FIVE-COLOUR OBSERVATIONS OF 24 CLASSICAL CEPHEIDS

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This paper presents light-curves and colour-curves for 24 Cepheids, mostly of type I. The periods vary from $5^d$ to $79^d$, but are mainly concentrated around $9^d$.

The observations were made with the simultaneous five-channel photometer attached to the 36-inch "light-collector" of the Leiden Southern Station on the Departmental Grounds near Hartebeespoordam, Transvaal, Republic of South Africa. The reduction took place at the Mount Stromlo Observatory of the Australian National University, Canberra A.C.T., Australia. The number of observations per Cepheid varies from 20 to 95. Each observation was accompanied by an observation of a nearby comparison star, while often standard stars were observed also.

1. Introduction

While studying the results of simultaneous five-colour observations of early-type stars, it was noticed that appreciable effects of spectral class and luminosity can also be observed for supergiants of a somewhat later type. Consequently the need was felt for a more detailed and complete knowledge of the colours of the various types of supergiants in the five-colour system. For this purpose numerous supergiants, both in the Magellanic Clouds and in the Galaxy, were observed. This led to the study of a number of classical Cepheids, which provide another extension to the system of supergiants. The Cepheids are especially valuable for this purpose, since the observations of one variable during its cycle of variation are equivalent to the study of a sequence of stars of different spectral types, but otherwise under constant conditions such as distance and reddening and, it may be assumed, with nearly constant luminosity.

Our interest was directed mainly towards the more luminous Cepheids. These may form a continuation of the supergiants of classes Ia and Ib, which we had already observed. Since the most luminous Cepheids with the longest periods are rare, most of the programme stars have periods around 9 days. Since we considered an investigation of the homogeneity of the colours as more important, we restricted ourselves to stars of this group, rather than studying a wide variety of periods and various types of population. Another reason for concentrating on the 9-day period group was that the sharp change of shape in the light-curve takes place at about this period. It may well be that the detailed study of these shapes will lead us to a better definition of the luminosity class, which, in view of the use of Cepheids as distance indicators, is highly important.

2. Programme

The stars selected for detailed observation are listed in table 1. The periods and epochs have all been taken from the second General Catalogue of Variable Stars (Kukarkin et al., 1958).

The two longer-period variables KN Cen and QT CrA were included in the programme at a later stage and have not been observed intensively. Likewise some variables of other types were included in the programme originally, but were abandoned soon after the observations were started, when it became apparent that no time would be available for these stars in a regular programme. The results of these observations are not discussed in this paper and these stars are not included in table 1. Only one star of a different type, i.e. Kappa Pav, was kept on the list.

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Table 8 gives the variations of brightness and colours of the Cepheids relative to those of the comparison stars. Table 3 gives the brightness and colours of the comparison stars in the natural photometric system of the telescope. A conversion to the $UBV$ system is given for $V$ and $V-B$ only.

The properties of the light and colour variations of the Cepheids are discussed briefly in section 5. A discussion of the stability of the comparison stars and standard stars, using the observations of the previous years, will be found in section 4. Of the 28 comparison stars, chosen at random near the Cepheids, four were identified by us as supergiants of type F or G.
The criteria used to select the comparison stars were proximity to the variable, matching brightness, and sufficient ultraviolet intensity. The latter consideration meant that stars of type K and M were excluded. The comparison stars are also listed in table 1. The programme included occasional observations of main standards for calibration purposes.

Only the first half of the night was available for the Cepheid programme, the other half being devoted to observations of the Magellanic Clouds. As a rule no observations were made in the week around full Moon; although at the time this was considered a welcome rest, the lack of these observations was regretted later.

No attempt was made to determine in advance the phase of the variable, but the observations were made at random times.

### Table 1
Cepheids and comparison stars

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1. Cf. IT Car  4. Cf. AQ Car
2. In cluster NGC 6097 5. Population II cepheid
3. Cf. XY Car

3. Observations

As described in an earlier publication (Th. and J. H. WALRAVEN, 1960), the five-colour photometer yields simultaneous measurements in five wavelength regions with an integration time of one minute. This integration time could not be varied and the variations in light intensity were taken up mostly by changing the attenuation in the recording devices (10 steps of 0°.5) or by changing the integrating capacitors (1 step of 2m.5). A neutral optical attenuator could be switched in for the brighter stars, reducing the light by nearly three magnitudes.

The greatest loss of observing time was due to the necessity to connect each of the five channels in turn to the recording potentiometer. Since this is done manu-
ally, it takes about one minute, as much as the integration time itself. During the minute of integration, the coordinates of the star under observation were noted down and the controls of the telescope preset to the coordinates of the star to be observed next.

As a rule a Cepheid was observed twice, once before and once after the comparison star. Now and again during the night, main standards were observed in the usual way, i.e. three or four stars at widely different hour angles, observed one after the other, so that the extinction coefficient could be determined. At a later period this standard procedure was neglected somewhat and we made supplementary determinations of the extinction from the many observations of the comparison stars.

4. Reduction

For normal programmes the reduction of the observations consists of the following steps:

a) Reading the deflections on the Brown recorder chart.
b) Multiplication by the attenuation factor.
c) Subtraction of the sky background.
d) Determination of the logarithms of intensity.
e) Determination of the difference between the logarithms of intensities in the different wavelength bands.
f) Determination of the extinction coefficients for brightness and colours by comparison of standard stars at large and small zenith distances.
g) Reduction of the brightness and colours to zenith.
h) Plotting, for each night, the deviations from the standard values for the known standard stars against time. These deviations are produced by so far unknown instrumental effects.
i) Drawing smooth curves (the “instrumental curves”) through these plots.
j) Correction of the observations of other stars with the values read off these “instrumental curves”.

Due to the enormous observing capacity of the telescope, these reductions are very time-consuming. In the case of the Cepheids we therefore applied a shortened procedure. The determinations of the extinction were omitted and constant average values were used. These values are given in the table below.

These average values are based on the results of other programmes, which proceeded in the normal way de-

scribed above. The brightness and colours of the Cepheids were determined relative to the comparison stars, so that the correction mentioned above under g) could be omitted.

The brightness and colours of the comparison stars were determined by the normal method described above, except that the constant average values of the extinction coefficients were used. This method can be applied only to those nights where a sufficient number of main standard stars with known brightness and colours were observed. The number of such determinations of the brightness and colours of the comparison stars varies between nine and zero.

Using the mean preliminary values of the comparison stars in addition to those of the standard stars, we constructed for every observing night new instrumental curves, now with more comprehensive data. Using these, we obtained new values of brightness and colours, now for all observations. These values were plotted against the data for all comparison stars and standards in order to detect signs of possible variability.

The diagrams show remarkable conformity. In all cases the scatter in the brightness is considerably larger than that in the colours. Moreover the scatter is consistently the same for all the stars, increasing only when the signals become fainter. No indication of variability could be found amongst the comparison stars. Obviously the atmospheric disturbances and instrumental effects produce most of the scatter, while for the faint stars the random fluctuations in the photocurrent become more important.

Table 2 lists the mean value of the deviation for one

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<th>B-U</th>
<th>U-W</th>
<th>B-L</th>
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</table>

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observation, for some standard stars. It should be noted that the mean deviation shown in the table is still larger than necessary, because a constant value of extinction has been assumed and also because iteration of the procedure starting from h) with the new mean values would certainly have reduced the scatter. However, it seems superfluous to repeat the procedure when we consider the difference between the preliminary values and the new values which we derived. The mean absolute value of this difference for all 28 comparison stars, expressed in logarithm of intensity, is shown in the table below.

<table>
<thead>
<tr>
<th>V</th>
<th>V - B</th>
<th>B - U</th>
<th>U - W</th>
<th>B - L</th>
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These figures represent primarily the errors of the preliminary values of the brightness and colours, since they are larger than one would expect from the data in table 2. The large value for U - W is due to the fact that the comparison stars of the Cepheids are on the average of a later spectral type than the standards and therefore have a very low intensity in the ultraviolet. On the whole, however, the differences between the preliminary and new values are sufficiently small and we decided not to repeat the procedure, but to consider the new values as definite. They are given in table 3 and are discussed at the end of this paper.

In table 4 we give the brightness and the colours of the standard stars, determined in the same way as those of the comparison stars of the Cepheids. In this table are also given the preliminary values used, which are based on the reductions of observations of preceding years and have much more significance. These

### Table 3

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<th>SP</th>
<th>V</th>
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<td>0.2375</td>
<td>0.3697</td>
<td>0.1992</td>
<td>0.2383</td>
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<tr>
<td>124 600</td>
<td>14.782</td>
<td>0.511</td>
<td>0.137</td>
<td>0.502</td>
<td>0.0586</td>
<td>0.4583</td>
<td>0.1495</td>
<td>0.1903</td>
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</tr>
<tr>
<td>136 023</td>
<td>7.23</td>
<td>0.286</td>
<td>A0</td>
<td>-0.146</td>
<td>0.0373</td>
<td>0.4776</td>
<td>0.1021</td>
<td>0.1950</td>
<td>41</td>
</tr>
<tr>
<td>141 736</td>
<td>6.37</td>
<td>0.151</td>
<td>B3</td>
<td>0.198</td>
<td>0.0934</td>
<td>0.1730</td>
<td>0.0642</td>
<td>0.0640</td>
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</tr>
<tr>
<td>154 666</td>
<td>7.33</td>
<td>0.128</td>
<td>A2</td>
<td>-0.128</td>
<td>0.5836</td>
<td>0.3536</td>
<td>0.1299</td>
<td>0.2078</td>
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<tr>
<td>164 975</td>
<td>7.17</td>
<td>0.508</td>
<td>F0</td>
<td>-0.132</td>
<td>0.2125</td>
<td>0.5406</td>
<td>0.2977</td>
<td>0.2424</td>
<td>32</td>
</tr>
<tr>
<td>164 975</td>
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<td>A2</td>
<td>-0.162</td>
<td>0.0777</td>
<td>0.4147</td>
<td>0.1177</td>
<td>0.1942</td>
<td>30</td>
</tr>
<tr>
<td>166 618</td>
<td>9.31</td>
<td>0.186</td>
<td>A3</td>
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<td>0.0776</td>
<td>0.4834</td>
<td>0.1637</td>
<td>0.2066</td>
<td>11</td>
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<tr>
<td>166 618</td>
<td>9.67</td>
<td>0.556</td>
<td>G5</td>
<td>-1.132</td>
<td>0.2390</td>
<td>0.6666</td>
<td>0.2000</td>
<td>0.2397</td>
<td>44</td>
</tr>
<tr>
<td>164 244</td>
<td>7.32</td>
<td>0.275</td>
<td>A5</td>
<td>-0.286</td>
<td>0.1140</td>
<td>0.4645</td>
<td>0.1664</td>
<td>0.2286</td>
<td>45</td>
</tr>
<tr>
<td>167 499</td>
<td>7.66</td>
<td>0.174</td>
<td>A0</td>
<td>-0.265</td>
<td>0.1774</td>
<td>0.4783</td>
<td>0.2776</td>
<td>0.1738</td>
<td>16</td>
</tr>
<tr>
<td>174 467</td>
<td>6.83</td>
<td>0.304</td>
<td>A0</td>
<td>0.009</td>
<td>0.2854</td>
<td>0.6666</td>
<td>0.2784</td>
<td>0.1132</td>
<td>26</td>
</tr>
<tr>
<td>174 787</td>
<td>7.61</td>
<td>0.332</td>
<td>F0</td>
<td>-0.302</td>
<td>0.1371</td>
<td>0.2578</td>
<td>0.1500</td>
<td>0.1846</td>
<td>17</td>
</tr>
<tr>
<td>177 171</td>
<td>5.17</td>
<td>0.553</td>
<td>G0</td>
<td>0.261</td>
<td>0.2972</td>
<td>0.3316</td>
<td>0.2037</td>
<td>0.2922</td>
<td>72</td>
</tr>
<tr>
<td>189 090</td>
<td>5.55</td>
<td>0.484</td>
<td>B9</td>
<td>0.368</td>
<td>0.0426</td>
<td>0.3592</td>
<td>0.0845</td>
<td>0.1137</td>
<td>15</td>
</tr>
</tbody>
</table>

* COORDINATES 1960: R.A. 15° 09' 40", DEC. -54° 36.3"
values form the link by which the colours of the Cepheids are finally connected with those of the supergiants of another programme. They have been obtained by a process of repeated approximation which included the closing of a belt of such standards around the sky. The final results for these standards can be obtained only by a discussion of all the observations, which is not given in this paper.

In table 5 we show the differences between the adopted values (1961) and the values derived from the Cepheid programme (1962) in the sense 1962 minus 1961. The differences are similar to those for the Cepheid comparison stars, but reveal a systematic component, which is shown in the last line of table 5. Since the reduction procedure used is such that we should find back the values that were originally used, there must be some external cause for this systematic deviation. It seems probable that variability of one of the standard stars, HD 178 175, is responsible for it, because for this star the discrepancy between 1962 and 1961 is appreciable (see table 4).

This is illustrated more clearly in table 6, where the differences 1962–1961 have been corrected with the systematic value of table 5. The table shows, that HD 178 175 has decreased in brightness, has become bluer in the $V - B$ and $U - W$, and redder in the $B - U$ and $B - L$. The most strongly varying colour is $B - U$. A similar effect has been found also for other stars in the B star programme, in each case the colour $B - U$ varying most, $V - B$ somewhat less, but in opposite sense, while the changes in colour are accompanied by relatively

### Table 4

<table>
<thead>
<tr>
<th>HD</th>
<th>YEAR</th>
<th>V</th>
<th>V-B</th>
<th>B-U</th>
<th>U-W</th>
<th>B-L</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>74 575</td>
<td>1962</td>
<td>+1.288</td>
<td>+0.536</td>
<td>-0.014</td>
<td>-0.016</td>
<td>-0.024</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>1961</td>
<td>+1.287</td>
<td>+0.539</td>
<td>-0.015</td>
<td>-0.018</td>
<td>-0.021</td>
<td>9</td>
</tr>
<tr>
<td>93 030</td>
<td>1962</td>
<td>+1.661</td>
<td>+0.171</td>
<td>-0.076</td>
<td>-0.037</td>
<td>-0.045</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>1961</td>
<td>+1.661</td>
<td>+0.171</td>
<td>-0.074</td>
<td>-0.039</td>
<td>-0.043</td>
<td>9</td>
</tr>
<tr>
<td>104 377</td>
<td>1962</td>
<td>+0.650</td>
<td>+0.067</td>
<td>-0.056</td>
<td>-0.017</td>
<td>-0.016</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>1961</td>
<td>+0.649</td>
<td>+0.066</td>
<td>-0.054</td>
<td>-0.017</td>
<td>-0.015</td>
<td>9</td>
</tr>
<tr>
<td>122 980</td>
<td>1962</td>
<td>+1.016</td>
<td>+0.063</td>
<td>+0.010</td>
<td>+0.026</td>
<td>+0.035</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>1961</td>
<td>+1.020</td>
<td>+0.064</td>
<td>+0.030</td>
<td>+0.018</td>
<td>+0.048</td>
<td>3</td>
</tr>
<tr>
<td>135 382</td>
<td>1962</td>
<td>+1.598</td>
<td>+0.025</td>
<td>+0.516</td>
<td>+1.320</td>
<td>+1.287</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>1961</td>
<td>+1.594</td>
<td>+0.026</td>
<td>+0.527</td>
<td>+1.335</td>
<td>+1.292</td>
<td>73</td>
</tr>
<tr>
<td>144 470</td>
<td>1962</td>
<td>+1.174</td>
<td>+0.005</td>
<td>+0.004</td>
<td>+0.010</td>
<td>+0.029</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>1961</td>
<td>+1.172</td>
<td>+0.002</td>
<td>+0.008</td>
<td>+0.011</td>
<td>+0.020</td>
<td>73</td>
</tr>
<tr>
<td>164 402</td>
<td>1962</td>
<td>+0.448</td>
<td>+0.002</td>
<td>-0.024</td>
<td>-0.019</td>
<td>-0.015</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>1961</td>
<td>+0.448</td>
<td>+0.002</td>
<td>-0.024</td>
<td>-0.019</td>
<td>-0.014</td>
<td>24</td>
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</tbody>
</table>

### Table 5

<table>
<thead>
<tr>
<th>HD</th>
<th>V</th>
<th>V-B</th>
<th>B-U</th>
<th>U-W</th>
<th>B-L</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>61 068</td>
<td>1962</td>
<td>+0.498</td>
<td>+0.064</td>
<td>+0.117</td>
<td>+0.086</td>
<td>+0.166</td>
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<tr>
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<td>1961</td>
<td>+0.476</td>
<td>+0.056</td>
<td>+0.128</td>
<td>+0.024</td>
<td>+0.167</td>
</tr>
<tr>
<td>178 175</td>
<td>1962</td>
<td>+0.354</td>
<td>+0.049</td>
<td>+0.078</td>
<td>+0.035</td>
<td>+0.176</td>
</tr>
<tr>
<td></td>
<td>1961</td>
<td>+0.356</td>
<td>+0.049</td>
<td>+0.086</td>
<td>+0.039</td>
<td>+0.176</td>
</tr>
</tbody>
</table>

* Sec 2 > 2.00

** Variable
small changes in brightness. In one case, HD 20 340, the variation in \( B - U \) amounts to 0\(^{m}.07\), but in many other cases the variations are only of the order of 0\(^{m}.01\) and their reality could only be suspected. It is an important result of the present discussion that a variation in the colour \( B - U \) of only 0\(^{m}.02\) is established with certainty. We have the impression that the variation is always in the same sense as for HD 178 175. So far the effect has only been noted for B stars.

Apart from these cases of colour variability, the colours of the stars are in general surprisingly stable, as is shown by the values in table 6.

**Table 6**

Final differences (1962 − 1961) of brightness and colours of standard stars

<table>
<thead>
<tr>
<th>HD</th>
<th>( \Delta V )</th>
<th>( \Delta V - B )</th>
<th>( \Delta B - U )</th>
<th>( \Delta U - W )</th>
<th>( \Delta B - L )</th>
<th>( \Delta N )</th>
</tr>
</thead>
<tbody>
<tr>
<td>61 068</td>
<td>-0.017</td>
<td>-0.005</td>
<td>0.0028</td>
<td>-0.021</td>
<td>0.0060</td>
<td>8</td>
</tr>
<tr>
<td>74 575</td>
<td>-0.011</td>
<td>-0.002</td>
<td>0.0014</td>
<td>0.007</td>
<td>-0.011</td>
<td>45</td>
</tr>
<tr>
<td>105 337</td>
<td>-0.011</td>
<td>-0.004</td>
<td>0.0009</td>
<td>0.006</td>
<td>-0.005</td>
<td>95</td>
</tr>
<tr>
<td>122 980</td>
<td>0.001</td>
<td>0.005</td>
<td>0.008</td>
<td>0.008</td>
<td>-0.009</td>
<td>9</td>
</tr>
<tr>
<td>155 362</td>
<td>-0.019</td>
<td>-0.006</td>
<td>0.0018</td>
<td>0.0017</td>
<td>0.001</td>
<td>26</td>
</tr>
<tr>
<td>114 470</td>
<td>-0.001</td>
<td>0.000</td>
<td>0.005</td>
<td>0.005</td>
<td>0.032</td>
<td>62</td>
</tr>
<tr>
<td>164 402</td>
<td>-0.002</td>
<td>-0.001</td>
<td>-0.003</td>
<td>0.0004</td>
<td>0.0001</td>
<td>4</td>
</tr>
<tr>
<td>173 175</td>
<td>-0.034</td>
<td>-0.023</td>
<td>-0.007</td>
<td>-0.0046</td>
<td>28</td>
<td></td>
</tr>
</tbody>
</table>

The unweighted means, without regard to sign, of the residuals shown in table 6, excluding HD 178 175, are:

<table>
<thead>
<tr>
<th>( \Delta V )</th>
<th>( \Delta V - B )</th>
<th>( \Delta B - U )</th>
<th>( \Delta U - W )</th>
<th>( \Delta B - L )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log intensity</td>
<td>0.0019</td>
<td>0.0006</td>
<td>0.0015</td>
<td>0.0008</td>
</tr>
<tr>
<td>Magnitudes</td>
<td>0(^{m}.0047)</td>
<td>0(^{m}.0015)</td>
<td>0(^{m}.0038)</td>
<td>0(^{m}.0020)</td>
</tr>
</tbody>
</table>

These values are larger than would be expected from the mean error of observation, as shown in table 2. Rather than being due to instrumental errors, they seem to reflect the intrinsic changes in brightness and colours of the stars over a period of a year. This is supported by the fact that the character of the fluctuations is different in the two cases; the instrumental errors are smallest for the colour \( B - L \), while the intrinsic variations are smallest for \( V - B \).

Independent of whether the deviations are due to an intrinsic or an instrumental cause, it may be concluded that the colours of stars in general do not vary by more than a few thousandths of a magnitude.

So far we have discussed the brightness and colours of the comparison and standard stars only as they are determined from the observations, i.e. the natural values for the instrument. The reason for this is that it turned out to be rather difficult to transform our colours to those of standard photometric systems such as the \( UBV \) system. Such transformations are non-linear and multivalued. For \( B - L \) and \( U - W \) no comparison exists, while for \( U - B \) the transformation is very complicated. The comparison of \( V - B \) with \( (B - V) \) of the \( UBV \) system is the only one worth while, although even here the relation is strongly non-linear and multivalued. The cause of this complication is that the spectral regions used in the \( UBV \) system are too wide. For the band \( U \), which contains the Balmer discontinuity, this is obvious, but for the band \( B \), which includes the region containing the higher members of the Balmer series, the undesirable effects are perceptible too.

Instead of forcing our colours into an unsatisfactory transformation, we decided to discuss the results in terms of natural colours. In order to make the confusion with colours of other systems less likely, we give the results not in magnitudes, but as logarithms of intensity. However, to make possible at least a rough comparison of our results with those obtained by other types of photometry, we give the two transformations which have reasonable accuracy.

By comparing our observations of about 240, mostly bright, field stars with those made at the Royal Observatory at the Cape (1963), and with some other sources, we found the following preliminary relations.

The relation between the \( V_I \) magnitude in the \( UBV \) system and our brightness \( V \) is

\[
V_I = 6.87 - 2.5[V + 0.05(V - B)].
\]

The relation between \( (B - V)_I \) and \( B - V \) is strongly nonlinear, viz. we find both the very blue and the very red stars to be redder than in the \( UBV \) system. The deviation reaches 0\(^{m}.08\) for the bluest O stars and 0\(^{m}.25\) for M-type stars. The transformation is given in table 7.

In this table may be noted the gradual changes from Orion stars to supergiants, due to the decreasing strength of the hydrogen lines included in the band \( B \) of the \( UBV \) system but not in our band B. The table gives the magnitudes to three decimal places; the actual accuracy is difficult to estimate and varies for the
Table 7
Transformation for $V - B$ of the five-colour system to $(B - V)_I$
of the $UBV$ system

<table>
<thead>
<tr>
<th>V-B</th>
<th>$(B-V)_I$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOG INT</td>
<td>2.5 LOG INT</td>
</tr>
<tr>
<td></td>
<td>ORION STARS</td>
</tr>
<tr>
<td>-0.0000</td>
<td>-0.250</td>
</tr>
<tr>
<td>0.0000</td>
<td>-0.260</td>
</tr>
<tr>
<td>0.0100</td>
<td>-0.275</td>
</tr>
<tr>
<td>0.0200</td>
<td>-0.275</td>
</tr>
<tr>
<td>0.0300</td>
<td>-0.250</td>
</tr>
<tr>
<td>0.0400</td>
<td>-0.215</td>
</tr>
<tr>
<td>0.0500</td>
<td>-0.200</td>
</tr>
<tr>
<td>0.0600</td>
<td>-0.195</td>
</tr>
<tr>
<td>0.0700</td>
<td>-0.190</td>
</tr>
<tr>
<td>0.0800</td>
<td>-0.185</td>
</tr>
<tr>
<td>0.0900</td>
<td>-0.180</td>
</tr>
<tr>
<td>0.1000</td>
<td>0.000</td>
</tr>
<tr>
<td>0.1100</td>
<td>0.095</td>
</tr>
<tr>
<td>0.1200</td>
<td>0.075</td>
</tr>
<tr>
<td>0.1300</td>
<td>0.060</td>
</tr>
<tr>
<td>0.1400</td>
<td>0.050</td>
</tr>
<tr>
<td>0.1500</td>
<td>0.040</td>
</tr>
<tr>
<td>0.1600</td>
<td>0.030</td>
</tr>
<tr>
<td>0.1700</td>
<td>0.020</td>
</tr>
<tr>
<td>0.1800</td>
<td>0.010</td>
</tr>
<tr>
<td>0.1900</td>
<td>0.000</td>
</tr>
</tbody>
</table>

It may be remarked here that the nonlinearity of the transformation has serious consequences for the discussion of the properties of the Cepheids. This should be kept in mind if the results in this paper are compared with the observations of Cepheids in the $UBV$ system. For example a typical unreddened Cepheid may vary in $V - B$ from +0.2000 to +0.4000, i.e. over a range of 0.50 magnitude. According to table 7 the range in $(B - V)_I$ would be 0.45 magnitude, which is considerably less. If the same star is reddened by 0.5 magnitude, the range in $(B - V)_I$ would decrease to 0.41 magnitude. Here again we see the influence of the wide band of the $UBV$ system. In this case the increasing strength of the metallic lines may be responsible for a considerable displacement of the effective wavelength. The apparent reduction of the amplitude is relative to the five-colour system, where the displacement of effective wavelength is much smaller. However, even in the five-colour system a small effect of the same kind may be present compared to the ideal system. It is difficult to estimate the strength of any such effect, but if present, it will make the discrepancies in the $UBV$ system still larger.

A general discussion of the colours will be included in a forthcoming paper on the intrinsic colours of supergiants in the five-colour system. In the present paper we restrict ourselves to presenting the variations with phase of the brightness and colour, together with a few comments. The light-curves and colour-curves are shown in figures 1 to 23. The curves for KN Cen and QT CrA are not shown, because the limited number of observations did not permit us to study the shape of their curves to the same extent as those of the other stars. Curves of the colour $U - W$ are not shown; except for a few bright stars, the accuracy for this colour is very low, due to the extreme weakness of the far ultraviolet (band W) for later type stars. In those cases where the accuracy is better, it appears that the amplitude variation in colour $U - W$ is rather small. In different parts of the table. In particular the supergiants showed a larger scatter in the comparison, which probably indicates a tendency to instability in these stars.

The transformations were applied to the $V$ and $V - B$ of the Cepheid comparison stars and the results are given in table 3 as $V_I$ and $(B - V)_I$.

5. Discussion

The brightness and colours of the Cepheids are given in table 8 at the end of this paper. The values are given as logarithms of intensity and represent the difference between the Cepheid and the comparison star. The brightness and colour of the latter in the natural photometric system may be found in table 3. By adding these values to those in table 8, the brightness and colours of the Cepheids may be found, also in the natural photometric system. By means of the transformations given in the previous section, the brightness $V$ and the colour $V - B$ may be translated into the $UBV$ system.

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figures 1 to 22 we have drawn a smooth line through the dots representing the individual observations. In cases where uncertainty exists, a broken line has been drawn. In the case of S Sge ($P = 8^{h}38216$), only a limited number of observations exist and the line drawn in figure 8 was given approximately the same shape as that in figure 7 (IQ Nor, a Cepheid of similar period: $P = 8^{h}2317$). For Kappa Pav, an abnormal Cepheid, no such comparison was available and the curves are very uncertain. The vertical lines denote zero phase (maximum brightness) according to the ephemerides given in table 1, which were taken from the second General Catalogue of Variable Stars (Kukarkin et al., 1958). Clearly some of the ephemerides need revision. A study of figures 1 to 23 leads to the following general remarks:

a) The scatter is not unduly large for any of the Cepheids. In the case of S Nor, a number of observations of previous years were available which fit the curves remarkably well. The deviations do not exceed the scatter of the other points in figure 13. In general the classical Cepheids seem to repeat their variations with high regularity.

b) The changes in character of the curves for $B - V$ relative to those for $V$ (and of $B - L$ relative to $V - B$ and so on) are similar for all stars. The curve for $V - B$ is shifted to an earlier phase relative to $V$. This is a well known effect of the classical Cepheids and has been interpreted as evidence of variation in the radius of the star. In the curve for $B - U$, which on the whole is rather flat, a hump often shows at the phase of increasing brightness. Consequently the relation between $B - U$ and $V - B$ is not singlevalued. The same effect, to a lesser extent, is seen in the comparison of $B - L$ with $V - B$. It presents itself as a shift in phase, $B - L$ coming earlier, and as a slight bulging upward of the ascending part of the curve for $B - L$.

In the colour-colour diagrams the Cepheids describe a rather elongated loop. Our observations show that this a a general property of the Cepheids.

c) The variation in the colour $B - L$ is remarkably strong, considering that the difference in effective frequency between bands B and L is much smaller than that between V and B. On the other hand, the amplitude of $B - U$ is smaller than would be expected from the change in temperature gradient.

It is interesting to compare this behaviour with that shown by variables with very short periods (J. Ponsen, 1961, 1963) e.g. V 703 Sco, RS Grus, EH Lib, BS Aqr, AI Vel (unpublished). The curve for $B - U$ for these stars resembles the curve for $V - B$, inverted, while $B - L$ shows hardly any variation. These differences in behaviour are to be expected, if one notes that in the colour-colour diagram the narrow closed loop described by the variable lies along a line of constant luminosity.

d) Figures 1 to 22 strongly suggest that the humps on the light-curves are a normal aspect of the classical Cepheids. Except that they tend to weaken when the amplitude is smaller than normal for the period, they are strongly pronounced in all light-curves for periods around 9 days. Their position and amplitude show a pronounced systematic relation with the period. The Cepheids V 500 Sco ($P = 9^{h}31665$) and YZ Sgr ($P = 9^{h}55345$) show, within the errors of observation, identical curves for V, and for $B - L$, $V - B$ and $B - U$. Likewise the behaviour of S Nor is practically identical with that of AQ Car in all respects.

All this gives the impression of regularity, so that there is no reason to classify the Cepheids in groups according to the character of the humps. In fact only S Mus ($P = 9^{h}65869$) stands out clearly from the general pattern. This star is abnormal in the following respects (figure 12):

a) The amplitude is small, while the humps are clearly pronounced.

b) The colour-curve $B - U$ is unlike that of other stars of the same period.

c) The intrinsic colours are abnormal as regards position in the colour-colour diagrams.

d) The intrinsic colours are abnormal as regards the tilt of the loops in the colour-colour diagrams.

With its abnormal behaviour S Mus stands out from all the other Cepheids observed by us (except of course Kappa Pav). The most probable explanation for this abnormality is the assumption that this star has an invisible companion.

A remark could be made about some of the comparison stars. As described in the previous section, these stars were chosen at random, in the vicinity of the Cepheids. Four of the 28 comparison stars are F or G-type supergiants. This fraction is somewhat larger than one would expect. It might be interesting to in-
Figures 19–23. Light-curves and colour-curves of Cepheids. \( V, V - B, B - L \) and \( B - U \) are expressed in logarithms of intensity.

vestigate whether the numbers of supergiants are normally under-estimated, either in general or perhaps in the vicinity of Cepheids. The four stars, whose supergiant character is established beyond any doubt from the colours \( U - W \) and \( B - L \), are

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### Table 8

Brightness and colours of 24 Cepheids relative to their comparison stars

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Acknowledgement

We conclude our paper with an expression of gratitude to Professor Bart J. Bok, Head of the Department of Astronomy of the Australian National University, for making available to us all the facilities of the Observatory at Mount Stromlo, including time on the IBM 1620 computer of the Australian National University, which greatly increased the speed of the reductions.

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J. Ponsen, 1963, B.A.N. 17 29

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**Table 8 (continued)**
ERRATA

In B.A.N. 17, 311, 1964 (“The formation of molecular lines in the solar spectrum” by A. Schadee) on p. 322, eq. (III, 26) should read as follows:

\[ \psi(x \beta) \equiv \psi'(x \beta)/kT. \]

On p. 323 in eq. (III, 30):

\[ \frac{N(\xi^++)}{N(\xi)} \text{ read } \frac{N(\xi^++)}{N(\xi^+)} . \]

In eq. (III, 36):

\[ \frac{\pi e^2}{m_e c^2} \text{ read } \frac{\pi e^2}{m_H m_e c^2} . \]

On p. 325 the left-hand side of eq. (III, 50) should read:

\[ \varphi(H) p_g \left[ 1 + \frac{p(H_2)}{p_g} \right] . \]

In B.A.N. 17, 381, 1964 (“The neutral hydrogen in the central region of the Galactic System” by G. W. Rougoor) on p. 382, right column, line 3:

for section 5.7
read section 4.7.

On p. 387, table 2, column 8:

for 1 of 8 channels
read 1 or 8 channels.

On p. 424, left column, line 2:

for at (\lambda = 3 \text{ cm})
read (at \lambda = 3 \text{ cm}).