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THE RADIAL VELOCITY CURVE OF THE ECLIPSING BINARY SYSTEM 9 CHAMAELEONTIS (BV 430)

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Summary

Fifteen spectrograms of dispersion 90 Å/mm at Hγ and eight spectrograms of dispersion 120 Å/mm of the eclipsing binary system 9 Chamaeleontis are used to obtain a radial velocity curve and orbital elements for the system as well as absolute dimensions for the components. The geometrical elements are in good agreement with those previously determined by the author from a photometric solution. The spectral types, masses and radii of the components are given as A5V, A7V, $1 \cdot 25\,\mathcal{M}_\odot$, $1 \cdot 05\,\mathcal{M}_\odot$, $2 \cdot 03\,R_\odot$ and $1 \cdot 60\,R_\odot$, respectively. Although the radii of the components are normal for A-type stars, the stars seem to be decidedly undermassive. The mass-ratio, however, is in good agreement with the theoretical value expected from the luminosity-ratio obtained from the photometric solution. The space motions of 9 Chamaeleontis are also given.

1. *Introduction.* The sixth-magnitude star 9 Chamaeleontis (HD 75747, Henry Draper spectral type A5) was first noted as being variable in 1964 from plates taken at the South African station of the Bamberg Observatory. The star was recognized as being an Algol-type eclipsing binary and was listed as BV 430 in the Bamberg list of variable stars (**1**).

A photoelectric study of this star was undertaken by the author in 1965–66 at the Mt John University Observatory in New Zealand (**2**). A total of 555 yellow observations and 559 blue observations was obtained. The visual magnitude of 9 Chamaeleontis is 6·04 at maximum light. The primary and secondary minima were found to be $0^m{\cdot}66$ and $0^m{\cdot}50$ deep respectively in yellow light, while in blue light the respective depths were $0^m{\cdot}70$ and $0^m{\cdot}49$. The light elements were given by the author as:

$$\text{JD Hel Min. } I = 2438380{\cdot}5272 + 1^d{\cdot}6698684\,E$$
$$\pm 34 \qquad\qquad \pm 70 \text{ p.e.}$$

Recently, another photoelectric study of 9 Chamaeleontis has been published by Lagerweij from the Cape Observatory in South Africa (**3**). This study was done in three colours. The light curves and period obtained were very similar to those obtained by the author.

The author computed orbital elements from his own observations. The eclipses are not complete and the primary minimum is a transit. The orbital elements, together with their probable errors, are as follows:

Geometrical elements

$k = 0{\cdot}79 \pm 0{\cdot}01$	$b_g = 0{\cdot}255 \pm 0{\cdot}005$	$p_0 = -0{\cdot}84 \pm 0{\cdot}02$
$a_g = 0{\cdot}264 \pm 0{\cdot}005$	$b_s = 0{\cdot}202 \pm 0{\cdot}004$	$\epsilon = 0{\cdot}033 \pm 0{\cdot}003$
$a_s = 0{\cdot}209 \pm 0{\cdot}004$	$i = 84^0{\cdot}7 \pm 0^0{\cdot}2$	$\theta_e = 27^0{\cdot}8 \pm 0^0{\cdot}3$

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Photometric elements

	Yellow	Blue
x	0·6 ± 0·1	0·6 ± 0·1
α_0^{oc}	0·95 ± 0·01	0·95 ± 0·01
α_0^{tr}	0·92 ± 0·01	0·92 ± 0·01
L_g	0·658 ± 0·004	0·669 ± 0·004
L_s	0·342 ± 0·004	0·331 ± 0·004
I_g/I_s	1·20 ± 0·02	1·26 ± 0·02

Preliminary orbital elements have also been calculated by Wild & Lagerweij for this system (**4**). In general, these are in fairly good agreement with the above.

2. *Observational material.* Plates were obtained of 9 Chamaeleontis using the Zeiss two-prism spectrograph mounted in the 50-in. Cassegrain reflector of Mt Stromlo Observatory and later using the Meinel grating spectrograph mounted on the 40-in. Cassegrain reflector at Siding Spring Observatory. The Zeiss spectrograph has a dispersion of 90 Å/mm at Hγ, while that of the Meinel spectrograph is 120 Å/mm (**5**). A total of 17 plates was obtained on four nights in 1967 April, using the Zeiss spectrograph, while 10 plates of four nights in 1967 May were obtained with the Meinel spectrograph. The average exposure times for each plate were 6 min for the Zeiss spectrograph and 12 min for the Meinel spectrograph. For all plates an argon lamp was used to obtain the comparison spectrum.

All of the spectrograms were measured with a photoelectric setting device of the type developed by Gollnow (**6**). Those which showed lines clearly double to the naked eye were also measured on a visual comparator. The measurements were reduced using a computer programme written by Mrs P. M. Kennedy of Mt Stromlo Observatory.

The spectra are typical of main-sequence A-type stars. The Balmer lines were very strong as was the K line of Ca II. Numerous other lines were also present. The λ4481 Mg II, λ4226 Ca I, and λ4134 Fe I lines were suitable for measurement on the Zeiss plates with the visual comparator, but they were too weak to be measured with the photoelectric setting device. With the setting device only the strongest lines (i.e. the Balmer lines and the K line of Ca II) could be measured. No spectrum peculiarities were noted. Using the spectral atlas of Morgan, Keenan & Kellman, the spectral type of the brighter component was determined as A5V. Judging from its colours the secondary component is about $+0^m\cdot05$ greater in $B-V$. This would put its spectral type at about A7V. The spectral type of the secondary component can also be estimated using the relation given by Plaut (**7**):

$$-2\cdot5 \log I_1/I_2 = -10 \log T_{e1}/T_{e2} + (\mathrm{B.C.}_1 - \mathrm{B.C.}_2).$$

If we use an effective temperature of 8220 °K for an A5V star as given by Johnson (**8**) and a value of 0·00 for the difference in bolometric corrections for the two stars, stars of about spectral type A5 all having bolometric corrections near +0·07, a value of 7855 °K is obtained for the smaller component of BV 430 using the intensity ratio for yellow light given by the author. This will also agree well with the effective temperature for an A7V star.

No systematic differences were found between the velocity measurements obtained with the photoelectric setting device and those obtained using the visual comparator. There was also good agreement between the velocity separations obtained from the Zeiss plates and those obtained from the Meinel plates. Plates from both spectrographs of single stars with known radial velocities were measured to see if there were systematic differences between the spectrographs and between the visual comparator and the photoelectric setting device. No systematic differences were found between the two measuring instruments, but the Meinel plates were found to have radial velocities somewhat lower than the Zeiss plates.

In Table I the radial velocity values obtained from the plates are listed together with the heliocentric Julian Date and phase of 9 Chamaeleontis for each plate. The phases were calculated from primary minimum using the light elements of the author. The serial letters NA refer to the Zeiss plates, while ML refers to the Meinel plates. Because of a very poor comparison spectrum or very divergent results, four plates were not used. These are not listed.

TABLE I

Radial velocities of 9 *Chamaeleontis*

Plate No.	*JD* ⊙	Phase	V_2 (km s^{-1})		V_1 (km s^{-1})
NA 4743	2439582·924	0·055		+25±1	
4747	582·977	0·087	+ 59±6		− 19±4
4749	583·018	0·111	+ 66±2		− 43±4
4780	584·868	0·219	+149±8		− 78±10
4795	584·905	0·241	+138±9		− 78±9
4714	579·927	0·260	+174±7		− 66±7
4716	579·978	0·291	+148±8		− 75±6
4720	580·029	0·321	+ 90±8		− 46±3
4724	580·070	0·346	+139±10		− 35±10
4729	580·117	0·374	+101±5		− 40±16
4731	580·171	0·406	+ 75±9		− 48±10
4802	585·230	0·436		+54±1	
4761	583·936	0·661	− 64±6		+121±5
4765	583·986	0·691	− 92±9		+135±11
4769	584·048	0·728	−108±13		+140±14
ML 482	2439632·933	0·002		+17±7	
502	634·849	0·150	+ 65±4		− 91±5
504	634·940	0·204	+ 96±8		− 85±4
486	633·878	0·568		+27±6	
489	633·919	0·593	− 69±8		+ 87±2
492	633·962	0·619	− 71±10		+ 92±3
510	635·859	0·755	−116±5		+ 87±5
512	636·008	0·844	− 97±6		+ 95±7

3. *Orbital elements.* From the photoelectric light curve, no phase shift was found between the primary and secondary minima. Also, the phase angle of first contact, $\theta_e = 27^{\circ}\cdot 8$, was found to be the same for both primary and secondary minima and hence the durations of the minima are the same. Any appreciable eccentricity in the orbit would manifest itself in either a phase shift or in unequal durations of minima or in a combination of the two effects. As neither has been found, it is assumed that the orbit is circular or very nearly so.

Least squares solutions were made considering the orbit as circular. As the Meinel plates were of poorer quality than the Zeiss plates, the former were given lower weight. From the velocity amplitudes and gamma-velocities obtained, the following geometrical properties of the components and their orbit were derived:

$K_1 = 108 \pm 2$ km s^{-1}	$\gamma = +26 \pm 3$ km s^{-1}
$K_2 = 128 \pm 3$ km s^{-1}	$r_1 = 2{\cdot}03 \pm 0{\cdot}03\ R_\odot$
$a = 5{\cdot}43 \pm 0{\cdot}07 \times 10^6$ km	$r_2 = 1{\cdot}60 \pm 0{\cdot}03\ R_\odot$
$a_1 = 2{\cdot}48 \pm 0{\cdot}05 \times 10^6$ km	$\mathcal{M}_1 = 1{\cdot}25 \pm 0{\cdot}06\ \mathcal{M}_\odot$
$a_2 = 2{\cdot}95 \pm 0{\cdot}05 \times 10^6$ km	$\mathcal{M}_2 = 1{\cdot}05 \pm 0{\cdot}06\ \mathcal{M}_\odot$
$e = 0{\cdot}00$	$\mathcal{M}_1/\mathcal{M}_2 = 1{\cdot}19 \pm 0{\cdot}03$

The values given for the radii are for the mean radii, i.e. $r_1 = \sqrt{(a_g b_g)}$, $r_2 = \sqrt{(a_s b_s)}$, the quantities a_g, b_g, a_s and b_s all having been determined from the photometric solution for the orbital elements.

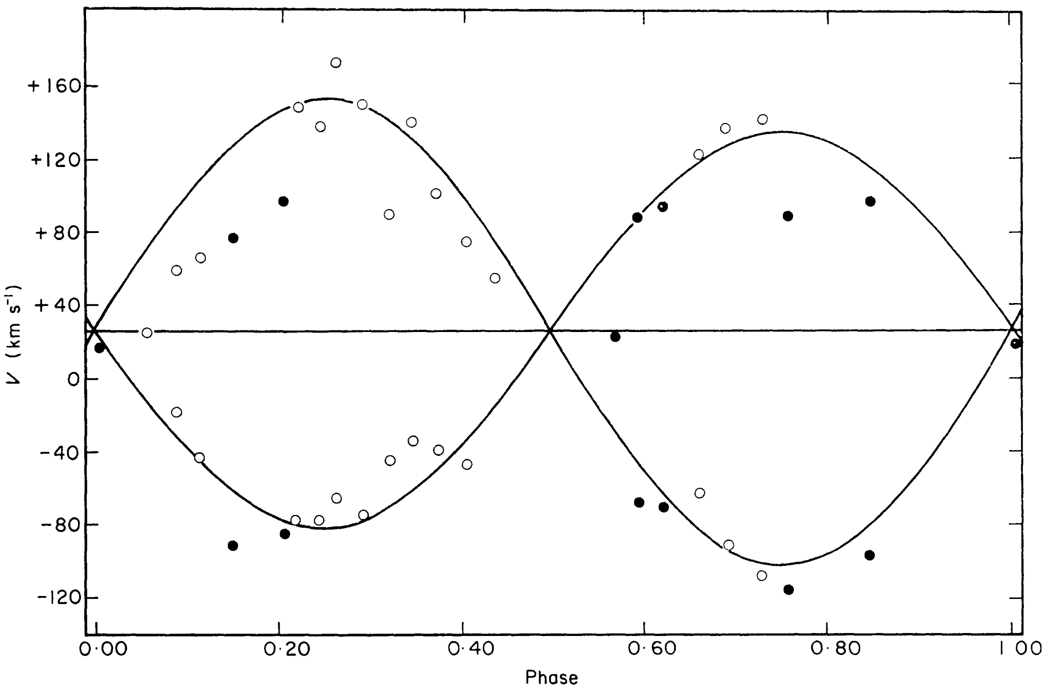

FIG. 1. *Radial velocity curve of 9 Chamaeleontis. The open circles represent the measurements of the Zeiss plates, while the solid circles represent those of the Meinel plates. The curves have amplitudes of K_2 = 128 km s^{-1} and K_1 = 108 km s^{-1}.*

In Fig. 1 the radial velocity values obtained are shown plotted together with sine curves of amplitudes equal to 128 km s^{-1} and 108 km s^{-1}, both being centred on a gamma-velocity of +26 km s^{-1}.

The adopted values of the radii are in good agreement with typical values for A5V stars. The masses, however, appear to be substantially lower than one would expect for stars of this type. Some mass may have been lost through mass exchange, but as 9 Chamaeleontis is a detached system, we should not expect that much mass exchange has taken place. The mass ratio of 1·19 is in good agreement with the luminosity ratio obtained from the photometric orbital solution. For yellow light a luminosity ratio of $L_1/L_2 = 1{\cdot}92$ was obtained, for blue light the value was 2·02. For A5V stars the mass–luminosity relation is about $L \propto \mathcal{M}^{3\cdot5}$. As $\mathcal{M}_1/\mathcal{M}_2 = 1{\cdot}19$, we should expect a luminosity ratio of 1·84, which is in good agreement with the photometric data.

Since the radial velocity of the system has been obtained, it is possible to compute space motions for 9 Chamaeleontis. The components of proper motion are given as $\mu_\alpha = -0^s\cdot0093$ and $\mu_\delta = +0''\cdot039$ in the *Smithsonian Astrophysical Observatory Star Catalog*. Considering $M_v = +1\cdot5$ as a realistic estimate of the absolute magnitude of the system, the distance modulus is 4·5 magnitudes, corresponding to a distance of 80 parsecs. The tangential velocities then are $t_\alpha = -10\cdot1$ km s^{-1} and $t_\delta = +14\cdot7$ km s^{-1}. Using the transformation equations given by Eggen (9), the space motion components for 9 Chamaeleontis are $U = +25$ km s^{-1}, $V = -29$ km s^{-1} and $W = -11$ km s^{-1}. These components are in a coordinate system in which the U axis is directed toward $l^{II} = 180°$, $b^{II} = 0°$; the V axis toward $l^{II} = 90°$, $b^{II} = 0°$; and the W axis toward $b^{II} = +90°$.

4. *Conclusion.* In its geometrical properties 9 Chamaeleontis appears to be typical of the detached eclipsing binary systems. The sizes of the components are in good agreement with the values obtained for other main-sequence A-type stars. The geometrical elements and the mass-ratio (and via the mass–luminosity relation, the expected luminosity-ratio) are also in good agreement with the photometric orbital elements obtained by the author. The system, however, does appear to be undermassive. As 9 Chamaeleontis is a detached system, we should expect that very little mass exchange or mass loss is going on at the present time. However, extensive mass exchange or mass loss may have occurred in the past history of the system and this may be responsible for the apparent low masses of the components. A radial velocity study of this system done at high dispersion should be able to confirm these masses. Further work on this star should enable it to become one of the best known of the detached eclipsing binary systems.

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