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VARIATIONS IN THE PERIOD AND LIGHT-CURVE OF THE SHORT-PERIOD ECLIPSING BINARY VW CEPHEI

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In this paper an analysis of variations in the period and the light-curve of the eclipsing binary VW Cephei has been made, based on more than 13 800 photo-electric observations made from 1957 till 1960. The individual observations have been published in *Bulletin of the Astronomical Institutes of the Netherlands Supplement Series*. It was found that on top of the long-term variation in the period there exists a second and smaller variation in the residuals of the observed minimum times. While the long-term variation has a period of about thirty years and an amplitude in the variation of the observed minimum times of about 0.03 day, the period of the smaller variation is about two years and its amplitude 0.001 day. It is demonstrated that this second variation is strongly correlated with variations in the light-curve, in particular with the differences in brightness between the two maxima. The conclusion is therefore reached that the smaller variations in the observed minimum times originated from distortions of the light-curve rather than from dynamical causes. Finally, in an attempt to explain these distortions in the light-curve, a model is discussed in which a ring-like envelope with variable density surrounds the eclipsing system, giving rise to more or less absorption at certain phases.

1. Introduction

In an investigation on period variations of a number of short-period eclipsing binaries (KWEE, 1958), there appeared some indications that on top of the large-scale variations in the period, which are quite common for this kind of variables, period fluctuations over relatively short time intervals exist. Because of the small number of accurate epochs for each of these variables, however, the existence of these phenomena could only be demonstrated by a comparison between the internal deviations of the observed epochs and their expected standard errors. In order to investigate these period fluctuations more closely, an elaborate programme was set up to study one of these variables extensively during a long interval of time. The system VW Cephei has been chosen because of its brightness, its favourable position and its short period. With a declination of about +75° the star never sets for the Leiden Observatory and even in lower culmination the zenith distance is still only 53°. Its period of about 400 minutes makes it quite possible to observe a complete cycle of the light-variation during one night, except in the summer months when the nights are shorter than seven hours.

After discovery by SCHILT (1926) the variable VW Cephei has been studied by various observers. PRAGER (1934) and SCHNELLER (1957) have accumulated extensive lists of references. Variations in the period have been studied over a long interval of time. In a more recent investigation, SCHMIDT and SCHRICK (1955) showed that these variations correspond well with an orbital movement of the eclipsing system around a third body. Furthermore, they noticed variations in the light-curve over relatively short intervals of time.

New photo-electric observations have been made at the Leiden Observatory. They were made through an orange colour filter and covered the period from October 1957 till May 1959. All these observations, amounting to a total of 4949, have been described and listed in a separate paper (KWEE, 1966a). In making these observations much effort has been made to obtain a complete and uninterrupted cycle of the light-variation in one night. At the end we succeeded in getting half a dozen of such completely covered light-curves, each containing 200 or 250 individual observations.

From September till November 1959, an international campaign has been organized on VW Cephei. One of the aims of this campaign was to investigate rapid variations in the light-curve. In total 8454 photo-electric observations in two or more colours have been secured by eleven different observatories. All these observations, together with their reductions to normal points in the standard BV system, have been given in another publication (KWEE, 1966b). At the Leiden Observatory, which served as coordination centre, the author has made 2840 observations in four colours (the standard UBV colours and one colour in the red) during the campaign. Furthermore, on 7 March 1960, additional observations in B and V have been secured to a total of 426. They have also been given in the paper just mentioned. All these 3266 observations were made on eight different nights, seven of which resulted in complete and uninterrupted cycles of the light-variations in two colours and contained at least 200 individual observations per colour.

2. The times of the minima

Minimum times have been computed by HERTZSPRUNG's (1928) method as modified by KWEE and VAN WOERDEN (1956), for all the single series of observations which extended to at least 0.1 of the period on both sides of the expected moment of minimum, and which contained at least eight individual observations in this phase interval. Magnitudes equidistant in phase have been formed from the individual observations by linear interpolation. For the one-colour observations of 1957–1959, the Leiden K observations of the campaign, and for the observations made at the Trieste Observatory, about the same number of interpolated magnitudes have been formed as there are individual observations in the phase interval in question. For all the other observation series the equidistant magnitudes were 0.0012 day apart, which means that the number of interpolated magnitudes was 48. The results of the computations are given in table 1 for the one-colour observations of 1957–1959, and in table 2 for the observations of the international campaign. The mean errors listed in column 2 of table 1 and in column 4 of table 2 resulted from the derivation by the method mentioned above. They will be influenced by systematic deviations caused by any asymmetry existing between the branches of the minimum in question. Column 5 of table 1 and column 7 of table 2 give the number N of individual observations involved in the computation of the epoch. Times of minimum computed in table 2 might differ slightly from epochs derived and published elsewhere (CESTER, 1960; DETRE and KANYÓ, 1961; HERCZEG and SCHMIDT, 1960; RAKOSCH, 1960), although in both cases the same series of observations have been used. This is due to the fact that if the minimum is asymmetrical, the derived epoch will be dependent on the total phase interval used for the computation. With all the epochs of table 2, however, a phase interval of .2 has been adopted and thus they should be consistent among each other.

TABLE 1

Minimum epochs observed at Leiden from October 1957 till May 1959

Hel. J. D. −2436000	m.e.	E	$O—C$	N
124.42829	0.00020	7998.0	+0.00049	48
124.56634	0.00020	7998.5	−0.00062	47
173.41238	0.00021	8174.0	+0.00062	42
173.54946	0.00039	8174.5	−0.00146	40
228.37717	0.00028	8371.5	−0.00238	48
232.41580	0.00026	8386.0	+0.00064	57
232.55256	0.00055	8386.5	−0.00176	54
277.36147	0.00028	8547.5	−0.00204	56
280.42183	0.00046	8558.5	−0.00317	57
280.56391	0.00025	8559.0	−0.00025	46
285.43163	0.00026	8576.5	−0.00310	58
285.57356	0.00012	8577.0	−0.00033	52
308.39596	0.00019	8659.0	0.00000	56
324.39722	0.00029	8716.5	−0.00202	46
324.53811	0.00027	8717.0	−0.00029	51
365.45080	0.00061	8864.0	−0.00033	41
368.51249	0.00017	8875.0	−0.00014	57
373.52202	0.00029	8893.0	−0.00033	56
415.40729	0.00028	9043.5	−0.00191	51
443.37932	0.00014	9144.0	−0.00083	53
448.38869	0.00022	9162.0	−0.00118	56
448.52571	0.00019	9162.5	−0.00332	52
449.50210	0.00026	9166.0	−0.00105	55
452.42256	0.00010	9176.5	−0.00292	54
454.37090	0.00018	9183.5	−0.00281	55
459.52124	0.00015	9202.0	−0.00135	54
637.36422	0.00018	9841.0	−0.00353	47
647.52560	0.00027	9877.5	−0.00075	49
676.47043	0.00012	9981.5	−0.00099	67
679.39031	0.00009	9992.0	−0.00345	68
679.53206	0.00021	9992.5	−0.00086	69
687.46195	0.00015	10021.0	−0.00303	69
701.51896	0.00017	10071.5	−0.00107	74

The internal deviations among the different minimum times of table 2 are so large, that for a close investigation we have also determined mean values for the epochs for each period of observation during the international campaign, by deriving additional minimum

TABLE 2

Individual minimum epochs from the observations of the international campaign in 1959 and of 7 March 1960

Observatory	Col.	Hel. J. D. −2430000	m.e.	E	$O—C$	N
Topeka	b	6820.63771	0.00027	10499.5	−0.00240	14
Topeka	y	6820.63810	0.00033	10499.5	−0.00201	14
Brorfelde	b	6826.34370	0.00016	10520.0	−0.00192	27
Budapest	b	6826.48256	0.00058	10520.5	−0.00222	18
Budapest	y	6826.48328	0.00033	10520.5	−0.00150	20
Brorfelde	b	6826.48371	0.00022	10520.5	−0.00107	34
Topeka	b	6826.76128	0.00019	10521.5	−0.00182	18
Topeka	y	6826.76144	0.00029	10521.5	−0.00166	19
Budapest	y	6827.45672	0.00016	10524.0	−0.00218	35
Budapest	b	6827.45739	0.00031	10524.0	−0.00151	35
Topeka	b	6827.73420	0.00037	10525.0	−0.00301	19
Topeka	y	6827.73548	0.00039	10525.0	−0.00173	19
Brorfelde	b	6828.43188	0.00018	10527.5	−0.00113	35
Leiden K	u	6829.40453	0.00014	10531.0	−0.00259	42
Leiden K	r	6829.40472	0.00039	10531.0	−0.00240	41
Brorfelde	b	6829.40530	0.00015	10531.0	−0.00182	44
Leiden K	r	6829.54460	0.00023	10531.5	−0.00168	48
Leiden K	u	6829.54567	0.00022	10531.5	−0.00061	49
Hoher List	y	6830.51715	0.00057	10535.0	−0.00324	10
Hoher List	b	6830.51769	0.00023	10535.0	−0.00270	10
Budapest	b	6830.51852	0.00013	10535.0	−0.00187	30
Budapest	y	6830.51898	0.00028	10535.0	−0.00141	31
Hoher List	b	6831.49176	0.00022	10538.5	−0.00275	10
Hoher List	y	6831.49254	0.00068	10538.5	−0.00197	10
Topeka	y	6839.70133	0.00044	10568.0	−0.00355	19
Topeka	b	6839.70183	0.00047	10568.0	−0.00305	19
Abastumani	b	6840.39747	0.00116	10570.5	−0.00321	10
Leiden K	r	6840.39812	0.00032	10570.5	−0.00256	42
Leiden K	u	6840.39944	0.00018	10570.5	−0.00124	42
Abastumani	y	6840.40237	0.00107	10570.5	+0.00169	11
Leiden K	r	6840.53733	0.00022	10571.0	−0.00251	45
Leiden K	u	6840.53755	0.00021	10571.0	−0.00229	46
Topeka	b	6840.67707	0.00030	10571.5	−0.00193	22
Topeka	y	6840.67729	0.00040	10571.5	−0.00171	22
Leiden K	y	6841.37241	0.00014	10574.0	−0.00238	49
Leiden K	b	6841.37255	0.00010	10574.0	−0.00224	49
Leiden K	y	6841.51222	0.00020	10574.5	−0.00173	47
Leiden K	b	6841.51249	0.00016	10574.5	−0.00146	46
Hoher List	y	6841.51253	0.00046	10574.5	−0.00142	14
Hoher List	b	6841.51334	0.00032	10574.5	−0.00061	15
Hoher List	y	6841.65049	0.00038	10575.0	−0.00262	11
Hoher List	b	6841.65121	0.00128	10575.0	−0.00190	11
Hoher List	y	6842.34703	0.00029	10577.5	−0.00187	16
Hoher List	b	6842.34790	0.00046	10577.5	−0.00100	16
Hoher List	y	6842.48484	0.00032	10578.0	−0.00322	15
Hoher List	b	6842.48550	0.00023	10578.0	−0.00256	15
Leiden K	u	6842.48629	0.00030	10578.0	−0.00177	49
Leiden K	r	6842.48630	0.00041	10578.0	−0.00176	49
Budapest	u	6843.32121	0.00029	10581.0	−0.00181	40
Budapest	r	6843.32121	0.00101	10581.0	−0.00181	30
Budapest	r	6843.45924	0.00050	10581.5	−0.00294	25
Brorfelde	b	6843.45980	0.00034	10581.5	−0.00238	20
Leiden K	b	6843.46003	0.00011	10581.5	−0.00215	46
Budapest	u	6843.46022	0.00037	10581.5	−0.00196	28
Leiden K	y	6843.46034	0.00019	10581.5	−0.00184	46
Leiden A	y	6843.46041	0.00019	10581.5	−0.00177	38
Brorfelde	b	6843.59884	0.00020	10582.0	−0.00250	27
Topeka	b	6850.69299	0.00102	10607.5	−0.00545	18

TABLE 2 *(continued)*

Observatory	Col.	Hel. J. D. —2430000	m.e.	E	$O—C$	N	Observatory	Col.	Hel. J. D. —2430000	m.e.	E	$O—C$	N
Topeka	y	6850.69560	0.00027	10607.5	—0.00284	18	Leiden K	r	6858.48837	0.00020	10635.5	—0.00297	50
Topeka	b	6853.61860	0.00026	10618.0	—0.00218	21	Trieste	y	6858.48874	0.00026	10635.5	—0.00260	22
Topeka	y	6853.61888	0.00035	10618.0	—0.00190	22	Graz	y	6858.48889	0.00056	10635.5	—0.00245	33
Brorfelde	b	6854.45365	0.00024	10621.0	—0.00208	29	Trieste	b	6858.48889	0.00026	10635.5	—0.00245	22
Brorfelde	b	6855.28853	0.00039	10624.0	—0.00216	27	Leiden K	u	6858.48926	0.00043	10635.5	—0.00208	49
Brorfelde	b	6855.42665	0.00037	10624.5	—0.00320	42	Hoher List	b	6858.48941	0.00039	10635.5	—0.00193	10
Topeka	y	6855.70525	0.00031	10625.5	—0.00292	19	Hoher List	y	6858.48986	0.00063	10635.5	—0.00148	10
Topeka	b	6855.70671	0.00166	10625.5	—0.00146	20	Graz	y	6859.32299	0.00044	10638.5	—0.00331	31
Budapest	b	6856.40193	0.00034	10628.0	—0.00203	26	Graz	b	6859.32421	0.00035	10638.5	—0.00209	28
Budapest	y	6856.40248	0.00022	10628.0	—0.00148	25	Graz	y	6859.46371	0.00058	10639.0	—0.00175	24
Trieste	y	6856.40270	0.00047	10628.0	—0.00126	16	Graz	b	6859.46381	0.00039	10639.0	—0.00165	24
Trieste	b	6856.40273	0.00029	10628.0	—0.00123	16	Graz	b	6867.39392	0.00053	10667.5	—0.00360	20
Trieste	b	6857.37476	0.00042	10631.5	—0.00331	19	Graz	y	6867.39517	0.00034	10667.5	—0.00235	22
Leiden K	y	6857.37480	0.00009	10631.5	—0.00327	48	Graz	b	6875.46576	0.00050	10696.5	—0.00298	28
Graz	y	6857.37488	0.00039	10631.5	—0.00319	23	Graz	y	6875.46606	0.00070	10696.5	—0.00268	28
Leiden K	b	6857.37529	0.00024	10631.5	—0.00278	47	Topeka	b	6875.60392	0.00033	10697.0	—0.00398	24
Trieste	y	6857.37588	0.00021	10631.5	—0.00219	20	Topeka	y	6875.60506	0.00036	10697.0	—0.00284	24
Leiden K	y	6857.51496	0.00023	10632.0	—0.00227	46	Graz	b	6877.27353	0.00073	10703.0	—0.00427	26
Leiden K	b	6857.51519	0.00015	10632.0	—0.00204	45	Graz	y	6877.27528	0.00044	10703.0	—0.00252	22
Graz	y	6857.51571	0.00073	10632.0	—0.00152	27	Stockholm	b	6879.36226	0.00020	10710.5	—0.00293	23
Topeka	b	6857.65318	0.00047	10632.5	—0.00321	21	Stockholm	y	6879.36260	0.00024	10710.5	—0.00259	22
Topeka	y	6857.65361	0.00052	10632.5	—0.00278	22	Abastumani	b	6880.33865	0.00111	10714.0	—0.00065	11
Leiden K	u	6858.34968	0.00021	10635.0	—0.00251	46	Abastumani	y	6880.33903	0.00150	10714.0	—0.00027	11
Graz	y	6858.34988	0.00010	10635.0	—0.00231	36							
Hoher List	y	6858.35007	0.00034	10635.0	—0.00212	10							
Leiden K	r	6858.35007	0.00017	10635.0	—0.00212	47	Leiden K	b	7001.40564	0.00035	11149.0	—0.00196	43
Hoher List	b	6858.35049	0.00039	10635.0	—0.00170	11	Leiden K	y	7001.40613	0.00033	11149.0	—0.00147	43
Trieste	b	6858.35073	0.00049	10635.0	—0.00146	21	Leiden K	b	7001.54210	0.00028	11149.5	—0.00466	47
Trieste	y	6858.35073	0.00048	10635.0	—0.00146	20	Leiden K	y	7001.54210	0.00032	11149.5	—0.00466	47

TABLE 3

Minimum epochs derived from the normal light-curves of the international campaign

Colour	Obs. period	Primary minimum				Secondary minimum			
		Phase epoch	m.e.	*O—C* (days)	*N*	Phase epoch	m.e.	*O—C* (days)	*N*
V	I	.9924	.0009	−0.00212	20	.4949	.0008	−0.00142	20
V	II	.9922	.0004	−0.00217	33	.4936	.0004	−0.00178	43
V	III	.9928	.0005	−0.00200	38	.4905	.0003	−0.00264	37
V	IV	.9917	.0013	−0.00231	18	.4907	.0010	−0.00259	16
B	I	.9930	.0005	−0.00195	33	.4945	.0004	−0.00153	30
B	II	.9924	.0005	−0.00212	39	.4938	.0003	−0.00173	47
B	III	.9935	.0006	−0.00181	45	.4902	.0005	−0.00273	39
B	IV	.9947	.0030	−0.00148	13	.4866	.0016	−0.00373	13

times from the normal light-curves resulting from all the observations of the campaign (KWEE, 1966b). In table 3 these results have been listed. Just like the normal points themselves, the epochs have been expressed in phases which are related to eq. (1). It can be seen from these epochs that the secondary minimum was placed about midway between two successive primary minima during the time of the campaign. A closer inspection shows, however, that for the first two observation periods the secondary minimum was a little later and for the last two periods it was a little earlier than the midpoint between the primary minima.

3. The variations of the period

Numerous times of minima have been observed and published apart from the present paper. A complete list of epochs can be compiled from publications by SCHMIDT and SCHRICK (1955), SZCZEPANOWSKA (1959), HERCZEG and SCHMIDT (1960), BALÁZS and DETRE (1961) and TODORAN (1963). It can be seen from an analysis of such a list, that a long-term variation in the period of VW Cephei is present. Such a variation, if periodic at all, should have a period of about 30 years, and the amplitude in the variation of the deviations of the minimum epochs from a linear relation with time should be about 0.03 day. Like some other investigators, HERCZEG and SCHMIDT (1960) and also TODORAN (1963) ascribed this variation to the presence of a third component near the eclipsing system. The light-time effect of the orbital motion of the eclipsing pair around this third component should then account for the observed variation. In an earlier publication (KWEE, 1958) it has been attempted to explain variations in the period by exchange or loss of mass by the components of the eclipsing system. It is hard to believe, however, that such processes can be periodic or reversed in sign. More recently KOPAL (1959) pointed out that period variations can also be caused by the mutual dynamical interaction of the two components of a close binary system. In the case of VW Cephei such an explanation would indeed be more attractive than the assumption of an invisible third component.

Because of the long-term variation in the period of VW Cephei, there is no sense in improving the period with our accurate photo-electric times of minimum. For the present investigation, therefore, we have adopted a period which represents our series of observations well enough. The adopted elements are

$$\text{Min I} = \text{Hel. J. D. } 2433898.44100 + 0.27831793\, E. \quad (1)$$

Eq. (1) has been used to compute the individual residuals *O–C* of the observed times of minimum in tables 1–3. The zero-epoch of the equation is based on the four minimum times derived from photo-electric observations made in 1951 and 1953 (KWEE, 1958).

Figure 1 shows the residuals *O–C* of all the epochs resulting from the present investigation, plotted against *E*. Instead of all the individual minimum times from the international campaign we have rather drawn in the figure the epochs of the normal curves as given in table 3. The inspection of figure 1 shows that all the residuals, regardless of their belonging to primary or secondary minimum, lay in a band which is slightly curved. This effect is caused by the long-term variation in the period mentioned above. Apparently in its 30-year cycle the period is going to lengthen again.

Apart from this long-term variation, one can see

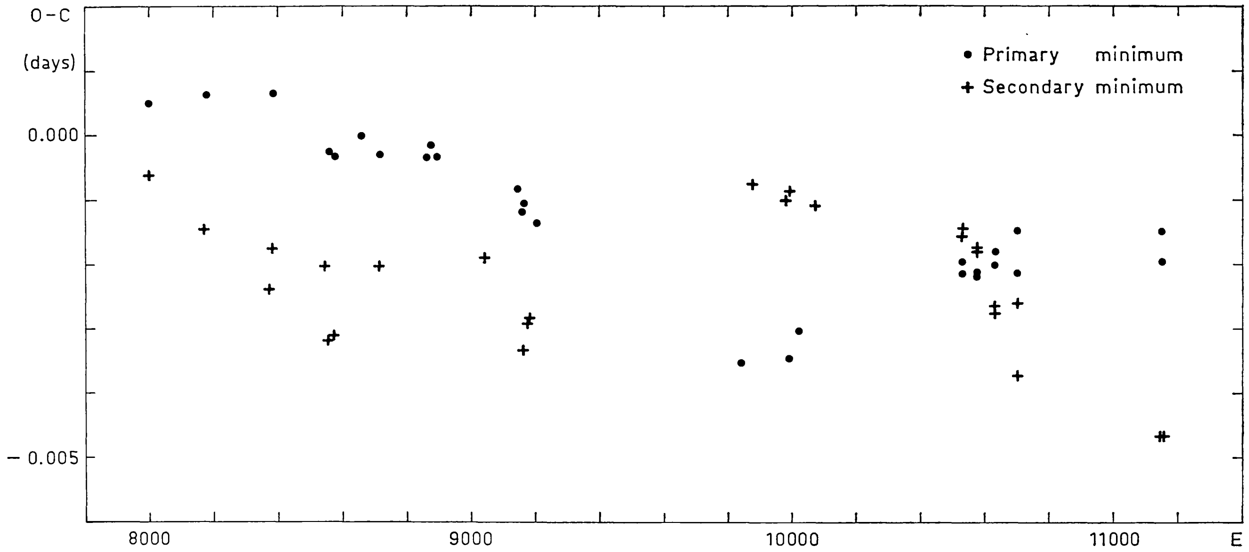

Figure 1. Time residuals, $O—C$, of the minima of VW Cephei from 1957 till 1960. Dots represent the primary and crosses the secondary minima.

mmediately from the figure that there definitely exist systematic differences between the residuals belonging to the primary and those corresponding to the secondary minima. For the observations of 1957 and 1958, i.e. $8000 < E < 9300$, secondary minima occurred earlier than the mid-phase between the primary minima; for E around 10000, corresponding to the first half of 1959, the secondary minima are later than mid-phase. The observations during the international campaign in the second half of 1959 showed that both minima are about half a period apart, although, as is said before, during the first two observation periods secondary minimum was slightly too late and during the last two periods it was slightly too early with respect to mid-phase. Finally, the observations made in March 1960, i.e. $E = 11149$, again showed the same situation as with the observations of 1958.

If this smaller variation is periodic, a period of about two years can be found. The amplitude in terms of the variation of the residuals of the observed minimum times would then be of the order of 0.001 day, which is much less than the 0.03-day amplitude for the long-term variation. The presence of the smaller variations has been suspected earlier (KWEE, 1958), when the four primary minimum epochs observed in 1952 and 1953 gave too large internal deviations to be accounted for by their expected mean errors. In the present paper it is confirmed without question.

HERCZEG and SCHMIDT (1960) as well as BALÁZS and DETRE (1961) have tried to retrace this smaller variation in the earlier observations. The first two investigators used all the earlier photographic and photo-electric material they could lay hands on. They could not disclose a clear variation of the kind found in the present paper; however, there was a trace of a variation with a period of 645 days, which is definitely too short to represent the plots in figure 1. Before drawing conclusions from Herczeg and Schmidt's results, one should keep in mind that most of the earlier determinations of the minimum times, and practically all of the most early of these, are very inaccurate and depend only on a small number of observations. None of them were based on long series of observations. The effect shown in figure 1 involves deviations of the order of 0.001 day only, while most of the earlier minimum times were less accurate than this amount. Another circumstance which might have influenced Herczeg and Schmidt's results is the inhomogeneity of the material; different investigators have used different methods for the determination of the minimum times. In the case of VW Cephei, where asymmetric minima are frequently occurring, the resulting minimum times will depend very much on the method used.

A more homogeneous material has been used by BALÁZS and DETRE (1961). They took only the photoelectric observations made between 1948 and 1953.

Their results are shown in the first figure of their paper. From their plots it can be seen that a same kind of variation was also present between 1948 and 1953, however with a variable period. In section 5, where we will try to explain this effect, we will return to this matter.

4. The variations of the light-curve

It has been known for some time that the light-curve of VW Cephei shows asymmetries in the relative brightness of the maxima. Sometimes the maximum following primary minimum (henceforth called Max I) was reported to be brighter than the maximum preceding primary minimum (Max II) and at other times the opposite occurred. In order to investigate these variations in the light-curve in more detail, we should compare one light-curve with another. Such a comparison will only be fruitful if the light-curves in question have been made in the same colour system. With the one-colour observations of 1957–1959 this was the case, and, moreover, by using the proper colour equation [Kwee, 1966a, eq. (3)] we were able to transform the final B and V light-curves, resulting from the international campaign and from March 1960, into this same colour system.

Instead of comparing the light-curves by graphical methods we have rather chosen a numerical method which conserved the initial scattering of the individual observations in the final results. Therefore, we have characterized the light-curve into four brightnesses, viz. the magnitudes at the two phases of conjunction and the magnitudes at the two phases of quadrature of the eclipsing binary system. On the assumption of circular orbits, these phases are exactly one quarter of the period apart and they will produce normally the two minima and the two maxima of the light-curve.

Subsequently, we have adopted a numerical method to determine these four characteristic brightnesses from the individual observations. In this method the representation of a parabola was assumed in the shape of the light-curve near the four characteristic phases. The equation of condition was then

$$m = X + Yt^2, \tag{2}$$

in which m is the magnitude of an individual observation and t is the difference between the phase of the observation and the exact characteristic phase in question. The constants to be solved, X and Y, then represent, respectively, the magnitude at the characteristic phase and a quantity which is a measure of the curvature of the adopted parabola and which has no further significance.

For the evaluation of t for the individual observations, the four characteristic phases should be exactly known, because it appeared that the constant X in eq. (2) is very sensitive for these phases, in particular for the minima. From figure 1 it can be concluded that the observed phases of the primary and secondary minima were not constant, but even fluctuated during the interval of time of the present observations. Moreover, the difference in phase between primary and secondary minimum time was not always exactly half a period. In agreement with the conclusions made in section 5, we will assume that the phase of conjunction need not coincide exactly with the phase of an observed minimum and that the exact time of conjunction corresponding to Min I will be given by

$$\text{Min I} = \text{Hel. J. D. } 2436637.36551 + 0.27831758 \times (E-9841) + 0.37 \times 10^{-9}\,(E-9841)^2 . \tag{3}$$

This equation gives the best representation, regardless of the type of minimum for the epochs deduced from the one-colour observations of 1957–1959. The quadratic term represents the effect of the long-term variation of the period, which influenced both minima equally and which had apparently a dynamical cause. For the observations of the international campaign we have adopted for the exact phase of conjunction corresponding to Min I the values .9937, .9930, .9918 and .9909, for the four periods of observation respectively. Finally, for the observations of 7 March 1960 the exact time of primary conjunction was taken to be Hel. J. D. 2437001.40443. All these values were based on the mean value of the observed times of primary and secondary minima.

Only those individual observations within a phase interval of .10 on both sides of the characteristic phase in question have been used for the least-squares solution of X and Y in eq. (2). The resulting values for X are listed in tables 4 and 5.

Table 4 gives the results from the one-colour observa-

TABLE 4

Magnitudes X at the four characteristic phases

E	Phase = .00		Phase = .25		Phase = .50		Phase = .75		E
	X	m.e.	X	m.e.	X	m.e.	X	m.e.	
7997							−0.495	0.004	7997
7998	−0.147	0.005	−0.477	0.002	−0.219	0.005			7998
8001			−0.455	0.017					8001
8173							−0.519	0.002	8173
8174	−0.147	0.004	−0.477	0.002	−0.219	0.005	−0.511	0.003	8174
8175	−0.149	0.036							8175
8371					−0.244	0.004	−0.529	0.009	8371
8385							−0.521	0.004	8385
8386	−0.124	0.005	−0.469	0.004	−0.240	0.005	−0.509	0.004	8386
8387	−0.128	0.005							8387
8547					−0.215	0.004	−0.521	0.002	8547
8548	−0.137	0.004							8548
8555	−0.142	0.004	−0.472	0.002					8555
8558			−0.467	0.002	−0.211	0.005	−0.517	0.003	8558
8559	−0.134	0.006							8559
8576			−0.462	0.002	−0.203	0.006	−0.521	0.002	8576
8577	−0.142	0.004							8577
8659	−0.134	0.005	−0.437	0.004					8659
8716					−0.213	0.005	−0.507	0.003	8716
8717	−0.116	0.005	−0.464	0.003					8717
8838							−0.515	0.004	8838
8839	−0.114	0.005							8839
8863							−0.522	0.034	8863
8864	−0.118	0.004							8864
8874							−0.519	0.003	8874
8875	−0.113	0.005	−0.485	0.007					8875
8892							−0.509	0.002	8892
8893	−0.102	0.004	−0.476	0.020					8893
9000					−0.236	0.005	−0.500	0.004	9000
9001	−0.100	0.006							9001
9043					−0.241	0.005			9043
9144	−0.088	0.004							9144
9162	−0.099	0.004	−0.478	0.004	−0.243	0.004			9162
9165					−0.242	0.006	−0.503	0.005	9165
9166	−0.096	0.003							9166
9176			−0.476	0.024	−0.248	0.004			9176
9183					−0.240	0.003	−0.501	0.004	9183
9202	−0.091	0.004							9202
9841	−0.115	0.005	−0.517	0.006					9841
9863	−0.137	0.008							9863
9877			−0.526	0.005	−0.239	0.007	−0.490	0.003	9877
9934					−0.243	0.008			9934
9970			−0.514	0.004					9970
9981			−0.512	0.003	−0.231	0.003	−0.481	0.003	9981
9982	−0.126	0.005							9982
9991							−0.470	0.028	9991
9992	−0.135	0.003	−0.512	0.003	−0.230	0.004	−0.477	0.003	9992
10020							−0.472	0.004	10020
10021	−0.122	0.003	−0.502	0.003	−0.216	0.009			10021
10042					−0.225	0.057			10042
10071	−0.142	0.007	−0.504	0.003	−0.207	0.003	−0.470	0.002	10071
10518	−0.145	0.007	−0.493	0.005	−0.191	0.006	−0.494	0.005	10518
10575	−0.147	0.006	−0.502	0.005	−0.200	0.006	−0.502	0.005	10575
10623	−0.151	0.006	−0.501	0.005	−0.201	0.006	−0.520	0.005	10623
10690	−0.145	0.008	−0.491	0.007	−0.211	0.008	−0.528	0.008	10690
11149	−0.164	0.008	−0.456	0.009	−0.200	0.008	−0.511	0.006	11149

TABLE 5

Magnitudes X at the four characteristic phases,
for the B and V light-curves of the international campaign and of 7 March 1960

Colour	Observation period	Phase = .00		Phase = .25		Phase = .50		Phase = .75	
		X	m.e.	X	m.e.	X	m.e.	X	m.e.
V	I	−0.106	0.002	−0.463	0.002	−0.154	0.002	−0.465	0.002
V	II	−0.110	0.002	−0.472	0.001	−0.164	0.001	−0.474	0.002
V	III	−0.115	0.001	−0.470	0.001	−0.166	0.001	−0.470	0.001
V	IV	−0.108	0.004	−0.458	0.004	−0.173	0.005	−0.496	0.005
V	7 March 1960	−0.124	0.004	−0.423	0.006	−0.163	0.005	−0.483	0.004
B	I	+0.104	0.002	−0.300	0.001	+0.048	0.002	−0.305	0.002
B	II	+0.091	0.001	−0.308	0.001	+0.028	0.001	−0.316	0.002
B	III	+0.084	0.001	−0.301	0.001	+0.027	0.001	−0.338	0.001
B	IV	+0.092	0.006	−0.273	0.004	+0.034	0.005	−0.324	0.006
B	7 March 1960	+0.093	0.005	−0.243	0.005	+0.036	0.004	−0.327	0.004

tions of 1957–1959. The first column represents the number of the cycle, E, appearing in eq. (1), and in the following columns the derived magnitudes are listed for the four characteristic phases. The mean errors given also resulted from the least-squares solutions. In table 5 the results are listed for the normal light-curves of the campaign and for the observations made on 7 March 1960, both of which were given in standard B and V magnitudes. After transformation into the magnitude system of the one-colour observations as mentioned above, the final X magnitudes are also given in the five last lines of table 4.

In figure 2 we have plotted the magnitudes at the characteristic phases against E. This figure shows very clearly that variations in brightness at these phases exist. In particular, for E between 8000 and 9300, Max II was brighter than Max I and this was also the case at $E = 11\,149$. Around $E = 10\,000$, however, Max II appeared to be fainter than Max I. The same kind of variations can be traced in the brightness of the two minima. It is remarkable in this case that when Min I is faint, Min II is relatively bright and vice versa. It is also notable that during the times that the two maxima were about equal in brightness, the two minima reached their extreme magnitudes. This occurred around $E = 9300$ and $10\,500$. The reversal in the brightness of the two maxima also seems to be periodical with a period of about two years. Figure 2 also shows that apart from these more or less periodical variations, fluctuations of a more random character seem to be present in all the four brightnesses.

5. Interpretation of the variations in the light-curve and in the observed minimum times

The inequality of the brightness at the two maxima of the light-curve can be readily explained by assuming the existence of an absorbing cloud surrounding the eclipsing system. When this cloud, which in order to be dynamically stable should have a more or less ring-like structure, is denser on one side, and when this side is seen in front of the eclipsing system at one of the maximum phases, the brightness of this maximum will be more depressed by absorption than the brightness at the other maximum phase.

The observed effect, that after a certain time a high maximum turns over into a low one, will then be caused by the non-synchronic rotation of the ring-like cloud with respect to the orbital revolution of the eclipsing system. In the case of VW Cephei the time needed for a high maximum to become a low one is about one year or 1400 orbital revolutions. This means that the rotation period of the cloud is not very different from the period of the eclipsing system. Furthermore, we can see from figure 2 that a depression of Max I is followed by a depression of Min I, next of Max II and finally of Min II. The order in this sequence supports a rotation period of the cloud which is slightly longer than the orbital period of the eclipsing system, so that the extra absorption is gradually lagging behind in phase of the orbital period.

We will now discuss the short-term variations in the period mentioned in section 3. Comparing figures 1

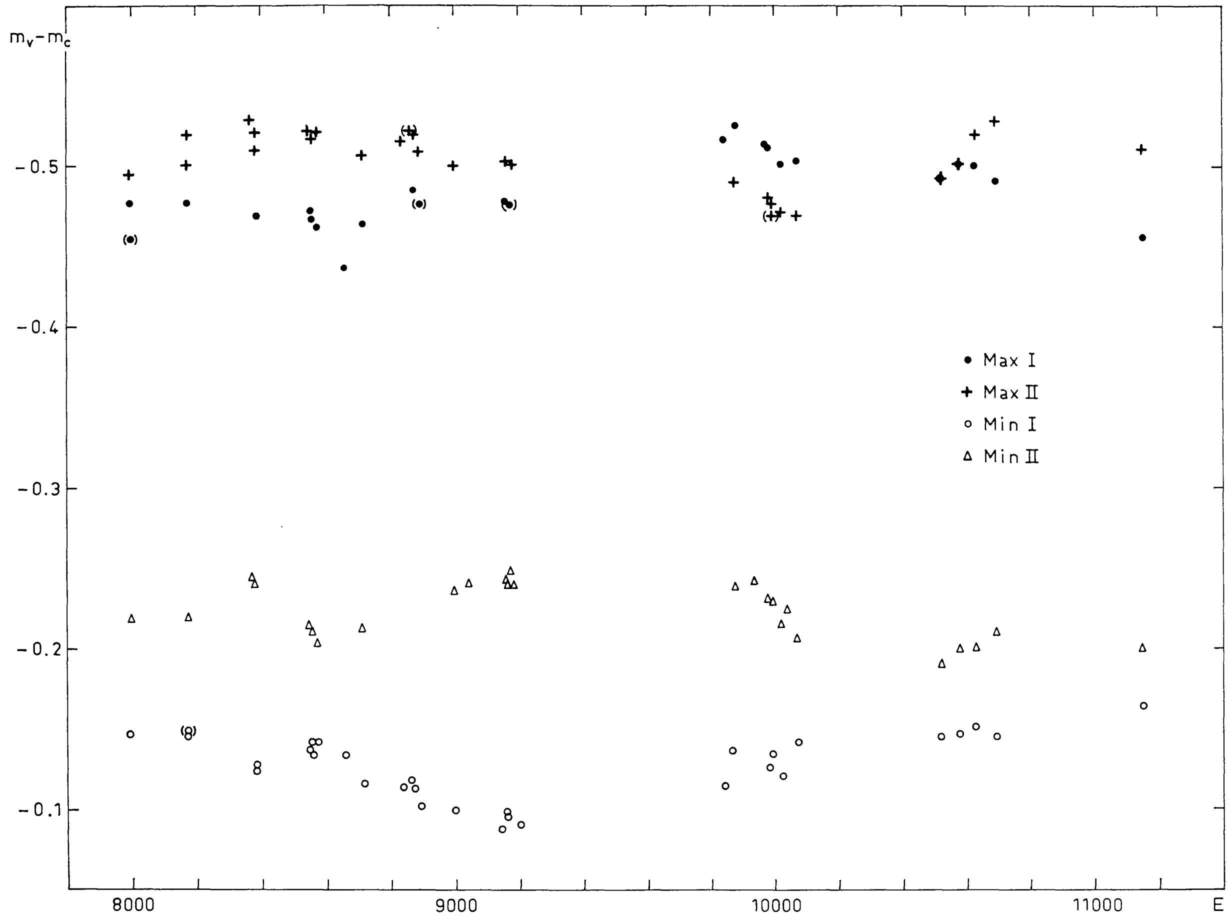

Figure 2. Variations in the brightness at the four characteristic phases of VW Cephei. As ordinate the magnitude difference VW Cephei — HD 199476 is plotted. Dots indicate Max I, crosses Max II, open circles Min I and triangles Min II. Parentheses indicate poor determinations.

and 2, we find a striking correlation between the behaviour of the brightness at maximum phases and that of the residuals of the minimum times. The cause of these correlations is quite evident and it lies in the method of determining the minimum epochs, which is based on the assumed symmetry of the descending and rising branches of the minimum. If one of the branches is depressed by extra absorption, the resulting minimum epoch will be shifted in the direction of that branch. This is exactly what we find in figures 1 and 2: when Max I is depressed, the rising branch of Min I and the descending branch of Min II will also be depressed and the primary minimum epoch occurs too late, while the secondary minimum epoch is too early.

According to such an explanation, the so-called short-term period variations are in fact not changes in the orbital period of the binary system, but are solely caused by distortions of the light-curve, as was suspected earlier (KWEE, 1958). Therefore the variations will not have any influence on the moments of conjunctions of the binary system. It was for this reason that we have ignored the differences between the primary and secondary minima in deriving eq. (3).

In their publications, HERCZEG and SCHMIDT (1960) and BALÁZS and DETRE (1961) have tried to retrace the correlation between the variation in the minimum times and the unequal brightness of the maxima for the older observations. Both found a rather good correlation. Balázs and Detre mentioned two cases which apparently do not fit, however; in both cases the light-curves showed distortions on a smaller scale at one of the maximum phases.

Some remarks should still be made on the hypothetical cloud. The first concerns the position of this ring around the binary system. It is clear from the observed secular period of about two years, that the actual period of revolution of the absorbing ring should be very close to the orbital period of the binary system. In fact, the ratio of the latter to the observed beat period is about 1/2800, which means that the two fundamental periods differ only by 0.035 per cent. According to Kepler's third law, the radius of the ring should then be of the same order as the distance between the centres of the two binary components. Therefore, we should regard this ring more or less as a common envelope around the two components rather than as a distinct ring at some large distance around the system. The absorbing material should envelop both components, however, because the observations suggest that the extra absorption is active at all phases successively.

Another remark concerns the stability of the material in this ring-like envelope. It is not necessary that the material remains there forever. In fact it is even more likely that a particle thrown out from the binary system by some reason or other, will revolve around the system a number of times, thus contributing to the material in the envelope. After a while the particle will fall back to the binary system from where it originated. If this process is going on continuously, it is clear that a more or less stationary ring-like structure may be formed. The mean density in such a ring will then be determined by the time that each particle will spend in the envelope. It is also easy to understand that one segment of the envelope might become denser than another, thus giving rise to the observed distortions in the light-curve. It will be expected that after a certain time a condensation in the envelope will gradually vanish and a new one will appear at some other place. Probably this has happened in the past as BALÁZS and DETRE (1961) have found the same periodicity in the variation of the minimum times, however with different phase shifts. Finally, smaller and less dense condensations might be responsible for the random fluctuations to be seen in figures 1 and 2.

As a final remark we would like to point out that the spectroscopical observations made during the international campaign (KWEE, 1966b) strongly suggest the presence of gas clouds in the vicinity of the binary system.

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