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THE CHEMICAL COMPOSITION OF YOUNG GALACTIC CLUSTERS AND ASSOCIATIONS

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1. *Introduction*

For a number of years QUB personnel have been engaged in the analysis of early-type stars. One area of interest is the investigation of the chemical composition of main-sequence B stars in young galactic clusters and loose associations. These objects can be used as tracers of element abundances in the interstellar medium, since their atmospheres should be uncontaminated by the products of interior nuclear reactions and thus reflect the composition of the interstellar medium from which they formed (Dufton 1972, 1979; Walborn 1976). The study of young open clusters is therefore useful in determining the nature and extent of any significant abundance variations in the interstellar medium, which may exist over small distance scales. If such chemical inhomogeneities were detected they would have serious implications for interstellar depletion studies and for models of the chemical evolution of the Galaxy where cosmic abundances are usually considered to be applicable.

Previously, Kane *et al* (1980) and Dufton *et al* (1981) investigated CNO abundances for field and loose-association B stars within 500 pc of the Sun, but found no significant abundance variations. Here we present results of an extensive study of 81 stars in seven clusters, namely NGC 2362, 3293, 4755, 6231, 6531, IC 2944 and a loose association first discussed by Feinstein (1964). These southern-hemisphere objects are typically 2 kpc from the Sun and, with the exception of NGC 2362 which is situated in the local spiral arm, are all located in the Sagittarius-Carina arm. Observations have been obtained for 13 stars in the northern-hemisphere clusters *h* and

χ Per, Cep OBIII and Be 94 and the preliminary results are also discussed in this paper. Cep OBIII is located in the local spiral arm, *h* and χ Per are situated in the Perseus arm, while Be 94 lies beyond the Perseus arm, approximately 5 kpc from the Sun. Clusters *h* and χ Per and the association Cep OBIII are of particular interest as Nissen (1976) detected helium deficiences using accurate photometric measurements of the 4026 A line. His results for *h* and χ Per have recently been supported by Wolff and Heasley (1985).

The spread in distances for the above clusters ($\sim$6 to $\sim$12 kpc from the Galactic Centre) also permits the investigation of systematic galactic abundance gradients of the type revealed by studies of planetary nebulae (Peimbert 1979) or HII regions (Shaver *et al* 1983). We note that preliminary results presented by Gehren *et al* (1985) for a few very distant B stars (6 – 7 kpc away) fail to provide evidence of such gradients, which are typically 0.05 – 0.10 dex kpc^{-1}.

2. *Observations*

Spectroscopic targets were chosen on the basis that they were considered to be main-sequence stars (i.e. log $g > 3.7$) within the effective temperature range 18000 – 32000 K. In nearly all cases subsequent model-atmosphere analysis (see Section 3) confirmed these criteria. For a complete listing of observed southern stars and their stellar parameters see Brown *et al* (1986a, b) (hereafter referred to as Papers 1 and 2). The observational data were obtained during six observing runs at three observatories between April 1984 and September 1985. These are summarized below.

2(a) *SAAO*. Spectroscopic observations were made at the South African Astronomical Observatory *(SAAO)* during April 1984 for 79 stars in NGC 2362, 3293, 4755, 6531, 6611, IC 2944 and the loose association. The spectra were exposed at a grating dispersion of approximately 23 A mm^{-1} (corresponding to a full-width-half-maximum resolution of 0.8 A), using the 1.9 m telescope and the *RGO* Cassegrain spectrograph with the Reticon photon-counting system *(RPCS)*. All stars were observed at a wavelength centred on 4050 A and covering approximately 400 A. Approximately 20 stars were also observed in a second region centred on 4550 A and again covering 400 A. Sky-background and flat-field corrections were applied to the spectra.

During April 1984 and July 1984 Stromgren photometry was undertaken for stars in NGC 6531, IC 2944 and the loose association, since no published results are available. The People's Photometer was used in conjunction with the *SAAO* 0.5 m telescope to determine four-colour ubvy magnitudes, and for brighter stars β indices.

2(b) *AAT*. Subsequent reduction of the Stromgren photometry showed that for stars in NGC 6611 it is difficult to derive effective temperature from the [c_1] index (see Section 3), which is probably due to the extreme variation in reddening across the cluster (Kamp 1974; Sagar and Joshi 1979). In order to obtain reliable effective temperatures from the silicon-ionization equilibria, it was therefore necessary to observe other wavelength regions. Five stars in NGC 6611 were reobserved, together with two stars in NGC 6231, during August 1984 using the 3.9 m Anglo-Australian Telescope *(AAT)*. The *RGO* spectrograph was used in conjunction with the 82 cm camera and 1200 R grating with an image photon-counting system *(IPCS)* as the detector (Boksenberg and Burgess 1973). All stars were observed in the wavelength regions 4430 to 4550 A and 4540 to 4660 A at dispersions of 5 A mm^{-1}. Five stars were also observed at wavelength regions 3900 – 4020 A and 4030 – 4150 A at a similar dispersion. A resolution of approximately 0.2 A *(FWHM)* was deduced for all wavelength regions.

2(c) *INT*. In August 1985 and September 1985 the Isaac Newton Telescope *(INT)* on La Palma, Canary Islands, was used to obtain spectra for four stars in h and χ Per, seven stars in Cep OBIII, and two members of Be 94. The *IDS* spectrograph was used with camera B and the Joyce-Yoon 2400 grooves mm^{-1} grating, with an *IPCS* as detector, yielding approximately 8 A mm^{-1} spectra corresponding to a resolution *(FWHM)* of approximately 0.3 A. All stars were observed in the wavelength regions 3900 to 4140 A and 4420 to 4660 A.

A major source of error in equivalent-width determination is due to the difficulty associated with estimating the position of the continuum. Here a consistent and objective approach was used to deduce a continuum based on fitting a polynomial to regions believed to be line free. Metal-line equivalent widths were then deduced by fitting a Gaussian profile (or multiple Gaussian profiles in the case of blends). This procedure is, however, unsuitable for the broad helium diffuse lines and hence equivalent widths for these features were measured by hand, continua being defined at ± 8 A from the line centre. Further details of observing procedures and reduction methods may be found in Papers 1 and 2 and Keenan *et al* (1986b).

3. *Method of analysis*

The method of analysis was to compare the observed line strengths and Stromgren photometry with those predicted from local thermodynamic equilibrium *(LTE)* radiative-transfer codes. The model atmospheres, which were line blanketed, were generated using the *ATLAS* 6 code of Kurucz (1979).

For most stars preliminary estimates of the effective temperature (T_{eff}) and gravity were derived from the Stromgren $[c_1]$ and β indices. Theoretical indices were calculated as discussed in Nissen (1974), the former agreeing well with those deduced from line-blanketed models by Relyea and Kurucz (1978). More accurate gravities were then deduced from comparing theoretical and observed Hδ line profiles, the former being calculated using the line-broadening theory of Vidal *et al* (1973). A new effective temperature was then calculated from the $[c_1]$ index and the process iterated to convergence. The gravities deduced from the β index and the Hδ line profile are normally in good agreement, and all stars appear to be near or on the main sequence. With the exception of stars in NGC 6611 effective temperatures derived in this way give results consistent with observed line strengths, being in good agreement with temperatures deduced, where possible, from silicon, carbon and nitrogen ionization equilibria (particularly when non-*LTE* effects are considered). Observational uncertainties lead to random-error estimates of ± 1000 K in T_{eff} and ± 0.2 dex in log g.

Effective temperatures derived for members of NGC 6611 are found to be incompatible both with the line strengths of the observed spectra and with the published spectral types. The discrepancies are probably due to heavy and anomalous reddening in the cluster leading to the $0.2(b\text{-}y)$ correction in the $[c_1]$ index being inappropriate for deriving a reddening-free quantity. Values of T_{eff} were therefore derived from ionization equilibria. For the two members of Be 94 and three stars in NGC 6531 Stromgren photometry is not available. Ionization equilibria were used to deduce the effective temperatures of the former, while for the latter less reliable effective temperatures were estimated from the Q parameter (Golay 1974), which was determined from UBV colours.

A microturbulent velocity of 5 km s^{-1} has been adopted in the present calculations since previous *LTE* fine analyses have shown this value to produce results consistent with observation for main-sequence stars (see for example Kane *et al* 1980).

Possible non-*LTE* effects have been investigated and in most cases changes in derived abundances compared with *LTE* calculations are small, being less than typical errors of measurement. Again, further details may be found in Papers 1 and 2.

4. *Results and discussion*

Radial velocities were measured from the wavelength shift of the stellar hydrogen, helium and metal lines and then corrected to heliocentric values. These are found to be in good agreement with values given for the clusters by Lynga (1981). Additionally, distance moduli were calculated for each star using methods similar to those discussed by, for example, Keenan *et al* (1986a). Again, in all cases these values are compatible with previously published results and hence it is assumed that all stars are members of their respective clusters.

The derived mean abundances for the southern clusters given in Table 1 together with normal B star values (see Paper 1 and references therein) are logarithmic on the scale log [H] = 12. The good agreement between the average abundances obtained for each cluster and those obtained for normal objects indicate that the stars in this region formed from relatively homogeneous interstellar material.

For the northern clusters *h* and χ Per and Cep OBIII preliminary results suggest normal chemical compositions i.e. our helium abundances are significantly different from those of Nissen (1976) and Wolff and Heasley (1985). This is mainly due to systematic differences in surface-gravity estimates. Nissen and Wolff and Heasley derive log *g* from Hβ photometry, while our results are based on profile fitting of Balmer lines. The latter should be more reliable and indeed the gravities we deduce give normal metal abundances, are compatible with published spectral types and lead to derived distances which are in good agreement with previously published results.

The preliminary results for the two stars in Be 94 ($\sim$5 kpc distant) are also very interesting. Although the sample size is too small for definite conclusions, these stars also appear to have a normal chemical composition. From HII region observations, abundance gradients of typically −0.08 dex kpc^{-1} have been deduced and these should certainly have been apparent in the stellar observations discussed above. It is therefore vital to observe further distant clusters and attempt to resolve the discrepancy between the HII region and stellar results. If the preliminary stellar results prove to be incorrect, the investigation would still be useful in providing abundance gradients for elements not available from HII region observations.

Table 1.

Mean logarithmic abundances in southern clusters (on the scale log [H] = 12.0)

	NGC 2362	NGC 3293	NGC 4755	NGC 6531	NGC 6611	IC 2944	Loose Association	Normal B-Stars
[He]	10.94±0.11	10.92±0.08	10.93±0.09	10.92±0.09	11.00±0.02	10.93±0.06	10.98±0.11	10.93
[C]	8.1±0.1	8.1±0.2	8.1±0.1	8.0±0.3	8.0±0.1	8.2±0.1	8.2	8.2
[N]	7.9±0.1	7.9±0.2	7.7±0.3	8.0±0.2	7.9±0.1	7.8±0.1	7.9±0.1	8.0
[O]	8.7	8.7±0.1	8.8±0.1	8.7	8.8±0.1	8.7±0.1	8.8±0.1	8.8
[Mg]	7.4±0.1	7.4±0.1	7.4±0.1	7.4	7.4±0.2	7.5±0.1	7.3±0.1	7.4
[Al]	6.4±0.1	6.3±0.1	6.4±0.1	6.4	6.4±0.1	6.5±0.1	6.4±0.1	6.5
[Si]	7.4±0.1	7.4±0.1	7.4±0.1	7.5±0.1	7.6±0.2	7.4±0.1	7.6±0.1	7.5
[S]	7.1±0.1	7.1±0.1	7.2±0.1	7.0	7.1±0.1	7.1±0.1	7.2±0.1	7.2
[Fe]	–	–	–	–	7.3	–	–	7.5

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