THE CLASSIFICATION OF THE RED CARBON STARS

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ABSTRACT

The subdivisions of spectral classes R and N do not appear to represent a consistent progression in temperature. In order to set up a more definite temperature sequence, a new classification is suggested on the basis of four criteria: (1) atomic line ratios which are sensitive to temperature changes; (2) intensity gradient of the continuous spectrum in the yellow and red regions; (3) strength of the D-lines of sodium; and (4) intensity gradient within the λ 5635-band group of the molecule C_2.

In the new classification the double maximum shown by the C_2 bands in the R-N system disappears and is replaced by a single broad maximum.

The "lithium" star, WZ Cassiopeiae, whose spectral type in the R-N system is N1p is reclassified at the low-temperature end of the carbon sequence; it appears to be the coolest carbon star known, and the great strength of *Li* may possibly be explained.

A group of five carbon stars has been found which is characterized by extreme weakness of the atomic lines in the photographic region. The bands of *CH* occur with great strength in their spectra; in addition, all five stars have very high radial velocities.

The intensities of the carbon bands vary greatly among stars of the same subclass; this is probably to be considered as evidence of different abundances of carbon in the atmospheres of different stars.

INTRODUCTION

The stars with spectra characterized by strong bands of C_2 and *CN* were grouped into classes R and N by Miss Cannon in the *Henry Draper Catalogue*.[1] Later the subdivisions which had been developed at Harvard were revised and extended by Shane.[2]

The R-N classification was designed to provide a good working summary of the appearance of these stars on spectrograms of low dispersion. It is based chiefly upon the strength of the band absorption and the redness of the spectra as judged from a comparison of the visual and photographic regions. The two criteria are not independent, for the extension of the bands is often so great that no part of the continuum can be assumed to be entirely free of their effect. Evidence that the color depends upon the choice of spectral region is provided in the observations of Wildt,[3] who found that the color differences, infrared *minus* ultraviolet, for a number of R and N stars were not in the same order as their assigned spectral types. These inconsistencies appeared to be too large to be due to errors and led Wildt to state that they ". . . . strengthen the doubts as to whether the physical changes along the sequence R-N can really be explained by the steady variation of a single parameter, namely, the surface temperature." Such doubts had been raised by Shane, largely on the basis of his study of the behavior of the λ 4737 Swan band of C_2. When plotted against spectral type the intensity of this band showed a double maximum,[4] which cannot be reconciled with a continuous decrease of temperature, if one employs the ordinary dissociation theory.

Since there is strong reason to accept the idea, originally put forward by Rufus,[5] that the R and N stars are distinguished from the ordinary stars by having a greater abundance of carbon in their atmospheres, it would not be surprising if the carbon abundance varied within the group also. Consequently, in any classification based in part upon

[1] For definition of the types see *Harvard Ann.*, **91**, 10, 1918. Class N had been proposed and the redder stars assigned to it by Pickering in 1891.

[2] *Lick Obs. Bull.*, **13**, No. 396, 123, 1928.

[3] *Ap. J.*, **84**, 303, 1936; *Mt. W. Contr.*, No. 551.

[4] *Op. cit.*, Fig. 2.

[5] *Pub. Univ. Michigan Obs.*, **2**, 103, 1916.

absolute band intensities there is danger of confusion of the two parameters—temperature and carbon abundance—and this probably occurs to some extent in the R-N system. In contrast, all other types in the *Henry Draper Catalogue*, with the possible exception of type S, are subdivided to run monotonically with respect to temperature. It is highly desirable that a similar arrangement of the carbon stars should be made, for not until this is done can the application of dissociation theory to their atmospheres be more than qualitative.

We attack the problem by first attempting to arrange the stars in a sequence based upon every clue which appears to give an indication of relative temperature. Afterward the strength of the carbon bands in stars of a given temperature class can be used to estimate carbon abundance.

The primary criteria for the temperature sequence are: (1) relative intensities of atomic lines in the blue region of the spectrum; (2) color as estimated from portions of the continuous spectrum in places where the distortion by band absorption is judged to be least; (3) strength of the D-lines of *Na;* and (4) relative intensity of molecular bands within a given system. In actual use each of the criteria has been estimated separately for as many stars as possible.

DISCUSSION OF THE CRITERIA OF CLASSIFICATION

1. *Atomic-line ratios.*—Certain of the atomic lines used in classifying the ordinary stars of types G, K, and M lie between the bands in the carbon stars, permitting estimates to be made of equivalent spectral types of the latter. It is essential to work only with intensity differences of adjacent lines, for absolute intensities are obviously affected by the increased opacity in the strongly banded stars. The lines which have proved most useful on the Yerkes one-prism spectrograms (scale: 120 A/mm at $H\gamma$) are the following:

$$Fe\ 4045 - Mn\ 4032\text{–}4\ ,$$

$$Fe\ 4250,\ 4260 - Cr\ 4254\ .$$

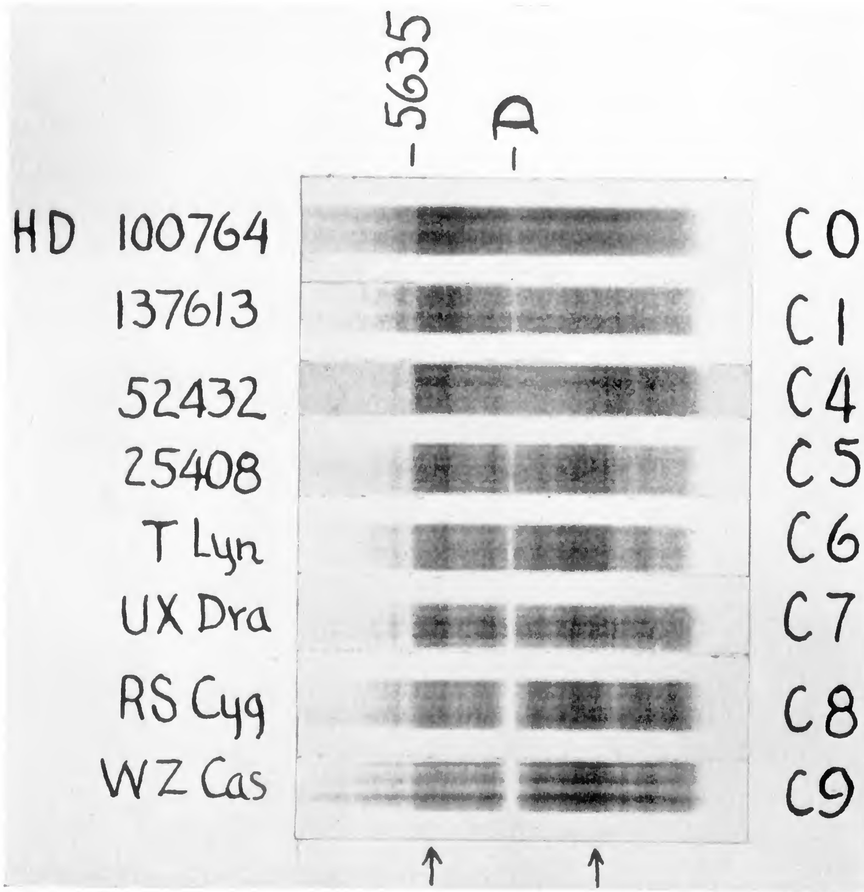
In a few stars *Ca* 4226, *Fe* 4325, and $H\gamma$ can also be taken into account, but the change in *Cr* 4254 with respect to the two adjacent iron lines is the best indicator of temperature.

There are not many carbon stars with spectra sufficiently bright to be observed in the blue region at Yerkes, but they are particularly important in establishing the zero point for the new classification. They are distinguished in Table 1 as the stars with equivalent spectral types (in parentheses) in the sixth column.

2. *Color.*—In the easily observed orange part of the spectrum there are short stretches near $\lambda\lambda$ 5190, 5670, and 6150 where it appears possible to estimate the intensity of the continuum without serious interference from the band absorption. Because of the short base-line the differences are not very sensitive to color changes, but the temperature range from the earliest to the latest carbon stars is so great that the increased reddening of the latter is conspicuous and should be taken into account in the classification. For this reason estimates of color on an arbitrary scale are included in Table 1 as the eighth column. The scale values range from -4 for the bluest of the stars to nearly $+2$ for the reddest.

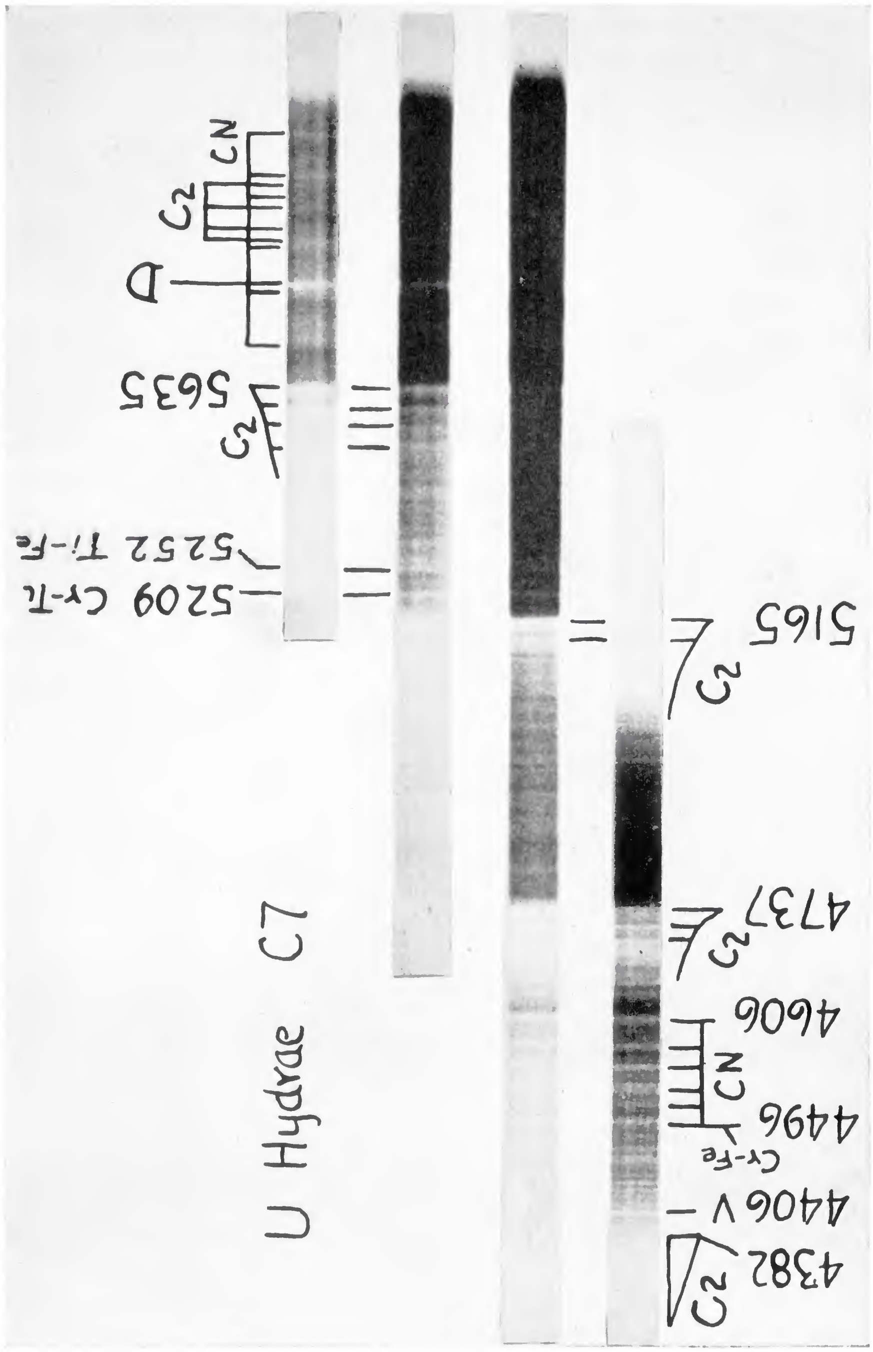
3. *Intensity of Na 5890, 96.*—Among all the atomic lines observable with low dispersion only the resonance D-lines of sodium reach such great strength in the later carbon stars that their absolute intensity is a valuable criterion. The extreme range of variation of the pair, unresolved on our spectrograms, can be seen in Plate XXI. It may be noticed also that their usefulness is limited to the later stars of the sequence illustrated, for in the earlier ones a broad region of absorption extending from λ 5750 to λ 6050 nearly blots out the D-lines (compare HD 137613 and HD 52432 in Plate XXI). This absorp-

PLATE XXI



SPECTRAL SEQUENCE OF THE CARBON STARS, REGION 5600–6500 A

Progressive changes in color (at the wave lengths indicated by the arrows), intensity of the D-lines, and bands of the 5635 group, can be followed.



Spectrum of the Green and Red Regions of the Typical Carbon Star U Hydrae as Observed with One-Prism Spectrograph on the 40-Inch Refractor

Scale of original negatives: 250 A/mm at λ 6100. The upper three spectra were taken on an Eastman Super Panchro Press Plate; the lower one, on a Cramer Hi Speed Special.

tion is due at least in part to the widening of the red-band systems of C_2 and *CN* in the hotter stars, but there may be some additional contributor. In using the D-lines for classification it is necessary to make allowance for the strength of the carbon bands.

4. *Band-intensity gradients.*—The relative intensities of the different vibrational bands in a sequence vary regularly with temperature in a manner which can be calculated in the case of symmetrical molecules. Computations for several bands of C_2 and *CN* have been made by Wurm,[6] who applied the method to estimate roughly the temperatures of the carbon stars; but for our purpose it is necessary to consider only the sequence of changes as the temperature is varied. From Wurm's Table 1 it is seen that the ratio of the bands λ 5635/λ 5585 increases from 5/4 at 3000° to 3/1 at 1500°. These bands are well situated for observation on our spectra, and in the thirteenth column of Table 1 their estimated ratio is given. It shows roughly the same range as the theoretical values given above; and, although the estimates are difficult because of overlapping and because of the strong continuum to the right of λ 5635, the ratio is evidently helpful in ordering the spectra according to temperature.

In practice additional bands of this and other C_2 groups are taken into account. On the other hand, such bands as the green sequence of *CN* are unsuitable for this purpose because of the effects of blends with strong atomic lines.

The temperature variation in the width of the red bands, which was mentioned in the preceding section, is also of some help in classification. In Plate XXI the progressive change in the appearance of the red region is apparent. In connection with the illustration it should be noted that the intensity estimates on the bands in the λ 5635 group are always made on spectra more strongly exposed than those shown.

THE SYSTEM OF CLASSIFICATION

For each of the representative stars listed in Table 1 some or all of the criteria described have been evaluated. The stars could then be arranged in order of decreasing temperature. The next step is the assignment of classes. Since the basis of arrangement is fundamentally different from that of the R-N system, it is preferable to avoid confusion by adopting a new notation. It is most logical to use the letter C for all these stars, inasmuch as the defining characteristic of the group is the predominance of carbon. In assigning subdivisions, the equivalent types established by criterion 1 provide a definite starting-point and have been distributed as follows:

Equivalent Types	Carbon Sequence Type	Approx. Effective Photospheric Temp.	Equivalent Types	Carbon Sequence Type	Approx. Effective Photospheric Temp.
G4–G6	C0	4500	K3–K4	C4	3650
G7–G8	C1	4300	K5–M0	C5	3450
G9–K0	C2	4100	M1–M2	C6	....
K1–K2	C3	3900	M3–M4	C7	....

It may be seen from the table that the branching of the carbon stars from the F-G-K sequence occurs between spectral types G4 and G6.

The stars observed in both the red and the blue regions allow a determination of the changes in the other criteria for each interval of one subdivision in type, whence the scale is extended to C9 for stars too red to be observed in the blue part of the spectrum. For this purpose criteria 2, 3, and 4 have been found to be of about equal usefulness.

The strength of the Swan bands of C_2 is the other parameter of classification and is described by the subscript following the type number. The scheme shown below gives

[6] *Zs. f. Ap.*, 5, 260, 1932.

TABLE 1

CATALOG OF C STARS

Star	α_{1900}	δ_{1900}	m_v	Former Type	Equiv. Type	C Type	Mean Color	I_D	I_{C_2}	I_{CN} (Red)	I_{CH}	$\frac{5635}{5585}$	Notes
HD 1994......	0h19m	+53°44′	9.7–	R5	(K4)	$C4_5$	......	.....	9	......	4	......	......
HD 5223......	0 49	+23 32	8.8–	R3	....	$C2p_2$	−2.7	1	3	2	6	0+	1
Z Psc.......	1 11	+25 14	7.4– 8.1	N0	....	$C7_3$	−0.2	5	5	5	......	2+	......
V Ari.......	2 10	+11 47	8.3– 9.0	R8	....	$C5p_5$	−2.2	2+	9	5	8	1	1
HD 16115.....	2 30	− 9 53	8.3–	R3	(G9)	$C2_3$	......	.....	5	......	8	......	2
HD 19557.....	3 04	+57 31	8.1–	R5	(K3)	$C4_5$	−2.2	0+	10	6	5:	0+	......
HD 25408.....	3 57	+61 32	7.9–	R8	(K5)	$C5_3$	−2.5	3+	6	5	6:	1	......
ST Cam......	4 41	+67 59	7.0– 8.3	N5	....	$C6_4$	−1.5	4	8	8	......	2	......
R Lep.......	4 55	−14 57	6.1– 9.7	N6e	....	$C7_4$+	+1:	6	8	6	......	3:	......
W Ori.......	5 00	+ 1 02	5.9– 7.7	N5	....	$C5_3$	−1.5	3	6	8	......	2	......
BD+16°1194..	6 29	+16 09	9.1–	N	....	$C8_3$	0	6	5	7	......	3	3
UU Aur.......	6 30	+38 31	6.2– 6.7	N3	....	$C5_3$	−1.5	4+	6	7	......	2	......
RV Mon......	6 53	+ 6 18	7.0– 8.2	Nb	....	$C5_4$	−1.5	3	8	8	......	1+	......
HD 52432.....	6 56	− 3 06	7.5–	R5	(K4)	$C4_4$	−2.7	1	8	5	6	1	......
RY Mon......	7 02	− 7 24	7.7– 9.1	N5	....	$C6_5$	0	4	9	8	......	1	......
RU Cam......	7 11	+69 52	7.9	K0	(G4)	$C0_1$–	......	.....	.....	......	3:	......	Max.
			9.0	R0	(K3)	$C3_1$	−2.5	1	2	0:	2:	......	Min.
HD 59643.....	7 26	+24 44	8.2–	R9	....	$C6_2$	−1.5	4	4	5	......	4	......
HD 60826.....	7 31	+ 2 18	8.7– 9.1	Na	....	$C5_5$	−1.7	2+	9	8	......	2:	......
T Lyn.......	8 16	+33 50	8.0–12.0	N0e	....	$C6_3$	−1	4	5	7	......	3	......
X Cnc.......	8 50	+17 37	6.1– 6.6	N3	....	$C5_4$	−2	4	7	8	......	2	......
HD 76396.....	8 51	+51 49	8.8–	R5	....	$C1p_2$	−3	1–	3	1	10	0	1
HD 79319.....	9 08	+14 37	8.9–	R4	....	$C4_4$	−3	2	8	5	......	1	......
Y Hya......	9 46	−22 32	6.5– 8.0	N3	....	$C5_4$	−1	2+	7	6	......	1	......
U Hya......	10 33	−12 52	4.5– 6.3	N2	(M4)	$C7_3$	−1.5	4+	6	8	4:	3	......
HD 92839.....	10 38	+67 56	6.3–	N0	(M2)	$C6_3$	−2	3+	5	7	4	3	......
V Hya......	10 47	−20 43	6.7–12.0	N6	....	$C7_5$	−2:	5	9+	9	......	2:	......
HD 100764....	11 31	−14 02	8.7–	R0	....	$C0_2$	−3.5	1+	3	1	......	0	......
SS Vir.......	12 20	+ 1 20	7.2– 9.0	Np	....	$C6_3$	0	4	6	8	......	2	......
Y CVn......	12 40	+45 58	4.8– 6.0	N3	....	$C5_4$	−2	2	7	5	2:	2	......
RY Dra.......	12 52	+66 32	6.1– 7.1	N4p	....	$C4_4$	−2	1	7	4	......	1	4
HD 112869....	12 55	+38 20	9.2– 9.6	R6p	....	Cp_5	−2.7	2	9	5	8	1+	1
HD 113801....	13 01	−19 31	8.7–	K5R	(G7)	$C1_1$	......	.....	1–	......	7	......	......
HD 137613....	15 22	−24 49	7.4–	R3	(G7)	$C1_2$	−3	2+	4	3	1	0	5
V CrB......	15 46	+39 52	7.2–12.0	N2	....	$C6_3$	−0.7	5	6	6	......	2+	Max.
RR Her.......	16 02	+50 46	7.8– 9.5	K5–N0e	....	$C7_2$	−1	6	4	5	......	3	Min.
V Oph......	16 21	−12 12	7.0–10.5	Nb	....	$C7_4$	0.2	5	7:	8	......	3	......
HD 156074....	17 10	+42 15	7.7–	R1	(G8)	$C1_2$	−2.7	1+	3	2	4	0	......
TW Oph......	17 24	−19 24	8.0– 8.7	Nb	....	$C6_5$	−1	3	9	9	......	1+	......
SZ Sgr.......	17 39	−18 38	8.5– 9.8	Nb	....	$C7_3$	−0.2	4+	6	8	......	3	......
T Lyr.......	18 29	+36 54	7.8– 9.6	N3	....	$C6_5$	−0.5	2+	10	6	......	1	......
HD 173291....	18 39	+36 51	8.1–	N4	....	$C6_4$	−1.5	4+	8	8	......	2	......
S Sct.......	18 45	− 8 01	6.4– 7.3	N3	....	$C5_4$	−1.5	4	8	9	......	1	......
V Aql.......	18 59	− 5 50	6.5– 8.0	N6	....	$C6_4$	−0.7	4	8	8	......	1	......
HD 182040....	19 18	−10 53	7.0–	R0	(G7)	$C1_2$	−2.5	2	3	1:	1	0	......
UX Dra.......	19 25	+76 23	6.1– 7.1	N0	(M3)	$C7_3$	−1.2	5	6	7	3	3	......
RS Cyg.......	20 10	+38 26	7.5– 8.7	Nope	....	$C8_2$	0.2	7	3	8	......	5	......
U Cyg.......	20 16	+47 35	6.1–11.8	Npe	....	{$C7_2$	−0.5	5	3	6	......	5	Max.
						{$C9_2$	+2:	10:	8:	6	......	......	m_v=9
S Cep.......	21 36	+78 10	7.9–13.1	N6e	....	$C7_4$	+1.5	5	7	8	......	2:	Max.
HD 206570....	21 38	+35 03	6.4–	N1	....	$C6_3$	−0.5	4	6	8	......	2	......
RV Cyg.......	21 39	+37 34	7.1– 9.3	N5	....	$C6_4$	−1	3	8	7	......	1+	......
RX Peg.......	21 52	+22 24	7.7– 8.6	N3	....	$C5_5$	−2.2	3	10	8	......	2:	......
HD 209621....	22 00	+20 34	8.8–	R3	....	$C3p_2$	......	1–	2	3:	9	......	1
HD 215484....	22 40	+61 12	9.0–	Nb	....	$C6_4$	−0.5	4+	8	7	......	2	......
19 Psc.......	23 41	+ 2 56	5.3–	N0	(M1)	$C6_2$	0	5	4	5	1	4	......
HD 223392....	23 44	+ 5 50	8.8–	R3	(K1)	$C3_2$	......	.....	3	......	4	......	......
WZ Cas.......	23 56	+59 48	6.9– 8.5	N1p	....	$C9_1$	0	8:	2	4	......	6	6

NOTES

1. Star belongs to peculiar group with *CH* strong and atomic lines weak.
2. Atomic lines somewhat weakened.
3. *Dearborn Obs. Ann.*, **4**, Part 16, 1940.
4. Sanford's green bands very strong.
5. $M_v = -0.6$ from interstellar *Na* (Sanford, *Ap. J.*, **51**, 238, 1939).
6. *Li* 6708 found to be very strong by McKellar.

the relation of the subscripts to the intensities of Table 1, tenth column, which are on essentially the same scale as that used by Shane for the λ 4737 band:

Intensity	Subscript
0–2	1
3–4	2
5–6	3
7–8	4
9–10	5

The use of subscripts makes the notation different from that in any of the HD classes; but, since the parameter described—abundance—is not represented in the other classes, the distinction seems appropriate. In using the system it must be remembered that near

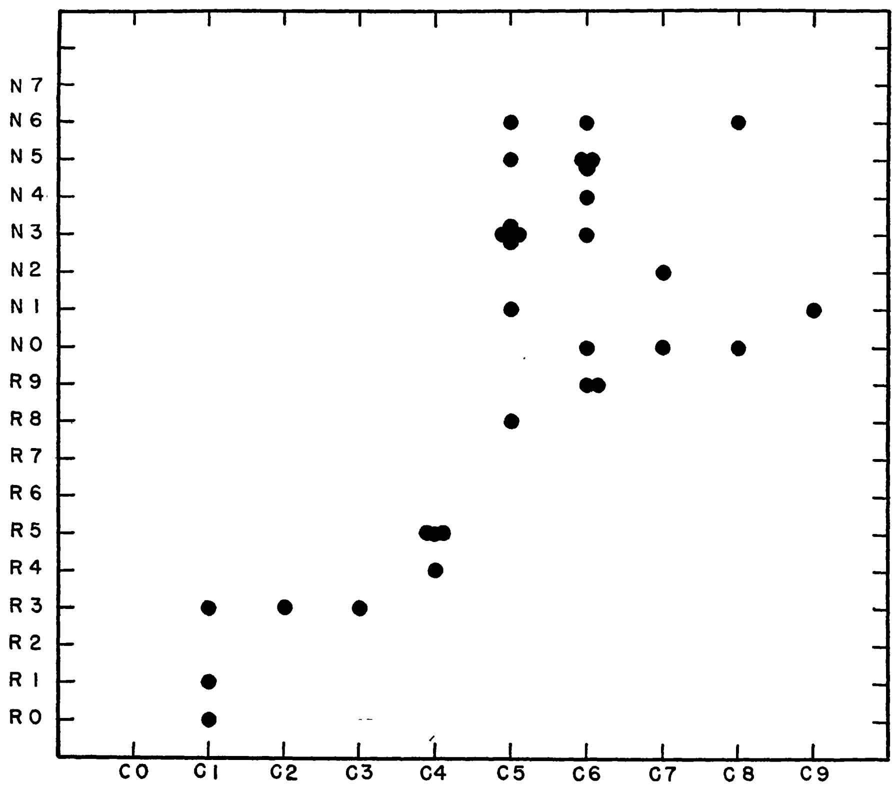


FIG. 1.—Comparison of R-N types with revised types for the carbon sequence

the beginning of the sequence the bands are never very strong and only the lower intensities are represented. This follows from the fact that band intensity depends upon temperature as well as upon abundance. However, since the classification has a definite empirical basis it should eventually prove possible to calibrate the scale to determine the abundance corresponding to a given intensity within each spectral type.

A comparison of C-types with the R-N system[7] is given in Figure 1. Through type R the agreement is good, but the old subdivisions of type N appear to have very little correlation with the reclassification. That the scatter is much greater than the uncertainty in assigning stars to the revised sequence is evident if the data in Table 1 are examined

[7] The types, which are due for the most part to Shane, are taken from Sanford's catalogue, *Ap. J.*, **82**, 202, 1935.

for the extreme cases. For example, all three red criteria agree in indicating that WZ Cas is at a lower temperature than V Aql, although the former types were N1p and N6, respectively.

The uncertainty in classifying stars on the C-system from the Yerkes plates is about ±1 subdivision. It is not feasible to estimate the error more closely from an analysis of the correlation of the criteria, for the weighting given to each varies rapidly with the type indicated. Thus I_D passes through a minimum at C3–C4 because the overlying band absorption in these classes averages much greater than in the earlier ones and the D-lines are consequently of little value at this point, though they become the most sensitive parameter for the redder stars.

VARIATION OF ABSORPTION FEATURES WITH TYPE

In Plates XXII and XXIII the more important absorption lines and bands seen on medium-dispersion spectra of the typical carbon stars are identified. The behavior of those not already discussed is summarized below:

C_2.—The Swan bands listed in Table 2 dominate the visual spectrum except in the stars at the extreme ends of the sequence. Since the band groups vary consistently in intensity, estimates of the λ 5635 group, expressed on the same scale as Shane's intensities for λ 4737, provide the values of I_{C_2} given in the tenth column of Table 1 and plotted against type in Figure 2. The diagram reveals two important points. First, there is a large range in band strength within each of the types that include any stars having strong bands. This can be interpreted as a variation in carbon abundance at constant temperature. Second, the curve obtained by plotting the mean band intensities for each spectral type shows a broad maximum centered at types C5–C6.

CN.—It was shown by Shane[2] that the λ 4215 group of bands passes through a maximum, becoming very weak in the redder carbon stars. On the other hand, it was known from the early observations of Rufus[5] and of Hale, Ellerman, and Parkhurst[8] that the group at λ 4606 remains strong throughout the subdivisions of type N, and Sanford[7] found the red bands to behave similarly. This behavior of band groups all originating from the same lower level appeared so anomalous that Wurm[6] doubted the correctness of the data. However, Figure 3 shows that the effect is clearly present when the λ 4215 band and the red bands are compared. The region of the green bands has been observed here for only a few stars, but the data indicate that if they have a maximum it must occur later than that of the λ 4215 band. On the other hand, the observations by Wildt suggest that the ultraviolet *CN* bands reach maximum intensity early in the carbon sequence, although here again the material is necessarily scanty.

It is likely that this weakening of the bands on the violet side of λ 4500 is due, at least in part, to the same continuous absorption which it was necessary to postulate in order to explain the abnormally steep intensity gradients in that part of the spectrum of many of the stars of types C4–C6, but it is not certain that the whole of the effect can be accounted for in this way.[9]

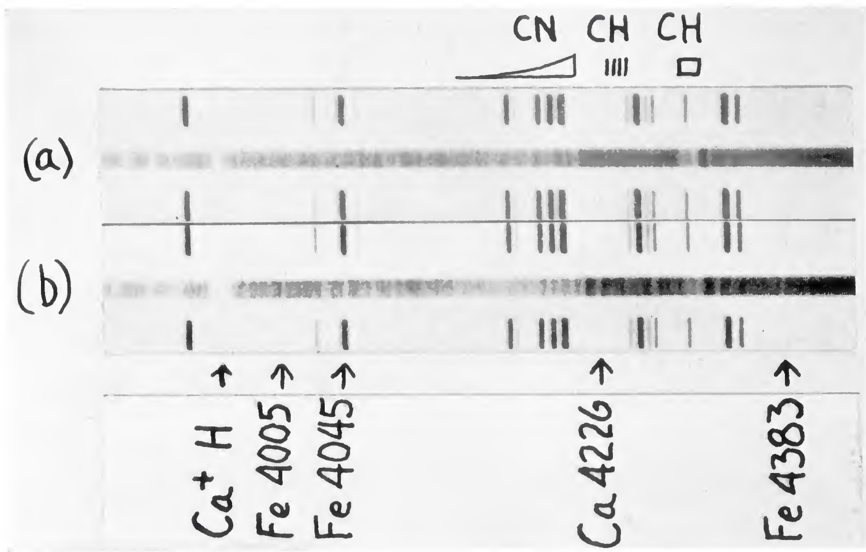
CH.—Among the normal carbon stars the narrow band at λ 4300 varies considerably in strength but never becomes much more intense than in the ordinary G-type giants. In the latter the pronounced maximum of the band occurs near types G4–G5, while the carbon sequence shows strong bands in some stars (HD 25408, HD 52432) with equivalent types as late as K4–K5 (C4–C5).

There exists also a noteworthy group of peculiar carbon stars characterized by unusually great *CH* intensity and almost complete absence of atomic lines in the blue region

[8] *Pub. Yerkes Obs.*, **2**, 253, 1903.

[9] The presence of absorption has been discussed by Wildt (cited in n. 3) and by Merrill, *Spectra of Long-Period Variable Stars*, p. 29, 1940.

PLATE XXIII



a) HD 5223, Cp_2; *b*) HD 223392, $C3_2$: COMPARISON OF A PECULIAR *CH* STAR (*above*) WITH A TYPICAL CARBON STAR (*below*)

Arrows point to some of the strongest atomic lines which are almost obliterated in the upper spectrum.

of the spectrum. These stars are easily recognized, for even so strong a line as *Ca* 4226 (see Pl. XXIII) is practically invisible on spectrograms of moderate scale. The five stars which have been assigned to this group are marked Cp in Table 1 and are collected in Table 3. The radial velocities in the sixth column are taken from Sanford's table.[7]

TABLE 2

PRINCIPAL ABSORPTION BANDS IN THE SPECTRA OF THE CARBON STARS

Band Head	Designation	Description
		C_2—Swan bands
	$B^3\pi - A^3\pi$	
λ 4383	2–0	Weak. Bands overlapping
4737	1–0	Strong. Bands overlapping
5165	0–0	Strong. Bands overlapping
5636	0–1	Strong. Bands overlapping
6191	0–2	Weak. Bands better separated
		CN
	$B^2\Sigma - X^2\Sigma$	
λ 3360	2–0	Very weak. Observed by Wildt.* Probably maximum intensity near C3–C4
3590	1–0	Strong. Observed by Wildt.* Probably maximum intensity near C3–C4
3883	0–0	Very strong. Observed by Wildt.* Probably maximum intensity near C3–C4
4216	0–1	Strong. Maximum at C3
4606	0–2	Rather weak. No maximum earlier than C6
	$A^2\pi - X^2\Sigma$	
6196	3–0	Rather weak. Possibly broad maximum near C6
6333	4–1	Rather weak. Possibly broad maximum near C6
6481	5–2	Rather weak. Possibly broad maximum near C6
		CH
λ 4300	$A^2\Delta - X^2\pi$	G-band. Very strong in peculiar stars
3900	$B^2\Sigma - X^2\pi$	Probably strong in peculiar stars
		NH
	$B^3\pi - A^3\Sigma$	
λ 3360	0–0	Observed by Wildt.* Narrow, symmetrical
3370	1–1	Observed by Wildt.* Narrow, symmetrical
		Green bands found by Merrill, Sanford, and Shane
λ 4540	....	Moderately wide and strong. Degraded to red
4572	....	Narrow
4642	....	Wide. Degraded to red. C_2?
4866	....	Strong. Moderate width. Degraded to red
4905	....	Narrow
4932	....	Weak
4976	....	Strong and wide. Degraded to red. C_2?
5035	....	Weak

* *Ap. J.*, **93**, 502, 1941.

The star HD 16115 shows some similarity to the group and may be an intermediate case.

To find the relation of these stars to the members of the normal carbon sequence it will be necessary to use spectra of higher dispersion; but so interesting are their peculiarities that we list provisionally here those which have been established in addition to the two definitive characteristics:

1. The average radial velocity is much greater than for normal carbon stars. Table 3 includes the three highest radial velocities in Sanford's catalogue.

2. The spectral type is probably in the range C2–C4. There may be some selection here, for only a few of the redder stars have been observed in the blue region.

3. The color is possibly bluer than the average for the same types. HD 76396 and HD 112869 have been observed in the far ultraviolet by Wildt,[10] who notes the unusual strength of the ultraviolet continuum of the former.

4. *CH* is increased in strength relatively to C_2 and *CN*. The intensities of bands of the latter two molecules show great scatter in Table 3. In contrast *CH* is so prominent that in Plate XXIII almost all the absorption features in HD 5223 between λ 4216 and λ 4290 have been identified as bands of the λ 4300 group, which in normal stars are

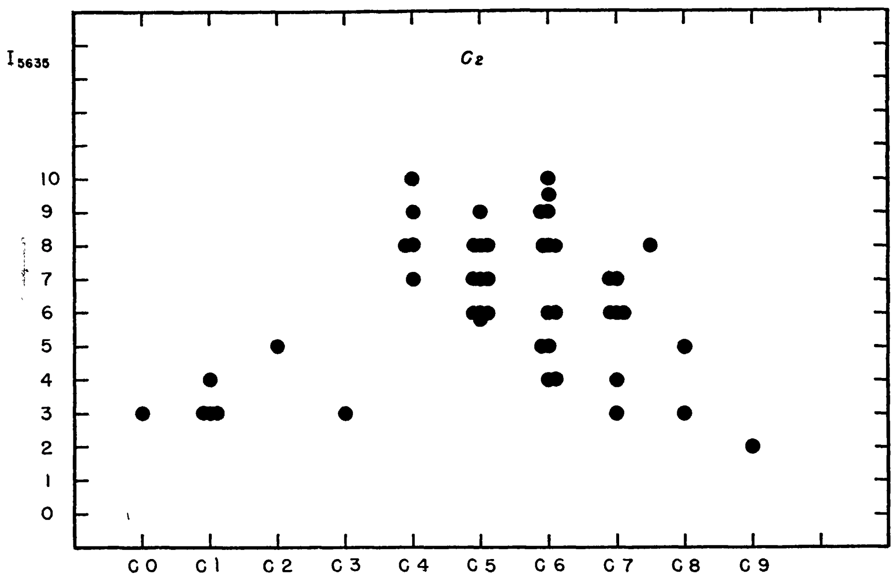


FIG. 2.—Variation of the intensity of the absorption bands of C_2 with spectral type

too faint to be detected without high dispersion. The λ 3900-band group also appears to be strengthened.

Unidentified green bands.—In 1926 Merrill[11] and Sanford[12] called attention to the presence in a number of carbon stars of five well-marked bands, of which the strongest were at λ 4976 and λ 4868. Their behavior was investigated by Shane,[2] who added three more to complete the list given in Table 2. These bands are not well situated for study on our plates, but from the data given by Shane their intensity is evidently correlated with the visual redness of the stars, i.e., with the depression of the blue end of the spectrum. For this reason Shane used them as supplementary criteria in assigning stars to the later subdivisions of class N.

In the C system the stars in which these bands are strong (W Ori, R Lep, V Aql, RY Dra) are scattered over the range C4–C7. Their correlation with the continuous absorption in the blue region suggests the possibility of a common molecular origin.

A tentative identification of two of these bands, λ 4976 and λ 4642, was made by Wurm,[13] who interpreted them as convergences of higher bands in the great C_2 groups with their heads at λ 4737 and λ 5165. However, the remaining bands remain unaccount-

[10] *Ap. J.*, **93**, 502, 1941.

[11] *Pub. A.S.P.*, **38**, 175, 1926.

[12] *Pub. A.S.P.*, **38**, 177, 1926.

[13] *Zs. f. Ap.*, **13**, 179, 1937.

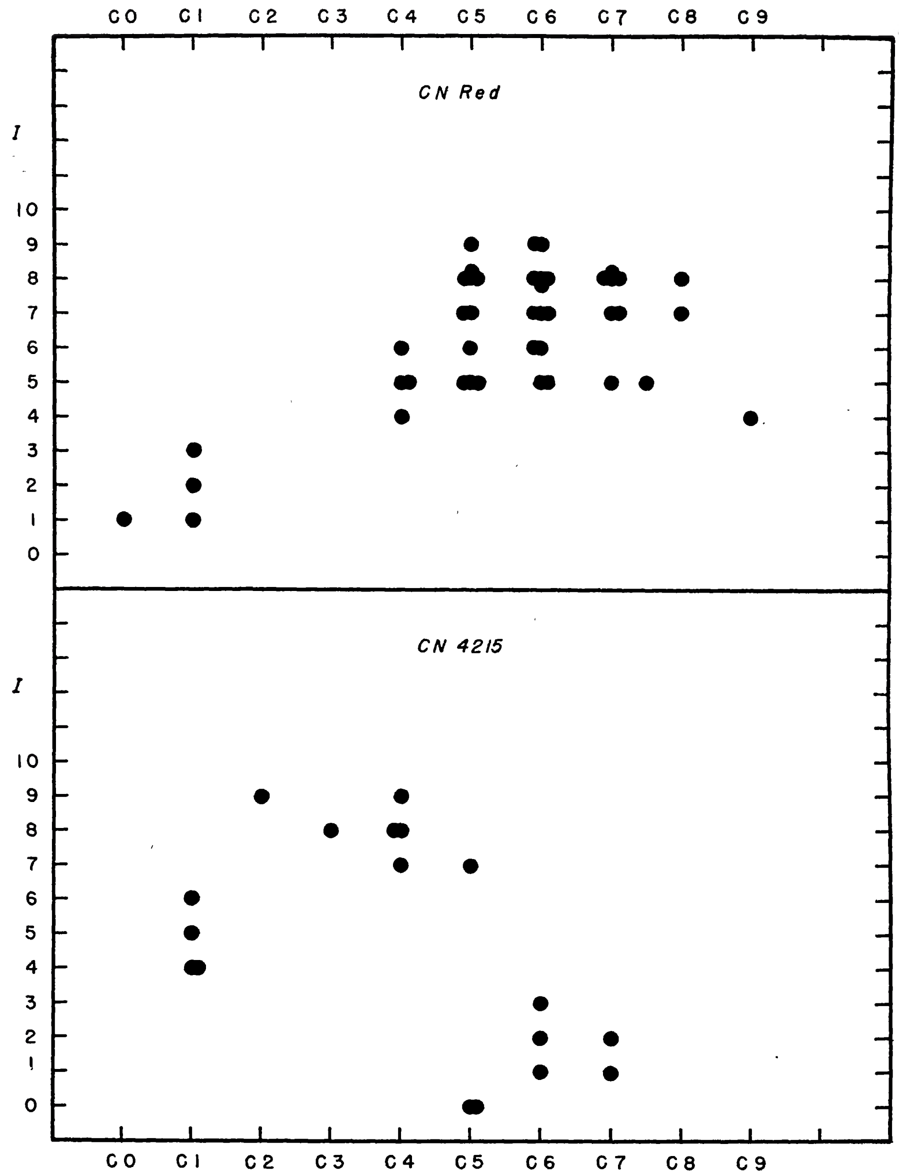


FIG. 3.—Variation with spectral type of the red and blue bands of *CN*

TABLE 3

STARS WITH *CH* STRONG AND ATOMIC LINES WEAK

Star	Former Class	I_{CH}	$I_{CN_{4215}}$	I_{C_2}	V_r
HD 5223	R3	6	3	2	−234 km/sec
V Ari	R8	8:	2	9	183
HD 76396	R5	10	1−	3	52
HD 112869	R6p	8	5	9	128
HD 209621	R3	9	8	2	−383

ed for; and the appearance of the whole set in such stars as RY Dra, where they are deeper than the main λ 4737 band head and practically obliterate the green *CN* group, leaves the question of their identification in doubt.

Absorption marking at λ 6269.—In stars near type C4 the most conspicuous absorption feature to the red of the D-lines on our plates is a band about 25 A wide centered at λ 6269.[14] The band can be seen in the spectrum of HD 52432 in Plate XXI and is especially strong in Y CVn and RY Dra. Whether it is a molecular band or a group of closely packed atomic lines is not certain, but in any case the rapidity with which it falls off in intensity on both sides of the maximum makes it of supplementary value in classification.

Li 6708.—The resonance doublet of neutral lithium at λ 6708 was observed as a strong unresolved line in WZ Cas by McKellar.[15] Since several other late carbon stars showed no well-marked line at this position, he suggested that an abnormal abundance of lithium is present in the atmosphere of WZ Cas. From the standpoint of the present classification this conclusion does not appear quite definite, for WZ Cas is the only star classified as C9, the subdivision corresponding to the lowest temperature. Resonance lines might be expected to be stronger in this star than in any of the others observed, but it must be admitted that the absence of λ 6708 in RS Cyg, which is only slightly earlier in type, remains puzzling.

Sr II 4077.—This line is of particular interest because it shows so strong a positive absolute-magnitude effect that the ratio λ 4077/λ 4045 is used as a criterion of luminosity in normal stars. The value of the ratio appears to be at least as high in several of the carbon stars as in the two giants chosen for comparison. For all the carbon stars showing good atomic lines in this part of the spectrum (types C0–C6) the indicated absolute magnitudes are slightly brighter than those of the ordinary giants. As a group they can be assigned to luminosity class II–III, with $\bar{M}_v \approx -1$. This spectroscopic evidence is in satisfactory agreement with the values of $\bar{M}_v$, -0.50 for the R-stars and -1.84 for the N-stars, derived by R. E. Wilson[16] from proper motions and radial velocities. It may be noted also that Sanford[17] used the intensities of the interstellar *Na* lines to find $M_v = -0.6$ for HD 137613, C1, and $M_v = -2.2$ for the N star HD 189711, not yet classified here.

CONCLUSION

By the use of four criteria the spectra of the carbon stars have been arranged in a sequence in which the independent variable is essentially temperature. Such disturbing factors as the variation in band absorption resulting from changing carbon abundance limit the accuracy of classification, and there is unquestionably room for further improvement. However, the system C0 . . . . C9 should be closer to a temperature sequence than the subdivisions of the old types R and N. The greatest discrepancies between the two systems occur for stars which are marked by a general depression of the blue end of the spectrum and the appearance of bands in the green which have not yet been completely identified. These discrepancies provide further evidence of the existence of heavy molecular absorption in such stars, affecting chiefly all wave lengths shorter than λ 5000.

YERKES OBSERVATORY
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NOTE ADDED IN PROOF.—Since the preparation of this paper a note has been published by Sanford in *Pub. A.S.P.*, **53**, 255, 1941, calling attention to the unidentified band near λ 6269. He finds that it is correlated in intensity with the band head of C^{12} C^{13} at λ 6168.

[14] For the measurement of wave lengths in this part of the spectrum Dr. Struve and Dr. Swings kindly made available several spectrograms of dispersion 150 A/mm at λ 6100 taken with the Cassegrain spectrograph of the McDonald reflector.

[15] *Pub. A.S.P.*, **52**, 407, 1940; *Observatory*, **64**, 4, 1941.

[16] *Ap. J.*, **90**, 352 and 486, 1939.

[17] *Pub. A.S.P.*, **51**, 237, 1939.