γ Draconis.

Keeping in view the different parameters used in several other studies, which are being debated and doubted, to solve the iron controversy, we do not normalise the log gf values obtained here and presented in Tables 2-4. The reader may do so, if he will, at his own risk.

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