ABUNDANCE VARIATIONS AMONG YOUNG CLUSTERS AND ASSOCIATIONS

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1. INTRODUCTION

The aim of this paper is to give a review of our knowledge of the chemical composition of young groups of stars in the Galaxy, i.e. open clusters and associations with ages less than about 10^9 years. In particular I shall discuss if abundance differences between these groups of stars do occur, and how large these possible differences can be. Such information is important in many astronomical fields. Thus, abundance differences between star clusters complicate the determination of their distances by ZAMS-fitting, and make the distance scale in the Universe more uncertain. Comparisons between theoretical isochrones and cluster sequences in color-magnitude diagrams with the purpose of testing the theory of stellar structure and evolution are also much more difficult if differences in abundances have to be taken into account. On the other hand the determination of abundances of clusters and associations as a function of their ages and places of formation give important information on the chemical evolution of our galaxy, in particular because abundances, ages and space velocities for clusters and associations can be determined much more accurate than for single stars.

In connection with a discussion of possible abundance differences between young groups of stars it is natural to ask whether all stars in a given cluster or association have the same primordial composition as is usually assumed. The discovery of the abundance differences between K giants in some globular clusters makes this assumption more questionable and calls for a critical study of abundances of stars in open clusters and associations.

In the following I shall present evidence that significant abundance differences between young groups of stars do indeed occur both in helium and metals, and I shall discuss in which way they are related to ages and places of formation of the clusters and associations. Furthermore we shall see that there is no evidence of primordial abundance differences between stars in a given young cluster or association.

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2. METAL ABUNDANCES

One of the most accurate ways to determine metal abundances for large samples of stars is problably through observations of the Strömgren m_1 index, and I would like to start by showing that m_1 is indeed an excellent metal abundance indicator for F-type stars. Then I shall apply the m_1-method to a number of clusters for which uvby,β photometry have been carried out and finally the metal abundances derived in this way will be compared with results obtained from other photometric and spectroscopic determinations of metal abundances.

2.1. *The calibration of* δm_o *in terms of* [Me/H]

In a paper on empirical calibrations of the uvby,β system for F-type stars Crawford (1975) has defined the metal abundance indicator $\delta m_1(\beta)$ as the standard Hyades m_1 value corresponding to the β index of the star minus the observed m_1 value of the star. In the case of reddened stars the observed m_1 index must of course be corrected for reddening. First the color excess E(b-y) is determined from the relation between β and $(b-y)_o$ derived by Crawford (1975), and then the color excess of m_1 is calculated from the relation, $E(m_1) = -0.32\ E(b-y)$, found by Crawford and Mandwewala (1976). The metal abundance index used in the present paper is therefore designated δm_o in order to indicate that m_1 has been corrected for reddening before the difference to the Hyades standard relation is taken.

The ratio $E(m_1)/E(b-y)$ was determined empirically by Crawford and Mandwewala from observations of reddened O stars. Their computations show that the same value can be used for F-type stars. As judged from Fig. 9 in Crawford and Mandwewala's paper the uncertainty of the ratio is on the order of ± 0.03. In the present study, where we are dealing with clusters with color excesses less than about 0.1 mag in (b-y), an error in $E(m_1)/E(b-y)$ of 0.03 leads to spurious differences in δm_o less than 0.003 mag corresponding to 0.03 in [Me/H] only.

The calibration of δm_o as a function of [Me/H], i.e. the logarithmic metal-to-hydrogen ratio of a star minus the same quantity for the sun, has recently been studied by Nissen and Gustafsson (1978). The metal abundances determined in that paper were based on observations of the strengths of two narrow groups of lines. One of the groups consists of weak metal lines and is primarily sensitive to the metal abundance, whereas the other group, that consists of stronger lines, provides a microturbulence measure. From a model-atmosphere analysis of the line groups metal abundances and microturbulence velocities were determined for 52 stars, and it was found that the microturbulence is a function of the effective temperature and the surface gravity of a star. Following this work a number of new stars in the upper part of the main sequence band have been observed. Details on these new results will be published elsewhere, but in Fig. 1 the resulting calibration of δm_o in terms of [Me/H] is shown.

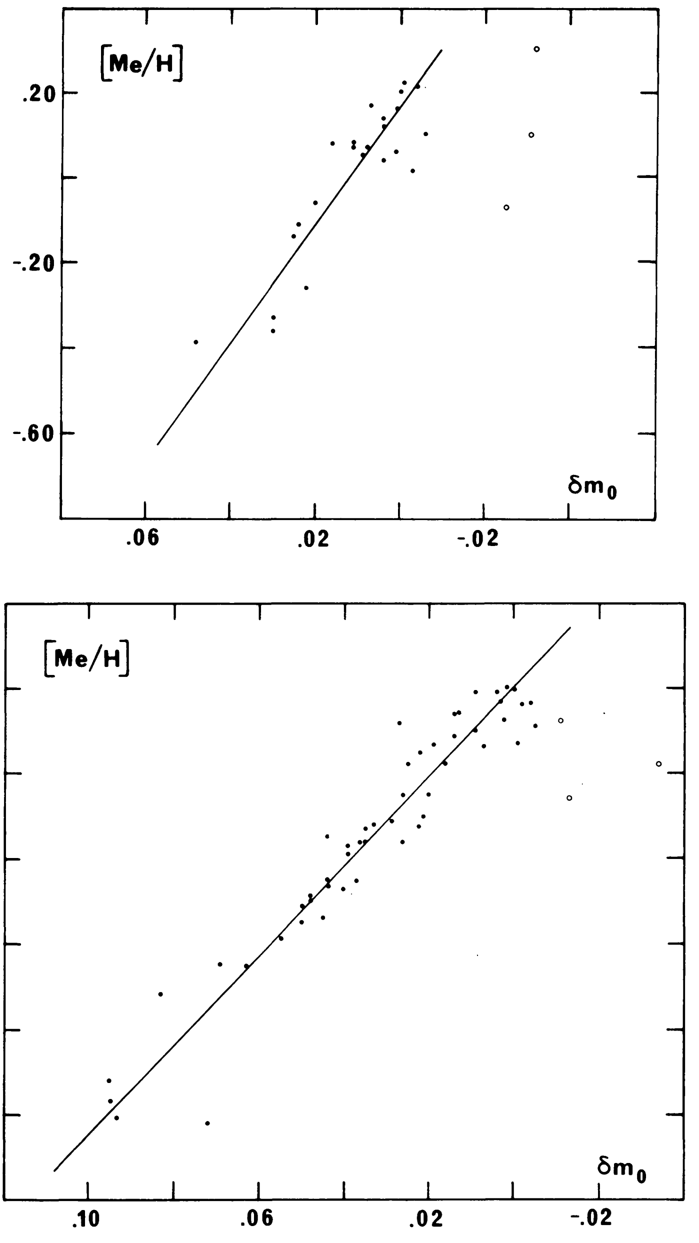

Fig. 1. The relation between the Strömgren δm_0 index and [Me/H] as determined from observations of narrow groups of lines. The upper figure refers to F-type stars with $2.66 < \beta < 2.73$, whereas the lower figure refers to stars with $2.59 < \beta < 2.66$. Stars plotted with open circles have been omitted from the regression analysis.

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Fig. 1 refers to southern stars for which the m_1 indices have been taken mainly from the catalogue of uvby photometry by Grønbech and Olsen (1976). As seen there is a good correlation between δm_o and [Me/H] except that a few stars with negative values of δm_o deviate strongly for some unknown reason. From Fig. 1 one gets the impression that these stars occur fairly frequent, but this is not the case. In large samples of F-type stars less than 1% have $\delta m_o < -0.015$.

If the strongly deviating stars with negative δm_o values are excluded the following calibrations for *southern* F-type stars are found:

$$2.66 < \beta < 2.73, \quad [\mathrm{Me/H}] = -13.8\ \delta m_o + 0.16, \quad \sigma = 0.09 \quad (1)$$
$$2.59 < \beta < 2.66, \quad [\mathrm{Me/H}] = -10.5\ \delta m_o + 0.20, \quad \sigma = 0.08 \quad (2)$$

where σ is the standard deviation of [Me/H] from the lines. Furthermore the observations of narrow line groups by Nissen (1970a) and Gustafsson and Nissen (1972) for northern stars have been reanalyzed using the same metal-line blanketed modelatmospheres as were applied for the analysis of the southern stars and the microturbulence variation with temperature and gravity found for the southern stars. This new analysis results in the following calibrations for *northern* F-type stars:

$$2.66 < \beta < 2.73, \quad [\mathrm{Me/H}] = -13.3\ \delta m_o + 0.14, \quad \sigma = 0.11 \quad (3)$$
$$2.59 < \beta < 2.66, \quad [\mathrm{Me/H}] = -10.6\ \delta m_o + 0.14, \quad \sigma = 0.10 \quad (4)$$

The derived [Me/H] values and the m_1 indices, taken from the catalogue of Strömgren and Perry (1965), are not quite as accurate as the values for the southern stars, which explains the somewhat higher standard deviations.

As seen from Eqs. (1) to (4) δm_o is more sensitive to [Me/H] for the late F-type stars than for the early F-type stars. An analysis that takes into account a linear dependence of the slope coefficient on β gives the following calibration for all F-type stars:

$$[\mathrm{Me/H}] = -\left(\underset{\pm 0.5}{10.5} + \underset{\pm 20}{50}(\beta - 2.626)\right)\delta m_o + \underset{\pm 0.02}{0.16} \quad (5)$$

where the formal mean errors of the two coefficients and the zero point resulting from the regression analysis are given. Systematic errors resulting from the model-atmosphere analysis may be larger.These errors have been thoroughly discussed by Nissen and Gustafsson (1978). The most important systematic error is ± 0.10 on the zero point, which is mainly due to the uncertainty of the color index of the sun.

Using δc_o (Crawford, 1975) as an indicator of absolute magnitude it has been investigated whether there is any dependence of the individual [Me/H]-deviations from Eq. (5) on absolute magnitude. Up to 2 magnitudes above the ZAMS-relation there is no such dependence, which shows that the δm_o calibration can be used also for clusters with a turn up from the ZAMS in the F-star region. One of the clusters that is investigated in this paper belongs to the category, namely NGC 752.

It should be noted, that Crawford (1975) has derived a calibration of δm_o from spectroscopic [Fe/H] values, that agrees very well with Eqs. (2) and (4) for late F-type stars. The standard deviation in [Fe/H] is considerably larger than the typical value of 0.10 found in the calibrations given above, but this is probably due to the greater errors in the rather inhomogeneous set of spectroscopic [Fe/H] values.

2.2. *Metal abundances of clusters as determined from* δm_o

In this section metal abundances are derived from δm_o for a number of clusters for which uvby,β photometry has been carried out. In these clusters F-type stars have been selected according to the criterion $2.59 < \beta < 2.72$, which limits are chosen because for $\beta < 2.59$ the standard Hyades relation between β and m_1 has not been determined, and for $\beta > 2.72$ a significant fraction of the stars is metallic-line stars.

Only clusters with at least 5 stars in the β range just mentioned have been included in the study. Furthermore a few clusters have been excluded, because the published m_1 indices have mean errors as large as 0.03 mag instead of 0.01 for the clusters that are included.

The sources of the uvby,β photometry for the clusters are as follows: Coma, Praesepe, NGC 752, IC 4665 and α Persei (Crawford and Barnes, 1969a, 1969b, 1970, 1972 and 1974), Hyades and Pleiades (Crawford and Perry, 1966 and 1976), the ζ Sculptoris cluster (Eggen, 1972 and Perry et al., 1978). Every F-type star considered to be a member in the above listed papers have been included in the following analysis, except that 3 stars in Praesepe with $\delta m_o < -0.015$ have been omitted, because as shown in the preceding section these stars tend to deviate strongly from the δm_o calibration. It is interesting, that Praesepe is the only cluster that contains this category of stars.

For each individual star E(b-y) and δm_o have been determined and [Me/H] computed from Eq.(5). The average values of E(b-y) and [Me/H] are given in Table 1, where the clusters have been arranged according to decreasing ages. σ is the standard deviation of [Me/H] from the average value. The quoted errors of the average [Me/H] are computed as $\sigma/\sqrt{N}$, where N is the number of stars in a given cluster.

It is seen from Table 1 that the average value of [Me/H] for the Hyades is not 0.16, as we should expect from the zero point of the δm_o calibration, Eq.(5). This is due to the fact that the average δm_o for the Hyades is not exactly zero, but 0.003 mag. The main contribution to the positive δm_o value comes from Hyades stars in the range $2.62 < \beta < 2.66$, where the average δm_o is 0.005 mag.

Table 1

Cluster	N	E(b-y)	[Me/H]	σ
NGC 752	29	$.^m022$	-.02 ± .02	.12
Praesepe	47	.003	.09 ± .02	.10
Hyades	49	-.002	.13 ± .01	.09
Coma	18	-.006	-.03 ± .02	.07
Pleiades	30	.030	.05 ± .02	.12
ζ Scul.	8	-.010	-.01 ± .07	
α Persei	19	.053	.04 ± .02	.10
IC 4665	5	.138	-.11 ± .07	

The number of stars in IC 4665 and ζ Sculptoris is so small, that the standard deviation of [Me/H] is quite uncertain. For the remaining clusters σ is, however, well determined and in no case larger than 0.12. The average value of σ is 0.10, which corresponds to 0.008 mag in δm_O, about what one would expect from the errors in the photometry. Thus, we conclude that there is no evidence for metal abundance differences between F stars in a given young cluster.

Turning now to the average metal abundances it is seen from Table 1, that the differences between the clusters are fairly small. However, in view of the very small errors of the average values of [Me/H] the differences are significant to a high degree of confidence. Thus we can conclude that the metal-to-hydrogen ratio for Hyades and Praesepe is about 40% higher than for Coma and NGC 752, whereas the ratio for α Persei and Pleiades lies somewhere in between. Due to the relative large errors for IC 4665 and the ζ Sculptoris cluster we can only conclude, that these clusters do not deviate strongly in metal abundance from the other clusters.

It seems clear from Table 1 that the metal abundance differences between the clusters are not related to the ages. They could be related to the large scale metal abundance gradient in our galaxy, that has been found by Mayor (1976) and Janes (1979). Both of these authors find a negative, radial gradient. However, the work of Palous et al. (1977) suggests that the place of formation of the Coma cluster lies between 9 and 10 kpc from the center of the galaxy, whereas the more metal rich clusters Hyades and Praesepe are formed between 10 and 11 kpc from the center. Thus it seems that in addition to the large scale abundance gradients in our galaxy and a possible over-all correlation between age and metal abundance, abundance inhomogeneities in the interstellar gas do occur.

2.3. *Other photometric determinations of metal abundances*

In this section we shall briefly review some recent photometric determinations of metal abundances of young groups of stars and compare with the results given in the preceding section.

2.3.1. Narrow line groups. Observations of the narrow line groups, on which the above given calibration of δm_0 is based, have also been carried out for a number of F stars in Hyades, Coma and Pleiades (Nissen, 1970b, Gustafsson and Nissen, 1972). A reanalysis of these observations based on the new metal-line blanketed model atmospheres and the microturbulence variation with temperature and gravity found for the southern F-type stars has given the following results:

Hyades:	[Me/H] = 0.12 ± 0.02,	N = 15
Coma:	[Me/H] = -0.09 ± 0.03,	N = 10
Pleiades:	[Me/H] = -0.08 ± 0.04,	N = 6

where N is the number of stars observed in each cluster, and the qouted errors are the sample standard deviations divided by $\sqrt{N}$. The Hyades abundance agrees very well with the value found from the δm_0 index, and the values for Coma agree satisfactorily. The Pleiades abundance is considerably lower than the value found from δm_0, but in view of the uncertainty there does not need to be a real discrepancy.

A narrow group of weak metallic absorption lines has also been observed for the K giant stars in Hyades and Praesepe by Gustafsson et al. (1974). For both clusters an average value of [Me/H] = 0.16 was found in good agreement with the results from the δm_0 method.

2.3.2. Calcium K-line photometry. The above given values of [Me/H] refer mainly to the abundance of iron, because the majority of the lines affecting the photoelectric indices are Fe I lines. It is therefore interesting to compare these results with the observations of a photoelectric narrow-band index of the calcium K-line for A-type stars by Hesser and Henry (1971), Henry et al. (1977), and Hesser et al. (1977). In summary they find that the calcium abundance in Hyades and Praesepe are considerably higher than in the clusters Pleiades, IC 2602 and the Orion association. The calcium abundance difference is estimated to be about a factor of two. Thus, this work also indicates that the Hyades and Praesepe clusters are rich in metals, as compared to a number of stellar groups.

2.3.3. DDO photometry. As shown by Janes (1975) there exists a rather good correlation between the DDO cyanogen strength index, δCN, and spectroscopic [Fe/H] values for K giants. For 44 stars Janes found the relation

$$[Fe/H] = 4.5\ \delta CN \div 0.2 \qquad (6)$$

with a rms deviation of ± 0.17 in [Fe/H].

This method of determining metal abundances has recently been applied by Janes (1979) to a large number of open clusters. As a good correlation between the ultraviolet excess, δ(U-B), and δCN was found, these two indices were given equal weight in the determination of the metal abundances. For the three clusters in common with Table 1 Janes finds the following results:

NGC 752:	[Fe/H] = -0.30 ± 0.03
Hyades:	[Fe/H] = 0.10 ± 0.03
Praesepe:	[Fe/H] = 0.08 ± 0.04

For Hyades and Praesepe there is a good agreement with the results from the δm_O analysis. For NGC 752 Janes finds a much lower metal abundance than derived from δm_O, which could be due to CNO anomalies in this cluster.

Janes (1979) has given a thorough discussion of the metal abundances obtained from δCN and δ(U-B) for 41 open clusters. An interesting result is that differences on the order of a factor of 2 in the metal-to-hydrogen ratio are found among clusters with the same galactocentric distance. Furthermore the metal abundances are found to be correlated with the galactocentric distances of the clusters. The gradient in [Fe/H] is .05 ± .01 kpc^{-1}. However, it should be noted that a few old clusters at large galactocentric distances and with large distances from the galactic plane have a high weight in the determination of this gradient. For clusters younger than about 10^9 years the gradient is smaller than for the older clusters and less certain: -0.04 ± 0.03 kpc^{-1}.

2.4. *Spectroscopic determinations of metal abundances*

2.4.1. Hyades. The metal abundance of stars in the Hyades has been determined several times from high-dispersion spectrograms. Results from the last 20 years have recently been reviewed by Tomkin and Lambert (1978). The majority of these spectroscopic works leads to a solar metal abundance, i.e. [Me/H] = 0.0, although a few investigations give higher values. As seen from the preceding sections all photometric determinations of the Hyades metal abundance give values of [Me/H] between 0.1 and 0.2. Thus there is a systematic difference between the two methods, but the difference is not as large as have been reported earlier. In fact all results agree with a Hyades metal abundance of [Me/H] = 0.10 within ± 0.10.

2.4.2. Other clusters. Spectroscopic determinations of the metal abundance of stars in other clusters than the Hyades are rare, due to the faintness of stars. Nearly all studies have been based on observations of equivalent widths of rather strong lines, which make the results less reliable, because the strength of these lines may be affected by differences in microturbulence and/or the damping parameter.

Chaffee et al. (1971) observed the strength of several Fe I lines for 6 F and G dwarfs in Pleiades and 14 in the Hyades. The iron abundance of the Pleiades was found to be equal to the solar value, whereas the Hyades abundance was found to be 50% higher, i.e. [Fe/H] = 0.18. This abundance difference between Hyades and Pleiades agree excellently with the difference found from the observations of narrow line groups.

Barry and Cromwell (1974) determined the equivalent widths of 13 hydrogen and metallic line features in the spectra of F and G stars in Hyades, Coma and M67. On the rough assumption that the metal abundance are proportional to the squares of the equivalent widths of the metallic lines, the [Me/H] ratio of Hyades was found to be about 50% higher than that of Coma. This agrees well with what is found from the δm_O index. In addition Barry and Cromwell obtained the result, that M67 has a metal abundance between the values for the Hyades and Coma.

2.5. *Summary of the metal abundance determinations*

In summary of the present chapter we conclude that the metal abundancesderived from the δm_O index generally agree well with values found by other photometric and spectroscopic methods, although these other methods tend to give slightly larger abundance differences than those inferred from δm_O.

The most important conclusion that can be derived from the discussion in the present chapter is, that the metal abundance of young clusters situated at about the same place in the Galaxy and formed at approximately the same time may have metal abundance differences that amount to 50%. For clusters at different galactocentric distances the work of Janes (1979) shows that larger differences in the metal abundance have to be considered.

3. HELIUM ABUNDANCES

Spectroscopic determinations of the helium abundances of B-type stars in young clusters and associations are relatively few. The view that the helium abundance has a universal value of $Y \simeq 0.25$, close to what is predicted by the standard theory for the Big Bang, seems to be generally accepted. However, as we shall see in the following, there is increasing evidence that differences on the order of $\Delta Y = 0.1$ occur even within our own galaxy.

The first systematic investigation of the helium abundance of B-type stars in clusters and associations was published by Peterson and Shipman (1973). They found the two associations Sco OBII and Lac OBI to have a "normal" helium-to-hydrogen ratio (by number) of $\varepsilon(\mathrm{He}) = 0.10$, whereas the cluster, NGC 2264, situated 800 pc away from the Sun in approximately the anticenter direction, was found to have $\varepsilon(\mathrm{He}) = 0.08$. The difference was estimated to be significant at the 3 σ level.

The most extensive study of helium abundances of young clusters and associations is that of Nissen (1974 and 1976). A photoelectric narrow-band index, I(4026), of the HeI λ4026 line was observed for a large number of B main-sequence stars. A model-atmosphere analysis of this index, the Strömgren $[c_1]$ index, and the H_β index was carried out and it was shown that for main sequence stars in the spectral range B0-B2 the relation between I(4026) and β is insensitive to differences in gravity but sensitive to differences in the helium-to-hydrogen ratio. The observations showed that stars in Sco-Cen, NGC 6231, Lac OBI and Ori OBI_b fall along the relation between I(4026) and β defined by nearby field stars, which indicates that all of these groups have the same helium abundance. On the other hand the stars in h+χ Per and Cep OBIII were found to deviate systematically from the field star relation in a way that indicates that their helium-to-hydrogen ratio is a factor of 1.7 lower than for the other clusters.

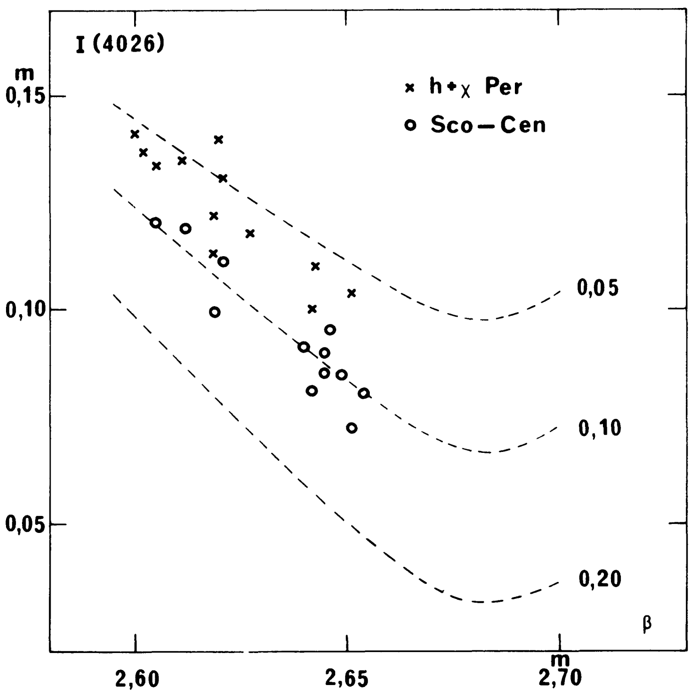

Fig. 2. The I(4026)-β diagram for two clusters. The theoretical relations between the two indices are drawn for three values of the helium-to-hydrogen ratio, ε(He) = 0.05, 0.10 and 0.20.

In order to illustrate this result the β-I(4026) diagram for Sco-Cen and h+χ Persei is shown in Fig. 2. The systematic difference in the position of the stars is clearly seen and as shown in the original paper this difference cannot be explained in terms of differences in effective temperature, gravity, rotation or reddening between the clusters.

The absolute values of the helium-to-hydrogen ratio is not well determined, but if we normalize the average helium abundance of near-by field stars to be $\varepsilon(He) = 0.10$, corresponding to $Y = 0.28$, then Cep OBIII and h+χ Persei are found to have a helium-to-hydrogen ratio of $\varepsilon(He) = 0.060 \pm .004$, corresponding to $Y = 0.19 \pm 0.01$. Thus the helium abundance difference is close to 0.1 in Y.

The helium abundance differences are not related to the ages of the clusters. The helium deficiency of h+χ Persei may be related to the radial helium abundance gradient in our galaxy found by Churchwell et al. (1978) from a study of helium and hydrogen radio recombination lines. However, the deficiency found by Nissen is larger than predicted from the gradient. Furthermore the galactocentric distance of the other helium deficient group, Cep OBIII, is the same as the distance of Lac OBI and Ori OBI, that was found to have a "normal" helium abundance. This suggests, that in addition to a possible galactic helium abundance gradient local variations of up to 0.1 in Y may occur.

Finally is should be mentioned that for a given cluster or association Nissen (1976) found the variations in the helium-to-hydrogen ratio among the member stars to be less than ± 20%.

4. CNO ABUNDANCES

Important contributions to the opacity in stars comes from carbon, nitrogen and oxygen. Furthermore the abundances of these elements are very interesting for studies of nucleosynthesis in stars and the chemical evolution of our galaxy. Thus it is of great importance to study these elements separately and to find out whether their abundances are proportional to the abundance of the iron-peak elements.

Although our knowledge to the CNO abundances in young clusters and associations is rather limited, a few important studies have been made recently. Tomkin and Lambert (1978) have determined the abundances of C, N and O in two Hyades F-type stars in relation to the abundances in the sun and Procyon. Within an estimated accuracy of ± 0.2 dex they find, that CNO abundances are solar. On the other hand Lambert and Ries (1977) find that the four Hyades giants all have a C/N ratio that are significantly less than the solar ratio, which is probably due to the mixing of material processed by the CNO cycle into the atmospheres of the giants.

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Another interesting result relating to the CNO abundances in clusters and associations have been obtained by Walborn (1976). From the inspection of stellar spectra he found that all of the O9.5-B0.7 supergiants in the Orion Belt association and in NGC 6231 are systematically nitrogen-deficient relative to the majority of supergiants with the same spectral types. This suggests the possibility that these groups of stars may have been formed from nitrogen-deficient clouds.

Whereas the discovery of Walborn is based on a visual inspection of spectrograms, Dufton (1979) has made a detailed abundance analysis of some B-type supergiants, including 3 stars in a loose association in Carina, that is situated approximately 2.4 kpc away in the direction of the galactic center. Dufton finds the stars in the association to have a nitrogen deficiency of 0.8 dex ± 0.3, whereas the C and O elements have solar abundances.

The findings of Walborn and Dufton suggest that the chemical composition of clusters and associations may be more complicated than can be described by the parameters Y and Z.

5. CONCLUSION

The results reviewed in the preceding chapters indicate, that young clusters and associations formed at nearly the same galactocentric distance and with the same age may have helium abundance differences of $\Delta Y = 0.1$, and metal abundance differences, that amount to 50%, corresponding to a variation in Z from 0.02 to 0.03. Furthermore the work of Janes (1979) suggests that over distances of the order of a few kpc the metal abundance may vary by a factor of 3, corresponding to a variation in Z from 0.01 to 0.03. These variations are probably related to a large scale radial metal abundance gradient in our galaxy.

There are no indications that the main sequence F stars in a given young cluster show any variation in the metal-to-hydrogen ratio in excess of ± 25%, which limit corresponds to the observational errors. The same conclusion is reached concerning the helium abundance of the early B-type main sequence stars in young clusters and associations.

It may be of interest to conclude this review by a brief discussion of the consequences of the variations in Z and Y for the determination of distances to clusters by fitting their unevolved main sequences to that of the Hyades. According to Perrin et al. (1977) the change in the bolometric magnitude of a zero-age-main-sequence F-type star is given by

$$\Delta M_{bol} = -16\ \Delta Z + 3\ \Delta Y \qquad (7)$$

at constant effective temperature. Thus a change of $\Delta Z = 0.02$ shifts the ZAMS by -0.3 mag, whereas $\Delta Y = 0.1$ corresponds to +0.3 mag.

Now the intersting question arises, whether the differences in Z and Y are correlated or not. If not, the zero-age-main-sequences of young clusters and associations may deviate by as much as 0.6 mag for a given effective temperature. The corresponding uncertainty in the distance as derived from ZAMS fitting is 30% for a cluster with unknown chemical composition. On the other hand it may be that $\Delta Y \simeq 5\ \Delta Z$, which according to Eq.(7) means that the ZAMS is independent of the abundance variations. In fact the work of Perrin et al. (1977), who studied the position of nonevolved solar-type star in a log T_{eff}-M_{bol} diagram gives some support to such a coherent variation of the abundance of helium and metals. However, this is a problem that certainly deserves further studies.

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DISCUSSION

KING: What is the limiting magnitude of the technique you are using?

NISSEN: With a 2 meter telescope the limiting magnitude is about 11 if one spends about half an hour on each star.

KING: Both for the metals and for the helium?

NISSEN: No, that is for the helium. For the metals it is around ninth magnitude, as the bands are somewhat narrower.

CARNEY: How affected are you by the presence of close binaries?

NISSEN: Concerning the δm_0 index, I studied the effect for the Hyades and it turns out, that the δm_0 index derived for close binaries is very close to the mean value of δm_0 for single stars. So I do not think there is a binary effect on the δm_0 index.

HARDY: What zero point did you use to derive the [Fe/H] values from the *DDO* system?

NISSEN: I used the equation given in the paper by Janes. I think that the zero point there is different from what has been given by you, and furthermore I note that you derived a metal abundance for NGC 752 that agrees better with the result from δm_0.

HARDY: That was what I was going to say. I did those measurements and my δCN values are consistent with those of Janes, although slightly more metal-rich. If I use the zero point suggested by Deming, and I think yourself, to correct the transformation between δCN and [Fe/H], the discrepancy is much smaller. The abundance of NGC 752 goes to -0.1 in [Fe/H], which is essentially consistent with your value, to within the errors.

JANES: I have several comments. Apparently I do have, for some reason or other, NGC 752 perhaps a bit metal weak. Part of that is that I have combined somebody else's *UBV* work with the *DDO*. My *DDO* does give a little bit higher value, although it should be perhaps even higher yet. I used a lower zero point on that. There is a real problem there in comparing the metallicities of the giants with main sequence stars. Mine are based on the sort of typical spectroscopic results of field giant stars, which have very little relationship to spectroscopic studies of main sequence stars. So the zero point is in considerable disarray. That is not really, I think, a very severe problem, because it should scale up and down in some way or another. I was uneasy about your conclusion, however, of there being a small or non-existent gradient. You are basing it on these small numbers of clusters. Certainly there is a dispersion in the metallacities of clusters of any given age and any given

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location in the Galaxy, and I think your sample is not large enough to say anything at all. The problem of the older clusters in my group being further from the plane is a valid comment. I have tried to correct for that in my work. I should also point out that there are others who get a gradient, some of them here in the audience, Grenon and Mayor; and they, incidentally, find steeper gradients among the younger objects than the older objects. Finally, Hawley has done, I think, the largest study now of HII regions. He finds a small, or non-existent gradient of He, although I guess the Peimberts do find a He gradient, so there may be some question about the helium gradient and it is certainly a point that should be looked into much more.

NISSEN: Let me comment on that. In connection with your work, if you look for a correlation between the metal abundances and the ages, do you find such a correlation?

JANES: Well, I've looked into that a little bit. Part of the problem is that since I did include the *UBV* thing and mixed the two all together, you are in a little bit of trouble, I think, in trying to compare young clusters with old clusters in the ultraviolet excesses, because there's an age effect there. Also possibly in the δCN thing. So you should really compare in that kind of study only old with old and young with young: trying to mix them in the *DDO* or *UBV* photometry can get you into some confusion.

CAYREL: I have to make a comment, a question and a statement. The comment is that I was interested to see that on the second diagram you showed, the metal-enhancement of field stars, there are no stars showing a metal enhancement greater than 0.2 dex. This confirms that the SMR population is not present in the solar neighbourhood and that the spread in heavy element content for disk stars lies approximately between 0.2 and -0.6 dex. The question is, and this is a more technical question, some high dispersion detailed analyses of the solar-type Hyades stars show that [m/H] could be slightly higher than solar, by no more than 0.10 dex. But, is a value of [m/H] of 0.10 large enough to explain the color of the Hyades in the photometric systems, with respect to stars having a solar composition? And the statement is that there is some indication that the observational width of the ZAMS limited to disk stars in the solar neighbourhood is not well explained by a variation of the metals alone. Existence of a simultaneous variation of helium in the stars also seems necessary, roughly, as you have pointed out, $\Delta y \sim 5\Delta Z$. An order of magnitude improvement in the accuracy of the parallaxes of nearby, low-mass stars could allow us to pass from a statement which is at the limit of statistical presumption to a well established result. Such an important increase in accuracy in parallax determination can be obtained with the help of the astrometric satellite Hipparcos.

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NISSEN: I didn't quite understand your question because I think there is a big problem about the zero point for our metal abundances, because it is so difficult to compare with the Sun. And concerning the difference between Hyades and Coma, you didn't study Coma so we cannot compare.

CAYREL: It is more a blanketing question, because we, in detailed analyses, cannot give our results to better than 0.2 dex. So we are agreeing now.

NISSEN: Well, we are in the same situation in the photometry. If we talk about the absolute value for the Hyades, we also have an uncertainty that may be up to 0.20, but I think the differences between the clusters and between the stars we can determine more accurately from photometry than you can.

CAYREL: Absolutely, I agree.

WALLERSTEIN: When you speak of inhomogeneities from cluster to cluster, I think one should think also of different processes of star formation rather than just different initial chemical compositions, because we have in the T Tauri Association very quiescent star formation going on: no evidence for supernova, OB stars, or anything like that. At the same time we see, as Herbst presented, regions of star formation where a great deal of activity has been going on: OB stars formed early; there have been stellar winds; there have been strong radiation fields; there have been, perhaps, supernovae, as well. And these will have strong effects because they will affect, for example, the ratio of gas to dust in the process of star formation. You will have different forms of cooling: in one case things cool very, very quietly and in another case there is a shock wave compression followed by a rapid cooling, or something like that. You don't really know what it is, so that these processes of star formation can be just as important, if not more important, and it is an almost unexplored field.

NISSEN: I think that was a very good point. Especially, it is interesting to see the two clusters that have the high metal content, namely Hyades and Praesape, have very nearly the same ages and space velocities, so they may have been formed in the same region of the Galaxy.

BOK: (To Wallerstein) That was a very helpful comment. Thank you very much.

LYNGA: There are some of these young clusters for which you have studied He abundances that are close to nebulae where Peimbert and others have studied the He abundance. Have you compared with those at all?

NISSEN: No, I have not tried that.

LEVATO: I want to make a comment concerning the present situation of the *m*-index measurements that were raised in Montreal. Some colleagues talk about the relation of the *m*-index with turbulence and they show a very tight relation. Others talk about the relation between the *m*-index and metallicity; and others talk about the relation between the *m*-index and *Vsini*; and, finally, Dr. Kurucz, referring to his new models, said you must not use the *m*-index or must be very cautious about that. So I think that the *m*-index appears to be correlated with a lot of things, so the situation is not very clear.

NISSEN: Well, I think the discussions in Montreal were more about A-type stars; here we're talking about F-type stars. And, concerning the microturbulence, there has been a long discussion on that in the literature. But I think it has more or less been settled now, because in the work I did with Bengt Gustafsson we also observed a group of strong lines; and we, in fact, derived both metal abundances and microturbulence velocities. The microturbulence was shown to be a nice function of the parameters like effective temperature and surface gravity, so although microturbulence certainly affects the m_1-index, it doesn't harm us because it's a nice function of the other parameters.

VAN DEN BERGH: I'd like to return to the interesting point that George Wallerstein made, and ask the question "Do we in fact know of a single cluster that is formed or appears to be forming in a quiescent T Tauri-type region?"

WALLERSTEIN: How about the T Tauri association itself? RY Tauri, and all the others in that group - I don't think you'd call it a cluster, but it's a bunch of stars forming out of the same dark cloud.

HERBST: If you look at the Taurus T Association, which I think is the best mapped in the CO, the clouds are extremely fragmentary. In fact, they look very much like the pictures of clouds hit by shocks that Paul Woodward produces in his models. So I don't think that the Taurus T association is an example of a region of quiescent star formation. I don't know of one, personally.

DEMARQUE: I should point out that the detailed comparison between the color-magnitude diagrams of NGC 2420 (an old metal-poor disk cluster) and 47 Tuc (a metal-rich globular cluster) that McClure and I made two years ago (*Astrophys. J.* 213, 716, 1977), was based on the belief that the two clusters have the same metal content. If 47 Tuc is indeed more metal-poor than NGC 2420, no simple conclusion can be drawn from such a comparison.

This does not change, of course, our conclusion that there is a fundamental difference between halo and disk stars with the same uv excess, nor does it mean that the approach we used in the comparison of the two clusters is faulty.

SHOBBROOK: May I draw attention to a paper I have outside, where I have plotted the H-R diagram in M_V, c_o for several of these clusters (h and χ Persei, Lac OB1 and NGC 6910 and 6913 in the North and 6231 and 3293, 4755 in the South) and there is about 0.8 mag difference in the zero-age main sequence. That is, for these young clusters the late B stars are near enough to the zero-age main sequence - something like 0.8 mag difference. But also in the $(u-b)_o, c_o$ plot there is a 0.08 mag difference in $(u-b)_o$ for a given c_o. Of course, $(u-b)_o$ contains the m_o index and it seems even in the B stars these things are being picked up, but I haven't correlated them with any of your numbers yet. I suspect this photometry, which is mostly Dave Crawford's (one cluster is mine, 3293), is showing similar things, and it would be interesting to correlate them. These effects are very much more than the errors.

BOK: You have your homework for tonight laid out. Very nice.

CHIOSI: You raise the point of the theoretical implication in the ΔY/ΔZ relation. Let me make a comment on this point in the sense that the theoretical stellar evolution background based on constant mass models gives us a ratio which is of the order of 1. Now, if we take into account the possibility that mass loss by stellar winds is occurring for stars more massive than 10 or 20 $M_\odot$, and if we keep constant all other parameters, we will find the result that this ratio, ΔY/ΔZ, rises to let's say, above 3, in the sense that the evolution for mass losing models lowers the metal enrichment for each generation of stars. And I also want to make another comment, if I understood the point raised by Dr. Wallerstein. Did he say that the absolute value of the abundance is correlated with the star formation rate?

WALLERSTEIN: I only meant that it might be. Some process may blow away the gas and leave the dust, or vice versa. I don't understand it.

CHIOSI: OK, this point is true in the sense that it is obvious if we have more efficient star formation over a given time scale we will increase the absolute values of the abundances. But as far as I know this problem, the ratio of ΔY/ΔZ is not very sensitive to the star formation rate, but rather to the yield per stellar generation. And in any model which is not strictly a purely closed model of galactic disc evolution, the enrichment of the interstellar medium is proportional to the yield by some factor. But the ratio of two different yields, let's say He and metals, is only correlated with the stellar evolution background for, let's say, 90% of these remnants.

BOK: Thank you; I have one final comment, and that's this. This morning Bill Herbst made the comment that he wished there had been more radio astronomers here to help out with the clusters. I spent a week at the symposium at Mont Tremblant on radio molecules. It was pathetic and sad that there were practically no optical astronomers present at that colloquium. Normally I am a quiet, mouse-like person, but I had to get up on my hind legs because I was one of the few. You optical astronomers, Mr. William Herbst, will you please remember that you should have been there, and you ought to be thoroughly ashamed. (Laughter).

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