OXYGEN AND $\alpha$-ELEMENT ABUNDANCES IN GALACTIC DISK STARS 
AS A FUNCTION OF STELLAR AGE.

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1. Introduction

In recent years, spectroscopic and photometric studies of the chemical evolution of the galactic disk in the solar neighborhood have provided a number of interesting results. Twarog (1980) has shown that the metal abundance has increased from $[\text{Fe/H}] \approx -1.0$ at the formation of the disk to about +0.1 at the present time. Clegg et al. (1981) have found the oxygen-to-iron ratio to vary systematically from $[\text{O/Fe}] \approx 0.5$ at $[\text{Fe/H}] = -1.0$ to $[\text{O/Fe}] \approx 0.0$ at $[\text{Fe/H}] = 0.0$. Edvardsson et al. (1984) and Tomkin et al. (1984) have found evidence that the abundance ratio between the $\alpha$-elements (Mg, Si, Ca, Ti) and iron is larger than the corresponding solar ratio for the most metal-poor disk stars.

These results provide important constraints on possible models for the chemical evolution of the galactic disk. The characteristic mass of supernovae producing the elements at various epochs, should be possible to estimate from accurate data on relative abundances of stars of different ages. A determination of the dispersion of the element ratios at a given age would give information of the degree of mixing of the interstellar gas and/or the importance of nucleosynthesis in connection with bursts of star formation.

In order to make an extensive contribution to the study of the problems just mentioned, we have started a programme aiming at determining very accurate abundance ratios of the elements O, Na, Mg, Al, Si, Ca, Ti, Cr, Fe, Ni, Y, and Ba for 270 F and early G type stars. The programme is carried out in collaboration with J. Andersen and E.H. Olsen (Copenhagen University Observatory) and D.L. Lambert and J. Tomkin (McDonald Observatory). A general description of the programme was given by Edvardsson et al. (1984) in the ESO Messenger. Here we report on our latest results for the O/Fe and $\alpha$/Fe ratios for a sample of 29 stars.


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2. Selection of stars.

It is important that the stars observed are selected in a well-defined way, so that possible biases can be corrected for. The basic source for selecting the stars is the magnitude limited (6.5 < V < 8.3) uvby-β catalogue of A5-G0 stars by Olsen (1983), supplemented with catalogues of the HR stars (Strömgren and Perry (1965), Crawford et al. (1966), Grønbech and Olsen (1976, 1977)). The about 15000 A5-G5 stars in these catalogues are first divided into 9 subgroups by means of the metal-line blanketing index δm₁(β) (Crawford, 1975). As shown by Nissen (1981) δm₁(β) is well correlated with overall metal abundance [M/H]. The 9 subgroups therefore correspond to an approximately equidistant division of the metal abundance range -1.0 < [M/H] < +0.2 into 9 intervals.

In each of the nine subgroups stars that lie between 0.4 and 2.0 magnitudes above the ZAMS are selected by means of the Balmer-discontinuity index δc₁(β), (Crawford, 1975). Thus the programme stars are situated in a region of the HR diagram where relatively accurate stellar ages can be determined.

Known spectroscopic binaries and visual binaries with no uvby-β photometry existing for the individual components are excluded from the observing list as are stars rotating faster than V sin i = 25 km/s, since in such cases the rotational line broadening makes the equivalent width measurements less accurate.

The final observing list consists of the 30 brightest stars in each of the nine metal abundance subgroups. All the stars selected are situated within 80 pc from the Sun. Reddening determinations from β and (b-y) by the method of Crawford (1975) show that the reddening is negligibly small for all the stars.

3. Observations and reductions.

Stars in the northern sky are observed with the McDonald Observatory 2.7 m telescope, Coudé spectrograph and Reticon detector. The southern stars are observed with the ESO 1.4 m CAT telescope, the Coudé echelle spectrograph and a 1870 channel Reticon detector. The resolving power is about 80 000 and typically a signal-to-noise ratio of about 100 is obtained for each channel. The five spectral regions listed in Table 1 are observed. Until now about 50 southern stars and a similar number of northern stars have been observed. Fig.1 shows typical examples of the quality of the spectra obtained.

The raw spectra are reduced for read-out signal, dark current, "flat fielded" and wavelength calibrated. The continuum is defined by a number of narrow spectral regions, selected to be free of lines in the solar and the Procyon spectra. The equivalent widths of the lines are measured by an interactive procedure, based on a Gaussian fit to the line profiles. Only lines weaker than 100 mÅ in the solar spectrum are included, and all lines showing asymmetric line profiles
Fig. 1. Typical spectra obtained with the ESO CAT/CES system. Lines used in the abundance determinations are marked with their corresponding elements. a) The 6155 Å region as observed for HR 35, \( V = 5.25 \), with 45 m integration time. Note the two weak oxygen lines at 6156.8 and 6158.2 Å, which in this star have equivalent widths of 11 and 9 mÅ, respectively. b) The region around the near infrared oxygen triplet at 7774 Å as observed for HR 573, \( V = 6.10 \), with 60 m integration time.
Table 1. Wavelength regions observed with the ESO CAT/CES system

<table>
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<th>Region</th>
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<td>8715 - 8780</td>
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Table 2. Atmospheric parameters, abundance ratios and logarithmic ages for the 29 stars analyzed in the present paper. [a/Fe] is defined by [a/Fe] = 1/4([Mg/Fe]+[Si/Fe]+[Ca/Fe]+[Ti/Fe])

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<th>HR</th>
<th>Teff (K)</th>
<th>log g cm⁻²</th>
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<th>[O/H]</th>
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4. Analysis.

The abundances of the various elements are derived by comparing observed equivalent widths with equivalent widths calculated for model atmospheres representing the individual stars. The models have been computed with an updated version of the programme presented by Gustafsson et al. (1975). Line blanketing and convection are taken into account. For each star a model is constructed with atmospheric parameters, $T_{\text{eff}}$, log $g$ and overall metal abundance [M/Fe] derived from the uvby-$\beta$ photometry of the star.

The equivalent widths of individual lines are calculated as a function of the abundance of the corresponding element. Oscillator strengths are determined from the solar flux spectrum as observed in reflected sunlight from the Moon and/or the 3.6 m dome with the ESO CAT/CES system. LTE is assumed in the computation of the populations of the various atomic states. Line broadening due to thermal motions and microturbulence, as well as radiative and collisional damping is taken into account. The microturbulence is assumed to be a depth-independent parameter and a function of $T_{\text{eff}}$ and log $g$, according to the formula derived by Nissen (1981).

The effective temperatures of the stars are determined from the b-y index using an empirical calibration recently derived by Saxner and Hammarbäck (1985). They determined effective temperatures from observed integrated fluxes and estimates of angular diameters, using the infrared flux method (Blackwell and Shaller, 1977). The calibration is based on data for 31 stars covering the range 5800 K to 7200 K in $T_{\text{eff}}$, 3.9 to 4.5 in log $g$, and -0.8 to 0.2 in [Fe/H]. The stars studied in this work fall in about the same intervals. The rms scatter of $T_{\text{eff}}$ around their calibration equation, which includes a [Fe/H] term, is $\pm 75$ K only. For the Sun they find a color index of $(b-y)_{\odot} = 0.407 \pm 0.010$, corresponding to $(B-V)_{\odot} = 0.64 \pm 0.02$.

This empirical calibration of Saxner and Hammarbäck agrees remarkably well with the theoretical calibration of b-y as a function of $T_{\text{eff}}$ derived by Nissen and Gustafsson (1978), if the zero point of the theoretical calibration is chosen such that $(b-y)_{\odot} = 0.407$.

The surface gravities of the stars are determined from the $\delta c_1(\beta)$ index using the method described in detail by Nissen and Gustafsson (1978).

The overall metal abundance [M/Fe] of a star is determined from $\delta m_1(\beta)$ using the calibration equation derived by Nissen (1981). The agreement between [M/Fe] and [Fe/H] determined from our detailed analysis of the CES spectra is very sat-
isfactory (the rms deviation of [Mg/H] is 0.08 only) confirming that accurate metal abundances can be derived from $\delta m$.

So far 29 stars, all observed with the ESO CAT/CES system, have been analysed. The results are given in Table 2.

5. Errors in the abundance determination.

A detailed discussion of possible errors in the abundances derived will be given in a future publication. Here we limit ourselves to a brief discussion of a few diagrams that contain some information on the accuracies obtained.

As the equivalent widths of the spectral lines are determined to high accuracy, the errors of the abundances, due to observational uncertainties, is smaller than about 0.05 dex. The error induced by the uncertainties in the $T_{\text{eff}}$-determination is in fact more important. Typically an increase of 100 K in $T_{\text{eff}}$ for the model of the star leads to $\Delta$[Fe/H] = 0.06, $\Delta$[O/H] = -0.10, and $\Delta$[α/H] = 0.03. Note that the change in [O/H] is of opposite sign to that of [Fe/H] and nearly twice as large numerically. This is due to the fact that the oxygen abundance is derived from high excitation lines ($\chi = 10.74$ eV for the 6158 Å OI lines, and $\chi = 9.14$ eV for the 7774 Å OI lines). Thus the derived [O/Fe] is very sensitive to temperature and the systematic trend of [O/Fe] with [Fe/H] discussed later could be spurious if a systematic error in $T_{\text{eff}}$ as a function of [Fe/H] is present. For the α/Fe ratio on the other hand, the effect of uncertainties in $T_{\text{eff}}$ is negligible small.

A check on the effective temperature scale can be obtained by plotting the [Fe/H] values derived from individual FeI lines as a function of the excitation energy of the lower state of the line. In Fig.2 this has been done for a metal-rich star, HR 370, and a metal-poor star HR 8181. Similar diagrams are obtained for the other stars. As is seen, the scatter in the derived abundances around the mean is very small indeed, 0.05 dex in both cases. Furthermore, there is no significant trend with excitation energy, suggesting that our effective temperatures are accurate within ±100 K. About the same error in $T_{\text{eff}}$ was estimated by Saxner and Hammarbäck (1985). We conclude that typical errors due to uncertainties in $T_{\text{eff}}$ are ±0.06 in [Fe/H], ±0.10 in [O/H], and ±0.03 in [α/H].

The uncertainties in surface gravity and microturbulence make a negligibly small error contribution as compared to that arising from the uncertainty in effective temperature. As shown by Nissen and Gustafsson (1978) the uncertainty in log g is about ±0.1, which in the worst case ([O/Fe]) causes an error of ±0.04 dex only. The value of the microturbulence parameter can be checked by plotting the derived [Fe/H] abundance versus equivalent width of the FeI lines. These plots show that the microturbulence is correct, to within ±0.3 km/s. The corresponding errors of the abundance ratios are negligible, because the bulk of lines
Fig. 2. Logarithmic iron abundances relative to the Sun derived from individual FeI lines as a function of the difference between ionization energy, \( I \), and excitation energy, \( \chi \), of the lower state of the line. Results for two stars, having about the same effective temperature and surface gravity but widely different metal abundances (see Table 2), are shown. The rms scatter around the average [Fe/H] abundance (indicated with a broken line) is only 0.05 dex for both stars.

from which the abundances are determined have equivalent widths well below the Doppler width of the lines.

A critical assumption in connection with abundance determinations is that of LTE. If deviations from the Boltzmann- and Saha distribution occur and if these deviations change systematically as a function of [Fe/H] or \( T_{\text{eff}} \) then spurious trends of abundance ratios will be introduced by assuming LTE. The non-LTE computations of Saxner (1984) suggests in fact that significant departures from LTE in F stars occurs. Saxner finds an overionization of iron in metal-poor stars, as compared with LTE populations, caused by the relatively strong ultraviolet radiation in these stars. If so, too low iron abundances will be derived for metal-poor stars from neutral lines when LTE is assumed. In the case of weak FeI lines Saxner finds the non-LTE effect on the derived [Fe/H] value to be about 0.15 dex.

In an attempt to confirm observationally the results of Saxner we have derived iron abundances from both ionized and neutral lines. In Fig. 3 the ratio [FeII/FeI]
Fig. 3. The logarithmic ratio between iron abundances derived from FeII and FeI lines as a function of [Fe/H] for the 29 stars studied. The FeII abundance is determined from the equivalent width of two weak lines at 5100.65 and 6149.23 Å. The FeI abundance is determined from about 20 lines. The error bars given here and in the following figures refer to the estimated rms errors of the abundances.

Fig. 4. The logarithmic oxygen-to-hydrogen ratio derived from each of the three lines in the 7774 Å triplet minus the average logarithmic oxygen-to-hydrogen ratio derived from the two weak oxygen lines at 6156.8 and 6158.2 Å is plotted as a function of the equivalent width of the line in the 7774 Å triplet.
derived by assuming LTE is plotted as a function of [Fe/H]. There is no tendency for an overionization of Fe by 0.15 dex for the most metal-poor stars. Thus it is not probable that the high [O/Fe] ratio derived for metal-poor stars is due to non-LTE effects for iron. Fig.3 contradicts Soker's non-LTE computations and the question arises whether his results could be caused by errors in the photoionization and collisional cross sections and/or a too simplified model for the iron atom.

Departures from LTE may be important in connection with the oxygen abundances derived from the high excitation oxygen lines. Sneden et al. (1979) discuss non-LTE computations for the near-infrared O-triplet at 7774 Å and conclude that in solar temperature dwarf stars the non-LTE line strengths essential match those predicted by LTE calculations. A somewhat different result was obtained by Sedin (1974), who found significant non-LTE effects for the λ7774 triplet in the solar spectrum. For A-type stars Baschek et al. (1977) have shown that the λ7774 triplet is subject to strong non-LTE effects. For F-type stars Clegg et al. (1981) have compared oxygen abundances derived from the forbidden [O I] 6300 Å line with oxygen abundances derived from the λ7774 triplet. They conclude that there is no significant non-LTE effect for the triplet lines, when they are weaker than ~60 mÅ. In Fig.4 we have plotted the difference between the oxygen abundance derived from the 7774 Å lines and the 6158 Å lines as a function of the equivalent width of the 7774 Å lines. As the 6158 Å lines are very weak (the equivalent widths range from about 2 mÅ to 20 mÅ in our stars) they are formed deep in the atmosphere, where one would expect LTE to be a better approximation than in the upper layers, where the λ7774 triplet is formed. This expectation is supported by Baschek et al. (1977), who show that the difference between the equivalent width of the O I 6158.2 Å line computed in LTE and non-LTE for a dwarf star with T_eff = 7500 K is less than 10%. In view of this result we interpret the difference between [O/H]_7774 and [O/H]_6158 seen in Fig.4 for W_7774 > 100 mÅ as the result of non-LTE effects for the 7774 Å lines, and derive oxygen abundances exclusively from the 6158 Å lines. In the range 50 < W_7774 < 100 mÅ there is, however, a good agreement between the two sets of abundances. In this interval the average of the oxygen abundance determined from the 6158 and the 7774 Å lines are given in Table 2. Finally, for the coolest and most metal-poor stars in which the 6158 Å lines are too weak (W < 5 mÅ) to be measured with good accuracy we have derived the oxygen abundance from the 7774 Å lines only.

Another source of error is the uncertainty in the temperature structure of the atmospheric model, due to the inadequate handling of convection by the mixing-length recipe. A study of this problem must await more detailed numerical simulations of convection similar to those made by Nordlund (1982) for the Sun.

Individual ages of the stars have been determined by comparing their positions in a $\log T_{\text{eff}} - \log g$ diagram with isochrones computed by Hejleson (1980). These isochrones are given for heavy element abundances by weight, of $Z = 0.04$, $0.03$, $0.02$, $0.01$, $0.004$, and $0.0004$. An age corresponding to the $Z$-value of a given star can then be found by interpolation. The choice of $Z$ for the star is, however, a problem. Hejleson's isochrones were calculated using solar ratios for the heavy elements. Thus, the enhancement of $\text{O}/\text{Fe}$ and $\alpha/\text{Fe}$ in the metal-poor stars is not taken into account. In order to make some allowance for this effect we have calculated $Z$ by the expression

$$\log Z/Z_\odot = \frac{1}{2}([\text{O}/\text{H}] + [\text{Fe}/\text{H}])$$

with $Z_\odot = 0.017$.

If we had instead used the usual expression, $\log Z = \log Z_\odot + [\text{Fe}/\text{H}]$, then the derived ages would have been larger by about 0.1 dex. This figure can be taken as an upper limit for the uncertainty in the age determinations due to an incorrect chemical composition of the stellar models. In the future, isochrones should be computed with full attention to the effects of the enhancement of $\text{O}/\text{Fe}$ and $\alpha/\text{Fe}$ on the opacity, on the mean molecular weight, and on the rate of the CNO cycle.

The isochrones used refer to a hydrogen abundance by mass of $X = 0.70$. For the mixing-length to scale-height ratio we have assumed a value of $\ell/H_p = 1.7$, i.e. we have interpolated between the ages derived for $\ell/H_p = 1.5$ and $\ell/H_p = 2.0$, the two values for which Hejleson has computed isochrones. The ages derived are quite sensitive to the adopted value of the mixing-length parameter, but according to the study by VandenBerg (1983 and 1985) of color-magnitude diagrams of star clusters, there is good evidence that this parameter is not changing as a function of metal abundance and has a value in the range of $1.5 \lesssim \ell/H_p \lesssim 1.7$.

As described earlier, the effective temperature and surface gravity are determined from the Strömgren indices $b-y$ and $c_1$. Typical uncertainties are $\sigma(\log T_{\text{e}}) = \pm 0.007$ and $\sigma(\Delta \log g) = \pm 0.07$, where $\Delta \log g$ is the difference between the ZAMS value of $\log g$ for the effective temperature of the star and the $\log g$ value of the star (Nissen and Gustafsson, 1978). To give an impression of the corresponding error in the age we have drawn a set of isochrones in Fig.5 and entered the six stars from Table 2 having $[\text{Fe}/\text{H}]$ and $[\text{O}/\text{H}]$ values around or slightly above 0.0. The $Z$-values of these stars are close to $Z = 0.02$, the value to which the isochrones refer. It is seen that a typical error of $\sigma(\log A) = \pm 0.1$ is induced by the errors in $\log T_{\text{eff}}$ and $\log g$. Note also the importance of having selected stars with $M_V > M_{\odot}$ (corresponding to $\Delta \log g > 0.15$) for making an accurate age determination possible.
For some of the stars absolute magnitudes can be determined from apparent magnitudes and observed trigonometric parallaxes. Ages can then be derived by plotting the stars in the $T_{\text{eff}} - M_{\text{bol}}$ diagrams of Hejlesen (1980) and compared to the ages derived from the position of the stars in the $T_{\text{eff}} - \log g$ diagram. For 13 out of 16 stars with reliable parallaxes ($\pi \geq 0.05$) the agreement between the two sets of logarithmic ages is very satisfactory. The rms deviation is 0.08 dex only. The remaining 3 stars (HR 573, 5019, and 7232) fall close to the ZAMS in the $T_{\text{eff}} - M_{\text{bol}}$ diagram.

Recently Strömgren (1984) has used essentially the same $(b-y) - \delta c_1$ method to derive ages of Intermediate Population II stars. From a discussion of possible error sources he estimates the mean error of $\log A$ to be ±0.05, but this does not include systematic errors due to uncertainties in the mixing-length parameter and in the chemical composition of the models used for the isochrone computation.

We intend to make a more detailed study of age determination for main sequence F and G type stars. As a preliminary result from the present investigation indi-
individual ages corresponding to \( \xi/\xi_p = 1.7 \) and \( X = 0.7 \) are given in Table 2. The ages refer to the position of the stars in the \( \log T_{\text{eff}} - \log g \) diagram. In the three cases, where the age derived from the \( \log T_{\text{eff}} - M_{\text{bol}} \) diagram is different, the value given in Table 2 is marked with a colon.

7. Results and discussion.

In Fig.6 the derived \([O/Fe]\) ratios are shown as a function of \([Fe/H]\). As seen the distribution of points agree well with the relation found by Clegg et al. (1981) for 20 F and G main sequence disk population stars. The rms scatter in \([O/Fe]\) around this relation is \( \pm 0.11 \) dex, which is about the error expected from the uncertainties in the analysis. Thus there is no evidence of a cosmic scatter in \([O/Fe]\) at a given \([Fe/H]\).

![Fig.6. The logarithmic oxygen-to-iron ratio as a function of \([Fe/H]\). The relation \([O/Fe] = -0.5[Fe/H]\) found by Clegg et al. (1981) is indicated by a broken line.](image)

In Fig.7 the average abundance of the even-Z nuclei elements Mg, Ca, Si, and Ti is shown as a function of \([Fe/H]\). The abundance of each of these so-called "\( \alpha \)-process" elements shows a very similar behaviour as a function of \([Fe/H]\), and
Fig. 7. The average abundance of even-Z elements as a function of [Fe/H]. \([\alpha/\Fe] \) is defined as \(\frac{1}{4}(\text{[Mg/Fe]} + \text{[Si/Fe]} + \text{[Ca/Fe]} + \text{[Ti/Fe]})\). The relation \([\alpha/\Fe] = -0.4([\text{Fe/H}] + 0.3)\) for \([\text{Fe}] \leq -0.3\) is indicated by a broken line.

Fig. 8. The average abundance of the odd-Z elements, Na and Al, as a function of [Fe/H]. \([\text{odd/Fe}] \) is defined as \(\frac{1}{2}([\text{Na/Fe}] + [\text{Al/Fe}])\).
we have therefore plotted the average value of [Mg/Fe], [Ca/Fe], [Si/Fe], and [Ti/Fe]. For the most metal-poor disk stars there is an enhancement of [a/Fe], but smaller than for [O/Fe]. Furthermore, the functional dependence of [Fe/H] is quite different for [O/Fe] and [a/Fe]. [O/Fe] changes linearly with [Fe/H] over the whole range \(-0.9 < [\text{Fe/H}] < 0.1\), whereas [a/Fe] remains constant at 0.0 for \([\text{Fe/H}] > -0.3\). Note that the scatter around the indicated relation between [a/Fe] and [Fe/H] is very small and corresponds to the expected error in the abundance determination.

From a study of light element abundances in 20 F and G stars Tomkin et al. (1984) have recently found a relation between [a/Fe] and [Fe/H] similar to that indicated in Fig.7. They also suggest such a relation for the odd-Z elements, Na and Al, but this is not confirmed by our analysis. As will be seen from Fig.8 the odd/Fe ratio is not changing significantly as a function of [Fe/H].

The different behaviour of [O/Fe], [a/Fe] and [odd/Fe] as a function of [Fe/H] is interesting, and should provide further constraints on models for galactic chemical evolution and theories for nucleosynthesis in supernovae. A discussion of these aspects is beyond the scope of the present paper. Some comments were, however, made in the paper by Edvardsson et al. (1984).

The ultimate aim of our programme is to study the abundances of the various elements as a function of stellar age and compare such observational relations with predictions from models of the chemical evolution of the galactic disk. Although the number of stars analysed so far is quite limited for this purpose, we show our preliminary results for [O/H] and [Fe/H] in Fig.9. Despite the large scatter a clear evolution in time for the average abundance of these elements is seen. The data are compared to the chemical evolution model by Twarog and Wheeler (1982) in which a constant star formation rate and a large infall rate (40% of the star formation rate) are assumed. The yields of oxygen and iron in supernovae explosions are taken to be constant and at the time of formation of the disk, 13 billion years ago, [O/H] = -0.4 and [Fe/H] = -1.0 are assumed. It is seen that the model represents our data fairly well. However, it should be noted that alternative models like the one of Vader and de Jong (1981), who assume that the star formation rate is proportional to the gas density and the infall rate of gas decreases exponentially with a time scale of \(5 \times 10^7\) y, can give an equally good fit to our data.

An interesting feature in Fig.9 is the large scatter. In the case of [O/H] the scatter is 50% greater than expected from the errors in the abundance and age determinations, and in the case of [Fe/H] the scatter is about a factor of two larger than expected. This suggests that, at a given time, rather large inhomogeneities (variations of 50%) in the chemical composition of the interstellar gas in the solar neighborhood are present. However, it can not be excluded that some
Fig. 9. The derived [O/H] and [Fe/H] values, plotted as a function of logarithmic stellar age. The broken line is the relation predicted from the model of chemical evolution of the galactic disk discussed by Twarog and Wheeler (1982). The position of the Sun is indicated with a. Stars for which the ages inferred from the log $T_{\text{eff}} - \log g$ and the log $T_{\text{eff}} - M_{\text{bol}}$ diagrams disagree have been marked with a colon.
of the disk stars now present in the solar neighborhood were born in other regions of our galaxy with a different chemical evolution history. When the whole programme has been finished and data for 270 stars is available, it will be interesting to study possible correlations between deviations from the chemical evolution curves in Fig.9 and the kinematics of the stars.

8. Summary and conclusion.

Abundances of oxygen and other light elements have been derived for a sample of 29 disk population, main sequence stars of spectral types F and G. The observational basis for the abundance determinations consists of high quality high-resolution spectra obtained with the ESO CAT/CES system. The atmospheric parameters of the stars and stellar ages have been determined from Strömgren uvby-β photometry.

The linear relation

\[ \frac{[O/Fe]}{[Fe/H]} = -0.5 \cdot [Fe/H] \]

found by Clegg et al. (1981) is confirmed. The α-elements are shown to follow a relation

\[ \frac{[a/Fe]}{[Fe/H]} = -0.4 \cdot ([Fe/H] + 0.3) \quad \text{for} \quad -1.0 < [Fe/H] \leq -0.3 \]

and

\[ \frac{[a/Fe]}{[Fe/H]} = 0.0 \quad \text{for} \quad -0.3 < [Fe/H] \leq +0.2 \]

The ratio of the abundance of the odd-Z elements, Na and Al, relative to that of iron seems to be solar for all stars. The scatter around these relations is small and corresponds to the errors in the abundance determination.

Plots of [O/H] and [Fe/H] as a function of stellar age indicate a significant chemical evolution of the galactic disk with time. Our data are well fitted by current models of galactic chemical evolution. However, the dispersion in [O/H] and [Fe/H] at a given age is considerably larger than the scatter expected from the errors in the abundance and age determinations. This points to rather great chemical inhomogeneities (>50% variations) in the solar region of the galactic disk at a given time and/or the presence in the solar neighborhood of stars formed in regions of the Galaxy with a different chemical evolution history. Despite these variations in [O/H] and [Fe/H] it is striking that [O/Fe] and [α/Fe] is a tight function of [Fe/H].

As is seen in our diagrams the Sun appears to be a chemically normal star, well representing the average properties of stars in the solar neighborhood.

Our conclusions are preliminary. Final results must await the completion of a larger programme (270 stars), which is carried out in collaboration with J. Andersen, D.L. Lambert, E.H. Olsen, and J. Tomkin, and a refined analysis, taking non-LTE effects and non-local convection effects into account.
References

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DISCUSSION

G. WALLERSTEIN: (1) When you have completed all 250 stars it will be interesting to look for correlations of the abundances with the eccentricity and semi-major axis of the stellar Galactic orbits.
(2) The excess of $\alpha$-elements in iron poor stars was first seen by Aller and Greenstein in HD 19445 in 1960.

P.E. NISSEN: (1) We intend to investigate the relationship between abundance and space velocity when we have completed the survey.

A. RENZINI: What is the uncertainty in a star's derived age which is induced by the uncertainty in metallicity?

P.E. NISSEN: Negligible, because the metal abundance is determined very accurately. The major uncertainty in the derived stellar ages comes from the errors in the $T_{\text{eff}}$ and log $g$ values of the stars.

R.C. PETERSON: Some error in the oxygen abundance inferred from the OI 7770 triplet may be introduced by errors in modeling the temperature gradient at large optical depth, where the line is formed (due to its very high excitation potential). Bell/Gustafsson models at 5500 K differ (are less steep) than Kurucz models, presumably due to differences in line blanketing. Depending on the choice of model, a different abundance would be deduced.

P.E. NISSEN: I agree. We certainly have to study this error source, and the effect of the uncertainty in the temperature gradient may be larger for the faint 6158 OI lines than for the OI 7770 triplet, because the former lines are formed even deeper in the atmosphere.

R.B.S. CLEGG: We (Clegg, Lambert and Tomkin, 1981) found that the $O$ abundances obtained from the forbidden line at 6300 Å disagreed with those from the permitted 7770 Å lines when the latter had equivalent width more than about 60-70 mÅ. This is similar to your result.

P.E. NISSEN: Yes, and I think that your work also showed that when the equivalent widths of the 7770 Å lines are below about 70 mÅ, they are close to being formed in LTE.
B. BARBUY: Just a comment on Clegg's comment. Indeed, if you determine [O/Fe] for the same star both from the λ6300 (OI) line and the OI triplet λ7700 lines you can find differences of 0.5-0.6 dex, if LTE is assumed and the equivalent width is above 80 mA.