REMARKS ON BOLOMETRIC CORRECTIONS AND EFFECTIVE TEMPERATURES

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ABSTRACT

The usually accepted systems of bolometric corrections and effective temperatures, based essentially on Kuiper's discussion of 20 years ago, are examined in the light of current knowledge. Bolometric corrections for stars cooler than type F0 can be improved with the use of photoelectric magnitudes and colors. For hotter stars, improved atmospheric models are available. Photoelectric colors rather than spectral types are used as argument for both bolometric corrections and temperatures. Stars redder than about $B - V + 1.4$ mag. are excluded from the discussion. A new fundamental determination of an effective temperature is that of Sirius from its angular diameter by Hanbury Brown and Twiss. The value is about 1000° lower than earlier determinations and is in agreement with the value from a model-atmosphere investigation of Vega by Hunger. Model-atmosphere computations for O and early B stars by various authors lead generally to much higher temperatures than Kuiper adopted. For stars cooler than the sun, the reliability of temperatures based upon interferometer measures of angular diameters is questioned. Moreover, the effective temperature of YY Gem is somewhat uncertain because its bolometric correction has not been measured. Thus, except for the sun, the scale of effective temperatures cannot be considered definitively established for any spectral class. Temperature differences between giants and main-sequence stars of the same spectral type are found to be smaller than those usually adopted. Observations for improving the temperature scale are discussed briefly.

INTRODUCTION

In discussing the luminosities of A-type eclipsing binaries and in comparing them with the luminosities of nearby stars (Popper 1959), I have felt it desirable to re-examine the scales of effective temperatures and bolometric corrections. The remarks in this paper will be concerned particularly, although not exclusively, with stars of type A.

The most recent comprehensive discussion of effective temperatures and bolometric corrections of which I am aware is that of Kuiper (1938). Keenan and Morgan (1951) give a temperature scale based upon that of Kuiper and upon the six-color photometry of Stebbins and Whitford. Their use of the latter over a wide range of temperatures is somewhat questionable, since it is tied to a scale of effective temperatures at only one point. The results of Kuiper's classical discussion can be improved for at least three important reasons. First, many photoelectric colors and magnitudes of high accuracy and on a consistent color system are now available. Second, the interpretation of stellar spectra has improved considerably. And, third, a new fundamental temperature determination has been made, namely, that of Sirius by Hanbury Brown and Twiss (1956). The present discussion is, for the most part, an extension of Kuiper's study with improved data and with emphasis upon stars of type A.

In this discussion it has been decided to adopt the photoelectric color index, $B - V$, rather than spectral type as the quantity with which the effective temperatures and bolometric corrections are to be correlated. The luminosity class should also be known, although one would expect the relations between color index and bolometric correction and between color index and effective temperature to be less dependent upon luminosity class than the relations using spectral type. Another advantage to the use of a color index, in addition to the precision of its determination, is that in the cases of many eclipsing binaries the spectral type of one or of both components cannot be readily evaluated because of blending of the spectral lines of the two stars. An accurate two-color light-curve can, on the other hand, often yield the values of $B - V$ for both stars, provided that the color system of the observations is carefully calibrated with respect to the standard system. It would be preferable to adopt a color index, such as the $R - I$ of Kron, White, and Gascoigne (1953), as standard instead of $B - V$, at least for the cooler stars. Two reasons for such a preference are that $R - I$ involves regions of the spectrum less affected by absorption lines than does $B - V$ and that $B - V$ is of little use for stars redder than about +1.3 mag. (Kron, White, and Gascoigne 1953). An index such as $R - I$ is, however, readily available neither for most of the stars upon which the calibrations of bolometric corrections and effective temperatures depend nor for the eclipsing binaries for which these quantities are desired.

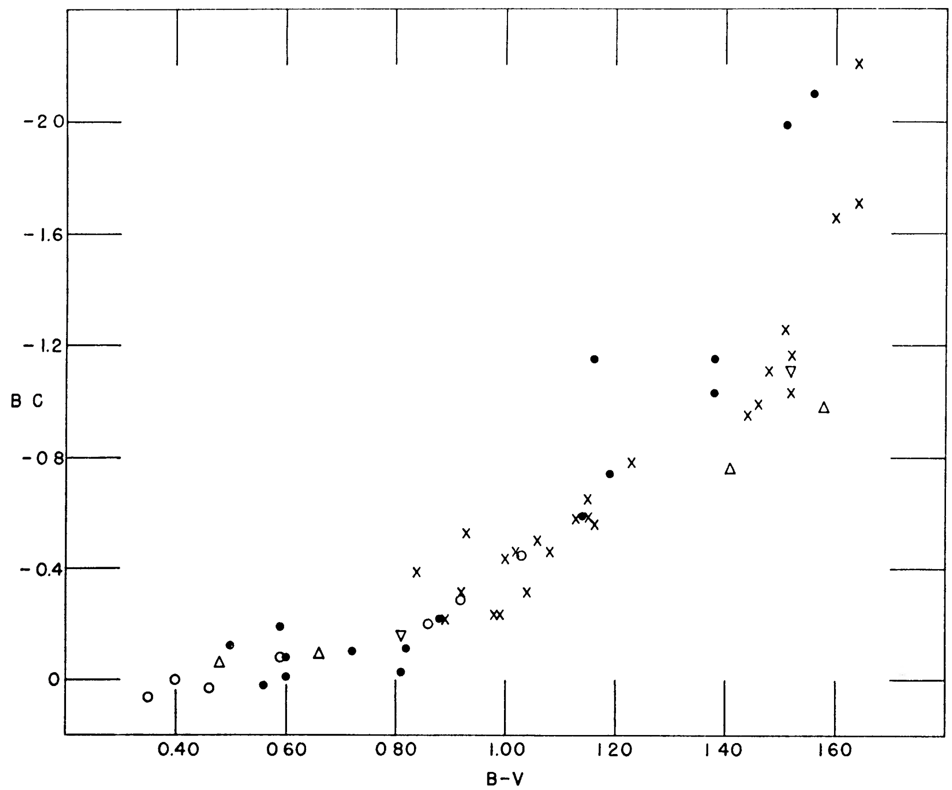

FIG. 1.—Bolometric corrections from radiometric and photoelectric magnitudes. *Dots:* luminosity class V; *circles:* IV; *crosses:* III; ▽: II; △: I.

A compilation of bolometric corrections and effective temperatures with $B - V$ as argument is given by Schwarzschild (1958). It appears to be based essentially upon Kuiper's study. Arp's (1958) tabulation of temperatures is the same as that given by Keenan and Morgan (1951) except for stars hotter than B5, for which atmospheric models of Underhill and McDonald (1952) are used. Lohmann (1948) and Eggen (1956) have discussed bolometric corrections from more restricted standpoints.

BOLOMETRIC CORRECTIONS

For stars cooler than type F0 it is the aim of the present discussion to improve the bolometric corrections given by Kuiper (1938) for the individual stars observed radiometrically by Pettit and Nicholson (1928). These bolometric corrections may be improved by subtracting photoelectric magnitudes, V, rather than the visual or photovisual magnitudes used by Kuiper, from the radiometric magnitudes. The individual improved bolometric corrections are plotted in Figure 1 with $B - V$ rather than spectral type as the abscissa. The values of V used in obtaining the bolometric corrections, as well as the values of $B - V$ of Figure 1, have been taken from the literature (especially Johnson and Morgan 1953) when available. Values of V and of $B - V$ for eighteen of the stars of Figure 1, obtained by the writer at the Lowell and Palomar Observatories, are given in Table 1. Seven of Emberson's (1941) radiometric observations of highest weight have also been used for Figure 1 after applying a systematic difference of +0.23 mag. to Emberson's magnitudes to reduce them to the same zero point as those of Pettit and Nicholson (see also Lohmann 1948). The zero point of the bolometric corrections of Figure 1 is chosen so that Kuiper's values for main-sequence stars of spectral types G0–G8 are reproduced. With this choice of zero point, the bolometric corrections for individual stars are given by

$$\text{B.C.} = m_r - \Delta m_r - V + 0.58 \ ,$$

TABLE 1

PHOTOELECTRIC MAGNITUDES AND COLORS

Star	Spectrum	V	$B-V$	Star	Spectrum	V	$B-V$
γ Cyg	F8 I*b*	2 23	+0 66	53 Eri AB	gK1	3.86	+1 08
ϵ Leo	G0 II	2.98	+0.81	ϵ Gem	G8 I*b*	2.99	+1 41
40 Eri A	K0 V	4 42	+0.81	α Hya	K3 III	1.97	+1 44
ϵ Eri	K2 V	3.72	+0.88	β UMi	K4 III	2 08	+1.46
ϵ Vir	G9 III	2 82	+0.92	ι Aur	K3 II	2.70	+1 52
δ Eri	K0 IV	3.52	+0.92	ζ Cep	K1 I*b*	3.36	+1.58
β Her	G8 III	2.78	+0.93	π Leo	M2 III	4.74	+1.60
ι Gem	G9 III	3.78	+1 02	α Cet	M2 III	2.52	+1.64
β Cet	K0 III	1.98	+1.04	μ Gem	M3 III	2.91	+1.64

TABLE 2

BOLOMETRIC CORRECTIONS

	$B-V$								
	+0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	+1.2
B.C.	0 00	−0.02	−0.07	−0.11	−0 17	−0.28	−0.40	−0.53	−0.72

where m_r and Δm_r are as defined by Pettit and Nicholson. The Δm_r cannot be evaluated for stars hotter than about type F0 because of the unknown ultraviolet fluxes. The bolometric correction from Figure 1 for a star of the same color as the sun, $B - V = +0.63$, is −0.07 mag. I have no explanation for the discrepancy of the point at $B - V + 1.6$, B.C. −1.21. The star is HD 154363 = CC 1017. The values of V and of $B - V$ for this star are from Johnson and Morgan (1953).

We may read the values of Table 2 from Figure 1. These values do not differ significantly from those compiled by Schwarzschild (1958). Although there is considerable scatter of the observed points in Figure 1, there does not appear to be a systematic effect depending upon luminosity except for the reddest stars. The inutility of $B-V$ as a color index for stars redder than about +1.3 mag. is clearly shown. An index such as $R - I$ should be useful for interpolation of bolometric corrections between measured values, although, in Kuiper's opinion (1938), "for the M stars . . . a direct determination of the radiometric magnitude should be made for all stars for which the bolometric magnitude is needed." Limber (1958) has given a discussion of the problems associated with evaluating bolometric corrections and effective temperatures of M dwarfs from existing data.

For the hotter stars, where bolometric magnitudes have not yet been observed because of absorption in the earth's atmosphere, one must compute bolometric corrections from stellar atmospheric models. The use of black-body corrections, as employed by Lohmann (1948) and by Eggen (1956), is not satisfactory. The theoretical treatment of stellar atmospheres has advanced considerably in the period since Kuiper's discussion. For the range of temperatures in which we are particularly interested here, spectral-energy distributions from atmospheric models have been obtained by Hunger (1954), by Osawa (1956), and by Saito (1956). Hunger's published bolometric corrections have been altered slightly because of the slightly different value of the solar bolometric correction used by him. Table 3 contains these values, as well as those computed by me from Osawa's and Saito's emergent fluxes. The values are shown in Figure 2, except for those from Saito's hotter models. Also shown is Kuiper's scale of bolometric corrections. Because of uncertainty in the temperature scale for early A stars (discussed later), we are unable

TABLE 3

COMPUTED BOLOMETRIC CORRECTIONS

Author	T_e	B.C.	Author	T_e	B.C.
Hunger.......	8160	−0.11	Osawa.......	7560	−0 15
	8660	− .14		8900	−0.24
	9000	− .18			
	9500	−0.24	Saito.........	10600	−0.39
				15400	−1.22
				20500	−2.00

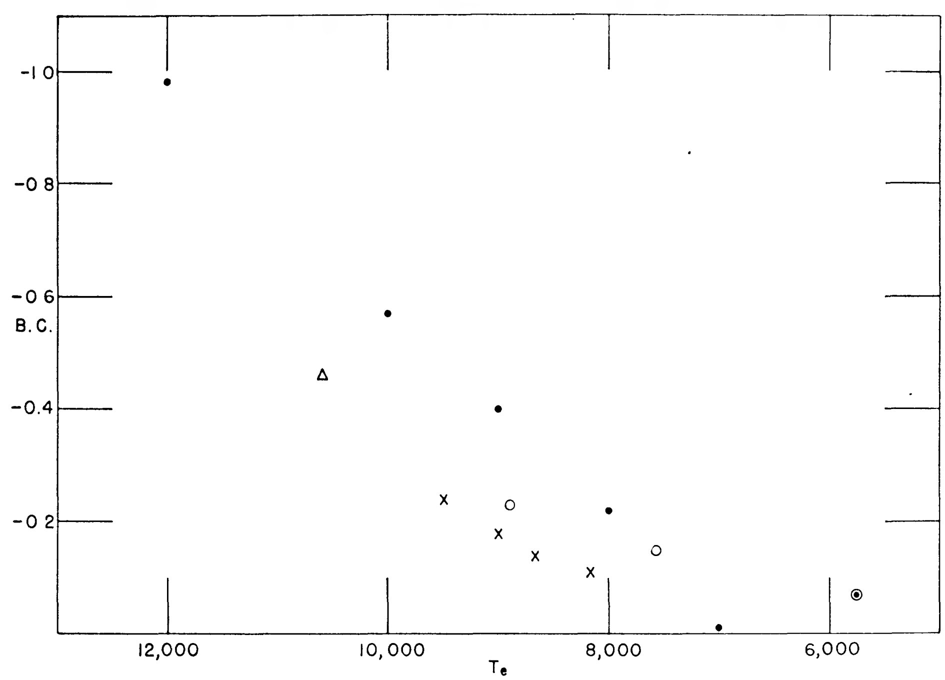

FIG. 2.—Computed bolometric corrections. *Dots:* Kuiper's scale; *circles:* Osawa's models; *triangle:* Saito's models; *crosses:* Hunger's models. The encircled dot represents the sun.

to use $B - V$ satisfactorily as the abscissa in Figure 2. In the vicinity of 10000° the newer bolometric corrections differ from the older ones by nearly 0.2 mag.

Compilations of bolometric corrections for O and early B stars, based upon atmospheric models, are given by Miss Underhill (1957*a*, *b*). They are not discussed here.

One hopes that the bolometric corrections for stars of all types earlier than A5 will be improved in the near future by observations from rockets and satellites. In general, there is reasonably good agreement, however, between the values obtained for a given effective temperature from the model atmospheres computed by different authors. The great uncertainty lies rather in the temperature-spectral type or temperature-color relation discussed in the next section.

EFFECTIVE TEMPERATURES

A-Type Stars

For stars of spectral types A and F, Kuiper's temperatures are based upon interpolation, with the help of colors, between fundamental values for the sun and β Aur (an eclipsing binary with measured parallax) and upon Pannekoek's analysis of equivalent widths of the K line. In the years since Kuiper's study, some important additional material has become available. Most important is the determination of the angular diameter of Sirius by Hanbury Brown and Twiss (1956). Their value, $d = 0\farcs0068 \pm 0\farcs0005$, is based on the assumption of no limb darkening. If we adopt a coefficient of limb darkening, $u = 0.45$, we must increase the diameter to $d = 0\farcs0072$ (Dünnweber 1936).[1] In order to obtain the effective temperature of Sirius from its angular diameter, we need, in addition to the angular diameter (1919″) and effective temperature (5750°) of the sun, the apparent magnitudes of Sirius, $V = -1.47$ (Johnson and Morgan 1953) and of the sun, $V = -26.73$ (Stebbins and Kron 1957), and the difference of their bolometric corrections. For this difference we adopt -0.20 mag. from the earlier discussion in this paper. The resulting effective temperature of Sirius ($B - V = +0.01$) is

$$T_e\,(\text{Sirius}) = 9350^\circ\ .$$

The probable error of this value, obtained from the internal probable error of d, is 340°. Perhaps a more realistic estimate would be 400°. This new fundamental determination by Hanbury Brown and Twiss is of the utmost importance. It is to be hoped that their technique will be extended to other stars.

Kuiper's evaluation of the effective temperature of β Aur ($B - V = +0.04$, Popper, unpublished) can be improved with the use of the new scale of bolometric corrections and with the photoelectric apparent magnitude on the V scale, determined by me on three nights at the Lowell Observatory, $V_{\max} = 1.90$, in agreement with Eggen (1958). The other quantities needed are the average radius of the components, for which we accept provisionally Piotrowski's (1948) value, 2.4 solar radii, and the parallax, $0\farcs037$. The resulting value of the effective temperature is

$$T_e\,(\beta\ \text{Aur}) = 10500^\circ\ .$$

This is close to the value, 10700°, adopted by Kopal (1955). The discrepancy between this temperature and the temperature found for Sirius will be discussed later.

Determinations of effective temperatures by means of comparisons between observations of stellar spectra and predictions from the theory of stellar atmospheres have

[1] The correction factors given by Dünnweber are corrections to diameters evaluated from the separations of the interferometer mirrors when the visibility of the fringes formed by the interferometer is zero. Hanbury Brown and Twiss evaluated the angular diameter of Sirius, on the other hand, by determining the dependence of the square of the visibility upon the mirror separations. In this case the correction factor depending upon the degree of darkening is not the same as that tabulated by Dünnweber. The difference between the correction factors in the two cases is, however, slight for moderate degrees of limb darkening.

been placed on a sounder basis since Kuiper's paper was written. With the exception of work on the sun and on hotter stars than those considered here, the most complete comparison between theory and observation appears to be that of Hunger (1955) for Vega ($B - V = 0.00$, Johnson and Morgan 1953). The temperature resulting from his analysis is T_e (Vega) $= 9500° \pm 300°$. Another determination of high weight is that of Code (1954) for the F2 V star σ Boo ($B - V = +0.37$), for which an effective temperature of 6800° is obtained. These two results are of high weight for two reasons. First, theory and observation are compared for features of the stellar spectrum that are strongly dependent upon the effective temperature, and, second, the comparison is for quantities observed with high precision in individual stars.

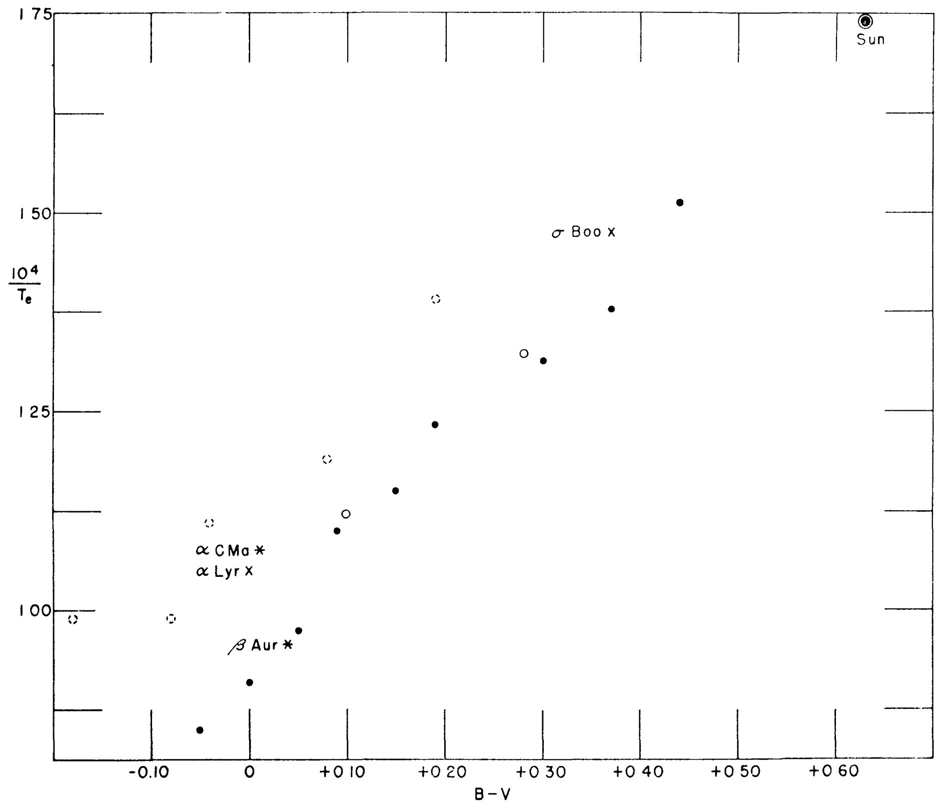

FIG. 3.—Effective temperatures. *Dots:* Kuiper's scale; *circles:* Osawa's values; *dotted circles:* values by Bonsack *et al.* Values for individual stars are labeled.

Values of effective temperatures of somewhat lower weight, obtained also from the theory of stellar atmospheres, are those that predict a single quantity, such as the color index. Determinations of this type have been made by Osawa (1956) for two temperatures and by Bonsack *et al.* (1957) for a number of temperatures. Osawa's results are more satisfactory, in that complete model atmospheres were computed, and, in particular, more complete corrections of the predicted fluxes for line absorption were carried out. Use of the theory of model atmospheres for evaluating effective temperatures is called into question to some extent, at least for cooler stars, by the difficulties encountered by Swihart (1956, 1957) in predicting correctly the emergent fluxes in the case of the sun.

The effective temperatures cited in this section are shown in Figure 3. The plotted points from Bonsack *et al.* are for electron pressures appropriate to the photospheres of main-sequence stars. The scale of Kuiper is also shown. The alternative temperature scales suggested by the points of Figure 3 are listed in Table 4. The temperatures adopted by Schwarzschild (1958) are approximately midway between these scales.

The difference of about 1000° between the effective temperature obtained for β Aur and those obtained for the somewhat bluer stars, Vega, and, in particular, Sirius requires examination. The spectral types, the $B - V$ colors, and the six-color observations of Stebbins and Kron (1956) all make β Aur redder than Sirius and Vega. On the other hand, the temperatures given earlier indicate that β Aur has greater bolometric surface brightness than Sirius. Any uncertainty in the determination of the surface brightness in the case of Sirius depends entirely on the uncertainty in the angular diameter. A redetermination of the angular diameter of Sirius, as well as a determination of the angular diameter of Vega, is needed.

Uncertainty about the surface brightness of β Aur is present because of uncertainty in both the parallax and the radius determined from the light-curve. The parallax of β Aur, 0".037 ± 0".005 (Jenkins 1952), is determined from values at two observatories that differ by 0".010. The value required to make the temperature of β Aur 9250° (Fig. 3 for $B - V = +0.04$) is, if we adopt a radius of each star equal to 2.4 solar radii, 0".047, a value not excluded by the parallax data. If, on the other hand, β Aur is a member

TABLE 4

EFFECTIVE TEMPERATURES FOR A AND F STARS

$B-V$	Effective Temperature: Based upon Sirius and Model Atmospheres	Effective Temperature: Based upon Kuiper's Scale	$B-V$	Effective Temperature: Based upon Sirius and Model Atmospheres	Effective Temperature: Based upon Kuiper's Scale
0.00	9400	21400	+0 30	7350	7500
+0.10	8800	9400	+0.40	6700	6850
+0 20	8100	8200	+0 50	6300	6300

of the Ursa Major stream (Roman 1949), its parallax determined from its proper motion is 0".029; if a member of the Sirius group (Eggen 1958), its parallax is 0".026. In either case, the effective temperature would be even higher than 10500°. We consider next the determination of the radius of β Aur. Since the velocity-curves of both components are well determined (Smith 1948), uncertainty resides only in the light-curve and its analysis. The several discussions of the light-curve (Stebbins 1911; Shapley 1915; Nekrassova 1936; Piotrowski 1948) all make use of Stebbins (1911) photoelectric observations. Because the minima are only 0.07 mag. deep, observations of the highest accuracy are required for a determination of the geometric elements. According to Piotrowski's analysis, Stebbins' normal points differ from a computed light-curve by an average of only 0.007 mag.—precision that is not often matched even today. Yet there are only eleven normal points used by Piotrowski within one minimum and only seven within the other, and residuals of individual normal points are as large as 0.02 mag. The determination of the geometric elements of β Aur cannot, in my opinion, be considered definitive. The small probable error of about 5 per cent quoted by Piotrowski for the ratio, r, of the radius of each star to the radius of the relative orbit depends upon the literal adoption of the very small internal probable error of the magnitude difference of the components given by Petrie (1939) and is misleading for reasons discussed elsewhere (Popper 1959). Piotrowski's value of r for the mean of the two stars is 0.136. Values as small as 0.11 (Nekrassova 1936) and as large as 0.16 (Shapley 1915) have been obtained from the same set of observations. The value of r would have to be

0.18 if the effective temperature were 9250° and the parallax 0".037. While Piotrowski's analysis is probably the most satisfactory that has been made from Stebbins' observations and a value of r as large as 0.18 appears larger than one might reasonably obtain from the observations, it is clear that the surface brightness of β Aur must still be considered poorly determined. A new light-curve of the utmost precision, as well as more measurements of the parallax, are urgently needed.

The possibility exists that, despite indications from the colors and from the line spectra, β Aur does have a greater effective temperature than Sirius and that color and spectral class are not related closely to surface brightness, or that close binaries are related differently from single stars. Until further data are available, however, we must consider the effective temperatures of early A-type stars uncertain, as the points of Figure 3 indicate.

Stars of Other Types

A detailed discussion of the large differences in the effective temperature scales for the O and early B stars recommended recently by different writers is beyond the scope of the present paper. The difference at B0 amounts to about 10000° between the scale proposed by Kopal (1955), based on the rather uncertain elements of the eclipsing binary, μ^1 Sco (with parallax evaluated from its proper motion and membership in the Scorpio-Centaurus cluster), and the scale indicated by Miss Underhill (1957*b*) and others from studies of model atmospheres. It appears that observations of far ultraviolet spectral-energy distributions are required to settle the question.

For stars cooler than the sun, Kuiper's temperature scale is based upon the sun, upon stars with measured angular diameters, and upon the eclipsing binary, YY Gem. The only important datum for temperature determination lacking in Kron's (1952) discussion of YY Gem is the bolometric correction. The star is too red, $B - V$ approximately +1.45 mag., to make use of Figure 1 of this paper. The bolometric correction obtained from the value of $[R - I]$ of YY Gem (Stebbins and Kron 1956) and the relation between $[R - I]$ and bolometric corrections of luminosity class III stars is -1.6 mag. The bolometric correction obtained from Limber's (1958) extrapolated relation between M_V and bolometric corrections for main-sequence M stars is -1.35 mag. The corresponding values of the effective temperatures are 3850° and 3650°, respectively. Limber (1958) adopted a temperature of 3460° and Kopal (1955) one of 3650°. The best value to adopt at present for YY Gem is perhaps 3650°.

The stars for which angular diameters have been evaluated from interferometer measures are all giants or supergiants. In obtaining the angular diameter, it is necessary to make an assumption about limb darkening. Kuiper assumed a cosine law of darkening with a coefficient, u, of about 0.5. Our lack of knowledge of the distribution of light over the visible disks of giant and supergiant stars introduces considerable uncertainty into the true values of the angular diameters and hence into the computed temperatures. It is probable that Kuiper's temperatures are systematically too high because the distributions of light are probably more concentrated toward the centers of the disks than Kuiper assumed. If, for example, the limb-darkening coefficient is 0.9, Kuiper's temperatures for these stars average about 3 per cent too high. If the intensity distribution corresponds to that computed by the Gaposchkins (Payne-Gaposchkin and Gaposchkin 1945) for the least extended atmosphere considered by them (their $n = 3$; the distribution in this case is similar to one discussed by Michelson and Pease in 1921, their $n = 2$), Kuiper's temperatures are about 20 per cent too high. This uncertainty is not one that can be readily removed.

Michelson and Pease (1921) point out, however, as do Hanbury Brown and Twiss (1954), that information concerning the nature of the intensity distribution over the disk of a star can be obtained by measuring the dependence of fringe visibility upon separation of the mirrors of the interferometer. It would appear well within the range of possibility to obtain some essential information in this basic matter for the stars under consideration by the powerful method of Hanbury Brown and Twiss. The best eclipsing binary for determining the limb darkening of a cool giant is probably RZ Cnc, a gaint K-type binary with spectral lines of both components visible in the spectrum. A definitive light-curve is badly needed for this system, in order to determine the masses of K giants, as well as for the problem discussed here.

It is possible that the recently discovered K5 main-sequence eclipsing binary with measurable parallax, HD 16157 (Evans 1957) may furnish us with a greatly needed fundamental temperature for a star cooler than the sun. The lines of both components would have to be found in the spectrum, however, as would a measurable secondary minimum in the light-curve, and an improved parallax would have to be determined.

At the present time we must conclude that only for the spectral type of the sun is the effective temperature definitively established, although the uncertainty for YY Gem, M1 V, is rather small. Limber's (1958) discussion of the M dwarfs makes use of data for individual stars not considered in this paper.

TABLE 5

EFFECTIVE TEMPERATURES OF STARS OF LUMINOSITY CLASSES V AND III

Type	Luminosity Class V		Luminosity Class III		
	$B-V$	T_e (Keenan and Morgan)	$B-V$	T_e (Keenan and Morgan)	T_e (Adjusted)
G8.........	+0 70	5320	+0.95	4440	4800
K0.........	+0.82	5120	+1.01	4200	4650
K1.........	+0 86	4920	....	4000	4550
K2.........	....	4760	+1.16	3810	4400
K3.........	+1.01	4610	+1.30	3660	4050:
K5.........	+1.18	4400	+1.52	3550	....

Whatever the correct temperatures of stars cooler than the sun may be, it appears that the temperature differences between stars of luminosity classes III and V in the spectral range G8–K3, given by Kuiper (1938) and tabulated by Keenan and Morgan (1951), are considerably too large. This conslusion is readily obtained from available data, given in Table 5. The values of $B - V$ for a given spectral type are from Johnson and Morgan (1953). Temperatures in the columns "T_e (Keenan and Morgan)" are from their compilation. The temperatures in the column "T_e (Adjusted)" are temperatures based upon the assumption that the relation between color and effective temperature is the same for the two luminosity classes. A similar comparison, in which the six-color index, $[G - I]$ (see the compilation by Morgan, Harris, and Johnson 1953), is used instead of $B - V$ gives "adjusted" temperatures for luminosity Class III slightly higher than those based upon $B - V$. At the present time my recommendation is to adopt the scale of effective temperatures for luminosity class III stars given in the last column of Table 5.

One may object to the assumption that the relations between color and effective temperature are the same for different luminosity classes. But, in the first place, Kuiper's evaluation of the temperature differences between giants and main-sequence stars, used by Keenan and Morgan, are quite uncertain and are themselves based upon older color measures. In the second place, one would expect, if the assumption were not justified, that the spectral-energy distributions for stars of the same effective temperature and different luminosity classes would differ appreciably. That such differences are not large for population I stars is indicated by the fact that the correlation between different color indices, such as $B - V$ and $[R - I]$ (six-color measures), measured in different parts of the spectrum, is found to be relatively independent of luminosity class for stars bluer than +1.20 mag. in $B - V$, as shown in Figure 4. The 150 values of $[R - I]$ contained in Figure 4 are by Stebbins and Whitford (1945) and Stebbins and Kron (1956). The values of $B - V$ are principally by Johnson and Morgan (1953); 38 values of $B - V$ are unpublished measurements by the writer.

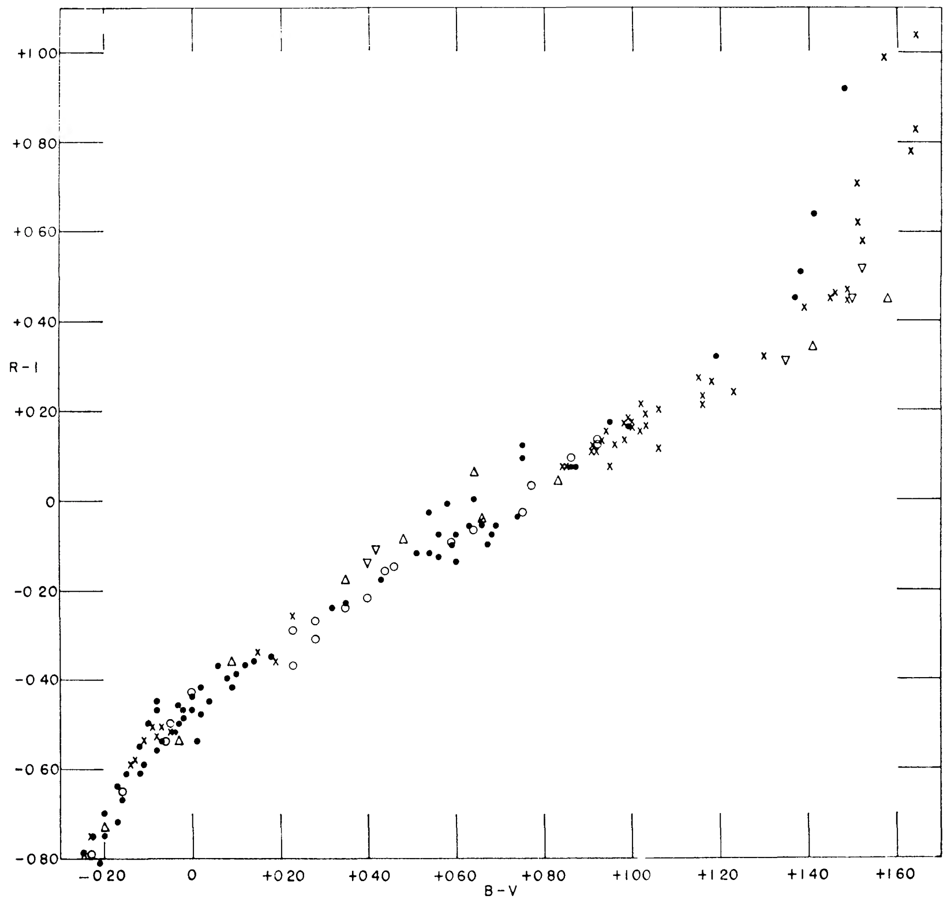

FIG. 4.—$[R - I]$ (six-color observations) versus $B - V$. *Dots:* luminosity class V; *circles:* IV; *crosses:* III; ▽: II; △: I.

There are insufficient data available to carry out a comparison such as that of Table 5 for stars of higher luminosity than class III. The few data indicate that smaller corrections to the table of Keenan and Morgan are needed for luminosity classes I*b* and II than for luminosity class III.

CONCLUSIONS

The principal aim of this paper has been to evaluate the strengths and weaknesses in our present knowledge of bolometric corrections and effective temperatures. The former are reasonably well known as a function of color for stars cooler than type F0 (except for stars redder than $B - V + 1.3$ mag.) and as a function of effective temperature for hotter stars. Effective temperatures are not known with certainty for any spectral type other than that of the sun. The work of Hanbury Brown and Twiss in obtaining the angular diameter of Sirius should be repeated. Determination of a definitive value of this quantity, as well as of the angular diameters of Vega, Altair, and Procyon, should remove the ambiguity of about 1000° in the temperature scale at A0 and should improve the scale between A0 and G0. A new light-curve and new parallax are required for β Aur in addition. For the hotter stars, rocket or satellite observations of the far ultraviolet spectrum are needed to determine the validity of different atmospheric models. For stars cooler than the sun, it appears difficult to obtain reliable temperatures. Blanketing effects in the photospheres cause increased difficulties in theoretical models at lower temperatures; main-sequence stars are too faint and small for angular-diameter determination; and lack of knowledge about limb darkening makes the determination of angular diameters of stars of higher luminosity uncertain. Basic information on limb darkening might be obtainable by investigation of the "visibility" patterns for bright cool stars by the methods employed by Hanbury Brown and Twiss on Sirius. An intensive study of the K-type giant eclipsing binary, RZ Cnc, might also throw light on this question. Improvement in the scale for cooler stars would result from a determination of the bolometric correction for YY Gem and from an analysis of the system HD 16157 if the lines of the fainter component are measurable in the spectrum and if the light-curve has a secondary minimum of appreciable depth.

In the analyses of stars with measured angular diameters and of eclipsing binaries with known parallax, what is obtained is the ratio of the effective temperature of the star to that of the sun. Any change in the effective temperature of the sun, such as may be indicated by Labs's (1958) recent measurements of the solar spectral-energy distribution, would require a proportional change in the temperatures established by these methods.

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