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THE CHEMICAL COMPOSITIONS OF TWO SUBGIANT CH STARS*†

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ABSTRACT

We present model-atmosphere analyses of the atmospheres of two "subgiant CH stars," HD 176021 and HD 204613. In agreement with earlier conclusions based on visual examination of low-dispersion spectrograms, we find these stars to possess small, but definite, iron-peak-element deficiencies; substantial overabundances of the *s*-process elements; and large, nearly solar, surface gravities. An excess scandium abundance is attributed to weak *s*-process irradiation on some of the lighter elements in the stellar material. Through spectrum-synthesis techniques, we derive overabundances of carbon but normal abundances of nitrogen. The derived log *g* values lead to absolute magnitudes near $M_v = +4$. HD 176021 and HD 204613 are interpreted as highly evolved Population II stars that have recently returned to the vicinity of the main sequence as a consequence of extensive internal mixing.

Subject headings: stars: abundances — stars: atmospheres — stars: carbon — stars: individual — stars: Population II

I. INTRODUCTION

Recently, one of us (Bond 1974; hereafter called Paper I) discussed a new group of G-type field stars, for which the name "subgiant CH stars" was proposed. These stars, found originally on Curtis Schmidt objective-prism survey plates, appear to show all the characteristics to be expected of stars of the same chemical composition as the well-known red-giant CH stars, but with higher surface temperatures. That is, they possess weak lines of the iron-group elements, very strong CH bands, relatively strong lines of the *s*-process elements (particularly strontium and barium), excess continuous absorption near 4000 Å, and high space velocities. Each of these five properties is also characteristic of the giant CH stars, as can be seen from the work of Keenan (1942), Bidelman (1956), Wallerstein and Greenstein (1964), and Bond and Neff (1969).

The absolute magnitudes of the subgiant CH stars, deduced statistically from their proper motions and radial velocities, were found to be roughly $M_v = +2$, so in the H-R diagram these stars lie between the horizontal branch and the main-sequence turnoff point. It was suggested in Paper I that these stars could be understood as having been red giants that underwent mixing events violent enough to mix some envelope hydrogen into the helium core; the stars would then undergo a new phase of hydrogen burning (as subgiant CH stars), and eventually climb the giant branch once again to become red-giant CH stars. Available evidence does not contradict the possibility that all Population II stars eventually go through this process.

Since this discussion was based largely on classification-dispersion spectrograms, it would appear highly desirable to confirm the peculiarities of these stars with a study of high-dispersion spectroscopic material. Accordingly, we chose two of the brighter subgiant CH stars, HD 176021 and HD 204613, for detailed analysis. The peculiarities of these two stars were first announced a few years ago by Bond (1970). Basic data

TABLE 1
BASIC DATA

Parameters	HD 176021	HD 204613
α(1900)	$18^h53^m.0$	$21^h24^m.7$
δ(1900)	−65°03′	+56°54′
l	331°	98°
b	−26°	+5°
V	7.58	8.24
B − *V*	0.58	0.61
U − *B*	−0.07	0.06
b − *y*	0.38	0.40
m_1	0.17	0.21
c_1	0.22	0.29
Radial velocity (km s^{-1})	+106.2	−89.9
Proper motion per year	0″.345	0″.225
Trigonometric parallax	0″.017	...

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TABLE 2

OBSERVATIONAL MATERIAL

Plate No.	Star	Date (UT)	Telescope	Dispersion (A mm^{-1})	Wavelength Range (Å)	Emulsion
CT-122.......	HD 176021	1971 Nov 5	Cerro Tololo 1.5 m	9	3850–4700	IIaO
CT-138.......	HD 176021	1971 Nov 9	Cerro Tololo 1.5 m	9	3850–4700	IIaO
7400..........	HD 204613	1971 May 15	McDonald 2.1 m	18	3850–4700	IIaO baked
7404..........	HD 204613	1971 May 16	McDonald 2.1 m	18	3340–3400	IIaO baked
7586..........	HD 204613	1971 Aug 5	McDonald 2.1 m	18	3850–4700	IIaO baked
7587..........	HD 204613	1971 Aug 5	McDonald 2.1 m	9	3900–4400	IIaO baked
D-3742.......	HD 204613	1973 Jun 24	Kitt Peak 2.1 m	18	5300–6000	IIaD
D-3749.......	HD 204613	1973 Jun 26	Kitt Peak 2.1 m	27	5300–6000	IIaD
EC-12889.....	HD 204613	1974 Nov 27	Lick 3.0 m	11	6500–6750	IIIaJ baked and image tube

for the stars are given in Table 1. Note in particular these stars' fairly large radial velocities and proper motions. For the most part, these data are repeated from Paper I with the addition of a new coudé radial velocity for HD 204613. Two radial-velocity determinations for HD 176021 and three for HD 204613 showed no significant variations.

II. OBSERVATIONS AND REDUCTIONS

The basic set of observational material consists of coudé spectrograms of HD 204613 and HD 176021 obtained with four different spectrographs. Details of these spectrograms are listed in Table 2; reproductions of two sections of the spectrum of HD 176021 are given in Figure 2 of Paper I. All plates were traced on the Lick Observatory microphotometer, yielding relative intensity tracings. Equivalent widths were measured for unblended atomic lines by employing an empirical relation between the measured central intensities and equivalent widths for selected lines from each plate. Intercomparison of the measured equivalent widths of the blue plates of each star revealed excellent agreement. However, the two yellow plates of HD 204613 are of lower resolution and higher noise level; not surprisingly, equivalent widths from these two plates showed large (up to 50%) differences. In the analysis that follows, we assign lower weight to the results from these plates.

For each star we averaged the line equivalent widths which were derived from plates of a single dispersion and spectral region. For HD 204613, we therefore have three sets of line measures (9 Å mm^{-1} blue, 18 Å mm^{-1} blue, and the yellow-region spectra). In view of the heterogeneous nature of the plate data, we derived atmosphere parameters for this star independently for each set of line data. Additionally, we averaged small sections of the actual spectra of each star in the CN band region (3865–3885 Å) and the CH band region (4288–4318 Å) to compare with synthetic spectra of these molecules.

III. ATMOSPHERE ANALYSIS

We derived atmospheric parameters for our stars using both coarse and fine analyses. The theory of a coarse analysis is well known; our procedure followed closely the method of Pagel (1964). The results of this analysis are given in Table 3a, in which the standard notations $[X] = \log X_* - \log X_\odot$, $\Delta\theta_{exc} = \theta_{exc,*} - \theta_{exc,\odot}$, and $\theta = 5040/T$ are employed. From this table we see immediately that the stars have roughly solar temperatures and, more importantly, that the electron pressures are more indicative of mainsequence stars than giants. Small metal deficiencies were found for each star, and the coarse analysis indicated substantial overabundances of the s-process elements.

TABLE 3

ATMOSPHERE PARAMETERS

Parameter	HD 176021	HD 204613 (9 Å mm^{-1})	HD 204613 (18 Å mm^{-1})	HD 204613 (yellow region)
Table 3a, coarse analysis:				
$\Delta\theta_{exc}$	-0.05 ± 0.05	$+0.00 \pm 0.05$	-0.03 ± 0.05	-0.03 ± 0.05
$[P_e]$..................	$+0.30 \pm 0.30$	-0.25 ± 0.3	-0.06 ± 0.30	...
$[V_t]$..................	-0.05 ± 0.10	-0.15 ± 0.10	-0.05 ± 0.10	$+0.05 \pm 0.10$
[Fe/H]...............	-0.31 ± 0.3	-0.50 ± 0.30	-0.14 ± 0.30	-0.25 ± 0.30
$[s\text{-process/Fe}]_{avg}$	$+0.66 \pm 0.30$	$+0.50 \pm 0.30$	$+0.64 \pm 0.30$	+0.5:
Table 3b, fine analysis:				
T_{eff}..................	6000 ± 200	5750:	5750 ± 250	5900 ± 250
Log g................	4.00 ± 0.4	4.00 ± 0.5	4.00 ± 0.4	...
ξ_t....................	2.00 ± 1.00	2.0:	2.50 ± 1.00	2.5:
[Fe/H]	-0.40 ± 0.25	-0.30 ± 0.25	-0.25 ± 0.30	-0.30 ± 0.30

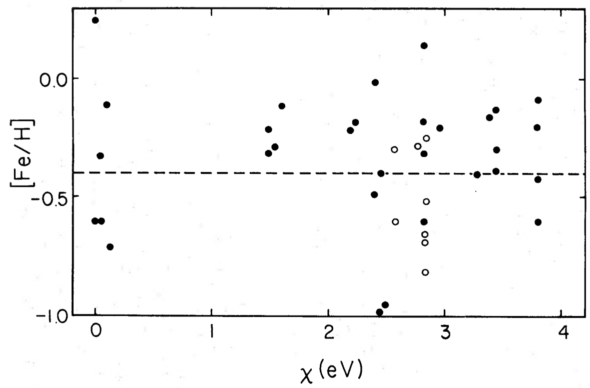

FIG. 1.—Derived abundances for iron lines in the spectrum of HD 176021. Filled circles are Fe I lines, and open circles are Fe II. The dashed line represents the mean derived iron abundance. No trend of abundance with line excitation potential is seen in this figure.

We then proceeded to the fine analysis. Following the method outlined by Sneden (1974; hereafter called Paper II), the coarse analysis parameters were converted to ones suitable for specifying model atmospheres: $T_{\rm eff}$, log g, [M/H] ≡ [Fe/H], and ξ_t = microturbulent velocity. Model atmospheres were derived through interpolation in the grid of models of Carbon and Gingerich (1969). The trial models were input to a line analysis program (Paper II), which generated theoretical curves of growth for neutral and ionized lines with varying excitation potentials of Fe, Ti, and Cr. The curves were computed for an assumed stellar abundance and a given excitation potential, by varying the line oscillator strengths. For a stellar line the measured equivalent width, excitation potential, and oscillator strength (see below) were then compared with these curves of growth to yield an element abundance.

The oscillator strengths of all atomic lines were derived from solar data. Equivalent widths of solar lines were taken from the tables of Moore, Minnaert, and Houtgast (1966); the adopted solar model was the Harvard-Smithsonian Reference Solar Atmosphere (Gingerich *et al.* 1971). We used the Lambert-Warner solar abundances, and computed line oscillator strengths, with the aid of the line analysis program, by forcing the calculated and observed solar equivalent widths to agree. Our atmosphere analyses became therefore differential fine analyses, with the Sun as the standard star.

In order to test our trial model atmospheres we examined the variations in derived abundances of Fe, Cr, and Ti with several variables. The assumed effective temperatures were changed to eliminate trends of abundances with excitation potential. Microturbulent velocities were altered to force abundances derived from moderately strong lines to agree with those from weak lines. Finally, gravities were varied until neutral lines and ionized lines predicted the same abundances. Figure 1 shows the iron abundances for our final model of HD 176021, plotted against the excitation potentials. To the limits of the scatter of individual points, there is no trend in the abundances. Our most satisfactory model parameters are seen in Table 3b. Neither [P_e] nor log g were determined for the yellow spectral region of HD 204613. This was due merely to the lack of suitable lines of any of the ions. The final atmospheric parameters for HD 204613 are therefore derived from the blue lines.

We have seen from the coarse analysis that HD 204613 has a slight metal deficiency of all the iron peak elements ([M/H] ≈ −0.25). It was not possible to interpolate reliably in the Carbon and Gingerich (1969) models in both temperature and metal abundance. In principle, neglect of this metal deficiency in the model computations could affect the electron and gas pressures, and therefore the derived abundances. In practice this difficulty does not appear to be serious in this ($T_{\rm eff}$, log g) domain. Trial abundances for HD 176021 were derived using two models: a blanketed (6000, 4.0, 0.0, 2.5) model, and an unblanketed (6000, 4.0, −0.4, 2.0) one. The derived abundances generally were consistent (±0.10 in the log) in the two models. Use of the model (5750, 4.0, 0.0, 2.5) should therefore not introduce a severe uncertainty in our abundances. For our final abundance determination for HD 176021 we have used the unblanketed (6000, 4.0, −0.4, 2.0) model.

The Strömgren color index $(b - y)$ can be used as a check on these adopted temperatures. Paper I notes the existence of a broad opacity source around 4000 Å in all subgiant CH stars. If this opacity is due to CH bound-free opacity, as suggested in Paper I, then it should have little effect on the b and y Strömgren filters. Table 1 gives $(b - y)_{\rm obs} = 0.38$ and 0.40 for HD 176021 and HD 204613, respectively. Bond (1970) has shown that although HD 204613 lies at low galactic latitude, the agreement between its $(b - y)$ index and spectral type (from classification dispersion spectra) indicates that the star is essentially unreddened. Olsen (1974) has computed theoretical Strömgren indices for the models of Carbon and Gingerich (1969). By interpolation of his indices we find that for a model (5750, 4.0, 0.0), $(b - y)_{\rm comp} =$ 0.425. Chaffee, Carbon, and Strom (1971) have computed for (6000, 4.3) models the expected changes in $(b - y)$ as a function of metallicity. A crude correction to the color index at 5750 K may therefore be made by adopting the values of Chaffee, Carbon, and Strom (1971) for a change in the metal abundance by a factor of 2: $\Delta(b - y)_{\rm comp} = -0.017$. Our "model color index" is therefore $(b - y)_{\rm comp} = 0.408$, in good agreement with the observed value.

For HD 176021 the problem is somewhat simpler, for it lies at a higher galactic latitude and reddening can be ignored. Olsen (1974) gives $(b - y)_{\rm comp} =$ 0.387 for a model with (6000, 4.0, 0.0). From Chaffee, Carbon, and Strom (1971), $\Delta(b - y)_{\rm comp} = -0.020$. Therefore, we expect $(b - y)_{\rm comp} = 0.367$, which is somewhat lower than $(b - y)_{\rm obs} = 0.38$. Taken at face value, the observed color index indicates $T_{\rm eff} \approx$ 5900 K. This temperature is well within our errors here. Since we cannot totally eliminate the possibility

TABLE 4

ELEMENT ABUNDANCES

Ion	HD 176021		HD 204613 (9 Å mm^{-1})		HD 204613 (18 Å mm^{-1})		HD 204613 (yellow region)	
	[M/Fe]	No. of Lines	[M/Fe]	No. of Lines	[M/Fe]	No. of Lines	[M/Fe]	No. of Lines
Li I	...	...	...	...	...	...	< +2.0	...
C (from CH)	+0.50	...	+0.40	...	+0.30	...	...	...
N (from CN)	−0.10	...	...	...	−0.20	...	...	...
N (from NH)	...	...	...	...	+0.10	...	...	...
Mg I	−0.20	3	+0.30:	1	+0.36	3	+0.20:	2
Al I	−0.10:	2	+0.37:	2	+0.00:	2	...	...
Si I	...	...	...	...	...	...	+0.18	4
Ca I	+0.02	7	+0.30	3	+0.21	7	+0.22	9
Sc II	+0.44	5	+0.55	4	+0.95	4	...	...
Ti I	+0.18	10	+0.11	2	+0.13	7	...	...
Ti II	+0.14	16	+0.06	7	+0.03	14	...	...
V I	+0.05	6	+0.00	5	−0.20	4	...	...
V II	−0.20:	2	−0.15:	2	...	...	...	...
Cr I	−0.02	10	+0.17	3	+0.07	9	−0.34	3
Cr II	+0.06	3	...	...	+0.09	3	...	...
Mn I	−0.05	3	−0.30:	2	+0.25:	1	...	...
Co I	+0.03	4	+0.10	4	−0.15	4	...	...
Ni I	+0.20	3	+0.05:	1	−0.35:	1	+0.28	6
Sr I	+0.95:	1	...	...	...	...	...	...
Sr II	+0.40	3	+0.55	3	+0.55	2	...	...
Y II	+0.75:	2	+0.76:	2	+1.02:	1	+1.03	2
Zr II	+0.44	5	+0.50	4	+0.35	3	...	...
Ba II	+1.22:	1	...	...	+1.05:	1	+0.70:	1
La II	+0.48:	3	+0.22:	3	...	...	...	...
Ce II	+0.52	9	+0.35	5	+0.65	3	...	...
Pr II	+0.87:	1	+0.72:	1	...	...	...	...
Nd II	+0.62	5	+0.45	4	+0.43	1	...	...
Sm II	+0.53:	3	...	...	...	...	...	...
Eu II	+0.14:	1	+0.09:	1	...	...	...	...
$[Fe/H]_{Fe\,I}$	−0.32	53	−0.30	27	−0.25	35	−0.40	61
$[Fe/H]_{Fe\,II}$	−0.50	9	−0.20:	2	−0.25	7	...	...

of a small amount of reddening from the broad opacity source, we regard the agreement between $b - y$ and the line spectrum in HD 176021 as satisfactory.

IV. THE ABUNDANCES

The abundances of the other elements were derived in the same manner as those of iron, titanium, and chromium. The results are presented in Table 4 along with the number of lines used in the analysis of each ion. The gaps in Table 4 for HD 204613 appear because of the inferior resolution of the 18 Å mm^{-1} blue plates, or the small spectral range of the single 9 Å mm^{-1} plate.

Carbon and nitrogen abundances were derived using a spectrum-synthesis technique. This type of analysis was considered in detail in Paper II. Briefly, given a model atmosphere and atomic and molecular line data for all relevant transitions in a spectral region, the synthesis program computes a set of line depths assuming local thermodynamic equilibrium. The line depths are then convolved with an appropriate spectrograph slit function to produce a synthetic spectrum which may be compared with the observed spectrum. Paper II discusses the slit function of the McDonald 82 inch (2.1 m) coudé spectrograph, which has been experimentally determined. The slit function for the Cerro Tololo spectrograph was derived by measuring the profiles of the iron comparison lines which appeared on the plates. The slit function could be well fit by a Gaussian profile of full width at half-maximum of 0.16 Å.

Figures 2 and 3 display parts of the CH and CN spectra of HD 176021. The CH spectrum was actually computed from 4290 Å to 4315 Å. Our best plate material covers this region in both stars; thus the carbon abundances should be well determined. In our calculations of the carbon equilibrium we set [O/Fe] = 0.0 in all cases. This approximation makes little difference in our results for the carbon abundance because the CO number density is less than 10 percent of the total carbon number density for both atmospheres. Our derived carbon abundances can only be seriously altered through a large increase in the oxygen abundance. In that case, the carbon enhancements would be even greater than those we have determined.

The nitrogen abundances have been derived from the CN bands (total synthesis length, 3869–3885 Å) for HD 176021 and HD 204613. Generally, placement of the continuum is more difficult in this shorter wavelength region than at 4300 Å. Our nitrogen abundances should therefore be given lower weight than the carbon abundances. This is even more true for HD 204613, for which we only had 18 Å mm^{-1} plates of the CN

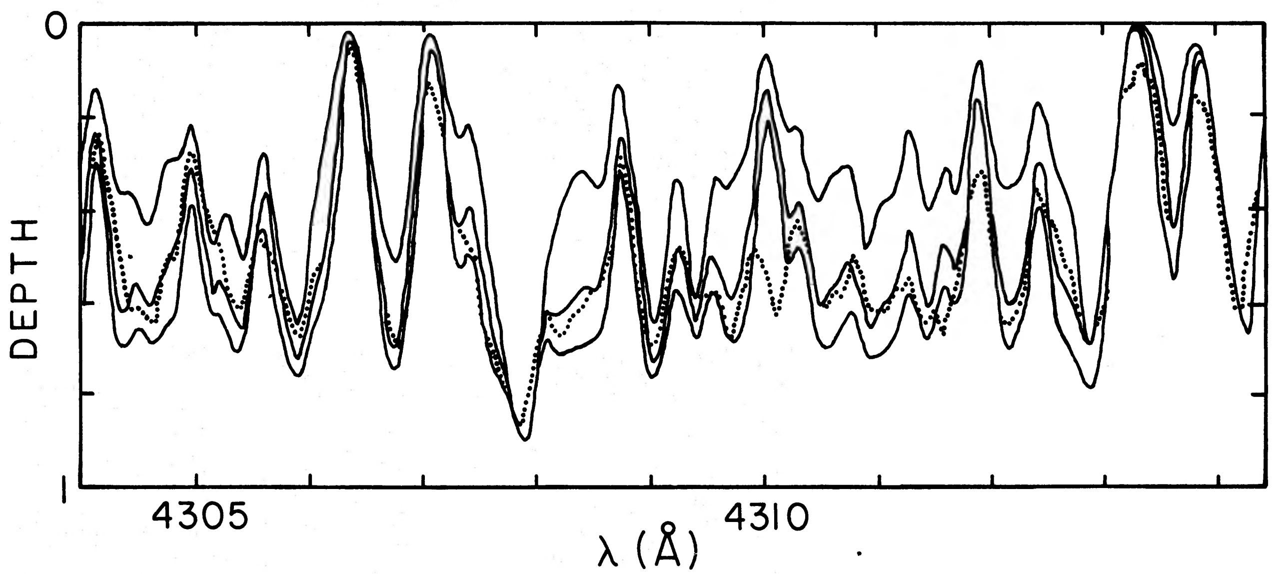

FIG. 2.—Part of HD 176021 CH spectrum. The synthetic spectra are shown with solid lines: the carbon abundances are [C/Fe] = +0.0, +0.5, and +0.8 (with increasing spectrum depth). The observed spectrum is indicated by a dashed curve.

band region. We obtained one underexposed plate of the NH bands region (3357 to 3380 Å) of HD 204613. The nitrogen abundance derived from these bands should be free from uncertainties in the carbon equilibrium (unlike the CN bands). However, since these bands registered only very weakly on our plate, and since the plate dispersion was 18 Å mm^{-1}, the nitrogen abundance derived from these bands should be viewed with caution.

The derived carbon and nitrogen abundances are heavily dependent on the assumed atmosphere parameters. However, it can be shown (Sneden 1973) that the ratio [C/N] is relatively insensitive to log g and the microturbulence. Also, there is little uncertainty due to the assumed temperature if carbon and nitrogen abundances are derived from the CH and NH bands. Therefore, for HD 204613, at least, our chief source of error seems to be due to placement of the continuum of the NH band region. We note that there is consistency among the abundances derived in HD 204613 using the CH, CN, and NH bands, which strengthens somewhat our results for nitrogen in this star. The probable errors of the carbon and nitrogen abundance analysis have been considered in some detail in

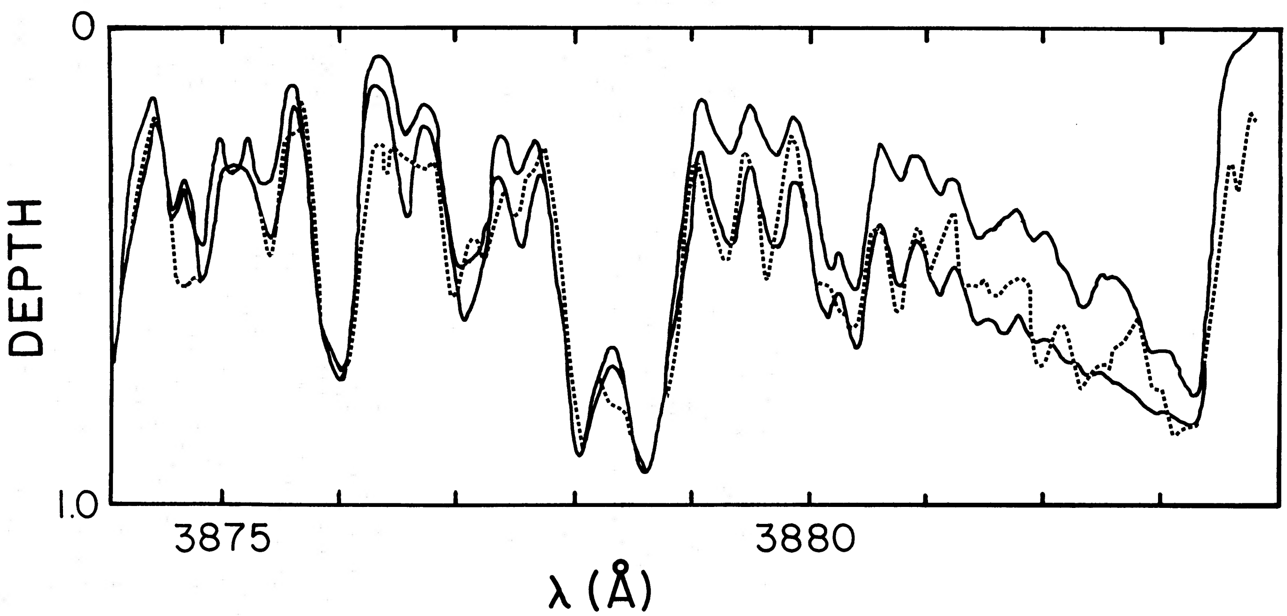

FIG. 3.—Part of the HD 176021 CN spectrum. The synthetic spectra (*solid lines*) are for [C/Fe] = +0.5 and [N/Fe] = +0.0 and −0.4. The observed spectrum is given by a dashed curve.

Paper II. Here, since we have 9 Å mm^{-1} plates of the CH region in both stars, we estimate the error in [C/H] to be ± 0.4. The nitrogen abundance uncertainties are higher, for reasons discussed above: the errors in [N/H] are about ± 0.5. Finally, we estimate the ratio [C/N] to be good to ± 0.3.

Table 4 reveals substantial overabundances of the *s*-process elements in both stars. This result is largely independent of errors in our atmosphere parameters. We can see this in the following manner. From the differential coarse analysis method (Pagel 1964) we have for an ionized line

$$[X_{\rm ion}] = [{\rm M_{ion}/H}] - [P_e] - \Delta\theta(\chi + 0.74) - 1.5[\theta]\,,$$

where χ is the excitation potential of the line. Therefore, when comparing the curve of growth shifts of *s*-process ionized lines with those of, say, Fe II, we have

$$[X_{s\text{-process}}/X_{\rm Fe\,II}] = [{\rm M}_{s\text{-process}}/{\rm M}_{\rm Fe\,II}] - \Delta\theta(\chi_{s\text{-process}} - \chi_{\rm Fe\,II})\,.$$

From Table 3a, all of our derived values of $\Delta\theta$ are 0.05 or less; thus even for a two volt difference in line excitation potentials, the second term in the above equation can amount to ~ 0.10 at most.

From the estimated errors in (1) the derived atmospheric parameters, (2) continuum placement on the spectrum tracings, and (3) internal scatter of abundance determinations for individual lines of an element, we estimate that our abundances [M/Fe] are accurate to ± 0.30 in HD 176021 and ± 0.35 in HD 204613. These errors are assigned to the entries in Table 4, except those abundances followed by a colon. These abundances are less accurate (± 0.5) due to the availability of only one or two lines of a given species, or large scatter in the abundance determination.

Finally, we investigated the possibility that the continuous absorption near 4000 Å could cause systematic errors in our analysis by weakening the line equivalent widths in that wavelength region. For a given solar equivalent width range, however, $\log W/\lambda_* - \log W/\lambda_\odot$ showed no apparent trend with line wavelength. This source of uncertainty can probably be neglected for the atomic lines. The above test cannot be applied to the molecular spectra. We note only that if this opacity is due to the dissociation of CH, and if the CN lines are formed in the same region of the stellar atmosphere as are those of CH, the CN lines could be anomalously weak; hence we could underestimate the abundance of nitrogen in these stars.

V. DISCUSSION

In Paper I it was concluded that the subgiant CH stars are metal-deficient objects with enhanced abundances of carbon and the *s*-process elements. It can now be seen that our detailed analysis of two of the subgiant CH stars has confirmed these conclusions,

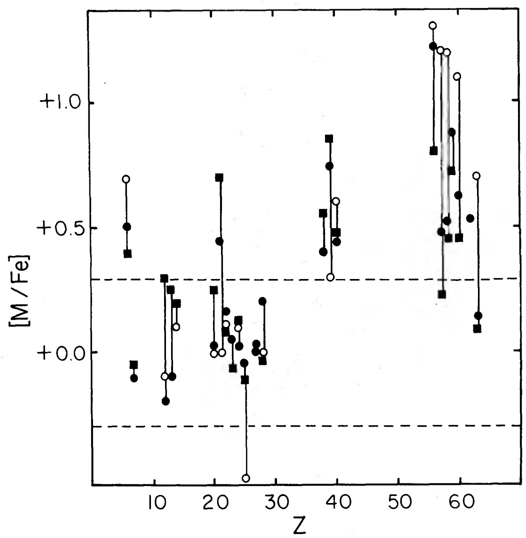

FIG. 4.—Derived metal abundances plotted against their atomic numbers. The dashed lines represent the probable uncertainties in the abundances. The symbols are the following: *filled circles*, HD 176021; *filled squares*, HD 204613; *open circles*, HD 26 (Wallerstein and Greenstein 1964).

which had been based primarily on visual examination of low-dispersion spectrograms.

Table 3 indicates that both stars show small metal deficiencies, by factors of 2.5 in HD 176021 and 2 in HD 204613, in accord with the visual estimates of Paper I. The metal deficiency of HD 176021 is greater than the probable errors, and the deficiency of HD 204613, while somewhat smaller, is confirmed on all three sets of plates. This metal deficiency is shared by all the iron peak elements: Ti, V, Cr, Mn, Fe, Co, and probably also Ni (see also Fig. 4). The anomalies in other elements to be discussed below therefore cannot be attributed to errors in the atmosphere parameters.

All *s*-process elements have enhancements [M/Fe] ranging from +0.4 to about +1.2 (Table 4, Fig. 4). Most of these elements are not only overabundant with respect to the iron peak elements in the stars but in fact are overabundant with respect to the Sun. The element enhancements are not limited to the strong lines of Sr II (4215 and 4077 Å) and Ba II (4554 Å) seen on low-dispersion spectrograms; very weak lines exhibit the same effects. In HD 176021 we are fortunate in being able to measure the Sr I line at 4607 Å. This line requires an even larger enhancement of strontium than do the Sr II lines. From the yellow plates of HD 204613 we obtain confirmation of the gross overabundances of Y II and Ba II. Still, the reader must be cautioned about the relatively large uncertainties in abundances based on only two or three lines. This warning must be stressed especially for Ba II, Sm II, and La II. Europium, which is mainly produced by the *r*-process, is probably normal, based on one measurable line. The Pr abundance has been determined from only one line, and hyperfine structure in the line has been ignored; thus the listed overabundance is too large (Allen and Cowley 1974), but probably real.

A surprising result is that scandium is significantly overabundant in both HD 176021 and HD 204613. The one stable isotope of scandium, ^{45}Sc, apparently can be produced only by the *s*-process acting on light seed nuclei (Burbidge *et al.* 1957). Available calculations of weak *s*-process irradiations (Peters, Fowler, and Clayton 1972; Couch, Schmiedekamp, and Arnett 1974) indicate that the synthesis of ^{45}Sc, under a wide variety of conditions, is always accompanied by comparable or larger enhancements of several of the following spectroscopically observable stable isotopes: ^{25,26}Mg, ^{42,43,46}Ca, ^{50}Ti, ^{54}Cr, and ^{58}Fe. However, all of these isotopes, unlike scandium, constitute small fractions of their elemental abundances (at least in solar-system material). Therefore, even considerable enhancements of these *isotopic* abundances do not produce large enhancements of the *elemental* abundances. It thus appears possible for a weak *s*-process acting on the light nuclei in some of the processed material to produce an enhancement of ^{45}Sc as its largest observable effect. One red-giant CH star, HD 198269, also appears to have a similar overabundance of scandium (Lee 1974), and Warner (1965) has noted a tendency for Sc to be somewhat overabundant in Ba II stars.

We have searched for the important lithium 6707 Å doublet in HD 204613 using a spectrum taken with the Varo image tube and 20 inch (51 cm) camera of the Lick Observatory 3 m telescope. No line could be detected on a tracing of this plate, and we have estimated $\log W/\lambda < -5.5$. The resulting upper limit for the lithium abundances is [Li/H] $< +1.7$. This large upper limit is not extremely helpful, but we have established that the lithium content in HD 204613 is much less than the large overabundance found in some carbon stars.

Paper I proposed that these stars be called subgiant CH stars because of their qualitative resemblance of the giant CH stars. Just how closely these two stars resemble the giant CH stars can be seen in Figure 4, in which we have also plotted the abundance determinations for HD 26 (Wallerstein and Greenstein 1964). We have selected this star for comparison because it has a metal deficiency not too different ([Fe/H] ≈ -0.67) from our stars. There is generally good agreement between the two types of stars, with the following exceptions: (1) HD 26 shows no enhancement of Sc; (2) the higher-Z *s*-process elements exhibit greater overabundances in HD 26 than in our stars. It therefore appears that the material in HD 26 was subjected to a somewhat heavier neutron irradiation than in these two subgiant CH stars. Other stars of this class do appear to show greater abundances of the *s*-process elements (Paper I).

We may estimate the luminosities of our stars using our derived $T_{\rm eff}$ and $\log g$ values. Since these stars appear to be highly evolved members of an old stellar population, we assume masses of $0.8 \pm 0.3\, \mathfrak{M}_\odot$ (to allow for the possibility of some mass loss during stages of advanced evolution). For HD 176021, with $T_{\rm eff} = 6000 \pm 200$ K and $\log g = 4.0 \pm 0.4$, we then obtain $M_v = 3.8 \pm 1.5$, in very close agreement with the luminosity implied by the known trigonometric parallax. For HD 204613, taking $T_{\rm eff} = 5750 \pm 250$ K and $\log g = 4.0 \pm 0.5$, we find $M_v = 4.0 \pm 1.8$. We therefore confirm the conclusion of Paper I that these stars are considerably less luminous than red giants that heretofore have been the only objects showing evidence of interior mixing. In fact, these two stars appear to be even less luminous than the $M_v \approx +2$ adopted in Paper I. The most important result of this study is therefore the demonstration of *s*-process and carbon enhancements in stars that lie near the main sequence.

We have shown these stars to exhibit many of the same abundance anomalies as the giant CH stars and the barium stars, and yet they lie well below the giant branch. Large overabundances of *s*-process material are hardly characteristic of metal-poor stars; indeed, overdeficiencies are sometimes seen (e.g., Pagel 1970). It appears therefore that these element anomalies must be attributed to internal nuclear processing in our stars. As was pointed out in Paper I, a plausible sequence of events places the subgiant CH stars in a stage following the first ascent of the giant branch. Rood (1970) has done numerical experiments with the assumption that helium flashing creates a convective region that reaches the hydrogen-rich envelope of the model star. If an appreciable amount of hydrogen is mixed into the core, the star will be driven back down to the subgiant branch to begin core hydrogen burning again. By the same process, the surface abundances of carbon, helium, and *s*-process elements which have been synthesized in the interior will rise. Since we have placed the subgiant CH stars at an earlier stage of evolution than the giant CH stars, it is plausible that the surface abundances of these elements can increase even further as the stars begin their second ascent of the giant branch. The higher *s*-process enhancements of HD 26 may possibly be explained in this manner.

There are several obvious directions for future work, of which we list a few here. (1) Certainly Rood's (1970) study of partially mixed stellar models should be reinvestigated, this time with more attention being paid to the expected nucleosynthesis. (2) Oxygen abundances would be helpful in these stars. One would expect that if carbon is overabundant in these stars, oxygen should also be overabundant. (3) Of great interest is the ratio ^{12}C/^{13}C, a low value of which appears to be the signature of many evolved stars. Since these stars are relatively hot, the CN red system cannot be used for this work. Attention will have to be centered on carefully selected lines of the CH molecule. The resolution and signal-to-noise ratio of the present spectroscopic material is inadequate for such an investigation. (4) A more realistic abundance, or upper limit at least, of lithium should be determined. (5) It would be of considerable interest to search for subgiant CH stars in globular clusters. A prime candidate cluster would be ω Centauri, which is now known to contain three giant CH stars (Bond 1976) and ought to contain many subgiant progenitors of these stars.

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