CLASSIFICATION OF THE B-TYPE STARS*

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ABSTRACT

The Draper system of classification is reviewed. Classification methods based on line intensities and on line ratios are distinguished, and objections to the former are raised. The principles to be observed and the procedure to be followed in using line ratios based on measured intensities are discussed. Seven ratios, most of which involve numerous lines of several elements, are set up, which apparently give a good index of average characteristics. Usually three ratios are applicable in any one case and their accordance is good. The stars observed having been reclassified, intensity-type and intensity-luminosity variations are examined for each atom. The very smooth progression of type of maximum with ionization potential substantiates the ionization-temperature basis of the classification.

For stars belonging to the main sequence, hydrogen shows a steady, fivefold increase in total absorption in passing from the earliest types to class A. Very luminous stars retain roughly the same low hydrogen intensity in all subtypes, and in class O the two groups are indistinguishable. The real central intensities in sharp-line stars decrease regularly from 60 per cent at O8 to 20 per cent at A0.

An absolute-magnitude effect similar to that for hydrogen is found for all helium lines. This observation, together with the intensity variations with serial number in the two diffuse series, supports the view that the lines are subject to Stark effect. A twofold increase occurs between O8 and B1 in the singlet-triplet ratio for the diffuse series, but no luminosity effect on this ratio is detected. The evidence is not against a similar fading-out of the sharp singlets with respect to the sharp triplets as the temperature increases.

Ten diagrams are given connecting type and intensity for metallic atoms. N^+, Si^+, Mg^+ show a very pronounced luminosity effect, the lines being stronger in the brighter stars. C^+ alone shows no such influence. For N^+ and O^+ the gradient effect is examined by grouping stars and treating the line intensities statistically. There is a progressive increase in gradient with luminosity. No appreciable difference is found between stars with sharp and nebulous lines, nor between types earlier and later than the maximum for O^+.

A statistical discussion of the proper motions and radial velocities of 56 stars with measured interstellar K lines establishes the linear relation:

K = K-line intensity = 0.37 equivalent angstroms per kiloparsec. Thus the expression

$$M = m - 12.2 - 5 \log K$$

may be used to compute absolute magnitudes.

The material (78 stars) is next divided into six type- and luminosity-groups solely from spectral criteria (neglecting K-line intensity). Mean absolute magnitudes derived for these groups from parallactic motions and the galactic rotational term and also from K-line intensities justify the spectroscopic division into the luminosity groups. To the brightest groups is assigned uniformly an absolute magnitude of -5.5, and a difference of 3 mag. is established between these groups and the low-luminosity group in early subtypes, and of more than 4 mag. for this group at B5.

Table VIII gives collected results for each star, including absolute magnitudes from both spectrometric grouping and K intensity. Comparison of these assigned magnitudes with those obtained from published spectroscopic parallaxes shows a serious systematic divergence, the range in our values being 2 mag. greater.

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Some peculiar spectra are commented on. Three Bne stars are found to have abnormally low total line intensity for their type. Of especial interest is the nucleus of the giant planetary NGC 1514, which has hydrogen lines as strong as those in a B8 dwarf, while both He^+ and Mg^+ are prominent.

Suggestions are made for the extension of the classification system adopted here to visual work on unstandardized spectra.

This paper attempts to find spectroscopic criteria of temperature and surface gravity. The spectral classification discussed is based on the observational material of the preceding paper, *Mount Wilson Contribution* No. 540.[1] When the behavior of the lines of the different atoms with respect to the revised type is examined, clear indications of absolute-magnitude effects are revealed which enable stars to be classed as "giants," "intermediates," or "dwarfs." In section III we attempt to establish these divisions on the basis of non-spectroscopic criteria, and to derive individual absolute magnitudes.

I. THE ASSIGNMENT OF SPECTRAL TYPE

The problem of the classification of the B-type stars has been discussed recently by numerous writers.[2] It is felt generally that there are unsatisfactory features in the present methods. The Henry Draper system,[3] which still forms the basis for almost all other classifications, is essentially one in which the absolute intensities of the absorption lines of an element, *and also* their intensities relative to those of other elements, are arranged in a continuous sequence.[4] The practical application of this system to the early-type stars is much as follows: Certain bright stars first photographed on large dispersion objective-prism plates have been defined as standards of Harvard subtype. Observers using slit spectrographs of moderate dispersion classify with reference to these standard stars largely by intensity ratios ("revised" types), whereas the great majority of faint stars have been classified in the *Henry Draper Catalogue* from objective-prism plates of such small dispersion that only the hydrogen and

[1] *Ap. J.*, **83**, 279, 1936.

[2] See R. H. Curtiss, *Handbuch d. Astrophys.*, **5**, Part I, 1, 1932; also, Edwards, *M.N.*, **87**, 364, 1927; Payne, Anger, Maulbetsch, and Wheelwright, *Harvard Circ.*, No. 365, 1931; Struve, *Ap. J.*, **78**, 73, 1933; Russell, Payne-Gaposchkin, and Menzel, *ibid.*, **81**, 107, 1935.

[3] *Harvard Ann.*, **91**, 1, 1918.

[4] For instance, we find in the Draper statement: "B3: . . . . *H* lines are 0.5 as intense as in *α* Canis Majoris. . . . . B5: . . . . Line 4481 is 0.7 as intense as 4471.5."

stronger helium lines are seen, with the result that types have been judged largely from the absolute intensities of these lines.

The system, when applied to the B stars, may be criticized on two main grounds. First, as has long been recognized, the one parameter, temperature, is insufficient to account for the details of these early-type spectra; the Draper statement takes no account of the widely different characters of absorption lines, which, though they may have the same total intensity, are deep and narrow in one star and shallow and broad in another of the same subtype. And, second, it is found that the various criteria of the method are, for a number of stars, mutually inconsistent.

In order to meet the difficulty about line character, it is customary to add symbols to the type describing their appearance. It should be noted, however, that these line grades refer primarily to the cores of the lines and ignore the wings, which, especially for hydrogen and helium lines, contribute the greater part of the intensity. Thus, for γ Pegasi and 55 Cygni, which are classified as B2ss and B2s by Pearce, the ratio of total absorption to depth for the hydrogen lines is 8.3 and 2.7, respectively. γ Pegasi is physically more closely related to stars with nebulous rotationally broadened lines than to a supergiant such as 55 Cygni.

It is important to realize that line-ratio methods must be clearly separated from absolute-intensity methods. Stars in which classification ratios are identical show wide variation in the total absorption of the lines involved.

Two methods based on absolute intensities only have been suggested, largely to meet the difficulty of conflicting criteria which appear even when ratios alone are used. The first of these, favored by the Harvard workers,[5] uses the strength of the hydrogen lines. The criterion has this to recommend it, that it gives at the same time a very fair measure of luminosity, because H-line intensity bears a much closer relation to absolute magnitude than it does to Draper type. It will, however, bring stars together which are widely separated on present standards. For example, 67 Ophiuchi, Harvard B5p, will fall with normal B1 stars. Struve,[6] on the other hand, concluded that a system based on the intensity of λ 4471 He would pro-

[5] Payne, Anger, Maulbetsch, and Wheelwright, *op. cit.* [6] *Op. cit.*, p. 85.

vide for the arrangement of spectra in an unambiguous order with reference to which all peculiarities could be discussed. The present investigation shows that the helium lines also are subject to a luminosity effect; in addition, helium attains a maximum around type B3, which means that Struve's method must be restricted to the late-B types if any semblance of the present order is to be preserved. There appears to be no line suited to the definition of a type sequence without a radical upsetting of the accepted scheme.

In this connection it is worth noting that some recent work of Barbier, Chalonge, and Vassy[7] on the intensity of the continuous hydrogen absorption at the head of the Balmer series suggests that this may provide the desired type criterion. Since Stark broadening, which so greatly affects the Balmer lines, is here absent, the luminosity effects disappear. For the B stars the smooth progression of absorption at the series limit with spectral subtype is quite remarkable.[8] The list of these observers includes one object here rated as a giant, one dwarf, and seven normal stars.

The classification scheme tried for the present study is based wholly on intensity ratios. In forsaking a single criterion it is best to recognize, as Morgan[9] found in the case of type A, that the B stars are a very mixed lot, and therefore to try to devise ratios based on lines of as many elements as possible. The main desiderata are criteria which shall arrange the stars in an ionization-temperature sequence without being sensitive to luminosity or abnormalities. A system based on theoretical line ratios would be desirable, but at the moment appears impracticable. The resulting sequence naturally parallels closely the Draper system; but, since many more lines are here utilized, it should give a more precise index of average characteristics for both normal and abnormal objects.

The range of usefulness of a line for classification ratios is roughly that over which its intensity varies unidirectionally. As most of the lines here used show maxima in type B, it has been necessary to use as many as seven ratios. A smoothing of measuring errors in the case of ratios involving weak lines was effected by the following pro-

[7] *J. de Phys.*, Sér. VII, **6**, 137, 1935.

[8] Be stars and possible B-type white dwarfs will, however, need special treatment.

[9] *Pub. Yerkes Obs.*, **7**, 133, 1935.

cedure: For each atom the sum of the intensities of all observed lines in the given star was expressed in terms of its maximum in the spectral sequence. (The mean B8 intensity replaced the maximum for Mg^+, Si^+, Fe^+.) Next, these reduced intensities for the atoms whose lines increase in strength with decreasing temperature were added and divided by the similar sum for those atoms with lines of decreasing intensity. For example, in the ratio, conveniently designated by $Mg^+ \, Si^+ \, Fe^+/C^+ \, N^+ \, O^+ \, Si^{++}$, the summed intensity for atoms represented in the numerator increases eightfold from B1 to B8, while that for atoms in the denominator decreases steadily almost to zero. Actually in this case the ratio is essentially $Mg^+ \, Si^+/C^+$; the added ions merely give weight to the ends of the curve connecting ratio and type.

The complete list of ratios and their values for each subtype are given in Table I. The second line gives the ratio of the mean depth of the three ^{3}D lines of helium to the mean depth of the hydrogen lines $H\gamma$ to $H\zeta$. This ratio is more useful than that of the total absorptions because the latter ratio depends markedly on luminosity, so much so, in fact, that B7 giants fall with B3 dwarfs. Further, it is probable that the depth ratio corresponds more nearly to visual estimates, since the eye is more influenced by depth than by total absorption, much of which passes unrecognized in the wings. In the last ratio, which is really a combination of Plaskett's[10] two type-criteria for the *O* stars, the hydrogen figure is halved, to make it comparable with the mean diffuse triplet intensity for helium.

It is well known that the classes B4, B6, and B7 are not used in the *Henry Draper Catalogue*. In the Victoria classification also, the numbers of B3 and B5 stars are out of all proportion to those in adjacent subtypes, as the following figures[11] show: B0, 66; B1, 50; B2, 130; B3, 374; B4, 9; B5, 240; B6, 13. Such fluctuations are artificial and indicate merely that the criteria defining some subdivisions cover wider spectral ranges than do those defining others. The curves on

[10] *Pub. Dom. Ap. Obs.*, **1**, 325, 1922.

[11] From a count in *Pub. Dom. Ap. Obs.*, **5**, 99, 1930. Much more uniformity is, however, shown by the Mount Wilson revised types (Adams and Joy, *Mt. W. Contr.*, No. 262; *Ap. J.*, **57**, 294, 1923). Edwards' latest figures (private communication) also show a greatly improved smoothness, though the number of B3 stars remains excessive.

TABLE I

CLASSIFICATION RATIOS

Ratio	O7	O8.0	O9.0	B0.0	B1.0	B2.0	B3.0	B4.0	B5.0	B6.0	B7.0	B8.0
a) $\frac{He}{H}$†	......	......	......	......	......	......	0.27*	0.21*	0.17*	0.13*	0.09*	0.07*
b) $\frac{He}{H}$ (depths)	......	......	......	......	......	0.82	0.74	0.60	0.47	0.36	0.27	0.16*
c) $\frac{Mg^+Si^+Fe^+}{C^+N^+O^+Si^{++}}$	......	......	......	......	0.0	0.2	0.5	1.1	1.9	4.0	7.5	12.5:
d) $\frac{N^+O^+Si^{++}Si^{+++}}{Mg^+\ Si^+}$	......	......	......	17:	8.1	2.9	0.7	0.1	0.0			
e) $\frac{C^+N^+O^+}{C^{++}N^{++}Si^{+++}}$	......	0.0	0.15	0.5	1.6	∞						
f) $\frac{C^{++}Si^{+++}}{O^{++}}$	0.5	1.3	2.8	5.1	8.5							
g) $\frac{He^+}{He^{\frac{H}{2}}}$ †	0.35	0.21	0.12	0.05	0.01							

* These figures are inapplicable to c stars.

† Equivalent widths in angstroms used for these ratios.

which Table I is based have been adjusted so that in dealing with a large typical section of stars the numbers assigned to each spectral subdivision should increase smoothly with advancing type. Victoria B2 corresponds to B2.0 in the present arrangement.

The adopted measured types are listed in the seventh column of Table VIII. In general the different ratios were accordant, but no attempt to classify more closely than to half a subtype was warranted. Cases of marked discordance between ratios are noted at the end of the table.

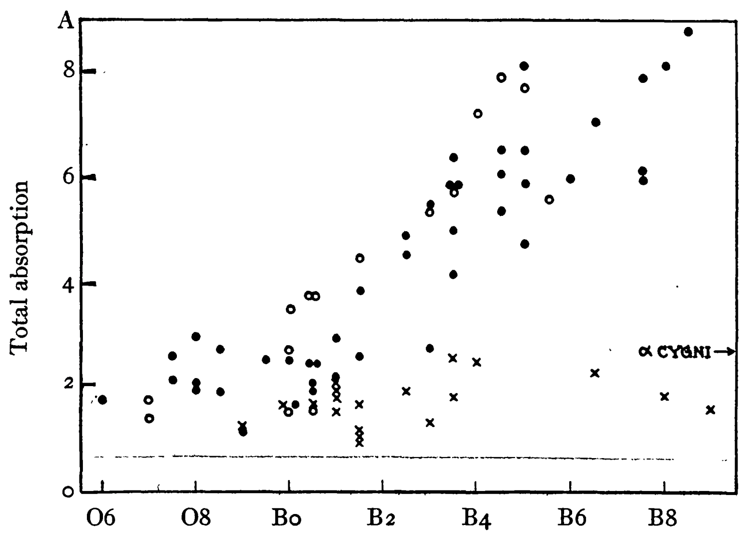

FIG. 1.—Variation of Balmer line intensity (equivalent width in angstroms) with spectral type. Crosses represent giants; dots, intermediate stars; and circles, dwarfs.

II. INTENSITY VARIATIONS WITH TYPE AND LUMINOSITY

Hydrogen.—The variation of total absorption for hydrogen is shown diagrammatically in Figure 1, where the mean intensity of the Balmer lines $H\gamma$ to $H\zeta$ for each star is plotted against the newly derived spectral class. Here, and in the following figures, the giants are indicated by crosses and the stars of abnormally low luminosity by circles, while intermediate or uncertain cases appear as dots.[12] It is of particular interest to note that for types later than Bo there is a well-marked separation of the very luminous stars from the normal B's,

[12] The assignment of stars to these luminosity groups is discussed farther on.

and that the normal stars have much stronger hydrogen lines. I can find no *measured* intensities occupying the wedge-shaped space between the two groups of B stars, though η Leonis, classed as A2 (Mount Wilson) but possessing reasonably strong helium lines, falls centrally in the gap with hydrogen intensity 473 units.

In class O the two groups merge completely; and two nuclei of planetaries, having absorption lines of hydrogen and absolute magnitudes in the neighborhood of $+1$, are not appreciably separated from typical O-type stars some hundred times more luminous.

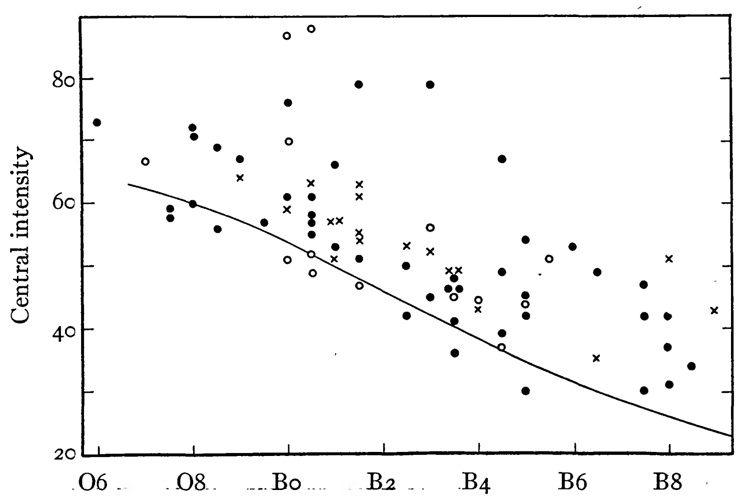

FIG. 2.—Relation between central residual intensity in the Balmer lines and spectral type. The curve represents the estimated mean relation for dwarf stars with perfectly sharp lines.

The giants of all subtypes retain roughly the same low hydrogen absorption. A curve published by Miss Payne[13] also illustrates this point.

Perhaps even more striking is the run of line depth with spectral type (Fig. 2). The high central intensity of the *H* lines in early B-type stars[14] is abundantly confirmed. With one possible exception no central intensities below 50 per cent are found for any star earlier than Bo.5. This fact is not to be explained as a filling of the line center

[13] *The Stars of High Luminosity* (1930), p. 269.

[14] C. T. Elvey, *Ap. J.*, **71**, 191, 1930; E. G. Williams, *Ann. Solar Physics Obs., Cambridge*, **2**, 25, 1932.

through rapid axial rotation, as stars with perfectly sharp lines show the same high intensity. Stars in which the "dish-shaped" appearance of the weaker lines has been ascribed by Shajn and Struve[15] and Elvey[16] to such rotation all fall well above the curve drawn to represent the probable true depth in dwarfs. The tendency for the giants to have shallower lines is real; only a fraction of the difference can be accounted for by instrumental filling of their narrower lines.

Helium.—Lines of five different *He* series are included in our measures. Of these the diffuse triplets are always the strongest, and for

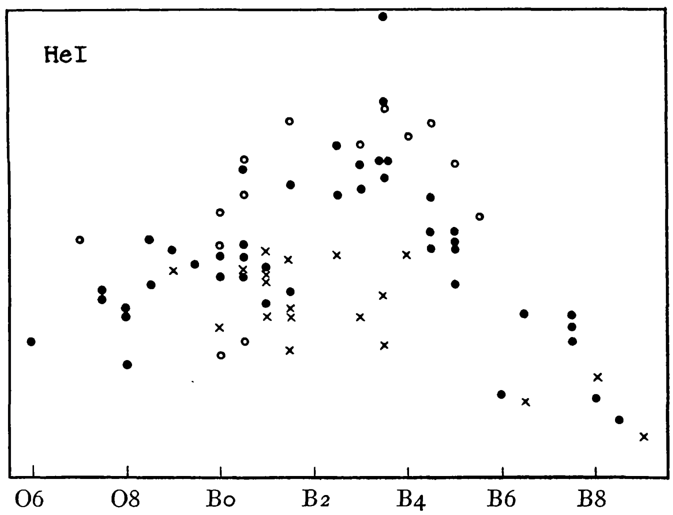

FIG. 3.—Variation with spectral type of total absorption in the diffuse triplet lines of helium. The two circles of low absorption at Bo.o and Bo.5 represent the bright-line stars X Persei and γ Cassiopeiae.

each star the mean strength of the three lines λλ 4471, 4026, 3820 has been taken as the most suitable and dependable measure of helium intensity. This mean intensity is plotted against spectral type in Figure 3. The large amount of scatter in each subclass is remarkable. Maximum and minimum values in type B3 differ by a factor of more than 3. An absolute-magnitude effect similar in sign to that found for the *H* lines extends from the earliest types (within which the helium criterion is capable of distinguishing giants from dwarfs although hydrogen intensity is not) to type B5 at least, although the

[15] *M.N.*, **89**, 222, 1929. [16] *Op. cit.*, p. 221.

effect must reverse before class A, in which the c stars alone show helium. Miss Payne[17] and Struve,[18] on the other hand, both found a positive luminosity effect for helium.[19]

For the giants the flatness of the maximum is remarkable; it extends from O9 to B4, in marked contrast to all our other curves. There is some indication that the maximum shifts from B3.0 in the case of dwarfs to B2.0 for giants. Elvey[20] put the maximum at B2.5, but Miss Payne[21] finds a shift from B1.5 for normal stars to B5 for supergiants.[22]

It is convenient to study the behavior of the individual lines in each series with respect to the diffuse triplets. To do this, the total intensities and depths of each line have been expressed in terms of the mean diffuse-triplet intensity in the same star, and are denoted by w and d. For statistical treatment the material has been divided into the four intensity-type groups of Table II. The last column of this table gives the ratio of relative area to relative depth for the 20 stars with plates of greatest weight. This ratio is a measure of the relative line width. For λ 4922, λ 4713, and perhaps for λ 4471, the figures are too high through lack of instrumental purity.

In the case of the Balmer lines we found that Stark effect seemed capable of explaining the relative line intensities. For helium also the data are on the whole favorable to the idea that Stark effect influences the intensities. In supergiants where mol-electric fields are smallest, the helium lines weaken regularly as the series number increases. The present data for lines in the photographic region (Table II) are supplemented by published results[23] for the visual region in the c stars ζ Persei and β Orionis. These show that λ 5876 (D3), the leading line of the diffuse-triplet series, is its strongest member and that in ζ Persei the first line of the diffuse singlets at λ 6678 has relative intensity as high as 140. In the early-

[17] *Op. cit.*, p. 268, Table XV, XIII.

[18] *Op. cit.*, p. 82.

[19] Later objective-prism work at Harvard showed a negative effect earlier than the helium maximum and a positive effect in later types. See n. 5.

[20] *Ap. J.*, **70**, 141, 1929. [21] *Op. cit.*, p. 280.

[22] From the ionization potential the maximum would be expected at B3.3.

[23] E. G. Williams, *M.N.*, **95**, 182, 1934.

type group with weak lines (giants) the intensity for the second singlet at λ 4922 is 107, which drops to 62 for the third at λ 4388.

But in the dwarf (high helium intensity) stars of type later than B2.0 we find maxima, pronounced at the third member in the case of

TABLE II

MEAN RELATIVE INTENSITIES FOR HELIUM LINES

(Expressed as Percentages of the Mean Intensity and Depth of the Diffuse Triplet Lines)

Lines	Types O6 to B1.5						Types B2.5 to B8						w/d*
	Intensity below Normal			Intensity above Normal			Intensity below Normal			Intensity above Normal			
	w	d	No. of Stars	w	d	No. of Stars	w	d	No. of Stars	w	d	No. of Stars	
$2^3P^o-m^3D$													
λ 4471.....	107.9	*95.2*	15	113.1	*101.7*	18	114.3	*100.6*	10	98.6	*90.8*	25	1.08
4026.....	100.3	*105.8*	15	98.2	*105.9*	18	103.6	*99.7*	10	109.0	*108.7*	26	0.97
3820.....	91.4	*97.9*	12	88.3	*91.6*	14	83.4	*95.8*	10	92.0	*101.3*	23	0.96
$2^1P^o-m^1D$													
λ 4922.....	106.3	*67.2*	15	67.9	*44.4*	18	94	*65*	9	71.6	*56.4*	24	1.46
4388.....	64.4	*72.9*	14	51.8	*62.0*	17	76	*68*	9	63.8	*68.7*	25	0.93
4144.....	46.1	*62.0*	15	40.9	*51.4*	17	70	*64*	9	58.8	*65.1*	24	0.82
4009.....	40.8	*47.3*	14	30.1	*40.0*	18	42	*53*	9	48.0	*53.8*	25	0.83
3927.....	36.4	*36.8*	14	26.8	*27.6*	18	45	*48*	9	37.5	*34.5*	24	1.00
3872.....	25.9	*28.8*	12	10.8:	*13.3*	16	30	*32*	9	23.5	*23.7*	21	0.73
$2^3P^o-m^3S$													
λ 4713.....	34.1	*36.7*	15	31.8	*35.9*	18	47	*38*	6	27.8	*33.0*	20	0.92
4121.....	44.4	*53.3*	15	33.4	*44.2*	18	37	*45*	7	27.4	*43.2*	24	0.77
3867.....	18.7	*33.3*	13	15.7	*26.9*	15	23	*39*	7	17.1	*34.4*	19	0.43
$2^1S-m^1P^o$													
λ 3965.....	29.0	*51.2*	13	18.4	*41.5*	16	39	59	7	14.4	*48.6*	9	0.46
$2^1P^o-m^1S$													
λ 4438.....	17.0	.....	8	6.2	.....	5	14	.....	4	14.4	.....	11	0.73
4169.....	8.3	.....	8	5.4	.....	5	9	.....	4	6.3	.....	11	0.38

* Twenty stars of weight 3.

the triplets, and suggested for the second line at λ 4922 in the singlets.[24] The decrease of both intensity and depth from λ 4922 to the

[24] This initial increase and final decrease with serial number was first noticed, for all series, by Struve (*Ap. J.*, 70, 97, 1929).

last line observable is very regular, though the total line-width remains approximately constant. For the leading triplet line, D3, two Cambridge measures for the dwarf stars η Ursae Majoris and α Leonis gave relative intensities as low as 50; also, the singlet λ 6678 was weaker than λ 4922.

The work of Ishida and Kamijima[25] has shown that the leading lines in helium series are relatively less affected by Stark effect than is $H\alpha$ with respect to other Balmer lines.[26] As Pannekoek and Verwey[27] predict that for hydrogen Stark effect produces a small initial intensity increase with series number, we may expect a rather greater enhancement from the first to the later series lines in helium. The above-noted differences between giants and dwarfs are therefore such as might be anticipated.

With Stark effect operating in the dwarfs, it is not surprising that the luminosity effect in the diffuse series is similar to that for hydrogen. For the two sharp series the enhancement in intrinsically fainter stars, though less in amount, is still present.[28] Hence, the intensity-type relation shows less scatter than Figure 1. The case for Stark enhancement of the two rather weak sharp singlet lines is, however, not clear, since in the laboratory λ 4169 is much more subject to electric fields than λ 4438, whereas our measures, though individually rather uncertain, plainly show the latter line to be stronger and more diffuse. An intensity ratio of 2+, similar for giants and dwarfs, is obtained when some allowance is made for a weak O^+ line at λ 4169.2. Actually, the last observed members of both sharp series are the two sharpest lines measured.

It will be noticed that in the diffuse singlets the depths decrease much more rapidly with series number for the dwarf than for the giant group. Thus for seven well-known c stars the mean depth ratio 3872/4414 is 0.63, while for five undoubted dwarf, or "normal,"

[25] *Sci. Papers Inst. Phys. and Chem. Research*, **9**, 117, 1928.

[26] This suggests that these leading lines are to be preferred as indices of helium abundance.

[27] *Proc. Amsterdam Acad.*, **38**, 479, 1935.

[28] The sharp singlets are about 15 per cent stronger in dwarfs. The figures for the principal singlet at λ 3965 are misleading. The line blends with $H\epsilon$ and the intensity tends to be underestimated, more so in dwarfs than in giants.

stars of similar type it is only 0.33. But in both these selections the total widths of the lines in angstroms decrease only slightly toward the ultra-violet.

The extra diffuseness of λ 3927 shown by the high value of w/d is somewhat puzzling. This diffuseness, common to all groups, was noticed on numerous tracings at the time of measuring.

A very noteworthy feature in helium, first noticed by Struve,[29] is the change with spectral type of the intensity ratio for singlet and triplet lines of the diffuse series. Elvey's[20] photometric measures showed up well the low relative intensity of the singlets in O-type stars, and the phenomenon has been further commented on by Marshall[30] and by Struve,[31] who has recently modified his earlier suggestion that the gradient effect was involved to an explanation in terms of departures from thermodynamic equilibrium.

The character of the variation is well shown by Figure 4, in which the ratio (mean intensity of 4388, 4144)/(mean diffuse triplet intensity) is plotted against spectral type. From O8 to B1 there is a twofold increase in the ratio, while for λ Cephei, O6, the singlets are relatively only one-eighth as strong as in B3 stars. Struve further suggested that the phenomenon might depend on the line intensity. This is not the determining factor, however, as the type relation is independent of luminosity. The abnormally high ratio for HD 14134, gB1, appears to be genuine. There is some evidence that the singlet-triplet ratio behaves in a similar manner for the sharp series, as the singlets could be detected in only one O-type star.

Lines of other elements.—As already mentioned, the individual intensities of the weaker lines are subject to considerable uncertainty. Nevertheless, the integrated intensities in cases where several lines of an atom have been measured are generally reliable and bear an almost linear relation to the intensities of the strongest lines of the atom. In order to weight lines in different parts of the spectrum according to the dispersion, these integrated intensities, which have been used already for classification purposes, were expressed in "tracing units" without correction to equivalent width in ang-

[29] *Nature*, **122**, 994, 1928.

[30] *Pub. Obs. U. Michigan*, **5**, 137, 1934.

[31] *Ap. J.*, **74**, 248, 1931; **82**, 252, 1935

stroms. The diagrams, Figures 5 and 6, show these intensities plotted for each atom against measured spectral class. The ordinates are arbitrary and on different scales for each atom. As in the figures for hydrogen and helium, crosses and circles represent giants and dwarfs, respectively. In drawing mean curves, points representing a few stars such as γ Cassiopeiae, Bonne, and π Aquarii, B1nne, were ignored, since, owing to the extreme diffuseness of the lines, the measured intensities are undoubtedly too small.

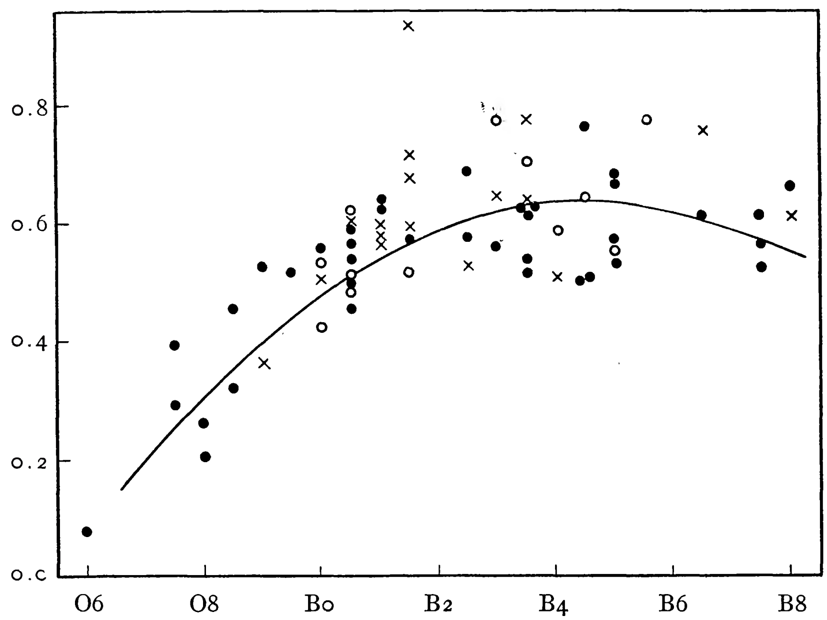

FIG. 4.—Variation of ratio of diffuse singlet to diffuse triplet lines of helium with spectral type.

Perhaps the most noteworthy feature of these diagrams is the sharpness of the maxima for C^{++}, N^{+}, N^{++}, and O^{+}, as compared with Miss Payne's[32] curves. This may result largely from the greater precision in classification. The mean curves for O^{+} and Si^{++} coincide almost exactly in shape and position. There is a very smooth progression of the spectral type of maximum for the curves as here drawn with the ionization potential of the corresponding atom; Figure 7 shows that except for C^{++} the expected maximum never differs from the observed by more than 0.2 of a subtype. This result from abso-

[32] *M.N.*, **92**, 368, 1932.

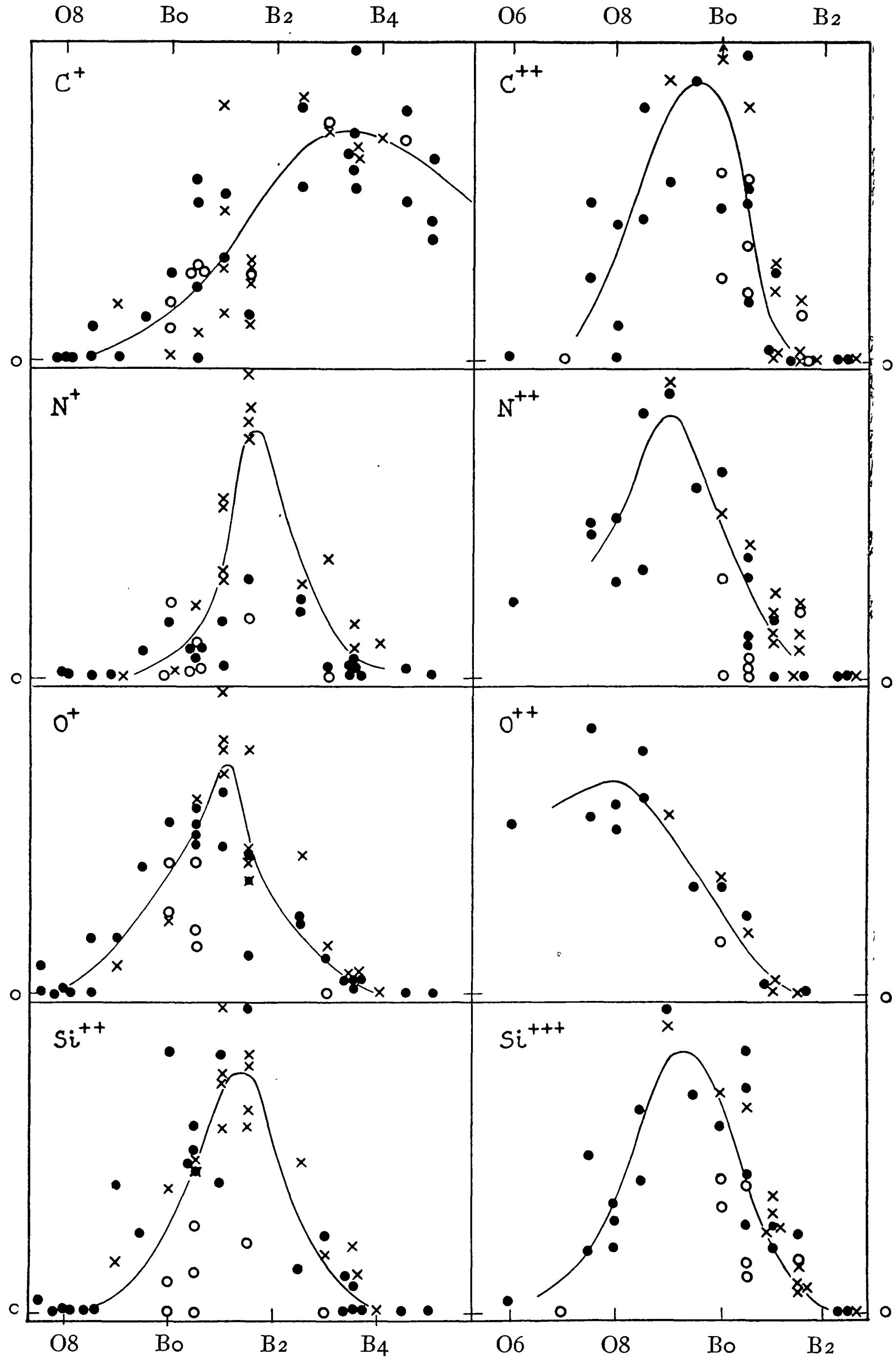

FIG. 5.—Variation of line intensity with spectral type. The scale of ordinates is arbitrary and differs for each atom.

lute line intensities demonstrates that the classification we have set up, based entirely on ratios, is indeed a temperature classification. As was noted by Struve,[33] lines of high excitation potential reach a

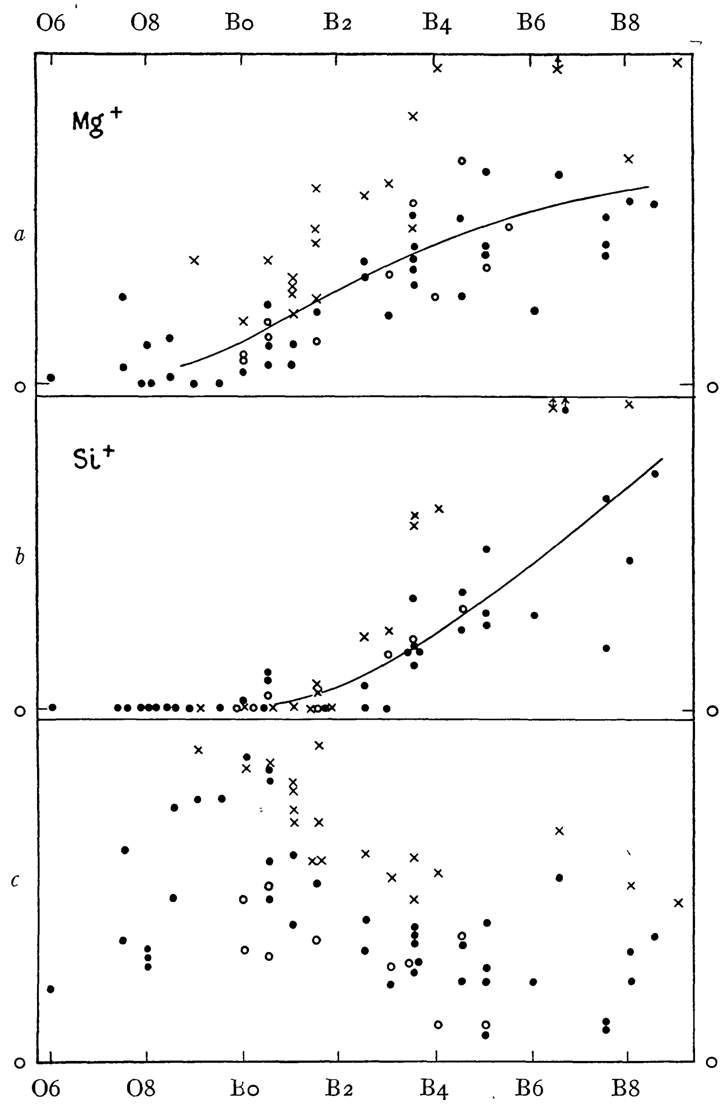

FIG. 6.—Line-intensity variations with spectral type: (*a*) for Mg^+; (*b*) for Si^+; (*c*) for all lines other than *H*, *He*.

maximum in an earlier subtype than do other lines of the same atom. Thus the two high-excitation O^+ lines, λ 4189 (28.2 volts) and λ 4275

[33] *Ap. J.*, **78**, 83, 1933.

(28.7 volts), attain greatest strength in type B0.5, whereas the normal maximum is at B1.0.

These curves must, however, be treated as representing statistical means, for in almost all the diagrams there is much scatter; and, though this might be reduced somewhat by adjustments to the assigned type, the greater part of it is undoubtedly real. The distribution of crosses and circles in nearly all the figures shows clearly that absolute-magnitude differences account for some, though not all, of this scatter; the stronger lines belong to the brighter stars. The effect is most pronounced for N^+, Si^+, Mg^+, while for C^+ it is totally absent.[34]

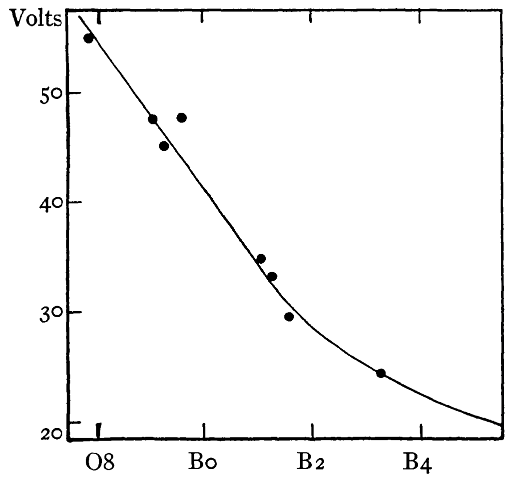

FIG. 7.—Relation between spectral type of maximum and ionization potential of corresponding atom.

The generality of this enhancement of line strength for giants is well illustrated by Figure 6*c*, which represents the summed intensities for all atoms other than *H* and *He*, the intensity for each atom being expressed in terms of its maximum. This diagram, in conjunction with those for *H* and *He*, gives us a powerful means of grading stars according to their intrinsic brightness; and the assignment of each star to one of the three categories—giant, intermediate, or dwarf, (Table VIII, col. 8)—has been made almost entirely by reference to its position in these three diagrams;[35] only in a few boundary cases has K-line intensity or total proper motion been invoked to determine the group.

Line character.—The measured spectral type in the seventh column of Table VIII is followed by the usual letters indicating line

[34] Morgan (*Ap. J.*, **77**, 291, 1933) and Struve (*ibid.*, **78**, 82, 1933) both found a null effect for Mg^+ in early subtypes.

[35] The occurrence of the effects was, of course, first found from consideration of other luminosity data. See a preliminary survey of Struve's luminosity groups in *Pub. A.S.P.*, **46**, 292, 1934.

grade. These letters have been assigned, not by visual inspection, but from the measures. For each spectrum a diagram was constructed showing the relation between measured width and depth for all lines other than those of *H* and *He*. Great variations from star to star were at once apparent, though in almost every case points from different plates of the same star agreed well with one another. The mean curves were graded according to slope, and the letters affixed to each grade were arranged to correspond in the mean to Pearce's grades. The several discordances between the two series of grades are not surprising, as ours take no account of the cores of *H* and *He* lines.

Following Edwards,[36] the grade intermediate between n and s is designated ns. Group nn covers a wider range of slope than any other. The width-depth relation for the interstellar K line is about one grade sharper than ss.

Gradient effects.—In numerous stellar spectra,[37] as well as for the sun,[38] it has been found that the relative intensities of absorption lines in multiplets depart from those predicted theoretically. The data for lines in type B are somewhat scanty, though Struve[39] has found in the case of O^+ that for giants all the stronger lines are greatly enhanced, while the weakest are visible only in the dwarfs. The effect was also noticed, though to a much less degree, for the Si^{++} lines.[40]

The present material is not well suited to a study of such gradient effects, since the weakest lines are completely lost, so that the maximum number of measured lines in any one multiplet is only four. For O^+ and N^+, however, we have totals of 19 and 11 measured lines, respectively; and the mean relative intensities of the strong and the weak lines, when grouped together irrespective of their multiplet membership, might reasonably be expected to show variation from star to star.

[36] *Op. cit.*

[37] For a full list of references see Struve and Elvey, *Ap. J.*, **79**, 409, 1934.

[38] Minnaert and van Assenbergh, *Zs. f. Phys.*, **53**, 248, 1929; Woolley, *Ap. J.*, **72**, 256, 1930; Allen, *Mem. Commonwealth Solar Obs. Canberra*, **1**, No. 5, 1935.

[39] *Ap. J.*, **78**, 73, 1933. See also the next reference, p. 412.

[40] Struve and Elvey, *op. cit.*, p. 413.

As a preliminary, the O^+ lines were divided into three groups (strong, 2 lines, mean intensity 42 units; medium, 11 lines, mean intensity 12; weak, 6 lines, mean intensity 5), and the N^+ lines into two groups (moderate, 2 lines, mean intensity 17; weak, 9 lines, mean intensity 5). For each star the ratios between the mean line intensities in each group were found for both O^+ and N^+. Spectra with but few weak lines were omitted. If the gradients persist unchanged throughout the measured intensity range for O^+, a high ratio between the strong and medium groups should repeat itself as between the medium and weak sets of lines. Actually, no correlation whatever was detected between the ratios, strong to medium and medium to weak, for the O^+ lines; nor, indeed, between either strong to medium or medium to weak, for the O^+ lines, and medium to weak for the N^+ lines.

This negative result is somewhat surprising. When, however, the stars are grouped and the line intensities treated statistically, effects are found which suggest a partial explanation.

For the purposes of Table III, where mean total absorptions are given for each of the O^+ and N^+ lines, the unit of equivalent width has been changed from 0.01 A to $10^{-6}\,\lambda$. Measured in this unit, the intensity of a line due to radiation damping only is proportional to the square root of the number of absorbing atoms at any wavelength.[41]

The second, third, and fourth columns divide the stars into luminosity groups; the next two, according to line sharpness; and the final three, for oxygen only, into types earlier than, at, and later than, the maximum. The individual lines behave in a consistent manner, but the effects are best seen by still further summarizing the results. This is done in Table IV, where means for lines in each intensity group are expressed relative to the middle group.

This table brings out clearly a progressive increase in gradient between the medium[42] and weak groups of O^+ as we pass from dwarfs through intermediate stars to giants. The weak lines are, relatively, over twice as strong in dwarfs as in giants. The same effect exists

[41] Dunham, *Pub. A.A.S.*, **7**, 215, 1933.

[42] We note that several lines in our "medium" group are normally rated as strong lines.

TABLE III

MEAN TOTAL ABSORPTIONS EXPRESSED IN MICRO-WAVE-LENGTHS

λ	Giants	Intermediates	Dwarfs	Sharp Lines	Others	O9.0–B0.5	B1.0	B1.5–B3.0
	Oxygen Lines							
4650	125	112	85	128	97	103	165	101
4641	85	65	31	81	52	56	114	56
4676	40	29	16	37	27	24	50	33
4662	38	30	11	41	26	25	60	31
4417	33	29	12	31	26	31	47	14
4415	39	25	13	37	22	26	52	21
4367	45	29	17	38	29	29	57	29
4320	39	23	14	38	18	20	49	30
4317	38	23	18	33	25	24	45	24
4076	46	39	44	47	39	36	67	42
4072	40	34	28	40	31	31	56	30
4070	46	40	35	47	38	36	72	34
3973	35	18	20	31	21	17	43	31
4326	13	10	10	14	9	8	23	9
4276	10	12	11	14	8	12	15	7
4190	7	14	22	13	13	13	17	10
3983	14	16	11	15	14	11	23	14
3954	15	15	12	17	13	11	27	12
3945	9	11	12	11	9	10	12	10
No. of stars	13	12	5	16	13	14	6	9
	Nitrogen Lines							
4631	71	15	....	57	8			
3996	77	26	12	64	21			
4614	22	2	....	17	1			
4607	29	1	....	21	1			
4602	30	1	6	21	5			
4447	29	5	11	23	7			
4242	19	4	18	18	5			
4237	13	2	14	12	4			
4044	17	14	11	19	8			
4041	16	7	8	13	8			
3955	21	4	1	16	3			
No. of stars	11	10	4	15	10			

between giants and dwarfs for the N^+ lines, though here the intermediate group of stars behaves curiously. The ratio for this group is, however, hardly comparable with that for the giants, as *all* N^+ lines are some four times stronger in the giant group. For none of the four dwarf stars is the normally strong N^+ line λ 4631 measurable. This line is relatively much weaker in stars with weak nitrogen lines.

The two O^+ lines forming the strong group behave anomalously, as they are relatively strongest in the stars of intermediate luminosity. One of them, λ 4649.2, often blends with λ 4650.8, also O^+; but, even so, both components belong properly to the strong group. The other line, λ 4641, though also strongest in intermediate stars, is much weakened in dwarfs, as would be expected.

TABLE IV

SUMMARIZED MEAN RELATIVE INTENSITIES

	Oxygen Lines	Nitrogen Lines
	Strong : Medium : Weak	Medium : Weak
Giants	257 : 100 : 28	100 : 28
Intermediates	297 : 100 : 45	100 : 16
Dwarfs	274 : 100 : 67	100 : 140
Sharp-line stars	271 : 100 : 37	100 : 29
Others	267 : 100 : 40	100 : 29
Type earlier than B1.0	285 : 100 : 40	
Type B1.0	256 : 100 : 35	
Type later than B1.0	265 : 100 : 36	

That the effect is genuinely one of luminosity and not of line character is shown by the similarity of the figures for the stars graded ss and s, on the one hand, and those graded ns and n, on the other. We conclude also from this table that the gradient does not depend systematically on spectral type.

III. ABSOLUTE MAGNITUDES

In the foregoing discussion the stars have been divided into groups of high, normal, and low luminosity. We shall now attempt to justify this division and to find absolute magnitudes for the individual stars.

The most reliable index of distance known at present for isolated early-type stars is almost certainly the intensity of the interstellar K line. In order to derive absolute magnitudes the first requirement is, therefore, the mean relation between K-line intensity and distance. We say "mean relation" advisedly, because it appears very probable that the relation varies in different parts of galactic space.[43]

For statistical discussion 56 stars with measured interstellar lines are available. This total includes two measured by Beals[44] in addition to those from Paper I. The material has been divided into three intensity groups with approximately equal numbers in each. Mean distances of the groups can be found both from proper-motion data and from the galactic rotational term present in the radial velocities. The proper motions will give more reliable results for the nearer stars and the rotational term for the distant ones.

Through the great courtesy of Dr. J. S. Plaskett and Dr. Pearce[45] the υ- and τ-components derived from the proper motions supplied to them by Dr. R. E. Wilson have been forwarded to me for most of my stars in advance of publication. In a few additional cases I have computed the components from the data of the *Boss Catalogue*.

The distances in parsecs derived from these proper motions for three K-intensity groups are given in Table V. Mean parallaxes from υ components were computed by the formula

$$\bar{\pi} = 4.74 \frac{\overline{\upsilon \sin D}}{\overline{V_0 \sin^2 D}} .$$

Plaskett and Pearce have pointed out that the use of the τ components through the formula $\bar{\pi} = 4.74\ \bar{\tau}/\bar{\rho}$, where ρ = residual radial velocity, is unsatisfactory for distant B stars: the mean parallaxes derived from them for the two nearer groups have here been given half-weight. The columns headed "reduced" in Table V were obtained by reducing the υ and τ values for each star to the value for the mean K intensity of the group, on the assumption that intensity is proportional to distance. These values were given equal weight with the unreduced figures.

[43] Struve, *Ap. J.*, **79**, 273, 1934.

[44] *M.N.*, **94**, 663, 1934.

[45] *Pub. Dom. Ap. Obs.*, **5**, 203, 1933.

In deriving the mean distance $\bar{r}$ from the mean parallax, we need to know the factor by which $\bar{r}\bar{\pi}$ differs from unity. This factor depends on the amount of scatter introduced by (*a*) dispersion in distance in each group, which can be ascertained with sufficient accuracy by finding the value of $\overline{K}\cdot\overline{(1/K)}$ (K = K-line intensity), which in our groups is about 1.05; (*b*) errors of intensity measurement; and (*c*) irregularity in distribution in the calcium cloud. This last was found by Plaskett and Pearce[46] to be the principal contributor to a factor with mean value 1.15, which represents the combined effect

TABLE V

RELATION BETWEEN K-LINE INTENSITY AND DISTANCE DERIVED FROM v AND τ COMPONENTS

Group	No. of Stars	Mean K* Intensity	Distance in Parsecs					K Intensity per Kpsc
			v	v Reduced	τ	τ Reduced	Weighted Mean	
I	21	5.2	234	....	343	....	270	19.3
II	16	14.7	....	....	543	....	708	20.6
	17	14.6	700	695	....	933		
III	18	28.2	(Distances range from 300 to 2200)				....	....

* For convenience the unit of Paper I, equivalent-width of 0.1 wave number, has been retained. Allowance has been made for stellar blends in those stars of type B2 and later which have sharp lines.

of *b* and *c*. We have adopted the round figure 1.2 as being sufficiently accurate for our limited material.

Group I includes all stars with measured interstellar lines of intensity less than 10 units. As might be anticipated, the proper motions are not very helpful in group III, K intensity >20; the derived distances depend greatly on whether or not the components are reduced to a common K intensity, and also on whether the two stars in *h* and χ Persei are treated as one object or two.

The term introduced into radial-velocity measures by the galactic rotation is given by

$$\rho = r\, A \sin 2(G - G_0) \cos^2 g \;.$$

[46] *Ibid.*, p. 206.

Adopting the Victoria[47] values for the constant A and the direction to the center, based on the study of 849 stars, we have found the mean distances of the three groups[48] of Table VI from the expression

$$\bar{r}=\frac{1}{0.0155}\,\frac{\bar{p}}{\sin 2(G-324.4)\cos^2 g}\,.$$

The use of this expression is equivalent to weighting each value of r by $\sin 2(G-G_0)\cos^2 g$. Five stars very close to the nodes had to be omitted, also several with uncertain orbits or abnormally high velocities. The two Perseus-cluster stars were treated as one object.

TABLE VI

DISTANCES DERIVED FROM THE GALACTIC ROTATIONAL TERM

Group	No. of Stars	K-Line Intensity	Distance in Parsecs		K Intensity per Kpsc
			Stars	Calcium	
a............	22	4.3	194	....	22.1
b............	17	19.6	....	595	33.0
	17	17.8	730	....	24.4
c............	12	38.3	....	1650	23.2
	10	38.1	1500	....	25.4

In the more distant groups, *b* and *c*, K-line velocities were also generally available. Since the rotational term $\bar{r}A$ for the interstellar lines is just half what it is for the stars, the inclusion of the independent mean distances from calcium velocities adds weight to the result. Incidentally, this two-to-one relation between $\bar{r}A$ for the stellar and calcium velocities found by Plaskett and Pearce[49] holds well for the present limited selection. Considering only stars with both velocities measured, we have: strong K-line group, 10 stars, ratio 1.86; medium group, 11 stars, ratio 2.50; all 24 stars together, ratio 2.02.

As may be seen from Figure 8, in which K-line intensity is plotted against distance, the material of Tables V and VI is satisfactorily

[47] *M.N.*, **94**, 679, 1934.

[48] The grouping is not the same as in Table V.

[49] *Op. cit.*, p. 167.

consistent in view of the limited numbers of stars employed. This figure and the last columns of these tables offer good confirmation, based on measured intensities, of Plaskett and Pearce's contention that interstellar line intensity is directly proportional to the distance. Too much weight must not, however, be placed on our most distant group, since 7 of the 12 objects in it are included within an interval of 4° of longitude.

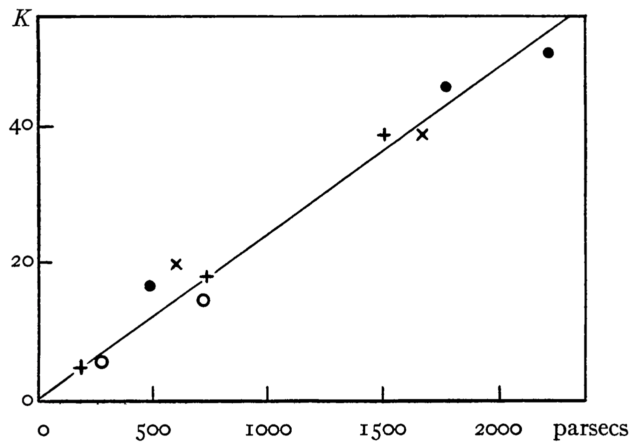

FIG. 8.—Mean relation between K-line intensity and distance. Circles represent proper-motion data; plus signs, radial velocities of stars; crosses, radial velocities of calcium lines; dots, galactic clusters.

The three dots in the figure represent galactic clusters in which I have measured K-line intensities. The adopted distances are based on the following published determinations:

h and χ Persei: Trumpler,[50] 1330; Anger,[51] 2200; mean, 1765 parsecs.
NGC 2264 (S Monocerotis): Trumpler,[52] 500; Anger, 480; mean, 490 parsecs.
NGC 6910. Trumpler,[50] 2200 parsecs.

These distances allow for space absorption. I have adjusted Miss Anger's distances to correspond to Trumpler's general absorption coefficient.

In Figure 8 the straight line represents the relation: *K* intensity =

[50] See R. S. Zug, *Lick Obs. Bull.*, 15, 138 (No. 454), Table 4, 1933.

[51] *Harvard Circ.*, No. 397, 1935.

[52] *Pub. Lick Obs.*, 14, 154, 1930.

24 units per kiloparsec. This rate of change leads to the following expression for determining absolute magnitudes:[53]

$$M = m - 3.1 - 5 \log K .$$

The material may now be divided into type- and luminosity-groups and the K-line intensity used, as well as the proper motions and radial velocities, for determining mean absolute magnitudes. The luminosity groups in Table VII are the so-called giants, intermediate stars, and dwarfs of the preceding sections to which the stars were assigned on the basis of spectral characteristics.

TABLE VII

MEAN ABSOLUTE MAGNITUDES FOR TYPE AND LUMINOSITY GROUPS

Luminosity Group	No. of Stars	Mean Type	v	v Red.	τ	τ Red.	Rotational Term	K-Line Int.	Weighted Mean
			Early Subtypes						
Giants.	10*	B1.0	$-4.5_{\frac{1}{2}}$	$-4.5_{\frac{1}{2}}$	. . . . . .	. . . . . .	-5.7_{3}	-5.35_{5}	-5.4
Intermediates.	20	O9.5	(Mean parallax negative)		. . . . . .	. . . . . .	-5.4_{3}	-3.9_{5}	-4.5
Dwarfs.	7	B0.5	-3.0_{1}	-4.2_{1}	$-2.9_{\frac{1}{2}}$	$-1.4_{\frac{1}{2}}$	-1.7_{1}	-2.1_{4}	-2.4
			Late Subtypes						
Giants.	9	B6	$-5.9_{\frac{1}{2}}$	$-4.5_{\frac{1}{2}}$	. . . . . .	. . . . . .	-5.8_{2}	-5.5_{3}†	-5.6
Intermediates.	15	B4.0	-2.7_{1}	-2.7_{1}	$-2.5_{\frac{1}{2}}$	$-2.4_{\frac{1}{2}}$	-2.2_{1}	-2.4_{1}	-2.5
Dwarfs.	6	B4.5	-0.6_{1}	-1.3_{1}	-2.5_{1}	-1.4_{1}	. . . . . .	$+0.2_{1}$‡	-1.1
(Intermediates)§. .	11	B4.5	-1.4_{1}	-1.5_{1}	$-2.6_{\frac{1}{2}}$	$-2.6_{\frac{1}{2}}$	. . . . . .	. . . .	-1.8

* Two stars in *h* and χ Persei treated as one object.
† Mean type B3.5.
‡ Value from trigonometrical parallaxes, K-line intensities, and other data.
§ Stars observed elsewhere.

The numbers do not permit division into more than the two type-groups with the limits O7.5–B1.5, B2.5–B5.5 (the giant group ex-

[53] When K is measured in equivalent angstroms, this expression becomes

$$M = m - 12.2 - 5 \log K .$$

tends to type A). The last line of the table comprises stars rated as "intermediates" on the basis of hydrogen-line intensity as measured by other observers. Small appended figures indicate the combining weights used for the final column.

The values in this column show unmistakably that our spectral criteria have successfully divided the stars on a luminosity basis. The large difference between the giant and dwarf groups of 3 mag. in early subtypes, and of more than 4 mag. in late ones, is noteworthy. Figure 9 shows the relation of the present groups to determinations of mean absolute magnitude for different subtypes based on much larger numbers of stars. The broken line represents the latest values of Plaskett and Pearce,[47] and the dotted line those of Öpik and Olmsted,[54] which are in close agreement with Strömberg's[55] curve for the main sequence. The fact that our intermediate groups are sensibly brighter than their means is not surprising, since many of our stars were chosen either on account of strong K lines or undue redness, both criteria favoring bright stars.

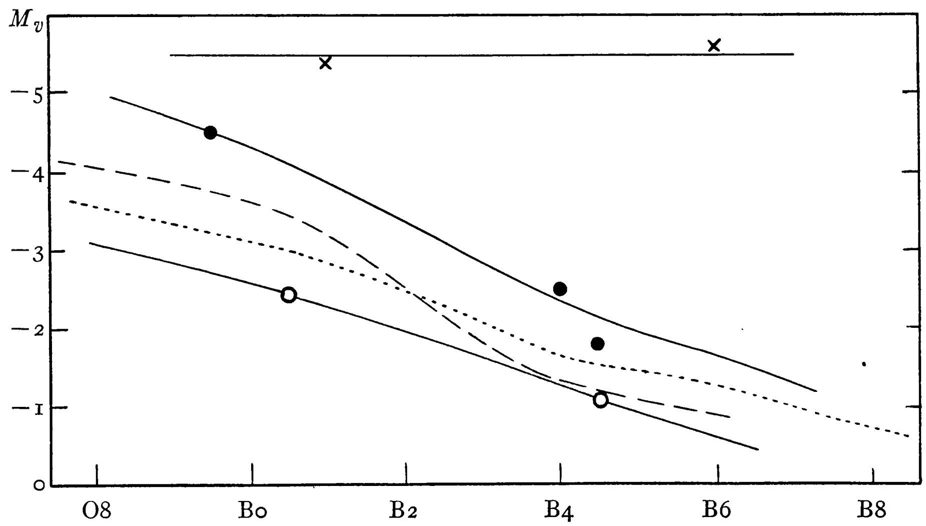

FIG. 9.—Mean absolute magnitude and spectral type. Crosses represent giants; dots, intermediate stars; circles, dwarfs. The dashed line represents Plaskett and Pearce's values; the dotted line, Öpik and Olmsted's.

[54] *Harvard Circ.*, No. 380, 1932.

[55] *Mt. W. Contr.*, No. 442; *Ap. J.*, 75, 115, 1932.

IV. COLLECTED RESULTS

For general purposes a B-type spectrum is sufficiently specified by (1) the mean spectral type, (2) the luminosity group, (3) the line grade.

The foregoing discussion has shown how measures of absorption lines enable a temperature classification to be established from ratios and, following this, how a luminosity grouping can be made from absolute intensities.

The spectral types and absolute magnitudes of the individual stars, assigning positions in this two-dimensional scheme, are collected with other general information in Table VIII. The arrangement of the table is as follows: The first two columns give the HD number and designation. In column 3, "c" signifies that the radial velocity is constant; "var," that it is variable; and "2 sp" that both spectra of a binary system have been recognized. Column 4 gives the apparent visual magnitude; columns 5 and 6, respectively, the Draper type, and the revised Victoria type with the emission symbol "e" added where needed. Types in parentheses are from sources referred to in the notes. Column 7 gives the spectral type and line grade as measured here. In column 8 the letters "g," "i," and "d" indicate giant, intermediate, and dwarf stars, as judged from the spectral measures alone.

The continuous curves as drawn in Figure 9 have been used to derive from the type and luminosity group the absolute magnitude, M_L, for each star. Column 9 in Table VIII gives this value; and column 10, the magnitude M_K derived from interstellar-line intensity. The mean, M_W, of these two columns, when the two values are reasonably accordant, should give a close approximation to the true luminosity.

For comparison column 11 lists M_{sp} the absolute magnitude corresponding to the spectroscopic parallax given by Schlesinger,[56] an adjusted value from several sources. Figure 10 compares M_W and M_{sp} and shows a serious difference in scale between the two systems. The straight line corresponds to $M_W = 1.67\ M_{sp}$.

[56] *General Catalogue of Stellar Parallaxes, Yale U. Obs.*, 1935.

TABLE VIII

CATALOGUE OF RESULTS

HD No. (1)	Star (2)	Vel. (3)	Mag. (4)	Spectral Type: HD (5)	Spectral Type: Vict. (6)	Spectral Type: Meas. (7)	Lum. Group (8)	Absolute Magnitude: M_L (9)	Absolute Magnitude: M_K (10)	Absolute Magnitude: M_{sp} (11)	Notes (12)
886......	γ Peg	c ?	2.9	B2	B2ss	B2.5ss	i	−3.1	....	−2.3	
3360.....	ζ Cas	c ?	3.7	B3	B2sk	B2.5s	i	−3.1	....	−2.0	
4180.....	o Cas	c	4.7	B2	B5ne	B5.0nn	i	−1.9	....	−1.7	
5394.....	γ Cas	c	2.3	B0p	B0nne	B0.5nn	d	−2.4	−2.5	.....	
11415....	ε Cas	c	3.4	B3	B5s	B4.5ns	i	−2.1	....	−1.4	
13854....	—	c	6.4	B1p	B0sek	B1.0s	g	−5.5	−5.2	−3.4	1
14134....	—	c	6.7	B0	B2sek	B1.5s	g	−5.5	−4.9	−2.9	2
21291....	2H Cam	c	4.4	B9p	....	B6.5s	g	−5.5	....	−2.6	3
21389....	—	var	4.8	A0p	....	B9s	g	−5.5	....	−5.2	4
22928....	δ Per	c	3.1	B5	B8n	B7.5nn	i	−1.1	....	−1.0	5
23480....	23 Tau	c	4.3	B5	B7ne	B6.0nn	i	−1.6	....	−0.5	6
24398....	ζ Per	c	2.9	B1	B1s	B1.0s	g	−5.5	−5.5	−2.8	7
24534....	X Per	c	6 v	B0p	B0nne	nn	d	−2.6	−2.1	.....	8
24760f...	ε Per f	.....	8.1	....	(B8)	....	d	.....	....	.....	9
24912....	ξ Per	var	4.1	Oe5	O7nek	O8.0n	i	−5.0	−4.4	.....	10
26125....	NGC 1514	.....	9	K0	(O8)	s	....	.....	....	.....	11
28446b..	1 Cam b	2 sp	5.8	B1	B2nk	B0.0n	d	−2.6	−3.3	−2.3	12
28446f...	1 Cam f	c	6.9	B1	B0sk	B0.5ss	d	−2.4	−2.2	.....	13
30614....	9 Cam	c	4.4	B0	O9sek	O9.0ns	g	−5.5	−5.8	−3.2	14
32343....	11 Cam	c	5.3	B3p	B3e	B5.0n	i	−1.9	....	−1.1	
32630....	η Aur	c	3.3	B3	B3	B4.5ns	d	−1.1	....	−1.1	15
34085....	β Ori	var	0.3	B8p	....	B8s	g	−5.5	....	−5.1	16
35497....	β Tau	c	1.8	B8	....	B7.5ns	i	−1.1	....	−0.4	
36371....	χ Aur	var	4.9	B1	B3ss	B3.5s	g	−5.5	−6.0	−2.0	17
36861....	λ Ori b	c	3.7	Oe5	O8sk	O7.5n	i	−5.0	−5.1	−3.2	18
36862....	λ Ori f	var	5.6	Oe5	B1sk	B0.5ns	d	−2.4	−3.2	.....	19
37128....	ε Ori	c	1.8	B0	B0k	B0.0s	g	−5.5	−6.2	−3.6	20
37202....	ζ Tau	var	3.0	B3p	B3e	....	....	.....	....	−1.3	20a
38771....	κ Ori	c	2.2	B0	B0k	B0.5ns	g	−5.5	−5.1	−3.8	21
39698....	57 Ori	var	5.9	B2	B3	B3.0ns	i	−2.7	−3.4	.....	
40111....	139 Tau	2 sp ?	4.9	B2	B0	B0.5ns	i	−4.1	−4.5	−2.0	22
41117....	χ^2 Ori	var	4.7	B2p	B2ssek	B1.5s	g	−5.5	−6.3	−3.8	23
41534....	—	c ?	5.6	B3	B3	B3.5ns	d	−1.4	....	.....	24
44743....	β C Ma	c ?	2.0	B1	B1ss	B1.0s	i	−3.8	−4.3	−3.2	
47839....	15 S Mon	c	4.7	Oe5	O7sk	O7.5ns	i	−5.0	−4.5	.....	25
58050....	—	c	6.4	B3	B3e	B3.0ns	d	−1.6	−1.6	−2.1	
59088....	NGC 2392	c	11	Pe	(O8w)	O7ns	d	.....	+0.6	.....	26
74280....	η Hya	var	4.3	B3	B5n	B5.0n	i	−1.9	....	−1.1	
87737....	η Leo	c	3.6	A0p	(A2)	B8.0s	....	.....	....	−2.9	27
87901....	α Leo	c	1.3	B8	B6n	B8.0nn	i	−1.0	....	−0.2	28

TABLE VIII—*Continued*

HD No. (1)	Star (2)	Vel. (3)	Mag. (4)	Spectral Type: HD (5)	Spectral Type: Vict. (6)	Spectral Type: Meas. (7)	Lum. Group (8)	Absolute Magnitude: M_L (9)	Absolute Magnitude: M_K (10)	Absolute Magnitude: M_{sp} (11)	Notes (12)
89688....	23 Sex	var	6.5	B3	B3	B3.5nn	i	−2.5	....	−1.1	29
91316....	ρ Leo	c ?	3.9	B0p	B0sk	B1.0s	g	−5.5	....	−3.0	
93521....	—	2 sp ?	6.9	B3	B3nn	nn	.....	.....	−2.0	.....	30
100600b.	90 Leo b	c	6.0	B3	B3	B4.5n	i	−2.1	−1.1	−1.0	31
100600f..	90 Leo f	var	7.3	B3	B5	B6.5n	i	−1.4	+0.2	.....	32
109387...	κ Dra	var	3.9	B5p	B5e	B7.5n	i	−1.2	....	−1.1	
120315...	η U Ma	c	1.9	B3	B3n	B5.0nn	d	−0.9	....	−1.1	
147394...	τ Her	c	3.9	B5	B7s	B5.0ns	i	−1.9	....	−0.7	33
148184...	χ Oph	c ?	4.9	B3p	B3e	nn	i	−2.8	−2.7	−1.6	
148479...	α Sco f	.....	6.5	A3	(B4.n)	B4.0n	d	−1.2	....	.....	34
149438...	τ Sco	c	2.9	B0	B1s	B0.0ss	d	−2.6	(−1.1)	−2.3	35
149757...	ζ Oph	c	2.7	B0	B0nn	nn	i	−4.3	−3.9	−2.7	36
149881...	—	var	6.6	B2	B2k	B0.5ns	i	−4.1	−3.2	−1.9	37
160762...	ι Her	c	3.8	B3	B3s	B3.5ss	i	−2.5	....	−2.2	
162732...	88 Her	c	6.4	B8	*note*	B8.5s	i	−1.0	....	−0.2	38
164353...	67 Oph	c	3.9	B5p	B3s	B3.5s	g	−5.5	−5.8	−2.1	39
167971...	—	.....	7.3	B0	....	O8.0ns	i	−5.0	−4.3	.....	
169454...	—	.....	6.8	B0	(B0se)	B1.0s	g	−5.5	−4.5	.....	40
187811...	12 Vul	c	4.9	B3	B5ne	B5.5nn	d	−0.8	....	−0.8	
190603...	—	c	5.7	B0	B0ssek	B1.5s	g	−5.5	−4.7	−2.8	
191201...	—	2 sp	7.1	B0	B0k	O9.5ns	i	−4.5	−3.6	.....	
192422...	—	c	7.1	B2	B0sk	B0.0ns	i	−4.3	−3.8	.....	41
193322...	—	var	6.0	B2p	O8k	O8.0ns	i	−5.0	−4.9	−1.6	42
194279...	—	c	7.0	B0	B0sk	B1.5ss	g	−5.5	−5.2	.....	43
194839...	—	c	7.5	B	B2sek	B0.5s	i	−4.1	−4.3	.....	44
195592...	—	var	7.2	B	B0sek	O9.0ns	i	−4.6	−3.6	.....	45
197345...	α Cyg	var	1.3	A2p	....	ss	g	.....	....	−4.1	
198478...	55 Cyg	c ?	4.9	B2	B2sk	B3.0s	g	−5.5	−5.9	−2.1	46
200120...	f^1 Cyg	var	4.9	B0p	B3nne	B4.5nn	i	−2.1	....	−2.1	47
204172...	69 Cyg	c	5.8	B0	B0k	B0.5ns	i	−4.1	−3.6	−4.2	48
205021...	β Cep	var	3.3	B1	B1	B1.5ns	i	−3.6	(−3.0)	−2.7	49
206165...	9 Cep	c	4.9	B2p	B2sk	B2.5s	g	−5.5	−5.6	−2.1	50
208185...	—	.....	8.2	B3	(B3s)	B3.5ss	i	−2.5	−1.8	−1.8	51
208392...	—	c	7.1	B3	B3nnek	B1.5ns	d	−2.1	−3.4	−1.7	52
208947...	—	2 sp	6.3	B3	B3k	B3.5ns	i	−2.5	−3.2	−2.2	53
210809...	—	.....	7.7	B2	(O8k)	O8.5ns	i	−4.8	−3.4	.....	
210839...	λ Cep	c	5.2	Od	O6wnek	O6ns	.....	−5.2	−4.9	−2.9	
212455...	—	.....	8.4	B2	(B3k)	B4.0s	g	−5.5	−4.4	.....	54
212571...	π Aqr	c	4.6	B1p	B1nnek	B1.5nn	i	−3.6	−3.1	−1.4	
213420...	6 Lac	c	4.5	B3	B3k	B3.5ns	i	−2.5	−4.1	−2.0	
214680...	10 Lac	c	4.9	Oe5	O9sk	O8.5ss	i	−4.8	−3.1	−2.2	55
+60°2522	NGC 7635	.....	8.7	....	(O7)	ns	.....	.....	....	.....	56
224151...	—	var	6.1	B0	B0k	B1.0ns	i	−3.8	−3.7	−2.4	57

NOTES TO TABLE VIII

No.	HD	
1	13854	Adams and Joy, B2. In *h* and χ Persei.
2	14134	Adams and Joy, B4; Merrill, B3seα. In *h* and χ Persei. *He* singlets abnormally strong relative to triplets.
3	21291	Large color excess (Elvey). Comp. 9 mag., 2″4.
4	21389	Large color excess (Elvey).
5	22928	Adams and Joy, B5. In Perseus moving cluster.
6	23480	Adams and Joy, B5ne. (*b*, B8.5; *c*, B4.5.) *H* and Si^+ have normal B4 intensity, but *He* and Mg^+ are much too weak for this type. In Pleiades.
7	24398	C^+ 2.5, C^{++} 1.5.
8	24534	Irregular variable, mag. 6.2–6.9.
9	247605f	Type by Mt. Wilson. 9″, c.p.m. with ϵ Persei, B2, in Perseus moving cluster. The spectroscopic parallax of the primary gives $M=+2.1$ for the companion.
10	24912	No N^{++} visible! Victoria notes emission wing to λ 4649. *H* lines relatively sharper than *He*.
11	26125	Type by Payne. Central star in an irregular ring, 2′×1′.5, of faint nebulous matter (Curtis). Payne gives nebular magnitude as 10, photographic. Van Maanen gives $\mu=0''.004$. Radial velocity $=+35.4$ km/sec (Hubble).
12	28446b	Adams and Joy, B1s. 10″ from, and c.p.m. with 28446f. *H* lines relatively sharper than *He*.
13	28446f	Adams and Joy, B2s.
14	30614	Struve, B0. Mg^+ very strong for type.
15	32630	In Perseus moving cluster.
16	34085	Comp. 7 mag., 9″, fixed, is itself a close binary.
17	36371	Si^+ 3, Mg^+ 2.
18	36861	Payne, O9. Mg^+ very strong for type. 4″ from HD 36862, fixed.
19	36862	(*d*, B2.0; *e*, B0.5; *g*, B0.0). O^+, N^+, N^{++}, Si^{++}, Si^{+++} are all about one-third normal intensity, while C^+, C^{++}, Si^+, Mg^+ are normal.
20	37128	He^+ weak; C^{++} 1.8; C^+ 0.
20*a*	37202	The spectrum of this star is very peculiar.
21	38771	Mg^+ 2.0
22	40111	C^+ 0; C^{++} 0.8. *H* lines relatively sharper than *He*.
23	41117	C^+ 0.3.
24	41534	Adams and Joy, B4n. (*b*, B2.5; *c*, B4.5; *d*, B3.5.) Voûte's star. $\mu=0''.123$. $\pi=0''.048$ (Voûte, trigonometric), whence $M_v=+4.1$. Radial velocity $+94.2\pm1.7$. Very close to solar antapex.
25	47839	Comp. mag. 8.0, 3″. In the open cluster NGC 2264.
26	59088	Type by Payne. Nucleus of planetory NGC 2392, irregular elliptical, 19″×15″. Interstellar K-line intensity = 29.0 (in 0.1 wave-number units). The magnitude is photographic.
27	87737	Type by Mt. Wilson. (*b*, B7.0; *c*, B9.0.) Si^+ 0.5; Mg^+ rather weak and much sharper than λ 4471 *He*. Included in Miss Payne's list of c stars.
28	87901	Adams and Joy, B8n.
29	89688	Adams and Joy, B4. C^+ 1.6. Strongest C^+ lines found.

NOTES TO TABLE VIII—*Continued*

30	93521	(*b*, B5.0; *c*, B3.5; *d*, B2.0; *e*, B0.5.) Almost certainly composite. Victoria notes "on a number of plates lines appeared double, but evidence not consistent nor definite enough to publish measures." *H* lines relatively much sharper than *He*.
31	100600b	3″ from HD 100600f, fixed.
32	100600f	Si^+ exceptionally strong, though the star is not a giant.
33	147394	The lines have exceptionally sharp cores.
34	148479	Type by Mt. Wilson. (*a*, B4.5; *b*, B5.0; *c*, B3.5; *d*, B2.5.) 3″ from and c.p.m. with Antares. The spectroscopic parallax of the primary gives $M_v = +1.3$ for the B4 star. The Harvard A3 spectrum is a mistake. Interstellar K-line intensity = 13.8 (in 0.1 wave-number units).
35	149438	In Scorpio-Centaurus cluster.
36	149757	*H* lines not exponential; relatively sharper than *He*.
37	149881	C^+ 2.5; C^{++} normal.
38	162732	Adams, A1sp; Joy, B9s. Edwards (*M.N.*, **92**, 389, 1932) gives B8, but notes that strong class A2 lines are present. This, coupled with the strength of the *He* lines, suggests a c star, but the hydrogen lines are normal for a dwarf. Their cores are very sharp.
39	164353	Si^+ 3. Comp. 8 mag., 55″, fixed.
40	169454	Type by Merrill. O^+ 1.3. Strongest oxygen lines found. O^{++} lines underexposed. This star, with many very sharp lines, is suggested as a suitable object for further study with higher dispersion. The K-line intensity given in Paper I is in error. The correct value is 34.8.
41	192422	Si^{++} 2; Si^{+++} normal. Interstellar K intensity = 32.9. (Incorrectly given in Paper I.)
42	193322	Comp. mag. 8.2, 2″.7, binary.
43	194279	Brightest star in NGC 6910.
44	194839	Mg^+ 2.
45	195592	Merrill, B1se. Si^{++} 3; Si^{+++} 1.3.
46	198478	Struve, B3. N^+ 2.5; Mg^+ 1.7; Si^+ 1.7.
47	200120	(*a*, B4.5; *b*, B5.5; *c*, B3.5.)
48	204172	C^{++} 2; Si^{+++} 2.
49	205021	C^+ weak; N^+ 0.4; O^+ 1.3. Short-period Cepheid. Comp. mag. 8, 14″, fixed.
50	206165	O^+ 2.0; Mg^+ 1.8; Si^+ 2; Si^{++} 1.7.
51	208185	Type by Mt. Wilson. Comp. mag. 8.3, 1″.8. Brighter star only on slit with good seeing. See note to Table VI, *Mt. W. Contr.*, No. 540.
52	208392	Comp. mag. 8.8, B8, 62″, c.p.m. The nitrogen lines suggest B0.5 and silicon lines B2.0. Victoria notes weak diffuse lines, $H\beta$ not distinct, $H\alpha$ emission suspected. This is not confirmed here. $H\beta$ is very distinct, and the lines are moderately sharp. Thus change is suggested. The probable error in the radial velocity (Moore) is only ± 1.8 km/sec (6 plates).
53	208947	Victoria notes similar spectra of nearly equal intensity.

NOTES TO TABLE VIII—*Continued*

54	212455	(*b*, B3.0; *c*, B5.0; *d*, B4.0.) Mg^{+} 2.2; Si^{+} 2.5. The lines have very sharp cores.
55	214680	N^{++} 0.5.
56	BD 60°2522	Nuclear star in the giant planetory NGC 7635. Type by Miss Payne. Magnitude is photovisual. The HD type is evidently a mistake. The spectrum is described by Hubble (*Ap. J.*, **56**, 186, 1922). Only the *H* lines have been measured here.
57	224151	(*b*, B1.5; *c*, B0.0; *d*, B1.0.) N^{+} 0.1. All the lines are asymmetrical on our plate.

The mean difference between the individual values of M_{sp}, after conversion to the present scale, and M_W is ± 0.88 mag. This value is

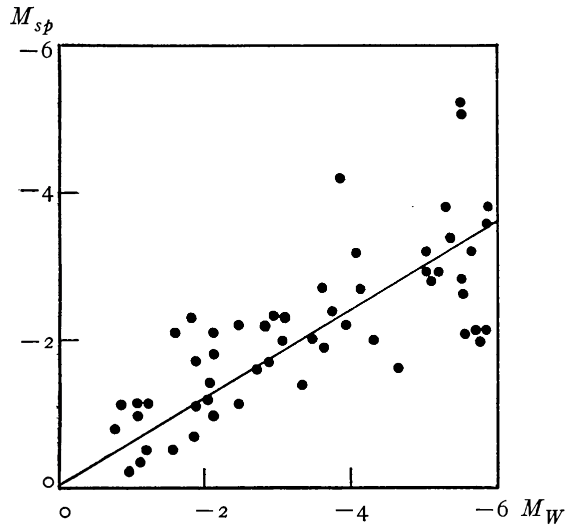

FIG. 10.—Comparison of published spectroscopic absolute magnitudes (ordinates) with those of the present paper (abscissae).

half as large again as the average difference between columns 9 and 10.

Notes following the table give spectral type and authority for determinations differing from the Victoria classification. Types in parentheses are discordant measured values preceded by letters "a" to "g," which refer to the classification ratios given in Table I. The figures following the atomic symbols indicate observed intensities, in terms of the normal for the spectral type.

As is evident from these notes, a large proportion of the stars listed show individual peculiarities the full interpretation of which will need detailed study with higher dispersion. Meanwhile attention may be drawn to some cases presenting such abnormality that they cannot be fitted into the scheme designed for the remainder.

In most of the bright-line B stars the *H* absorption lines, though they may be diffuse, are roughly equal in total intensity to those in normal stars. The spectra of γ Cassiopeiae and X Persei are exceptional in this respect. The total absorption of the very diffuse *H* lines on which the comparatively narrow emission components are centered is unusually low; in addition, the intensity decreases from $H\delta$ to $H\beta$, and in γ Cassiopeiae the latter line is too shallow to be seen on our plates. The *He* lines also are much weaker than in normal stars of the same type. In χ Ophiuchi, B3e, the *H* lines are again weak, but *He* is strong, and normal for a dwarf of this class. Some explanation other than rotation is necessary to account for the dish-shaped lines in these stars.

The spectrum of HD 93521 suggests the admixture of a B3 dwarf and an O-type star. Such a combination would imply an unusually low absolute magnitude for the O component. On the assumption of equality of brightness, the interstellar line intensity gives -1.3 for the absolute magnitude of each star, but the high galactic latitude and considerable distance render this estimate of low weight.

The spectra of the nuclear stars in the giant planetaries NGC 1514, 7635 have been examined by Hubble.[57] He remarks that the Pickering series of He^+ is prominent, λ 4542 being the strongest line other than the lines of *H*, while λ 4686 is faint and hazy. A casual inspection of the first of these objects would, however, suggest a late-B type, for the *H* lines are very strong with wings, typical, in fact, of a B8 dwarf and nearly three times as intense as those in any other O-type star. In addition, as Hubble notes, the Mg^+ line is nearly as strong as λ 4542. The second object has very weak *H* lines. Hubble mentions that the intensity in the ultra-violet is characteristically strong for both stars. For NGC 1514 he finds a photovisual magnitude of 9.4 against a mean photographic value of 8.5 (three observers). The HD visual magnitude is, however, only 8.6. In view of the possible white-dwarf nature of this star, further observations in the region of the Balmer limit would be of great interest.

[57] *Mt. W. Contr.*, No. 241; *Ap. J.*, **56**, 186, 1922.

It may be useful to add a few words on the extension and adaptation of the scheme of classification discussed in this paper to fresh material. In the case of calibrated plates the foregoing procedure could be considerably shortened. Thus, for classification ratios a limited number of suitably chosen and rapidly measurable line depths would suffice. The addition of total absorptions for one or two *H* and *He* lines would provide all the data necessary for settling the luminosity group with some certainty, though an estimate of absolute magnitude based on K-line intensity would be a useful addition. It is obvious, however, that future classifications of large numbers of stars for statistical purposes will continue to be based on visual inspection of uncalibrated spectra. The line ratios customarily used for this purpose are not really consistent with the methods of the present paper; for instance, the use of the ratio of *He* 4471 to Mg^{+} 4481 is clearly inadvisable, at least in types earlier than B6, as the lines are subject to opposite luminosity effects. I prefer to suggest that intensity estimates should be made for two or three of the more prominent lines of each atom, and that ratios based on these estimates should be used to determine the mean type through a simplified form of Table I. The estimation on an arbitrary scale of, say, a dozen of the fainter lines in each spectrum should be a simple matter, for the scale need be consistent only for the one plate.

Precise luminosity grading presents more difficulties. For the later subtypes it must depend on hydrogen-line sharpness; in the earliest types the relative intensities of the metallic and the fainter helium lines will doubtless prove most useful. It is hoped to attempt to establish some such rapid visual method in the near future.

In conclusion, my hearty thanks are due to Professor H. H. Plaskett for helpful discussions and for his interest and advice during the course of this work, and to Dr. J. S. Plaskett and Dr. Pearce for their unpublished proper-motion data.

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