THE ASTROPHYSICAL JOURNAL, 469:355–365, 1996 September 20

TRANSFORMATIONS FROM THEORETICAL HERTZSPRUNG-RUSSELL DIAGRAMS TO COLOR-MAGNITUDE DIAGRAMS: EFFECTIVE TEMPERATURES, $B-V$ COLORS, AND BOLOMETRIC CORRECTIONS

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Received 1995 November 27; accepted 1996 April 2

ABSTRACT

This paper provides improved numerical relations between effective temperatures of stars, their $B-V$ colors, and their bolometric corrections (BCs) for the purpose of comparing theoretical stellar evolutionary calculations to color-magnitude diagrams of star clusters. Temperatures and bolometric correction measurements for 335 stars from the literature form the observational basis for the transformations. Measured temperatures range from 2900 to 52,500 K. Polynomial fits to the observations give relations between effective temperatures and $B-V$ colors and between temperatures and bolometric corrections. Hot supergiants appear to have a $T_{\rm eff}:B-V$ relation slightly different from those of main-sequence stars, subgiants, and giants. All luminosity classes appear to follow a unique $T_{\rm eff}$:BC relation. The $T_{\rm eff}$:BC relation for stars with temperatures less than ~5000 K, however, is uncertain because temperatures of the coolest stars are determined from uncertain angular diameters.

Subject headings: Hertzsprung-Russell diagram — stars: atmospheres — stars: early-type — stars: fundamental parameters — stars: late-type — stars: supergiants

1. INTRODUCTION

Many observational tests of stellar evolutionary theory rely on the ability to compare theoretical parameters (log L and log $T_{\rm eff}$) of theoretical evolutionary tracks to observed parameters (V and $B-V$, for instance) of stars in star clusters. It is of primary importance, therefore, to establish accurate empirical scales of bolometric corrections (BCs), colors, and effective temperatures to convert the theoretically derived parameters to observational parameters. Since the publication of the comprehensive scales by Flower (1977), observers and theoreticians have made improved empirical scales possible by determining temperatures, bolometric corrections, and colors for several hundred stars.

This paper collects temperature and bolometric correction measurements for 335 stars for the purpose of establishing refined numerical relations between effective temperature and bolometric correction and between effective temperature and $B-V$ color. The stars span luminosity classes from main-sequence stars (V) to supergiants (I) and temperatures from 2900 to 52,500 K.

Most of the improvements and additions in the last decade to Flower's (1977) scales rely on new temperature measurements of early-type stars (Chlebowski & Garmany 1991; Fitzpatrick & Garmany 1990; Humphreys & McElroy 1984; Malagnini et al. 1986; Massey, Parker, & Garmany 1989; Napiwotzki, Schönberner, & Wenske 1993); some additions have been made to the cool end as well (Habets & Heintze 1981; Humphreys & McElroy 1984).

At the same time, many groups have concentrated on determining temperatures and bolometric corrections for individual stars using a variety of techniques. Temperature and bolometric correction estimates for the hottest stars require fitting observed photospheric line profiles to stellar atmosphere models (Bohannan et al. 1986; Kudritzki 1980; Kudritzki, Simon, & Harmann 1983; Simon et al. 1983; Voels et al. 1989). For cooler stars, observed flux distributions are used instead (Bell & Gustafsson 1989; Beeckmans 1977; Blackwell, Lynas-Gray, & Petford 1991; Cayrel de Strobel et al. 1989; Code et al. 1976; Fitzpatrick 1987; Leggett et al. 1986; Malagnini & Morossi 1990; Malagnini et al. 1985, 1986). For nearby stars, it is possible to use angular diameters and observed bolometric fluxes to derive effective temperatures (Faucherre et al. 1983; Ridgway et al. 1980).

The above references to temperature and bolometric correction measurements form the basis of the new $T_{\rm eff}:B-V$:BC scales derived in this work. Of 335 stars, 297 have measured effective temperatures with reliable $B-V$ colors and 122 have measured bolometric corrections as well as effective temperatures. This database is rich enough to numerically fit measured temperatures, colors, and bolometric corrections with polynomials over the entire range of temperature for each luminosity class.

Although bolometric corrections seem to be well determined for cool stars, temperatures for the coolest giants derived from angular diameters (Ridgway et al. 1980) are in disagreement with temperatures determined by other means. Since these bolometric corrections constitute the bulk of those for cool stars in this study, the $T_{\rm eff}$:BC scale for the coolest stars remains uncertain.

2. METHOD

The first step in establishing the temperature scales was to separate the stars by luminosity class and then to fit both effective temperatures and colors and effective temperatures and bolometric corrections with polynomials. I used straight averages of temperatures and bolometric corrections for stars observed by more than one group.

2.1. $T_{\rm eff}:B-V$ *Scales*

A total of 297 stars form the database for the $T_{\rm eff}:B-V$ transformations. Of these, 93 were measured more than once, resulting in 530 individual temperature determinations. Figure 1 shows the measurements separated by luminosity class and Table 1 lists the data for individual

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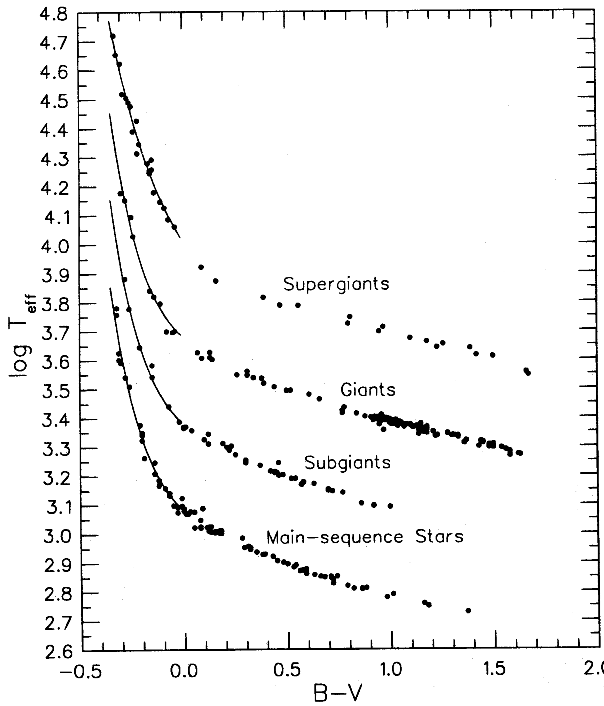

FIG. 1.—Effective temperatures and colors for all stars in Table 1 separated by luminosity class. Temperatures of giants, subgiants, and main-sequence stars are lower by 0.3 in log T_{eff} than the next more luminous class. The lines are to help guide the eye at high temperatures

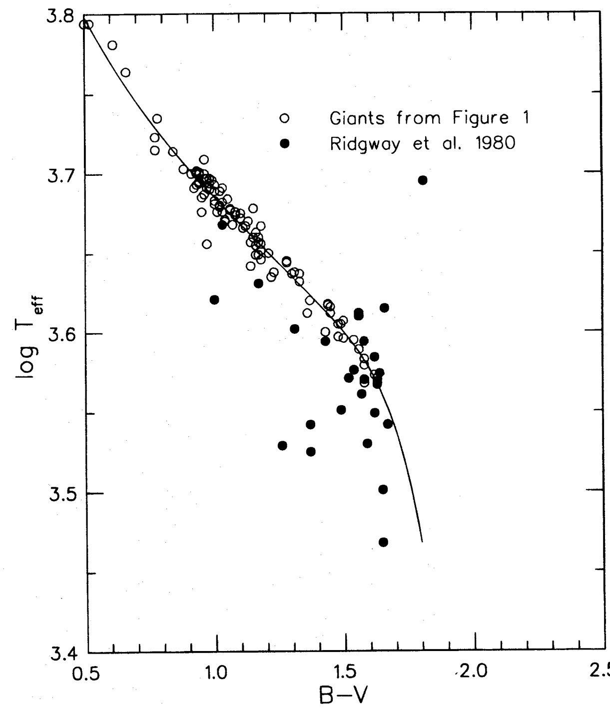

FIG. 2.—Temperatures of Ridgway et al. (1980) compared to the temperatures of the giants in Fig. 1. The curve is a polynomial fit to giants, subgiants, and main-sequence stars.

stars. The uncertainties in derived temperatures, Δ log T, listed in Table 1 are by those making the measurements. Uncertainties in measured colors, $\Delta(B-V)_0$, are taken from measurements or from FitzGerald (1970). Since most stars in these studies are bright and nearby, individual reddening values are generally very small and do not significantly contribute to the uncertainties in colors. Most star numbers under the heading "Star" in Table 1 are HR numbers but a few HD numbers are listed. Also, Fitzpatrick (1987) uses Sanduleak (1969) numbers for the LMC supergiants. The column "LC" gives the luminosity class of each star.

A problem arose in comparing the temperatures of Ridgway et al. (1980) to other temperatures for giants. Figure 2 shows the comparison of the giants shown in Figure 1 to the temperatures measured by Ridgway et al. (1980). For the most part, the Ridgway et al. (1980) temperatures are lower than the rest. Of four stars in common with Blackwell et al. (1990) and Bell & Gustafsson (1989), the Ridgway et al. (1980) temperatures averaged 380 K lower. The tight grouping of the giants in Figure 1 suggests the presence of systematic uncertainties in the Ridgway et al. (1980) temperatures and perhaps with temperatures derived from angular diameters in general.

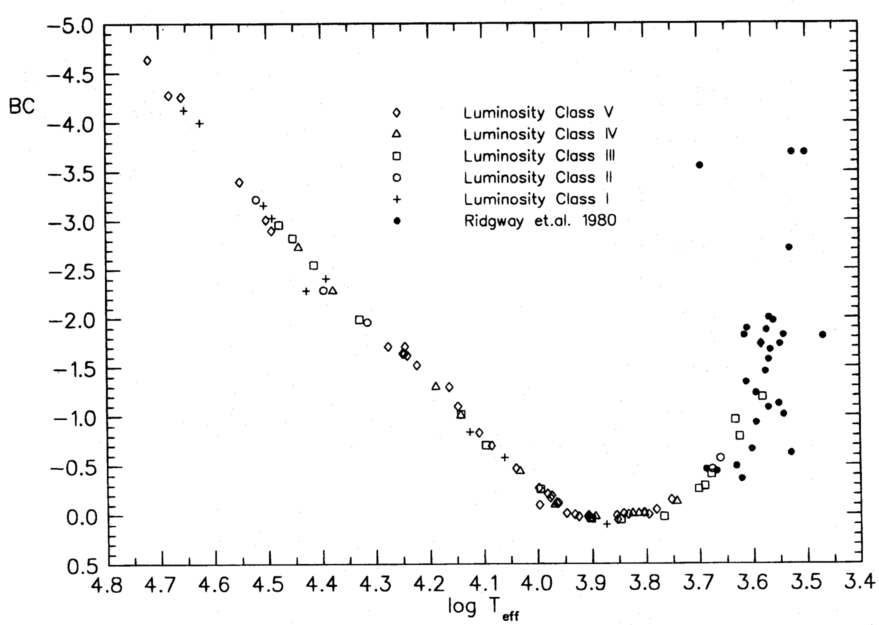

FIG. 3.—Bolometric corrections by luminosity class for all stars in Table 2. The Ridgway et al. (1980) temperatures are their "uncorrected" values.

TABLE 1

T_{eff}: $B-V$ DATA

log T	$(B-V)_0$	Δ log T	$\Delta(B-V)_0$	Star	LC	Reference
3.838	0.34	0.006	0.030	0021	3	b
3.911	0.17	0.016	0.030	0100	5	mm
4.041	–.07	0.017	0.025	0126	5	mm
3.644	1.28	0.010	0.079	0165	3	b
3.678	1.15	0.027	0.079	0168	3	f
3.774	0.57	0.016	0.050	0219	5	b bg
3.596	1.50	0.011	0.080	0224	3	b bg
3.907	0.13	0.005	0.030	0269	5	b mm m2
3.701	0.93	0.009	0.062	0271	3	b
3.583	1.58	0.011	0.050	0337	3	b f
3.904	0.17	0.003	0.052	0343	5	b
3.925	0.13	0.019	0.030	0403	5	mm
3.816	0.42	0.007	0.041	0417	4	b
3.612	1.36	0.009	0.080	0434	3	b bg
3.792	0.54	0.002	0.035	0458	5	b
3.645	1.28	0.010	0.080	0464	3	b bg
4.163	–.19	0.015	0.020	0472	5	be c
3.728	0.72	0.002	0.054	0509	5	b
3.803	0.48	0.007	0.041	0544	4	b
3.886	0.28	0.017	0.030	0591	5	mm m2
3.661	1.18	0.023	0.100	0603	2	f
3.642	1.14	0.022	0.080	0617	3	bg f
3.926	0.10	0.005	0.030	0620	4–5	b
3.679	0.98	0.009	0.062	0753	5	bg
3.921	0.08	0.014	0.030	0804	5	mm
4.108	–.14	0.010	0.020	0811	5	m2
3.860	0.31	0.009	0.020	0813	3–4	mm
3.666	1.11	0.009	0.079	0824	3	bg
3.573	1.62	0.012	0.048	0911	3	b
3.944	0.12	0.015	0.020	0919	4	mm
3.778	0.59	0.002	0.050	0937	5	b
3.750	0.68	0.012	0.050	0996	5	b bg mm m2
4.246	–.16	0.013	0.020	100–67	1	fi
3.789	0.47	0.007	0.100	1017	1	b
3.703	0.88	0.009	0.062	1030	3	b
3.840	0.40	0.025	0.030	1083	4–5	mm
3.712	0.88	0.008	0.062	1084	5	bg
3.774	0.58	0.002	0.035	1101	5	b
4.141	–.16	0.010	0.020	1122	3	m2
3.697	0.92	0.009	0.089	1136	4	bg
3.970	0.01	0.028	0.030	1251	5	mm
3.678	1.06	0.009	0.079	1256	3	b
3.696	0.95	0.009	0.100	1303	1	b
3.710	0.82	0.008	0.060	1325	5	b bg
3.696	0.99	0.009	0.079	1346	3	b
3.694	0.98	0.009	0.079	1373	3	b
3.905	0.15	0.001	0.030	1380	5	b
3.691	0.97	0.009	0.062	1396	3	b
4.279	–.17	0.013	0.020	14–67	1	fi
3.693	1.00	0.009	0.060	1409	3	b bg
4.086	–.07	0.013	0.020	145–67	1	fi
3.595	1.54	0.011	0.080	1457	3	b bg
3.697	0.98	0.009	0.062	1464	3	bg
3.910	0.12	0.001	0.030	1473	5	b
4.249	–.20	0.014	0.020	1641	5	m2
3.922	0.09	0.010	0.020	1666	2	mm
3.845	0.30	0.006	0.030	1676	4	b
4.061	–.04	0.011	0.020	1713	1	be c
3.772	0.63	0.007	0.078	1729	4–5	b
4.441	–.28	0.015	0.020	1756	5	m2
4.329	–.24	0.030	0.020	1790	3	be c
4.060	–.04	0.013	0.020	18–65	1	fi
4.390	–.24	0.054	0.020	1903	1	be c
3.676	0.95	0.009	0.080	1907	3	b bg
3.908	0.13	0.005	0.030	1937	3	b
4.490	–.26	0.028	0.020	1948	1	be c
3.649	1.16	0.010	0.079	1963	3	b
3.693	0.93	0.009	0.060	1995	3	b bg
3.922	0.08	0.016	0.030	1998	5	mm
4.427	–.22	0.018	0.020	2004	1	c
4.033	–.07	0.010	0.020	2010	5	m2
3.655	1.16	0.010	0.079	2040	3	bg
3.767	0.59	0.007	0.050	2047	5	bg
3.547	1.67	0.025	0.100	2061	1	t
3.683	1.00	0.009	0.080	2077	3	b bg
3.679	1.02	0.009	0.062	2219	3	b
4.395	–.25	0.036	0.020	2294	2–3	be c
3.874	0.16	0.029	0.020	2326	1–2	be c
3.969	0.00	0.019	0.020	2421	4	be c mm
3.650	1.21	0.010	0.079	2427	3	b
3.639	1.39	0.010	0.100	2473	1	b
3.997	–.01	0.009	0.020	2491	5	be c
3.672	1.10	0.009	0.079	2506	3	b
3.907	0.09	0.005	0.030	2540	3	b
3.899	0.21	0.016	0.030	2550	4	mm
4.292	–.15	0.013	0.020	256–67	1	fi
3.600	1.43	0.011	0.079	2574	3	bg
4.314	–.22	0.022	0.020	2618	2	b2 c
3.787	0.56	0.030	0.020	2693	1	c
3.926	0.07	0.005	0.030	2751	3	b
3.676	1.03	0.009	0.062	2821	3	b
4.125	–.09	0.023	0.020	2827	1	be c
3.848	0.32	0.014	0.030	2852	5	b mm m2
3.819	0.39	0.007	0.150	2930	3	b
3.814	0.44	0.010	0.020	2943	4–5	mm m1 m2 b2 c
3.689	1.00	0.009	0.080	2990	3	b bg f
4.658	–.32	0.028	0.020	303308	5	s
4.477	–.30	0.024	0.020	3055	3	m2
3.605	1.48	0.011	0.079	3249	3	bg
3.714	0.84	0.008	0.062	3323	3	bg
3.657	1.17	0.010	0.079	3403	3	bg
3.978	0.00	0.007	0.020	3410	5	mm
4.258	–.15	0.013	0.020	35–66	1	fi
3.912	0.19	0.014	0.030	3569	4	mm m2
3.965	0.00	0.021	0.020	3685	4	mm c
3.617	1.44	0.010	0.080	3748	2–3	bg
3.723	0.77	0.008	0.100	3771	3–4	bg
3.801	0.46	0.017	0.030	3775	4	mm m2
3.724	0.80	0.008	0.100	3873	2	bg
3.902	0.18	0.019	0.020	3874	5	m2
3.912	0.18	0.007	0.030	3974	5	mm
3.612	1.45	0.011	0.079	3980	3	bg
4.085	–.12	0.014	0.020	3982	5	mm m1 m2 be c
4.179	–.14	0.013	0.020	40–68	1	fi
3.976	0.05	0.006	0.030	4023	5	mm
3.847	0.31	0.020	0.030	4031	3	m2
3.970	0.01	0.023	0.020	4033	4	mm
3.605	1.48	0.011	0.079	4094	3	bg
4.346	–.21	0.013	0.020	41–68	1	fi
4.147	–.14	0.014	0.020	4119	5	m2
3.747	0.81	0.008	0.100	4166	2	bg
3.671	1.04	0.009	0.080	4247	3–4	bg
3.987	–.02	0.027	0.030	4295	4	mm m2
3.668	1.07	0.009	0.079	4301	3	bg
3.657	1.14	0.010	0.079	4335	3	bg
3.924	0.12	0.031	0.030	4357	5	mm m2
3.836	0.37	0.010	0.020	4399	4	mm m2
3.681	1.00	0.009	0.062	4471	3	bg
3.742	0.72	0.008	0.050	4496	5	bg mm
3.646	1.18	0.010	0.079	4518	3	bg
3.947	0.08	0.017	0.020	4534	5	mm c
3.785	0.53	0.007	0.035	4540	5	mm m2
3.637	1.33	0.010	0.079	4630	3	bg
3.977	0.03	0.027	0.030	4660	5	mm
4.096	–.11	0.019	0.020	4662	3	c
3.854	0.30	0.009	0.020	4694	4	mm
3.670	1.13	0.010	0.079	4737	3	bg
3.762	0.59	0.013	0.050	4785	5	bg mm
4.452	–.28	0.013	0.020	4853	3	c
3.764	0.66	0.008	0.150	4883	3	bg m2
3.589	1.56	0.011	0.048	4920	3	b
3.701	0.94	0.009	0.060	4932	3	bg L
3.769	0.57	0.023	0.050	4983	4	bg L mm
3.752	0.71	0.008	0.054	5019	5	bg
4.378	–.26	0.014	0.020	5056	4	c
3.909	0.15	0.012	0.030	5062	5	b mm m2
3.748	0.71	0.008	0.050	5072	5	b bg
3.923	0.11	0.003	0.030	5107	5	b
3.571	1.63	0.012	0.048	5154	3	b
3.811	0.45	0.013	0.040	5185	4	b mm
4.223	–.20	0.016	0.020	5191	5	m2 (L)
3.778	0.58	0.007	0.080	5235	4	b bg mm
3.925	0.08	0.018	0.030	5264	5	m2
3.667	1.12	0.010	0.079	5287	3	bg
3.790	0.54	0.007	0.041	5304	4	b
3.794	0.52	0.008	0.035	5338	3	b mm
3.638	1.23	0.010	0.080	5340	3	b bg
4.024	–.01	0.014	0.020	5350	5	mm
3.796	0.50	0.007	0.040	5404	5	L mm m2
3.752	0.70	0.008	0.078	5409	4	bg
3.637	1.30	0.010	0.080	5429	3	b bg
3.837	0.35	0.006	0.030	5447	5	b L m2
3.836	0.38	0.006	0.030	5487	3	b L mm
3.992	–.03	0.009	0.025	5511	5	mm
3.616	1.45	0.011	0.080	5563	3	bg f
3.846	0.32	0.002	0.030	5570	5	b
3.605	1.49	0.011	0.079	5600	3	b
3.697	0.97	0.009	0.060	5602	3	b bg
3.821	0.43	0.007	0.040	5634	5	b mm
3.685	0.95	0.009	0.060	5681	3	b bg
4.068	–.12	0.028	0.025	5685	5	L
3.857	0.31	0.008	0.030	5733	5	mm
3.676	1.01	0.009	0.080	5777	3–4	bg
3.660	1.17	0.010	0.080	5854	3	b bg
3.692	1.00	0.009	0.089	5901	4	bg
4.000	–.04	0.010	0.030	7528	3	mm m2
3.903	0.23	0.013	0.020	7557	4–5	mm be c
3.704	0.86	0.009	0.080	7602	4	b bg L
3.689	1.02	0.009	0.079	7615	3	bg
4.241	–.20	0.015	0.020	7688	5	m2
4.246	–.20	0.013	0.020	7739	5	m2
3.694	0.94	0.009	0.062	7754	3	b
3.998	–.05	0.009	0.025	7773	5	m2
4.245	–.21	0.016	0.020	7790	4	be c
4.146	–.11	0.013	0.020	78–67	1	fi
3.632	1.33	0.010	0.079	7806	3	bg
3.835	0.37	0.009	0.020	7822	4	mm
3.815	0.39	0.007	0.100	7834	2	b
3.845	0.46	0.013	0.030	7882	4	mm
4.040	–.07	0.008	0.025	7906	4	m2

TABLE 1—*Continued*

log T	$(B-V)_0$	Δ log T	$\Delta(B-V)_0$	Star	LC	Reference
3.680	1.02	0.009	0.062	5908	3	bg
3.772	0.56	0.002	0.035	5914	5	b
3.802	0.48	0.007	0.040	5933	5	L mm
3.635	1.22	0.010	0.080	5947	3	bg L
4.482	−.28	0.014	0.020	5953	4	be c
3.810	0.44	0.013	0.030	5977	4	mm
3.789	0.52	0.007	0.041	5986	4	b
4.410	−.26	0.024	0.020	5993	5	m2
3.579	1.58	0.010	0.050	6056	3	b L
3.687	0.96	0.009	0.060	6075	3	b L
4.182	−.15	0.044	0.020	6092	4	L m2
3.852	0.32	0.012	0.030	6093	5	mm
3.849	0.26	0.006	0.030	6095	3	b L
3.700	0.91	0.009	0.062	6132	3	b
3.700	0.93	0.009	0.062	6148	3	b
3.597	1.48	0.011	0.079	6159	3	b
4.491	−.30	0.035	0.020	6175	5	be c L
3.691	0.92	0.009	0.062	6220	3	bg
3.620	1.37	0.011	0.079	6271	3	bg
3.660	1.15	0.010	0.079	6299	3	bg
3.568	1.58	0.012	0.048	6337	3	b
4.120	−.14	0.010	0.020	6396	3	mm
3.957	0.04	0.016	0.030	6410	4	L mm
3.615	1.42	0.015	0.100	6418	2	bg L
3.830	0.39	0.010	0.040	6493	5	b mm m2
3.610	1.50	0.011	0.100	6498	2	bg
3.746	0.72	0.012	0.020	6516	4–5	mm
3.902	0.14	0.022	0.020	6556	3	be c L mm ml m2
3.663	1.16	0.010	0.079	6603	3	bg
3.749	0.70	0.023	0.080	6623	4	b bg mm m2
3.970	0.02	0.019	0.025	6629	5	mm
3.656	1.18	0.010	0.079	6688	3	b
3.690	0.98	0.009	0.079	6698	3	b L
3.700	0.94	0.009	0.062	6703	3	b
3.607	1.50	0.011	0.080	6705	3	b bg f L
3.709	0.96	0.009	0.062	6770	3	bg
3.911	0.12	0.005	0.030	6771	4	b
3.695	0.94	0.009	0.080	6869	3–4	bg
4.276	−.21	0.044	0.020	6875	5	m2
3.974	−.03	0.014	0.020	6879	5	be c
3.652	1.18	0.010	0.079	6895	3	b
3.670	1.04	0.009	0.079	6913	3	bg
3.982	0.00	0.009	0.020	7001	5	be c L mm
3.807	0.45	0.007	0.040	7061	5	b mm m2
3.672	1.10	0.009	0.100	7063	2	b bg
3.927	0.13	0.005	0.030	7069	3	b
3.715	0.77	0.008	0.150	7133	3	b
3.667	1.18	0.009	0.079	7150	3	bg
3.674	1.08	0.010	0.079	7176	3	b
3.999	−.08	0.024	0.025	7178	3	L
3.986	0.00	0.008	0.025	7235	5	mm m2
4.058	−.09	0.015	0.025	7236	5	mm
3.656	0.97	0.019	0.062	7310	3	f
3.653	1.26	0.010	0.100	7314	2	bg
3.700	0.96	0.009	0.062	7328	3	b
3.753	0.74	0.012	0.054	7368	5	mm
3.741	0.77	0.008	0.010	7373	4	mm
3.853	0.30	0.012	0.030	7377	4	mm
3.649	1.17	0.010	0.079	7429	3	bg
3.720	0.79	0.008	0.062	7462	5	bg
3.829	0.38	0.011	0.040	7469	5	b mm
3.697	0.97	0.009	0.100	7478	3–4	bg
3.735	0.78	0.008	0.100	7479	3	b bg
3.758	0.63	0.014	0.050	7503	5	bg mm
3.753	0.66	0.008	0.050	7504	5	bg
3.618	1.44	0.016	0.090	7525	3	b L
3.682	1.03	0.009	0.079	7949	3	b
3.695	0.92	0.009	0.090	7957	4	b bg
3.650	1.18	0.010	0.062	8085	5	bg
3.629	1.37	0.010	0.062	8086	5	bg
3.889	0.22	0.010	0.020	8162	4–5	mm
3.675	1.10	0.009	0.079	8173	3	b
3.676	1.08	0.009	0.080	8255	3	b bg
3.873	0.25	0.008	0.020	8270	4–5	mm
3.641	1.23	0.020	0.100	8308	1	L&L
3.712	0.97	0.008	0.100	8414	1	b
4.142	−.15	0.022	0.020	8425	4	be c mm
3.806	0.44	0.007	0.150	8454	3	b
3.697	0.96	0.009	0.070	8499	3–4	b bg
3.671	1.04	0.009	0.079	8551	3	b
4.501	−.31	0.020	0.020	8622	5	m2
3.638	1.31	0.010	0.079	8632	3	b
3.794	0.50	0.007	0.050	8665	3–4	b
3.702	0.93	0.009	0.060	8684	3	b bg
3.684	1.05	0.009	0.079	8694	3	bg
3.922	0.05	0.021	0.030	8709	5	mm
3.988	0.09	0.013	0.030	8728	5	c mm ml m2
3.557	1.66	0.012	0.100	8775	2	b
3.996	−.05	0.005	0.025	8781	3	mm
3.853	0.29	0.003	0.030	8830	5	b
3.690	1.01	0.009	0.062	8832	5	bg
3.781	0.61	0.007	0.150	8905	3	b
3.677	1.06	0.009	0.079	8916	3	b
3.701	0.93	0.009	0.062	8923	3	b
3.691	1.03	0.009	0.080	8974	3–4	bg
4.253	−.16	0.013	0.020	90–67	1	fi
4.681	−.32	0.026	0.020	93128	5	s
4.653	−.32	0.028	0.020	93129	1	s
4.720	−.33	0.020	0.020	93250	0	k1
4.525	−.31	0.015	0.020	AE Aur	5	v
3.710	0.86	0.008	0.020	OphA36	5	cy
3.708	0.86	0.008	0.020	OphB36	5	cy
3.658	1.16	0.010	0.020	OphC36	5	cy
4.477	−.25	0.015	0.020	α Cam	1	v
4.519	−.29	0.015	0.020	δ Ori	1	v
4.505	−.27	0.015	0.020	ξ Ori	1	v
4.623	−.30	0.015	0.020	ζ Pup	0	v bo b2 k2

References
b Blackwell et al. (1991)
be Beeckmanns (1977)
bg Bell & Gustafsson (1989)
bo Bohannan et al. (1986)
c Code et al. (1976)
cy Cayrel de Strobel et al. (1989)
f Faucherre et al. (1983)
fi Fitzpatrick (1987)
k1 Kudritzki (1980)
k2 Kudritzki et al. (1983)
L Leggett et al. (1986)
mm Malagnini & Morossi (1990)
ml Malagnini et al. (1985)
m2 Malagnini et al. (1986)
s Simon et al. (1983)
v Voels et al. (1989)

2.2. $T_{\rm eff}$:*BC Scales*

For the 122 stars with measured effective temperatures and bolometric corrections, I found no differences in the relation between $T_{\rm eff}$ and BC for different luminosity classes (see Fig. 3). Chlebowski & Garmany (1991) have noted this to be true for the hottest stars, and it appears to hold for cooler stars as well. The fit to the data for cool stars requires some discussion because of the uncertainties in the Ridgway et al. (1980) temperatures.

The importance of the Ridgway et al. (1980) data is that they measured bolometric fluxes for all their stars, providing nearly all the available bolometric corrections for temperatures less than 4500 K. I used their bolometric fluxes, based on infrared photometry, and their equation (3) relating the fluxes to bolometric magnitude to derive bolometric corrections for their sample of stars.

The problem, noted in § 2.1, with the Ridgway et al. (1980) data is that their temperatures appear unreliable. Figure 3 shows the difficulties this causes at low temperatures. This figure seems to imply large uncertainties in the bolometric corrections for cool stars.

In an attempt to understand the apparent spread in bolometric corrections in Figure 3 and in light of the significant temperature differences shown in Figure 2, I "corrected" the Ridgway et al. (1980) temperatures by assigning the temperatures from the fit to the giants in Figure 2 for the colors of their giants. Furthermore, I corrected the temperature of δ DRA measured by Faucherre et al. (1983) in the same manner as I did for the Ridgway et al. (1980) giants, since its temperature lies well below the giants in Figure 2. Figure 4 shows the corrected temperatures and bolometric corrections. Added to this figure are data from Dyck, Lockwood, & Capps (1974) for cool giants. I

TABLE 2

$T_{\rm eff}$: BC DATA

log T	BC	Δlog T	ΔBC	Star	LC	Reference
3.678	-0.41	0.027	0.10	0168	3	f
3.604	-1.12	0.000	0.00	0224	3	r
3.907	0.01	0.016	0.05	0269	5	m2
3.552	-1.82	0.000	0.00	0284	3	r
3.582	-1.19	0.034	0.12	0337	3	f
4.163	-1.30	0.015	0.20	0472	5	be c
3.853	0.05	0.025	0.05	0591	5	m2
3.587	-1.89	0.000	0.00	0601	3	r
3.661	-0.57	0.034	0.09	0603	2	f
3.642	-0.45	0.031	0.10	0617	3	r
4.108	-0.83	0.010	0.08	0811	5	m2
3.629	-3.69	0.000	0.00	0867	3	r
3.753	-0.15	0.039	0.06	0996	5	m2
4.141	-1.02	0.011	0.08	1122	3	m2
4.249	-1.64	0.013	0.10	1641	5	m2
4.061	-0.58	0.011	0.05	1713	1	be c
4.441	-2.73	0.015	0.08	1756	4	m2
4.329	-1.99	0.030	0.09	1790	3	be c
4.390	-2.41	0.054	0.14	1903	1	be c
4.490	-3.03	0.028	0.20	1948	1	be c
4.427	-2.28	0.018	0.13	2004	1	c
4.033	-0.44	0.003	0.06	2010	4	m2
3.566	-2.00	0.000	0.00	2286	3	r
4.395	-2.29	0.036	0.13	2294	2-3	be c
3.874	0.10	0.029	0.08	2326	1-2	be c
3.969	-0.10	0.019	0.05	2421	4	be c
3.997	-0.10	0.009	0.05	2491	5	be c
4.314	-1.96	0.022	0.20	2618	2	be c
4.125	-0.84	0.023	0.07	2827	1	be c
3.855	0.01	0.014	0.04	2852	5	m2
3.587	-1.34	0.000	0.00	2938	3	r
3.814	-0.01	0.010	0.05	2943	4-5	be c m2
3.690	-0.29	0.019	0.08	2990	3	f
4.658	-4.26	0.028	0.25	303308	5	s
4.477	-2.96	0.014	0.10	3055	3	m2
3.649	-0.62	0.000	0.00	3095	3	r
3.894	0.02	0.023	0.06	3569	4	m2
3.965	-0.12	0.010	.049	3685	4	c
3.804	-0.01	0.024	0.04	3775	4	m2
3.629	-1.01	0.000	0.00	3779	3	r
3.582	-1.57	0.000	0.00	3950	3	r
3.617	-0.93	0.000	0.00	3980	3	r
4.085	-0.70	0.014	0.10	3982	5	be c m2
3.847	0.05	0.020	0.05	4031	3	m2
4.147	-1.10	0.014	0.09	4119	5	m2
3.559	-1.81	0.000	0.00	4127	3	r
3.962	-0.12	0.010	0.05	4295	5	m2
3.907	0.02	0.018	0.05	4357	5	m2
3.825	-0.01	0.020	0.04	4399	4	m2
3.597	-1.08	0.000	0.00	4432	3	r
3.696	-0.36	0.000	0.00	4471	3	r
3.947	-0.01	0.017	.048	4534	5	c
3.781	-0.05	0.030	0.06	4540	5	m2
4.096	-0.71	0.017	.069	4662	3	c
4.452	-2.82	0.013	.108	4853	3	c
3.767	0.02	0.056	0.07	4883	3	m2
3.584	-1.97	0.000	0.00	4902	3	r
4.378	-2.28	0.014	.108	5056	4	c
3.908	0.02	0.013	0.04	5062	5	m2
4.413	-2.55	0.016	.140	5132	3	c
3.566	-1.67	0.000	0.00	5150	3	r
4.223	-1.52	0.016	0.10	5191	5	m2
3.925	0.02	0.013	0.05	5264	5	m2
3.556	-1.82	0.000	0.00	5301	3	r
3.795	0.00	0.026	0.04	5404	5	m2
3.842	-0.01	0.019	0.04	5447	5	m2
3.625	-0.79	0.031	0.12	5563	3	f

log T	BC	Δlog T	ΔBC	Star	LC	Reference
3.582	-1.23	0.000	0.00	5622	3	r
3.640	-0.66	0.000	0.00	5824	3	r
4.188	-1.30	0.015	0.10	6092	4	m2
4.491	-2.90	0.035	0.30	6175	5	be c
3.833	0.00	0.019	0.05	6493	5	m2
3.902	0.04	0.022	0.05	6556	3	be c m2
3.743	-0.13	0.035	0.07	6623	4	m2
3.633	-0.96	0.022	0.10	6705	3	f
3.974	-0.19	0.014	0.05	6829	5	be c
3.482	-3.55	0.000	0.00	6861	3	r
4.276	-1.71	0.042	0.16	6875	5	m2
3.691	-0.44	0.000	0.00	6913	3	r
3.982	-0.21	0.009	0.05	7001	5	be c
3.559	-3.69	0.000	0.00	7023	3	r
3.804	-0.02	0.021	0.04	7061	5	m2
3.666	-0.49	0.000	0.00	7150	3	r
3.977	-0.17	0.009	0.05	7235	5	m2
3.702	-0.26	0.021	0.12	7310	3	f
3.995	-0.26	0.009	0.06	7528	3	m2
3.903	0.04	0.013	0.05	7557	4-5	be c
4.241	-1.62	0.015	0.09	7688	5	m2
4.246	-1.64	0.014	0.09	7739	5	m2
3.998	-0.27	0.009	0.06	7773	5	m2
3.676	-0.46	0.000	0.00	7776	2-3	r
4.245	-1.71	0.016	0.11	7790	5	be c
3.570	-1.73	0.000	0.00	7900	3	r
4.040	-0.47	0.008	0.06	7906	5	m2
3.584	-1.73	0.000	0.00	8318	5	c m2 (r)
4.142	-1.01	0.020	0.11	8425	4	be c
4.501	-3.01	0.020	0.12	8622	5	m2
3.563	-1.87	0.000	0.00	8698	3	r
3.932	0.00	0.010	0.04	8728	5	c m2
3.592	-1.45	0.000	0.00	8834	3	r
3.579	-2.71	0.000	0.00	9047	3	r
4.681	-4.28	0.026	0.25	93128	5	s
4.653	-4.13	0.028	0.25	93129	1	s
4.720	-4.64	0.020	0.25	93250	5	k s
4.550	-3.40	0.012	0.10	AE Aur	5	v
3.530	-2.75	0.000	0.00	BS 5299	3	d
3.584	-1.23	0.000	0.00	Leo75	3	d
3.530	-3.10	0.000	0.00	R Lyr	3	d
3.516	-2.78	0.000	0.00	R Tri	3	d
3.569	-2.55	0.000	0.00	RR Umi	3	d
3.468	-5.35	0.000	0.00	T Ari	3	d
3.562	-1.65	0.000	0.00	UMa 83	3	d
4.477	-2.88	0.024	0.13	α Cam	1	v
3.569	-1.63	0.000	0.00	α Cet	3	d
3.591	-1.20	0.000	0.00	β And	3	d
3.562	-1.85	0.000	0.00	β Peg	3	d
4.519	-3.22	0.014	0.10	δ Ori	2	v
3.514	-4.23	0.000	0.00	g Her	3	d
3.539	-2.48	0.000	0.00	ρ Per	2-3	d
3.577	-1.60	0.000	0.00	χ Peg	3	d
4.505	-3.16	0.014	0.10	ξ Ori	1	v
4.623	-4.00	0.017	0.10	ζ Pup	0	bo k2 v

References

be Beeckmanns (1977)
bo Bohannan et al. (1986)
c Code et al. (1976)
d Dyck et al. (1974)
f Faucherre et al. (1983)
k1 Kudritzki (1980)
k2 Kudritzki et al. (1983)
m2 Malagnini et al. (1986)
r Ridgway et al. (1980)
s Simon et al. (1983)
v Voels et al. (1989)

corrected their temperatures by 0.020 in log $T_{\rm eff}$ to reflect the more recent temperature determination in the database—Dyck et al. (1974) have four stars in common with the database. Table 2 lists all the measurements, including the corrected temperatures for Ridgway et al. (1980) and Dyck et al. (1974). The listed uncertainties in bolometric corrections, ΔBC, are those estimated in the references.

The corrected temperatures significantly tightened up the $T_{\rm eff}$: BC relation for the coolest stars. This further strengthens the conclusion that the Ridgway et al. (1980) temperatures are uncertain. Consequently, I did not include the Ridgway et al. (1980) temperatures (corrected or uncorrected) in the fit for the $T_{\rm eff}$: $B-V$ data for giants.

3. RESULTS

Table 3 lists the $B-V$ colors, effective temperatures, and bolometric corrections for main-sequence stars, subgiants,

TABLE 3

$T_{\rm eff}$: $B-V$: BC SCALES FOR MAIN SEQUENCE STARS, SUBGIANTS, AND GIANTS

B–V	log T	BC	T	B–V	log T	BC	T	B–V	log T	BC	T	B–V	log T	BC	T
-0.35	4.7538	-4.720	56728	0.19	3.8935	0.031	7825	0.73	3.7380	-0.146	5470	1.27	3.6401	-0.707	4366
-0.34	4.7031	-4.506	50477	0.20	3.8902	0.032	7766	0.74	3.7358	-0.153	5442	1.28	3.6384	-0.722	4349
-0.33	4.6551	-4.197	45196	0.21	3.8869	0.033	7707	0.75	3.7335	-0.161	5413	1.29	3.6368	-0.736	4333
-0.32	4.6098	-3.861	40719	0.22	3.8836	0.033	7648	0.76	3.7313	-0.168	5386	1.30	3.6351	-0.752	4316
-0.31	4.5670	-3.534	36897	0.23	3.8804	0.034	7592	0.77	3.7291	-0.176	5359	1.31	3.6335	-0.766	4300
-0.30	4.5266	-3.234	33620	0.24	3.8771	0.034	7535	0.78	3.7270	-0.184	5333	1.32	3.6318	-0.782	4283
-0.29	4.4884	-2.966	30789	0.25	3.8740	0.035	7481	0.79	3.7249	-0.192	5307	1.33	3.6301	-0.798	4266
-0.28	4.4523	-2.730	28333	0.26	3.8708	0.035	7426	0.80	3.7228	-0.200	5282	1.34	3.6285	-0.814	4251
-0.27	4.4183	-2.523	26199	0.27	3.8676	0.035	7372	0.81	3.7207	-0.208	5256	1.35	3.6268	-0.831	4234
-0.26	4.3863	-2.341	24338	0.28	3.8645	0.035	7319	0.82	3.7186	-0.216	5231	1.36	3.6251	-0.848	4217
-0.25	4.3561	-2.177	22703	0.29	3.8614	0.035	7267	0.83	3.7166	-0.225	5207	1.37	3.6235	-0.865	4202
-0.24	4.3276	-2.028	21261	0.30	3.8583	0.034	7216	0.84	3.7146	-0.233	5183	1.38	3.6218	-0.883	4186
-0.23	4.3008	-1.891	19989	0.31	3.8552	0.034	7164	0.85	3.7126	-0.242	5159	1.39	3.6201	-0.901	4169
-0.22	4.2755	-1.762	18858	0.32	3.8521	0.033	7113	0.86	3.7107	-0.250	5136	1.40	3.6184	-0.920	4153
-0.21	4.2517	-1.641	17852	0.33	3.8490	0.032	7063	0.87	3.7088	-0.259	5114	1.41	3.6167	-0.939	4137
-0.20	4.2294	-1.525	16958	0.34	3.8460	0.031	7014	0.88	3.7068	-0.268	5090	1.42	3.6149	-0.960	4120
-0.19	4.2083	-1.414	16154	0.35	3.8429	0.030	6964	0.89	3.7049	-0.277	5068	1.43	3.6132	-0.980	4103
-0.18	4.1885	-1.307	15434	0.36	3.8399	0.028	6916	0.90	3.7031	-0.285	5047	1.44	3.6114	-1.002	4086
-0.17	4.1699	-1.205	14787	0.37	3.8368	0.026	6867	0.91	3.7012	-0.295	5025	1.45	3.6096	-1.024	4070
-0.16	4.1524	-1.107	14203	0.38	3.8338	0.025	6820	0.92	3.6994	-0.304	5004	1.46	3.6078	-1.047	4053
-0.15	4.1360	-1.013	13677	0.39	3.8307	0.022	6771	0.93	3.6976	-0.313	4984	1.47	3.6060	-1.071	4036
-0.14	4.1205	-0.923	13197	0.40	3.8277	0.020	6725	0.94	3.6958	-0.322	4963	1.48	3.6041	-1.096	4018
-0.13	4.1060	-0.839	12764	0.41	3.8247	0.018	6678	0.95	3.6940	-0.332	4943	1.49	3.6022	-1.122	4001
-0.12	4.0923	-0.759	12368	0.42	3.8217	0.015	6632	0.96	3.6922	-0.342	4922	1.50	3.6002	-1.150	3982
-0.11	4.0795	-0.684	12008	0.43	3.8187	0.012	6587	0.97	3.6904	-0.352	4902	1.51	3.5982	-1.178	3964
-0.10	4.0674	-0.614	11678	0.44	3.8157	0.009	6541	0.98	3.6887	-0.361	4883	1.52	3.5961	-1.209	3945
-0.09	4.0560	-0.549	11376	0.45	3.8127	0.006	6496	0.99	3.6869	-0.372	4862	1.53	3.5940	-1.241	3926
-0.08	4.0453	-0.488	11099	0.46	3.8098	0.003	6453	1.00	3.6852	-0.382	4843	1.54	3.5918	-1.276	3906
-0.07	4.0353	-0.432	10846	0.47	3.8068	-0.001	6409	1.01	3.6835	-0.392	4825	1.55	3.5895	-1.312	3885
-0.06	4.0258	-0.381	10612	0.48	3.8039	-0.004	6366	1.02	3.6818	-0.403	4806	1.56	3.5872	-1.350	3865
-0.05	4.0169	-0.334	10396	0.49	3.8010	-0.008	6324	1.03	3.6800	-0.414	4786	1.57	3.5847	-1.393	3843
-0.04	4.0084	-0.290	10195	0.50	3.7981	-0.012	6282	1.04	3.6783	-0.426	4767	1.58	3.5822	-1.437	3821
-0.03	4.0005	-0.252	10011	0.51	3.7952	-0.016	6240	1.05	3.6766	-0.437	4748	1.59	3.5795	-1.486	3797
-0.02	3.9930	-0.216	9840	0.52	3.7923	-0.021	6198	1.06	3.6750	-0.448	4731	1.60	3.5767	-1.539	3773
-0.01	3.9859	-0.184	9680	0.53	3.7895	-0.025	6158	1.07	3.6733	-0.459	4713	1.61	3.5738	-1.595	3748
0.00	3.9791	-0.155	9530	0.54	3.7866	-0.030	6117	1.08	3.6716	-0.471	4694	1.62	3.5707	-1.658	3721
0.01	3.9728	-0.129	9392	0.55	3.7838	-0.035	6078	1.09	3.6699	-0.482	4676	1.63	3.5674	-1.728	3693
0.02	3.9667	-0.106	9261	0.56	3.7811	-0.039	6040	1.10	3.6682	-0.494	4658	1.64	3.5640	-1.802	3664
0.03	3.9609	-0.085	9139	0.57	3.7783	-0.045	6002	1.11	3.6666	-0.505	4640	1.65	3.5604	-1.885	3634
0.04	3.9555	-0.067	9026	0.58	3.7756	-0.050	5964	1.12	3.6649	-0.517	4622	1.66	3.5565	-1.978	3601
0.05	3.9502	-0.050	8916	0.59	3.7729	-0.055	5927	1.13	3.6633	-0.528	4605	1.67	3.5525	-2.078	3568
0.06	3.9452	-0.036	8814	0.60	3.7702	-0.061	5891	1.14	3.6616	-0.540	4587	1.68	3.5482	-2.191	3533
0.07	3.9404	-0.024	8717	0.61	3.7676	-0.067	5855	1.15	3.6599	-0.552	4569	1.69	3.5436	-2.318	3496
0.08	3.9358	-0.013	8625	0.62	3.7649	-0.073	5819	1.16	3.6583	-0.564	4553	1.70	3.5387	-2.460	3457
0.09	3.9314	-0.004	8538	0.63	3.7623	-0.079	5784	1.17	3.6566	-0.576	4535	1.71	3.5335	-2.620	3415
0.10	3.9271	0.004	8454	0.64	3.7598	-0.085	5751	1.18	3.6550	-0.588	4518	1.72	3.5279	-2.803	3372
0.11	3.9229	0.010	8373	0.65	3.7572	-0.091	5717	1.19	3.6533	-0.601	4500	1.73	3.5220	-3.007	3326
0.12	3.9189	0.015	8296	0.66	3.7547	-0.098	5684	1.20	3.6516	-0.614	4483	1.74	3.5157	-3.239	3278
0.13	3.9150	0.019	8222	0.67	3.7523	-0.104	5653	1.21	3.6500	-0.626	4466	1.75	3.5090	-3.502	3228
0.14	3.9113	0.022	8152	0.68	3.7498	-0.111	5620	1.22	3.6483	-0.640	4449	1.76	3.5018	-3.805	3175
0.15	3.9076	0.024	8083	0.69	3.7474	-0.117	5589	1.23	3.6467	-0.652	4433	1.77	3.4941	-4.152	3119
0.16	3.9040	0.026	8016	0.70	3.7450	-0.124	5559	1.24	3.6450	-0.666	4415	1.78	3.4860	-4.544	3061
0.17	3.9004	0.028	7950	0.71	3.7426	-0.132	5528	1.25	3.6434	-0.679	4399	1.79	3.4772	-5.004	3000
0.18	3.8969	0.029	7886	0.72	3.7403	-0.139	5499	1.26	3.6417	-0.694	4382	1.80	3.4678	-5.535	2936

and giants and Table 4 lists them for supergiants. The polynomial fits to main-sequence stars, subgiants, and giants did not differ significantly from each other. Figure 5 shows the fit to the supergiants and the fit for the fainter luminosity classes compared to each luminosity class. The error bars for the temperatures and $B-V$ colors are from the uncertainties listed in Table 1. Figure 6 shows the polynomial fit to the bolometric correction data; error bars are from Table 2. Because I corrected the temperatures of Ridgway et al. (1980) and Dyck et al. (1974) and calculated bolometric corrections for Ridgway et al. (1980), no error bars are drawn for their data.

Tables 5 and 6 give coefficients to the polynomial fits to the data for $B-V$ color and bolometric corrections, respectively. Because of the particular shape of the log $T_{\rm eff}$: BC relationship, I fitted curves to three regions, log $T_{\rm eff} \geq 3.9$, $3.9 <$ log $T_{\rm eff} < 3.7$, and log $T_{\rm eff} \leq 3.7$, and then smoothed the fit between them by eye. I joined the latter two fits at log $T_{\rm eff} = 3.6816$ for supergiants and at log $T_{\rm eff} = 3.6800$ for main-sequence stars, subgiants, and giants. At the hotter end, I smoothed the curves in the $B-V$ range of $0.13 \leq B-V \leq 0.18$ for the supergiants and $0.14 \leq B-V \leq 0.26$ for the others.

4. DISCUSSION

Figure 7*a* shows a comparison of the polynomial fits for supergiants to that for main-sequence stars, subgiants, and giants over the entire parameter range. The scales appear to differ for temperatures between 10,000 and 30,000 K and between 6000 and 8000 K. Below 6000 K, the scales are nearly identical. Since the supergiant fit above $\sim 10{,}000$ K is based on 21 stars, over half that defining the main-sequence, subgiant, and giant scale, the differences may be real. A similar difference is noted by Böhm-Vitense (1981). Between 8000 and 6000 K, however, only five supergiants have measured temperatures (see Fig. 1); hence, the significance of the differences at those temperatures is uncertain.

Figure 7*b* emphasizes the differences in the scales at high temperatures by comparing the two fits and by showing the observations for individual stars with temperatures greater than 8000 K. For temperatures between 10,000 and 30,000 K, all supergiants lie to the right of the fit to the fainter luminosity classes. The fits merge at the highest temperatures probably because $B-V$ becomes increasingly insensitive to temperature changes. In Böhm-Vitense's (1981) review of temperature scales, she also notes that the

TABLE 4

$T_{\rm eff}$: $B-V$: BC SCALES FOR SUPERGIANTS

B–V	log T	BC	T	B–V	log T	BC	T	B–V	log T	BC	T	B–V	log T	BC	T
-0.35	4.7704	-4.751	58938	0.19	3.8739	0.034	7479	0.73	3.7467	-0.119	5580	1.27	3.6474	-0.647	4440
-0.34	4.7339	-4.655	54187	0.20	3.8693	0.035	7401	0.74	3.7450	-0.124	5559	1.28	3.6457	-0.661	4422
-0.33	4.6986	-4.480	49957	0.21	3.8648	0.035	7324	0.75	3.7432	-0.130	5536	1.29	3.6439	-0.675	4404
-0.32	4.6643	-4.261	46163	0.22	3.8605	0.035	7252	0.76	3.7414	-0.135	5513	1.30	3.6422	-0.689	4387
-0.31	4.6312	-4.023	42775	0.23	3.8564	0.034	7184	0.77	3.7396	-0.141	5490	1.31	3.6404	-0.705	4369
-0.30	4.5991	-3.779	39728	0.24	3.8525	0.033	7120	0.78	3.7378	-0.147	5467	1.32	3.6386	-0.720	4351
-0.29	4.5681	-3.543	36991	0.25	3.8487	0.032	7058	0.79	3.7360	-0.153	5445	1.33	3.6369	-0.735	4334
-0.28	4.5380	-3.317	34514	0.26	3.8451	0.031	7000	0.80	3.7342	-0.159	5422	1.34	3.6351	-0.752	4316
-0.27	4.5089	-3.108	32277	0.27	3.8416	0.029	6943	0.81	3.7324	-0.165	5400	1.35	3.6333	-0.768	4298
-0.26	4.4808	-2.915	30255	0.28	3.8382	0.027	6889	0.82	3.7305	-0.171	5376	1.36	3.6315	-0.785	4280
-0.25	4.4536	-2.738	28418	0.29	3.8350	0.025	6839	0.83	3.7287	-0.178	5354	1.37	3.6297	-0.802	4262
-0.24	4.4274	-2.577	26754	0.30	3.8319	0.023	6790	0.84	3.7268	-0.185	5330	1.38	3.6279	-0.820	4245
-0.23	4.4020	-2.429	25234	0.31	3.8289	0.021	6743	0.85	3.7250	-0.191	5308	1.39	3.6260	-0.839	4226
-0.22	4.3774	-2.292	23845	0.32	3.8260	0.019	6698	0.86	3.7231	-0.199	5285	1.40	3.6242	-0.858	4209
-0.21	4.3537	-2.164	22578	0.33	3.8232	0.017	6655	0.87	3.7212	-0.206	5262	1.41	3.6223	-0.878	4190
-0.20	4.3308	-2.045	21419	0.34	3.8205	0.014	6614	0.88	3.7194	-0.213	5240	1.42	3.6204	-0.898	4172
-0.19	4.3087	-1.931	20356	0.35	3.8179	0.012	6575	0.89	3.7175	-0.221	5217	1.43	3.6184	-0.920	4153
-0.18	4.2874	-1.823	19382	0.36	3.8154	0.009	6537	0.90	3.7156	-0.229	5195	1.44	3.6164	-0.943	4134
-0.17	4.2668	-1.718	18484	0.37	3.8130	0.007	6501	0.91	3.7137	-0.237	5172	1.45	3.6144	-0.966	4115
-0.16	4.2470	-1.617	17660	0.38	3.8106	0.004	6465	0.92	3.7118	-0.245	5149	1.46	3.6124	-0.990	4096
-0.15	4.2278	-1.517	16896	0.39	3.8083	0.001	6431	0.93	3.7099	-0.254	5127	1.47	3.6103	-1.016	4076
-0.14	4.2094	-1.420	16195	0.40	3.8061	-0.001	6398	0.94	3.7080	-0.262	5105	1.48	3.6081	-1.043	4056
-0.13	4.1916	-1.324	15545	0.41	3.8039	-0.004	6366	0.95	3.7061	-0.271	5082	1.49	3.6059	-1.072	4035
-0.12	4.1744	-1.230	14941	0.42	3.8018	-0.007	6335	0.96	3.7042	-0.280	5060	1.50	3.6037	-1.101	4015
-0.11	4.1579	-1.138	14384	0.43	3.7997	-0.010	6305	0.97	3.7023	-0.289	5038	1.51	3.6014	-1.133	3993
-0.10	4.1420	-1.047	13867	0.44	3.7977	-0.012	6276	0.98	3.7004	-0.299	5016	1.52	3.5990	-1.167	3971
-0.09	4.1267	-0.959	13387	0.45	3.7958	-0.015	6248	0.99	3.6985	-0.308	4994	1.53	3.5965	-1.203	3949
-0.08	4.1119	-0.873	12938	0.46	3.7938	-0.018	6220	1.00	3.6966	-0.318	4972	1.54	3.5940	-1.241	3926
-0.07	4.0977	-0.791	12522	0.47	3.7919	-0.021	6192	1.01	3.6947	-0.328	4951	1.55	3.5914	-1.282	3903
-0.06	4.0841	-0.711	12136	0.48	3.7900	-0.024	6165	1.02	3.6928	-0.339	4929	1.56	3.5887	-1.326	3878
-0.05	4.0710	-0.635	11776	0.49	3.7882	-0.027	6140	1.03	3.6909	-0.349	4907	1.57	3.5859	-1.372	3853
-0.04	4.0583	-0.562	11436	0.50	3.7864	-0.030	6115	1.04	3.6891	-0.359	4887	1.58	3.5831	-1.421	3829
-0.03	4.0462	-0.493	11122	0.51	3.7846	-0.033	6089	1.05	3.6872	-0.370	4866	1.59	3.5801	-1.475	3802
-0.02	4.0345	-0.428	10826	0.52	3.7828	-0.036	6064	1.06	3.6853	-0.381	4845	1.60	3.5770	-1.533	3775
-0.01	4.0233	-0.368	10551	0.53	3.7811	-0.039	6040	1.07	3.6834	-0.393	4823	1.61	3.5738	-1.595	3748
0.00	4.0126	-0.312	10294	0.54	3.7793	-0.043	6015	1.08	3.6816	-0.404	4803	1.62	3.5705	-1.662	3719
0.01	4.0022	-0.260	10050	0.55	3.7776	-0.046	5992	1.09	3.6797	-0.416	4782	1.63	3.5670	-1.736	3689
0.02	3.9923	-0.213	9824	0.56	3.7759	-0.049	5968	1.10	3.6779	-0.429	4763	1.64	3.5634	-1.816	3659
0.03	3.9828	-0.170	9611	0.57	3.7742	-0.053	5945	1.11	3.6760	-0.441	4742	1.65	3.5597	-1.901	3628
0.04	3.9736	-0.132	9410	0.58	3.7724	-0.056	5921	1.12	3.6742	-0.453	4722	1.66	3.5558	-1.995	3595
0.05	3.9648	-0.099	9221	0.59	3.7707	-0.060	5897	1.13	3.6724	-0.466	4703	1.67	3.5518	-2.096	3562
0.06	3.9564	-0.070	9044	0.60	3.7691	-0.063	5876	1.14	3.6705	-0.478	4682	1.68	3.5475	-2.210	3527
0.07	3.9483	-0.045	8877	0.61	3.7674	-0.067	5853	1.15	3.6687	-0.491	4663	1.69	3.5432	-2.329	3493
0.08	3.9406	-0.024	8721	0.62	3.7657	-0.071	5830	1.16	3.6669	-0.503	4644	1.70	3.5386	-2.463	3456
0.09	3.9332	-0.007	8574	0.63	3.7640	-0.075	5807	1.17	3.6651	-0.516	4624	1.71	3.5338	-2.611	3418
0.10	3.9261	0.006	8435	0.64	3.7623	-0.079	5784	1.18	3.6633	-0.528	4605	1.72	3.5289	-2.769	3379
0.11	3.9192	0.015	8302	0.65	3.7606	-0.083	5762	1.19	3.6615	-0.541	4586	1.73	3.5237	-2.947	3339
0.12	3.9127	0.021	8178	0.66	3.7589	-0.087	5739	1.20	3.6597	-0.554	4567	1.74	3.5183	-3.141	3298
0.13	3.9064	0.024	8061	0.67	3.7571	-0.091	5716	1.21	3.6580	-0.566	4549	1.75	3.5127	-3.355	3256
0.14	3.9004	0.028	7950	0.68	3.7554	-0.096	5693	1.22	3.6562	-0.579	4531	1.76	3.5068	-3.592	3212
0.15	3.8947	0.030	7846	0.69	3.7537	-0.100	5671	1.23	3.6544	-0.593	4512	1.77	3.5007	-3.853	3167
0.16	3.8891	0.031	7746	0.70	3.7520	-0.105	5649	1.24	3.6527	-0.606	4494	1.78	3.4943	-4.142	3121
0.17	3.8839	0.033	7654	0.71	3.7502	-0.110	5626	1.25	3.6509	-0.619	4476	1.79	3.4877	-4.460	3073
0.18	3.8788	0.033	7564	0.72	3.7485	-0.114	5604	1.26	3.6492	-0.633	4458	1.80	3.4807	-4.817	3024

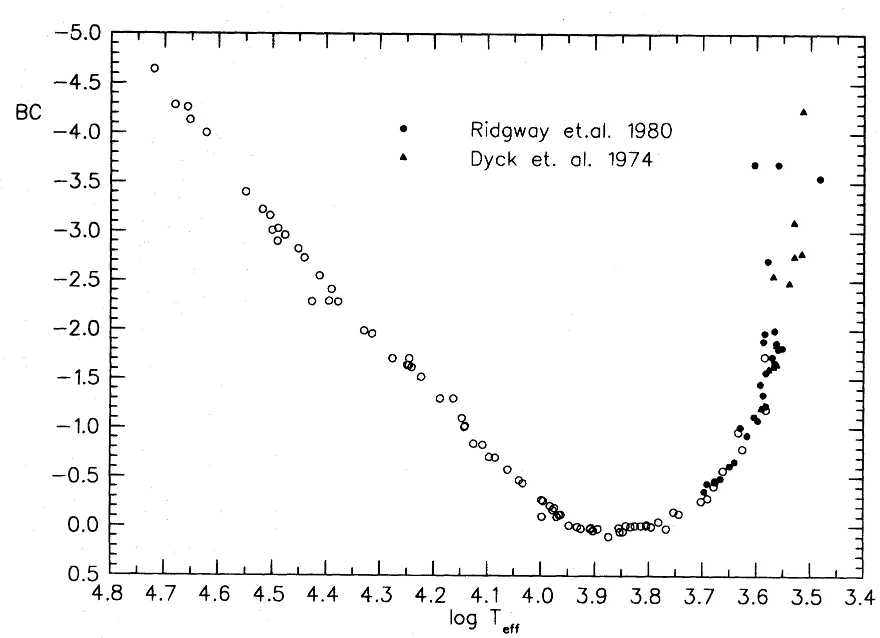

FIG. 4.—Bolometric corrections for all stars with the "corrected" temperatures of Ridgway et al. (1980). The temperatures of Dyck et al. (1974) were increased by 0.02 in log $T_{\rm eff}$.

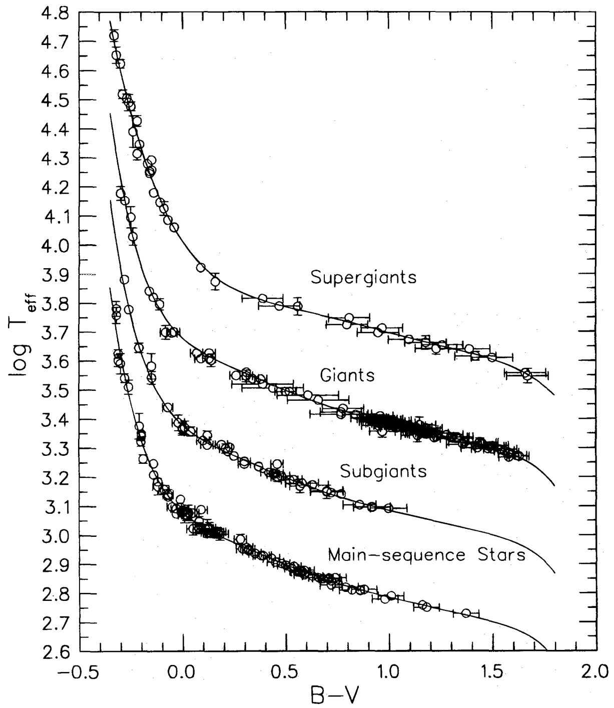

FIG. 5.—Polynomial fits to temperatures and colors. Temperatures of giants, subgiants, and main-sequence stars are lower by 0.3 in log T_{eff} than the next more luminous class. The lower three curves are identical; the curve is the polynomial fit to all giants, subgiants, and main-sequence stars in the database listed in Table 5 (except those of Ridgway et al. 1980). Symbols for stars without error bars are larger than the error bars.

scales merge at high temperatures and that they merge at lower temperatures.

Figure 8 compares the new polynomial fits with previous $T_{eff}:B-V$ scales. I used the color–spectral type relation of FitzGerald (1970) to obtain colors for the effective temperature–spectral type scales of Fitzpatrick & Garmany (1990). No significant differences exist between any of the scales, except for the luminosity class V scale of Habets & Heintze (1981), and they only differ at low temperatures.

Habets & Heintze (1981) base their scale on several older calibrations, including Flower (1977), instead of relying on measured temperatures. They also calibrate their temperatures with spectral type instead of $B-V$ color. To compare their scale with others, I used the colors of FitzGerald (1970) for main-sequence stars. Figure 5, however, shows that the most recent temperatures for main-sequence stars, subgiants, and giants define a tight scale as red as $B-V = 1.6$ that does not support the lower temperatures of Habets & Heintze (1981). Perhaps the differences reflect assignments of temperatures to spectral types or in the color transformation between spectral type and $B-V$ color.

Figure 9*a* compares the new T_{eff}:BC scale with Flower's (1977, 1975) scales. The differences above 10,000 K are most likely due to the greater number of stars with measured bolometric corrections available today (compare, for instance, Fig. 6 in this paper with Fig. 3 in Flower 1977). For cooler temperatures, the new scale is hotter than Flower's (1975) giant scale because I increased the temperatures of Dyck et al. (1974) by 0.02 in log T_{eff}.

Unfortunately, the present database does not contain any cool supergiants with accurately known bolometric corrections. Flower's (1977) supergiant T_{eff}:BC scale for cool temperatures relies on the temperature estimates by Lee (1970) and his measured bolometric corrections. He did not have many angular diameters from which to estimate temperatures, so he used infrared color calibrations and blackbody temperatures. It is not clear how modern temperature estimates will change the supergiant scale at low temperatures from Flower's (1977) scale.

Figure 9*b* shows that the new temperature scale agrees at the hot end with those of Chlebowski & Garmany (1991) and Humphreys & McElroy (1984). The Habets & Heintze (1981) scale, however, deviates significantly from the new scale as well as from Flower's (1977) older scales. Habets & Heintze (1981) base their bolometric corrections on data from visual and astrometric binaries. They determine bolometric corrections as a function of mass using mean radii and mean effective temperatures. In doing so, for instance,

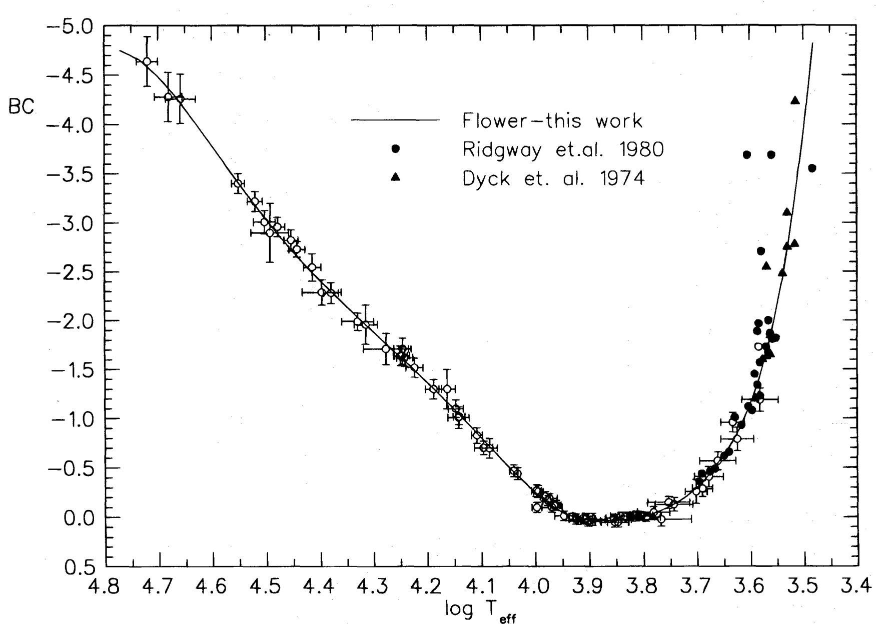

FIG. 6.—Polynomial fit to temperatures and bolometric corrections for all stars. Temperatures of Ridgway et al. (1980) and of Dyck et al. (1974) are "corrected" temperatures as in Fig. 4.

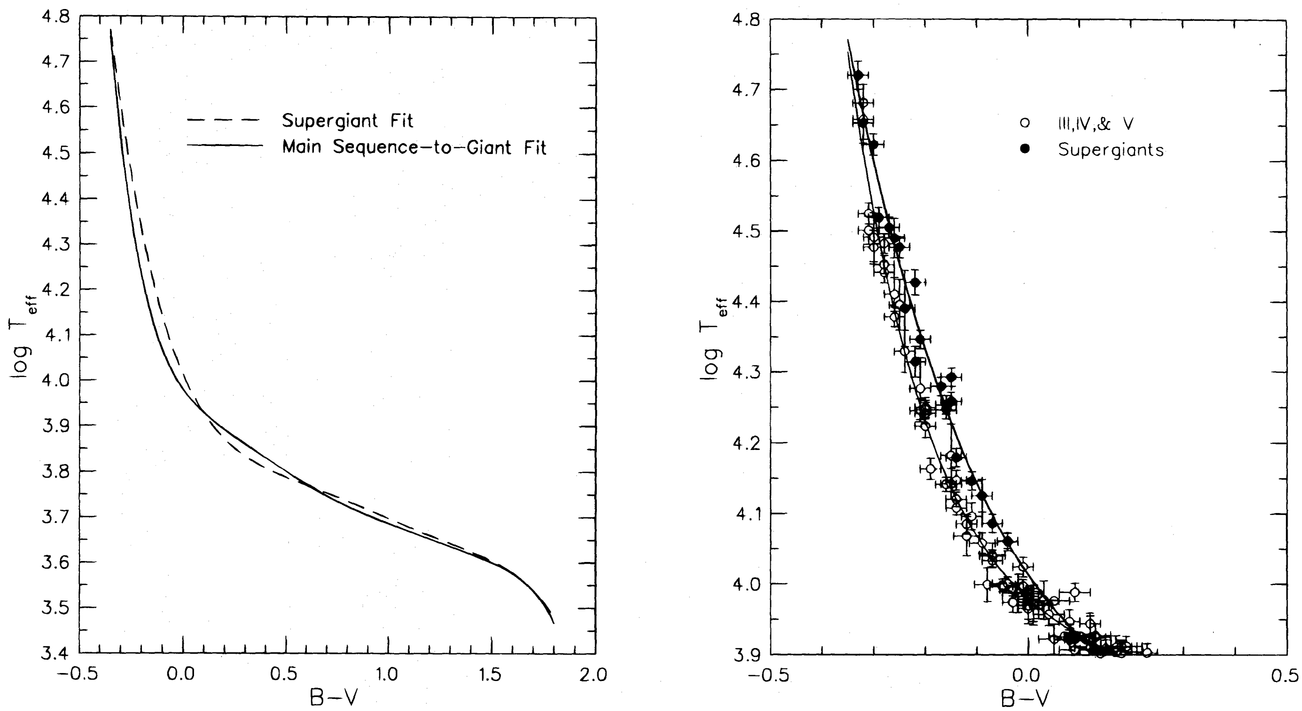

Fig. 7*a* Fig. 7*b*

Fig. 7.—(*a*) Supergiant fit compared to the fit for the other luminosity classes over the entire T_{eff} and $B-V$ range. (*b*) Fits and observations compared. Error bars are the same as in Fig. 5.

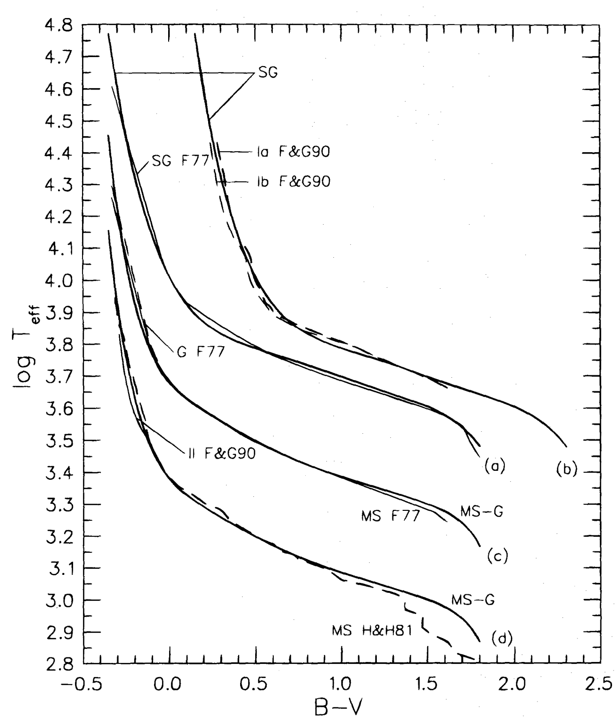

Fig. 8.—Polynomial fit for supergiants compared to the fit for the other luminosity classes. Curves in (*b*) are shifted by 0.5 to the right and curves in (*c*) and (*d*) are shifted 0.3 and 0.6 in log T_{eff}, respectively. (*a*) Supergiants from this paper (SG) and from Flower (1977) (SG F77). (*b*) Supergiants from this paper and luminosity class Ia and Ib from Fitzpatrick & Garmany (1990). (*c*) Main-sequence stars, subgiants, and giants fits from this paper (MS-G) compared to main-sequence fit (MS F77) and giant fit (G F77) from Flower (1977). (*d*) This paper compared to main-sequence scales (MS H&H81) of Habets & Heintze (1981) and luminosity class II from Fitzpatrick & Garmany (1990).

they determine the Sun's bolometric correction to be −0.32, much greater than the canonical value of −0.07. Their different bolometric corrections are apparently due to differences in temperature, radius, and absolute magnitude between the Sun and their mean relations for main-sequence stars.

Figure 9*b* also shows a comparison with the temperatures and bolometric corrections computed by Alonso, Arribas, & Martínez-Roger (1995) for a solar composition. The favorable comparison gives support to the adjustments made to the temperatures of Ridgway et al. (1980).

Figure 10 shows the effect of the transformations on stellar evolutionary tracks (calculated by El Eid, Flower, & Hartmann 1996). The overall effect of the bolometric corrections when transforming to color-magnitude diagrams is to stretch the tracks in magnitude. This is especially appar-

TABLE 5

B−V Colors

$B-V = a + b \log T_{\text{eff}} + c (\log T_{\text{eff}})^2 + \cdots$

Coefficient	Supergiants	Main-Sequence Stars, Subgiants, Giants
a	4.0125597	3.979145
b	−1.055043	−0.654499
c	2.133395	1.740690
d	−2.459770	−4.608815
e	1.349424	6.792600
f	−0.283943	−5.396910
g	...	2.192970
h	...	−0.359496

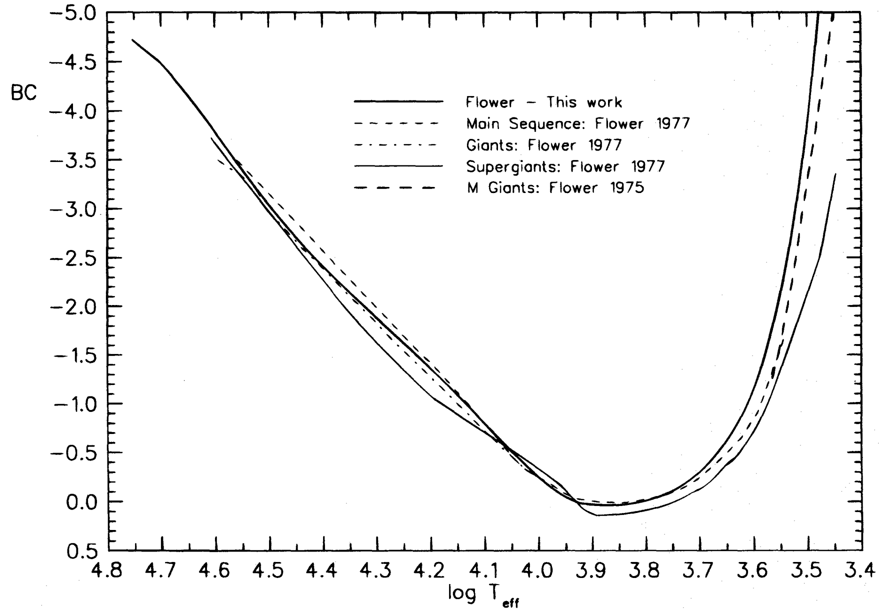

FIG. 9a

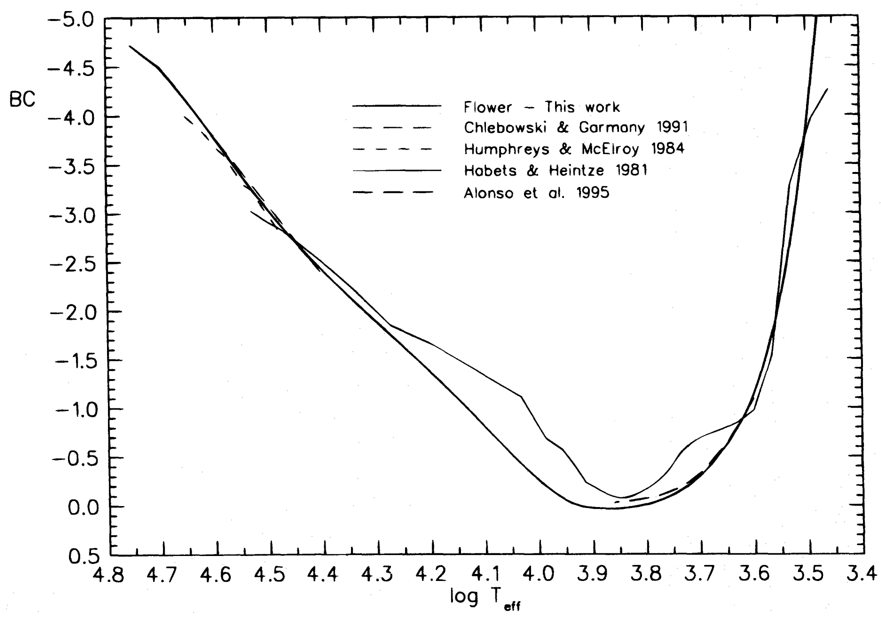

FIG. 9b

FIG. 9.—(*a*) The new bolometric correction scale compared with the scales of Flower (1977, 1975). (*b*) Comparison with other $T_{\rm eff}$:BC scales. The models of Alonso et al. (1995) are for solar composition and log $g = 4$.

ent for hydrogen-burning phases. The steep bolometric corrections together with large changes in temperature for small changes in color in the $T_{\rm eff}:B-V$ scales cause the helium-burning phases to lie nearly directly over the hydrogen-burning phases for massive stars. The differences in the tracks of the same mass in Figure 10*b* reflect the slight differences between the supergiant scale and the main-sequence–giant scale (Fig. 7).

To summarize, I found that supergiants have a $T_{\rm eff}:B-V$ relation slightly different from those of the other luminosity classes above 10,000 K, but all luminosity classes appear to follow a unique $T_{\rm eff}$:BC relation. Uncertainties exist, however, at the cool end of the $T_{\rm eff}$:BC scale because of uncertainties in temperatures of giants and the lack of observations of supergiants. It is not certain if cool supergiants have smaller bolometric corrections than cool giants and main-sequence stars for a given effective temperature. It may be fair to say that we do not know the bolometric

TABLE 6

BOLOMETRIC CORRECTIONS

$\mathrm{BC} = a + b \log T_{\rm eff} + c (\log T_{\rm eff})^2 + \cdots$

Coefficient	$\log T_{\rm eff} > 3.90$	$3.90 < \log T_{\rm eff} > 3.70$	$\log T_{\rm eff} < 3.70$
a	−0.188115	−0.370510	−0.190537
b	0.137146	0.385673	0.155145
c	−0.636234	−0.150651	−0.421279
d	0.147413	0.261725	0.381476
e	−0.179587	−0.170624	...
f	0.788732	...	...

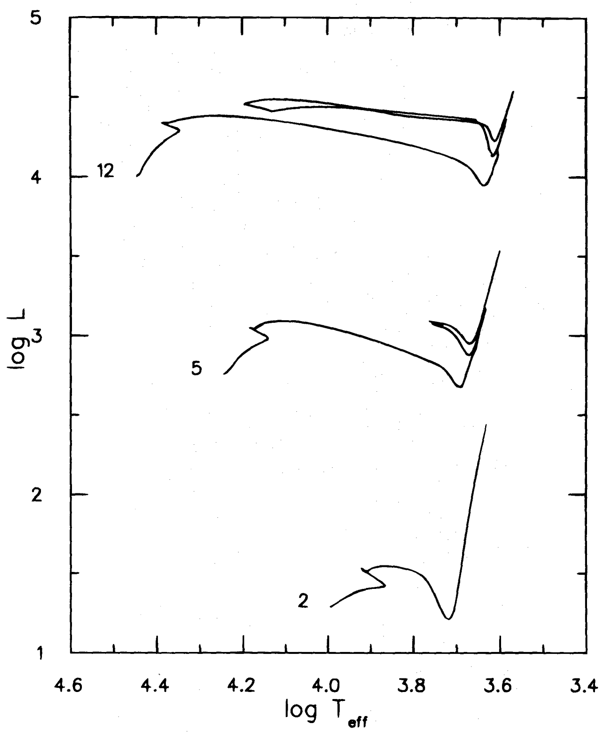

FIG. 10a

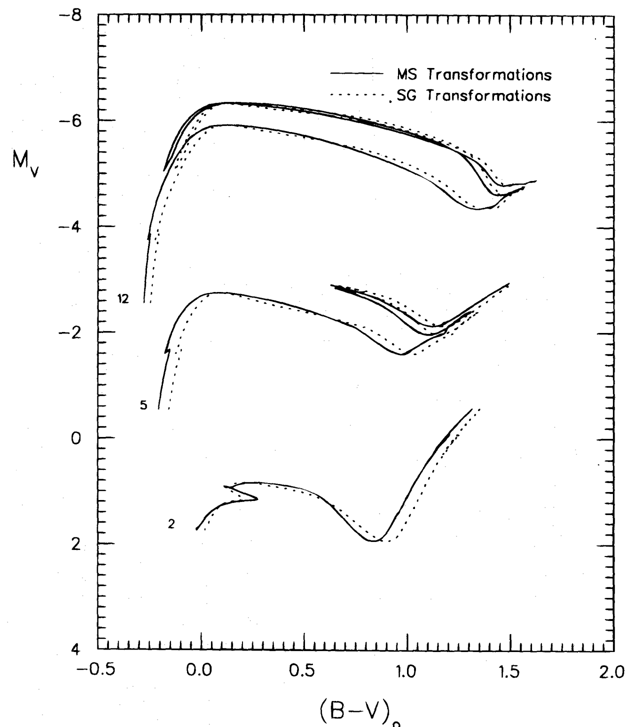

FIG. 10b

FIG. 10.—(*a*) Evolutionary tracks for 2, 5, and 12 solar masses from El Eid et al. (1996) in log L and log T_{eff}. (*b*) The same evolutionary tracks transformed with the two new scales.

corrections of cool supergiants.

Further improvements to $T_{eff}: B-V$ scales and T_{eff}: BC scales must await reliable temperatures for cool giants and more temperatures and bolometric corrections for cool supergiants. In the meantime, the polynomial fits presented here represent the current observational status of temperature and bolometric correction measurements of stars.

This work was supported in part by a URGC grant from Clemson University. The author thanks M. F. El Eid for many discussions of stellar evolution and comparisons with observations, Mark Leising for insights into the differences between temperature scales of the different luminosity classes, and Dieter Hartmann for many discussions and critical readings of the manuscript.

REFERENCES

Alonso, A., Arribas, S., & Martínez-Roger, C. 1995, A&A, 297, 197
Beeckmans, F. 1977, A&A, 60, 1
Bell, R. A., & Gustafsson, B. 1989, MNRAS, 236, 653
Blackwell, D. E., Lynas-Gray, A. E., & Petford, A. D. 1991, A&A, 245, 567
Bohannan, B., Abbott, D. C., Voels, S. A., & Hummer, D. G. 1986, ApJ, 308, 728
Böhm-Vitense, E. 1981, ARA&A, 19, 295
Cayrel de Strobel, G., Perrin, M.-N., Cayrel, R., & Lebreton, Y. 1989, A&A, 225, 369
Chlebowski, T., & Garmany, C. D. 1991, ApJ, 368, 241
Code, A. D., Davis, J., Bless, R. C., & Brown, R. H. 1976, ApJ, 203, 417
Dyck, H. M., Lockwood, G. W., & Capps, R. W. 1974, ApJ, 189, 89
El Eid, M. F., Flower, P., & Hartmann, D. 1996, in preparation
Faucherre, M., Bonneau, D., Koechlin, L., & Vakili, F. 1983, A&A, 120, 263
FitzGerald, M. P. 1970, A&A, 4, 234
Fitzpatrick, E. L. 1987, ApJ, 312, 596
Fitzpatrick, E. L., & Garmany, C. D. 1990, ApJ, 363, 119
Flower, P. J. 1975, A&A, 41, 391
———. 1977, A&A, 54, 31
Habets, G. M. H. J., & Heintze, J. R. W. 1981, A&AS, 46, 193
Humphreys, R. M., & McElroy, D. B. 1984, ApJ, 284, 565
Kudritzki, R. P. 1980, A&A, 85, 174
Kudritzki, R. P., Simon, K. P., & Harmann, W.-R. 1983, A&A, 118, 245
Lee, T. A. 1970, ApJ, 162, 217
Leggett, S. K., Mountain, C. M., Shelby, M. J., Blackwell, D. E., Booth, A. J., Haddock, D. J., & Petford, A. D. 1986, A&A, 159, 21
Malagnini, M. L., & Morossi, C. 1990, A&AS, 85, 1015
Malagnini, M. L., Morossi, C., Rossi, L., & Kurucz, R. L. 1985, A&A, 152, 117
———. 1986, A&A, 162, 140
Massey, P., Parker, J. W., & Garmany, C. D. 1989, AJ, 98, 1305
Napiwotzki, R., Schönberner, D., & Wenske, V. 1993, A&A, 268, 653
Ridgway, S. T., Joyce, R. R., White, N. M., & Wing, R. F. 1980, ApJ, 235, 126
Sanduleak, N. 1969, Cerro Tololo Inter-American Obs. Contrib. No. 89
Simon, K. P., Jonas, G., Kudritzki, R. P., & Rahe, J. 1983, A&A, 125, 34
Voels, S. A., Bohannan, B., Abbott, D. C., & Hummer, D. G. 1989, ApJ, 340, 1073