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THE SPECTRA OF THE CARBON STARS

BY

C. D. SHANE

INTRODUCTION

The spectra of the carbon stars are particularly difficult to photograph. The stars themselves are faint, and in those of later Class R and of Class N the spectral intensity decreases very rapidly toward the violet. Nevertheless, it is in this region that some of the most significant features of their spectra are to be found. Moderate or high dispersion spectrograms of normal exposure record only the longer wave-lengths. Low dispersion for the most part suffices for a study of the most prominent characteristics and permits the examination of many faint stars in the more refrangible region.

The present paper contains the observations of 50 stars of Classes R and N made with very low dispersion. Higher dispersion plates are included wherever possible. The behavior of the prominent spectral features is described and on this basis certain adjustments in the Harvard Classification are made. Finally the significance of this classification is briefly discussed.

INSTRUMENTS AND OBSERVATIONS

Three spectrographic arrangements were used in securing these plates.

Spectrograph *a* is a small slitless instrument with one quartz prism and quartz lenses and is used with the Crossley reflector.¹ The average dispersion between 5100Å and 3900Å is 650Å per mm.

Spectrograph *b* is the large 2-prism quartz spectrograph designed by Mr. Wright.² It was used in its slitless adaptation in conjunction with the Crossley reflector. The average dispersion between *H*β and *H*ε is 120Å per mm.

¹ *Lick Obs. Bull.*, **2**, 47, 1902.

² *Ibid.*, **9**, 52, 1917.

Spectrograph *c* is a slit spectrograph having one light flint 60° prism and a 16-inch camera. It was attached to the 36-inch refractor. The dispersion at 4500Å is 64Å per mm.

Plates of 50 stars were secured with Spectrograph *a*, the exposure times varying from a few seconds to 5 hours. In most cases several exposures of different lengths were impressed on one plate in order to obtain properly exposed images over as long a stretch of spectrum as possible. In this way records of the Class R spectra extending from about 5200Å to 3400Å were ordinarily secured. In Class N they ranged from about 5400Å to 3800Å although among the later Class N stars, the spectrum usually extended only as far toward the violet as 4400Å.

Higher dispersion plates of a few typical stars of the spectral sub-classes were secured with Spectrograph *b*. These were used when a more detailed examination was desirable.

The plates with Spectrograph *c* were taken by Dr. Moore for radial velocity and were kindly placed at my disposal for this study.

The results are summarized in Tables I and II. Table I includes all the observations made with Spectrograph *a*. The first four columns are self explanatory. The fifth column tabulates the readjustment in the Harvard Classification which the present observations indicated. The significance of the remaining columns is described in the discussion of the prominent spectral features. Table II includes a few additional stars of which no observations were secured with Spectrograph *a*. Material homogeneous with that of Table I was therefore not available, and the stars are tabulated separately with their reclassification and such comments on their spectra as seem important.

TABLE I

α 1900	δ 1900	Mag.	Harvard Class.	Reclassification	Int. Cy. Bands	Int. 4737A Bands	Faintness in short wave-length	Int. 4600A Int. 4800A	Designation
19 ^b 17 ^m 7	-10°53'	7.0	R0	R0	4	3	1	.8	HD182040
23 57.0	- 3 23	9.9	R0	R0	5	1	1	.9	HD224959
17 10.4	+42 15	7.7	R0	R1	6	3	2	.8	HD156074
19 43.8	+85 9	9.6	R3	R2	6	5	3	.9	HD187216
2 30.2	- 9 53	8.3	R3	R3	9	5	2	.8	HD 16115
7 20.1	+22 7	10.0	R5	R3	8	6	2	.8	HD 58337
7 20.2	+22 5	9.8	R5	R3	8	6	2	.8	HD 58364
15 21.9	-24 49	7.4	R0	R3	7	3	3	.8	HD137613
21 59.7	+20 34	8.8	R3	R3	8	2	3	.9	HD209621
23 44.0	+ 5 50	8.8	R3	R3	8	3	3	.8	HD223392
9 8.3	+14 37	8.9	R5	R4	8	9	3	.7	HD 79319
19 3.0	-17 26	10.6	R0	R4	8	5	3	.7	HD178316
0 19.1	+53 44	9.7	R5	R5	9	9	3	.6	HD 1994
3 3.7	+57 31	8.1	R5	R5	8	10	4	.6	HD 19557
8 56.2	+50 29	9.5	R5	R5	10	10	4	.6	HD 77234
18 4.0	+ 9 26	10.0	R5	R5	10	9	4	.6	HD166097
12 54.7	+38 20	9.2-9.6	Na	R6p	5	8	3	.8	HD112869
8 42.4	-29 21	7.6	R8	R7	6	7	5	.6	HD 75021
2 9.6	+11 47	8.3-9.0	Nb	R8	2	9	5	.7	V <i>Arietis</i>
3 57.2	+61 32	7.9	R8	R8	7	6	5	.6	HD 25408
19 52.5	- 0 2	9.8	R3	R8	6	3	5	.8	HD188934
7 25.8	+24 44	8.2	R8	R9	3	4	5	.8	HD 59643
1 10.6	+25 14	7.4-8.1	Na	N0	2	4	6	.8	Z <i>Piscium</i>
5 4.9	- 5 38	8.6	Nb	N0	1	5	6	.7	HD 33404
5 41.7	+30 36	9.0-9.3	Na	N0	2	6	6	.8	HD 38572
19 25.1	+76 23		Nb	N0	1	6	6	.7	UX <i>Draconis</i>
23 41.3	+ 2 56	5.3	Na	N0	1	4	6	.8	HD223075
21 37.8	+35 3	6.4	Nb	N1	0	6	7	.7	HD206570
23 56.2	+59 48	7.6	Na	N1p	0	2	7	.9	HD224855
5 39.1	+24 23	8.7-9.5	Nb	N2 ³		6		.6	TU <i>Tauri</i>
5 39.7	+20 39	6.9-8.9	Nb	N2	0	7	7	.5	Y <i>Tauri</i>
4 45.2	+28 21	8.1-8.8	Nb	N3	0	8	8	.5	TT <i>Tauri</i>
6 4.7	+26 03	7.4-8.3	Na	N3		6	8	.4	TU <i>Geminorum</i>
6 29.7	+38 31	6.2-6.7	Na	N3		6	8	.5	UU <i>Aurigae</i>
12 40.4	+45 58	4.8-6.0	Nb	N3	0	7	9	.5	Y <i>Canum Venaticorum</i>
18 44.9	- 8 1	6.4-7.3	Nb	N3		5	9	.5	S <i>Scuti</i>
18 50.0	- 8 19	8.8-9.3	Nb	N3		6	9	.5	T <i>Scuti</i>
20 6.4	+47 33	8.5-9.4	Nb	N3		6	9	.5	SV <i>Cygni</i>
21 51.7	+22 24	7.7-8.6	Nb	N3	0	10	8	.5	RX <i>Pegasi</i>
12 52.5	+66 32	6.1-7.1	Np	N4		7	9	.4	RY <i>Draconis</i>
18 54.0	+14 14		Nb	N4		7	9	.4	UV <i>Aquilae</i>
5 0.2	+ 1 2	5.9-7.7	Nb	N5				.3	W <i>Orionis</i>
6 39.4	+ 3 25	9.6	Nc	N5				.3	HD 48664
21 39.1	+37 34	7.1-9.3	N	N5				.3	RV <i>Cygni</i>
4 55.0	-14 57	6.1-9.7	Nc	N6				.3	R <i>Leporis</i>
18 59.1	- 5 50	6.5-8.0	Np	N6				.3	V <i>Aquilae</i>
0 14.6	+44 09	8.1-9.5	Nc	N7				.2	VX <i>Andromedae</i>
5 30.2	+68 45	7.8-10.8	R8	Np ⁴					S <i>Camelopardalis</i>
12 20.1	+ 1 20	7.2-9.0	Pec.	Np ⁵					SS <i>Virginis</i>
20 16.5	+47 35	6.1-11.8	R8	Np ⁶					U <i>Cygni</i>

³ The spectrum is composite indicating a Class A0 companion of eleventh magnitude. *Publ. A.S.P.*, 37, 35, 1925.

⁴ S *Camelopardalis* Var. 7.8-10.8. One plate was secured with spectrograph *a* on March 21, 1925, when the star's magnitude was about 10. This spectrum is exactly like that of U *Cygni* at minimum light.

⁵ SS *Virginis* Var. 7.2-9.0. The Draper Catalogue describes the spectrum as similar to VX *Andromedae* which would make it late Class N. A plate taken with spectrograph *a* on March 21, 1925, when the magnitude was 8.1 records a spectrum closely resembling U *Cygni* at minimum.

⁶ U *Cygni* Var. 6.1-11.8. The spectrum is variable. A discussion of the variations based on numerous observations covering a light range mag. 6.8 to mag. 9.5 is given in *Lick Obs. Bull.* 10, 89, 1920. A plate obtained with spectrograph *a* on July 20, 1925, when the star's magnitude was 10.4 records a spectrum somewhat resembling Class N6. The Swan band at 4737A is not quite so strong as in Class N6 but to the violet of this band the spectrum fails to increase appreciably in strength, a feature peculiar to stars of classes later than N4. There is some slight evidence of the unidentified bands peculiar to the late Class N stars, but owing to the small dispersion used this is very uncertain.

TABLE II

α 1900	δ 1900	Mag.	Harvard Class.	Reclassification	Instruments	Designation
3 ^b 33 ^m 2	+62°19'	6.9-9.0	Nb	N5	b	U <i>Camelopardalis</i>
4 40.8	+67 59	7.0-8.3	Nb	N5	c	ST <i>Camelopardalis</i>
6 19.8	+14 48	6.6	Nb	N0	c	HD44984
8 49.7	+17 37	6.1-6.6	Nb	N3	bc	X <i>Cancr</i>
9 46.4	-22 32	6.5-8.0	Np	N3	c	Y <i>Hydrae</i>
10 32.6	-12 52	4.5-6.3	Nb	N2	bc	U <i>Hydrae</i>
10 38.1	+67 56	6.3	Na	N0	c	HD92839
18 39.4	+36 51	8.1	Nb	N4	c	HD173291
19 13.4	-16 5	7.2	Na	N2	bc	HD180953
19 28.6	-16 35	(8.5-9.7) ⁷	Nb	N3	c	AQ <i>Sagittarii</i>
20 9.8	+38 26	7.5-8.7	Pec.	Nop ⁸	bc	RS <i>Cygni</i>

DESCRIPTION OF PROMINENT SPECTRAL FEATURES

Cyanogen bands.—The cyanogen band groups with heads at 4216A, 3883A and 3590A are found in varying strength in stars of Classes G and K. An investigation by Lindblad⁹ has shown that in the giant stars, the bands reach a maximum intensity between Classes G5 and K5, after which they rapidly decline.

The cyanogen bands exhibit a similar behavior among the carbon stars but on a much intensified scale. They are very prominent features of the Class R spectra but sink into insignificance early in Class N. Among the earliest Class R stars they exert several times the absorbing effect observed in the giant stars of Classes G and K. In Class R0 the 3883A group absorbs roughly 20% of the star's light between 3883A and 3590A, while in Class R5 the amount absorbed rises to 50% or more. In the latter case the absorption appears to be complete for a distance of at least one hundred angstroms from the head of the group. The absorption decreases rapidly beyond Class R5 and disappears entirely before Class N3 is reached.

Numbers on an arbitrary scale indicating the intensities of these bands are given in the sixth column of Table I. In the case of the earlier type stars the estimates are based principally on the 3883A group, but after R8 the spectra were frequently so weak in the ultra-violet that it was necessary to rely on estimates of the 4216A group, allowance being made for its smaller intensity. This involves a slight uncertainty because there is some evidence that as the spectral type advances the less refrangible group increases in intensity relatively to the other. This source of error is not great, however, and can not affect the qualitative value of the results.

Figure 1 illustrates graphically the variations of intensity of the cyanogen bands with spectral class. Already very strong in the Class R0 stars, they increase

rapidly as the spectral type advances reaching a maximum at R5. Beyond R5 the decrease is even more rapid and by the time N3 is reached they have entirely disappeared.

Fig. 1. Intensity of the cyanogen bands. (The open circles indicate stars with peculiar spectra.)

The above discussion relates only to the three groups at 4216A, 3883A and 3590A. Another group of cyanogen bands at 4606A behaves in an entirely different manner. Its separate bands have very little extension toward the violet, being scarcely distinguishable under low dispersion from broad lines. The intensities of these bands do not vary rapidly from one spectral subdivision to another. An examination of 17 plates taken with Spectrograph *b* reveals a noticeable increase in their strength as far as Class R8, beyond which they are nearly constant through Classes N0, N3 and N5. This behavior differs markedly from that of the other cyanogen groups.¹⁰

Carbon bands.—The spectra of the carbon stars are readily distinguished from all other stellar spectra by the presence of the "Swan Bands." If, as is generally

⁷ These magnitudes are photographic.

⁸ RS *Cygni* Var. 7.5-8.7. The spectrum resembles Class N0 except that the intensity to the violet of 4600A decreases much more rapidly than in other early Class N stars.

⁹ *Contrib. Mt. Wilson Obs.*, 11, 1, 1921.

¹⁰ Conclusions regarding the behavior of the cyanogen spectrum in the carbon stars have been heretofore largely drawn from studies of the group at 4606A. It is now clear that this group is not typical of the entire cyanogen spectrum. For references see *Publ. Yerkes Obs.*, 2, 379, 1904. *Publ. Detroit Obs.*, 2, 139, 1916. *Lick Obs. Bull.*, 10, 85, 1920.

believed, the carbon stars form a secondary branch of the spectral sequence, departing from the main stem in Class G or Class K, we might expect to observe a progressive increase in the carbon absorption with advancing spectral type. Rufus,¹¹ however, has indicated that, instead of such a progressive increase in carbon absorption running through Classes R and N, there exist two parallel sequences, one for Class R and one for Class N.

The seventh column of Table I contains estimates of the intensity of the 4737A group of the Swan spectrum. These intensities are plotted against spectral class in Figure 2. It is evident that if the badly scattered points at R7 and R8 are omitted, the conclusions

Fig. 2. Intensities of the Swan band at 4737A.

of Rufus are verified. If we include them, however, there is a clearly defined maximum at R5 followed by a minimum at N0 with a subsequent rise. Reliable estimates of the intensities in Classes N5-N7 could not be made in the case of the 4737A band because of rapidly increasing absorption toward the violet in this region.

The Swan groups at 5636A, 5165A and 4383A are represented in all the carbon stars. Their intensities appear to vary with spectral class in the same manner as that of 4737A. This is certainly true of 4383A and a rather limited number of spectrograms in the visual region supports the same conclusion in the case of the other bands.

The group with heads at 6191A, 6122A and 6060A is visible on spectrograms of the visual region. The bands, however, are very narrow, being little more than broadened lines in marked contrast to the bands of other groups which are frequently so broad as to be entirely run together. No plates are available for their study in Classes R3-R8, but spectrograms of other Class R and of Class N stars indicate the same variations of intensity that are exhibited by the band at 4737A.

Spectral intensity distribution.—In the main branch of the spectral sequence, it is observed that the more

¹¹ *Publ. Detroit Obs.*, 2, 140, 1916.

refrangible portions of the spectrum decrease in relative intensity with advancing spectral class. This same effect is present to a much greater extent in the carbon stars. Among the Class R0 stars, the intensity distribution, as shown on plates taken with the small slitless spectrograph, does not differ greatly from that of the Class G stars. As we proceed beyond Class R0, there is an increasing faintness in the ultra-violet which continues at an accelerated rate until in Class N3 it is practically impossible to photograph the spectrum beyond 3900A. The most striking illustration is afforded by *Y Canum Venaticorum* (Class N3). This star is brighter than the sixth magnitude and with the small slitless spectrograph can be photographed near 4800A in one second. An exposure of five hours, however, failed to show any light of wave-length shorter than 3900A. No doubt the stars of Classes N4-N7 are even fainter in the ultra-violet, but in the case of the brightest of these, exposures of the order of fifteen or twenty hours would probably be required to settle the question.

While it is true that among the Class N stars the decrease in spectral intensity toward the shorter wavelengths is continuous throughout the entire region photographed, the most rapid decrease occurs between 4380A and 4200A. This sudden drop is not observable among the Class R stars, except slightly in Class R8. In Class N0 it is more pronounced and in Class N3 there is a very sudden decrease of intensity in this region. Nearly all of the later Class N stars are too faint here to be easily photographed.

Numbers on an arbitrary scale from 1 to 10, indicating the increasing faintness of the spectrum in the more refrangible region, are recorded in column 8 of Table I. These numbers are plotted in Figure 3.

Fig. 3. Faintness in the more refrangible region.

As in the main spectral sequence, it is evident that the relative weakening of the violet spectrum parallels the increasing redness of the stars.

Relative intensities on either side of the 4737A band.—In the Harvard Classification the subdivisions of Class N depend largely on the ratio of the spectral intensities on either side of the 4737A band. This ratio was also

determined in the present study, the intensities at approximately 4600Å and 4800Å being compared. The estimated values are tabulated in column 9 of Table I and are plotted against spectral class in Figure 4.

Fig. 4. $\frac{\text{Intensity at 4600Å}}{\text{Intensity at 4800Å}}$

The ratio is of course influenced by the general weakening of the spectrum toward the violet, and so might be considered a measure of the redness of the stars. An examination of Figure 4, however, reveals a definite maximum at Class R5. The similarity of this curve to that of Figure 2 suggests that we are dealing with a property depending on the intensity of the 4737Å band in addition to the general weakening of the spectrum toward the violet. If such a relation actually exists, there should be a tendency for stars departing from the mean positions for their spectral classes in Figure 2 to depart in the same sense in Figure 4. This was tested in the following manner: Mean values of the intensity of the 4737Å band and of the ratio Int. 4600Å/Int. 4800Å were calculated for each spectral subdivision, and these values compared with corresponding results for individual stars. Among 23 cases in which departures from the mean existed, 16 were favorable to the hypothesis and 7 unfavorable. It therefore appears very probable that the ratio Int. 4600Å/Int. 4800Å depends on the strength of the carbon absorption as well as on the general faintness in the short wave-lengths.

The G band.—The hydrocarbon band designated as G by Fraunhofer is present in most of the carbon stars. The small dispersion of Spectrograph *a* did not record this band satisfactorily, so that observations were limited to 12 plates secured with Spectrograph *b*. A study of these revealed an increase in the intensity of G from R0 to R3 where it appears with unusual strength. Beyond R3 its intensity decreases slowly at first and then more rapidly until in N3 it is nearly or quite absent.

There are, however, some curious irregularities in intensity. In the star HD82040 (Class R0) it is scarcely visible, while in HD156074 (Class R1), it is very strong. The existence of such irregularities combined with the small number of stars examined causes

some uncertainty in the position of maximum development but there is not much doubt that it lies somewhere in the range R2–R5.

Unidentified bands.—Sanford¹² has directed attention to five bands of unknown origin which occur in a number of the Class N stars. The two most prominent bands, of wave-lengths 4979Å and 4868Å, appear to be degraded toward the red. The remaining three bands with the more refrangible edges at 5035Å, 4932Å and 4905Å are of uncertain character and are not definitely degraded in either direction.

On plates of the late Class N stars secured with Spectrographs *b* and *c* in the present study, the bands measured by Sanford at 5035Å and 4932Å are faintly recorded while the remaining three are conspicuous features of the spectrum. Their wave-lengths derived from plates of *W Orionis* and *V Aquilae* are 4976Å, 4905Å and 4866Å. In addition to these, three new bands were measured at 4642Å, 4572Å and 4540Å.

An examination of the plates at once suggests that these six bands fall into two very similar groups. In the two groups the separations of corresponding bands

Group I	Group II	Description of bands
4642Å	4976Å	Wide, strongly degraded toward red
4572Å	4905Å	Narrow
4540Å	4866Å	Moderate width, slightly degraded toward red

are nearly the same. Furthermore the relative intensities within each group appear to remain constant. These facts strongly suggest a common origin for the six bands.

TABLE III
INTENSITIES OF UNIDENTIFIED BANDS

Star's α	Class	Int.	4868Å	4979Å	Designation
6 ^b 19 ^m 8	N0	0			HD44984
10	38.1	N0	0		HD92839
19	25.1	N0	0		UX <i>Draconis</i>
23	41.3	N0	0		HD223075
21	37.8	N1	0		HD206570
23	56.2	N1p	0		HD224855
5	39.7	N2	1		Y <i>Tauri</i>
10	32.6	N2	2	V. Weak	Weak U <i>Hydrae</i>
19	13.4	N2	0		HD180953
6	29.7	N3	0	V. Weak	Moderate UU <i>Aurigae</i>
8	49.7	N3	1	?	Weak X <i>Cancris</i>
9	46.4	N3	1		Y <i>Hydrae</i>
12	40.4	N3	1	?	V. Weak Y <i>Canum Venaticorum</i>
18	44.9	N3	0		S <i>Scuti</i>
19	28.6	N3	0		AQ <i>Sagittarii</i>
18	39.4	N4	2		HD173291
3	33.2	N5	5		U <i>Camelopardalis</i>
4	40.8	N5	3		ST <i>Camelopardalis</i>
5	00.2	N5	4	Moderate	Strong W <i>Orionis</i>
21	39.1	N5	5	Strong	V. Strong RV <i>Cygni</i>
4	55.0	N6	5	Weak	Moderate R <i>Leporis</i>
18	59.1	N6	5		V <i>Aquilae</i>

¹² *Publ. A.S.P.*, 38, 177, 1926.

Although the relative intensities of the bands remain essentially the same in all stars, the absolute intensities vary greatly. Estimates were made on an arbitrary scale of the mean strength of 4976A and 4866A as an index of the group intensity and are included in Table III with Sanford's remarks. There is clearly a rapid increase in the intensity of the bands at Class N5. This is so marked that their prominent occurrence in Classes N5 and N6 gives these spectra a very characteristic appearance and is valuable in classifying the later Class N stars.

CLASSIFICATION

In classifying the spectra of the carbon stars, it is desirable to consider the region of short wave-length. Among the Class R stars the very characteristic cyanogen bands occur in this part of the spectrum, while in Class N the weakness or absence of the cyanogen absorption is equally important. Moreover the rapid decrease in the spectral intensity toward the violet is of prime significance in classification. If the more refrangible region is not observed, it is possible to fall into serious error. An example is afforded by Classes R5 and N3. If through underexposure the recorded spectrum of a Class R5 star does not extend beyond 4400A, there is little to distinguish it from a Class N3 star, unless high dispersion is employed. This is also exemplified in Classes N3 to N6. The visual spectra of these classes exhibit no appreciable variation throughout the sequence and are therefore not suitable for use in classification.

With these considerations in mind the stars were reclassified according to the following criteria:

Class R0: Cyanogen bands strong.¹³ Spectral intensity distribution as in Class G or K. Swan bands weak.

Class R3: Intermediate between R0 and R5.

Class R5: Cyanogen bands very strong. Considerably weaker in short wave-lengths than Class R0. Swan bands very strong.

Class R8: Cyanogen bands much weaker than in Class R5. Swan bands show a great range of intensity in this class. Spectral intensity distribution intermediate between Class R5 and Class N0.

Class N0: Cyanogen bands very weak. Spectrum can be photographed as far as H and K only with difficulty. Swan bands weak or moderate.

Class N3: Cyanogen bands missing. Spectrum extremely weak to the violet of 4383A. Swan bands strong.

Class N5: Spectrum very faint to the violet of the Swan band at 4737A. Unidentified bands at 4979A and 4686A strong.

¹³ The cyanogen group at 4606A was not used in the classification.

Classes N6 and N7: Continue in greater strength the characteristics of Class N5.

The spectral class assigned on the basis of these criteria is tabulated in the fifth column of Tables I and II. The fourth column indicates the Harvard class. Since the new criteria were chosen to follow the Harvard system, the two classifications are for the most part in agreement, discrepancies in individual stars being due to accidental error or perhaps in some cases to actual variations in spectral class.

Spectrograms of typical stars belonging to various subclasses are reproduced in Plate XI. These were all secured with the quartz 2-prism spectrograph, referred to here as Spectrograph b.

DISCUSSION OF CLASSIFICATION

The problem of spectral classification would be much simplified if stellar spectra could be accurately arranged in a one dimensional system. In such a case, a smooth curve would be obtained if the intensity of any spectral feature were plotted against spectral class. From this we could infer the complete dependence of stellar spectra on a single variable.

Among the stars of the main spectral sequence, however, we find that in general such a diagram represents a band rather than a line. This indicates that not less than two independent variables are required for a complete description of stellar spectra. Although some progress has been made toward such a classification, a sufficiently comprehensive system has not been devised.

A similar situation probably exists among the stars of the R-N branch. An examination of Figures 1 to 4 shows that by plotting the different spectral features against spectral class, a band instead of a smooth curve is obtained. The notable scattering of points, particularly where the intensities of the carbon bands are concerned, is a very definite indication that a one-dimensional system is valuable only as a rough means of describing the spectra. The small amount of observational material available for these stars would render an attempt at a more elaborate classification unprofitable.

It is of interest to inquire into the physical significance of the R-N spectra. Along the main branch of the spectral sequence, temperature is undoubtedly a controlling factor, while pressure, density and chemical composition probably exert some influence. Despite the progressive redness of the carbon stars, there is considerable doubt that temperature plays as important a role in this branch of the sequence. In the first place, let us consider the black body temperature of the carbon stars. Making the conservative estimate that the spectrum of *Y Canum Venaticorum* at 4800A is five

hundred times as intense as the spectrum at 3900A (see page 126), we find the black body temperature to be 953°K. This is unreasonably small and leads to the conclusion that the redness of the star is not entirely due to low temperature. In the second place the behavior of the Swan bands is puzzling. It is difficult to see how a progressive decrease in temperature or in fact a steady variation in any single physical condition, could lead to the peculiar forms of the curves in Figures 2 and 4. A maximum of a spectral feature followed by a decrease in its prominence is readily understandable, but it is not evident how this can be followed by another increase unless rather complicated changes in a number of physical conditions are involved. It appears from these considerations that temperature may not be of prime importance in determining the spectrum of the carbon stars.

The physical interpretation of the R-N spectrum is evidently a problem of some complexity. In the main spectral sequence, the variation of the spectrum from

class to class unquestionably depends in great part upon temperature. Among the stars of Classes R-N, however, neither the behavior of the carbon bands nor the redness of the stars, two most prominent spectral characteristics, can be satisfactorily related to temperature. Lack of observational material contributes further to the difficulty of the problem. In the present state of our knowledge, it is advisable to regard the classification in this spectral sequence as purely descriptive and not to insist on any particular physical interpretation.

I wish to express my deep obligation to Associate Director Aitken for the privilege of using the equipment of the Lick Observatory, to Dr. Moore for placing the 1-prism spectrograms at my disposal and to Dr. Bobrovnikoff for securing spectrograms of *W Orionis* which were used in the foregoing discussion.

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