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Mid-Ultraviolet and Optical Photometry of Helium Stars

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Abstract. Mid-ultraviolet and optical photometric analysis of helium stars are presented. A linear relation exists between the effective temperature derived from model atmospheres and $(1965\text{-V})_0$ index. The effective temperatures derived from $(1965\text{-V})_0$ index are somewhat higher than that of MK spectral type estimates especially for late B-type helium objects.

Key words: Helium stars—photometry—effective temperature.

1. Introduction

Spectroscopic investigations of some B-type stars have shown anomalous helium abundances to that of normal B-type objects of similar temperatures. These anomalous objects are termed as 'Helium-stars' and are further subclassified into extreme, intermediate or rich or strong and weak-line stars based on He I/H line intensity ratios. These stars have spectral types generally in the range B0–B9 III–V and effective temperatures of the order of 11000–30000 K. Except in the extreme helium stars, the helium peculiarity in these objects is believed to be confirmed to the atmospheric layers as a consequence of the complex interaction of diffusion processes, a weak stellar wind and a strong periodically varying magnetic field (Osmer and Peterson, 1974; Vauclair, 1975; Landstreet and Borra, 1978; Borra and Landstreet, 1979 and Michaud *et al.*, 1987). Recent reviews of these stars may be found in Hunger (1986) and Bohlender *et al.* (1987). Walborn (1983) showed from the line strength measurements that the majority of helium-rich stars do not indicate any outstanding CNO or other metal anomalies compared to the stars of similar spectral types and has classified this subgroup members as Population I main-sequence objects with some exceptions.

So far, the classification of helium stars is being done mainly through spectroscopic investigations and no attempt has been made in identifying these subgroups through photometric investigations. In this analysis, an attempt has been made to identify these subgroups through photometric observations using both optical and mid-ultraviolet regions of the spectrum, as these stars are hot and emit a considerable amount of energy in the *UV* region and to estimate effective temperatures for a large sample, using calibrations based on the existing spectroscopic analysis of some of these stars.

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2. Observational data and reduction

Around 100 stars classified as 'Helium stars' and for which both optical and mid-ultraviolet measurements are available have been selected from the literature for this analysis. Some of these stars are classified as weak, strong or rich and extreme, and the rest have no subclassification and the latter group has been treated as 'unclassified' in this investigation. The m_1 and c_1 indices for these stars have been taken from the Catalogue compiled by Mermilliod and Hauck (1979). The V, $B-V$, $U-B$ values and spectral types have been taken from the Photometric Catalogue compiled by Blanco *et al.* (1968) and Underhill *et al.* (1979). Table 1 gives the data for these stars. Though some other objects also have been classified as helium stars and for which *UBV* and *uvby* photometric indices are available in the literature, the non-availability of mid-uv measurements in Thomson *et al.*'s (1978) study restricts their inclusion in the present analysis. Thus, only three EHe stars have been found in the catalogue and are not further discussed in the present study. In addition, Table 1 also gives data for two O-type stars, one A-type star and two stars of luminosity class II which are all classified as helium stars and have both optical and mid-uv measurements, though these stars marginally deviate from the general definition of helium stars as 'B0–B9 III–V'.

The ultraviolet fluxes for all these stars at 2740 A (310 A), 2365 A (330 A), 1965 A (330 A) and 1565 A (330 A) have been taken from the Catalogue compiled by Thomson *et al.* (1978). These fluxes were recorded by the Sky Survey Telescope (S2/68) aboard the ESRO Satellite TD-1. The observed fluxes (F_λ) were converted to the visual magnitude scale through the absolute calibration formula given by Hayes and Latham (1975)

$$m(\lambda) = -2.5 \log F_\lambda - 21.175.$$

Table 2 gives the details of the data and all columns are self explanatory.

In the following analysis, we have used the reddening relations mainly applicable for normal stars in order to estimate various intrinsic colours for helium stars as Groote and Hunger (1982) have demonstrated that helium enrichment in the temperature range and abundance range seen in these stars has little effect on their fluxes, at least in the optics region. This is justifiable because of the fact that the observed colours, luminosities, estimated radii of these stars are consistent with normal B-type Population I objects. (Greenstein and Wallerstein, 1958; Osmer and Peterson, 1974 and Walborn, 1983). In addition, the presence of several of these stars in very young clusters and associations and their coexistence with other normal B-type stars within a cluster or association and their location near the galactic plane definitely suggest that they are very young objects and of Population I inspite of their abnormal helium abundances (Odell, 1981; MacConnell *et al.*, 1970; Nissen, 1974, 1976). In addition, satellite observations show that the flux distributions in the ultraviolet of a majority of He-weak objects is normal for their *UBV* colours although a few He-weak stars are fainter in the ultraviolet than normal stars with the same *UBV* colours. Bernacca and Molar (1972) and Ciatti *et al.* (1978) had interpreted the flux deficiency in some of these stars to a possible line blocking by many spectral features.

The estimation of colour excess, $E(B-V)$, for interstellar reddening correction to the observed magnitude has been made by using the following procedure:

i. In the case of stars for which reliable spectral types are available, the estimation of colour excesses has been made from the intrinsic colour-spectral type relation given

Table 1. Basic data.

HD No.	V	$B-V$	$U-B$	β	m_1	c_1	Sp. type	Remarks
5737	4.31	−0.16	−0.56	2.660	0.098	0.498	B7IIIp	Weak, HR 280
19400	5.53	−0.14	−0.51	2.709	0.111	0.512	B3V + A0IV	HR 939
21699	5.47	−0.10	−0.57	—	0.127	—	B8IIIp MN	HR 1063
22470	5.23	−0.13	−0.49	2.731	0.135	0.475	B9p	Weak, Var., HR 1100
22920	5.53	−0.15	−0.57	2.687	0.104	—	B9IIIp	HR 1121
23408	3.87	−0.07	−0.40	2.691	0.089	0.622	B8III	HR 1149
28843	5.81	−0.14	−0.54	2.718	0.103	0.409	B9III	Weak, HR 1441
30353	7.76	+0.46	−0.17	2.546	0.126	0.400	A1pe/A5p	Extreme
35298	7.89	−0.14	−0.62	2.709	0.091	0.369	B9V	
36046	8.07	−0.10	−0.55	2.721	0.088	0.414	B9	
36526	8.31	−0.11	−0.59	2.703	0.110	0.345	B8	
36540	8.11	+0.05	−0.49	—	0.066	0.393	B9	
36549	8.56	−0.08	−0.40	2.766	0.119	0.648	B9	
36629	7.68	−0.01	−0.65	—	—	—	B2V	
36668	8.06	−0.11	−0.45	2.730	0.124	0.594	B9	
36916	6.73	−0.05	−0.58	2.705	—	0.486	B9	
37017	6.56	−0.13	−0.77	—	—	—	B1.5V	Strong
37043	2.80	−0.24	−1.08	—	0.051	−0.105	O9III	HR 1899
37129	7.14	−0.15	−0.73	—	—	—	B2Vp	
37235	8.17	−0.10	−0.45	—	—	—	B9	
37321	7.09	−0.08	−0.55	—	—	—	B3V	
37776	6.98	−0.14	−0.86	2.632	0.108	0.058	B2V	Strong
44953	6.60	−0.15	−0.64	2.694	0.118	0.313	B8III	Weak, HR 2306
49333	6.08	−0.19	−0.62	—	—	—	B8	
49606	5.70	−0.13	−0.52	2.703	0.116	0.489	B7III	Weak, HR 2519
51688	6.30	−0.11	−0.47	2.705	0.110	0.519	B8III	HR 2605
57219	5.11	−0.16	−0.66	—	0.108	0.270	B2IVne	HR 2790
58260	6.73	−0.12	−0.74	2.614	0.086	0.134	B3III	Strong
60344	7.71	−0.17	−0.83	2.646	—	—	B5	Strong
61641	5.80	−0.16	−0.70	2.662	0.090	0.253	B2IV–V	Weak, HR 2954
62712	6.40	−0.16	−0.48	—	0.106	0.510	B9Vp	HR 3001
62714	7.30	−0.10	—	—	—	—	B9	

Table 1. Continued

HD No.	V	$B-V$	$U-B$	β	m_1	c_1	Sp. type	Remarks
64740	4.63	−0.23	−0.93	2.613	0.101	0.008	B1.5Vp	Strong, HR 3089
74196	5.61	−0.14	−0.50	—	0.104	0.515	B7Vn	HR 3448
79158	5.30	−0.14	−0.45	2.709	0.122	0.553	B0.5II	Weak, HR 3652
79447	3.97	−0.18	−0.67	2.661	0.100	0.299	B3III	HR 3663
82984	5.12	−0.12	−0.58	2.693	0.101	0.382	B4IV	Weak, HR 3817
84046	6.43	−0.09	−0.41	—	—	—	B8	
90264	4.99	−0.13	−0.51	2.717	0.114	0.427	B8V	Weak, HR 4089
96446	6.68	−0.15	−0.85	2.646	—	—	B2V	Strong
100340	10.19	−0.24	−0.94	—	0.088	−0.017	B9	
109026	3.87	−0.15	−0.62	2.692	0.110	0.346	B5V	Weak, HR 4773
120640	5.77	−0.16	+0.75	2.644	0.098	0.178	B2Vp	Strong, HR 5206
120709	4.32	−0.13	−0.60	—	0.096	0.251	B5IIIp	Weak, HR 5210
125823	4.42	−0.18	−0.75	2.664	0.089	0.204	B7IIIp	HR 5378
133518	6.39	−0.10	—	2.635	—	—	B3III	Strong
135038	8.50	—	—	2.692	—	—	B8	
135485	8.20	−0.07	—	2.703	0.106	0.406	B3	Strong
137509	7.00	(0.10)	—	—	0.183	0.411	B8	
142301	5.87	−0.06	−0.58	2.693	0.118	0.301	B8III	Weak, HR 5912
142884	6.79	+0.01	−0.48	2.737	0.092	0.383	B9	
142990	5.43	−0.09	−0.64	2.682	0.108	0.251	B5IV	Weak, HR 5942
143699	4.89	−0.14	−0.58	2.706	0.094	0.382	B6IV	Weak, HR 5967
144334	5.92	−0.08	−0.55	2.717	0.121	0.353	B8IIIp	Weak, HR 5988
144661	6.33	−0.06	−0.53	2.708	0.092	0.401	B7IIIp	Weak, HR 5998
144844	5.88	+0.02	−0.31	2.792	0.120	0.594	B9IVp	HR 6003
144941	10.11	+0.05	−0.70	2.748	—	—	B8	
146001	6.05	+0.04	−0.36	2.750	0.094	0.510	B7IV	Weak, HR 6054
151346	7.90	+0.41	−0.18	2.706	—	—	B8	
160641	9.84	—	—	—	—	—	O9	Extreme
162374	5.90	−0.10	−0.64	—	—	—	B8	
164769	9.90	(−0.80)	—	—	—	—	B3	Strong
165207	8.80	(−0.60)	—	—	—	—	B5	
168785	8.48	+0.06	−0.74	2.604	—	—	B	Strong

Table 1. Continued

HD No.	V	$B-V$	$U-B$	β	m_1	c_1	Sp. type	Remarks
169467	3.51	−0.17	−0.64	2.681	0.099	0.317	B3IV	HR 6897
172854	7.70	(−0.10)	—	2.644	—	—	B9	
175156	5.00	+0.17	—	2.626	0.029	0.472	B5II	HR 7119
175362	5.38	−0.14	−0.71	2.686	0.123	0.254	B8IV	HR 7129
176582	6.41	−0.17	−0.70	2.692	0.094	0.260	B5IV	HR 7185
177003	5.38	−0.18	−0.75	2.675	0.090	0.245	B2.5IV	HR 7210
178993	9.00	(+0.50)	—	—	—	—	A0	
181615	4.61	+0.10	−0.53	2.480	0.100	0.246	B2V + A2Ia	Extreme, HR 7342, υ Sgr
182568	4.97	−0.10	−0.71	2.667	0.071	0.237	B3IV	HR 7372
183339	6.60	−0.15	−0.56	2.706	0.088	—	B8IV	Weak, HR 7401
184927	7.46	−0.17	−0.82	2.659	—	—	B2	Strong
186205	8.53	+0.05	—	2.646	—	—	B2V	Strong
191980	8.10	(−0.30)	—	—	—	—	B5	
202671	5.40	−0.12	−0.49	2.683	0.098	0.552	B8III	Weak, HR 8137
207538	7.31	+0.33	−0.64	2.594	−0.042	−0.024	B0V	
208266	8.13	+0.26	−0.57	—	—	—	B5	
209339	6.66	+0.06	−0.82	2.595	−0.014	−0.022	B0IV	HR 8399
212454	6.16	−0.13	−0.55	2.694	0.098	0.416	B8	HR 8535
217833	6.50	−0.08	−0.55	2.691	0.100	0.365	B9III	Weak, HR 8770
224926	5.10	−0.12	−0.51	2.703	0.104	0.104	B7III–IV	HR 9087
+13°3224	—	—	—	—	0.069	—	—	Extreme

Table 2. Mid-ultraviolet data.

HD No.	$m(2740)$	$m(2365)$	$m(1965)$	$m(1565)$	$E(B-V)_{uv}$	$E(B-V)_{sp}$	$(2740-V)_0$	$(2365-V)_0$	$(1965-V)_0$	$(1565-V)_0$
5737	3.23	2.84	2.46	2.15	.00	.00	−1.08	−1.47	−1.85	−2.17
19400	4.53	4.15	3.76	3.46	.00	.06	−1.19	−1.71	−2.09	−2.37
21699	4.35	4.04	3.74	3.37	.01	.01	−1.15	−1.48	−1.78	−2.15
22470	4.27	4.01	3.59	3.33	.03	.00	−1.05	−1.38	−1.80	−2.05
22920	4.39	4.06	3.67	3.37	.01	.00	−1.17	−1.52	−1.91	−2.21
23408	3.25	3.03	2.58	2.14	.09	.04	−0.74	−1.06	−1.50	−1.93
28843	4.64	4.29	3.90	3.50	.02	.00	−1.23	−1.63	−2.02	−2.41
30353	8.72	—	8.94	9.85	—	.46	−1.06	—	−1.22	−0.22
35298	6.78	6.47	6.14	5.77	.02	.00	−1.17	−1.53	−1.86	−2.22
36046	7.04	6.61	6.34	6.03	.00	.00	−1.03	−1.46	−1.73	−2.04
36526	7.23	6.94	6.42	6.27	.02	.00	−1.14	−1.48	−2.00	−2.14
36540	7.30	—	—	—	—	.12	−1.18	—	—	—
36549	7.79	7.34	7.02	6.92	.00	.00	−0.77	−1.22	−1.54	−1.64
36629	6.50	6.38	5.70	4.98	.23	.23	−1.89	−2.55	−3.18	−3.87
36668	7.32	7.15	6.55	6.53	.06	.00	−0.93	−1.24	−1.83	−1.83
36916	5.67	5.35	5.00	4.77	.00	.02	−1.12	−1.49	−1.84	−2.06
37017	5.07	—	—	—	—	.12	−1.86	—	—	—
37043	0.66	−0.08	−0.56	−1.00	.00	.07	−2.36	−3.26	−3.73	−4.16
37129	5.58	5.10	4.65	4.09	.01	.09	−1.84	−2.53	−2.96	−3.51
37235	7.11	6.85	6.56	5.95	.08	.00	−1.31	−1.76	−2.03	−2.63
37321	5.95	5.59	5.13	4.58	.06	.12	−1.51	−2.15	−2.59	−3.12
37776	5.32	4.82	4.42	3.92	.00	.10	−1.97	−2.42	−3.08	−3.57
44953	5.44	5.16	4.78	4.41	.04	.00	−1.28	−1.66	−2.03	−2.39
49333	4.68	4.26	3.89	3.50	.00	.00	−1.40	−1.82	−2.19	−2.58
49606	4.89	4.51	4.16	3.78	.00	.00	−0.81	−1.19	−1.54	−1.92
51688	5.47	5.10	4.71	4.37	.00	.00	−0.83	−1.20	−1.59	−1.93
58260	5.23	4.77	4.41	3.88	.00	.08	−1.75	−2.40	−2.74	−3.26
60344	5.97	5.39	5.05	4.48	.00	.00	−1.74	−2.32	−2.66	−3.23
61641	4.27	3.71	3.27	2.68	.00	.08	−1.78	−2.53	−2.95	−3.53
62712	5.33	4.91	4.45	4.04	.01	.00	−1.10	−1.54	−2.00	−2.41
62714	6.38	5.98	5.61	5.17	.00	.00	−0.92	−1.32	−1.69	−2.13
64740	2.65	2.01	1.55	0.92	.00	.02	−2.04	−2.73	−3.19	−3.81

Table 2. Continued

HD No.	$m(2740)$	$m(2365)$	$m(1965)$	$m(1565)$	$E(B-V)_{uv}$	$E(B-V)_{sp}$	$(2740-V)_0$	$(2365-V)_0$	$(1965-V)_0$	$(1565-V)_0$
74196	4.69	—	—	—	—	.00	−0.92	—	—	—
79158	4.42	4.16	3.73	3.52	.00	.00	−0.88	−1.14	−1.57	−1.78
79447	2.50	1.98	1.57	1.12	.00	.02	−1.53	−2.10	−2.51	−2.95
82984	3.90	3.46	3.08	2.58	.00	.06	−1.41	−1.99	−2.35	−2.84
84046	5.67	5.51	4.98	4.84	.07	.02	−0.82	−1.03	−1.56	−1.69
90264	3.87	3.47	3.06	2.70	.00	.00	−1.12	−1.52	−1.93	−2.29
96446	5.09	4.58	4.20	3.59	.00	.05	−1.74	−2.37	−2.74	−3.34
100340	7.92	7.52	7.17	6.37	.07	.00	−2.49	−3.05	−3.39	−4.18
109026	2.55	2.09	1.67	1.18	.00	.02	−1.38	−1.89	−2.31	−2.79
120640	4.17	3.72	3.27	2.66	.03	.08	−1.85	−2.49	−2.92	−3.52
125823	2.75	2.21	1.79	1.27	.00	.00	−1.67	−2.21	−2.63	−3.15
133518	4.96	4.75	4.27	3.54	.16	.10	−1.74	−2.18	−2.65	−3.36
135038	8.03	7.71	6.85	7.03	.01	.11	−0.81	−1.39	−2.23	−2.03
135485	7.08	6.79	6.39	5.98	.05	.05	−1.27	−1.68	−2.07	−2.47
137509	6.23	6.15	5.60	5.55	.09	.01	−0.80	−0.90	−1.45	−1.50
142301	4.84	4.64	4.26	3.78	.09	.05	−1.18	−1.50	−1.87	−2.34
142884	6.03	5.98	5.57	5.12	.15	.08	−1.01	−1.25	−1.64	−2.08
142990	4.18	3.92	3.51	2.93	.09	.08	−1.50	−1.95	−2.34	−2.91
143699	3.65	3.22	2.83	2.37	.00	.01	−1.27	−1.72	−2.11	−2.57
144334	4.83	4.57	4.18	3.76	.06	.03	−1.18	−1.51	−1.90	−2.31
144661	5.43	5.28	4.84	4.34	.13	.07	−1.12	−1.43	−1.86	−2.34
144844	5.34	5.22	4.85	4.41	.11	.09	−0.82	−1.15	−1.50	−1.93
144941	—	10.63	8.28	7.71	—	.16	—	−0.35	−2.67	−3.21
146001	5.51	5.40	4.87	4.26	.18	.17	−1.07	−1.58	−2.07	−2.65
151346	8.57	9.11	8.12	8.22	.39	.52	−0.94	−1.53	−2.48	−2.31
160641	8.85	8.38	8.44	7.99	.00	—	−0.99	−1.46	−1.40	−1.85
165207	6.76	6.36	5.88	5.28	.06	.00	−2.23	−2.77	−3.24	−3.82
168785	7.34	7.20	6.77	5.95	.19	—	−1.73	−2.35	−2.74	−3.53
169467	2.03	1.46	1.02	0.49	.00	.03	−1.57	−2.21	−2.65	−3.17
172854	7.75	7.87	7.75	7.21	.18	.00	−0.51	−0.81	−0.90	−1.40
175156	4.91	5.12	5.08	4.61	.19	.33	−1.11	−1.67	−1.65	−2.06
175362	4.07	3.71	3.34	2.96	.01	.00	−1.34	−1.72	−2.09	−2.47

Table 2. Continued

HD No.	$m(2740)$	$m(2365)$	$m(1965)$	$m(1565)$	$E(B-V)_{uv}$	$E(B-V)_{sp}$	$(2740-V)_0$	$(2365-V)_0$	$(1965-V)_0$	$(1565-V)_0$
176582	5.00	4.57	4.18	3.75	.00	.00	−1.41	−1.84	−2.23	−2.66
177003	3.80	3.26	2.82	2.27	.00	.04	−1.70	−2.34	−2.77	−3.31
178993	9.90	9.67	9.45	9.79	.00	—	+0.90	+0.67	+0.45	+0.79
181615	4.67	5.19	5.27	5.14	.22	.34	−0.99	−1.24	−1.11	−1.20
182568	3.66	3.20	2.75	2.14	.03	.10	−1.62	−2.31	−2.75	−3.34
183339	5.46	5.00	4.59	4.17	.00	.00	−1.14	−1.60	−2.01	−2.43
184927	5.77	5.32	4.87	4.25	.03	.07	−1.91	−2.52	−2.96	−3.57
186205	7.71	7.77	7.15	6.52	.27	.29	−1.72	−2.33	−2.89	−3.49
191980	6.63	6.23	5.91	5.61	.00	.00	−1.47	−1.87	−2.19	−2.49
202671	4.47	4.10	3.75	3.36	.00	.00	−0.93	−1.30	−1.65	−2.04
207538	6.83	7.38	6.79	6.38	.42	.63	−2.43	−3.24	−3.76	−4.13
208266	7.60	7.48	6.99	6.76	.10	.43	−1.86	−2.95	−3.38	−3.55
209339	5.43	5.44	4.98	4.30	.23	.35	−2.31	−3.09	−3.50	−4.14
212454	5.09	4.74	4.37	3.99	.01	.00	−1.10	−1.47	−1.84	−2.22
217833	5.57	5.35	4.95	4.54	.07	.00	−1.15	−1.57	−1.95	−2.35
224926	4.09	3.70	3.29	2.87	.01	.01	−1.04	−1.45	−1.86	−2.28
+13°3224	8.64	8.20	7.95	7.67	.00	—	—	—	—	—

by FitzGerald (1970). The colour excess in $(U-B)$ has been estimated through the relation $E(U-B)=0.70\ E(B-V)$.

ii. The intermediate band indices, $(b-y)$, m_1 and c_1 have been corrected for the effects of reddening using the above estimated $E(B-V)$ and also through the standard relations given by Crawford (1973, 1975):

$$E(b-y)=0.70E(B-V),$$

$$E(m_1)=-0.30E(b-y) \text{ and}$$

$$E(c_1)=0.20E(b-y).$$

The apparent magnitude, V is corrected using the ratio of total to selective absorption value $R=3.0$.

iii. The mid-ultraviolet magnitudes of each star have been corrected for reddening effects from the relation

$$A(\lambda)=\frac{A(\lambda)}{E(B-V)}E(B-V)$$

where the values of $A(\lambda)/E(B-V)$ have been given in Table 2 of Thomson's *et al.* Catalogue for each passband as a function of spectral type and reddening.

As a further check, $E(B-V)$ values have also been computed using the relation given in the same Catalogue for B-type stars: $E(B-V)=0.40\,(m(1565)-m(2740))-0.60(m(1565)-m(2365))$. This relation is based on the UV colours alone without recourse to the spectral type and adequately represents the reddening.

As an independent check to our earlier estimate of colour excess, $E(B-V)$, we have computed the colour excesses for a sample of helium stars using the mean interstellar extinction (A_v) maps given by Neckel and Klare (1980) for a given l, b and distance along the plane of the galaxy. In estimating these mean values, we have adopted an absolute magnitude, $M_v \sim -2.0$ based helium stars located in the OB associations (Drilling 1981) and also a value of $R=3.0$. The mean colour excesses thus derived are: HD 60344 (0.06), HD 96446 (0.07 to 0.08), HD 133518 (0.14 to 0.15), HD 168785 (0.16) and HD 184927 (0.06 to 0.07). Inspite of different procedures used in the estimation of $E(B-V)$, in the majority of cases, the values obtained agree quite well. In the event of a large discrepancy between these values, more weight was given to the value obtained through spectral type – intrinsic colour relation. In a few cases where the derived $E(B-V)$ has a negative value, it is treated as zero. In Table 2, columns 6 and 7 show the colour excesses derived from the above procedures, and the rest of the columns give the reddening free parameters. Table 4 shows the data for normal B-type stars used for comparison in this analysis. All columns are self-explanatory.

3. Analysis

Figure 1 shows the position of helium stars on (β, c_0) plane, where c_0 is the c_1-index corrected for interstellar reddening. As we already know from Crawford's work (1975), β-index is an indicator of gravity and c_0 is a temperature parameter for B-type stars.

Table 3.

HD No.	Δ_1	Δ_2	Δ_3	Δ_4	log T_{eff}
5737	+0.01	+0.06	+0.77	0.70	4.21
19400	−0.01	+0.09	0.77	0.69	4.24
21699	+0.03	−0.07	0.63	0.67	4.20
22470	−0.08	+0.15	0.74	0.67	4.20
22920	−0.05	+0.09	0.73	0.69	4.22
23408	−0.16	+0.02	0.74	0.88	4.15
28843	00.00	−0.00	0.78	0.78	4.23
35298	+0.03	−0.05	0.67	0.69	4.21
36046	+0.16	−0.04	0.70	0.58	4.19
36526	−0.19	+0.38	0.85	0.66	4.23
36549	+0.13	+0.22	0.77	0.42	4.16
36629	−0.17	−0.04	1.13	1.34	4.41
36668	−0.29	+0.58	0.89	0.60	4.20
36916	+0.02	+0.13	0.72	0.57	4.21
37043	+0.43	+0.04	1.37	0.90	4.49
37129	+0.05	−0.11	0.95	1.01	4.38
37235	+0.16	−0.31	0.72	0.87	4.23
37321	−0.05	−0.08	0.87	1.00	4.32
37776	+0.15	−0.09	0.95	0.89	4.39
44953	00.00	00.00	0.74	0.74	4.23
49333	+0.05	−0.02	0.79	0.76	4.26
49606	+0.03	−0.03	0.73	0.73	4.16
51688	−0.02	+0.05	0.76	0.73	4.17
58260	+0.21	−0.17	0.91	0.87	4.34
60344	+0.24	−0.23	0.92	0.91	4.33
61641	+0.33	−0.16	1.17	1.00	4.37
62712	−0.03	+0.05	0.89	0.87	4.23
62714	+0.04	−0.07	0.78	0.81	4.18
64740	+0.23	−0.16	1.15	1.08	4.41
79158	−0.17	+0.22	0.69	0.64	4.16
79447	+0.16	−0.03	0.98	0.85	4.31
82924	+0.22	−0.13	0.94	0.85	4.28
84046	−0.35	+0.39	0.71	0.67	4.16
90264	−0.01	−0.05	0.81	0.77	4.22
96446	+0.26	−0.23	1.00	0.97	4.34
100340	+0.22	−0.45	0.90	1.13	4.44
109026	+0.06	−0.07	0.90	0.91	4.28
120640	+0.21	−0.17	1.07	1.03	4.37
125823	+0.12	−0.10	0.96	0.94	4.33
133518	−0.02	−0.24	0.92	1.18	4.33
135038	−0.30	+0.05	1.40	0.65	4.26
135485	+0.01	−0.02	0.79	0.80	4.24
137509	+0.26	+0.51	0.82	0.57	4.15
142301	−0.07	−0.10	0.67	0.84	4.21
142884	−0.15	−0.05	0.63	0.83	4.17
142990	+0.02	−0.17	0.82	0.97	4.28
143699	+0.04	−0.07	0.82	0.85	4.25
144334	−0.08	−0.02	0.70	0.80	4.21
144661	−0.14	−0.02	0.72	0.88	4.21
144844	−0.02	−0.08	0.68	0.78	4.15
144941	—	+1.78	—	2.86	4.33
146001	+0.02	−0.09	1.00	1.07	4.24
151346	−0.36	+1.10	1.52	0.78	4.30

Table 3. Continued.

HD No.	Δ_1	Δ_2	Δ_3	Δ_4	log T_{eff}
160641	+0.53	−0.51	0.41	0.39	4.14
165207	+0.07	−0.11	1.01	1.05	4.42
168785	+0.21	−0.40	0.99	1.18	4.34
169467	+0.20	−0.08	1.08	0.96	4.33
172854	+0.21	−0.41	0.39	0.59	4.06
175156	+0.53	−0.55	0.49	0.51	4.18
175362	+0.92	−0.47	0.74	0.29	4.24
176582	+0.04	−0.04	0.82	0.82	4.26
177003	+0.21	−0.11	1.07	0.97	4.35
178993	+0.01	+0.56	0.45	−0.12	3.86
181615	−0.09	−0.21	−0.31	−0.01	4.09
182568	+0.25	−0.15	1.13	1.03	4.34
183339	+0.05	−0.01	0.87	0.83	4.23
184927	+0.17	−0.17	1.05	1.05	4.38
186205	−0.15	−0.02	1.01	1.18	4.37
191980	+0.08	+0.02	0.72	0.62	4.26
202671	+0.02	−0.04	0.72	0.74	4.18
207538	+0.21	+0.12	1.15	0.82	4.50
208266	+0.69	+0.25	1.51	0.57	4.44
209339	+0.53	−0.25	1.29	1.01	4.46
212454	+0.00	−0.01	0.74	0.75	4.21
217833	+0.04	−0.02	0.80	0.78	4.22
224926	00.00	−0.01	0.82	0.83	4.21
+13°3224	+0.19	−0.03	0.69	0.53	—

The observed positions of these stars on β, c_0 diagram suggest that these stars are not too different in nature when compared to the normal stars of similar spectral types and luminosity classes except the ones which are sub-classified as extreme. However it is likely that some stars are effected by variable $H\beta$ emission as seen in σ Ori E and HD 64740.

Figures 2a, b, c and d show the relation between $(m_{2740} - V)_0$, $(m_{2365} - V)_0$, $(m_{1965} - V)_0$ and $(m_{1565} - V)_0$ against c_0-index respectively for both helium stars and normal stars. The late-type helium stars lie considerably above the band drawn for normal stars indicating less flux in the *uv* bands relative to normal stars and show maximum deviation towards shorter wavelength region. These indices can thus be effectively used to distinguish the helium stars from normal stars.

Further, we have defined the following indices in order to see the nature of mid-ultraviolet fluxes of these stars:

$$\Delta_1 = m_0(2740 - 2365) - m_0\,(2365 - 1965)$$

$$\Delta_2 = m_0(2365 - 1965) - m_0\,(1965 - 1565)$$

$$\Delta_3 = m_0(2740 - 2365) + m_0\,(2365 - 1965)$$

and

$$\Delta_4 = m_0(2365 - 1965) + m_0\,(1965 - 1565)$$

The values of Δ_1, Δ_2, Δ_3 and Δ_4 are given in Table 3 for each of the stars and Table 4 gives these values for normal stars.

Table 4. Normal stars.

HR No.	Sp. type	$E(B-V)$	m_{2740}	m_{2365}	m_{1965}	m_{1565}	Δ_1	Δ_2	Δ_3	Δ_4
801	B3V	0.07	3.35	2.90	2.47	1.96	+0.19	−0.08	1.03	0.92
811	B7V	0.00	3.33	2.96	2.53	2.14	−0.06	+0.04	0.80	0.82
1144	B8V	0.04	4.98	4.70	4.25	3.84	−0.06	+0.04	0.82	0.84
1641	B3V	0.02	1.77	1.20	0.77	0.24	+0.20	−0.11	1.04	0.95
1861	B1V	0.07	3.40	2.83	2.38	1.77	0.33	−0.20	1.13	1.00
2056	B5V	0.01	3.64	3.19	2.75	2.25	0.03	−0.06	0.91	0.94
2845	B7V	0.04	2.31	1.97	1.62	1.30	0.10	+0.03	0.78	0.65
3454	B4V	0.02	2.70	2.13	1.71	3.67	0.20	+2.39	1.04	−1.55
3849	B5V	0.02	3.79	3.32	2.89	2.41	+0.09	−0.04	0.95	0.90
3856	B9V	0.00	4.05	3.72	3.31	3.04	−0.08	+0.14	0.74	0.68
3982	B7V	0.02	0.77	0.32	−0.05	−0.38	+0.13	+0.05	0.87	0.69
6165	B0V	0.05	0.73	−0.02	−0.57	−1.24	0.33	−0.13	1.41	1.21
39	B2IV	0.01	1.07	0.37	−0.04	−0.60	0.31	−0.15	1.13	0.97
153	B2IV	0.04	1.93	1.33	0.93	0.40	0.31	−0.13	−1.09	0.91
1956	B7IV	0.01	1.80	1.38	1.02	0.64	0.08	−0.02	0.80	0.74
2106	B2.5IV	0.04	2.95	2.46	2.07	1.59	0.21	−0.09	0.97	0.85
5953	B0.3IV	0.18	0.68	0.23	−0.26	−0.93	0.42	−0.20	1.32	1.10
6092	B5IV	0.02	2.68	2.20	1.79	1.33	0.12	−0.04	0.94	0.86
6588	B3IV	0.02	2.31	1.80	1.37	0.82	+0.14	−0.13	0.98	0.97
7906	B9IV	0.01	3.45	3.11	2.71	2.38	−0.04	+0.07	0.76	0.73
9076	B9IV	0.00	4.09	3.77	3.42	3.20	−0.03	+0.13	0.67	0.57
193	B5III	0.10	3.70	3.46	3.04	2.54	+0.09	−0.10	0.87	0.88
1552	B2III	0.08	2.06	1.56	1.29	0.73	+0.44	−0.30	0.94	0.80
7178	B9III	0.02	4.63	4.40	4.07	3.91	−0.05	+0.18	0.61	0.48
7446	B0.5IIIn	0.27	3.52	3.39	3.07	2.33	+0.38	−0.33	1.12	1.07
7447	B5III	0.09	3.50	3.24	2.77	2.30	+0.02	−0.01	0.92	0.91
8353	B8III	0.00	2.33	1.96	1.55	1.21	−0.04	+0.07	0.78	0.75
8781	B9.5III	0.00	2.55	2.32	1.95	1.87	−0.14	+0.29	0.60	0.45

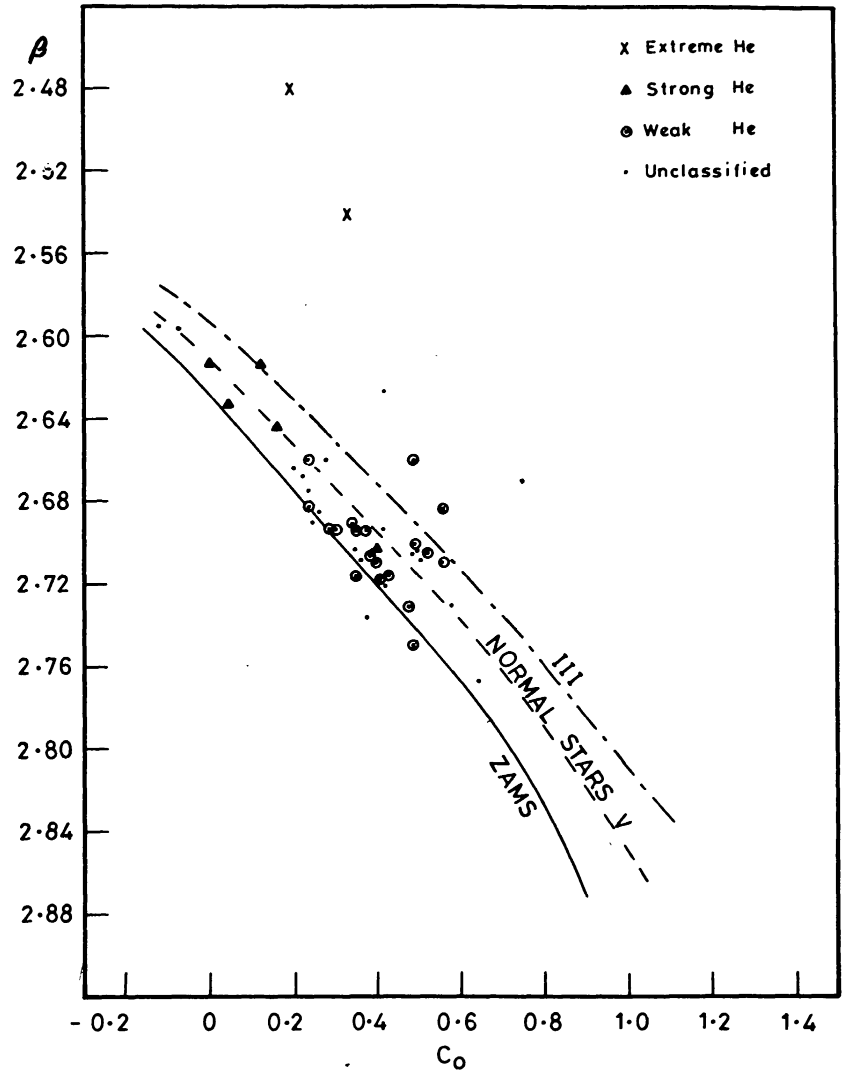

Figure 1. The relation between β-index and c_0.

Figure 3a shows the relation between Δ_1 and $(U-B)_0$ for all program and normal stars. Around 50 percent of the program stars lie above the band described for normal stars. In addition, both helium-weak and helium-strong stars are separated and the mean Δ_1-index of these two groups differs by $0^m.2$.

Figure 3b shows the relation between Δ_3 and $(U-B)_0$. In this diagram, almost all program stars clearly lie above the band drawn for normal stars and thus enable one to distinguish the peculiar stars from the normal stars.

In the plots between Δ_1, Δ_2 and Δ_3, Δ_4 the helium stars lie within the band described by the normal stars.

3.1 *Effective Temperatures of Helium Stars*

Lesh (1977) found a linear correlation between Θ and the $(1910-V)_0$ colour index using OAO-2 band at 1910 A and T_e values from Code *et al.* (1976) for stars earlier

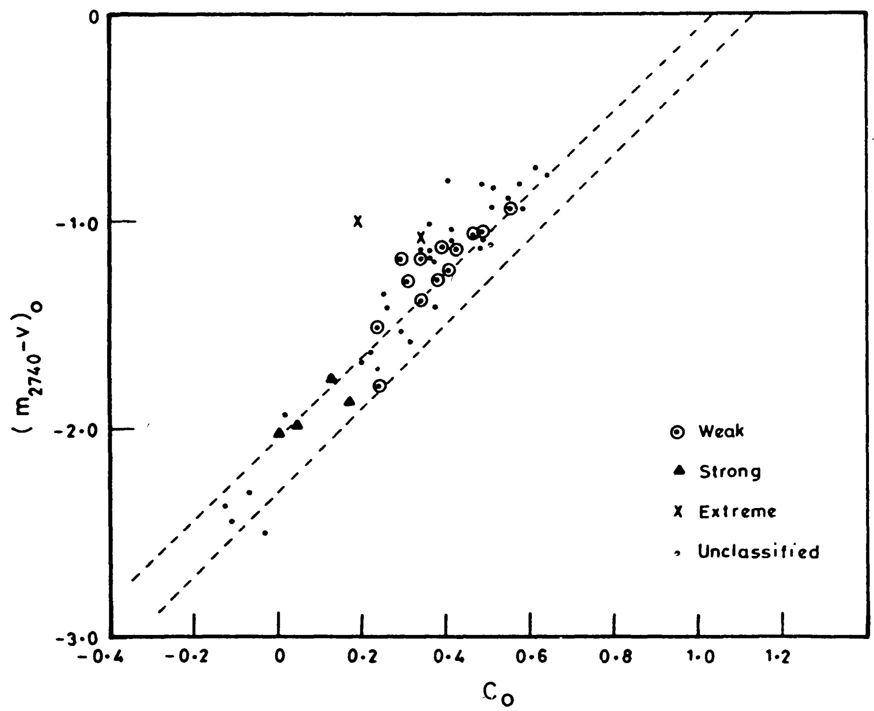

Figure 2a. The relation between $(m(2740) - V)_0$ and c_0-index.

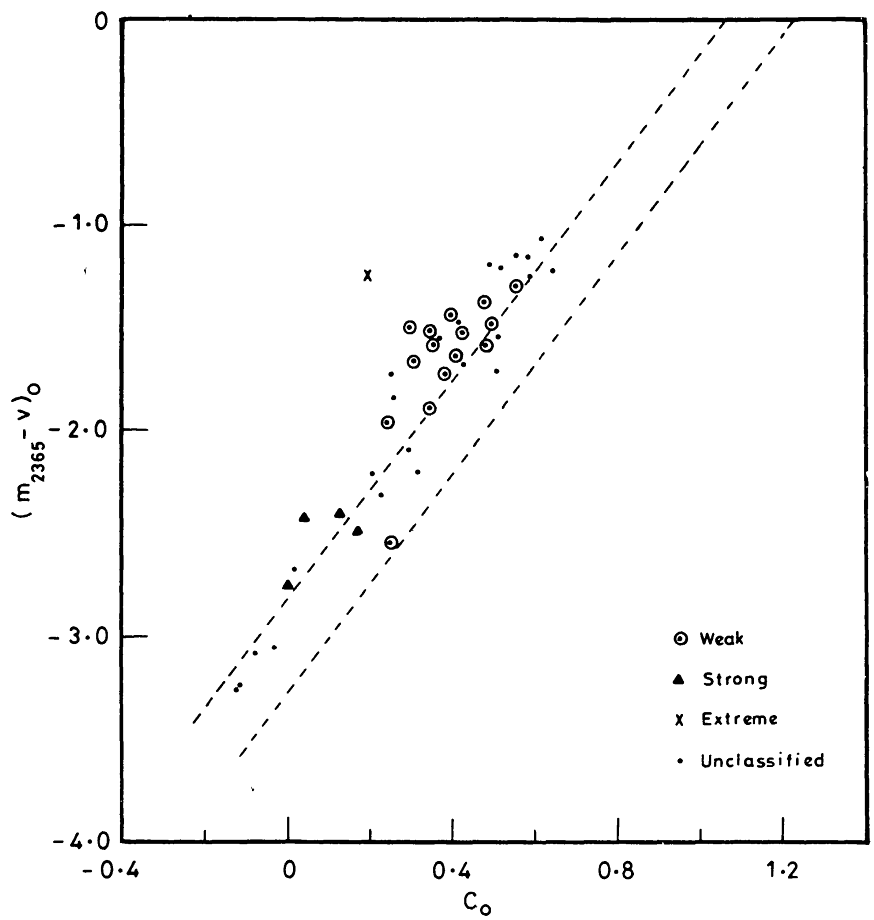

Figure 2b. The relation between $(m(2365) - V)_0$ and c_0-index.

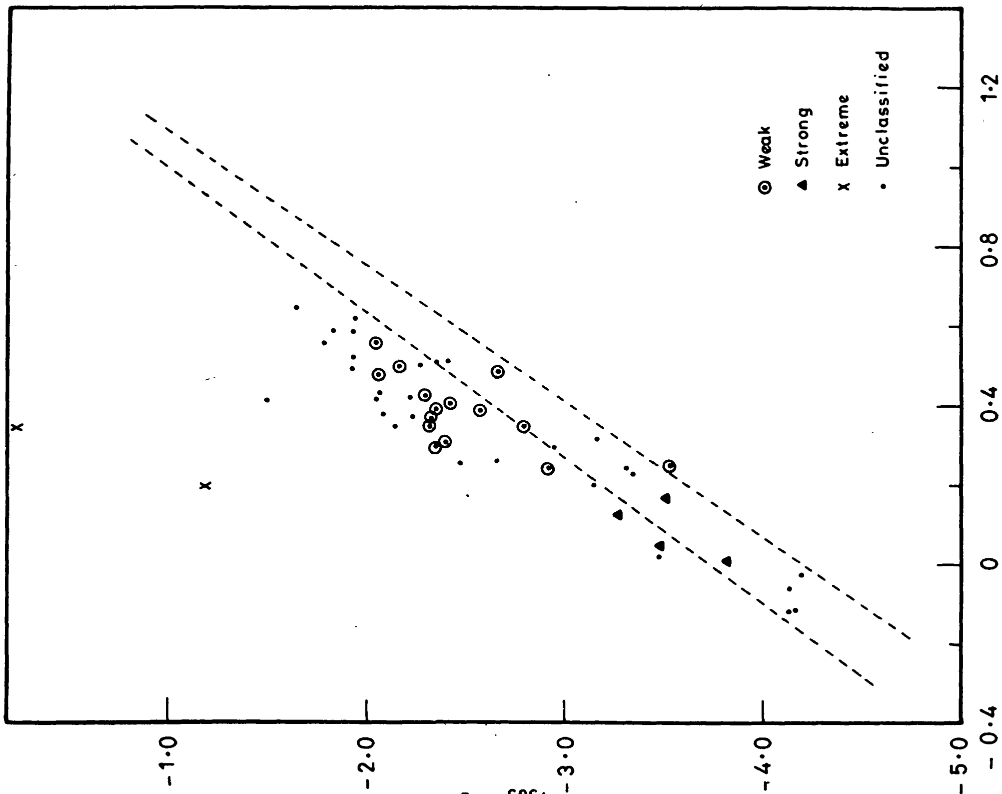

Figure 2d. The relation between $(m(1565) - V)_0$ and c_0-index.

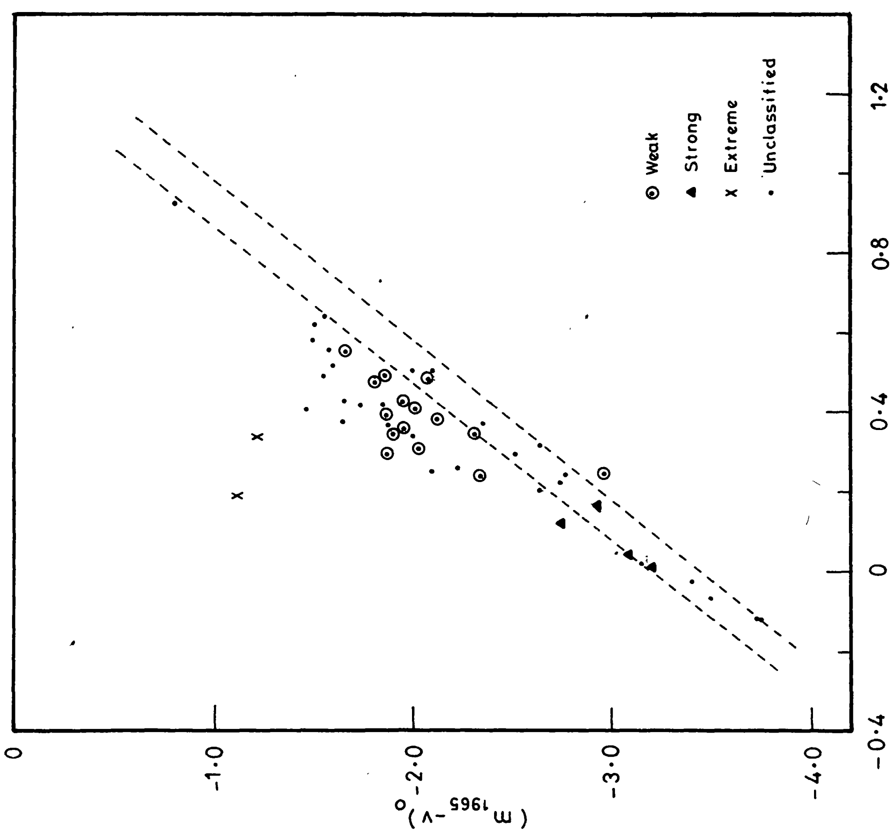

Figure 2c. The relation between $(m(1965) - V)_0$ and c_0-index.

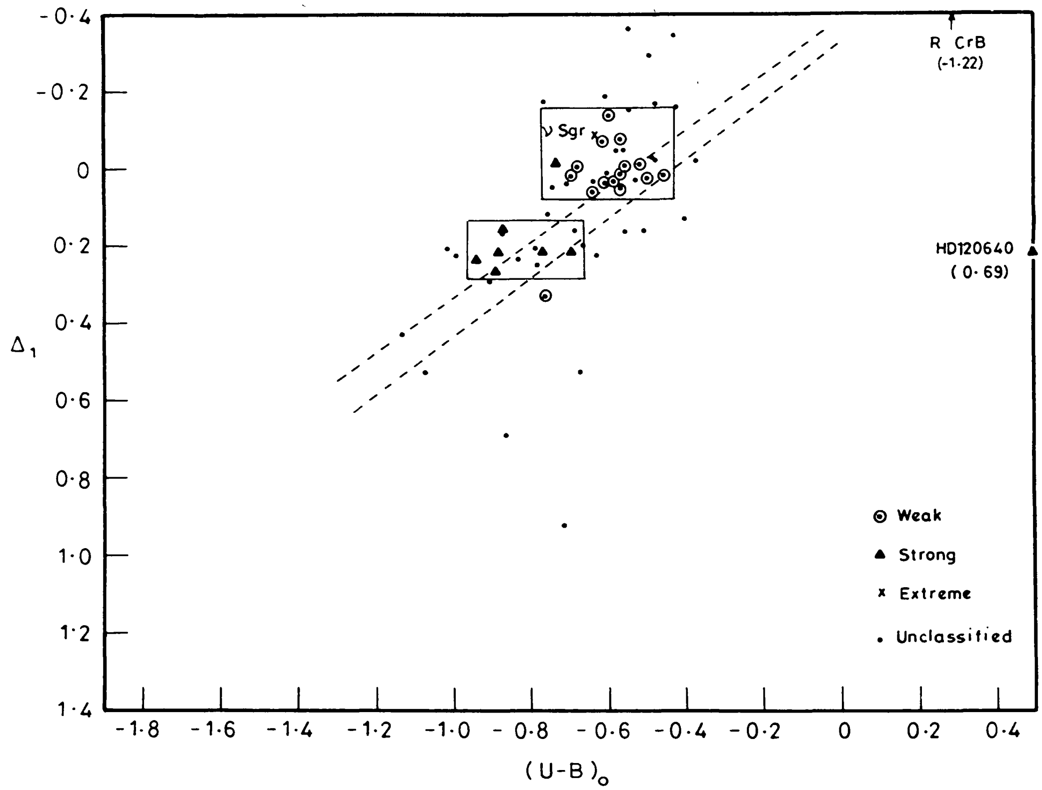

Figure 3a. The relation between Δ_1 and $(U-B)_0$.

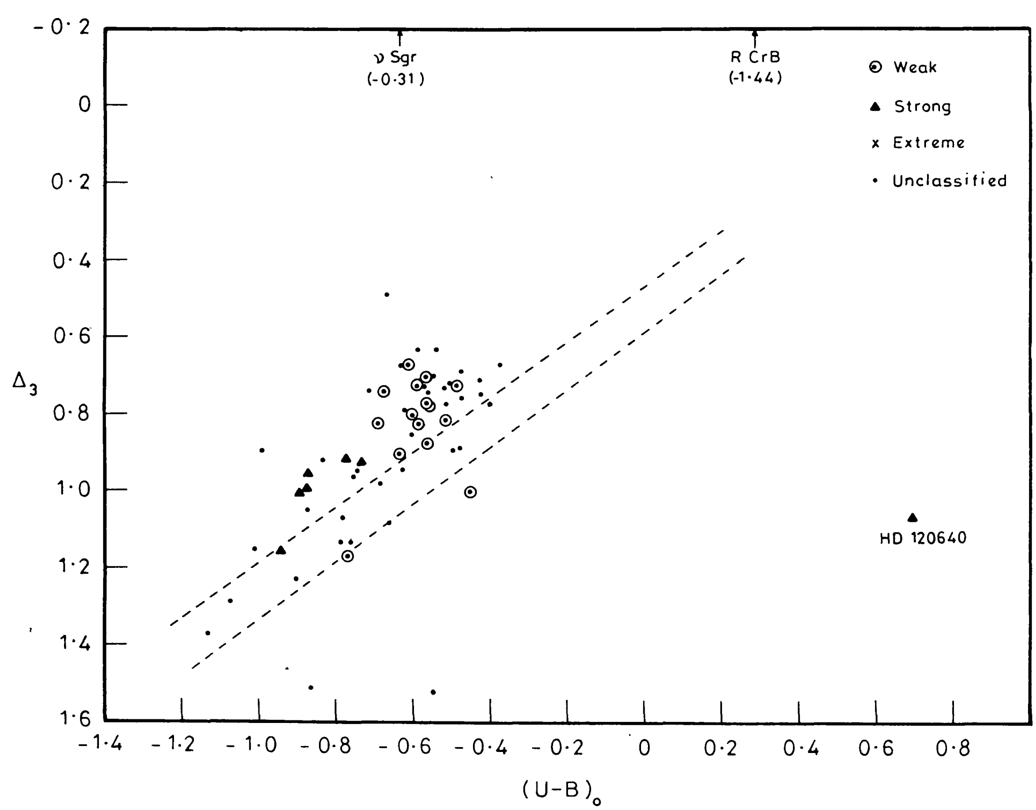

Figure 3b. The relation between Δ_3 and $(U-B)_0$.

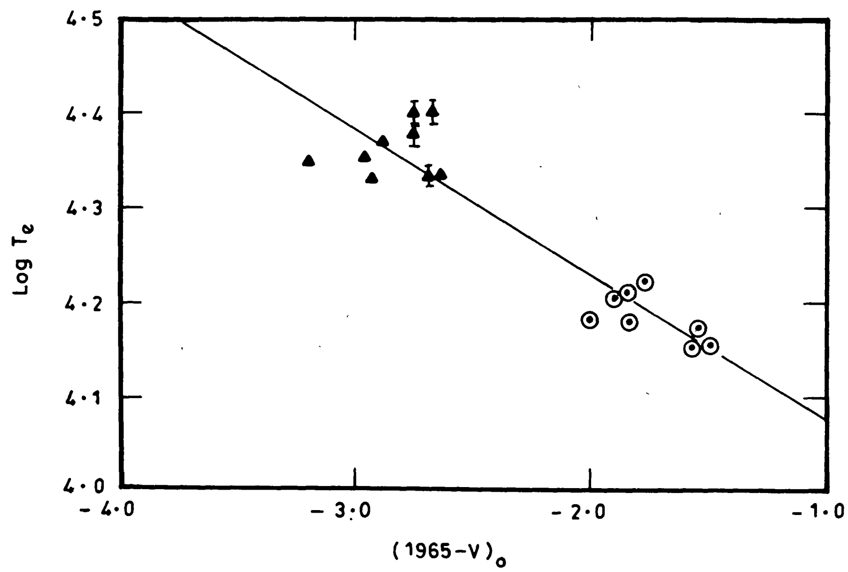

Figure 4. The relation between log T_e and $(1965 - V)_0$ index for Helium stars. The solid line represents the linear least-square relation.

than A2. Malagnini *et al.* (1984) had derived a quantity, $R = \log F(1965)/F(5445)$, proportional to a $(UV - V)$ colour index, and found that to correlate with Θ_e for B5 to F non-supergiant stars. Since in the present analysis, one of the photometric passbands (1965 A) closely matches with that of OAO-2 passband (1910 A) and since the band 1965 A does not include any major spectral features which differ between normal and the peculiar stars, we tried to investigate whether the index $(1965 - V)_0$ refers to the effective temperature for all the B-stars, both peculiar or otherwise.

Figure 4 shows the relation between log $T_{\rm eff}$ and $(1965 - V)_0$ for helium stars, both strong-line and weak-line, irrespective of luminosity classification. The effective temperatures used are the estimated ones from model-atmosphere analysis. Table 5 gives the list of helium objects used for this calibration. A linear least-square relation,

$$\log T_{\rm eff} = (-0.1508 \pm 0.0165)(1965 - V)_0 + 3.9278 \pm 0.0376$$

is obtained for B-type helium stars. From this relation, we had derived the effective temperatures of other helium stars from their observed $(1965 - V)_0$ indices and are given in Table 3. Figure 5 shows the difference in the estimation of effective temperature, in the sense, $T_{\rm eff}(1965 - V)_0 - T_{\rm eff}$ (spectral type) against the spectral type for all those stars for which spectral type and luminosity class are given. It is evident that the effective temperatures derived from $(1965 - V)_0$ index are somewhat higher than those of MK spectral type for a majority of helium stars. Besides, the difference increases as we progress towards the later spectral types reaching a value of around 4000–6000 K for B8 and B9 types of helium weak objects. For strong-line stars, an average difference of 1000 K–1500 K has been estimated. There are a few stars, HD 183339 (B8IV + 9100 K) a helium weak object, HD 125823 (B7IIIp, + 8400 K) an unclassified object which differ considerably from the mean differences mentioned above; HD 79158, a weak-line object, (B0.5II, − 10,400 K). Thus the $T_{\rm eff}$ estimated from spectral type alone can at best be only a lower limit.

From figure 5, it is also seen that a large dispersion exists in $T_{\rm eff}$ within any given spectral subclass and the dispersion seems to be much larger than the uncertainties

Table 5. Helium stars used for effective temperature calibration.

HD No.	Model atmosphere*	$(1965-V)_0$ index**	Spectral type	Spectral class	Nature
5737	15300 K	16070 K	11930 K	B8III	Weak
21699	16600	15700	10780	B9III	Weak
23408	14000	14220	12750	B7III	Weak
49606	14800	14320	11930	B8III	Weak
60344	25000 ± 1000	21380	22820	B2V	Strong
64740	22400	25700	25720	B1.5V	Strong
79158	14000	14590	25000	B0.5II	Weak
96446	25250 ± 350	21980	22820	B2V	Strong
120640	21300	23390	22820	B2V	Strong
133518	21400	21280	18530	B3V	Strong
144334	16000	16370	11930	B8III	Weak
144941	21500 ± 500	21430	—	B8	Strong
168785	24000 ± 1000	21980	—	B3	Strong
183339	15300	17020	11900	B8IV	Weak
184927	22500	23710	22820	B2V	Strong
186205	23500	23170	22820	B2V	Strong
217833	16300	16670	10780	B9III	Weak

*From B stars with and without emission eds. A. Underhill and V. Doazan, NASA SP-456, p. 159–163.
**From this analysis

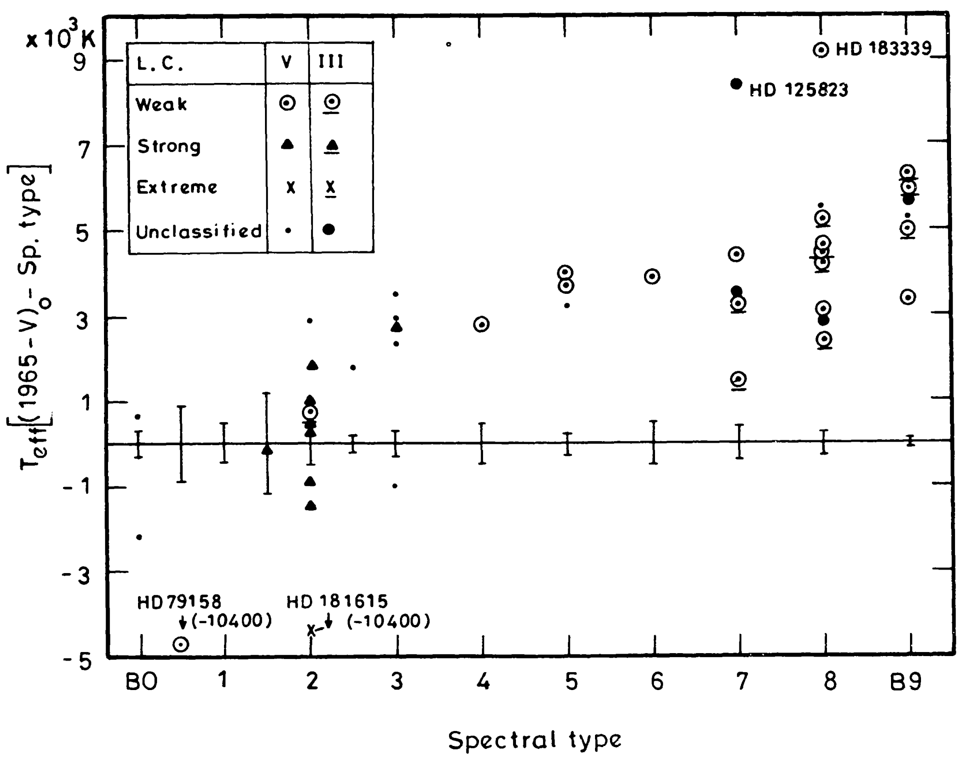

Figure 5. The relation between $\Delta T_e = T_e(1965-V)_0 - T_e$ (sp. type) and spectral type. The vertical bar corresponds to the mean difference in the effective temperatures between luminosity classes III and V.

associated with the individual T_{eff}. Malagnini *et al.* (1984) have also noticed a similar kind of dispersion for B5 and later types while estimating the effective temperatures from *U V* index. For B5 stars, they had obtained extremes in T_{eff}, around 2500 K apart and interpreted the observed dispersion in terms of the different behaviour of spectral energy distribution in the *U V* and visual regions and emphasized that the noticeable dispersion is not a result of the errors in $E(B-V)$. In the present analysis, we had estimated the colour excess, $E(B-V)$, for each star using two or three different techniques and in a majority of cases, the dispersion noticed in $E(B-V)$ is of marginal nature and thus, the differences in effective temperatures reflect the behaviour of energy distribution between *U V* and visual regions.

Finally, it is interesting to note the position of HD 61641 (B2IV–V), a weak-line star, in the figures 2 to 4. Kroll (1987) had inferred from the IRAS data that HD 61641 has a circumstellar dust shell on the basis of excess flux in the IRAS passbands.

4. Conclusions

The following conclusions could be drawn from the above investigation:

1. Regarding the attempts to segregate helium stars from normal B-type objects it is possible to separate these objects using with some care Δ_3 and $(U-B)_0$ plane and also $(2365-V)_0$, $(1965-V)_0$ with c_0.
2. A linear relation is obtained between $(1965-V)_0$ index and the effective temperature derived from model atmosphere analysis.
3. The effective temperatures estimated from $(1965-V)_0$ index are higher, especially for weak-line stars in the spectral range B6–B9, compared to the effective temperatures derived from spectral types.

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