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978-0-521-10240-7 - The Behavior of Chemical Elements in Stars
Carlos Jaschek and Mercedes Jaschek
Excerpt
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Part One

Content description

This part is divided into 80 sections, each devoted to one element. The elements are ordered by their English names. Cross references between names, formulae and atomic numbers are given in the appendices (part four, tables 2–4).

For the description of the behavior of each element we have kept a constant order, which is as follows.

1 The formula, the English name and the atomic number.
2 A short history of the discovery of the element and an explanation of its name and/or abbreviation. If not indicated otherwise, these data are taken from Elmsley (1989).
3 The ionization energies, in electron-volts (eV), rounded off to the nearest tenth of an electron-volt. The data were taken from Samsonov (1968) and Elmsley (1989). We have only quoted those ionization stages that are observed in stars, plus the next one.
4 We then start a description of the behavior of the lines of each ionization stage (i.e. each species), beginning with the neutral lines. In order to be as precise as possible, we have given the behavior of the equivalent widths of one or more absorption lines with spectral type. Wavelengths and equivalent widths are given in ångström units ($1\ \text{Å}=10^{-8}\ \text{cm}=0.1\ \text{nm}$), except when stated otherwise. These values are listed in tables and, if sufficient values are available, plotted in figures. The figures provide only smoothed curves, based upon the values listed in the tables. All figures give the spectral types on the abscissae and the equivalent width (in ångström units) on the ordinates.

    If data exist in the literature, separate curves have been plotted for dwarfs and supergiants and sometimes also for giants. Uncertain trends (few data points or large dispersions) are indicated by broken lines. Readers interested in more details should consult chapters 2–4 in part three. The multiplet to which the line belongs is indicated in parentheses after the wavelength.

    After the tables and figures follows a summary of the behavior of the species in the HR diagram, with mention of luminosity effects. The term ‘positive luminosity effect’ expresses the fact that the line is stronger in stars of higher luminosity, i.e. stronger in supergiants than in dwarfs. ‘Negative luminosity effect’ implies on the contrary that the line is stronger in dwarfs than in supergiants.

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If possible we comment upon the behavior of the species in different wavelength ranges – ultraviolet, photographic, visual and infrared.

5 For each species then follows information on emission lines, both permitted and forbidden. (For more details on the terminology see chapter 1 of part three.)

After the information for neutral lines (both in absorption and in emission) we proceed to do the same for the singly and doubly ionized lines.

6 After describing the behavior of the lines in normal stars, the next section deals with the behavior of the element in non-normal stars. As explained in the preface, we have refrained from going into detail concerning the behavior of lines in individual peculiar stars, so we only discuss the behavior of the species in groups of stars. The groups quoted (which are italicized in the text) are those discussed in our book *The Classification of Stars* (Jaschek and Jaschek 1987a) plus additional groups. Short definitions of all groups mentioned in the book are given in chapter 2 of part three. Wherever possible the behavior of the lines is quantified in terms of equivalent widths (W), taken from the sources indicated in the references. In those cases in which the behavior of an element is described differently by different authors we have inserted the note ‘under discussion’.

Readers should be attentive to the fact that the behavior of some of the non-normal groups is also described under the heading ‘emission lines’ of the different species.

7 A short summary is provided of the key isotopes. The data are taken from the compilation of R. L. Heath in the CRC Handbook, 63rd edition. Two modifications in the terminology have been introduced in this book. The first is that, if an isotope has a half life shorter than 10^4 years, it was simply called ‘short-lived’ and further comment omitted. The second modification is that we have also called ‘stable’ those isotopes whose half life is longer than 10^9 years, because their life time is then comparable to the age of the sun.

The percentages of occurrence of the different isotopes are quoted for the solar system. The data have been taken from Anders and Grevesse (1989). The values quoted have been rounded off. Their sum should always be 100%, except if one isotope is present in a minute fraction (like 0.1%). In such cases the sum is slightly greater than 100. Besides the information for isotopes in the solar system, we have also summarized observations of isotopes of the element in stars.

Whenever an isotope exists with a half life longer than 10^7 years, we have added the comment ‘can be used for radioactive dating’.

8 Origin. We provide a short note on the processes through which the element can be produced from a nucleosynthetic point of view. This information was also taken from Anders and Grevesse (1989). The following processes are mentioned, either with the complete name or with an abbreviation:

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cosmological nucleosynthesis
hydrogen burning
hot hydrogen burning
helium burning
carbon burning
oxygen burning
neon burning
explosive nucleosynthesis
nuclear statistical equilibrium (the so-called e process)
slow neutron process (s process)
rapid neutron process (r process)
proton process (p process)
cosmic spallation
actinide-producing r process (ra)

For a general overview of which elements are visible in given types of stars, see figure 1 at the end of this part (page 209).

Readers should be aware that as an exception we have dealt with the 'collective' behavior of some elements in chapters 2 and 3 of part two.

In some places in the text we have used the notation 'dex'. This notation provides the decimal logarithm of the quantity. For instance -3 dex means 10^{-3}.

ALUMINUM Al Z=13

The element was discovered in 1827 by F. Woehler. The name comes from the Latin *alumen* (alum). The element is also called aluminium.

Ionization energies

Al I 6.0 eV, Al II 18.8 eV, Al III 28.4 eV, Al IV 120 eV.

Absorption lines of Al I

Table 1. *Equivalent widths of Al I*

	W(3944) (resonance line UV M.1)		W(6699)(5)		
Group	V	Ib	V	III	Ib
B 7	0.006				
B 9	0.051				
A 0	0.085	0.05			
A 1	0.098				
A 2	0.14	0.085(Ia)			
A 3		0.050(0)			
A 7	0.18				
F 0		0.30(Ia)			
F 4	0.29				
F 5					0.015
F 6	0.47				
F 8	0.35	0.28			
G 1	0.4				0.056
G 2	0.50		0.018		0.073,0.092
S	0.488		0.021		
G 5					0.093
G 6					0.142
G 8			0.022(IV)		0.119
K 0			0.006	0.052	
K 2				0.062	0.188
K 3				0.11	
K 5			0.063		0.157
M 2					0.117

Al I (for instance the line at 3944) is present in dwarfs from late B-type stars onwards, increasing steadily in strength toward G-type stars. This line shows no luminosity effect. The line at 6699 shows a positive luminosity effect from late F-type onwards.

Emission lines of Al I

That at 3944 (1) appears in emission from some *T Tau stars* (Joy 1945)

Absorption lines of Al II

Al II has its resonance line at 1671 (UV M.2). Sadakane *et al.* (1983) provide the following values.

Table 2. *Equivalent widths of Al II 1671(2)*

Group	V
B 5	0.59(IV)
B 7	1.02
B 9	1.60

The ultraviolet blend at 1723(6) shows a positive luminosity effect in B-type stars (Heck *et al.* 1984).

In the sun a line at 3900.66 is probably Al II

Al III is present in B-type and more weakly in A-type stars.

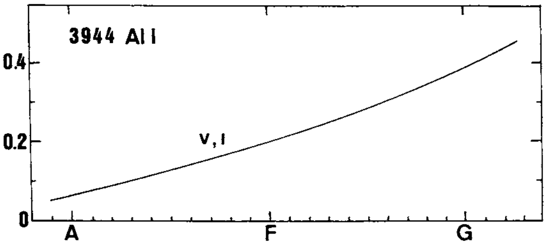
Absorption lines of Al III

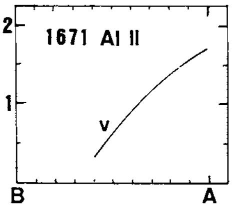
Al III has its resonance lines in the ultraviolet (1854 and 1863 – UV M.1). Sadakane *et al.* (1983) provide the following values.

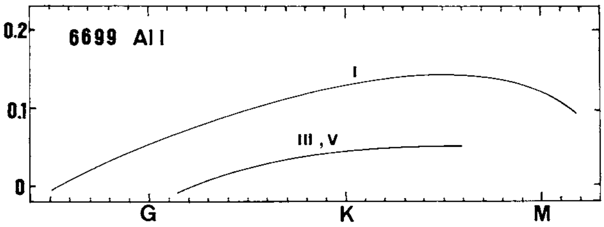
Table 3. *Equivalent widths of Al III*

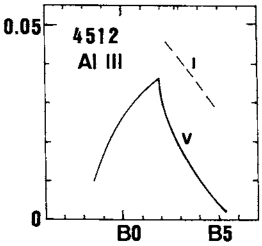
	W(1863)(1)	W(3612)(1)	W(4512)(3)		
Group	V	V	V	III	Ia
0 7			0.004		
0 9			0.015		
B 0		0.012	0.022		
B 0.5			0.032	0.030	
B 2		0.027(IV)	0.036	0.046	
B 3		0.012	0.017		0.031
B 5	0.48(IV)		0.004		0.039
B 7	0.40				
B 9	0.20				

Al III (for instance the line at 4512) is present in B-type stars with a maximum around B5 and a positive luminosity effect. Al III 4149(5) is present in the solar chromosphere, besides Al I and Al II (Pierce 1968).









Behavior in non-normal stars

Sadakane *et al.* (1983) found that both Al II and Al III are weak in *Bp* stars of the Hg–Mn, Si and He-weak subgroups. The extent of weakening varies from star to star, with equivalent widths lesser by factors two to six than in normal stars.

Al I is normal or slightly weak in *Ap* stars of the Cr–EU–Sr type (Adelman 1973b).

Al is either slightly strengthened in *Am* stars (Burkhart and Coupry 1991) or normal (Smith 1973, 1974).

Al is probably underabundant with respect to Fe in the most *metal-weak stars* (Fe/H$\times 10^{-4}$) by factors of the order of 4–5 (Molaro and Bonifacio 1990). This is also true for *horizontal branch stars* (Adelman and Philip 1990, 1992a). Magain (1989) suggests that Al has a normal (i.e. solar) abundance in normal stars, whereas it is increasingly deficient in increasingly metal-weak dwarfs, a fact that was also pointed out by Gratton and Sneden (1988). Since not all authors use the same lines, the abundances differ between authors more than would seem reasonable (Spite 1992).

Al apparently has an erratic behavior from star to star in *globular cluster stars*, but seems to be overabundant with respect to iron (Francois 1991). However, Gonzalez and Wallerstein (1992) find it underabundant in one F-type *globular cluster supergiant*.

In *novae* Al II and Al III lines usually appear in emission in the ultraviolet region during the 'principal spectrum' phase. Lines of [Al IV] and [Al VIII] sometimes appear during the nebular stage (Warner 1989).

Al is very overabundant in the spectra of novae of the O–Ne–Mg subgroup (Andreae 1993).

Isotopes

Al has eight isotopes and isomers. The only stable one is Al^{27}. One of the isotopes, Al^{26}, has a half life of 7.4×10^5 years. Branch and Peery (1970) derive $Al^{26}/Al^{27} < 0.15$ from the AlH bands in one S-type star.

Origin

The element can be produced by neon burning or by explosive nucleosynthesis.

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AMERICIUM Am Z=95

This transuranium element was discovered by T. Seaborg, R. James, L. Morgan and A. Ghiorso in Chicago in 1944. Its name alludes to America.

Ionization energies

Am I 6.0 eV

Several lines of Am II were found by Jaschek and Brandi (1972) in the spectrum of one *Ap star* of the Cr–Eu–Sr subgroup. The authors regarded this identification as dubious because of the lack of agreement with laboratory line intensities.

Later work did not confirm the presence of this transuranium element.

Isotopes

The longest lived isotope of this unstable element (Am^{243}) has a half life of 7.4×10^3 years. A total of 13 isotopes and isomers exist.

Origin

Am is produced by the r process.

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ANTIMONY Sb Z=51

This element was already known in antiquity. The name alludes to the Greek words *anti* and *monos* (not alone). In Latin this element is called *stibium*.

Ionization energies

Sb I 8.6 eV, Sb II 18.6 eV.

Absorption lines of Sb I

The equivalent width of Sb I 3267(2) in the sun is 0.011.

Isotopes

There exist 29 isotopes and isomers. The two stable isotopes are Sb^{121} and Sb^{123}. In the solar system their abundances are respectively 57% and 43%.

Origin

Sb^{121} can be produced by the r and s processes whereas Sb^{123} is a pure r process product.

ARGON Ar Z=18

This element was discovered in 1894 by D. Rayleigh and W. Ramsay in Great Britain. The name comes from the Greek *argos* (inactive). The name of the element has also been abbreviated as A instead of Ar (for instance by Moore (1945)).

Ionization energies

Ar I 15.8 eV, Ar II 27.6 eV, Ar III 40.7 eV, Ar IV 59.8 eV.

Absorption lines of Ar II

Table 1. *Equivalent widths of Ar II*

	4371(1)	4431(1)		4590(21)	
Group	V	V	Ia	IV	III
B 0.5		0.004			
B 1				0.0025	
B 2				0.0065	
B 3	0.006	0.008	0.052		
B 6					0.004

Source: Data are from Keenan *et al.* (1990).

Ar II (for instance the line at 4590) is represented by weak lines in early type B-stars. It has a maximum around B2. The line at 4431 (see table) shows a positive luminosity effect.

Emission lines of Ar II

The lines at 920 and 932 (UV M.1) are seen in emission in the ultraviolet solar spectrum (Feldman and Doschek 1991). *Supernova* 1987A also showed Ar II lines in emission (Arnett *et al.* 1989).

Emission lines of Ar III

The 7135 line of [AR III] (M.1F) has been observed in at least one *nova* (Thackeray 1953).