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Abundance Analysis of the Silicon Star HR 6958

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Abstract

The elemental composition of the chemically peculiar star HR 6958 has been studied with emphasis on doubly ionized rare earths. A visual region spectrum taken with the ELODIE spectrograph at the Haute-Provence Observatory was analyzed. A total of 40 elements including Pr III, Nd III, Tb III, Dy III, Ho III, and Er III were identified and their abundances computed. He is deficient by over 1 dex with respect to the Sun; the light elements (C–Ca), except for Si, have solar abundances; the iron group elements (Sc–Fe) are overabundant by 1 dex to 2 dex, with Ti and Cr highly overabundant; and the lanthanide rare earths are overabundant by 3 dex to 4 dex. This abundance pattern with He deficient, Si, Ti, Cr, Sr, and Pr overabundant indicates that HR 6958 is a member of Si stars.

Key words: stars: abundances — stars: chemically peculiar — stars: individual (HR 6958)

1. Introduction

Since the classification of stars with peculiar spectral features into an apparent temperature sequence was made by Morgan (1933), a large number of studies have been made to clarify the nature of a group of these stars. Preston (1974) classified the peculiar stars into four groups. The magnetic chemically peculiar (CP) stars are designated as CP2, which consist of two groups having different effective temperatures: a cooler one, which shows an enhancement of elements, such as Cr, Sr, and Eu; and a warmer group, which exhibits an unusual strength of Si lines.

HR 6958 (= HD 170973, MV Ser) is an A0pSiCr CP2 star and its brightness changes by 0.03 mag (in the U band) with a period of 0.945099 d as cited in the Bright Star Catalogue (Hoffleit, Warren 1991). Recently, Adelman (1997) has revised this period to 18.065 d based on his own $uvby$ photometry.

López-García et al. (2001) performed a fine analysis of HR 6958 for 27 atomic species. He I lines are not seen. The light elements are mostly of solar abundance, except for Si, which is overabundant by a factor 4. All of the heavy elements except for Ni, which is solar, are greatly overabundant. In addition, C is underabundant, S and Ca are overabundant, and the iron-peak elements are typically 10-times overabundant, except for Ti and Cr, which are overabundant by factors of 75 and 35, respectively. Mn is about 50-times solar, Sr is overabundant by 1000, and the rare earths are 1000 or more times overabundant.

Cowley (1984) emphasized that the behavior of lanthanide rare earths provides a key to understand the surface chemistry of CP2 stars. In a previous study, Cowley (1976) tried to identify rare earths in HR 6958 by using a statistical method of wavelength coincidences, and showed the possible presence of singly ionized lines for Ce, Pr, Nd, Sm, Eu, Gd, Tb, and Dy. In later work, Mathys and Cowley (1992) reported the identification of Pr III lines in magnetic CP stars, including HR 6958. With the efforts of atomic physicists, some data on oscillator strengths are now available for doubly ionized rare earths (e.g., Bord et al. 1997; Biémont et al. 2002). Based on these data, the abundances or presence of doubly ionized rare earths have been studied for several CP stars (e.g., Cowley et al. 2000; Wahlgren et al. 2000; Dolk et al. 2002; Nishimura et al. 2003).

2. Spectrogram and Measurement of Lines

We used an echelle spectrum of HR 6958 obtained with the ELODIE spectrograph at the Haute-Provence Observatory, which was chosen from the HYPERCAT database (Prugniel, Soubiran 2001). The spectrum, ranging from 4100 Å to 6800 Å with a nominal resolution of 42000, is supplied after the spikes due to cosmic rays, and the features of telluric lines were removed from the crude spectrogram. The sequential number of the spectrum used in this study was 00602.fits, the observation being made on 1999 July 22, with an exposure time of 40 min. Its S/N ratio was 84.8 at 5550 Å.

In addition, a high-dispersion photographic 2.4 Å mm^{-1} spectrum in the violet–blue region ($\lambda\lambda$ 3800–4600 Å), obtained at the Dominion Astrophysical Observatory (DAO), was referred to in order to measure Hγ line profiles and also in order to compare the equivalent widths of other lines with those of ELODIE. The plate number was 10010. Its observational date was 1975 August 13. The spectrogram digitized using a PDS machine during the stay of Professor K. Sadakane of Osaka Kyoiku University at the DAO in 1990 was kindly provided to the author.

We computed the synthesized spectra by adopting the same atmospheric parameters as López-García et al. (2001) to make line identifications and to select clean or minimally contaminated lines. We used the program SPTOOL, modified and developed by Dr. Y. Takeda from the Kurucz's programs SYNTHE and WIDTH (Kurucz 1993a,b). The synthesized spectra were also used to draw the continuum line.

The equivalent widths of lines were measured by assuming a Gaussian profile with the program *Nijiboshi* written by T. Hasui. We identified 578 lines as being suitable for abundance computations, and an additional 303 unidentified lines were also measured, whose equivalent widths were

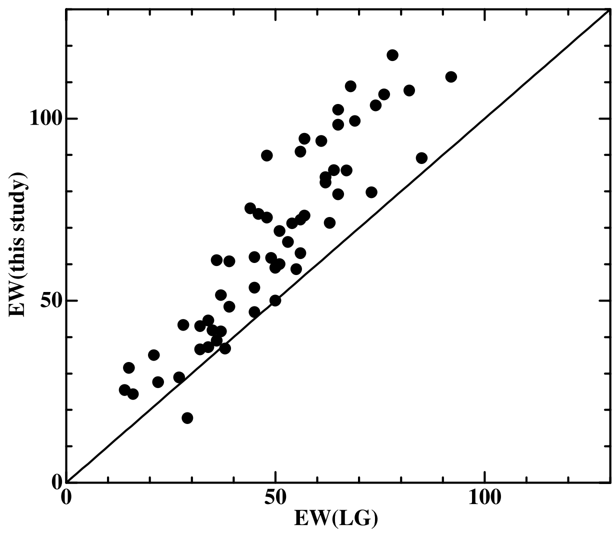

Fig. 1. Comparison of the equivalent widths (in mÅ) between this study and López-García et al. (2001) for HR 6958.

between 9 mÅ to 126 mÅ. These identification lists are available at the web site of Osaka Science Museum.[1]

The measured lines were compared with the results of López-García et al. (2001). They used four photographic 4.3 Å mm^{-1} spectrograms of HR 6958, obtained with the 2.5 m telescope at the Mt. Wilson Observatory. Their equivalent widths are systematically lower than those of this study. In figure 1, we compare the equivalent width in this study (ordinate) with that of López-García et al. (2001) (abscissa). A least-squares comparison of the equivalent widths W_λ's was made for 58 lines with equivalent widths of 10 mÅ to 120 mÅ:

$$W_\lambda(\text{this study}) = (1.30 \pm 0.08) W_\lambda(\text{López-García et al.}) + (1.36 \pm 4.24). \quad (1)$$

Similarly, we compared the ELODIE data with equivalent widths deduced from the DAO spectrogram. The result is

$$W_\lambda(\text{this study}) = (0.92 \pm 0.05) W_\lambda(\text{DAO}) - (4.38 \pm 3.42). \quad (2)$$

The difference between the Mt. Wilson spectrum and CCD-based ELODIE spectrogram is up to 30%. This is partly due to the difference in the S/N ratio, scattered light, accuracy of the continuum placement between the photographic spectrum and CCD-based Echelle spectrograms. However, the difference mentioned above seems to be somewhat large to be accounted for in terms of these reasons. HR 6958 may be a spectrum variable, like a spectroscopic binary, as suggested by Catalano and Renson (1998).

3. Atmospheric Parameters and the Magnetic Field

The effective temperature, $T_{\rm eff}$ = 10750 K, and the surface gravity, $\log g$ = 3.5, were obtained for HR 6958 by Adelman and Rayle (2000) from spectrophotometric data and Hγ line profiles (Adelman 1983; Adelman et al. 1989). They pointed out that the measured fluxes beyond the longward part of the λ 5200 feature are systematically brighter than model fluxes. From a measurement of the DAO plate, we can confirm the result for Hγ line profiles of Adelman and Rayle (2000). In this study, we adopted their effective temperature and surface gravity to make the analysis consistent with López-García et al. (2001). This effective temperature is slightly higher than that of Sokolov (1998) ($T_{\rm eff}$ = 10050 K). The rotational velocity of HR 6958 has been reported to be 15 km s^{-1} (Hoffleit, Warren 1991) or 10 km s^{-1} (Abt, Morrell 1995). We determined its rotational velocity by fitting the ELODIE spectrum with synthetic spectra computed for various rotational velocities. The best fit was achieved for a rotational velocity, $v \sin i$, of 8 km s^{-1}, which was adopted in this study.

With these parameters, we estimated the abundances for some elements to determine the microturbulent velocity. The condition used is that the elemental abundances should not be dependent on the equivalent widths. The best values found were 0.0 km s^{-1} for Ti II (62 lines) and Cr II (56 lines), 0.9 km s^{-1} for Fe I (35 lines), 0.4 km s^{-1} for Fe II (276 lines). On the other hand, López-García et al. (2001) obtained the slightly different values such as 1.0 km s^{-1} for Ti II, 1.4 km s^{-1} for Cr II, 0.6 km s^{-1} for Fe I, and 0.0 km s^{-1} for Fe II. Finally, we adopted a microturbulent velocity of 0.5 km s^{-1} as a mean value in the abundance computation.

The effects of a magnetic field on the spectral lines were investigated to compare the strengths of the Fe II lines at 4385.38 Å and 4416.81 Å. These lines were studied in detail by Takeda (1991) as a line pair suitable for searching stellar magnetic fields. They have the same multiplet number, and the gf values are essentially the same, while their effective Landé factors (Z) are different (Z = 1.333 and 0.833 for 4385.38 Å and 4416.82 Å, respectively). The present result for HR 6958 shows both lines to be the same strength; their measured equivalent widths are 106.6 mÅ and 103.6 mÅ for 4385.38 Å and 4416.82 Å, respectively. Moreover, the Fe II line at 6149.24 Å (Z = 1.333) is a single component. These features suggest that the effect of a magnetic field is not so remarkable on HR 6958, as already pointed by Mathys and Lanz (1992).

4. Chemical Abundances

We computed the chemical abundances from the equivalent widths with WIDTH9 (Kurucz 1993a), supplemented by the spectrum synthesizing program SPTOOL to determine their abundances from lines heavily blended or affected by neighboring lines. Ten-times the solar metal content ATLAS model atmospheres (Kurucz 1993a) were employed in the computation.

No effect of Zeeman broadening was taken into account because of the weak magnetic field on HR 6958. The oscillator strengths were taken from DREAM database (e.g., Biémont et al. 2002)[2] and Kurucz and Bell (1995) for rare earths and other elements, respectively. The hyperfine splitting was applied to three Eu II lines listed in table 1 by adopting data from Kurucz and Bell (1995).

[1] ⟨http://www.sci-museum.kita.osaka.jp/~kato/⟩.

[2] see also, ⟨http://www.umh.ac.be/~astro/dream.shtml⟩.

Table 1. Line list of lanthanide rare earth elements.*

Atom	λ (Å)	χ (eV)	$\log gf$	W_λ [†] (mÅ)	$\log \varepsilon$ ⟨mean⟩
La II	4238.390	0.403	−0.280	10	4.10
					⟨4.10⟩
Ce II	4137.680	0.517	0.440	47	5.59
	4144.500	0.478	−0.230	27	5.38
	4152.000	0.684	0.510	35	5.08
	4165.630	0.910	0.530	42	5.47
	4185.400	0.417	−0.560	9	4.92
	4214.030	0.609	−0.470	24	5.58
	4248.680	0.684	0.140	25	5.06
	4373.800	0.561	−0.360	13	5.02
	4382.180	0.684	0.200	18	4.73
	4429.290	1.088	0.330	36	5.51
	4460.230	0.478	0.320	30	4.94
	4463.430	0.957	0.080	20	5.08
	4483.940	0.864	0.150	21	4.98
	4523.060	0.517	−0.030	28	5.22
	4527.350	0.320	−0.110	24	5.08
	4560.290	0.910	0.310	25	5.02
	4560.900	0.684	−0.170	10	4.75
	4562.380	0.478	0.230	32	5.07
	5274.260	1.044	0.150	32	5.46
					⟨5.15⟩
Pr II	4206.719	0.550	0.480	syn	4.7
	5173.902	0.968	0.340	syn	4.9
	5815.331	1.591	0.271	syn	4.9
					⟨4.83⟩
Pr III	4437.610	0.000	−3.400	12	5.66
	4612.010	1.759	−1.260	28	5.10
	4642.260	0.960	−1.770	18	4.78
	4725.590	2.078	−1.320	28	5.33
	4775.300	1.947	−1.280	23	5.02
	4929.140	0.359	−1.880	24	4.80
	4964.580	0.173	−2.210	25	5.11
	5299.990	0.359	−0.530	80	5.55
	5449.380	0.359	−2.190	30	5.36
	5765.300	1.549	−1.100	22	4.65
	5844.450	1.244	−0.850	53	5.38
	5998.950	0.173	−1.800	44	5.39
	6090.000	0.359	−0.820	60	5.13
	6160.240	0.173	−0.980	61	5.20
	6195.630	0.000	−1.040	63	5.25
	6361.660	0.173	−2.080	20	4.80
	6500.080	1.722	−1.140	27	5.00
	6501.540	1.458	−1.400	36	5.44
	6616.529	1.549	−1.720	16	5.07
	6706.750	0.552	−1.640	32	5.04
					⟨5.15⟩
Nd II	4706.580	0.000	−0.880	10	5.44
	5130.600	1.304	0.570	34	5.63
					⟨5.54⟩
Nd III	4483.400	0.631	−1.340	48	5.37
	4903.260	0.000	−1.830	syn	4.90
	4927.490	0.461	−0.830	63	5.34
	5085.000	0.296	−0.660	72	5.39
	5633.541	0.141	−2.060	syn	5.20
	5677.180	0.631	−1.410	49	5.48
	5845.000	0.631	−1.130	57	5.48
	6145.050	0.296	−1.290	57	5.43
	6327.260	0.141	−1.360	55	5.36
	6690.860	0.461	−2.310	29	5.53
					⟨5.39⟩
Sm II	4279.7	0.277	−0.798	syn	5.0
	4378.235	0.659	−0.590	syn	4.9
					⟨4.95⟩
Eu II	4129.725	0.000	0.204	syn	4.3
	4205.042	0.000	0.117	syn	4.0
	4435.578	0.207	−0.092	syn	4.1
	6645.030	1.380	0.204	23	4.37
					⟨4.25⟩
Gd II	4215.022	0.427	−0.550	20	4.85
					⟨4.85⟩
Tb III	5847.232	0.348	−0.980	28	4.03
	6092.896	0.587	−1.110	22	4.07
	6687.698	1.027	−1.330	syn	4.1
					⟨4.06⟩
Dy II	4364.207	2.427	0.260	syn	4.9
	4754.992	2.417	−0.090	syn	4.8
					⟨4.85⟩
Dy III	4355.296	0.516	−1.610	syn	4.6
	4363.489	1.151	−1.720	syn	4.6
	4401.567	0.881	−1.430	33	4.77
	4409.897	1.366	−1.620	syn	4.9
	4434.269	0.516	−1.270	syn	4.9
	4502.917	1.151	−1.950	24	5.07
	4510.027	0.881	−1.850	syn	4.9
	4995.538	0.881	−2.250	syn	5.0
	5099.734	0.881	−2.440	syn	5.2
					⟨4.89⟩
Ho III	4416.250	0.000	−1.550	29	4.16
	4494.523	0.000	−1.360	syn	3.9
					⟨4.10⟩
Er II	4630.882	1.951	0.033	syn	4.48
					⟨4.48⟩
Er III	4356.549	1.639	−1.460	syn	4.47
	4422.410	0.000	−1.740	24	4.13
	4540.700	0.000	−2.540	16	4.61
	4735.510	0.630	−1.580	syn	3.9
	5068.447	1.546	−1.660	6	3.97
					⟨4.23⟩

* The abundance, $\log \varepsilon$, is expressed in the scale of $\log \varepsilon(\mathrm{H}) = 12.00$.

† The symbol syn indicates that the abundance was derived using the method of spectrum synthesis.

Table 2. Chemical composition of HR 6958 in logarithmic units compared with the study of López-García et al. (2001), the Sun, cool magnetic CP stars, and three Si stars.

Atom	n	This study	Standard deviation	López-García et al. (2001)	Sun	Cool magnetic CP	HR 2258 Si	HR 5597 Si	HD 192913 Si
He I	≤ 3	≤ 9.99	···		10.99				
C II	1	8.60	···	8.26	8.55		8.22	8.92	8.84
O I	2	9.09	0.01		8.87				
Na I	1	7.23	···		6.33				
Mg I	1	7.00	···	7.10	7.58		6.99		6.90
Mg II	5	7.30	0.25	7.48	7.58	7.48	7.28	7.74	7.30
Al I	1	6.47	···	6.54	6.47				6.67
Al II	5	≤ 7.40	···		6.47				
Si II	9	8.53	0.16	8.18	7.55	7.62	8.12	8.64	7.94
Si III	2	8.92	0.08	7.84	7.55				
P II	3	5.65	0.50		5.45				
S II	1	7.33	···	7.81	7.33		6.54	7.16	7.33
Ca II	1	6.66	···	7.09	6.36	6.82	6.88	6.28	6.67
Sc II	2	3.69	0.11	3.93	3.17	3.19	2.89		3.32
Ti II	62	7.46	0.27	6.89	5.02	4.70	6.19	5.98	6.40
V II	3	5.10	0.20		4.00	3.92			
Cr I	2	7.59	0.47		5.67	6.67	7.31		8.40
Cr II	56	7.48	0.26	7.20	5.67		6.98	7.85	7.08
Mn II	9	6.62	0.19	6.92	5.39	6.98	6.45	7.00	7.24
Fe I	35	8.94	0.21	8.83	7.50	8.21	8.52	8.68	8.74
Fe II	276	9.14	0.27	8.50	7.50		8.34	8.72	8.64
Fe III	4	9.25	0.41	9.08	7.50		8.30	8.82	9.32
Sr II	3	5.84	0.31	6.26	2.97	4.95	6.37	4.99	6.97
Zr II	2	4.57	0.03	5.02	2.60	4.17	4.19	4.47	4.78
Ba II	1	≤ 2.40	···		2.13	2.20		3.32	3.48
La II	1	4.10	···		1.17	2.23			
Ce II	19	5.15	0.27	5.74	1.58	3.36	5.14	4.86	5.14
Pr II	3	4.83	0.12	5.96	0.71	3.09	5.31	5.02	5.34
Pr III	20	5.15	0.27		0.71				
Nd II	2	5.54	0.13	5.52	1.50	3.92	4.66	5.28	5.19
Nd III	10	5.39	0.18		1.50				
Sm II	2	4.95	0.07	5.60	1.01	3.89			5.66
Eu II	4	4.25	0.17	5.73	0.51	4.30	3.85	3.56	6.71
Gd II	1	4.85	···	5.31	1.12	4.48	4.82		4.56
Tb III	3	4.06	0.04		−0.10				
Dy II	2	4.85	0.07	5.59	1.14				5.44
Dy III	9	4.89	0.20		1.14				
Ho III	2	4.10	0.18		−0.26				
Er II	1	4.48	···		0.93				
Er III	5	4.23	0.31		0.93				
$T_{\rm eff}$		10750		10750			11300	11200	10900
$\log g$		3.50		3.5			3.2	3.84	3.40

The resultant abundances are exhibited in table 1, where the lines of lanthanide rare earth elements employed in this abundance work are listed. A full list of lines is available via links from the URL appeared in the footnote 1. The final results are presented in table 2. The second column shows the number of lines used in the analysis. In the third and fourth columns, the mean abundances and standard deviation for the means are displayed for each element. The result of López-García et al. (2001) for HR 6958 is exhibited in the fifth column. The abundances of the Sun (Grevesse et al. 1996), cool magnetic CP stars (Adelman 1973; Adelman, Cowley 1986), and three Si stars as samples of moderately hot CP2 stars are also given for comparison.

4.1. *Helium*

The neutral helium lines in HR 6958 are too weak to detect. We failed to find a line at 6678.15 Å, which is well-known to be a strong He I line in usual B and A stars, although the spectral region around the line is fairly clear. HR 6958 is helium-poor relative to the Sun, with a value typical of Si stars. Thus, we can confirm the result of López-García et al. (2001) for the He abundance.

4.2. *Light Elements (C to Ca)*

Lines of C II, O I, Na I, Mg I, Mg II, Al I, Al II, Si II, Si III, P II, S II, and Ca II lines were measured and their abundances, or upper limits of the abundances, were computed. However, a small number of elements give reliable abundances. The final abundances are nearly solar, except for Si, which is greater by 1 dex than the solar abundance.

4.3. *Iron Group Elements (Sc to Fe)*

Sc is slightly enhanced, and the other iron group elements show overabundances by 1.1 dex to 2.4 dex. In particular, Ti is about 300-times the solar value. For Fe, doubly ionized lines were also detected as well as neutral and singly ionized ones. A complete ionization balance for all three species of iron can be achieved, if we adopt a higher effective temperature model of $T_{\rm eff} = 11100$ K and $\log g = 3.5$. Although we can find features of Ni and Co lines from a comparison of the synthesized spectra with the observation, all of them show no clean line profiles suitable for an abundance computation.

4.4. *Heavy Elements (Sr, Zr, and Ba)*

These elements are enhanced by 0.3 dex to 2.8 dex. The resonance line of Ba at 4554.03 Å is fairly weak and subject to blending with the Zr II line at 4553.934 Å. No other Ba line was detectable in the spectral range of this study.

4.5. *Rare Earths*

Lines were identified using sources, including the line list of Kurucz and Bell (1995), National Institute of Standard and Technology (NIST)[3], and DREAM database (Biémont et al. 2002)

The lines of singly ionized rare earths were detected and measured for La, Ce, Pr, Nd, Sm, Eu, Gd, Dy, and Er. The Lu II lines seem to be present, but this has not been confirmed.

Doubly ionized rare earths lines of Pr, Nd, Tb, Dy, Ho, and Er were measured and their abundances evaluated. In addition, four Gd III lines listed in the NIST atomic spectra database[3] were possibly identified, but their abundances were not obtained due to a lack of atomic data. We failed to detect the Ce III lines listed in Bord et al. (1997). Tm III lines as well as Yb III and Lu III lines in the DREAM database (Biémont et al. 2002) were not seen in the spectrum. It was impossible to find the Ba III and Eu III lines in the NIST atomic spectra database.

Their elemental abundances are in table 1.

HR 6958 is very enhanced in rare earth elements by 2.8 dex to 4.4 dex relative to the Sun. Pr III is highly overabundant comparing with those of the neighboring atoms (Ce and Nd), although Eu is *normally* enhanced and holds the odd–even rule. Thus, Eu is not selectively overabundant on HR 6958. This seems to be specific to HR 6958 (generally, to silicon stars) when compared with the mean abundances of cool magnetic CP stars (Adelman 1973; Adelman, Cowley 1986).

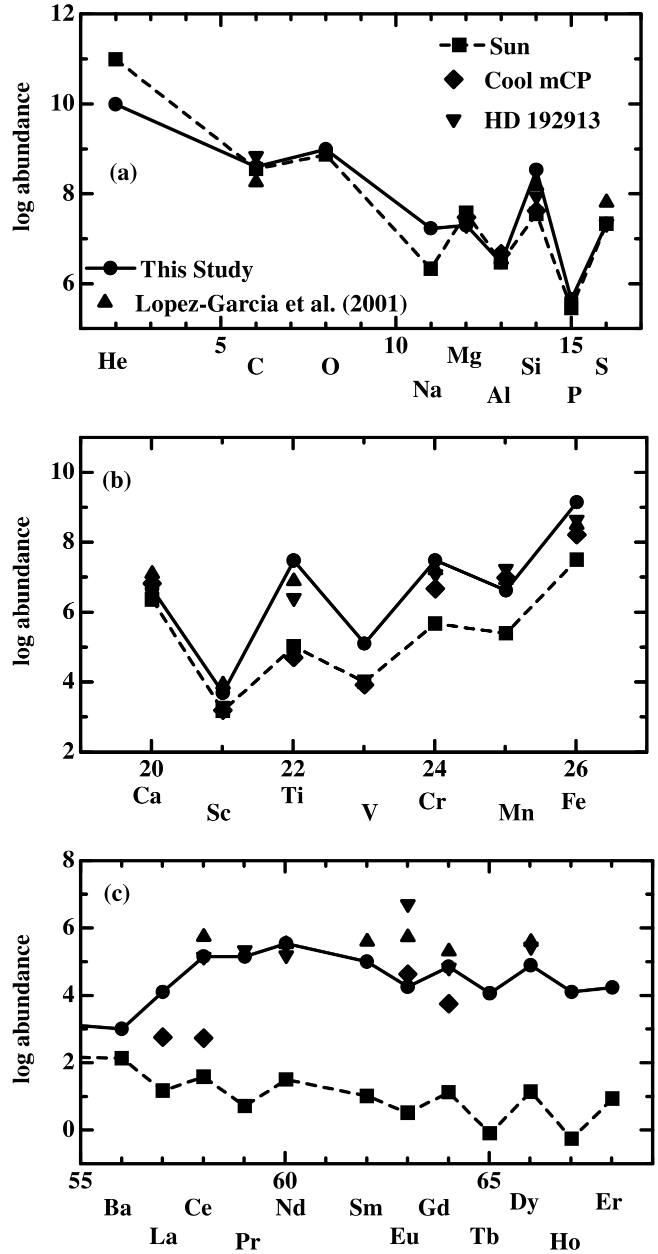

Fig. 2. Abundances of HR 6958 for (a) light elements, (b) iron group elements, and (c) Ba and rare earths, compared to the result of López-García et al. (2001) for HR 6958, the solar abundances (Grevesse et al. 1996), and the abundances of cool magnetic CP stars (Adelman 1973; Adelman, Cowley 1986) and the silicon star HD 192913 (López-García, Adelman 1999).

5. Results and Discussion

Table 2 and figure 2 present the abundances obtained in this analysis with those of López-García et al. (2001) for HR 6958,

[3] ⟨http://physics.nist.gov/PhysRefData/contents-atomic.html⟩.

together with abundances of the Sun, cool CP2 stars, and Si stars.

When comparing the abundances in this study with those of López-García et al. (2001), Ti II, Cr II, and Fe II (for which a fairly large number of lines are available in the abundance computation) show clearly large discrepancies of more than 0.3 dex. This result reflects the disagreement concerning the equivalent widths noted in section 2. However, the abundances of rare earths in this study are systematically lower than their results.

Compared with the Sun, light elements are mostly of solar abundances, except for He, Na, and Si. An interesting feature of light elements is an underabundance of magnesium. Leone et al. (1997) showed that the magnesium abundance tends to be lower in peculiar stars, especially in silicon stars; magnesium is obviously less abundant than that of main-sequence stars (figures 1 and 2 in their paper). HR 6958 seems to be a typical star with a lower magnesium abundance. Ca and Sc are subsolar, while other iron group elements are on the order of 10-times overabundant, except for Ti, which has 300-times solar abundance. Sr and Zr are on the order of 100-times solar abundances. As shown in figure 2c, there is a clear gap in the abundance between Ba and rare earths. Ba is not so enhanced, while rare earths show fairly large excess, and preserve the odd–even rule. These features mark HR 6958 as a Si star (Jaschek, Jaschek 1971; Jaschek, Jaschek 1987).

When compared with the mean abundances of cool magnetic CP stars, there are a few disagreements in the abundances for Si, Ti, Fe, Sr, and Ce.

HR 5049 ($T_{\rm eff} = 10300$ K, $\log g = 3.81$) is a B-type magnetic CP star with a strong magnetic field of 4.7 kG. The atmospheric parameters are similar to those of HR 6958 ($T_{\rm eff} = 10750$ K, $\log g = 3.5$). Recently, Nishimura et al. (2003) have studied the chemical composition of HR 5049 based on the spectra taken at the European Southern Observatory, and revealed the extreme deficiency of He and the overabundances of Cl, Co, and rare earths. Since Cl and Co lines of HR 6958 are very weak, it was impossible to detect their lines. On the other hand, Si and Ti of HR 6958 are enhanced more than those of HR 5049.

Table 2 compares the final abundances of HR 6958 with those of three silicon stars: HR 2258 (= HD 43819; $T_{\rm eff} = 11300$ K, $\log g = 3.20$; López-García, Adelman 1994), HR 5597 (= HD 133029; $T_{\rm eff} = 11200$ K, $\log g = 3.84$; López-García, Adelman 1999), and HD 192913 ($T_{\rm eff} = 10900$ K, $\log g = 3.40$; López-García, Adelman 1999). The agreement between HR 6968 with these stars is quite good. The exception is Ti II, whose abundance in our analysis is greater by 1 dex than that of the three silicon stars. The abundance pattern of HR 6958 is very similar to that of HD 192913, except for Eu, which is extremely enhanced by 6.20 dex compared to the Sun in HD 192913. Since the model parameters of both stars closely resemble each other, the abundance pattern supports HR 6958 to be a silicon star.

Recently, Dolk et al. (2002) and Nishimura et al. (2003) have shown that the abundance ratio between Nd and Pr in CP stars (Hg-Mn stars, Am stars, and CP2 stars) decreases linearly with the effective temperature. It is interesting to know that the logarithmic abundance ratio of $+0.24$ dex (the abundance difference between Nd III and Pr III) for HR 6958 is just on the sequence.

After determining the final abundances, we retried to synthesize the spectrum. In spite of such an effort, a total of 303 lines remained unidentified. The rate of the unidentified lines with respect to the total measurable lines is about 20%, which is fairly greater than the rate of 7% for the case of the cool magnetic CP star HR 7575 (Kato, Sadakane 1999). One half of the unidentified lines have candidates (most of them are lines of singly ionized rare earths and iron group elements), but are too weak to reproduce the observed line features. Although about 70% of the unidentified lines can be seen in the spectrum of the cool magnetic CP star 10 Aql ($T_{\rm eff} = 7750$ K, $\log g = 4.0$; Ryabchikova et al. 2000), only about 40% of them are presented in the spectrum of the hot magnetic CP star α^2 CVn, whose effective temperature ($T_{\rm eff} = 10410$ K; Sokolov 1998) closely resembles that of HR 6958. This implies that most of the unidentified lines can be attributed to some atoms abundant both in HR 6958 and in 10 Aql but less in α^2 CVn than in HR 6958. To identify these unknown elements and lines, more accurate atomic line data are desirable.

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