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CHEMICAL COMPOSITION OF OPEN CLUSTERS. I. Fe/H FROM HIGH-RESOLUTION SPECTROSCOPY

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ABSTRACT

The abundance ratio Fe/H is the key indicator of chemical composition and chemical evolution of the Galaxy. An age-metallicity relation has been found to exist for older disk stars (e.g., Twarog); here we have looked at stars in clusters younger than a few billion years. With "precision" global Fe/H abundances we have looked at the age-metallicity relation at younger eras and at the extent, time scale and homogeneity of mixing in the Galactic disk.

Our sample includes F dwarfs in the α Per, the Pleiades, and the Hyades clusters, and the UMa, Hyades, and Wolf 630 moving groups, and a selection of bright F field dwarfs; the objects span the age range from 5×10^7 to 2×10^9 yr.

We have made high-resolution, high signal-to-noise (S/N) spectroscopic observations in three spectral regions: 6540–6655 Å, 7048–7182 Å, and 7740–7852 Å. There are 15 Fe I lines with well-determined *gf*-values in these regions. The observations were obtained at the coudé focus at the CFHT with a Reticon detector and at the Hale 200 inch (5.08 m) with a CCD detector at resolutions of 0.11 and 0.21 Å, respectively. Abundances of Fe/H were determined for each line with a model atmosphere/abundance routine. The means, [⟨Fe/H⟩], were found for each star and then the global cluster means. The global means are estimated to be accurate to typically ± 0.04 dex. We find that the intrinsic dispersion in the Fe abundances in each cluster or group is extremely small; the observed dispersion about the mean cluster Fe abundances is consistent with observational error alone.

There is no evidence of a trend in [Fe/H] with age for these young clusters and groups, but there are clear differences in [Fe/H] among the groups. There must be intrinsic differences in the metal content in the local gas out of which these groups were formed. Clusters of the same age have metallicities differing from each other by amounts well beyond the errors. The time scale for mixing in the disk exceeds $\sim 10^9$ yr. Although clusters of different ages may have different metallicities, there is no pattern to it. Age and [Fe/H] values for the older visual binaries ($\sim 2 \times 10^9$) also show no age-metallicity relation.

Subject headings: clusters: open — stars: abundances — stars: atmospheres

I. INTRODUCTION

The key indicator of the chemical composition and chemical evolution of the Galaxy is the abundance ratio Fe/H. In the Galactic disk this ratio, expressed as $[\mathrm{Fe/H}] = \log(\mathrm{Fe/H})_* - \log(\mathrm{Fe/H})_\odot$, is seldom less than -1.0 and probably does not exceed $+0.5$. The study of Twarog (1980) shows that [Fe/H] has increased over time by a factor of 5 over the interval from 12 to 5 billion years. A more recent evaluation of Twarog's data by Carlberg *et al.* (1985) flattens out this relationship; they find a change of less than 50% over the same range in ages. Although the exact form of the age-metallicity relationship for old disk stars is not agreed upon, it is generally agreed that older stars will tend to be more metal poor.

The age-metallicity relationship for open clusters may be quite different from that for field stars in the solar neighborhood. The existence of both very old clusters with solar metallicity (e.g., NGC 188 and NGC 6791) and intermediate-age, moderately metal poor clusters (e.g., NGC 2420 and NGC 2506) stand out as distinct counterexamples to either of the age-metallicity relationships for the solar neighborhood field discussed above (Janes, Tilley, and Lynga 1988; Lynga 1987). Data on the clusters suggest that position in the Galaxy, and not age alone, is the over-riding factor in determining a cluster's metallicity.

These results hold primarily for the older stars; Carlberg *et al.*'s relationship is applicable only for ages greater than a billion years. The study of metallicity of stars in clusters younger than a few billion years provides information on the age-metallicity relationship at younger eras as well as the extent of and time scales for mixing in the disk.

The study of the metallicity of the young cluster stars requires very accurate values of [Fe/H] to distinguish the trends with age or galactocentric distance. Spectroscopic observations at high signal-to-noise ratios and at high spectral resolution of [Fe/H] in many F dwarfs in several open clusters can provide global values for the clusters that are of excellent accuracy. If clusters of different ages show an overall trend of composition with age, the "present-day" chemical evolution will be revealed. If they show the same composition at all ages, it indicates that there is little ongoing universal enrichment in the galactic disk. If clusters having the same age show a wide range in metallicity, they provide evidence for incomplete mixing in the disk over the last 5 billion years and compositions that are primarily a function of place of formation.

Cayrel, Cayrel de Strobel, and Campbell (1985) have found a global value of [Fe/H] in the Hyades, at the age of 7×10^8 yr, of $+0.12 \pm 0.03$ from high-resolution, high signal-to-noise

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Reticon spectra from the Canada-France-Hawaii telescope. Their value is based on ~ 35 Fe lines in 10 G dwarfs. A recent investigation of metallicity in young clusters with high-resolution, high signal-to-noise spectroscopy has been done by Boesgaard (1989). That study was of three to 14 F dwarfs in each of six clusters and used six Fe I lines. The two youngest clusters, Pleiades and α Per, were found to have solar metallicity, [Fe/H] $= +0.02 \pm 0.05$. The older Hyades and Praesepe were slightly metal enhanced with [Fe/H] $= +0.13 \pm 0.03$, while the older Coma and UMa groups were slightly metal deficient with [Fe/H] $= -0.08 \pm 0.04$. The lack of an age-metallicity relation for these younger star groups shows that the enrichment and mixing in the disk has not been uniform, at least on time scales of less than 10^9 yr.

The present work extends the previous high-quality spectroscopic data to include more Fe lines, more F stars, and more star groups. It is part of a larger program to be published in this series in which the C and O abundances are determined. See second paper, Friel and Boesgaard (1990) on [C/H] and [C/Fe], which follows this one. Future observations are planned for M67 and the Coma cluster also.

II. OBSERVATIONS

We have made high-resolution, high signal-to-noise (S/N) spectroscopic observations in three spectral regions: 6540–6655 Å (including Hα), 7048–7182 Å (including C I lines), and 7740–7852 Å (including the O I triplet). There are ~ 15 Fe I lines with well-determined *f*-values in those regions.

The Hα and O I regions were observed with a Texas Instruments 800×800 CCD at the 72 inch (1.8 m) camera and the 600 line mm^{-1} mosiac grating (No. 1) of the coudé spectrograph of the Palomar 200 inch telescope on the nights of 1987 November 8, 9, 10, 11, and 12 (UT). The Palomar CCD cameras have been described by Gunn *et al.* (1987); the chip was uv-flooded and liquid-nitrogen cooled. On-chip binning perpendicular to the dispersion of 1×2 was used. The spectral coverage is ~ 110 Å. At a dispersion of 9.1 Å mm^{-1} or 0.14 Å px^{-1} with 15 μm pixels and a measured full width at half-maximum (FWHM) of the comparison lines of 1.5 pixels, the spectral resolution was 0.21 Å. A Bowen–Walraven image slicer was used which gave about eight slices of spectrum in the usual seeing conditions. Typical exposure times for $V = 9$ were 45 minutes for a S/N ratio of 160 in the Hα region and 30 minutes and S/N of 130 in the O I region. The brighter stars were observed at S/N ratios of 200–500.

Two or more master flat-field exposures were taken each night, and the spectra from that night were divided by that night's mean flat field. Any cosmic rays that appeared in the stellar exposures were removed by a routine that replaced the number of counts in the affected pixel(s) by the mean of the neighboring pixels. A sum of the counts was made across the spectrum slices perpendicular to the dispersion. Comparison spectra taken each night could be used to apply a wavelength scale to the stellar spectra. In addition, spectra were taken of the daytime sky both as a wavelength calibration and, more important, as a source of solar equivalent widths obtained with the same equipment.

The C I region was observed with a liquid-nitrogen–cooled Reticon detector (Walker *et al.* 1985) at the f/8.2 camera with the 830 line mm^{-1} mosiac grating of the coudé spectrograph of the Canada-France-Hawaii telescope on Mauna Kea on the nights of 1987 August 5, 6, and 7 and October 30, 31, and November 1 (UT). The detector has 1872, 15 μm pixels. The spectra were centered at 7115 Å and covered 135 Å. A spectral resolution of 0.11 Å results from the dispersion of 0.072 Å pixels^{-1} and the measured FWHM of 1.5 pixels. The red mirror train and a Richardson image slicer optimized for the red were used. For $V = 9$ the typical exposure times were 35 minutes for S/N ratios of 170. On all six nights the seeing was better than 1″, often <0″.8. The brighter stars were observed at S/N ratios of 200–600. The C I region observations were made at Mauna Kea to minimize the strengths of the atmospheric water vapor lines in that region. Spectra of rapidly rotating B stars were taken at air masses similar to those of the program stars each night. Except for the few strong H_2O lines near 7170 Å, no atmospheric lines were detectable at the dry CFHT site. Consequently, we did not have to divide our program star spectra by the B star spectra to remove the (nonexistent) complication of telluric lines on any of the six nights.

Along with the stellar spectra we obtained comparison spectra for each night for the establishment of the wavelength scale. Several series of four flat-field spectra, with mean exposure levels within 10% of the stellar continuum value, were taken each night. Each set of four flat fields was averaged and each stellar spectrum was divided by the appropriate mean for it. Two spectra of the daytime sky, each at S/N ratios of 700, were taken in the October run. These were used as a source of solar equivalent widths, obtained with the same equipment, for the stellar-to-solar abundance ratios.

The stars observed, some of their properties, and the dates and S/N ratios of the observations are given in Table 1. The stars are arranged according to cluster or moving group, along with a few special field stars and visual binaries. Our sample of F dwarfs includes 14 stars in the Hyades, 12 stars in the Pleiades, seven in α Per, eight in the Hyades Moving Group, 11 in the UMa Moving Group, and four in the Wolf 630 Group. (It is not certain that all the stars in the moving groups are bona fide members, however.) We also observed a sample of field stars from visual binaries of known age (Duncan 1984; Boesgaard and Tripicco 1987) and the early F dwarfs studied by Boesgaard and Tripicco (1986*b*, hereafter BT) for Li abundances. All the BT field stars observed lie in the temperature range of the Li dip found in the Hyades by Boesgaard and Tripicco (1986*a*), and most, but not all, are severely Li-depleted.

The continua were placed using IRAF[1] at Caltech and at the Institute for Astronomy. (For the Palomar Hα data the region through the Hα line itself was not included in the continuum fitting routine.) Samples of the spectra from all three regions are shown in Figures 1, 2, and 3. An interactive continuum-fitting procedure was also used for the August CFHT C I data, but no systematic differences in the final equivalent widths were found.

The equivalent widths of several Fe I lines were measured through an IRAF routine. Repeat measurements of the same line at different times show a reproducibility of 0.8 mÅ. In the few instances where we had more than one spectrum of a given star, the agreement in equivalent widths was 1.4 mÅ on average with no dependence on line strength. The reliability of the equivalent width is a function of $v \sin i$, however. For some of the stars some of the lines were blended with neighboring lines and were either not measured or not included in the later

[1] IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Associated Universities for Research in Astronomy under contract to the National Science Foundation.

TABLE 1

STARS OBSERVED

A. HYADES

VB	V	B–V	Sp. Type	T_{eff} (K)	$v \sin i$ (km s^{-1})	CFH(C I) Night	S/N	Pal(Hα) Night	S/N	Pal(O I) Night	S/N
11	6.01	0.40	F3V	6850	25	Nov. 1	530	...	...	Nov. 9	290
13	6.62	0.42	F6V	6725	18	Oct. 31	370	Nov. 11	185	Nov. 9	245
14	5.73	0.36	F4V	7040	6	Oct. 31	550	Nov. 7	210	Nov. 8	310
19	7.10	0.51	F8V	6300	<12	Oct. 31	430	Nov. 7	215	Nov. 8	200
37	6.61	0.41	F4V	6815	12	Oct. 31	570	Nov. 7	180	Nov. 8	170
48	7.14	0.52	F5	6245	<12	Nov. 1	550	Nov. 11	275	Nov. 8	190
57	6.46	0.49	F7V	6370	15	Oct. 30	460	Nov. 11	235	Nov. 9	275
61	7.10	0.51	F5V	6260	18	Nov. 1	580	...	...	Nov. 10	175
62	7.50	0.54	F8V	6185	<6	Nov. 1	530	...	...	Nov. 11	285
78	6.92	0.45	F6V	6510	20	Oct. 30	460	...	...	Nov. 11	320
81	7.10	0.47	F6V	6470	18	Oct. 30	470	...	...	Nov. 10	175
86	7.04	0.47	F5	6485	20	Nov. 1	560	...	...	Nov. 11	300
121	7.29	0.50	F8	6340	12	Nov. 1	400	Nov. 7	170	Nov. 8	135
128	6.76	0.45	F5V	6560	25	...	...	...	...	Nov. 9	190

B. PLEIADES

H II	V	B–V	Sp. Type	T_{eff} (K)	$v \sin i$ (km s^{-1})	CFH(C I) Night	S/N	Pal(Hα) Night	S/N	Pal(O I) Night	S/N
233	9.66	0.53	F5V	6485	<20	Oct. 30	180	Nov. 7	166	Nov. 8	165
470	8.95	0.39	F5V	6845	<40	Nov. 1	170	Nov. 7	150	Nov. 8	130
530	8.95	0.39	F3V	6770	<12	Aug. 5 Oct. 31	170 200	Nov. 7	200	Nov. 8	160
627	9.68	0.50	F7V	6335	25	Oct. 31	185	...	...	Nov. 9	140
739	9.56	0.62	G1V	5870	<12	Nov. 1	160	...	...	Nov. 10	92
948	8.66	0.60	F9V	5960	<12	...	...	Nov. 11	230	Nov. 10	106
1122	9.29	0.46	F5V	6610	28	Nov. 1	160	...	...	Nov. 9	150
1200	9.99	0.54	F6V	6470	<20	Aug. 6 Nov. 1	105 165	...	...	Nov. 8	130
1613	9.88	0.54	F6V	6250	18	Oct. 31	155	...	...	Nov. 9	120
1726	9.25	0.55	F7V	6365	<12	Oct. 30	190	Nov. 7	155	Nov. 8	140
1766	9.13	0.47	F5V	6730	20	Oct. 30	185	Nov. 11	160	Nov. 9	125
1856	10.02	0.56	F7V	6155	12	Nov. 1	160				

C. α PERSEI

He	V	B–V	Sp. Type	T_{eff} (K)	$v \sin i$ (km s^{-1})	CFH(C I) Night	S/N	Pal(Hα) Night	S/N	Pal(O I) Night	S/N
135	9.71	0.41	F5V	6710	<20	Oct. 30	210	...	...	Nov. 10	93
361	9.68	0.36	F4V	6730	30	Oct. 31	170	...	...	...	...
490	9.56	0.37	F3IV–V	6805	<20	Oct. 30	220	...	...	Nov. 10	100
635	9.05	0.26	A8V	7285	<20	Oct. 31 Nov. 1	170 145	...	...	Nov. 10	100
799	9.69	0.37	F4V	6705	20	Oct. 30	200	...	...	...	...
1225N	8.88	0.41	F7IV–V	6415	20	Oct. 31	165	...	...	...	...
1225S	8.88	0.41	F7IV–V	6415	<20	Oct. 31	150	...	...	...	...

analysis. We conclude that we can measure equivalent widths to an accuracy of better than 2 mÅ. The equivalent widths for 15 Fe I lines (four from the Hα region, eight from the C I region and three from the O I region) are listed in Table 2 along with the measured values from the sky spectra for the Sun. Since not all stars were observed in all spectral regions, there are blanks for some of the lines for some stars. Where a star was observed twice, the entries are the average, weighted by the S/N ratio if the two observations were very different in S/N.

III. ANALYSIS

For comparisons among clusters and groups it is necessary to use temperatures that are both reliable and consistently determined. We have chosen to adopt the temperature cali-

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TABLE 1—*Continued*

D. Hyades Moving Group

Name	V	B−V	Sp. Type	T_{eff} (K)	$v \sin i$ (km s^{-1})	CFH(C I) Night	CFH(C I) S/N	Pal(Hα) Night	Pal(Hα) S/N	Pal(O I) Night	Pal(O I) S/N
HR 88	6.39	0.66	G2V	5785	7	Aug. 6	590	...	...	Nov. 8	370
						Nov. 1	560				
HR 410	6.31	0.47	F7V	6385	32	Aug. 7	570	Nov. 7	425	Nov. 8	415
HR 878	5.80	0.41	F5IV	6620	20	Aug. 5	550	...	...	...	...
HD 197039	6.74	0.45	F7V	6510	...	Oct. 31	520	...	...	Nov. 9	300
HR 8548	5.75	0.52	F7V	6170	7	Aug. 6	530	Nov. 7	400	Nov. 8	440
						Oct. 30	590				
HR 8772	6.68	0.58	F8V	5965	...	Aug. 6	520	...	...	Nov. 8	420
HR 8788	6.13	0.44	F6V	6500	...	Aug. 5	600	...	...	Nov. 8	500
						Oct. 30	580				
HR 8792	6.30	0.49	F7V	6150	7	Aug. 5	570	...	...	Nov. 8	440
						Oct. 31	540				

E. UMa Moving Group

Name	V	B−V	Sp. Type	T_{eff} (K)	$v \sin i$ (km s^{-1})	CFH(C I) Night	CFH(C I) S/N	Pal(Hα) Night	Pal(Hα) S/N	Pal(O I) Night	Pal(O I) S/N
HR 235	5.19	0.50	F7IV–V	6200	0	Nov. 1	580	...	...	Nov. 11	355
HD 11131B	6.76	0.43	G1V	5820	...	Aug. 6	600	...	...	Nov. 11	315
HR 534	5.94	0.30	F2V	7100	...	Oct. 31	660	...	...	Nov. 9	310
HR 647	6.06	0.40	F4V	6500	<26	Aug. 7	600	...	...	...	...
HR 2047	4.41	0.59	G0V	5900	6	...	...	Nov. 11	460	Nov. 9	365
HR 5634	4.93	0.43	F5V	6600	45	Aug. 6	660	...	...	...	...
HD 151044	6.60	0.48	F8V	6130	...	Aug. 6	600	...	...	...	...
HR 7061	4.19	0.46	F6V	6370	14	Aug. 6	600	...	...	Nov. 9	325
						Nov. 1	500				
HR 7172	5.23	0.53	F8V	6115	26	Aug. 6	680	...	...	Nov. 9	390
HR 7451	5.73	0.48	F7V	6240	6	Aug. 5	590	...	...	Nov. 10	320
HR 8170	6.40	0.53	F8V	6125	12	Aug. 5	590	...	...	Nov. 8	460

F. Wolf 630 Group

Name	V	B−V	Sp. Type	T_{eff} (K)	$v \sin i$ (km s^{-1})	CFH(C I) Night	CFH(C I) S/N	Pal(Hα) Night	Pal(Hα) S/N	Pal(O I) Night	Pal(O I) S/N
HD 6479A	6.35	0.38	F3	6700	...	Aug. 5	600	...	...	Nov. 11	365
HD 6480B	7.25	0.49	F6–7	6265	...	Aug. 6	530	...	...	Nov. 11	330
HR 7947	5.14	0.49	F7V	6330	<25	Aug. 5	590	...	...	Nov. 9	440
										Nov. 11	380
HR 8077	5.94	0.54	F8V	6130	<6	Aug. 5	590	...	...	Nov. 8	310
										Nov. 9	280

G. Stars of Known Age

Name	V	B−V	Sp. Type	T_{eff} (K)	$v \sin i$ (km s^{-1})	CFH(C I) Night	CFH(C I) S/N	Pal(Hα) Night	Pal(Hα) S/N	Pal(O I) Night	Pal(O I) S/N
HD 16232B	6.50	0.41	F6V	6440	30	Aug. 7	550	...	...	...	...
HD 196310A	7.98	0.38	F0	6760	...	Aug. 6	450	...	...	...	...
HD 206751A	7.90	...	F2V	6785	...	Aug. 6	530	...	...	Nov. 11	260
						Nov. 1	520				
HD 216582B	7.80	...	F5V	6390	...	Aug. 6	560	...	...	...	...

TABLE 1—*Continued*

H. Boesgaard and Tripicco Field Stars

Name	V	B−V	Sp. Type	T_{eff} (K)	$v \sin i$ (km s^{-1})	CFH(C I) Night	CFH(C I) S/N	Pal(Hα) Night	Pal(Hα) S/N	Pal(O I) Night	Pal(O I) S/N
HR 7496	5.49	0.46	F5IV	6470	21	Oct. 31	510	...	...	...	...
HR 7697	5.85	0.39	F5V	6635	<10	Oct. 30	590	...	...	Nov. 10	290
HR 7756	5.91	0.38	F5V	6570	<10	Oct. 30	560	...	...	Nov. 10	260
HR 7925	6.01	0.46	F6IV	6475	30	Oct. 30	610	...	...	Nov. 10	300
HR 7936	4.14	0.43	F4V	6590	37	Oct. 31	470	...	...	...	...
HR 8205	6.13	0.44	F5V	6525	12	Oct. 30	550	...	...	Nov. 9	285
HR 8222	6.57	0.41	F0V	6600	<15	Oct. 31	510	...	...	...	...
HR 8805	5.70	0.44	F5V	6550	9	Oct. 30	650	...	...	Nov. 10	265
HR 8885	5.77	0.46	F5V	6475	12	Oct. 30	650	Nov. 7	410	Nov. 11	470
HR 8907	5.52	0.40	F4V	6640	0	Oct. 31	530	...	...	...	...
HR 8977	6.23	0.39	F1V	6660	30	Oct. 30	610	Nov. 7	425	Nov. 11	345

brations and temperatures that were found previously in a series of papers on Li in F stars; Hyades, Boesgaard, and Tripicco (1986*a*) and Boesgaard and Budge (1988); Pleiades and α Per, Boesgaard, Budge, and Ramsay (1988); UMa Group, Boesgaard, Budge, and Burck (1987); Hyades Moving Group, Boesgaard and Budge (1988). For the Wolf 630 Group, the visual binary stars, and the BT F dwarfs in the field, the temperatures were newly determined, but in the same manner as the cluster work (see Boesgaard, Budge, and Ramsay 1988 for a longer discussion of the method). The temperature calibrations for these F stars are primarily those of Saxner and Hammarbäck (1985). Table 3 gives those photometrically

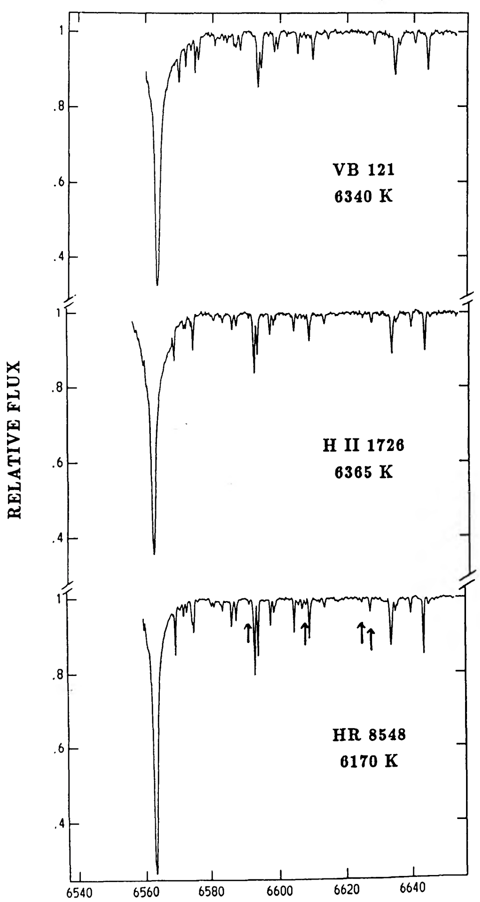

Fig. 1.—Palomar CCD spectra in the Hα region of a Hyades star, VB 121, a Pleiades star, H II 1726, and a Hyades Moving Group star, HR 8548. The Fe I lines that were used for the analysis are indicated by arrows in the lower panel. The temperatures adopted for the stars are given in each panel. The S/N ratios per pixel of the spectra are 170, 155, and 400, respectively.

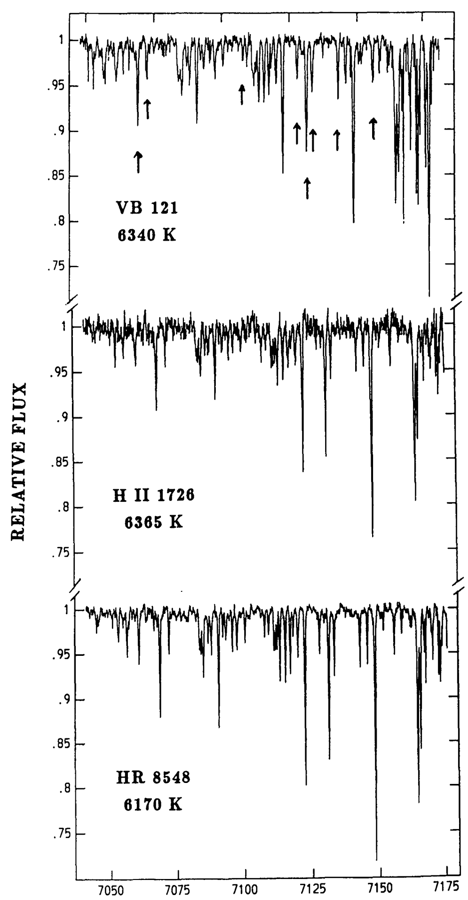

Fig. 2.—CFHT Reticon spectra in the C I region of the same three stars as in Fig. 1 in the Hyades, the Pleiades, and the Hyades Moving Group. The Fe I lines that were measured for the analysis are indicated by arrows in the upper panel. The temperatures are given in each panel. The S/N ratios per pixel of the spectra are 400, 190, and 590, respectively.

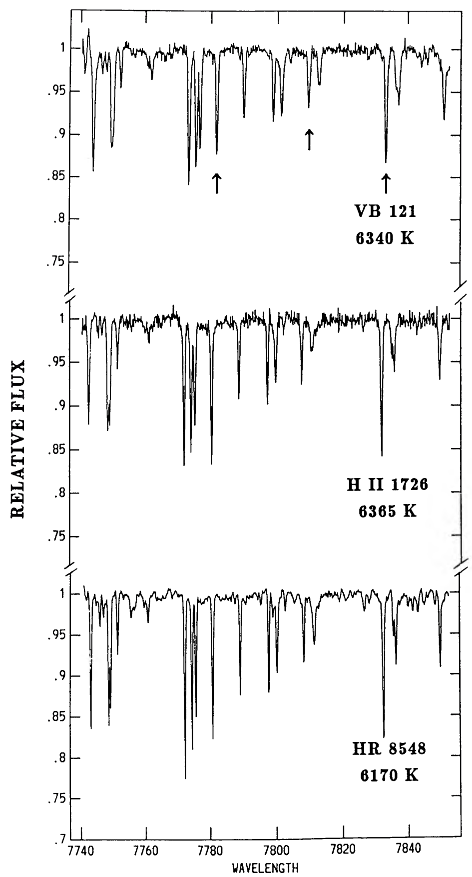

FIG. 3.—Palomar CCD spectra in the O I region of the same three stars as in Figs. 1 and 2, in the Hyades, the Pleiades, and the Hyades Moving Group. The Fe I lines that were used for the analysis are indicated by arrows in the upper panel. The temperatures are given in each panel. The S/N ratios per pixel of the spectra are 135, 140, and 440, respectively.

determined temperatures and the temperatures adopted. In fact, we shall see later that there is no systematic trend of the derived abundances with temperature which indicates that the temperature calibration is good. Stronger evidence for this comes from the comparison of [Fe/H] versus temperature with [C/H] versus temperature in Paper II; neither abundance shows a trend with temperature even though the Fe I lines increase in strength while the C I lines decrease in strength with decreasing temperature.

The reality of the membership of stars in moving groups is not certain. For the UMa Group and the Hyades Moving Group we have used the criteria discussed in papers by Johnson and Soderblom (1987), Boesgaard, Budge, and Burck (1988), and Boesgaard and Budge (1988). Eggen (1969, 1971) gives the four stars we have listed in Table 1 as Wolf 630 group members. The combination of the U, V, W velocities and the metallicities may indicate that only the pair, HD 6479/6480, belongs to the group; possibly HR 8077 is a bona fide member also. The high metallicity of HR 7947 appears to exclude it from membership. In addition, it is unclear that He 1225 N and S are real members of the α Per cluster, based on radial velocity measures by Kraft (1967).

Abundances were determined with the model atmosphere abundance program of M. Spite, RAI10, and a grid of Kurucz (1979) model atmospheres. The atmospheres were for $\log g = 4.5$ and $T = 7000$, 6500, and 6000 K, and $\log g = 4.44$ and 5770 K (Sun). For these the microturbulence used were from Nissen (1981), $\xi = 3.2 \times 10^{-4}$ $(T_{\rm eff} - 6390) - 1.3$ $(\log g - 4.16) + 1.7$, and were 1.45, 1.3, 1.1 and 1.14 km s^{-1}, respectively. The abundances from these Fe I lines are virtually insensitive to the values of log g and microturbulence. The gf-values are primarily from Gurtovenko and Kostik (1981). For each Fe I line we took the ratio of the stellar Fe/H to the solar Fe/H so errors in the gf-values are minimized; for weak lines, $W_\lambda \lesssim 70$ mÅ, virtually no error occurs from errors in the gf-values, unless they are incorrect by orders of magnitude. (The mean value of Fe/H found for the sun this way from 20 Fe I lines is $3.59 \pm 0.86 \times 10^{-5}$ or $\log N(\mathrm{Fe/H})_\odot = 7.56 \pm 0.11$, where $\log N(\mathrm{H}) = 12.00$.) For each star we found the average of the $(\mathrm{Fe/H})_*/(\mathrm{Fe/H})_\odot = \langle \mathrm{Fe/H} \rangle$ and then the logarithmic version of this, $[\langle \mathrm{Fe/H} \rangle]$. Many of these same stars had been observed in the Li I region also where measurements of five to six Fe I lines are given in the references quoted in the first paragraph of this section. A summary of the values of cluster metallicities from those five to six Fe I lines is given in Boesgaard (1989). (Those Fe I lines were included here for the cluster stars where they were measured.) In that paper also there is a discussion of the possible effect of chromospheric activity on the abundances derived; it is concluded that there is little influence on [Fe/H] from activity.

The model atmosphere calculations show that the Fe/H abundance results are not sensitive to the adopted gravity or to the microturbulence. There are random errors due to the temperature determination and the equivalent width measurements. A typical temperature uncertainty of ± 50 K is ± 0.01 in [Fe/H] and the equivalent width uncertainty of less than 2 mÅ is ± 0.025. Although there may be systematic temperature errors, we can say that random errors produce less than ± 0.03 uncertainty in [Fe/H]. Some error is introduced by our comparison of stellar to solar values due to the scatter in the solar values. The standard deviation about the mean solar value is 0.11 dex from 20 Fe I lines. Only if the solar values were known perfectly would the stellar uncertainties be 0.03 dex; in fact, they are closer to 0.10 in Table 4.

IV. RESULTS

Table 4 gives the mean Fe abundances for each star, both as the numerical ratio, $\langle \mathrm{Fe/H} \rangle$ with the standard deviation about this mean, σ, and as the logarithmic ratio of that mean, $[\langle \mathrm{Fe/H} \rangle]$, with the numerical standard deviation expressed in logs. For each cluster or group the weighted mean of all the stars is given as the cluster value; the weights are inversely proportional to the standard deviations of the individual stars. These numerical weighted means and standard deviations are converted to the logarithmic values and appear in the bottom line of each section of Table 4. The "errors" in the global cluster means are consistent with the random observational errors from the temperatures and equivalent widths. A summary of the cluster/group [Fe/H] and σ's are given in Table 5 along with the estimated cluster ages.

A comparison of the means in Table 5 with the Boesgaard (1989) means is given in Table 6 for the four clusters in common. The agreement is very good, well within the errors quoted for the two studies.

Figures 4a–4f shows the [Fe/H] values and the 1 σ error bars for each star as a function of temperature. There seems to be no dependence on temperature for any of the clusters or groups which indicates that our temperatures and temperature calibrations are good. The Hyades in particular shows a well-

TABLE 2

Fe I EQUIVALENT WIDTHS IN mÅ

A. HYADES

VB	T(K)	6591	6608	6625	6627	7068	7072	7107	7128	7131	7133	7143	7156	7780	7808	7832[a]
14	7040	2.9	...	...	16.6	34.0	13.4	6.3	13.8	56.3	18.6	22.6	19.2	85.3	35.2	91.4
11	6850	...	...	...	...	38.7	16.1	...	15.7	66.5	25.9	28.6	25.7	84.1	43.4	100.3
37	6815	5.6	3.2	...	19.6	49.5	17.6	8.2	18.8	75.2	29.4	31.5	...	89.7	51.1	97.8
13	6725	...	...	...	24.0	47.1	16.8	10.5	20.9	76.3	33.1	26.1	22.2	92.4	55.0	108.5
128	6560	...	...	...	...	...	...	...	...	...	...	...	...	93.9	53.6	114.9
78	6510	...	...	...	...	58.1	21.8	10.5	17.7	80.7	31.2	28.1	30.9	105.0	55.9	112
86	6485	...	...	...	...	56.3	22.0	10.7	21.7	79.9	36.7	36.2	...	107.6	54.1	115.2
81	6470	...	...	...	...	61.7	23.9	10.9	20.5	82.6	28.3	26.1	28.3	107.2	57.6	115.4
57	6370	8.7	...	...	23.8	64.7	...	15.1	19.9	85.1	27.5	30.1	31.7	104.0	53.9	124.4
121	6340	8.4	8.9	7.6	23.8	61.0	28.1	13.6	25.6	86.8	39.6	35.9	33.7	98.4	53.6	119.3
19	6300	8.5	10.0	5.0	26.6	69.3	24.6	17.0	28.1	92.2	41.3	40.1	37.3	114.4	63.3	127.9
61	6260	...	...	...	...	59.6	25.4	15.1	25.0	90.3	37.7	39.2	33.8	103.1	55.1	118.1
48	6245	11.5	11.8	8.5	26.3	62.0	25.9	15.5	26.0	86.3	38.9	35.0	30.7	113.3	61.3	124.5
62	6185	...	...	...	...	67.9	29.5	20.4	30.4	95.2	42.8	41.6	34.2	114.8	64.7	139.6

B. PLEIADES

HII	T(K)	6591	6608	6625	6627	7068	7072	7107	7128	7131	7133	7143	7156	7780	7808	7832[a]
470	6845	...	...	...	...	40.4	19.8	...	...	...	...	...	17.4	101.5	40.9	107.6
530	6770	...	...	...	9.1	...	13.4	...	8.1:	53.9	16.7	16.7	...	71.4	34.2	86.9
1766	6730	...	...	...	...	43.1	8.8:	...	12.2	64.1	17.6	22.0	...	82.8	43.4	103.8
1122	6610	...	...	...	...	...	...	...	21.3	74.3	30.4	...	...	93.1	52.8	102.7
233	6485	3.7	...	...	13.1	44.6	...	...	20.6	61.6	24.0	20.7	22.6	83.6	48.1	101.4
1200	6470	...	...	...	...	42.5	12.4	10.6	9.0	66.9	23.6	...	18.8	100.2	39.9	103.8
1726	6365	...	7.8	5.9	16.2	54.1	17.3	...	...	78.2	28.2	19.1	20.4	113.3	48.1	114.5
627	6335	...	...	...	...	52.6	...	...	16.8	77.5	25.5	...	...	89.5	47.7	105.6
1613	6250	...	...	...	...	51.2	20.0	11.5	19.2	79.7	27.8	19.0	22.1	108.6	49.5	125.1
1856	6155	...	...	...	...	...	28.3	17.1	26.0	85.6	36.6	29.0	28.8	...	...	...
948	5960	9.5	16.6	11.9	24.2	...	...	...	...	...	...	...	...	121.5	59.7	132.0
739	5870	...	...	...	...	70.4	...	...	...	87.8	38.6	30.0	...	133.0	52.8	151.8

C. α PERSEI

He	T(K)	7068	7072	7107	7128	7131	7133	7143	7156	7780	7808	7832[a]
635	7285	28.4	...	...	9.5	42.6	...	12.6	14.7	75.2	27.7	...
490	6805	29.5	12.9	...	13.0:	50.8	18.0	...	14.8	76.1	33.8	...
135	6710	39.4	15.0	7.1	...	62.4	18.5	16.4	21.7	79.4	32.1	81.5
799	6705	37.4	11.4	...	14.5	71.1	10.2	...	18.3	...	...	...
1225N	6415	53.1	29.9	14.0	...	76.9	29.8	31.3	23.8	...	...	...
1225S	6415	45.0	15.8	...	11.1	67.6	24.3	23.9	19.6	...	...	...

D. HYADES MOVING GROUP

Name	T(K)	6591	6608	6625	6627	7068	7072	7107	7128	7131	7133	7143	7156	7780	7808	7832[a]
HR 878	6620	...	...	...	...	49.6	23.4	12.2	16.2	71.1	26.2	25.6	31.1	...	...	...
HD 197039	6510	...	...	...	...	...	26.8	14.2	21.4	75.9	30.2	...	24.0	107.5	60.3	127.7
HR 8788	6500	...	...	...	...	...	31.1	...	27.8	92.8	40.2	34.2	32.4	104.1	...	...
HR 410	6385	...	...	6.1	23.3	65.4	29.8	16.6	25.6	87.5	42.0	35.6	30.7	106.6	57.5	166.4
HR 8548	6170	7.4	9.5	6.4	20.6	57.6	21.8	13.8	19.6	77.8	34.1	29.6	24.4	100.7	47.3	115.6
HR 8792	6150	...	...	...	...	62.6	26.0	19.5	25.2	87.9	37.2	32.6	36.4	117.2	...	...
HR 8772	5965	...	...	...	...	56.7	18.1	16.0	18.2	78.3	32.8	27.5	27.8	100.4	50.2	122.6
HR 88	5795	...	...	...	...	85.2	38.0	30.0	38.5	119.5	53.7	49.1	51.7	151.8	86.8	195.0

TABLE 2—*Continued*

E. UMa Moving Group

Name	T(K)	6591	6608	6625	6627	7068	7072	7107	7128	7131	7133	7143	7156	7780	7808	7832[a]
HR 534	7100	...	...	...	...	17.1	7.1	...	3.9	36.3	...	10.2	...	56.4	17.3	65.5
HR 5634	6600	...	...	...	...	43.6	...	11.4	27.0	82.7	30.6	26.2	29.5	...	...	...
HR 647	6500	...	...	...	...	32.1	8.6	8.6	9.0	53.0	18.9	16.8	...	...	...	...
HR 7061	6370	...	...	...	...	43.3	15.8	...	18.1	69.7	28.2	23.6	24.6	89.1	45.5	100.2
HR 7451	6240	...	...	...	...	46.2	18.5	13.2	16.4	69.6	25.8	22.3	24.0	94.5	41.2	102.3
HR 235	6200	...	...	...	...	46.2	19.2	11.2	19.1	73.0	27.3	27.2	25.5	95.6	46.6	107.2
HD 151044	6130	...	...	...	...	60.1	24.2	14.9	23.0	78.3	34.9	30.1	29.3	...	...	...
HR 8170	6125	...	...	...	...	52.8	19.7	16.4	21.9	74.6	26.5	25.0	23.7	103.6	45.3	...
HR 7172	6115	...	...	...	...	60.3	23.7	15.2	22.9	81.8	34.9	31.4	25.2	94.9	48.2	105.1
HR 2047	5900	10.0	16.5	10.4	23.6	...	...	...	...	...	...	...	...	121.5	58.7	141.1
HD 11131	5820	...	...	...	...	64.6	23.4	20.6	25.2	92.0	40.1	34.9	33.8	125.1	63.2	144.4

F. Wolf 630 Group

Name	T(K)	6591	6608	6625	6627	7068	7072	7107	7128	7131	7133	7143	7156	7780	7808	7832[a]
HD 6479A	6700	...	...	...	...	31.8	12.2	...	14.1	53.2	18.6	14.7	12.0	73.2	30.3	78.1
HR 7947	6330	...	...	...	...	62.8	26.7	16.9	22.8	82.5	39.3	32.0	30.6	103.2	56.2	121.7
HD 6480B	6265	...	...	...	...	43.6	15.0	11.6	14.5	65.1	23.6	20.2	18.0	87.4	41.0	99.9
HR 8077	6130	...	...	...	...	56.1	21.8	16.9	21.8	76.7	32.5	27.2	31.1	99.1	52.4	116.1

G. Stars of Known Age

Name	T(K)	6591	6608	6625	6627	7068	7072	7107	7128	7131	7133	7143	7156	7780	7808	7832[a]
HD 206751A	6785	...	...	...	...	28.6	11.9	5.6	11.0	49.3	14.2	16.7	15.0	71.5	33.6	82.1
HD 196310A	6760	...	...	...	...	23.4	12.2	5.9	10.8	53.0	15.4	15.6	14.5	...	...	...
HD 16232B	6440	...	...	...	...	64.8	...	13.9	36.0	96.0	46.0	32.9	23.0	...	...	...
HD 216582B	6390	...	...	...	...	44.6	19.2	10.9	14.0	68.6	26.5	25.9	22.0	...	...	...

H. Boesgaard and Tripicco Field Stars

Name	T(K)	6591	6608	6625	6627	7068	7072	7107	7128	7131	7133	7143	7156	7780	7808	7832[a]
HR 8977	6660	...	...	2.1	16.2	50.3	15.2	9.8	19.3	76.0	28.1	28.4	24.8	99.0	46.4	102.7
HR 8907	6640	...	...	...	...	34.2	14.1	...	14.7	58.1	22.6	23.4	21.1	...	...	...
HR 7697	6635	...	...	...	...	47.4	17.6	10.1	17.0	65.0	26.5	23.4	20.1	93.9	40.0	102.9
HR 8222	6600	...	...	...	...	34.3	16.2	8.4	11.7	63.0	15.9	16.1	17.1	...	...	...
HR 7936	6590	...	...	...	...	38.4	10.9	...	13.0	66.9	23.1	19.6	16.0	...	...	...
HR 7756	6570	...	...	...	...	44.1	15.8	9.1	15.3	68.0	23.7	21.7	19.6	85.6	41.2	99.5
HR 8805	6550	...	...	...	...	35.6	14.3	6.9	13.0	62.3	21.4	19.5	17.4	79.2	32.3	90.7
HR 8205	6525	...	...	...	...	49.9	21.2	10.9	21.4	78.2	33.0	30.0	16.8	99.1	49.0	112.2
HR 7925	6475	...	...	...	...	46.2	16.5	...	17.8	70.5	29.0	27.0	22.7	97.2	42.7	100.1
HR 8885	6475	5.0	4.7	2.4	17.5	48.6	16.2	12.4	14.0	72.3	30.3	...	19.4	94.1	44.6	101.2
HR 7496	6470	...	...	...	...	47.6	18.7	...	18.9	74.6	33.6	25.3	23.4	...	...	...
α CMi	...	...	...	...	...	...	...	...	...	...	...	...	...	85.3	44.2	99.5

I. Sun

Name	T(K)	6591	6608	6625	6627	7068	7072	7107	7128	7131	7133	7143	7156	7780	7808	7832[a]
Sun	5770	15.4	19.3	17.5	28.8	70.6	34.6	21.5	31.6	96.5	42.8	38.5	41.9	127.5	66.1	144.0

[a] Equivalent width measurements are given for λ7832, but only those with $W_\lambda \leq 100$ mÅ for those stars with T < 6500 K were used.

TABLE 3

NEWLY DETERMINED TEMPERATURES

Number	$T(\beta)$	$T(b-y)$	$T(B-V)$	T(adopted)
BT Field Stars				
HR 7496	6490	6460	6455	6470
HR 7697	6675	6555	6670	6635
HR 7756	6590	6550	...	6570
HR 7925	6550	6420	6455	6475
HR 7936	6580	6610	6588	6590
HR 8205	6600	6430	6540	6525
HR 8222	6620	6585	6600	6600
HR 8805	6590	6515	6540	6550
HR 8885	6510	6455	6455	6475
HR 8907	6740	6550	6636	6640
HR 8977	6710	6605	6670	6660
Stars of Known Age				
HD 6479A	6700	6695	6705	6700
HD 6480B	6190	6295	6310	6265
HD 16232B	6490	6230	6600	6440
HD 196310A	6810	6770	6705	6760
HD 206751A	6810	6760	...	6785
HD 216581B	6345	6430	...	6390
Wolf 630 Group				
HR 7497	...	...	6330	6330
HR 8077	6105	6145	6135	6130

determined cluster value for [Fe/H]. For the moving groups we have used a different symbol for the stars which are questionable members, as discussed above.

Some comments can be made regarding NLTE effects on the basis of Figure 4. Holweger (1988) shows that corrections for NLTE in the Sun would be ~0.03–0.06 dex in log Fe/H from Fe I lines and that they would increase to ~0.07–0.12 for Procyon at 6500 K. The error bars in Figure 4, especially for the Hyades, are so small that those plots can be used as an empirical test of the NLTE calculations. There is no evidence of a systematic trend of higher [Fe/H] with higher temperatures so the effects of NLTE must be very small.

The field stars from Tables 4G and 4H show a range around the solar value with [Fe/H] from −0.20 to +0.09 (excluding HD 16232 which has by far the largest σ of all the stars). Note that the eight BT field stars that we observed that are Li-deficient and in the temperature range of the Li dip found by Boesgaard and Tripicco (1986) in the Hyades do not distinguish themselves by their [Fe/H] values. They appear as an ordinary subset of the F dwarfs in the Cayrel de Strobel *et al.* (1985) catalog of [Fe/H] values.

Figure 5 shows the nonrelationship between the mean metallicities and the cluster ages. The upper panel shows the results from this work while the lower panel includes the results for Coma and Praesepe from Boesgaard (1989). The

TABLE 4

MEAN IRON ABUNDANCES

A. HYADES

VB	T_{eff}	$v \sin i$	<Fe/H>	σ	[<Fe/H>]	σ	N lines
11	6850	25	1.279	0.277	+0.107	0.092	15
13	6725	18	1.503	0.415	+0.177	0.121	11
14	7040	6	1.190	0.334	+0.076	0.123	13
19	6300	12	1.489	0.301	+0.173	0.096	20
37	6815	12	1.451	0.367	+0.162	0.112	13
48	6245	12	1.312	0.174	+0.118	0.060	20
57	6370	15	1.277	0.223	+0.106	0.061	16
61	6260	18	1.297	0.212	+0.113	0.067	16
62	6185	6	1.437	0.260	+0.157	0.083	16
78	6510	20	1.336	0.199	+0.126	0.068	15
81	6470	18	1.317	0.254	+0.120	0.084	16
86	6485	20	1.355	0.303	+0.132	0.101	14
121	6340	12	1.367	0.268	+0.136	0.087	20
128	6560	25	1.357	0.303	+0.133	0.102	8
Weighted means:			1.339	±0.069	+0.127	±0.022	

B. PLEIADES

HII	T_{eff}	$v \sin i$	<Fe/H>	σ	[<Fe/H>]	σ	N lines
233	6485	<20	0.760	0.191	−0.119	0.111	14
470	6845	<40	1.205	0.228	+0.081	0.088	10
530	6770	<12	0.783	0.129	−0.106	0.074	14
627	6335	25	0.869	0.130	−0.061	0.063	10
739	5870	<12	0.954	0.222	−0.020	0.099	12
948	5960	12	1.010	0.148	+0.004	0.068	12
1122	6610	28	1.191	0.297	+0.076	0.111	8
1200	6470	<20	0.850	0.245	−0.071	0.132	12
1613	6250	18	0.908	0.175	−0.042	0.089	15
1726	6365	<12	0.994	0.210	−0.026	0.098	17
1766	6730	20	0.954	0.181	−0.020	0.100	12
1856	6155	12	1.069	0.233	+0.029	0.105	[illegible]
Weighted means:			0.924	±0.052	−0.034	±0.024	

TABLE 4—*Continued*

C. α PERSEI

He	T_{eff}	$v \sin i$	<Fe/H>	σ	[<Fe/H>]	σ	N lines
135	6710	<20	0.970	0.256	−0.013	0.114	15
490	6805	<20	0.820	0.177	−0.086	0.093	13
635	7285	<20	0.908	0.142	−0.042	0.066	9
799	6705	20	0.809	0.283	−0.092	0.149	8
1225N	6415	20	1.158	0.210	+0.064	0.079	12
1225S	6415	<20	0.735	0.155	−0.134	0.097	7
Weighted Means:[a]			0.884	±0.096	−0.054	±0.046	

[a] Omitting 1225N,S from mean.

D. HYADES MOVING GROUP

Name	T_{eff}	$v \sin i$	<Fe/H>	σ	[<Fe/H>]	σ	N lines
HR 88	5785	7	1.587	0.332	+0.200	0.094	16
HR 410	6385	32	1.452	0.242	+0.162	0.074	18
HR 878	6620	20	1.179	0.260	+0.072	0.110	14
HD 197039	6510	...	1.406	0.276	+0.148	0.094	12
HR 8548	6170	7	0.909	0.147	−0.042	0.074	20
HR 8772	5965	...	0.802	0.224	−0.096	0.112	16
HR 8788	6500	...	1.776	0.321	+0.249	0.078	13
HR 8792	6150	7	1.235	0.166	+0.092	0.059	15
Weighted Means:[b]			1.360	±0.164	+0.134	±0.052	

[b] Using *bona fide* members, HR 88, 878, and HD 197039.

E. UMa MOVING GROUP

Name	T_{eff}	$v \sin i$	<Fe/H>	σ	[<Fe/H>]	σ	N lines
HR 235	6200	0	0.739	0.092	−0.131	0.054	16
HD 11131	5820	...	0.877	0.158	−0.057	0.079	16
HR 534	7100	...	0.481	0.126	−0.318	0.114	12
HR 647	6500	<26	0.551	0.139	−0.259	0.106	13
HR 5634	6600	45	1.272	0.382	+0.104	0.143	11
HD 151044	6130	...	0.974	0.107	−0.011	0.047	14
HR 2047	5900	6	0.896	0.121	−0.048	0.058	12
HR 7061	6370	14	0.816	0.107	−0.089	0.056	16
HR 7172	6115	26	0.886	0.173	−0.053	0.088	16
HR 7451	6240	6	0.750	0.100	−0.125	0.055	16
HR 8170	6125	12	0.740	0.132	−0.131	0.071	16
Weighted means:[c]			0.823	±0.041	−0.085	±0.021	

[c] Omitting HR 534, HR 647, and HR 5634 from mean.

F. WOLF 630 GROUP

Name	T_{eff}	$v \sin i$	<Fe/H>	σ	[<Fe/H>]	σ	N lines
HR 7947	6330	<25	1.311	0.208	+0.118	0.068	10
HR 8077	6130	<6	0.888	0.120	−0.052	0.057	10
HD 6479	6700	...	0.652	0.157	−0.186	0.103	9
HD 6480	6265	...	0.633	0.111	−0.199	0.074	10
Weighted means:[d]			0.730	±0.072	−0.137	±0.043	

[d] Omitting HR 7947 from mean.

TABLE 4—*Continued*

G. STARS OF KNOWN AGE

Name	T_{eff}	$v \sin i$	<Fe/H>	σ	[<Fe/H>]	σ	N lines
HD 16232	6440	30	1.880	0.711	+0.274	0.195	7
HD 196310	6760	...	0.654	0.127	−0.185	0.096	8
HD 206751	6785	...	0.669	0.092	−0.175	0.060	10
HD 216582	6390	...	0.850	0.148	−0.071	0.077	8
α CMi	6620	6	0.973	0.105	−0.012	0.049	3

H. BT FIELD STARS

Name	T_{eff}	$v \sin i$	<Fe/H>	σ	[<Fe/H>]	σ	N lines
HR 7496	6470	21	1.040	0.247	+0.017	0.093	7
HR 7697	6635	10	1.038	0.168	+0.016	0.074	10
HR 7756	6570	10	0.887	0.105	−0.052	0.052	10
HR 7925	6475	30	0.943	0.173	−0.025	0.079	9
HR 7936	6590	37	0.780	0.190	−0.108	0.107	7
HR 8205	6525	12	1.194	0.285	+0.077	0.129	10
HR 8222	6600	15	0.727	0.126	−0.139	0.073	8
HR 8805	6550	9	0.679	0.119	−0.168	0.074	10
HR 8885	6475	12	0.888	0.240	−0.052	0.117	13
HR 8907	6640	0	0.855	0.182	−0.068	0.090	7
HR 8977	6660	30	1.217	0.241	+0.085	0.093	12

Hyades, Hyades Moving Group, and Praesepe are all clearly enriched relative to the Sun, whereas Coma and UMa (slightly younger), and Wolf 630 and the field stars (slightly older) are deficient. The two youngest, Pleiades and α Per, are close to solar metallicity. The time scale to produce uniform enrichment and mixing in the Galactic disk must exceed the age of the Hyades, 7×10^8 yr.

V. CONCLUSIONS

These global values for [Fe/H] for open clusters and moving groups extend the results of Boesgaard (1989) by including more Fe I lines, more stars and more groups. For the clusters in common, the agreement is well within the quoted error bars of the two studies as Table 6 shows. The differences in composition among the clusters are small, but the global cluster means are well determined because of the high quality of the data, the large number of lines and stars used for the results, and the advances that have been made in stellar atmosphere theory. There is no evidence of any trend in [Fe/H] with age for these young clusters, but there are distinct differences in [Fe/H] among the groups. The metal content in the local gas out of which each group was formed must be the source of the differences.

Combining the results in Table 5 with the results of Boesgaard (1989), as in Figure 5, one can see that there is no relationship between age and metallicity for young groups of stars. Clusters of different ages have different metallicities, but there are no global trends. Clusters with the same age have metallicities differing from each other well beyond the errors, indicating incomplete mixing in the galactic disk. The time scale for mixing in the disk must be greater than 10^9 yr. Our age data on the visual binaries (from Duncan 1984) and the rough estimates of the ages of the BT field stars (from Boesgaard and Tripicco 1986*b*) seem to show no age-metallicity relation for them either, but the sample is small and the ages of field stars can only be poorly determined.

The eight Li-deficient BT field stars in the Li "gap" show no distinctions compared to the three Li-normal "gap" stars in [Fe/H], age, $v \sin i$, or [C/H] (see Friel and Boesgaard 1989 for C/H values). The evolutionary histories of these field stars are more difficult to trace and better insight on the cause of the Li-deficiencies comes from the study of cluster stars.

TABLE 5

CLUSTER AGES AND METALLICITIES

Cluster	Age (yr)	$\overline{[Fe/H]}$	σ	n
α Per	5×10^7	−0.054	±0.046	4
Pleiades	7×10^7	−0.034	±0.024	12
UMa group	3×10^8	−0.085	±0.021	8
Hyades	6.7×10^8	+0.127	±0.022	14
Hyades group	6.7×10^8	+0.134	±0.052	3
Wolf 630 group	1.4×10^9	−0.137	±0.041	3
Known age stars	1.4×10^9	−0.154	±0.042	3
BT field stars	1.9×10^9	−0.063	±0.025	11
All field stars	1.8×10^9	−0.093	±0.021	14

TABLE 6

COMPARISONS OF CLUSTER [Fe/H] VALUES

Cluster	Boesgaard 1989 [Fe/H] σ	This Paper [Fe/H] σ
Hyades	+0.130 ± 0.026	+0.127 ± 0.022
Pleiades	+0.022 ± 0.062	−0.034 ± 0.024
α Per	+0.004 ± 0.033	+0.054 ± 0.046
U Ma	−0.095 ± 0.046	−0.085 ± 0.021

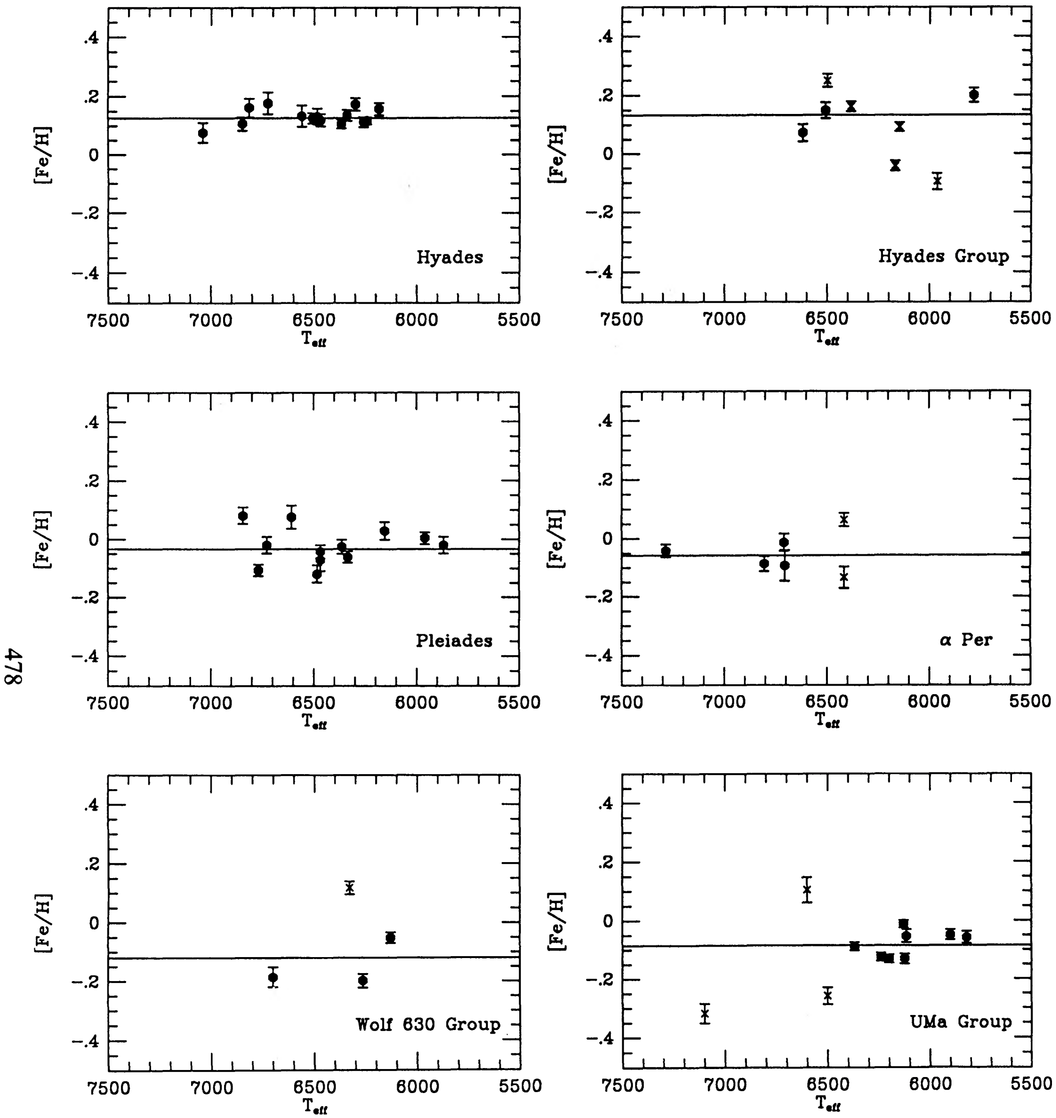

FIG. 4

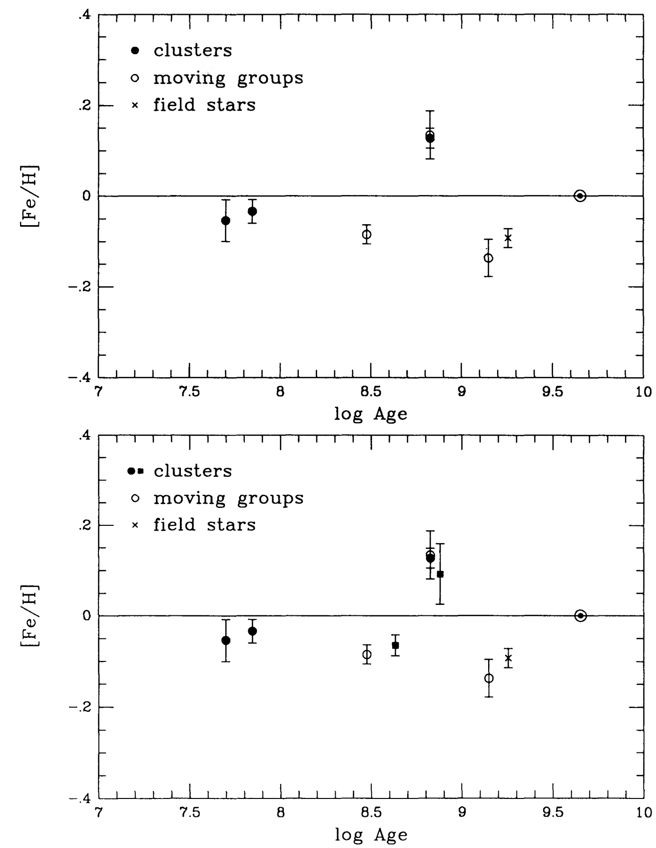

FIG. 5

FIG. 4.—The [Fe/H] abundances plotted against effective temperature for each star in each cluster and moving group. The filled circles are definite cluster or group members, the crosses are for stars for which the membership is uncertain. There seem to be no trends of abundance with temperature which indicates that our temperature scales are good. The error bars for each star show the standard error in the mean. The horizontal lines represent the group mean [Fe/H]. Note that Hyades and Hyades Moving Group are enhanced in [Fe/H] over solar, Pleaides and α Per are about solar, and the Wolf 630 and UMa Groups are slightly below solar.

FIG. 5.—Two panels showing the (non)relationship of [Fe/H] with age. The symbols give the cluster means and the error bars are the standard deviations about that mean. The filled circles are for the clusters, open circles for the moving groups, and the cross for the mean of the field stars. The circle with the dot is the solar point. The upper panel is the analog to Fig. 3 in Paper II; the lower panel adds the Coma and Praesepe clusters from Boesgaard (1989).

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