

## THE MAGNETIC FIELDS OF THE HELIUM-WEAK B STARS

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### ABSTRACT

We have carried out a survey of magnetic fields in 30 helium-weak B stars, one horizontal-branch B star, and one sdOB star. Typical measurement errors for the He-weak stars are in the range of 100–400 gauss, and fields have been detected or confirmed in 12 stars, nine of which are known to belong to the Si and Sr–Ti He-weak spectroscopic subclasses. He-weak stars of these subclasses thus share with Ap stars and the He-strong stars the property of commonly showing detectable magnetic fields. However, our observations are consistent with the view that the P–Ga He-weak stars are hotter analogs of the (nonmagnetic) Hg–Mn Ap stars, since none of the four P–Ga stars observed show detectable fields. The fraction of He-weak stars showing large fields ( $\langle B_l^2 \rangle^{1/2} > 1$  kilogauss) appears to be larger than for Ap stars but smaller than for He-strong stars.

*Subject headings:* stars: abundances — stars: early-type — stars: magnetic — stars: peculiar A

### I. INTRODUCTION

The helium-weak stars are a class (or possibly several classes) of B stars that when examined spectroscopically at classification dispersion show approximately normal metal line strengths, but have helium lines that are too weak for the photospheric temperatures inferred from intrinsic photometric colors and hydrogen line profiles (Molnar 1972; Jaschek and Jaschek 1974, 1981; Baschek 1975). He-weak stars are thus morphologically similar to the silicon and mercury-manganese peculiar B stars, with which they share the characteristics of anomalously weak helium lines and slow rotation, although they lack the distinctive strong metal lines of the two latter classes. This spectroscopic similarity has led to the supposition that the He-weak stars form a hot continuation of the classical A and B peculiar stars.

This point of view is supported by fine abundance analyses of a number of He-weak stars. At high dispersion, abnormal abundances are found for several elements. It appears that the anomalies vary strongly from star to star, and that the He-weak stars do not form a homogeneous class. Three general subclasses of abundance peculiarities have been identified: a group having overabundance of silicon, which includes 20 Psc, 3 Sco, and HD 144334; a group characterized by strongly

overabundant phosphorus and gallium, which includes  $\iota$  Ori B and 3 Cen A; and a group with strongly overabundant titanium and strontium, which includes  $\alpha$  Scl, HD 37058, and HD 168733 (Norris 1971*a*; Jaschek and Jaschek 1974; Baschek 1975; Little 1974). These classes may not be entirely distinct; for example, lines of P are observed in the Ti–Sr stars  $\alpha$  Scl and HD 37058.

Evidence of a relationship between He-weak and other Ap and Bp stars is also found in spectral and photometric variations observed in some He-weak stars, particularly among stars of the Si and Ti–Sr groups, which suggests that these groups are related to the Si Ap stars. Thus, for example, the Ti–Sr star  $\alpha$  Scl is found to be photometrically variable in the ultraviolet (Bernacca and Molnar 1972), and the Si star 3 Sco exhibits helium line-strength variations (Pedersen and Thomsen 1977). The unique star  $\alpha$  Cen varies in helium line strength between anomalously weak and anomalously strong helium lines, but shows no other abundance peculiarities or obvious spectral variability. On the other hand, variations are weak or not detected in such P–Ga stars as 3 Cen A.

Magnetic fields have previously been detected in a few He-weak stars, which also strengthens the link with the magnetic Si Ap stars. A first search for magnetic fields was carried out by Sargent, Sargent, and Strittmatter (1967), who reported a field of 2.5 kilogauss in HD 37058 and 1.4 kilogauss in HD 36629, on the

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basis of one Zeeman-analyzed plate of each star. However, a more extensive study of these two stars and two other He-weak stars by Conti (1970) did not provide conclusive evidence for fields in any of the four stars studied, although  $2\sigma$  detections of fields of a little over 1 kilogauss were reported for both HD 36629 and HD 37058. More recently, the He-weak stars HD 175362 (Wolff and Wolff 1976) and 3 Sco (Landstreet, Borra, and Fontaine 1979) have been conclusively shown to have variable longitudinal fields ranging up to several kilogauss, while a Cen (Wolff and Morrison 1974) and HD 168733 (Jones and Wolff 1974) are reported to have fields of the order of 1 kilogauss.

The He-weak stars have unreddened photometric colors that place them in the effective temperature interval corresponding to spectral types B6–B2.5 V. They thus overlap in temperature only the very hottest Si-type Ap stars, such as HD 34452 and HD 215441. They are not found at temperatures as high as those of the He-strong stars, which all cluster at colors corresponding to spectral types B1–B2.5; the He-strong anomaly thus forms an upper bound to the He-weak anomaly. One star, a Cen, appears to cross the gap; it varies in spectral appearance between He-weak and He-strong. Most (but not all) He-strong stars are known to be magnetic (Landstreet and Borra 1978; Borra and Landstreet 1979).

In an effort to clarify the relationship of the He-weak stars to other peculiar upper main-sequence stars, and perhaps to shed some light on the nature of the various subclasses, we have carried out a survey of He-weak stars for magnetic fields. We have chosen to observe a fairly large number of stars (32), so we have been able, in general, to obtain only a few observations (typically four or five) per star. This is usually only enough to indicate whether or not a star has a detectable field, and in most cases we can say rather little about the amplitude of fields detected in individual stars or about possible periods of variation. We have, however, observed the known magnetic He-weak stars a Cen and HD 175362 through their full magnetic cycles to confirm the existence of the fields and to establish the shapes and amplitudes of the magnetic curves as observed with a Balmer-line Zeeman analyzer (both stars were originally found to be magnetic by photographic Zeeman analysis), and we have derived more or less unique magnetic curves for five of the newly discovered magnetic stars.

## II. OBSERVATIONS

All the magnetic observations reported in this paper were obtained using the University of Western Ontario photoelectric Pockels cell polarimeter, which is similar to the one described by Angel and Landstreet (1970), as an  $H\beta$  Zeeman analyzer. Observations were obtained both on the 2.5 m telescope of Las Campanas Observa-

tory (all Julian dates after 2,443,730) and the 1.5 m telescope of Palomar Observatory (all earlier dates). Circular polarization measurements were made using 5 Å HPBW  $H\beta$  filters, which were both set on either the short or the long wavelength wings of the line. In observations prior to JD 2,444,000, the filters were set at  $\pm 4.5$  Å from line center; for later observations they were set at  $\pm 3.6$  Å from line center. Integration of typically 10 minutes duration were obtained alternately in the short and long wavelength line wings, with a complete observation of a star lasting  $\sim 1$  hr (for observations at Las Campanas Observatory) or 2 hr (observations at Palomar Observatory). Integrations on a single line wing were averaged to give net normalized  $V_s/I$  and  $V_l/I$ , and then these values were combined to give  $\langle V/I \rangle = (V_l - V_s)/2I$ . Finally,  $\langle V/I \rangle$  was converted to longitudinal magnetic field values  $B_l$  using the relationship  $\langle V/I \rangle = 4.67 \times 10^{-13} B_l \lambda^2 (dI/d\lambda) I^{-1}$ , where  $I(\lambda)$  is the observed line profile of  $H\beta$  as a function of wavelength  $\lambda$ , as discussed by Borra and Landstreet (1977, 1979, 1980) and Landstreet (1982).

Line profiles were observed for most of the stars of our sample measured at  $\pm 4.5$  Å, and for all the stars observed at  $\pm 3.6$  Å, by using the polarimeter as a two-channel photoelectric scanner, holding one filter fixed while setting the other to a series of different wavelengths through the  $H\beta$  line. Using the observed values of  $(dI/d\lambda) I^{-1}$  to determine the conversion constant  $\gamma$  between observed polarization and inferred longitudinal field strength ( $B_l = \gamma \langle V/I \rangle$ ), we find that at  $\pm 4.5$  Å,  $\gamma$  ranges in our sample from 14.0 to 19.7 kilogauss per percent circular polarization (kG/%). The mean  $\gamma$  over the sample is 16.5 kG/%, with a dispersion (standard deviation) of  $\pm 1.6$  kG/%. At  $\pm 3.6$  Å, the range, mean, and standard deviation are 13.4–17.6, 14.7, and 1.2 kG/%, respectively. The value of  $\gamma$  does not vary in any obvious systematic fashion with either effective temperature (determined from unreddened colors), or with projected rotational velocity (which is less than  $\sim 200$  km s $^{-1}$  for all the stars observed, and is thus substantially smaller than the filter bandwidth in every case). For this reason, we assume  $\gamma = 16.5$  kG/% for all the observations at  $\pm 4.5$  Å for which we have no empirical value available. Since this mean differs from the observed extremes by less than  $\pm 20\%$ , it is probably accurate in almost all cases to within perhaps  $\pm 15\%$ .

Many of our observations of He-weak stars were made during the same observing runs on which the observations of classical magnetic Ap stars discussed by Borra and Landstreet (1980) were obtained. The present observations are thus securely tied into a standard system of calibrations.

The sample of stars to be observed was chosen from stars reported in the literature to be He-weak, and those actually observed were selected from available candidates mainly by brightness and suitable coordinates for

observation during the observing runs devoted to this project. The sample is thus in no way homogeneous; some of the stars observed are very well known and extensively studied He-weak stars, while almost nothing is known about others. The present survey is essentially exploratory.

The stars observed are listed in Table 1, and the individual magnetic measurements are in Table 2. The first two columns of Table 1 list the HD number and constellation name or HR catalog number for each star in the observed sample. A photometric spectral type is given for each star with observed  $UBV$  colors, obtained by dereddening the observed colors back to the main sequence in the  $U-B$ ,  $B-V$  diagram in the standard way. (MK spectral types for these stars, which rely heavily on He line strengths, may be quite misleading). These tabulated spectral types should give reasonable indications of the stellar effective temperatures. The principal spectral peculiarities (other than He weakness) are given for the stars for which they are available or

may be inferred, following the scheme outlined in the Introduction.

Projected rotational velocities are given for those stars for which reliable values are available. The catalog of Uesugi (1976) provided valuable bibliographic guidance to  $v \sin i$  values obtained in surveys such as those of Slettebak (1968), Levato and Mallaroda (1970), and Balona (1975a). However, we found in comparing the  $v \sin i$  values derived from such surveys (usually based on the width of strong He lines observed at  $\sim 40 \text{ \AA mm}^{-1}$ ) with  $v \sin i$  values derived from high-dispersion material that occasional glaring discrepancies occurred. The worst discrepancies involved HD 144844, with  $v \sin i \leq 20 \text{ km s}^{-1}$  according to Norris (1971a) and Hartoog (1977) but  $180 \text{ km s}^{-1}$  according to Slettebak (1969), and HD 175362, with  $v \sin i = 35 \text{ km s}^{-1}$  according to Balona (1975b) or  $28 \text{ km s}^{-1}$  according to Wolff and Wolff (1976), but  $v \sin i = 218 \text{ km s}^{-1}$  according to Balona (1975a). In such cases, the problem appears to have arisen because the star is classified from

TABLE 1  
HELIUM-WEAK STARS OBSERVED FOR MAGNETIC FIELDS

HD (1)	Name (2)	Sp( $UBV$ ) (3)	Spectral Peculiarities (4)	$v \sin i$ ( $\text{km s}^{-1}$ ) (5)	$P$ (d) (6)	$n$ (7)	$\langle B_l^2 \rangle^{1/2}$ (G) (8)	$\langle \sigma^2 \rangle^{1/2}$ (G) (9)	$\chi^2/n$ (10)	Association (11)
5737	..... $\alpha$ Scl	B5	SrTi	15	19?	7	246	129	5.18 <sup>a</sup>	
19400	.... $\theta$ Hyi	B6	...	...	...	4	198	157	1.46	
22470	.... 20 Eri	B6	Si	80	0.68 or 1.94	12	743	168	20.80 <sup>a</sup>	
22920	.... 22 Eri	B5	Si	...	...	4	295	159	3.79 <sup>a</sup>	
28843	.... HR 1441	B5	Si	...	1.37	5	344	239	2.59	
36916	.... ...	B4	Si	100	...	2	628	178	12.62 <sup>a</sup>	Ori
37043B	... $\iota$ Ori B		PGa	0	...	1	310	720	0.19	Ori
37058	.... ...	B2.5	SrTi	0	14.61	3	727	317	5.33 <sup>a</sup>	Ori
37129	.... ...	B2.5	normal	35	NV	1	15	280	0.00	Ori
49333	.... 12 CMa	B4	...	...	2.18	2	534	320	3.05	2287
79158	.... 36 Lyn	B7	SrTi	45	...	2	952	307	8.06 <sup>a</sup>	
109026	... $\gamma$ Mus	B4	...	(180)	NV	5	342	95	14.30 <sup>a</sup>	Sco
120709	... 3 Cen A	B4	PGa	$\leq 3$	NV	4	135	104	1.47	Sco
125823	... a Cen	B2.5	Si	18	8.82	9	328	96	11.92 <sup>a</sup>	Sco
131120	... HR 5543	B2.5	Si	...	...	4	106	168	0.39	
142301	... 3 Sco	B3-4	Si	80	1.46	20	2103	420	30.01 <sup>a</sup>	Sco
142884	.... ...	B5	Si	$> 100$	...	4	285	279	1.31	Sco
142990	... HR 5942	B3	...	(150)	0.49 or 0.98	14	1393	258	42.21 <sup>a</sup>	Sco
143699	... HR 5967	B4	...	(210)	NV	4	167	140	1.45	
144334	... HR 5988	B4	Si	65	3.61	12	783	258	13.14 <sup>a</sup>	Sco
144661	... HR 5998	B4	PGa	40	NV	5	542	319	1.54	Sco
144844	... HR 6003	B5	PGa	20:	...	4	318	266	2.13	Sco
145501	... $\nu$ Sco CD	B4:	...	...	...	4	1387	203	47.28 <sup>a</sup>	Sco
146001	... HR 6054	B6	...	...	(NV)	5	647	382	1.62	Sco
151346	.... ...	B4:	...	$\leq 20$	...	1	245	495	0.24	Sco
162374	... HR 6647	B3	Si	40	1.66?	5	270	280	1.00	6475
175156	... HR 7119	B4:	SrTi	...	...	8	136	116	1.57	Sco
175362	... HR 7129	B2.5	SrTi	28	3.67	12	3918	216	333.50 <sup>a</sup>	Sco
202671	... 30 Cap	B6	SrTi?	25	...	4	183	148	1.44	
224926	... 29 Psc	B5-6	Si?	65	NV	4	47	169	0.10	
.....	..... Feige 86	HB-B	PGa	$\leq 12$	...	1	100	2800	0.00	
149382	.... ...	sdOB	...	$\leq 10$	...	1	300	2900	0.01	

<sup>a</sup>Almost certainly magnetic.

TABLE 2  
MAGNETIC FIELD MEASUREMENTS

JD (2,440,000+)	$B_l \pm \sigma_B$ (G)	Phase	JD (2,440,000+)	$B_l \pm \sigma_B$ (G)	Phase
HD 5737 = $\alpha$ Scl (16.5)/-			HD 37129 -/15.7		
3710.956	$340 \pm 155$	0.000	5308.738	$+15 \pm 280$	...
3712.959	$255 \pm 215$	0.104	HD 49333 = 12 CMa 14.7/13.4		
3733.835	$-70 \pm 100$	0.182	3563.777	$+700 \pm 425$	...
3734.849	$-150 \pm 95$	0.235	5066.520	$+285 \pm 155$	...
3739.784	$-375 \pm 85$	0.490	HD 79158 = 36 Lyn (16.5)/-		
3741.837	$-20 \pm 100$	0.596	3650.699	$-290 \pm 270$	...
3744.801	$+275 \pm 100$	0.749	3651.698	$-1315 \pm 340$	...
HD 19400 = $\theta$ Hyi (14.4)/13.0			HD 109026 = $\gamma$ Mus 16.4/15.5		
3733.885	$+15 \pm 145$	...	3510.844	$+330 \pm 100$	...
3734.898	$-255 \pm 155$	...	3511.834	$+390 \pm 80$	...
3739.830	$+165 \pm 145$	...	4773.532	$+290 \pm 105$	...
5296.615	$+280 \pm 180$	...	4775.491	$+470 \pm 90$	...
HD 22470 -/14.9			5065.695	$+140 \pm 100$	...
5297.581	$-1170 \pm 160$	...	HD 120709 = 3 Cen A 14.0/13.7		
5298.593	$+1120 \pm 165$	...	3739.482	$-90 \pm 95$	...
5299.578	$-1120 \pm 160$	...	3742.481	$+15 \pm 95$	...
5299.845	$+740 \pm 175$	...	4773.595	$-205 \pm 125$	...
5300.549	$+990 \pm 170$	...	4775.525	$+150 \pm 100$	...
5300.750	$+145 \pm 170$	...	HD 125823 = a Cen (16.5)/-		
5304.534	$+690 \pm 160$	...	3733.545	$-430 \pm 90$	0.000
5305.525	$-175 \pm 165$	...	3734.542	$-445 \pm 90$	0.113
5306.537	$+95 \pm 185$	...	3735.531	$-180 \pm 95$	0.225
5307.572	$+70 \pm 175$	...	3736.526	$+315 \pm 95$	0.338
5308.533	$-100 \pm 170$	...	3737.544	$+365 \pm 100$	0.453
5309.536	$+820 \pm 155$	...	3738.534	$+375 \pm 100$	0.566
HD 22920 = 22 Eri (16.5)/-			3739.526	$+170 \pm 100$	0.678
3736.887	$+380 \pm 140$	...	3740.482	$-75 \pm 90$	0.787
3737.876	$+200 \pm 120$	...	3741.492	$-380 \pm 100$	0.901
3738.846	$+185 \pm 185$	...	HD 131120 = HR 5543 16.7/15.8		
3740.863	$+360 \pm 180$	...	4774.506	$+45 \pm 155$	...
HD 28843 = HR 1441 17.2/15.3			4776.568	$-45 \pm 180$	...
3441.823	$-65 \pm 330$	...	4778.479	$+190 \pm 170$	...
3739.874	$+170 \pm 205$	...	4779.506	$+70 \pm 165$	...
3740.902	$-405 \pm 205$	...	HD 142884 16.3/14.8		
5305.573	$-570 \pm 220$	...	4326.899	$+315 \pm 345$	...
5306.572	$+265 \pm 210$	...	4329.867	$+250 \pm 165$	...
HD 36916 15.8/13.8			4332.774	$+195 \pm 180$	...
4328.536	$-640 \pm 190$	...	4421.732	$+355 \pm 365$	...
4331.526	$-615 \pm 165$	...	HD 142990 = HR 5942 17.9/17.6		
HD 37043B = $\iota$ Ori B 18.0/-			3563.026	$-1490 \pm 300$	0.000
3442.843	$+310 \pm 720$	...	3564.021	$-2450 \pm 300$	0.017
HD 37058 -/16.0			3648.882	$+110 \pm 340$	0.749
5305.802	$-210 \pm 320$	...	3708.707	$-870 \pm 310$	0.893
5308.666	$-880 \pm 305$	...			
5309.660	$-875 \pm 325$	...			

TABLE 2—Continued

JD (2,440,000+)	$B_I \pm \sigma_B$ (G)	Phase	JD (2,440,000+)	$B_I \pm \sigma_B$ (G)	Phase
HD 142990 = HR 5942 17.9/17.6 ( <i>cont.</i> )			HD 146001 = HR 6-54 19.3/- ( <i>cont.</i> )		
3709.707	-1440 ± 300	0.915	3737.590	-165 ± 255	...
3711.703	-1180 ± 320	0.955	3741.536	-210 ± 255	...
3742.575	+650 ± 160	0.507	HD 151346 16.0/15.1		
3743.539	+500 ± 300	0.493	5070.821 ..... +245 ± 495 ...		
5070.696	-1160 ± 250	0.907	HD 162374 = HR 6647 (16.5)/-		
5070.778	-1415 ± 245	0.991	2613.751	+245 ± 360	...
5070.895	-1500 ± 145	0.111	3710.782	+415 ± 385	...
5071.708	-1355 ± 205	0.942	3734.721	+315 ± 205	...
5071.852	-1750 ± 170	0.089	3735.682	+100 ± 205	...
5073.759	-1880 ± 170	0.038	3741.675	-150 ± 170	...
HD 143699 = HR 5967 16.1/14.5			HD 175156 = HR 7119 15.2/13.8		
3739.625	-240 ± 125	...	3737.678	+115 ± 130	...
3740.637	-45 ± 135	...	3738.673	-300 ± 105	...
3741.627	-90 ± 120	...	3739.669	+115 ± 125	...
4785.483	-210 ± 175	...	4774.846	+10 ± 105	...
HD 144334 = HR 5988 19.7/15.1			4777.879	+5 ± 110	...
3703.726	-1400 ± 450	0.000	4778.864	+95 ± 105	...
3707.695	-190 ± 440	0.099	4780.871	+45 ± 140	...
3735.584	-1060 ± 230	0.825	4783.867	-145 ± 105	...
3736.575	-620 ± 230	0.099	HD 175362 = HR 7129 (16.5)/(15.0)		
3740.535	+270 ± 200	0.196	3733.655	-4880 ± 215	0.071
3742.523	-680 ± 230	0.747	3734.644	+1460 ± 215	0.340
5070.741	-770 ± 170	0.675	3735.721	+1490 ± 215	0.633
5071.748	-1165 ± 175	0.953	3736.693	-6465 ± 215	0.898
5071.899	-1045 ± 170	0.995	3737.711	-3320 ± 215	0.175
5072.715	+140 ± 165	0.221	3738.718	+4310 ± 215	0.449
5072.907	+500 ± 220	0.275	3738.746	+4810 ± 210	0.457
5073.905	+100 ± 195	0.551	3739.707	-2600 ± 215	0.718
HD 144661 = HR 5998 15.8/13.1			3740.690	-5640 ± 215	0.986
3704.704	+1130 ± 440	...	3741.721	-170 ± 210	0.266
3706.698	-430 ± 450	...	3742.737	+4595 ± 215	0.543
3741.582	+25 ± 225	...	4330.870	+1325 ± 235	0.623
4332.863	-30 ± 150	...	HD 202671 = 30 Cap (16.5)/-		
4336.872	-75 ± 195	...	3735.756	-270 ± 160	...
HD 144844 = HR 6003 (16.5)/-			3736.732	-20 ± 140	...
3705.700	-290 ± 400	...	3737.752	+100 ± 145	...
3739.576	+475 ± 200	...	3740.732	-225 ± 145	...
3740.593	+290 ± 200	...	HD 224926 = 29 Psc (16.5)/-		
3742.623	+105 ± 205	...	3707.963	+45 ± 235	...
HD 145501 = $\nu$ Sco CD 15.3/14.6			3735.799	-70 ± 140	...
4774.691	-1420 ± 200	...	3736.783	+20 ± 140	...
4776.707	-1190 ± 210	...	3741.754	-40 ± 140	...
4778.580	-1440 ± 200	...	Feige 86 19.7/-		
4779.698	-1480 ± 200	...	3562.853	+100 ± 2800	...
HD 146001 = HR 6054 19.3/-			HD 149382 30.3/-		
3706.782	+1315 ± 565	...	3561.032	-300 ± 2900	...
3710.700	+525 ± 455	...			
3735.636	-135 ± 270	...			

its low-dispersion spectrum as B7 or B8, while it is actually a star with a temperature appropriate for a B5 star. Furthermore, it probably has regions of very low helium abundance and others of roughly normal helium. The result is that the normal helium abundance regions contribute absorption with strong damping wings to the integrated helium line profiles, while the helium-poor regions contribute little absorption at all. The star thus looks like a later spectral type than is appropriate for its effective temperature, but its helium lines are intrinsically anomalously broad for the assigned temperature, which at low dispersion is attributed to a substantial projected rotation velocity. Such anomalous line profiles are found, for example, in 3 Sco, for which they have been discussed by Norris and Strittmatter (1975). For stars for which the assigned MK spectral type is B6 or earlier and for which both low- and high-dispersion  $v \sin i$  values are available ( $\iota$  Ori B, 3 Cen A, a Cen, and HD 162374) this problem seems not to arise. For this reason, we have entered in Table 1 only  $v \sin i$  values determined from high-dispersion observations of metal lines, or from low-dispersion observations in which the assigned MK spectral class is B6 or earlier and is within two subclasses of the spectral type corresponding to the unreddened colors. Values of  $v \sin i$  based only on low-resolution helium line observations are enclosed in parentheses.

Periods of variation are tabulated for stars known to be photometric, spectrum, or magnetic variables. Many of these periods have been found from photoelectric Strömgen photometry or He  $\lambda 4026$  measurements made by Pedersen and Thomsen (1977) or Pedersen (1979). Stars observed by these authors for which no helium variability was found, and for which no other strong evidence for variability is available, are noted in the table as "NV."

The next four columns summarize the magnetic observations of Table 2. The number  $n$  of measurements is given, followed by the observed rms field strength ( $B_{li}$  is the  $i$ th observed value of  $B_l$ , from Table 2)

$$\langle B_l^2 \rangle^{1/2} = \left( \frac{1}{n} \sum_{i=1}^n B_{li}^2 \right)^{1/2},$$

the rms standard error ( $\sigma_{B_l}$  is the standard error of  $B_{li}$ )

$$\langle \sigma^2 \rangle^{1/2} = \left( \frac{1}{n} \sum_{i=1}^n \sigma_{B_{li}}^2 \right)^{1/2},$$

and the value of  $\chi^2/n$ , where

$$\chi^2/n = \frac{1}{n} \sum_{i=1}^n \left( \frac{B_{li}}{\sigma_{B_{li}}} \right)^2.$$

The value of  $\chi^2/n$  is used to test the hypothesis that the observed field strength values  $B_l$  for a given star are large enough that they are unlikely to be produced simply by photon shot noise; the stars for which  $\chi^2$  exceeds the value expected for  $n$  degrees of freedom at the 99% confidence level are considered to be almost certainly magnetic and are noted in column (10). For these magnetic stars, the value of  $\langle B_l^2 \rangle^{1/2}$  (when it is substantially larger than  $\langle \sigma^2 \rangle^{1/2}$ ) gives an estimate of the amplitude of the field present that is useful for stars for which we do not yet have enough data to construct full magnetic curves. For completeness, we include in Table 1 (but not in Table 2) a summary of the photoelectric magnetic measurements of 3 Sco obtained by Landstreet, Borra, and Fontaine (1979); the table thus lists all the known He-weak magnetic stars except HD 168733.

A final column notes membership in an OB association; Ori refers to Ori OB1, Sco refers to Sco OB2, and numerals are NGC numbers.

Table 2 lists next to the name of each star the values of  $\gamma$  determined for that star from line profile scans, with the notation  $\gamma(\pm 4.5 \text{ \AA})/\gamma(\pm 3.6 \text{ \AA})$ . A dash indicates no measured value; a number in parenthesis is an assumed value as discussed above. The units of  $\gamma$  are kG/% polarization. We then list the Julian Date of mid-observation and the measured longitudinal field with its standard error (from counting statistics) for each individual magnetic observation. In a few cases periods are well enough known to permit construction of magnetic curves. In these cases, the phases calculated are also tabulated in Table 2.

At the bottom of both tables we list observations of two stars perhaps distantly related to the main-sequence He-weak stars. These stars were observed once each on an experimental basis to see what sort of measurement precision could be obtained. Feige 86 is a horizontal-branch B9 star with  ${}^3\text{He}/{}^4\text{He} \approx 0.7$ ; HD 149382 is a sdOB star with a helium deficiency and a sulphur overabundance of a few times 10. Both were observed at the suggestion of Professor B. Baschek.

### III. INDIVIDUAL STARS

*HD 5737 =  $\alpha$  Scl.*—This star is the prototype of the Ti-Sr subclass of the He-weak stars discussed in the Introduction. Atmospheric analyses have been carried out by Norris (1971*a*), Schmitt (1972), and Vilhu (1972). It is characterized by an abundance of He that is about a factor of 10 low; roughly normal C, N, O, Ne, Mg, Al, Si, S, Ar, and Ca; P, Cl, Cr, Mn, and Fe overabundant by a factor of 10; and Sc, Ti, V, and Sr overabundant by a factor of  $10^2$  (Baschek 1973, 1975). According to A. Cowley (private communication) it shows excess  ${}^3\text{He}$ . Pedersen (1979) discovered that the strength of the  $\lambda 4026$  line of He varies and found a best-fit period to his observations of  $24^d \pm 2^d$ .

Our seven magnetic observations of this star include one field measurement at the  $4.3\sigma$  level and two measurements between  $2\sigma$  and  $3\sigma$ , and the  $\chi^2$  test rejects the hypothesis of zero field at the 99.9% confidence level. Observations of normal, nonmagnetic upper main-sequence stars by Landstreet (1982) indicate that zero-point errors of the Balmer-line Zeeman analyzer technique used here are reliably given by errors calculated from photon-counting statistics, although measurements of magnetic stars show some excess noise around mean magnetic curves over that calculated from counting statistics. We conclude from the large value of  $\chi^2/n$  that this star is very probably magnetic, even though the longitudinal field does not appear to rise much above 400 G.

We have analyzed our magnetic observations for periodic variations using both a power spectrum analysis and a least-squares sine-wave fitting procedure for all independent periods between  $300^d$  and  $0^d.45$ . In spite of the small number of magnetic observations, only a few periods are acceptable. The best fits to our data occur at periods of  $18^d.5 \pm 3^d$ ,  $1^d.052 \pm 0^d.008$ ,  $0^d.943 \pm 0^d.008$ ,  $0^d.539 \pm 0^d.002$ , and  $0^d.484 \pm 0^d.002$ . Since our best long period does not agree with that proposed by Pedersen (1979), we have subjected his data to the same analysis as our own. Pedersen's data yield best periods slightly, but significantly, different from ours at each of the periods for which good fits to both data sets can be found. The best compromise consistent with the low  $v \sin i$  appears to be a period of either  $19^d.4 \pm 1^d$  or  $16^d.7 \pm 0^d.5$ . Both periods fit our data quite well and give an acceptable, although not really good, fit to Pedersen's observations. For both periods the mean fields  $B_0$  are not far from zero, and the semi-amplitudes  $B_1$  are  $\sim 400$  G. To illustrate a possible magnetic curve, we show our data on a period of  $19^d.35$  in Figure 1. Other possible periods that satisfy both data sets are  $0^d.949 \pm 0^d.003$  and  $0^d.486 \pm 0^d.001$ . The question of the period of  $\alpha$  Scl can really only be settled by more observations. The nearly equal positive and negative field extremes observed could occur either because we view the star nearly from the

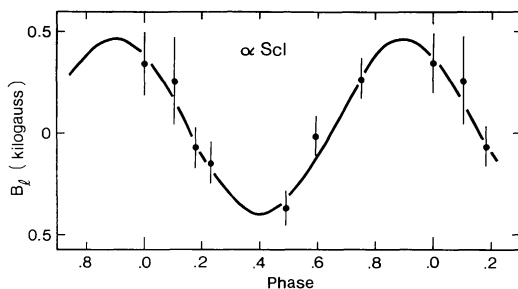


FIG. 1.—Magnetic observations of  $\alpha$  Scl phased with an assumed period of  $19^d.35$ . The first observation of Table 2 is arbitrarily taken as phase 0.0. Error bars show  $\pm 1\sigma$ . Smooth curve is the least-squares best-fit sine wave.

equatorial plane ( $i \approx 90^\circ$ ), or because the field axis is nearly perpendicular to the rotation axis ( $\beta \approx 90^\circ$ ). With the present uncertainty in period and  $v \sin i$  it is not possible to decide which of these conditions occurs.

*HD 19400 =  $\theta$  Hyi.*—This star has received little individual study since the discovery by Jaschek, Jaschek, and Arnal (1969) that its colors are too blue for its MK spectral type. It is not noticeably peculiar at classification dispersion. Four magnetic observations reveal no evidence of a magnetic field.

*HD 22470 = 20 Eri.*—This is another star that was found to have colors too blue for its MK spectral type by Jaschek, Jaschek, and Arnal (1969). Apart from a measurement of  $v \sin i$  by Abt, Chaffee, and Suffolk (1972), no high-dispersion observations of this star are known to us. Since it has been classified as a Si star in both the papers above, we tentatively assign it to the Si subclass of the He-weak stars.

Twelve magnetic observations reveal unambiguous evidence of a reversing field having extreme values of more than 1 kG. The magnetic data have been analyzed with our period-finding program for all periods between  $100^d$  and  $0^d.45$ . Two periods fit the data essentially equally well. A period of  $0^d.6785 \pm 0^d.0030$  corresponds to a magnetic curve with  $B_0 = 75 \pm 50$  and  $B_1 = 1150 \pm 50$  G; the data are roughly equally spaced along the magnetic curve, with  $\chi^2/\nu = 1.36$  ( $\nu =$  number of degrees of freedom  $= n - 3$ ). The data also fit a period of  $1^d.935 \pm 0^d.012$ , with  $B_0 = 115 \pm 50$  G,  $B_1 = 1650 \pm 200$  G, and  $\chi^2/\nu = 1.45$ ; if this period is correct, our observations sample mainly the rising the falling branches of the magnetic curve, so that the extrema are not well determined. No other acceptable periods occur in the interval considered.

The observed value of  $v \sin i$  does not enable us to discriminate between the periods. The star, at  $\text{Sp}(UBV) = B6$ , probably has  $1.75 \leq R \leq 3.5 R_\odot$ . If  $P = 0^d.6785$ , we find from  $\sin i = (Pv \sin i) (50.6R)^{-1}$  that  $i$  lies in the range  $18^\circ - 38^\circ$ ; then, using  $\tan \beta = \cot i(1-r)/(1+r)$ , where  $r = (|B_0| + B_1)/(|B_0| - B_1)^{-1}$  (Preston 1971), we find  $\beta = 87^\circ \pm 3^\circ$ . Alternatively, the longer period leads to  $i \geq 60^\circ$  (and  $R \geq 3.0 R_\odot$ ), in which case  $\beta$  can have any value substantially different from zero.

Since either period is possible, we show the magnetic data on both periods in Figure 2.

*HD 22920 = 22 Eri.*—Jaschek, Jaschek, and Arnal (1969) discovered that the colors of this star are too blue for its MK spectral type. It is classified as B9 IIIp Si  $\lambda 4200$  by Cowley (1972), and Cucchiari and Maccau-Hercot (1977) report that it is a Si star. It is listed as a Be star by Boyarchuk and Kopylov (1964), but a recent spectrogram of  $H\alpha$  obtained by P. K. Barker (private communication) shows no emission in 1981 October. Approximate atmospheric parameters for the star have been derived by Fischel and Klinglesmith (1973) from the last visible Balmer line and the equivalent width of

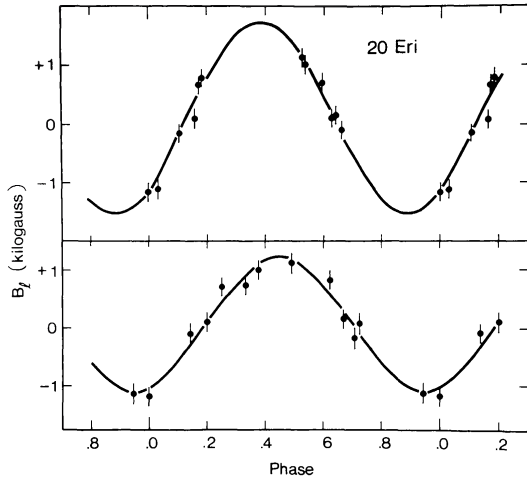


FIG. 2.—Magnetic observations of 20 Eri plotted with assumed periods of  $1^{\text{d}}935$  (upper panel) and  $0^{\text{d}}6785$  (lower panel). Symbols as in Fig. 1.

$H\gamma$ . Our four magnetic observations are all positive, with fields of  $1\sigma$  to  $2.7\sigma$ . The value of  $\chi^2/n$  strongly suggests (at the 99% level) the real presence of a field. Its strength is  $\sim +300$  G; the weighted mean of the four observations is  $B_0 = 276$  G, with an uncertainty of the mean of  $\sigma = (\sum_i \sigma_i^{-2})^{-1/2} = 74$  G, so that the mean value is nonzero at the  $3.7\sigma$  level. There is no evidence for any magnetic variability over the five-night interval covered by our measurements; the value of  $\chi^2/\nu$  (where  $\nu =$  number of degrees of freedom  $= n - 1$ ) for scatter of the observed field strengths about  $B_0$  is only 0.49. Presumably the star has a long period ( $\geq 30^{\text{d}}$ ), or the magnetic and rotation axes are closely aligned ( $\beta \approx 0^\circ$ ), or we view the star from near the rotational pole ( $i \approx 0^\circ$ ).

$HD\ 28834 = HR\ 1441$ .—This star was discovered to be He-weak by Jaschek, Jaschek, and Arnal (1969). Davis (1977) reports an overabundance of Si, which suggests that it probably belongs to the Si subclass. Pedersen and Thomsen (1977) and Pedersen (1979) find the He  $\lambda 4026$  line strength to be variable, with a period of  $1^{\text{d}}37375$ . Our five magnetic observations show rather marginal evidence of a magnetic field of up to  $\sim -600$  G. The value of  $\chi^2/n$ , which corresponds to  $\sim 97\%$  probability for a nonzero field, also hints at the presence of a field without clearly establishing that one is present. It is unlikely that the longitudinal field of this star (assuming from our observations and the spectrum variability that one is present) exceeds a few hundred gauss.

$HD\ 36916$ .—Abt and Levato (1977) classified this star as B9 IVp Si, but its colors, which correspond to an unreddened spectral class of B4, place it firmly among the He-weak stars. The only high-dispersion material available on the star seems to be a spectrogram obtained by Wolff (1981) for measurement of  $v \sin i$ . We provisionally consider the star to be a member of the Si subgroup on the basis of the MK classification. Both our measurements, three nights apart, reveal fields at the

$\sim 3.5\sigma$  level; the field is the same ( $\sim -600$  G) within errors in both observations. With  $v \sin i = 100$  km  $s^{-1}$  and  $R \leq 4 R_\odot$ , we have  $P < 50.6 R / (v \sin i) = 2^{\text{d}}0$ , so either we fortuitously observed the same phase twice, or the field is constant.

$HD\ 37043B = \iota\ Ori\ B$ .—This star is one of the prototypes of the P-Ga subclass of He-weak stars. Abundance analyses by Conti and Loonen (1970) and Norris (1971a) reveal strongly deficient He, nearly normal C, N, O, He, Mg, Al, Si, S, and Fe, and very strongly overabundant P and Ga. Dworetzky (1973) reports a very pronounced helium isotope anomaly, with  $^3\text{He}/^4\text{He} > 5$ . Spectrum variability is suspected by Norris (1971a), but this has not been established. Conti (1970) observed  $\iota\ Ori\ B$  photographically for a magnetic field but found no evidence for one in three observations with standard errors of  $\sim 600$  G. Our one observation has a very large standard error, due to the faintness of the star, but is consistent with no field being present.

$HD\ 37058$ .—Sharpless (1952) reported the anomalously weak helium lines in this Orion aggregate member. Abundance analyses have been carried out by Sievers (1969), who recognized that the large overabundances of Ti and Sr make this star similar to the much cooler  $\alpha\ Scl$ , and by Norris (1971a). Both authors find that abundances are approximately normal apart from very mild ( $\times 2$ ) He underabundance and the Sr-Ti overabundance. The star was found to be a helium spectrum variable by Pedersen and Thomsen (1977), and Pedersen (1979) has derived a period of  $14^{\text{d}}612 \pm 0^{\text{d}}075$ , consistent with the low values of  $v \sin i$  reported by McNamara and Larsson (1962) and Norris (1971a).

Magnetic observations of HD 37058 were first made by Sargent, Sargent, and Strittmatter (1966), who reported a field of  $+2500 \pm 450$  (s.d.) G on one Zeeman-analyzed plate. Five further observations by Conti (1970) with standard deviations of 600–900 G showed only marginal evidence for the presence of a field. All five measurements showed positive fields, with the largest value being  $+1300 \pm 600$  (s.d.) G, but the value of  $\chi^2/n$  for the five measurements is only 1.77.

Our data support the hypothesis that a field is present at about the 99.9% confidence level; two of the three photoelectric field measurements differ from zero by almost  $3\sigma$ . It seems very probable that HD 37058 is indeed magnetic, although this cannot be regarded as completely established by the data available. The fact that all five observations by Conti are of positive fields while all three of ours are negative poses no particular problem; using Pedersen's (1979) period it is found that all Conti's observations fall within a phase interval of  $\sim 0.55$ , while ours are confined to an interval of 0.26. Putting all available observations together, it appears likely that the positive field extremum is between 1200 and 2000 G, while the negative one may be  $\sim -1000$  G.

At B2.5, this star probably has  $R \geq 2.7 R_\odot$ . Assuming that  $v \sin i \leq 10$  km  $s^{-1}$ , we find  $\sin i = (Pv \sin i)$

$(50.5R)^{-1} \lesssim 1.07$ , so  $i$  could have any value substantially greater than zero (to produce field and spectrum variations). If the magnetic curve does indeed reverse, as we have inferred from somewhat inadequate data, then either  $i$  or  $\beta$  must be large (i.e., greater than  $\sim 50^\circ$ ).

*HD 37129*.—Like HD 37058, this star was reported by Sharpless (1952) to have anomalously weak helium lines. However, Norris (1971*a*) found that the abundances of all the elements studied, including He, are essentially normal, and he was unable to account for the original classification as a He-weak star. Molnar (1972) also concluded that the star is in fact normal. Pedersen and Thomsen (1977) found no evidence of He spectrum variability. It appears quite likely that this is indeed a normal B2 or B3 V star, not He-weak at all.

Our one magnetic observation, which shows no evidence of a field, is consistent with this view.

*HD 49333 = 12 CMA*.—This star was discovered by Jaschek, Jaschek, and Arnal (1969) to be He-weak. It has been found by Pedersen and Thomsen (1977) and Pedersen (1979) to show variability of the He  $\lambda 4026$  line with  $P = 2^d.1800$ . We have no information on its subclass type. Neither of our two magnetic observations reveal any clear evidence of the magnetic field suggested by the spectrum variability.

*HD 79158 = 36 Lyn*.—Some controversy surrounds the spectrum of this star. Cowley (1972) classified it as a B8 IIIp Mn star that is also He-weak, but neither Aikman (1976) nor Vilhu, Tuominen, and Boyarchuk (1976) find any evidence for the presence of Mn. Atmospheric abundance analyses have been carried out by Searle and Sargent (1964) and Vilhu, Tuominen, and Boyarchuk (1976); the latter authors find low He, normal C, Si, and Cr, and strongly overabundant Ti and Fe, and they conclude that the star is a member of the Sr–Ti subclass. One of our two magnetic observations shows a field at the  $3.8 \sigma$  level; the star is almost certainly magnetic.

*HD 109026 =  $\gamma$  Mus*.—Cayrel (1971) lists this star as He-weak. Six observations of the He  $\lambda 4026$  line over  $14^d$  by Pedersen and Thomsen (1977) show no evidence of variability. Three of our five magnetic observations show clear evidence of a field of  $\sim +400$  G at the  $3\text{--}5 \sigma$  level; the star is certainly magnetic. The weighted mean of the five observations is  $+337$  G, and only one of the five measurements deviates from this value by as much as  $2 \sigma$ . The value of  $\chi^2/\nu$  of the difference of single measurements from the mean is 1.68 ( $\nu = 4$ ), so that the hypothesis of a varying field is supported only at the 85% confidence level. The field may well be constant, or vary only with a small amplitude. The lack of either field or line-strength variations suggests that at least one of  $i$  or  $\beta$  is small.

*HD 120709 = 3 Cen A*.—Bidelman (1960) discovered the anomalous spectrum of this star; it was one of the first He-weak stars found. The spectrum has been studied by several authors (Hardorp 1966; Hardorp, Bidelman,

and Prölss 1968; Norris 1971*a*). The photosphere has deficiencies of He, C, and O, is normal in N, Ne, Mg, Si, Ar, Ca, and perhaps Fe, and has overabundances of Mn and especially P, Ga, and Kr.  $^3\text{He}$  is more abundant than  $^4\text{He}$  (Sargent and Jugaku 1961; Dworetzky 1973; Hartoog and Cowley 1979). Jaschek and Jaschek (1974) suggest that spectrum variations occur in P, but this has not been definitely established. Pedersen and Thomsen (1977) find no variation in He in nine observations spaced over  $14^d$ . Our four magnetic observations of this star, spread over 3 yr, are all of high precision ( $\sigma \approx 100$  G); they reveal no hint of a field.

*HD 125823 = a Cen*.—This star is a striking helium variable, ranging in helium spectral type from a He-rich B2 to B8 with a period of  $8^d.82$  (Jaschek, Jaschek, and Kucewicz 1968; Norris 1968). In fact, a Cen seems to be a transition object between the He-weak and He-rich stars, with unreddened colors just at the boundary between the two groups in the *UBV* color-color diagram. High-dispersion studies have been carried out by several authors (Norris 1971*b*; Underhill, KlingleSmith, and Frey 1973; Wolff and Morrison 1974), but no abundance analysis is available. The star has not been reported to show the distinctive abundance anomalies of either the P–Ga or Sr–Ti subgroups. Since members of these two subgroups occur that have virtually the same effective temperature as a Cen (19,200 K; Norris 1971*b*), and that do show the distinctive anomalies ( $\iota$  Ori B among the P–Ga stars, and HD 37058 and HD 175362 from the Sr–Ti stars), we conclude that a Cen is probably a member of the Si subgroup (although this subgroup may not be homogeneous, or indeed always Si-rich). Confirmation of this view comes from low-dispersion ultraviolet spectroscopy by Molnar (1974), who found silicon varying between normal and  $\sim 5$  times overabundant.

The period of helium variation has been discussed by several authors (Jaschek, Jaschek, and Kucewicz 1968; Norris 1968, 1971*b*; Wolff and Morrison 1974; Pedersen and Thomsen 1977). Norris (1971*b*) suggested that the period has not been constant, but Pedersen and Thomsen (1977) make a convincing case that the helium variations have occurred with constant period on the ephemeris:

$$\text{JD (He max)} = 2,442,807.75 + [8^d.8171(\pm 0^d.0003)] E. \quad (1)$$

Photographic magnetic observations of a Cen have been reported by Wolff and Morrison (1974). They find a field varying from a few hundred gauss positive to a few hundred gauss negative. Their individual magnetic observations are not accurate enough to make a very strong case for the presence of a field, but the magnetic observations define a fairly clear magnetic curve when plotted on the period of helium variation. Wolff and

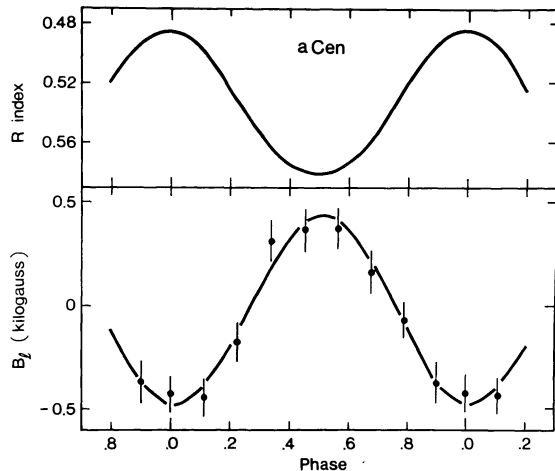


FIG. 3.—Magnetic observations (*lower panel*) and photoelectric measurements of the strength of He  $\lambda 4026$  (*upper panel*, Pedersen and Thomsen 1977; minimum  $R$ -index = maximum line strength) of a Cen plotted on the ephemeris given in the text. Symbols as in Fig. 1.

Morrison (1974) find that helium maximum coincides approximately with the negative field extremum.

Our magnetic observations cover one cycle of the helium variation. Our data clearly confirm the presence of a field and give a magnetic curve that agrees reasonably well with that of Wolff and Morrison (1974). Our observations are phased with equation (1) in Table 2 and plotted in Figure 3, where we also show the He  $\lambda 4026$  line strength variation reported by Pedersen and Thomsen (1977) (minimum  $R$ -index occurs for maximum He line strength). The negative magnetic extremum coincides closely in phase with the maximum helium strength.

The star has an unreddened spectral type of  $\sim B2.5$  and probably has a mass of  $\sim 10 M_{\odot}$ . From the measured  $\log g = 4.2$  (Norris 1971*b*), we infer a radius of  $R \approx (4.5 \pm 1) R_{\odot}$ , so that the equatorial velocity is  $v = 26 \pm 6 \text{ km s}^{-1}$ . With  $v \sin i = 18 \pm 5 \text{ km s}^{-1}$  (Wolff and Morrison 1974),  $i \geq 30^{\circ}$ . If the star is seen from an inclination  $i$  substantially different from  $90^{\circ}$  (say less than  $75^{\circ}$ ), the angle  $\beta$  between magnetic and rotation axes must be nearly  $90^{\circ}$  to produce such symmetrical field reversal. If the line of sight is quite near  $i = 90^{\circ}$ ,  $\beta$  is required to differ substantially from  $0^{\circ}$  (say,  $\beta \geq 20^{\circ}$ ) but is otherwise unconstrained.

It is notable that, although the field reverses nearly symmetrically and our view of each magnetic pole is much the same (either  $i \approx 90^{\circ}$  or  $\beta \approx 90^{\circ}$ ), only the positive magnetic pole shows a He-deficient cap. There is absolutely no trace of a secondary helium strength minimum associated with the negative magnetic pole, either in the photoelectric  $\lambda 4026$  line observations or in the helium spectral type variations (Pedersen and Thomsen 1977). The two magnetic poles are associated

with very different helium abundances. This result effectively rules out the two-cap or symmetric model of a Cen discussed by Mihalas (1973). It lends support to the single-cap or asymmetric model discussed by Norris and Baschek (1972) and by Mihalas (1973).

*HD 131120 = HR 5543.*—Spectral peculiarities similar to those found in 3 Sco and HD 144334 were first reported by Hiltner, Garrison, and Schild (1969). On the strength of this classification we tentatively assign the star to the Si subclass of the He-weak stars. It does not appear to have been studied at high dispersion or for He line variations. Our four magnetic observations, spaced over five nights, show no sign of a magnetic field.

*HD 142301 = 3 Sco.*—Spectroscopic observations of 3 Sco (first discovered to be He-weak by Garrison 1967) have been discussed by Norris (1971*a*) and by Norris and Strittmatter (1975). The star has weak helium lines with abnormal profiles, normal Mg and C, and  $\sim 60$  times overabundant Si. The distinctive lines of the P-Ga and Sr-Ti subgroups are not seen. The star is a helium spectrum variable (Pedersen and Thomsen 1977). The period and magnetic curve of 3 Sco have been discussed by Landstreet, Borra, and Fontaine (1979). In contrast to a Cen, regions of low helium abundance appear at both poles; more nearly normal helium abundance is found near the equator.

*HD 142884.*—Garrison (1967) classified this star as B9p (Si  $\lambda 4200$ ) and noted the discrepancy between the spectral type and the photometric colors that is the identifying characteristic of He-weak stars. It is classified as He-weak by Nissen (1974). On the basis of the MK spectral type, we provisionally assign the star to the Si subclass. The star has been observed by Hartoog (1977) and Wolff (1981) for  $v \sin i$ , but no detailed study of it has been carried out. In four magnetic observations we find no trace of a field.

*HD 142990 = HR 5942.*—Garrison (1967) found this star to be He-weak. It does not seem to have been studied at high dispersion, probably because of the large value of  $v \sin i = 200 \text{ km s}^{-1}$  reported by Slettebak (1968). A more recent observation by Wolff, Edwards, and Preston (1982) yields  $v \sin i = 150 \text{ km s}^{-1}$ . Pedersen and Thomsen (1977) found the star to be a helium variable with possible periods of  $\sim 40^{\text{d}}$ ,  $0^{\text{d}}0976$ ,  $\pm 0^{\text{d}}015$ , or  $0^{\text{d}}492 \pm 0^{\text{d}}003$  day. The large  $v \sin i$  value definitely excludes the  $40^{\text{d}}$  period; if the star is less than twice as large as a zero-age main-sequence star of spectral type B3 (i.e.,  $R \leq 4.8 R_{\odot}$ ), then  $P \leq 1^{\text{d}}$ .

The magnetic observations clearly reveal the presence of a large and variable magnetic field. Unfortunately, even with a data set of 14 observations, we are unable to define a unique period because the period is so close to  $1^{\text{d}}$  or  $0^{\text{d}}5$ . However, we have fitted sine waves to our data by least squares for periods around those proposed by Pedersen and Thomsen (1977), and we do find periods consistent with theirs. Our data may be repre-

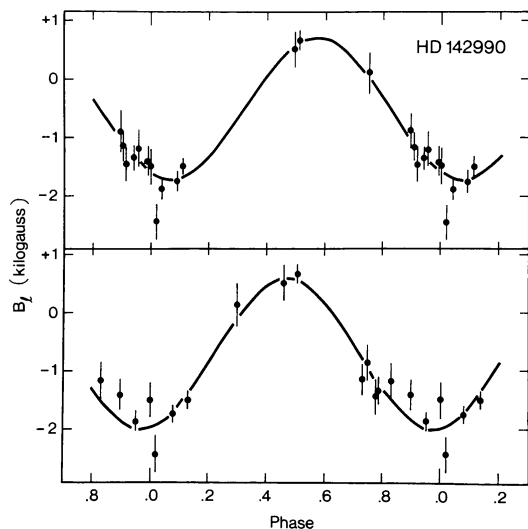


FIG. 4.—Magnetic observations of HD 142990 plotted with assumed periods of  $0.97843$  (upper panel) and  $0.492585$  (lower panel). Symbols as in Fig. 1.

sented by eight different periods having  $1.0 < \chi^2/\nu < 1.5$ , all lying within the errors of Pedersen and Thomsen's (1977)  $0.976$  period; near their  $0.492$  period we find three acceptable periods with  $1.4 < \chi^2/\nu < 1.7$ . The best overall fit to our data is given by the period  $0.97843$  ( $\pm 0.00008$ ) ( $\chi^2/\nu = 1.08$ ,  $B_0 = -500$ ,  $B_1 = 1220$ ). The best fit near the shorter period is  $0.492585$  ( $\pm 0.000015$ ) ( $\chi^2/\nu = 1.43$ ,  $B_0 = -710$ ,  $B_1 = 1280$ ). With a period of  $0.978$ ,  $v \sin i \approx 150 \text{ km s}^{-1}$ , and  $2.4 \leq R \leq 4.8 R_\odot$ , we have  $i \geq 35^\circ$  and  $\beta \leq 85^\circ$ . Similarly, the shorter  $0.493$  period leads to  $15 \leq i \leq 40^\circ$  and  $65 \leq \beta \leq 80^\circ$ .

Because the correct period for this star is almost certainly one of the two short periods quoted by Pedersen and Thomsen (1977), we display our data on our two best periods in Figure 4.

*HD 143699 = HR 5967.*—Nissen (1974) found this star to be He-weak. Pedersen and Thomsen (1977) observe no variation in the He  $\lambda 4026$  line in nine observations made over  $13^d$ . We know of no high-dispersion studies of this star. Our four magnetic observations show no indication of a magnetic field.

*HD 144334 = HR 5988.*—This star was discovered to be He-weak by Garrison (1967). Its spectrum has been studied by Norris (1971a), who found strongly underabundant He and C, normal Mg, and Si variable between roughly normal and rather overabundant. It does not appear from Norris's (1971a) study that the star is a member of the P–Ga or Sr–Ti subgroups, so we assume it to be a Si star. Pedersen and Thomsen (1977) found no He  $\lambda 4026$  variations in four observations spaced over 11 days.

Relatively low values of  $v \sin i$  are reported by Norris (1971a),  $65 \text{ km s}^{-1}$ , and Hartoog (1977),  $44 \text{ km s}^{-1}$ ; a discordant value is given by Wolff, Edwards, and Preston

(1982),  $140 \text{ km s}^{-1}$ . Since Norris's value is based on higher dispersion plate material and the closer examination implied by an abundance analysis, we accept it; in addition, the discordant value of  $140 \text{ km s}^{-1}$  is inconsistent with the period discussed below.

Our magnetic observations show clear evidence of the presence of a large and variable magnetic field, confirming the variability reported by Norris (1971a) for this star. A search for periodicity has been carried out by fitting sine waves by least squares to various subsets of the data, allowing periods between  $250^d$  and  $0.45^d$ . The last six data points define a unique period between  $3.3^d$  and  $4.4^d$ . The only period satisfying this constraint that fits the first six data points acceptably is  $3.61$  ( $+0.04$ ,  $-0.06$ ). The two halves of our data are spaced too far apart in time to be phased uniquely or to refine the period further at present. To present the data we assume a period of  $3.6100$  which acceptably phases the two data sets ( $\chi^2/\nu = 0.71$ ,  $B_0 = -310$ ,  $B_1 = 940$ ). The data are shown in Figure 5 on this period, together with the best fitting sine wave. This period is only consistent with the low observed  $v \sin i$ ; if the star is no more than twice the size of a zero-age main-sequence B4 star and has  $v \sin i = 65 \text{ km s}^{-1}$  the period must be  $\leq 3.2^d$ . It appears that  $i \geq 60^\circ$ , and, in fact, either  $i$  or  $\beta$  must be large to produce the observed field reversal.

When the He  $\lambda 4026$  observations of Pedersen and Thomsen (1977) are plotted on the  $3.61$  period, they cover the full cycle fairly well (phases 0.00, 0.05, 0.28, and 0.56 relative to the first  $\lambda 4026$  observation). The lack of variability revealed by the helium observations, in spite of the fact that we get a good view of both magnetic poles, suggests that helium is deficient more or less uniformly over the entire star rather than being localized at one pole. This conclusion is not yet secure because of the limited number of  $\lambda 4026$  observations, which could fortuitously fall at phases of equal line strength even if the helium abundance does vary, but it is quite interesting. Further helium line observations of this star are needed.

*HD 144661 = HR 5998.*—Garrison (1967) discovered that this star is He-weak and reported that the spectrum resembles that of the Hg–Mn Ap star  $\alpha$  And. It is also

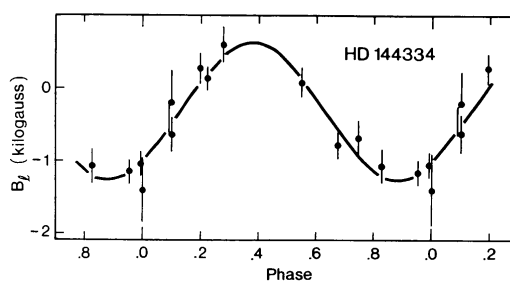


FIG. 5.—Magnetic observations of HD 144334 plotted with an assumed period of  $3.6100$ . Symbols as in Fig. 1.

described as a Hg–Mn star by Wolff and Wolff (1974). The star has been studied at high dispersion by Norris (1971*a*), who found underabundant He and C, normal or slightly low Mg and Si, and also reported the presence of lines of P. Baschek (1975) has argued that the P–Ga subgroup is similar enough in chemical composition to consider it a hot continuation of the Hg–Mn Ap stars, so we provisionally classify HD 144661 as a P–Ga star.

The star shows the  $^3\text{He}$  anomaly mildly, with  $^3\text{He}/^4\text{He} = 0.79$  (Hartoog and Cowley 1979). Pedersen and Thomsen (1977) find no evidence of variability in He  $\lambda 4026$  in seven observations spaced over 15<sup>d</sup>.

Our magnetic observations include one (low precision) measurement at the 2.6  $\sigma$  level, but overall there is no strong evidence for the existence of a magnetic field.

*HD 144844 = HR 6003.*—This is another He-weak star found by Garrison (1967). Norris (1971*a*) found He and C quite underabundant, Mg somewhat underabundant, and Si normal. Lines of P and Ga are present, so the star belongs to the P–Ga subgroup. It is classified as a Hg–Mn star by Wolff and Wolff (1974).

In spite of one 2.4  $\sigma$  magnetic observation, our data are consistent with no field being present.

*HD 145501 =  $\nu$  Sco CD.*—This close visual binary system (2'' separation) is composed of two stars classified B9 III and B9p by Garrison (1967), who pointed out that both have anomalous hydrogen line profiles and that the combined colors of the pair of stars are too blue to be consistent with the MK spectral types. The stars are not very different in brightness; component D is  $\sim 0.7$  mag fainter than C.

Our magnetic measurements were made with both stars in the diaphragm because of the small separation. All four observations reveal clear evidence of a field. Reducing the polarization measurements to field strength in the normal way, we find the field values given in Table 2. All four measurements are within 1  $\sigma$  of the weighted mean ( $-1387$  G); there is no evidence of variation over the five nights spanned by our data. However, the tabulated data should not be taken at face value. Presumably only one of the two stars has a strong field, although it is not *a priori* clear which one. The light from the other less or nonmagnetic star presumably dilutes the polarization produced by the strongly magnetic star, unless we have the unlikely situation that both stars have similar field strengths. If the brighter star is the magnetic one, then the tabulated field strengths should be multiplied by a factor 1.5 to correct for dilution; if the faint star is magnetic, the correction for dilution is a factor of  $\sim 2.9$ . In any case, it is clear that at least one of these stars has a very respectable magnetic field.

*HD 146001 = HR 6054.*—Garrison (1967) found this star to be possibly He-weak; Nissen (1974) finds definite helium weakness. No high-dispersion studies are available. Pedersen and Thomsen (1977) only observed HD

146001 on two successive nights; they found no evidence of He  $\lambda 4026$  variability, but the limited observations place little constraint on possible variation.

We have one very low accuracy magnetic observation at the 2.3  $\sigma$  level, but overall there is no strong evidence for a field in our data.

*HD 151346.*—This star was identified as He-weak by Garrison (1967); the classification was confirmed by Nissen (1974). The only spectroscopic study known to us is Hartoog's (1977) measurement of  $v \sin i$ , and it does not yet seem possible to assign it to one of the He-weak star subgroups. Our one magnetic measurement, of rather low precision, shows no trace of a field.

*HD 162374 = HR 6647.*—This star shows underabundant and variable He, underabundant C, nearly normal Mg, and Si varying between normal and strongly overabundant (Norris 1971*a*). Presumably it belongs to the Si subgroup. The helium line variations are confirmed by Pedersen and Thomsen (1977), who find  $P = 1^d658$  or  $2^d52$ .

In spite of the observed variability, our five magnetic observations reveal no significant evidence of a field; any field present has a longitudinal strength generally less than  $\sim 400$  G.

*HD 175156 = HR 7119.*—This star was discovered to be He-weak by Guthrie (1965). It has been studied by Vilhu, Tuominen, and Boyarchuk (1976), who found mildly underabundant He, normal C, Si, and Cr, and overabundant Ti and Fe. P may be present; Sr definitely is. The star belongs to the Sr–Ti subgroup. Hartoog and Cowley (1979) find no excess  $^3\text{He}$ .

Our eight magnetic observations include one at the 2.9  $\sigma$  level, but all the other observations are nulls. This does not appear to be a magnetic star; the probability of observing the value of  $\chi^2/n = 1.57$  by chance in eight observations of a nonmagnetic star is  $\sim 15\%$ .

*HD 175362 = HR 7129.*—Nissen (1974) discovered that this star is He-weak; almost simultaneously it was found by Balona and Martin (1974) to be a helium spectrum variable, similar to a Cen, with a 3<sup>d</sup>.7 period. The spectrum has been analyzed by Balona (1975*b*), who finds He underabundant, C roughly normal, Si slightly overabundant, and Mg, Ti, and Fe strongly overabundant. Sr is also present. Variations of Si and Fe line strengths are observed. The star belongs to the Sr–Ti subclass. Spectrum variations have been studied more quantitatively by Pedersen (1979), who found a very smooth but slightly asymmetric single wave variation for the strength of the He  $\lambda 4026$  line. Spectrum variations of several elements are discussed quantitatively by Wolff and Wolff (1976), who also discovered the second strongest longitudinal magnetic field found to date in the star. Finally, Hartoog and Cowley (1979) find  $^3\text{He}/^4\text{He} = 1.6$ .

Oblique rotator models of HD 175362 with caps having anomalous abundances have been discussed qualitatively by several of the authors above, and more

extensively by Hensler (1979). Hensler finds that the best established spectrum variations, those of He and Si, can be reproduced with a cap of normal He abundance extending to  $60^\circ$  from the negative magnetic pole (the rest of the star is  $\sim 10$  times underabundant in He), and with a cap of high Si overabundance extending to  $40^\circ$  from the positive magnetic pole (the rest of the star is assumed to have normal Si). It should be noted that on this model both spectral anomalies, He underabundance and Si overabundance, are associated with the positive magnetic pole, while the negative pole has normal abundances.

Our magnetic observations fully confirm the existence of the magnetic field found by Wolff and Wolff (1976), although we find extreme field strengths of  $-6500$  and  $+4800$  G, roughly reversed in relative strength from those observed by Wolff and Wolff. (Differences of this sort between photographic and photoelectric field strength measurements are common: see Borra and Landstreet 1980.) To phase our observations with other observations of this star, it is necessary to have a more accurate period than any quoted in the literature. The most accurate period is that derived by Wolff and Wolff (1976) from observations covering  $95^d$ ; they obtain  $P = 3^d.670$ , with an uncertainty that we estimate to be no worse than  $\pm 0^d.03$ . To improve this period, we use the fact that the line strength maximum coincides quite closely with negative magnetic field extremum (Wolff and Wolff 1976). We have He line strength maxima on JD  $2,441,899.92 \pm 0^d.7$  (Balona and Martin 1974),  $2,442,255.97 \pm 0^d.7$  (Balona 1975*b*),  $2,442,248.89 \pm 0^d.4$  (Wolff and Wolff 1976), and  $2,443,068.40 \pm 0^d.2$  (Pedersen 1979). When we plot our own data on the  $3^d.67$  period, we find negative field extremum at JD  $2,443,740.60 \pm 0^d.4$ . The only period consistent with these data between  $3^d.62$  and  $3^d.72$  is  $P = 3^d.6740$ , with an uncertainty that we estimate to be  $\sim 0^d.0015$ . We thus adopt the ephemeris (using as zero point the most accurate date of He maximum from Pedersen's 1979 data):

$$\begin{aligned} \text{JD(He max, } B_l \text{ negative extremum)} \\ = 2,443,068.40 + (3^d.6740 \pm 0^d.0015) E. \end{aligned}$$

Our data and Pedersen's are plotted on this ephemeris in Figure 6; the relative phase uncertainty is  $\sim \pm 0.07$ . With our magnetic data we also show the best fitting sine wave. It is not a very good fit, having  $\chi^2/\nu = 16.0$ ; this reflects the noticeably nonsinusoidal shape of the curve defined by the observations. HD 175362 has the distinction of giving the highest signal-to-noise ratio (for fixed integration time) of any magnetic star; our observations, with photon-statistical signal-to-noise ratios of up to 30:1, were obtained in above 30 minutes per point on the Las Campanas 2.5 m telescope. At such high signal-to-noise ratios, we really do not know just

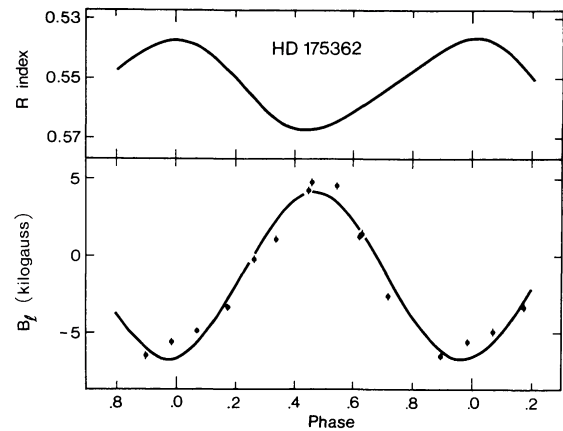


FIG. 6.—Magnetic observations of HD 175362 (*lower panel*) and photoelectric measurements of the strength of He  $\lambda 4026$  (*upper panel*, Pedersen 1979) plotted on the ephemeris given in the text. Symbols as in Fig. 1.

how accurate or repeatable our magnetic observations are. The deviation from a sine wave could either be due to a truly nonsinusoidal magnetic curve or to small unidentified errors in our measurements. However, our measurements do suggest that the rate of change of the field with time is larger on the negative-going branch than on the positive-going branch. This effect was also observed by Wolff and Wolff (1976).

Adopting  $i \approx 27 \pm 6^\circ$  (Hensler 1979), we find from our magnetic curve  $\beta = 83^\circ \pm 5^\circ$ , in agreement with Hensler's result, except that we find the negative pole rather than the positive pole closer to the visible rotation pole.

*HD 202671 = 30 Cap.*—The classification of this star is somewhat uncertain. Wolff and Wolff (1974) find enhanced Mn lines but mention no other peculiarities. Vilhu, Tuominen, and Boyarchuk (1976) find underabundant He, normal C and Si, and overabundant Cr, Fe, and Ti, but Sr is absent. They regard 30 Cap as possibly a member of the  $\alpha$  Scl subtype of the He-weak stars. Hartoog and Cowley (1979) find no evidence of  $^3\text{He}$ . Our four magnetic observations reveal no evidence of a field.

*HD 224926 = 29 Psc.*—Klingesmith (1971) carried out an abundance analysis of the spectrum of this star. He found underabundant He, normal C and Mg, and overabundant Si, Ti, and Fe. The  $\text{Sr}^+$  resonance line at  $4215 \text{ \AA}$  is not seen. Wolff and Wolff (1974) find Mn overabundant. The star appears to be similar to HD 202671 above, and perhaps is related to the  $\alpha$  Scl (Sr–Tr) group, but Baschek (1975) lists it as a Si star. Pedersen (1979), in 10 observations of the strength of He  $\lambda 4026$  scattered over  $60^d$ , finds no evidence of variability. Our four magnetic observations reveal no sign of a field.

*Feige 86.*—This blue horizontal-branch halo star was found by Sargent and Searle (1967) to be spectroscopi-

cally very similar to the He-weak P–Ga star 3 Cen A. A detailed analysis by Baschek and Sargent (1976) confirmed this, showing atmospheric parameters and abundance anomalies which (apart from more deficient C in Feige 86) are almost identical to those found in 3 Cen A. Feige 86 has also been found to contain excess  $^3\text{He}$ , with  $^3\text{He}/^4\text{He} = 0.7$  (Hartoog 1979).

We observed this star to find out whether its similarity to the Population I He-weak stars extends to the presence of a magnetic field. Because the star is  $\sim 10^2$  times fainter than most of the stars surveyed by us ( $V=10.0$  compared to  $V=4-6$ ), the standard error of measurement for a given integration time is  $\sim 10$  times larger than normal. Our one measurement thus reveals little more than that Feige 86 probably does not possess a field much larger than the largest fields found in any Ap or Bp stars, and that really useful measurements of such stars are still a long way off.

*HD 149382.*—This is the brightest subdwarf OB star. Like the Population I He-weak stars, it is helium deficient, but otherwise it is a very different type of star. It has  $T_e = 35,000$  K,  $\log g = 5.5$ , underabundant He, C, O, Al, Si, and Fe, and overabundant Ca, Ti, V, Cr, and Mn (Baschek and Norris 1975; Baschek *et al.* 1982). The deficiencies and excesses are typically one order of magnitude, but Si is depleted by more than a factor of  $10^4$ . Like Feige 86, it is faint, and our one magnetic observation is of low accuracy, but for HD 149382 our measurement gives a much more powerful constraint on a possible field than is the case for Feige 86. The detectable (i.e., largest) fields in stars increase with decreasing radius from typically  $10^3$  G for main-sequence stars of  $R \approx 10^{11}$  cm (Borra and Landstreet 1980), to  $10^7$  G for white dwarfs of  $R \approx 10^9$  cm (Angel, Borra, and Landstreet 1981), to  $10^{13}$  G for neutron stars of  $R \approx 10^6$  cm (Ruderman 1972). This is equivalent to scaling essentially as  $R^{-2}$ , and so if this star had been magnetic on the main sequence with  $B \sim 10^3$  G, it might be expected now to have  $B \approx 3 \times 10^4$  G, much larger than our 2800 G  $\sigma$ . Alternatively, we could say that our measurement has an accuracy equivalent to  $\sigma \approx 10^2$  G for a main-sequence star, and is thus a respectably accurate measurement. However, there is no sign of a magnetic field.

#### IV. DISCUSSION

Two general conclusions emerge from this study. First, some He-weak stars are confirmed as objects continuous in their peculiarities with both cooler and hotter analogs. They share with the magnetic Ap stars and the He-rich stars not only the properties of spectroscopic peculiarity and variability but also the presence of magnetic fields.

Second, our observations are consistent with the view that the P–Ga stars constitute a hot continuation of the

Hg–Mn stars, while the Si and Sr–Ti stars are related to the magnetic Ap and He-strong stars. No Hg–Mn star shows a detectable field (Conti 1970; Borra and Landstreet 1980), nor do any show well-established spectrum or light variations. The P–Ga stars likewise show no variability, and none of the four observed by us shows any sign of a field. In contrast, some members of both the Si and the Sr–Ti subclasses show spectrum variation and definite magnetic fields, like the Sr–Cr–Eu and Si Ap stars, and the He-strong B stars.

A further point of interest is that magnetic peculiar stars appear to be rather common in the Sco–Cen OB association, a conclusion first suggested by the work of Garrison (1967) and later confirmed by Brown, Landstreet, and Thompson (1981) in a study of the magnetic fields of cluster and association Ap stars. The magnetic stars  $\gamma$  Mus, a Cen, 3 Sco, HD 142990, HD 144334,  $\nu$  Sco CD, and HD 175362 are all members of this association. This seems to be a rather general property of young associations; two of the four Orion stars observed by us are magnetic, Borra (1981) reports a number of magnetic stars in Orion association, and several of the He-strong stars discussed by Borra and Landstreet (1979) are members of this association. IC 2602 and Lac OB1 also contain magnetic stars (Brown, Landstreet, and Thompson 1981).

It is of interest to compare the magnetic field strengths found for He-weak stars with those observed for Ap and He-strong stars. One method of making this comparison is to examine the distribution of the rms fields observed for each star over each of the three category samples. The rms field observed for a single star is certainly dependent on the inclination  $i$  of the rotation axis to the line of sight, but a sample of reasonable size will presumably have a random distribution of  $i$ . Then if the distribution of polar field strength or mean surface field is the same for Ap stars, He-weak stars, and He-strong stars, the distributions of observed rms field should be very similar. This result is not affected by the apparently different rotation velocity distributions of the three category samples (Jaschek and Jaschek 1981), since the field measurement technique used here, and for the comparison samples, is insensitive to  $v \sin i$ .

Before making a comparison of the rms field distributions, we make two changes to the data listed under  $\langle B_i^2 \rangle^{1/2}$  in Table 1. First, since the values of  $\langle B_i^2 \rangle^{1/2}$  are somewhat inflated by nonzero errors, especially for stars of small or zero magnetic fields, we correct the measured rms values by defining

$$\langle B_e \rangle = \left[ \frac{1}{n} \sum_{i=1}^n (B_{li}^2 - \sigma_{Bi}^2) \right]^{1/2} = [\langle B_i^2 \rangle - \langle \sigma^2 \rangle]^{1/2}.$$

We shall actually compare distributions of  $\langle B_e \rangle$  rather than  $\langle B_i^2 \rangle^{1/2}$ . Second, for stars with a well-established

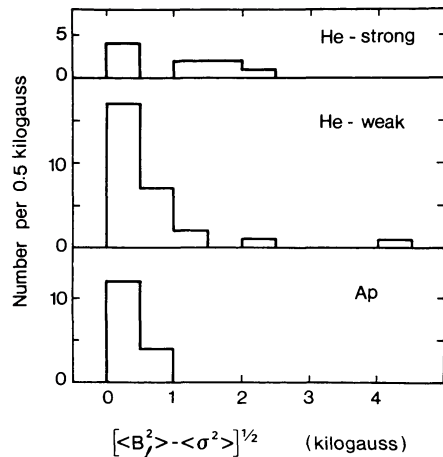


FIG. 7.—Histograms showing the distribution of rms magnetic field strength over samples of classical Ap stars (*bottom panel*), He-weak stars (*middle panel*), and He-strong stars (*top panel*) as discussed in the text.

magnetic curve of the form  $B(\phi) = B_0 + B_1 \sin[2\pi(\phi - \phi_0)]$ , an unbiased rms field strength may easily be obtained from the mean curve. It is easily shown that

$$\langle B_e \rangle = (B_0^2 + \frac{1}{2}B_1^2)^{1/2}.$$

In Figure 7 we display in histogram form the  $\langle B_e \rangle$  distributions over the present He-weak star sample, the He-strong star sample composed of the stars observed by Landstreet and Borra (1978) and Borra and Landstreet (1979), and for the complete  $V \leq 5.0$ ,  $\delta \geq -20^\circ$  Ap star sample discussed by Borra and Landstreet (1980). The values of  $\langle B_e \rangle$  in the figure are obtained from mean curves wherever possible; cases in which  $\langle B_l^2 \rangle - \langle \sigma^2 \rangle < 0$  have been artificially set to  $\langle B_e \rangle \equiv 0$ ,

and all the P-Ga He-weak stars and the subdwarf have been eliminated from the He-weak star sample.

Comparing the distribution of  $\langle B_e \rangle$  for the He-weak stars with those of the Ap and He-strong stars, the He-weak stars appear to form a population intermediate between the other two groups. The He-weak stars, like the Ap stars, mostly have rms fields of less than 500 G, in contrast to the He-strong sample, where more than half the sample consists of stars with  $\langle B_e \rangle$  of more than 1 kG. On the other hand, none of the 16 Ap stars of the magnitude-limited sample have  $\langle B_e \rangle$  over 1 kG, while four of the 23 helium weak stars do.

We may also compare the distribution of  $r$ -values for these three populations. We define

$$r = \frac{\min(B_l^+, B_l^-)}{\max(B_l^+, B_l^-)} = \frac{|B_0| - B_1}{|B_0| + B_1},$$

where  $B_l^+$  and  $B_l^-$  are the positive and negative magnetic curve extrema; it is a quantity that measures the amplitude of the smaller field extremum relative to the larger one, and varies from +1 for stars of constant fields to -1 for stars of equal positive and negative extrema. Its distribution is related to the distribution of field obliquity  $\beta$  over a sample, with stars that usually have large  $\beta$  values also usually having  $r$  near -1 (Preston 1967, 1971; Landstreet 1970). We summarize the available information on magnetic curves of the magnetic stars studied in this survey in Table 3. For each star we list both the number of observations,  $n$ , and the number of days from first to last observation,  $n_d$ , as well as the period. The tabulated values for  $B_0$  and  $B_1$  are best-fit values, with estimated uncertainties, for stars with well-determined periods and magnetic curves (a Cen, 3 Sco, HD 144334, HD 175362); for the rest, the values are rough averages over the range of  $B_0$

TABLE 3  
MAGNETIC CURVE PARAMETERS

HD	Name	$n$	$n_d$	$P$ (d)	$B_0$ (G)	$B_1$ (G)	$r$	$i$	$\beta$
5737	.... $\alpha$ Scl	7	34	19.35?	$30 \pm 80$	$410 \pm 80$	$-0.86 \pm 0.30$		(one large)
22470	.... 20 Eri	12	12	1.935	$115 \pm 50$	$1650 \pm 200$	$-0.87 \pm 0.15$	$\geq 60^\circ$	$\geq 20^\circ$
				0.6785	$75 \pm 50$	$1150 \pm 50$	$-0.88 \pm 0.08$	$28 \pm 10$	$\geq 85$
22920	.... 22 Eri	4	4	...	...	...	...		
36916	....	2	3	...	...	...	...		
37058	....	3	4	14.61	$300 \pm 300?$	$1300 \pm 300?$	$-0.63 \pm 0.31?$		(one large?)
79158	.... 36 Lyn	2	1	...	...	0	$< +0.22 \pm 0.21$		
109026	.... $\gamma$ Mus	5	1555	...	$340 \pm 50$	$100 \pm 100?$	$+0.54 \pm 0.30$		(one small)
125823	.... a Cen	9	8	8.817	$-20 \pm 50$	$450 \pm 50$	$-0.92 \pm 0.18$		(one large)
142301	.... 3 Sco	20	704	1.46	$-1220 \pm 200$	$2900 \pm 300$	$-0.41 \pm 0.09$	$30 \pm 10$	$78 \pm 8$
142990	.... HR 5942	8	1510	0.978	$-340 \pm 150$	$1380 \pm 200$	$-0.60 \pm 0.16$	$\geq 35$	$\leq 85$
				0.493	$-700 \pm 70$	$1290 \pm 70$	$-0.30 \pm 0.05$	$28 \pm 10$	$73 \pm 8$
144334	.... HR 5988	12	1370	3.61	$-330 \pm 30$	$900 \pm 90$	$-0.46 \pm 0.08$		(one large)
145501	.... $\nu$ Sco CD	4	5	...	...	...	...		
175362	.... HR 7129	12	597	3.674	$-1300 \pm 500$	$5300 \pm 500$	$-0.61 \pm 0.12$	$27 \pm 6$	$83 \pm 5$

and  $B_1$  values that lead to acceptable fits at any acceptable period in the range surveyed, and the (generally rather larger) uncertainties reflect the variation in  $B_0$  and  $B_1$  as the best-fit curve changes from one acceptable period to another. Because we have two possible periods for 20 Eri and HD 143990, each of these stars has two entries in Table 3. Finally, we summarize the available fits for  $i$  and  $\beta$ , with the notation (one large) where at least one of  $i$  or  $\beta$  needs to be near  $90^\circ$ , and (one small) where at least one of  $i$  or  $\beta$  needs to be near  $0^\circ$ .

It is apparent that  $r$  is frequently negative. The seven well-studied stars (six or more observations, spread over nine or more nights) all have  $r < 0$ . Only for the six less well-observed stars might  $r$  be greater than 0, and, of course, further observations may reveal variable fields for more of these stars as well. The preponderance of negative values of  $r$  is not as striking for He-weak stars as the preponderance of negative values found in Ap stars (Borra and Landstreet 1980), where it presumably reflects a strong tendency toward large  $\beta$  values. The He-strong stars are rather different from the Ap stars; only half of the six He-strong magnetic stars reverse  $B_1$  in the data available, but the number of stars in the sample and the limited length of time most were observed make this characteristic rather uncertain. Again, the He-weak stars are intermediate between He-strong and Ap stars.

In keeping with the behavior of the He-weak stars as somehow intermediate between magnetic Ap stars and He-strong stars, we do find a small fraction of the magnetic stars in this sample to have (probably) large values of  $v \sin i$ , analogous to those found in several of the He-strong stars. But whereas four of the six detectably magnetic He-strong stars have  $P < 2^d$  and  $v \sin i \geq 150 \text{ km s}^{-1}$ , only  $\gamma$  Mus and HD 142990 of the magnetic He-weak stars have  $v \sin i \geq 150 \text{ km s}^{-1}$ , and seven of the 13 stars of Table 3 have  $v \sin i \leq 80 \text{ km s}^{-1}$ .

For only a small fraction of the stars observed is there enough information available to discuss the relationship

of the field geometry to abundance patches. For the very hot (B2.5) He-weak stars  $\alpha$  Cen and HD 175362, the region of helium deficiency is concentrated near one magnetic pole, while the other pole has roughly normal or even excessively large helium abundance. For the substantially cooler (B3–4) star 3 Sco, both poles appear helium deficient, while the equator is more nearly helium normal. In each of these three cases, the striking abundance anomaly appears to occur near a magnetic pole, but some magnetic poles seem nearly normal. Such an asymmetry presumably reflects physical differences between the poles such as those discussed for dipole-quadrupole field configurations in Ap stars by Michaud, Megessier, and Charland (1981).

However, note that in the still cooler star HD 144334 (B4) the helium appears—on the basis of rather limited data—to be uniformly depleted over the whole surface. If this situation is confirmed, it will stand in substantial contrast to the cases above.

Finally, we point out that of the stars studied here, there are at least six ( $\alpha$  Scl, HD 37058,  $\alpha$  Cen, 3 Sco, HD 142990, and HD 175362) that combine measurable fields with detectable spectrum variations, and thus should prove rewarding for further studies aimed at clarifying the relationship between magnetic field geometry and abundance anomaly distribution.

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