# 29. COMMISSION DES SPECTRES STELLAIRES

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There has been a marked change in the past few years in the incidence of interest in stellar spectra. The great initial task of classification has attained its first objective—though the Henry Draper Extension, and other investigations are still progressing. Perhaps a million stars are still accessible to classification with existing instruments; but more and more time is being spent upon individual spectra, and upon theoretical investigations. In these fields progress has been very rapid, and only some of the more important results may be mentioned here.

Stars of almost every spectral class have been studied in detail. Among investigations of groups may be mentioned those of Beals, Miss Payne and Edlén on the Wolf-Rayet stars; of Struve on Class B; of Morgan on Class A and of Hynek on Class F (soon to be published); of Sanford on Classes R and N, and of Merrill on all classes in the infra-red. Among individual stars observed with high dispersion are $\tau$ Scorpii (Struve and Dunham), Procyon (Albrecht), and Arcturus (Hacker, unpublished). Two remarkable stars, RS Ophiuchi and $\zeta$ Aurigae, have received much attention.

These studies have greatly diminished the number of unidentified stellar lines, and led to the astrophysical identification of several additional elements. The characteristic Wolf-Rayet radiations have been almost completely identified with lines of light atoms (*C*, *N*, *O*) in high stages of ionization. The presence of absorption lines of *N* V in some stars indicates a very high temperature.

Neon (I and II) and argon (II) have been detected in stars of Class B, and phosphorus in the Sun. In all problems of identification multiplet relations and excitation potentials are fundamental. These are fortunately now available for almost all lines, and have been summarized in Miss Moore's multiplet and term lists.

The great strength of the lines of *C* I in R Coronae Borealis indicates that the long-sought analogue at higher temperatures of the N-stars has been found.

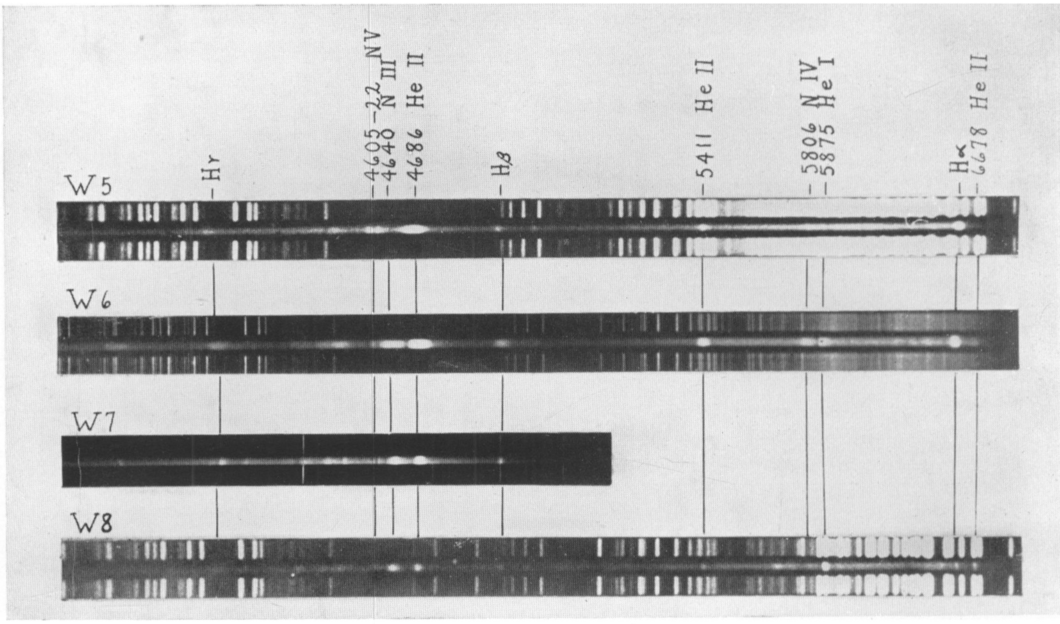
In the cooler stars, bands of *CaH* and *MgH*, with enormous strength of $\lambda$ 4227 (*Ca* I), are characteristic of dwarfs, while the puzzling "bright lines" in Classes R and N have been found to be only interspaces in the heavy *CN* bands.

The existence of an extended gaseous envelope, surrounding the giant red component of $\zeta$ Aurigae, is proved by absorption of enhanced metallic lines from the light of the small white companion, just before and after the eclipse. Two new white dwarfs have been discovered by Kuiper.

While some outstanding questions are thus settled, new ones have been raised. The division of the Wolf-Rayet stars into two sequences, one characterized by bright lines of carbon and oxygen, the other by nitrogen, is the strangest of these. The new hazy interstellar lines discovered by Merrill are also perplexing. Whether the appearance of the characteristic lines of the solar corona in RS Ophiuchi will aid in determining their origin remains to be seen.

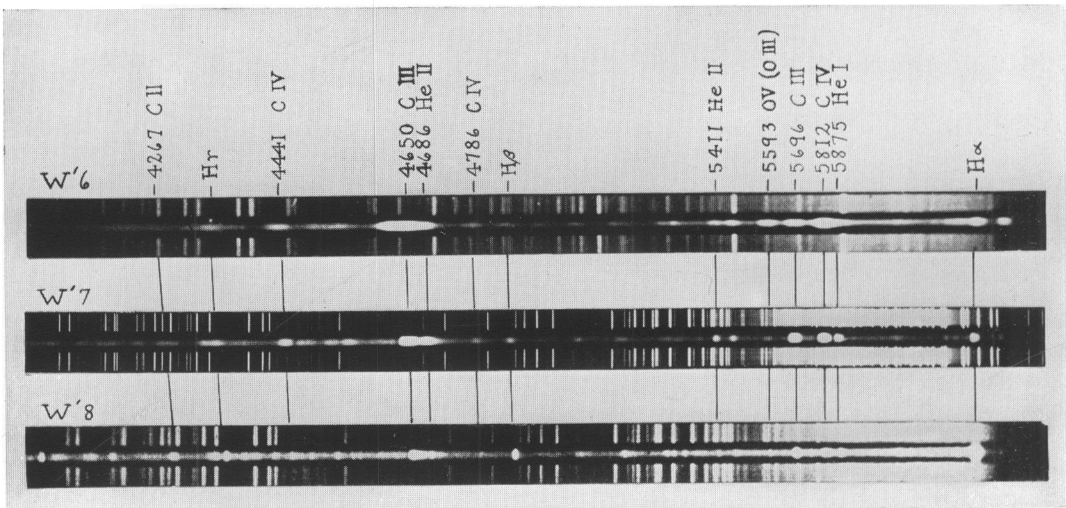
Much work has been done upon the intensities and contours of lines by Pannekoek, Struve, and many others. Struve's important discovery that the intensity-gradient for lines of the same multiplet differs widely in different stars was made by in-

WOLF-RAYET STARS, NITROGEN SEQUENCE




W5, H.D. 187282; W6, H.D. 192163; W7, H.D. 151932; W8, H.D. 177230

WOLF-RAYET STARS, CARBON SEQUENCE




W'6, H.D. 16523; W'7, H.D. 192103; W'8, H.D. 184738

(C. S. Beals, Dominion Astrophysical Observatory, Victoria)

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spection, but has been confirmed by measurement. A device for shortening the laborious reduction of microphotometer tracings has been described by Dunham.

Detailed study of contours is necessary for investigations of stellar rotation, or for those of the Stark effect, and is also required for the difficult study of emission lines.

Progress in theoretical investigation has been equally rapid. Studies by Swings, Cambresier and Rosenfeld, Russell, and Unsöld have shown that the elementary theory founded by Milne has proved adequate to give a satisfactory general account of the changes in intensity and the maxima of the prominent lines and bands in all classes from O to N, and of the effects of absolute magnitude (surface gravity) including that on the *CN* bands. The first approximation to a theoretical interpretation of the spectral sequence is thus completed. The most outstanding discrepancy—the great strength of enhanced lines in red super-giants—may be solved observationally by the case of $\zeta$ Aurigae.

A good start on the second approximation has been made by such work as that of Minnaert and Slob on the combined influence of Doppler effect and resonance broadening on faint lines, and of Struve and Elvey on the additional effect of possible turbulence in the atmosphere. Rotation has been discussed by several investigators, especially by Carroll, who has devised an elegant method for separating it from other causes of widening.

The interpretation of emission lines is more difficult. It is generally believed that these originate, in many if not in most cases, in an extensive envelope surrounding the star, that they are more closely allied to nebular than to ordinary stellar spectra, and that the energy supplying the visible emission comes from absorption of far ultra-violet radiation from a central nucleus.

Struve accounts for the double emission lines in Be stars by a rotating envelope, and Beals for the lines in the P Cygni type and the wide Wolf-Rayet bands by one consisting of atoms expelled in all directions from the central star. The division of the latter stars into two parallel sequences remains a mystery. A very complete confirmation of the fluorescence theory of the luminosity of the nebulae is found in Bowen's explanation of the appearance of a few "permitted" lines of *O* III and *N* III as a result of a very close chance coincidence of lines of different elements, permitting one to absorb radiation emitted by the other.

It is highly gratifying to find that, despite this rapid advance in many directions, the system of spectral classification already adopted by international agreement remains satisfactory. Few, if any, suggestions for change have been made for the more abundant classes. Struve has advocated some new criteria for the classification of B-stars, and Miss Davis has recently proposed a subdivision of the small and previously undifferentiated Class S.

A new scheme of classification, based on established physical theories, and expressing its results by significant numerical parameters, rather than by empirical letters, may be devised at some future time; but the very rapidity of present progress shows that this time has not yet arrived.

One practical point, however, may now be considered. At least two parameters are required for the complete description of the contour of a stellar absorption line (e.g., the half-width and depth). Unfortunately the highest available resolving power is not adequate to give true contours of the fainter lines, even for the Sun. For most purposes we have to be content with a single parameter, so chosen as to be as little influenced as possible by instrumental limitations. By informal common consent, the amount of energy which the line cuts out of the spectrum has been adopted, and defined in terms of the widths of a perfectly black sharp-edged line which would cut out the same total energy. How may this equivalent width best be defined? It is usually given in Angstrom units (or in milli-Angstroms) but it may also be expressed in frequency units, or as a fraction of the wave-length.

The first notation, $d\lambda$, best describes the appearance of the spectrum; the second, $10^8 d\lambda/\lambda^2$, would give the effective "fuzziness" of the energy levels (provided that several serious causes of complication did not exist); while the third (say $10^6 d\lambda/\lambda$) is the quantity which is theoretically related to the number of atoms active in the production of a line, when its width is due to resonance.

A uniform notation (and a name for the adopted unit, if a new one) is desirable. This matter might well be considered at a joint session of this Commission with Commissions 12 (Solar Spectroscopy) and 36 (Spectral Photometry).

The classification of Wolf-Rayet spectra, upon which a sub-committee is engaged, has been delayed by the lamented death by accident of Mr Waterfield, in consequence of which certain spectra of southern stars, required for completion of this work, were not obtained in time. The sub-committee would therefore report progress and request that it be continued.

## Report of Sub-Committee on Criteria for Classification of Stellar Spectra

This Committee has been chiefly concerned in an attempt to collect and bring together for purposes of comparison and practical use the principal criteria used at different observatories for the classification of stellar spectra. It has not included in its field the classification of Wolf-Rayet and related spectra which are being considered by an independent sub-committee.

The Henry Draper System of classification as developed at the Harvard College Observatory is almost universally used by observatories throughout the world. It is sufficiently elastic to admit of wide extension, and such changes as have been made in it have been almost wholly in the nature of additions and refinements brought about through intensive study of special types of stars. The recognition of the spectral differences between giant and dwarf stars and of the peculiarities of the spectra of very luminous stars, the distinction between stars of early type with sharp and diffuse lines, an effect probably due mainly to rotation, and important discoveries and identifications of lines in the spectra of both early- and late-type stars are some of the most valuable of these additions to the Draper System.

The accompanying summary of the more important criteria used at five observatories is based upon spectra taken with objective prisms, or with slit-spectrographs of very moderate dispersion. Investigations of bright stars with very high dispersion or with the use of fine-grained plates of high contrast would doubtless enable an observer to formulate many new and valuable criteria; but for general use upon stars of average brightness it seems preferable to limit the list to those conspicuous criteria which can be observed in essentially all cases.

At the Harvard and Stockholm Observatories the material used consists of objective prism spectra; at the Mount Wilson, Victoria and Yerkes Observatories, of slit spectrograms. Spectra of stars of standard type are used extensively for classification purposes, especially at Victoria and Mount Wilson. At Harvard the classification is based mainly upon the strongest lines, while at Stockholm certain very rapid drops in the energy curve are also used in the case of spectra of very low dispersion. At Mount Wilson, Victoria and the Yerkes Observatory the sharp or diffuse characteristics of lines are noted in types B and A and indicated by the letters *s* and *n*. In addition the designation introduced at Harvard of "c-stars" for the group of highly luminous stars with sharp lines is retained at Mount Wilson.

In the following list some of the primary criteria are italicized.*

*Type B*

B0 Harvard: He *II present but faint; O* II 4649 strong; *Si* IV at maximum; *H* lines 0·3 as strong as in α Canis Majoris.
Mount Wilson: He *II faint;* O *II* 4649 *strong; Si* III lines visible; *He* I lines moderate; *H* lines and *Mg* II 4481 weaker than in later types.
Victoria: He *II faint;* O *II at maximum;* Si *IV conspicuous.*
*Mg* II 4481 = 0·1 *He* I 4471.
Yerkes: He *I* 4471*;* Mg *II* 4481*; O* II lines; *Si* III 4552.

B1 Harvard: He *II not seen;* He *I more prominent than* O *II and* Si *IV.*
Mount Wilson: He *II very faint;* O *II and* Si *IV decreasing;* He *I increasing.*
Victoria: He *II absent;* N *II at maximum;* O *II and* Si *IV decreasing; Si* III increasing; *Mg* II 4481 = 0·15 *He* I 4471.
Yerkes: criteria as above (that is, the same lines are used).

B3 Harvard: He *I at maximum; H* lines 0·5 as strong as in α Canis Majoris; *O* II and *Si* IV not seen; *Ca* II K weak.
Mount Wilson: *Ratio of* He *I* 4471 *to* Mg *II* 4481*;* He *I at maximum.*
Victoria: He *I and* C *II at maximum;* Mg *II* 4481 = 0·3 He *I* 4471*;*
*Mg* II 4481 = 0·1 *Hγ*; *C* II 4267 = 1·3 *Mg* II 4481; *C* II 4267 = 0·4 *He* I 4471.
Yerkes: criteria as above; B-stars may be separated into two absolute magnitude classes by certain spectral criteria.

B5 Harvard: Si *II* 4128 *and* 4131 *stronger than* He *I* 4121*;*
*Mg* II 4481 = 0·7 *He* I 4471.
Mount Wilson: *Ratio of* He *I* 4471 *to* Mg *II* 4481*; Si* II 4128 and 4131 strong.
Victoria: Si *III absent;* Si *II increasing;* Mg *II* 4481 = 0·5 He *I* 4471*;*
*C* II 4267 = *Mg* II 4481; *C* II 4267 = 0·5 *He* I 4471.
Yerkes: criteria as above.

B8 Harvard: Mg *II* 4481 = He *I* 4471*; Ca* II [K] less than *He* I 4026.
Mount Wilson: Mg *II* 4481 = He *I* 4471.
Victoria: Mg *II* 4481 = He *I* 4471*; C* I 4267 = 0·1 *Mg* II 4481;
*C* I 4267 = 0·1 *He* I 4471.
Yerkes: criteria as above.

B9 Harvard: Mg *II* 4481 *stronger than* He *I* 4471*; He* I 4026 easily seen; metallic lines appear.
Mount Wilson: He *I* 4026 *and* 4471 *faint.*
Victoria: Mg *II* 4481 = 1·6 He *I* 4471*;* Mg *II* 4481 = 0·3 Hγ.

*Type A*

A0 Harvard: H *lines at maximum; Ca* II [K] = 0·1 *Hδ*; *Mg* II 4481 strong; metallic lines inconspicuous except with high dispersion.
Stockholm: increasing intensity of *Ca* II [K].
Mount Wilson: *metallic lines;* H *lines at maximum; Mg* II 4481; *Ca* II [K]; ratio of *Ca* I 4227 to *Hγ*.

* Note that in italicized passages symbols for elements, conventionally in italics, are printed in ordinary type.



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Victoria: Ca *II* [*K*] = 0·1 Hδ.
Yerkes: Ca *II* [*K*]; Fe *II* 4233; *Fe* I 4045; *Si* II 4131; *Sr* II 4215; *Mg* II 4481; *Ti* II 4501; *Fe* II 4508; *Cr* II 4558.

A2 Harvard: Ca *II* [*K*] = 0·4 Hδ; *Ca* I 4227 = *Fe* II 4233; metallic lines well marked.
Stockholm: criteria as above.
Mount Wilson: criteria as above.
Victoria: Ca *II* [*K*] = 0·4 Hδ; Ca *II* [*K*] = 0·4 (Ca *II* [*H*] + Hε).
Yerkes: criteria as above.

A5 Harvard: Ca *II* [*K*] = 0·9 (Ca *II* [*H*] + Hε); *Ca* II [K] stronger than *H*δ; metallic lines stronger.
Stockholm: criteria as above.
Mount Wilson: criteria as above.
Victoria: Ca *II* [*K*] = 1·2 Hδ; Ca *II* [*K*] = 0·9 (Ca *II* [*H*] + Hε); metallic lines used as secondary criteria.
Yerkes: criteria as above.

## *Type F*

F0 Harvard: H *lines* 0·5 *as strong as in α Canis Majoris;*
*Ca* II [K] = (*Ca* II [H] + *H*ε); *Ca* II [K] = 3·0 *H*δ.
Stockholm: Hydrogen; ratio of G band to *H*γ increasing.
Mount Wilson: *metallic lines;* Hydrogen; G band; ratio of 4227 to *H*γ.
Victoria: Ca *II* [*K*] = 3·0 Hδ; Ca *II* [*K*] = (Ca *II* [*H*] + Hε).
Yerkes: Fe *I* 4045; Ti *II* 4501; *Ca* II [K]; *Sr* II 4215; *H*β; *CH*; *Ca* I 4227.

F5 Harvard: H *lines twice as strong as in the Sun; Fe* I 4325 = 0·1 *H*γ; G band; *Ca* I 4227 = 0·5 *H*γ.
Stockholm: ratio of G band to *H*γ increasing.
Mount Wilson: criteria as above.
Victoria: Ca *I* 4227 = 0·5 Hγ; Fe *I* 4326 = 0·2 Hγ.
Yerkes: criteria as above.

F8 Mount Wilson: Ca *I* 4227 = Hγ.

## *Type G*

G0 Harvard: *H*γ = 1·5 *Fe* I 4325; *Sr* II 4077 = *H*δ = *Ca* I 4227; *Ca* II [H] and [K] very strong; G band well defined; comparison with solar spectrum.
Stockholm: ratio of G band to *H*γ increasing; increasing intensity drop in G band, first seen clearly in G0; *CN* bands (especially at 4216) used to separate giants and dwarfs.
Mount Wilson: Ca *I* 4227; G band; hydrogen lines; *Cr* I 4254, 4274; *H*γ = *Fe* I 4325 at G2.
Victoria: comparisons made with standard sequences.

G5 Harvard: Hγ *less than* Fe *I* 4325.
Stockholm: criteria as above; a sudden drop of intensity at the G band is used in this type.
Mount Wilson: *ratios of* Cr *I* 4254 *and* 4274 *to* Fe *I* 4250 *and* 4271; ratio of *H*γ to *Fe* I 4325.
Victoria: comparison with standard sequences.



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## *Type K*

Ko Harvard: $H\gamma = 0{\cdot}5$ *Fe* I 4325; *Ca* I 4227 three times as strong as in Go; *Ca* II [H] and [K] at maximum; *Ca* I 4227 = 2·0 *Fe* II 4172; *Ca* I 4227 = 3·0 *Fe* I 4383; G band stronger than *Ca* I 4227.

Stockholm: *Ca* I 4227 increasing; *Fe* I 4383; *Fe* I 4405; G band; intensity drop at G band and at $\lambda$ 4080 increases.

Mount Wilson: Ca *I 4227;* Cr *I* 4254, 4274*;* hydrogen lines.

Victoria: comparison with standard sequences.

K5 Harvard: *Ca* II [H] and [K] and *Ca* I 4227 most conspicuous; G band not continuous; *Fe* I 4383 and 4405 prominent.

Stockholm: criteria as above.

Mount Wilson: criteria as above.

Victoria: comparison with standard sequences.

## *Type M*

Harvard: *Bands of* TiO *increase throughout types Ma, Mb, Mc; Ca* I 4227 increases in width; fainter lines disappear in Mc; spectrum faint in violet.

Stockholm: *Bands of* TiO increasing.

Mount Wilson: *Bands of* TiO *increasing; Ca* I 4227 increasing in width.

Victoria: *Bands of* TiO *increasing.*

## *Dwarf K5, K6, M*

Harvard: Notes in Draper Catalogue refer to strength of *Ca* I 4227 and 4455.

Stockholm: *Ca* I 4227 increases in width and becomes more asymmetrical.

Mount Wilson: Width and intensity of *Ca* I 4227; *Ca* I 4435, 4454 and *Ti* I 4535; sub-class K6 used for dwarfs but not giants.

## *Super-giant F, G, K, M*

Harvard: Notes in Draper Catalogue refer to sharp lines and c stars.

Mount Wilson: *Hydrogen and enhanced lines abnormally strong.*

It is the opinion of this Committee that the criteria of classification should so far as possible be given in the form of line or band ratios and that several ratios should be given for each main spectral type. These ratios should extend over the length of the spectrum so that it will always be possible, no matter what the performance of the instrument in different regions of the spectrum, to find one or more line ratios in the region under investigation. Ratios in which the intensities of the lines compared are nearly equal are of especial value and should give the most accurate results.

The ratios of line intensity should be estimates of total absorption, such, for example, as can be made with a low power eyepiece on a spectrum of any dispersion, and should be as nearly as possible independent of the effects of blending, no matter how small the dispersion.

In the case of the simplified system of classification used at Stockholm the attempt is made to standardize the criteria by quantitative measurements on microphotometer tracings.

W. S. Adams, *Chairman*
Annie J. Cannon
Bertil Lindblad
H. H. Plaskett
Otto Struve

Henry Norris Russell,
*President of the Commission*

# (APPENDIX TO REPORT OF COMMISSION 29)

## Report of Sub-Committee on the Classification of Wolf-Rayet Stars

### Introductory: Tentative Definition

The Wolf-Rayet stars constitute an exceedingly interesting class of emission line objects, the first three examples of which (H.D. 191765, H.D. 192103 and H.D. 192641) were discovered by Wolf and Rayet* at the Paris Observatory in 1867. The spectrum of a typical Wolf-Rayet star, as exemplified by the three objects mentioned above, consists of a continuous spectrum on which are superposed numerous strong emission bands due to atoms of high ionization potential, the most important in the ordinary region being identified with the atoms *He* I, *He* II, *C* II, *C* III, *C* IV, *N* III, *N* IV and *N* V. The relationships existing between different members of the class are rather complicated, and it is impossible to give a completely unambiguous definition of a Wolf-Rayet star apart from a detailed description of the spectrum. Perhaps the best that can be done in a short space is to say that a Wolf-Rayet star is one that finds a logical place in one or the other of two clearly developed sequences of stars, of which H.D. 191765 and H.D. 192103 are typical examples.

### The Two Parallel Sequences

Since it has recently been demonstrated that the Wolf-Rayet stars may be divided into two parallel sequences of approximately the same general level of ionization,† a discussion of classification will probably be more intelligible if the two sequences are first separately described. For the sake of brevity the two sequences will be designated as the carbon sequence and the nitrogen sequence, respectively. The general characteristics of the two sequences may briefly be described as follows.

*The Carbon Sequence.* In addition to *He* I and *He* II which are common to the spectra of both sequences, the carbon sequence has, as the most important constituents of its spectrum, bands due to *C* II and *C* III, *C* IV, *O* II, *O* III, *O* IV, *O* V and *O* VI. Silicon is also present in various stages of ionization as are also *Ca* II, *Mg* II and, probably, *S* II, but they occupy a relatively unimportant position as compared with oxygen and carbon. The wave-lengths of principal bands representing the successive spectra of oxygen and carbon are as follows: *C* II, 4267; *C* III, 3609, 4187, 4325, 4650 and 5696; *C* IV, 4441, 4658 (blended with 4650) 4786 and 5812; *O* II 4154, 4317, 4349, 4366, 4414 and 4417; *O* III 3714, 3760, 3961; *O* IV 3385, 3405, 3412, 3562, 3725, 3736; *O* V 5470, 5592; *O* VI 3815, 3835.

In the ordinary photographic region the most striking feature of spectra of the carbon sequence is the appearance of very strong bands due to *C* III at 4650 and *He* II at 4686. In the visible regions strong bands due to *C* III at 5696 and to *C* IV at 5812,‡ accompanied by weaker ones at 5411, 5470, 5593 and 5875, are characteristic features of the spectrum. There appears to be a definite and clearly marked relation between band width and spectral type in stars of the sequence. The band widths vary from approximately 80 A in stars of earliest type to some 10 A or less for those of lowest excitation. There is no clear indication of nitrogen in any of the stars of the carbon sequence.

*The Nitrogen Sequence.* Apart from bands due to *He* I and *He* II which are common to both sequences, the important feature of the nitrogen sequence is the

* *C.R.* **65**, 292, 1867. † *Zs. f. Ap.* **7**, 1, 1933; *Pub. D.A.O.* **6**, 130, 1932.

‡ Blended band.

presence of bands due to *N* III, *N* IV and *N* V. The wave-lengths of the most important nitrogen bands are as follows: *N* III 4099,* 4340; *N* IV 3483, 4057, 4939, 5806; *N* V 4605, 4622, 4945.

In the ordinary region the most conspicuous feature of the spectra of members of this sequence is the appearance of 4686 of *He* II in company with various bands due to nitrogen. Members of the Pickering series are present but are of less intensity than 4686. In the lowest excitation stars the *N* III band at 4640 is conspicuous and is of intensity comparable to 4686. Passing along the sequence to earlier types 4640 grows weaker and is replaced by a broad composite band stretching from approximately 4600 to 4660. It is probable that *N* III (4640) and *N* V (4605–22) contribute to the intensity of this band but they are not clearly distinguishable as separate wave-lengths. In the earliest types of all the broad band disappears and its place is taken by two conspicuous narrow bands due to *N* V at 4605, 4622. These bands are usually accompanied by a weaker band at 4945 due to the same atom.

In the visible region bands at 5411 due to *He* II, at 5875 due to *He* I and a band at 5806 due to *N* IV are the important features. The bands 5411 *He* II and 5875 *He* I are unblended and so form convenient criteria of excitation.

## Nomenclature

In the first Draper Catalogue† the single Wolf-Rayet star included was designated as class O, and it was at that time apparently the only star so designated. Later, in the H.D. Catalogue, the letter O was used for both emission and absorption stars of early type. Since the publication of the H.D. Catalogue a new decimal system has been adopted in which the symbol O is more or less pre-empted for the designation of absorption line stars of the earliest spectral type now generally referred to as class O.‡

While the Wolf-Rayet stars and the absorption O stars are probably of much the same general level of ionization, there are important differences between them which are not obviously related to the bright or dark line character of their spectra. Accordingly, in connection with other proposals for a scheme of classification for these objects, it has seemed desirable to put forward a new symbol to designate the Wolf-Rayet class. The letter W immediately suggests itself and, since its adoption would not interfere with any previously established usage, the committee definitely recommend it as an appropriate designation for stars of this class.

The existence of parallel sequences introduces obvious complications in nomenclature, and the following suggestions have been advanced to distinguish the two sequences. (1) The use of separate letters for the two sequences, such as U and V. (2) The use of additional letters in brackets for the carbon and nitrogen sequence, i.e. W (*C*), W (*N*). (3) The use of a plain letter (W) for one sequence and a primed letter (W′) for the other.

The third suggestion appears to have most to recommend from the point of view of clearness, convenience and economy of space and it has accordingly been used in the preliminary draft, the plain letter (W) indicating stars in the nitrogen sequence and the primed letter (W′) being used for the carbon sequence stars.

*Grouping of Stars in Subdivisions: the Nitrogen Sequence.* For the purpose of subdividing the nitrogen sequence there are available the following criteria of excitation:

(1) *N* III/*He* II ratio: available over lower range of sequence; bands employed 4640 *N* III and 4686 *He* II.

* Blended with *H*δ. † *H.A.* **27**. ‡ *Pub. D.A.O.* **1**, 363, 1922.

(2) Presence of broad band between 4600 and 4660. This must be regarded as a subsidiary criterion of excitation because the band is not certainly identified. It is clear and unambiguous, however, and enables many Wolf-Rayet stars to be classified at a glance. Useful in one subdivision only.

(3) *N* V/*He* II ratio: bands employed 4605–22 of *N* V and 4686 of *He* II. Useful in one subdivision only. Upper part of sequence.

(4) *He* I/*He* II ratio: available throughout the sequence; bands employed 5875 *He* I and 5411 *He* II.

The spectra of the nitrogen sequence have been grouped into four subdivisions which, in accordance with the discussion on nomenclature, have been designated as W5, W6, W7 and W8. The numbering has been so chosen as to allow a place for new discoveries at either end of the sequence. The values given for intensity ratios are subject to a degree of latitude depending upon the amount of variation, from class to class. A list of the subdivisions with excitation criteria and typical stars follows.

Class W5: Ratios 4605–22/4686 = 0·2, 5875/5411 = 0·1, 4645 present. Typical stars H.D. 187282 and H.D. 211564.

Class W6: Ratio 5875/5411 = 0·5, band 4600–4660 present and strong, 4938 present. Typical stars H.D. 191765 and H.D. 192163.

Class W7: Ratios 4640/4686 = 0·5, 5875/5411 = 1·5.* Typical stars H.D. 151932 and H.D. 92740.

Class W8: Ratios 4640/4686 = 1·5, 5875/5411 = 5·0. Typical stars H.D. 177230 and H.D. 96548.

*Grouping of Stars in Subdivisions: the Carbon Sequence.* For the purpose of subdividing the carbon sequence there are available the following criteria of excitation.

(1) *C* II/*C* IV ratio: available only over the lower range of sequence; bands employed 4267 *C* II and 4786 *C* IV.

(2) *C* III/*C* IV ratio: available throughout the sequence; bands employed 5696 *C* III and 5812 *C* IV.

(3) *C* III/*O* V ratio: useful only in the upper range of the sequence; bands employed 5696 *C* III and 5592 *O* V.

(4) *C* III/*He* II ratio: available in the lower range of the sequence; bands employed 4650 *C* III and 4686 *He* II.

(5) *He* I/*He* II ratio: available in the lower range of the sequence; bands employed 5875 *He* I and 5411 *He* II.

(6) Band width. The correlation between band width and spectral type in the carbon sequence has already been mentioned. This correlation is so clearly marked and consistent that estimates of band width form a useful subsidiary criterion of excitation. This is especially true of the earlier types where some of the bands ordinarily resolved are blended to form a single band.

The spectra of the carbon sequence have been grouped into three subdivisions which, in accordance with the discussion on nomenclature, have been designated respectively as W′6, W′7, W′8. The numbering has been chosen so as to allow a certain latitude for new discoveries at either end of the sequence. The values given for intensity ratios must be regarded as approximate means for the class, and subject to a degree of latitude which depends on the value of the ratio in the preceding and following groups. The band widths given are approximate. The edge

* Interpolated. W7 not observed in visible region.

of the band is taken as the point where its intensity drops to 0·1 of its central value.

The newly suggested groups with intensity ratios or other excitation criteria and standard stars representing each class are as follows.

Class W′6:

Ratios 5696/5812 = 0·3, 5696/5592 = 1·2, 4267/4786 = 0·0, 4650 and 4686 not resolved, 5812 and 5875 not resolved. Band width approximately 70 A. Typical stars H.D. 16523 and H.D. 165763.

Class W′7:

Ratios 5696/5812 = 0·7, 5696/5592 = 8·0, 5875/5411 = 1·5, 4650/4686 = 4·0, 4267/4786 = 1·0, 4650 and 4686 just resolved. Band width approximately 35 A. Typical stars H.D. 192103 and H.D. 119078.

Class W′8:

Ratios 5696/5812 = 3·0, 5875/5411 = 6·0, 4650/4686 = 9·0, 4267/4786 = 2·0. Band width approximately 10 A. Typical stars H.D. 184738 and H.D. 164270.

C. S. Beals, *Chairman*
H. H. Plaskett

I am in full agreement with the descriptive part of the report, noting that certain types of "Nitrogen stars" are not specifically described, as spectra of the specimens in the southern hemisphere were not available.

I feel, however, that as the Sub-Committee was appointed to consider the possibility of classifying the Wolf-Rayet stars, rather than to devise a classification, I am at liberty to state that in my opinion the adoption of a classification is not at present to be desired. I will state my reasons briefly.

(*a*) The Wolf-Rayet "spectrum" is not, stricly speaking, a spectrum, but is a series of superimposed spectra, differing in excitation over a considerable range. It may be compared to the integrated spectrum of a planetary nebula, to which it appears to be closely related, the differences probably arising chiefly from differences of density.

(*b*) The Wolf-Rayet objects (for the word "star" may in this case be misleading) are so rare, and differ so much among themselves, that a classification, if adopted, would have but few applications.

I realise that these objections to the adoption of a classification are fundamental, and are not based on the argument that the spectra are as yet insufficiently known. Our knowledge of these spectra is very complete, when compared with our knowledge of many other spectral classes. It is possible that when our knowledge of nebular spectra has progressed equally far, the close relationship of the two types of object will appear so clearly that some system of physical parameters will be found that can adequately describe both. Such a system must inevitably be more complex than the formation of one, or two parallel, series.

If it is assumed that linear classification of the Wolf-Rayet stars is desirable, the system proposed by the Sub-Committee's draft report would seem to be the best that can be devised.

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