

Солнце The Sun

The solar element abundances and the scale of Kurucz and Peytremann's oscillator strengths

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In a previous work (Dobrichev, Raikova, 1981) we have tested the intrinsic consistency of the oscillator strengths from Kurucz and Peytremann's (1975) list using the curve of growth for selected lines in the solar spectrum. However, this method says nothing about the zero point of the oscillator strength system.

Using these curves of growth we have determined the abundances of eleven chemical elements in the solar atmosphere. During the last fifteen years the classical method of curves of growth has been rarely used and mainly for relatively faint and nonstationary stars when either the observational material or the nature of the object itself allow only rough investigations and estimates. Its principal disadvantage is the tacit assumption of the homogeneity of the atmosphere although it is *a priori* clear that all the characteristics as temperature, pressure, ionization state, etc. change with depth.

The modern methods of analyzing stellar atmosphere use model atmospheres which accounts precisely for these changes and should give more exact results. In practice, however, it turns out that for a given star on the basis of the same observational data and oscillator strengths different models often give quite different results. It is the same with the Sun although the solar atmosphere models are considered to be the best due to the detailed observational data to fit with.

For instance, the titanium abundance $\log A_{\text{Ti}}$ derived from TiI lines with Oxford oscillator strengths (Blackwell et al., 1982) is 4,90 using the Vernazza et al. (1976) model atmosphere and 5,08 using the Holweger and Müller's (1974) one. $\log A_{\text{Fe}}$ derived from ground level FeI solar lines is 7,440 and 7,640 respectively (Blackwell, Shllis, 1979). Such differences are due to the differing temperature structure and other details of the two models.

There is an opinion (Blackwell et al., 1976) that the main cause of uncertainty in the solar abundances now lies probably with the models rather than in oscillator strengths, microturbulence or thermodynamic equilibrium

details. In view of all this the results obtained by the classical curve of growth method may be considered representative within some accuracy.

Through the differences of the abscissae of the theoretical curve of growth

$$(1) \quad X_0 = \log \frac{\sqrt{\pi} e^2}{m_e C} + \log N_r + \log (gf \lambda) - \theta_e \epsilon_i - \log (\kappa_\lambda v_D U_r)$$

and the empirical curves (Dobrichiev, Raikova, 1981) the number densities per gram N_r have been found for r -times ionized atoms. We have adopted $v_D = 1,57$ km/s. The partition function $U_r(T)$ values have been taken from Drawin and Felenbok (1965). The continuous absorption coefficient per gram of stellar material κ_λ has been computed from the Bode's (1965) tables for the ratio of the numbers of atoms He/H=1/10. For each ion a value of κ_λ has been adopted corresponding to the middle of the wavelength range of the lines used. Thus for the wavelength of a given line an error in $\log \kappa_\lambda$ not more than 0.1 dex may occur, but the ensemble of lines does not shift and the error of the obtained column density is considerably smaller.

Electron number densities $\log n_e$ found from Sc, Ti, V, Cr and Fe (for $\theta = 0,916, T_i = 5500$ K) are respectively 12,73; 12,57; 12,40; 12,33 and 12,71. Because of the large number of used lines, the data for Fe are the best ones. The large deviations of $\log n_e$ obtained from Ti, V and Cr show that at least for one of the used ionization states the result is not good and the intrinsic consistency of the oscillator strengths is bad. As a probable source of inaccuracy we consider the zero point of the oscillator strength scale. We have adopted $\log n_e = 12,72$ (from Sc and Fe) to use in the Saha equation.

The number densities per gram ($\log N$) of the atoms of different chemical elements derived from one or two ionization states are given in Table 1. They are compared with a compilation of the available relative abundances $\log A_{st}$ obtained after 1970 without Kurucz and Peytremann's oscillator strengths. It is as follows: for titanium — 12 determinations from 10 authors (Blackwell et al., 1982; Grevesse, 1970b; Wolnik and Berthel, 1973; Biéumont, 1974a, b; Foy, 1975; Bell et al., 1975; Ellis, 1976; Whaling et al., 1977; Gehlsen et al., 1978), for chromium — 6 determinations from 5 authors (Grevesse, 1970a; Cocke et al., 1973; Garwood and Evans, 1974; Bieniewski, 1976;

Table 1

ions used	$\log N$	$\log A_{st}$	$\log A$	Δ
NaI	17,58	6,28	6,26	-0,02
SiI	18,65	7,65	7,33	-0,32
CaI	17,46	6,35	6,14	-0,21
ScI	14,38	3,04	3,06	+0,02
ScII	14,38	3,04	3,06	+0,02
TiI	16,02	4,86	4,70	-0,16
TiII	16,17	4,86	4,85	-0,01
VI	15,16	4,02	3,84	-0,18
VII	15,47	4,02	4,15	+0,13
CrI	16,99	5,65	5,67	+0,02
CrII	17,37	5,65	6,05	+0,40
MnI	16,89	5,42	5,57	+0,15
FeI	18,88	7,51	7,56	+0,05
FeII	18,89	7,51	7,57	+0,06
CoI	16,42	4,91	5,10	+0,19
NiI	17,48	6,27	6,16	-0,11

Bié mont et al., 1978), for manganese — 5 determinations from 5 authors (Blackwell et al., 1972; Martinson et al., 1973; Pinnington and Lutz, 1974; Bié mont, 1975; Greenlee and Whaling, 1979), for iron — 14 determinations from 7 authors (Blackwell and Shallis, 1979; Blackwell et al., 1976; Richter and Wulff, 1970; Baschek et al., 1970; Ross, 1973; Smith and Whaling, 1973; May et al., 1974), and for nickel — 5 determinations from 5 authors (Grevesse, 1970a; Grevesse and Swings, 1970; Garz, 1971; Lennard et al., 1975; Bié mont et al., 1980). For cobalt the average of the only known recent determination (Cardon et al., 1982) and Ross and Aller's (1976) value has been taken. For the other five elements $\log A_{st}$ have been taken from the compilation of Ross and Aller (1976). We have placed our results ($\log N$) on the standard scale $\log A$ (at $\log A_H=12,00$) by the mean difference for all 16 determinations $(\log N - \log A_{st})=11,32$. Taking into account the probable sources of errors in determining the abundances and their reduction to the standard scale, we consider the uncertainties in $\log A$ to be smaller than 0,2 dex.

In the last column of Table 1 the differences

$$(2) \quad \Delta = \log A - \log A_{st}$$

are given. They exceed the supposed error of 0,2 dex for three cases only.

The abundance of chromium derived from CrII lines exceeds the standard one by 0,4 dex. Twenty-six "good" lines (which have no great deviations from the curve of growth) have been used. Nineteen of them have $\log(10^6 W_\lambda/\lambda) < 1$ and lie in the linear part of the curve of growth. They belong to different multiplets of excitation energies from 2,71 to 4,76 eV. Maybe the oscillator strengths for CrII (Kurucz, Peytremann, 1975) are too low about 0,2-0,4 dex.

We have obtained the abundance of silicium lower than the standard one by 0,32 dex. With oscillator strengths from Wiese et al. (1969) a curve of growth has been plotted using 14 lines and $\log A_{Si}=7,53$ has been found. It is in good agreement with the standard one. In Kurucz and Peytremann's oscillator strength system the abundance has been obtained from 21 lines (neglecting $\lambda 3905 \text{ \AA}$), the great majority of which lies on the linear part of the curve of growth. Six of these lines have oscillator strengths in the compilation of Wiese et al. (1969) and the mean difference

$[\log(gf)_{KP} - \log(gf)_{NBS}] = 0$. The other 15 lines in fact determine the position of the curve of growth. Fourteen of them originate from the same lower level $3p^3 \text{ } ^3D^0$ with excitation energy 5.61 eV (multiplets 27-30). It seems that the $\log(gf)_{KP}$ values for transitions from this level are too large with about 0,3 dex. A curve of growth constructed after such a correction of the oscillator strengths of the lines from the level $3p^3 \text{ } ^3D^0$ gives $\log A_{Si}=7,53$.

The calcium abundance exceeds the standard one by 0,21 dex. Forty lines have been used to obtain it. Eighteen of them lie well on the curve of growth and 5 are on its linear part. Another curve of growth has been constructed using 32 lines of CaI with oscillator strengths from Wiese et al. (1969). At the same θ_i and n_e it gives $\log A_{Ca} = 6,35$ coinciding with the standard one. A direct comparison of the 16 used lines common for the lists of Kurucz and Peytremann (1975) and Wiese et al. (1969), gives a mean difference $[\log(gf)_{PK} - \log(gf)_{NBS}] = +0,19$ which explains our result and suggests a certain doubt about the accuracy of the used oscillator strengths.

In the range 3500-6500 \AA the lists of Wiese et al. (1969) and Kurucz and Peytremann (1975) have 81 common lines of CaI. The dif-

Table 2

Multi- plets	Low EP, V	Upper EP, V	\bar{D}	δ	Number of lines
3	1,88	3,89	-0,10	0,01	3
4	1,88	4,66	+0,06	0,18	6
6	1,88	5,00	-0,25	0,01	3
9	1,88	5,28	+0,12	0,02	6
18	2,51	4,42	+0,05	0,08	6
20	2,51	4,52	-2,01	0,01	6
21	2,51	4,72	+0,29	0,04	7
22	2,51	4,86	+0,28	0,04	6
23	2,51	5,21	-0,62	0,01	6
25	2,51	5,53	-0,56	0,01	6
26	2,51	5,70	-0,50	0,04	6
27	2,51	5,80	-0,40	0,01	6
28	2,51	5,87	-0,35	0,02	6

ferences $D = \log(gf)_{KP} - \log(gf)_{NBS}$ vary greatly being nearly the same for the lines of a given multiplet. The mean differences \bar{D} for some multiplets are presented in Table 2. Herein δ is the mean of the absolute values of the deviations from \bar{D} for the individual lines. The most of the used solar spectrum lines in the analysis by chance belong to the multiplets 4, 21 and 22, for which $\log(gf)_{KP}$ are overestimated.

This analysis and the results about SiI and CaI confirm once more the conclusion in our previous work (Dobrichev, Raikova, 1981) that the use of Kurucz and Peytremann's oscillator strengths for stellar atmosphere analysis on the basis of individual lines or small number of lines per ion entails some risk.

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Солнечные обилия элементов и шкала сил осцилляторов Куруча и Пейтремана

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(Резюме)

По кривым роста, построенным по неблендированным линиям солнечного спектра (Добричев, Райкова, 1981), определены обилия 11 химических элементов в атмосфере Солнца. Они сравниваются со стандартным содержанием этих элементов, определенным по публикациям последних лет. По различиям обилий, превышающим ожидаемую ошибку, выявлены систематические ошибки сил осцилляторов для некоторых мультиплетов Ca I и Si I и возможное занижение нуля шкалы для Cr I.

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