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A catalogue of [Fe/H] determinations : 1996 edition

G. Cayrel de Strobel[1], **C. Soubiran**[2], **E.D. Friel**[3], **N. Ralite**[2], **and P. François**[1]

[1] Observatoire de Paris-Meudon, DASGAL, 92195 Meudon Cedex, France
[2] Observatoire de Bordeaux, BP 89, 33270 Floirac, France
[3] National Science Foundation, Washington DC, USA

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Abstract. A fifth Edition of the Catalogue of [Fe/H] determinations is presented herewith. It contains 5946 determinations for 3247 stars, including 751 stars in 84 associations, clusters or galaxies. The literature is complete up to December 1995. The 700 bibliographical references correspond to [Fe/H] determinations obtained from high resolution spectroscopic observations and detailed analyses, most of them carried out with the help of model-atmospheres. The Catalogue is made up of three formatted files :
File 1 : field stars
File 2 : stars in galactic associations and clusters, and stars in SMC, LMC, M33
File 3 : numbered list of bibliographical references

The three files are only available in electronic form at the Centre de Données Stellaires in Strasbourg, via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5), or via http://cdsweb.u-strasbg.fr/Abstract.html.

Key words: catalogues – stars: abundances – stars: atmospheres – stars: fundamental parameters

1. Introduction

Our knowledge of the chemical history of the Galaxy is based primarily on metal/hydrogen determinations in stars. There are two ways of obtaining such determinations : by photometry or by spectroscopy. If photometric determinations are less time consuming and have good internal precision, spectroscopic detailed analysis is the only primary method from which photometry can be calibrated. The general approach of a spectroscopic detailed analysis is to derive metal abundances by matching equivalent widths of weak lines of an observed spectrum to those computed from a grid of model atmospheres of various effective temperatures, gravities and metallicities.

Send offprint requests to: C. Soubiran

A first list of [Fe/H] determinations was published by Cayrel & Cayrel de Strobel (1966), but it was Pr. Hauck's idea to publish a "Metal Abundance" Catalogue as an Appendix to the proceedings of the IAU symposium 72 on "Abundance effects on classification" (Morel et al. 1976). Since then, thanks to the energy of Pr. Hauck, four editions of the Catalogue of [Fe/H] determinations have been published in the A&A Supplements (Cayrel de Strobel et al. 1980, 1981, 1985, 1992).

Since the end of 1970, spectroscopic abundance researches rely more and more on high resolution, high S/N spectra taken with solid state detectors. The increase in accuracy, thanks to an important gain in S/N ratio and a better control of systematic errors, has sometimes reached a full order of magnitude (Cayrel 1988). The number of stars subjected to detailed analysis has been increasing continuously in the successive editions, as shown in Table 1. The present version of the [Fe/H] Catalogue includes 2694 new measurements of [Fe/H], and 1571 new stars, corresponding to an increase of 83% and 94% with respect to the 1991-Edition. This strong increase in number of stars and in number of [Fe/H] determinations does not correspond only to the use of Reticons and CCDs in spectroscopy, but also to the development of powerful workstations and elaborate software for data reduction, which make it possible to analyse a large number of spectra in a reasonable time. For instance, three papers are included in this new Edition with respectivly 671 stars (McWilliam 1990), 199 stars (Balachandran 1990), 183 stars (Edvardsson et al. 1993).

Literature searches for references presenting [Fe/H] determinations from high resolution spectroscopy were made easier than in previous versions of the Catalogue thanks to the use of the NASA Astrophysics Data System Abstract Service. The version of the Catalogue presented here should not omit any article that has been published in the principal refereed journals of astrophysics before December 1995.

Table 1. Growth of data of the [Fe/H] Catalogue

Reference	Number of stars	Number of [Fe/H]
Cayrel & Cayrel de Strobel 1966	154	204
Morel et al. 1976	515	973
Cayrel de Strobel et al. 1980	628	1109
Cayrel de Strobel et al. 1981	707	1298
Cayrel de Strobel et al. 1985	1035	1921
Cayrel de Strobel et al. 1992	1676	3252
Cayrel de Strobel et al. 1997	3247	5946

The main aspects of a detailed analysis are briefly reviewed in Sect. 2. The presentation of the Catalogue, which was completely revised and reformatted, is fully described in Sect. 3. Some important comments about the Catalogue are given in Sect. 4 for the input data, and in Sect. 5 for the stellar content. The conclusion is given in Sect. 6.

2. Spectral detailed analysis

To a great extent, the spectra of the stars listed in the Catalogue have been interpreted by differential curve of growth analysis, the Sun having been adopted in the majority of the cases as reference star. In the mid-sixties, the availability of powerful computers has pushed the authors to perform detailed analysis instead of coarse analysis. The theoretical line equivalent widths and curves of growth were then computed from detailed model atmospheres, interpolated in a grid of constant flux models. Authors interested in early type stars (early F, A, Am, Ap) ordinarily use the Kurucz grid of Atlas models (Kurucz 1991a, 1991b, 1993), those interested in late F, G and K stars use mostly the Gustafsson's grid of atmosphere models (Gustafsson et al. 1975, Edvardsson et al. 1993). Both, Kurucz and Gustafsson models were computed with the assumption of Local Thermodynamical Equilibrium (LTE). In a strictly differential analysis, this is not very important, because a large part of Non-LTE effects cancel out when the programme star is sufficiently similar to the reference star.

A very important step in a spectral analysis of a star is the determination of accurate atmospheric parameters for the selection of the appropriate model atmosphere. No abundance can be derived unless the three physical parameters, effective temperature (Teff), surface gravity (log g), and microturbulence (ξ_t) have been obtained. The effective temperature of a star, which is the critical parameter, is most often derived from wide or narrow-band photometry, but in some cases, it is derived on purely spectroscopic grounds from the comparison between H_α observed profiles and H_α computed profiles. The spectroscopic surface gravity is determined from ionisation and excitation equilibria, as obtained from neutral and ionized lines carefully chosen in the stellar spectrum and from wings of strong lines, broadened by collisional damping. The microturbulence is determined by fitting a theoritical curve of growth, computed with an appropriate model, to the observational curve of growth. The metal abundance is obtained by comparing the observed equivalent widths of weak and medium-weak lines (possibily between 10 and 50 mÅ), in the spectrum of a programme star to those resulting from a model atmosphere computed with the appropriate stellar parameters (Teff, log g, ξ_t) previously determined for the star under investigation. Attention has been paid by the authors of the recent analyses to treat the reference star in the same way as the programme star. According to our own experience, many differential analyses with respect to the Sun show spurious effects just because the Sun has not been analysed with the same grid of model atmospheres as the programme star (Cayrel de Strobel 1996).

3. Description of the Catalogue

The Catalogue presents, as metal/hydrogen parameter, the usual logarithmic difference between the relative abundance of iron in the atmosphere of a star and the relative abundance of iron in the atmosphere of a reference star. This difference is written in the form :

$$[Fe/H] = \log(Fe/H)_{star} - \log(Fe/H)_{ref}$$

Files 1 and 2 of the Catalogue contain the following columns :

1. *Identifier*
   Great care has been taken to choose for each star its most common designation. For field stars, the HD number was taken, when available. If not, the BD or CD or CPD number was taken, with the usual convention of declinations. For very few stars only Giclas or other names were available. For cluster stars, a great variety of names were used in the references for the same object. The Dictionary of Nomenclature of Celestial Objects (Lortet et al. 1994) was consulted, together with the SIMBAD database and the NASA-ADS service in order to adopt the most appropriate name for each star. Except for a dozen unidentified objects (designated with "?" at the beginning of their name), the chosen identifier can be used in a SIMBAD interrogation. There is no redundancy between the list of field stars and the list of cluster stars.

2. *Spectral type*
   The spectral types come from the cross-identification of the Catalogue and the SIMBAD database. The same syntax has been used (see the SIMBAD user's guide and reference manual, chapter 15). It helps the user of

the Catalogue to locate a normal star in the HR diagram, and also to recognize peculiar stars. We have not corrected the spectral types, even if in a few cases (mainly metal deficient population II stars) they disagree with the effective temperature and gravity resulting from a detailed analysis.

3. *Object type*
   This column indicates a star's peculiarity. We have adopted the same designation as in SIMBAD database, reduced to two characters (see the SIMBAD user's guide and reference manual, appendix F). The most frequent types of peculiarities are high proper-motion stars (PM), spectroscopic binaries (SB), variable stars (V), stars in multiple systems (**), etc ...

4. *Visual magnitude V*
   The sources of the visual magnitudes in SIMBAD are various and heterogeneous. As a consequence, this value should be considered only as an indicator of brightness. For precise photometry, the users have to consult a specialised catalog, like the latest edition of the General Catalogue of Photometric Data (GCPD) (Mermilliod et al. 1996). In some cases, the magnitude indicated in this column is the B magnitude (a letter B follows the value of the magnitude in this case). Only a few faint stars do not have any visual magnitude at all.

5. *Colour index B−V*
   The colour comes from SIMBAD database.

6. *Photometric flag*
   The character ":" indicates a large uncertainty in photometry. A letter "D" indicates a joint magnitude in the case of binaries. A letter "V" indicates a variable magnitude.

7. *Effective temperature Teff*
   The value listed is that which was adopted by the author for the metallicity determination in the detailed analysis. In the previous versions of the Catalogue, we used as effective temperature parameter the quantity $\Theta_{eff} = \frac{5040}{Teff}$. We have converted Θ_{eff} of the 1991-Edition into Teff, which is now much more widely used. In the preceding edition, the parameter Θ_{eff} was presented with two digits of precision. The conversion to retrieve Teff has led to an inaccuracy of a few tens of degrees for cool stars, about 50 K for solar-like stars, and 100 to 200 K for hot stars. All the new determinations listed in the present edition, give Teff directly and no correction was necessary for them.

8. *Logarithm of gravity log g*
   As for the case of Teff, the value of log g listed is that which was used by the author in the spectrum analysis.

9. *[Fe/H]*
   The [Fe/H] value is given with respect to the standard star listed in column 11.

10. *Note*
    The following rare cases are indicated with a letter in this column :
    - S : [Fe/H] has been obtained with a spectrum of S/N lower than 50
    - M : several values of [Fe/H] were given in the article (for example from FeI and FeII lines, or from different instruments), and we give the mean of them
    - C : in the absence of any indication of the author, we calculated the metallicity with respect to the Sun with $\log \epsilon(Fe) = 7.50$
    - T : combination of cases M and C
    - D : combination of cases S and C

11. *Standard*
    The reference star which was employed in the analysis.

12. *Reference*
    Bibliographical reference with respective number to be found in File 3.

In this Edition, as in the previous 1991-Edition, the microturbulence velocity has been omitted because not all authors use the same definition for it. People interested in the value of the microturbulence must consult individual references.

File 1 includes 4716 determinations of [Fe/H] for 2497 different stars. File 2 includes 1230 determinations of [Fe/H] for 751 stars in 84 associations, clusters or nearby galaxies.

File 3 gives the list of the 700 bibliographical references (130 more than in the previous version) sorted in chronological order. We have adopted for all the references the journal abbreviations of the NASA-ADS Abstract Service.

Several mistakes have been corrected in the previous edition and in this latest version, but the Catalogue undoubtedly still contains incorrect data and misprints. We encourage users to bring to our attention any error they find. The Catalogue is kept at the CDS and available by the usual methods. It will be updated and corrected regularly.

4. Some remarks on the parameters listed in the Catalogue

The authors of this Edition decided to give to the Catalogue a more spectroscopic aspect than in the previous versions, keeping only as photometric parameters, the visual magnitude V and the colour index B−V. As a great work has been done by Pr. Hauck and Drs Mermilliod to bring the GCPD up to date, it would have been superfluous to repeat the same information in this spectroscopic Catalogue. Then, why has a Catalogue of atmospheric parameters of stars been called a "Catalogue of [Fe/H] determinations" ? Because the understanding of the chemical composition of stars, interstellar matter, and galaxies has become one of the central issues of modern astronomy. Therefore we wanted to emphasize the importance of the abundance parameter [Fe/H].

As was already mentionned in Sect. 2, the atmospheric parameters listed in the Catalogue are deduced from models generally computed with the assumption of LTE. But not all the time. The reader is urged to consult the individual references for more details on the techniques used in each analysis.

The colour index B−V is a convenient photometric parameter because it has been determined for a very large number of stars (in File 1, 98% of the stars have a colour index B−V). This index is commonly used as a temperature indicator in galactic studies in which a large number of very faint stars are considered. The plot in Figure 1 shows the distribution of the field stars of the Catalogue (File 1) in the plane (B−V,Teff) for stars ranging between $3000^o K$ and $8000^o K$. There is a clear trend of Teff with respect to B−V, but the dispersion about the correlation is very high. The relation between Teff and B−V is particularly uncertain around B−V=0.5 where the corresponding Teff spans more than $1000^o K$. The dispersion in this relationship is undoubtedly heavily influenced by the sensitivity of B−V to the metallicity of the star, showing the limitation of B−V as a temperature indicator.

In most cases, the Sun is used as the reference star in the analyses. However, for early type stars, peculiar Ap and Am stars, yellow giants etc ... other well analysed stars like ϵ Vir, α Boo or o Peg, are also used as reference. In some cases, the authors have not observed their reference stars with the same observational and optical equipment as their program stars. Also they have not always analysed their program and reference stars using the same model atmospheres and the same physical and atomic parameters. As a result, even for most recent analyses, the abundance determinations from different authors may show significant disagreement in spite of the excellent quality of the observations. Instead of taking the mean of the abundances listed for a star with many determinations, the reader is encouraged to carefully examine the details of individual analyses to understand the differences. An illustration of this problem can be given with the well-known star ϵ Vir (HD 113226). This star is frequently used as a comparison star in detailed analyses. The Catalogue gives 15 values of [Fe/H] with respect to the Sun for ϵ Vir, ranging between -0.10 dex and +0.21 dex. What value should be taken as the true metallicity of ϵ Vir ? Due to such disagreements, we did not attempt to standardize the [Fe/H] values of the Catalogue to the solar one.

We have been requested several times, between the successive editions, to include an average value of the different determinations of [Fe/H] for each star. But also for this Edition we have upheld our initial decision to publish the original values from the literature, the mean value being subjected to change at each edition, and a straight mean between values of unequal quality being physically unjustified. A weighted mean would have involved a number of subjective judgements and the development of some scheme for compensating for systematic differences and normalizations between individual investigations. For those who want to use a mean anyway, without making an "educated" weighting, we recommend keeping only recent determinations obtained with high S/N ratios, from spectroscopy with Reticon or CCD detectors. However it must be noted that [Fe/H] determinations are also affected by the adopted effective temperatures, gravities and microturbulent velocities, and that a stellar metal abundance can be in error, even if the observations are of excellent quality.

5. Some remarks on the stellar content of the Catalogue

The sample of stars of this new Edition of the Catalogue has conserved several biases, and cannot be considered as representative of the stellar content of the solar neighbourhood. Figure 2 represents the distribution of observations listed in File 1 in the plane (Teff, log g). Some parts of this diagramme have a higher density of observations than in an usual HR diagramme. This correspond probably to the personal interest of astronomers in problems concerning Am stars ($\sim 6400^o K$), F dwarfs and subgiants ($\sim 6050^o K$), early G solar type stars ($\sim 5750^o K$), early G giants ($\sim 4950^o K$), late G and K giants ($\sim 4550^o K$). One can note also a lack of G and K dwarfs. The principal reason is that these stars, being intrinsically faint, are more difficult to observe at high resolution and high S/N than the giants of the same Teff. It is a pity for the study of stellar evolution, because it is well known that the full span of ages is still present among low mass G and K and later type stars. M star spectra are very complicated and are difficult to analyse in detail, and in this Edition there is still a very low number of them.

In Figure 3, we present an histogram of the 4716 [Fe/H] determinations given in File 1. The most frequent metallicity is around -0.15 dex. This value is of the same order as the mean metallicity of the solar neighborhood found from *ubvy* photometry by Eggen (1978). It is important to remember that the sample listed in the Catalogue is strongly biased and no statistical conclusion can be given, but one can note that the solar metallicity is on the metal rich part of the histogram, which is in the same sense than Eggen's conclusion : the Sun seems to have a higher

Fig. 1. Teff plotted against B−V colour for field stars (File 1) of the Catalogue

Fig. 2. $\log g$ plotted against Teff for all the entries of File 1 in the temperature range $[8500^{o}K, 3500^{o}K]$.

metallicity than the majority of stars in the solar neighbourhood.

Non-solar metallicities, as shown in Figure 3, may reflect very different astrophysical phenomena. Many stellar metallicities reflect the interstellar medium from which the star formed, and whose chemical composition is appreciably different from the Sun. This interpretation applies to most solar and lower mass stars, and it is just these, from late F or early G type, that span the full range of stellar ages present in galaxies. Abundances of these stars interest experts in chemical evolution, age and population effects in field stars and cluster stars.

The peculiar [Fe/H] values found in more massive stars reflect not the original abundances, but the alteration by physical processes (selective mass-loss, radiative diffusion, modified or not by magnetic fields, nuclear burning induced by convection and turbulent mixing). These stars are studied by experts of the physical structure of stars.

Fig. 3. Distribution of the 4716 [Fe/H] determinations in the File 1

An interesting feature of the histogram in Figure 3 is the fraction of deficient metallicities which is much higher than the true proportion of metal-poor stars in the solar neighbourhood. The comparison of this histogram with the same one published in the 1991-Edition shows that the number of deficient stars observed during the last 5 years has considerably increased. A large number of nearby metal deficient stars have been observed also in several surveys of halo and thick disk stars, conducted either with low resolution spectroscopy (Beers et al. 1992), or from high resolution spectroscopy at low S/N ratio, from high proper motion lists (Carney et al. 1994). It must be mentioned that over 3000 determinations of [Fe/H] have been obtained by these authors, but only [Fe/H] obtained by detailed analyses triggered by those lists are quoted in our Catalogue. The interest in the first generation of stars will continue to grow in the next years because these stars provide clues about the chemical evolution of the Galaxy, and on nucleosynthesis processes in general. The problem is that halo and thick disk stars are faint and difficult to observe at high dispersion. Figure 4 shows the histogram of the visual magnitude of the field stars of File 1. It can be seen that the proportion of stars fainter than V=10 which have been observed at high resolution, is quite low. The dotted histogram represents the stars of File 1 which have [Fe/H] $\leq$ -0.8. These stars are the faintest of the sample.

Fig. 4. Distribution of the visual magnitude V for the nearly 2500 stars of File 1. The dotted histogram represent the metal deficient stars ([Fe/H] $\leq$ -0.8)

The problem of the limiting magnitude of high resolution spectroscopy is particularly important for clusters and the Magellanic Clouds. Except for a few nearby clusters, the 84 systems listed in File 2 are very distant and the most frequent magnitude of the stars listed in this table is V=12.5. Another consequence of the large distance of clusters is that the cool dwarfs are poorly represented in File 2 by comparison to giants. Also, only 43% of the stars of the sample have a spectral type, by contrast to File 1 where 96% of the field stars have a spectral type. The wide availability of 10-m class telescopes will soon increase greatly the limiting magnitude of high resolution spectroscopy and this will have an important impact on the understanding of the chemical properties of the globular clusters and nearby galaxies.

6. Discussion and conclusion

The Catalogue of [Fe/H] determinations provides a database for various topics related to chemistry in the stars or in the galaxies. This Catalogue has been foreseen for two kinds of users. The first, often photometrists, are those interested in the Catalogue because they are specialists in the chemical evolution of the Galaxy, or of other galaxies (see for instance the calibrations performed by Golay et al. 1977a, 1977b, 1978).

The second kind of user of the Catalogue, and probably the more numerous, is working in high resolution high S/N spectroscopy. These astronomers use the Catalogue in preparing their observing programs, in verifying whether some of their program stars have high resolution, high S/N observations, and in studying what kind of literature already exists in connection with their observing program. And, once having reduced their spectra, the Catalogue can be useful in helping the authors to interpret the results.

We want to conclude by saying that many of the stars contained in the Catalogue have been included in different programs for the Hipparcos mission, particularly those concerning the observational study of galactic structure and chemical evolution of the solar neighbourhood. The imminent availability of precise distances and proper motions for those stars, together with good atmospheric parameters, will give the opportunity to study the correlation between kinematics and metallicity with excellent observational material.

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