PART VI

THE WAVE-LENGTHS OF THE NEBULAR LINES

AND

GENERAL OBSERVATIONS

OF THE

SPECTRA OF THE GASEOUS NEBULAE

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INTRODUCTORY NOTE

Before attempting to describe the observations which are the subject of this paper I may be permitted to give some account of the manner in which, from time to time, direction has been given to the work to which they relate; for the aim with which that work was begun has been so altered by factors developed by the investigation itself that the purpose toward the end was quite different from that with which it was originally undertaken.

In a former paper[1] I published the wave-lengths of some of the brighter nebular lines. These wave-lengths had been measured for the purpose of investigating the numerical relations between the positions of certain features of the bands in *Nova Persei* No. 2 and the positions of the nebular lines. At that time it was planned to extend the measures to the fainter nebular lines, but other work claimed my attention for a very considerable period, and it was not until about ten years later that the observations were taken up as a sort of stop gap in another investigation, to be fitted in as occasion offered, when one or another of the necessary instruments was available. The observations naturally centered on a few of the bright nebulae which supplied in their spectra all of the known lines, the object being not primarily discovery but rather added accuracy in the measurement of wave-length. This fact accounts for the comparatively large number of observations of three or four of the brightest objects. High and low dispersion spectrographs were used as occasion demanded, one series of plates being secured with a grating. The observations were believed to be complete in the summer of 1914, but the last plate of the series, a long exposure on the nebula N.G.C. 6572, revealed the fact that the center of that object emits the radiation 4686A as a band having a width of about fifteen Angstroms. This line is known to be common to both the nebulae and the Wolf-Rayet stars. In the nebulae it is normally narrow like the other nebular lines and in the Wolf-Rayet stars it is a broad band. Its occurrence as a broad band in a nebula therefore indicated a relationship between the nebulae and this group of stars. The relationship referred to is an important one and is discussed at some length in Chapter III. Further observation showed the presence of four additional bands characteristic of the Wolf-Rayet spectra. The observation appeared to be of sufficient importance to warrant the examination of other nebular nuclei, a work which was undertaken and which constitutes what I may term the second division of the investigation. A detailed account of this phase of the work will be found in later pages. At present I should like to draw attention to the necessity imposed by observations of this sort of accurately following the object under observation, in order to insure that the spectrum of the nucleus will be properly isolated from that of the rest of the nebula. In ordinary observing with an astronomical spectrograph the object is allowed to "drift" so as to furnish long and easily measurable spectral lines, and this practice has in

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[1] *L. O. Bull.*, 1, 153, 1902.

the past undoubtedly been responsible for the concealment of valuable information with respect to the spectra of nebulae. When accurate following was resorted to the nuclei of quite a number of planetaries were satisfactorily photographed, and in addition a number of interesting facts were developed with regard to the localization of lines in some of the nebulae. One of the most striking of these is the peculiar restriction of the radiation 4686A to the inner areas of certain objects, resulting in a shortening of the spectral line. The phenomenon had, unknown at the time to me, previously been observed by Max Wolf in the ring nebula in *Lyra*. The shortening is more pronounced in some nebulae than in others, and the behavior of 4686A is shared by other lines, singularly enough by the members of a group in the immediate vicinity. In an attempt to systematize the data resulting from these observations a number of spectra were arranged in an order determined by the length of 4686A[2] and other lines, and a sequence was obtained in which spectra lying in juxtaposition closely resemble each other while between the extremes there is little in common other than the hydrogen lines and 3727A.[3] The series might have been completed without a considerable hiatus by adding the spectrum of a Wolf-Rayet star without surrounding nebulosity.

Whatever significance this exhibit may have, it seemed at the time to be suggestive of an order of nebular development, and directed attention to the necessity of a study of the distribution of line intensity throughout the nebulae if we are to understand more fully the relationship between these objects and the stars which appear to be forming within them. With respect to such an investigation the method of long and short lines has the obvious limitation of measuring the distribution only along the diameter or other line traversed by the slit, and some form of slitless spectrograph or prismatic camera seemed more suited to the requirements of the proposed observations. It chanced that at about this time I had in hand the re-design of a quartz spectrograph for the Crossley reflector, and this instrument was therefore so constructed that it could be used either with or without a slit. Its performance as a slitless instrument has been most satisfactory. Monochromatic images are recorded from the ultra-violet to $H\beta$ with practically the same faithfulness to detail that characterizes a direct photograph. Figure 2 of plate L illustrates to advantage the definition obtainable with it under the best conditions. The diameters of the slightly elliptical hydrogen rings recorded on this plate are about 2″ by 3″. The instrument has proved most effective in the observation of the distribution of the various lines throughout the nebulae. This phase of the work I have termed the third division. It occupied, almost exclusively, the observing time during the years 1916–17.

To recapitulate, the parts into which the work has divided itself are three in number:

1. The measurement of wave-lengths and the intensities of nebular lines.
2. The study of the nebular nuclei.
3. The investigation of the distribution of nebular radiations throughout the nebulae.

The first chapter is devoted to a description of the observations, the second, third, and fourth to the aspects of the work indicated by the above divisions, while the fifth concerns itself with a number of miscellaneous results.

Acknowledgments are due to Director Campbell for placing at the disposal of this research the necessary instrumental equipment and for the generous provision, by purchase, of optical accessories as the need for them developed. The labor of preparing the observing list was facilitated through the privilege of consulting the extensive series of photographs of planetary nebulae secured by Dr. H. D. Curtis. In the computation of the effect of atmospheric absorption on the nebular lines assistance has been rendered by Miss Mary Heger of the Berkeley Astronomical Department of the University of California. Miss Adelaide Hobe and Magister Holger Thiele of this Observatory have aided in the preparation of the manuscript for publication. The writer desires to express his gratitude for this encouragement and assistance.

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[2] *Proc. Nat. Acad. Sci. Am.*, 1, 590, 1915.

[3] The sequence referred to is that indicated in plate XLV with the addition at the lower end of the spectrum of N.G.C. 40. Better reproductions of individual spectra are found in some of the other plates.

CHAPTER I

OBSERVATIONS OF THE NEBULAE

The following descriptions of the observations of the spectra will, it is believed, be found self-explanatory. Included with the account of each object is a table in which are entered such details of observation as are likely to be required. It has seemed best not to burden the pages with data which will not be used, but if the process of abbreviation has been too thorough supplementary information can be secured by communicating with the Lick Observatory. The letter under the head of Instruments refers to the description, to be found in the appendix, of the particular spectrograph used in the observation.

A majority of the observations were made with the quartz slitless spectrograph (g), and the frequent references to the "images" refer to the monochromatic images given by each line in the spectrum of the nebula.

The dates given are in Greenwich Mean Time.

LIST OF NEBULAE OBSERVED

Object	α		δ		Classification		Nucleus spectrum
					Cannon	Wright	
N.G.C. 40	0^{h}	$7^{m}6$	+71°	32′	Pf	III	continuous and bright bands
I.C. 1747	1	50.3	+62	49	Pd	IIa	continuous and bright bands
I.C. 351	3	41.1	+34	45		Ib	continuous and bright bands?
N.G.C. 1535	4	9.6	—13	0	Pd	Ic	continuous
I.C. 418	5	22.8	—12	46	Pa	III	continuous and bright bands
Orion		30.4	— 5	27	Pb	IIb	
N.G.C. 2022		36.6	+ 9	2	Pf	Ia	continuous
I.C. 2149		48.9	+46	6	Pd	IIb	continuous
I.C. 2165	6	17.1	—12	56	Pe	Ib	
N.G.C. 2392	7	23.3	+21	7	Pe	Ia	continuous and bright bands
N.G.C. 2440		37.5	—17	58	Pe	Ia	
N.G.C. 3242	10	19.9	—18	8	Pe	Ib	continuous
N.G.C. 4361	12	19.3	—18	13	Pf	Ic	continuous
I.C. 3568		30.4	+83	7	Pd	IIa	continuous
N.G.C. 6058	16	1.0	+40	57			continuous
I.C. 4593		7.0	+12	20	Pc	IIb	continuous
N.G.C. 6210		40.3	+23	59	Pe	IIa	continuous and bright bands?
I.C. 4634		55.6	—21	40	Pd	IIa	continuous
N.G.C. 6309	17	8.4	—12	48	Pe	I	
N.G.C. 6543		58.6	+66	38	Pd	IIa	continuous and bright bands
N.G.C. 6572	18	7.2	+ 6	50	Pd	IIa	continuous and bright bands
N.G.C. 6629		19.6	—23	16	Pd	IIb	continuous
N.G.C. 6644		26.4	—25	13	Pd	Ic	
I.C. 4732		27.9	—22	43	Pd	IIa	
I.C. 4776		39.3	—33	27	Pd	IIa	continuous and bright bands?
N.G.C. 6720		49.9	+32	54	Pb	Ic	continuous
N.G.C. 6741		57.5	— 0	35	Pd	Ia	
N.G.C. 6751	19	0.5	— 6	8	Pf	IIa	continuous and bright bands
I.C. 4846		11.0	— 9	14	Pd	IIa	
N.G.C. 6790		17.9	+ 1	19	Pd	IIa	
N.G.C. 6803		26.6	+ 9	52	Pd	IIa	
N.G.C. 6807		29.6	+ 5	29		IIa	
B.D.+30°3639		30.8	+30	18	Ocp	III	continuous and bright bands
N.G.C. 6818		38.3	—14	24	Pe	Ia	
N.G.C. 6826		42.1	+50	17	Pd	IIa	continuous and bright bands
N.G.C. 6833		46.9	+48	42	Pd	IIa	
N.G.C. 6879	20	5.9	+16	38		IIa	continnous
N.G.C. 6884		7.2	+46	10	Pd	Ic	
N.G.C. 6886		8.3	+19	41		Ia	
N.G.C. 6891		10.4	+12	24	Pd	IIb	continuous
I.C. 4997		15.6	+16	25	Pc	IIa	
N.G.C. 6905		17.9	+19	47	Pd	I	continuous and bright bands
N.G.C. 7009		58.7	—11	46	Pe	Ib	continuous
N.G.C. 7026	21	2.9	+47	27	Pe	Ic	bright bands
N.G.C. 7027		3.3	+41	50	Pe	Ia	
I.C. 5117		28.7	+44	10	Pd?	IIa	
I.C. 5217	22	19.9	+50	28	Pd	Ib	continuous and bright bands
N.G.C. 7662	23	21.1	+41	59	Pe	Ib	continuous

The system used in assigning intensities to the nebular lines is explained on page 242. There are two scales, depending on whether the optical parts of the instrument used are of glass or of quartz, Ig corresponding to glass and Iq to quartz.

Two systems of classification are given in the observing list: the well known one developed by Miss Cannon[4] and a tentative system, described in Chapter V, which the writer has found to be useful.

N.G.C. 40. $\alpha = 0^h\ 7^m6;\ \delta = +71°\ 32'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time	Region of Spectrum
1914 Dec. 29.76	685	i	$6^h\ 0^m$	blue-violet
1915 Mar. 3.66	687	i	1 25	blue-violet
Mar. 18.71	689	i	3 0	blue-violet
1916 Aug. 31.92	753	g (slitless)	4 0	ultra-violet

A large dim nebula, nearly circular in outline, brightest at the outer edge, and showing considerable structure. There is a comparatively bright central star, or nucleus.

The character of the spectrum is very well indicated in plates XLIV, figures 3, 4, 5, and L, figure 3. 3727A is the brightest line and forms the most conspicuous of the monochromatic images in plate L, figure 3. Five of the hydrogen images are also shown. These and the bright image are alike in size and structure. N_1 and N_2 are not recorded on this plate, but appear as exceedingly faint lines on the strongest of the slit spectrograms. They seem to be shorter than the other lines, but they are so faint this is uncertain. The slit spectrograms were made with a 5-inch camera, and are on a very small scale.

The relative intensities of the images are:

line	I_q	line	I_q
$H\beta$	51	$H\epsilon$	(15)
$H\gamma$	49	$H\zeta$	(10)
$H\delta$	25	3727	97

The nucleus is exceedingly interesting. It furnishes a Wolf-Rayet spectrum of the most unmistakable type. It was first observed by Paddock, who found the broad band 4650A to be present. This is the brightest radiation in the entire spectrum of the nebula. Prolonged exposure brings out numerous other nucleus bands. The lumpy appearance of the nucleus spectrum is due to the presence of these. Figure 5 of plate XLIV is a cylindrical enlargement which exhibits the details to better advantage. Along the top of the spectrum are indicated the positions of the principal Wolf-Rayet bands given by Campbell. The correspondence is more definitely shown in table 2, where the second column gives, with a single exception, the wave-lengths of bright bands in B.D. +30° 3639, as measured by the writer. The noted exception is 4334A, which is a band found in other stars of this class. The reason for selecting B.D. +30° 3639 for this comparison is that the wave-lengths are better determined in this star than in any of the others, and include the ultra-violet.

Paddock has photographed some of the brighter bands, using several times the linear dispersion of the present observations. He finds that the narrow nebular hydrogen line $H\beta$ broadens in the nucleus to a wide band, and the same is doubtless true of the other hydrogen lines. This behavior is analogous to that of 4686A in N.G.C. 2392, which furnishes another of the few

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[4] *Ann. H. C. O.*, 76, 19, 1914–16.

cases that have come under my observation of the occurrence in the same object of a nebular line and nucleus band of identical origin. The phenomenon would appear to be of comparatively rare occurrence.‡

TABLE 1

N.G.C. 40. WAVE-LENGTHS

No. 753* (slitless)	No. 685	No. 687	No. 689	Means	Remarks
331±	....	....	....	331±	Beginning of recorded continuous spectrum
(335±)	....	....	....	(335±)	suspected v. ft. nucleus band
3385±	....	....	....	3385±	nucleus band
3403±	....	....	....	3403±	nucleus band
3412±	....	....	....	3412±	nucleus band rather bright
3449±	....	....	....	3449±	nucleus band v. ft.
(3493±)	....	....	....	(3493±)	suspected v. ft. nucleus band
3561±	....	....	....	3561±	nucleus band
3609±	....	....	....	3609±	nucleus band
3690±	....	....	....	3690±	nucleus band
....	3726	....	....	3726	strong nebular line
3759±	....	....	....	3759±	nucleus band
....	3834	....	....	3834	v. v. ft. nebular line
3889±	3889	....	....	3889	nucleus band
....	3890	....	....	3890	v. ft. nebular line
....	3913	....	....	3913	v. v. ft. nebular line
3925	....	....	....	3925	nucleus band v. broad
3963	....	....	....	3963	nucleus band
....	3969.6	....	....	3970	ft. nebular line
....	4029	4028	4027	4028	ft. nucleus band
....	4071	4068	4069.4	4069	strong nucleus band
....	4101.7	....	....	4102	fairly strong nebular line
....	....	4121	4122	4122	v. ft. nucleus band
....	....	4155	4157	4156	rather ft. nucleus band
....	....	4184	4186	4185	v. ft. nucleus band
....	....	4228	4232	4230	rather ft. nucleus band
....	....	....	4250	4250	edge
....	....	4268	....	4268	center broad nucleus band probably compound
....	....	....	4277	4277	edge
....	....	....	4323	4323	strong nucleus band
....	....	4329	....	4329	center of broad double band
....	....	....	4336	4336	nucleus band, a shade fainter than preceding
....	4340.6	....	....	4341	strong nebular line
....	....	4371±	4378	4377	ft. nucleus band, extra broad
....	....	....	(4412)	(4412)	suspected ft. nucleus band
....	4443	4441.4	4442.6	4442	strong nucleus band
....	....	....	(4474)	(4474)	suspected ft. nucleus band
....	....	4514	4513	4514	fairly strong nucleus band
....	....	4543	4547	4545	ft. nucleus band
....	4652	4653	4653	4653	extremely strong nucleus line
....	4686.6	4686.1	4687.0	4686.6	v. strong nucleus band
....	....	4786.6	4786.3	4786	ft. nucleus line
....	4863	....	....	4863	strong nebular line
....	....	4858	4860	4859	fairly strong nucleus band
....	....	4922±	4917±	4920	v. v. ft. nucleus band
....	4960±†	....	....	4960	v. ft. nebular line
....	5010±†	....	....	5010	v. ft. nebular line

* These wave-lengths are determined by extrapolation and are therefore uncertain.

† These lines are so faint that it is impossible to describe them accurately. They are probably shorter than the hydrogen lines, and N_1 impresses one as being strengthened in the nucleus. A longer exposure would be required to settle these points.

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‡ The astronomers of Harvard College Observatory have called attention to the spectrum of this nebula (*H.C.O. Circ.*, No. 98, 1905; *Ann. H.C.O.*, **76**, 40, 1916) as possibly being intermediate between a nebula and a fifth type (Class O) star. "Its spectrum resembles the fifth type, its appearance is that of a nebula." The spectrum is reproduced in plate 1 of the second of the references just given.

The relationship of the nebulae to the stars is such an important one that it seems appropriate to examine this statement somewhat critically, particularly in view of the vagueness of the context from which it is taken. The spectrum is shown in the publication referred to in juxtaposition with the spectrum of N.G.C. 7662, and, aside from the weakness or absence of N_1 and N_2, there is little to differentiate it from the spectrum of a nebula in which 4686A (which is the wave length assumed, incorrectly as Paddock has pointed out, for the brightest spectrum band) is unduly strong. Furthermore, this critical band, which is actually broad, appears narrower than the really monochromatic nebular lines. As indicated in the present text the spectrum has stellar characteristics, but they are due to the involved star and not to the nebula, which is quite a large one. An objective prism spectrogram of the *Orion* nebula would present a combination of stellar and nebular spectrum, analogous in certain respects to the one under discussion, yet we should hardly venture to say of that object that its spectrum resembles one of a Class B star, while its appearance is that of a nebula.. In any event attention should be directed to the fact that the stellar characteristics pertain to the stellar nucleus, and not to the comparatively large nebula as the context of the reference appears to indicate.

A valuable account of certain features of the spectrum of N.G. C. 40 is given by Paddock (*Lick Obs.*, *Bull.*, **9**, 30, 1915).

TABLE 2

COMPARISON OF NUCLEUS OF N.G.C. 40 AND WOLF-RAYET SPECTRUM

N.G.C. 40 nucleus	W–R bands	N.G.C. 40 nucleus	W–R bands
(335)	334	4185	4188
3385±	....	4230	4230
3403	3404	4268 broad	4267
3412	3414	4323	4326
3449	....	4336	4334
(3493)	....		$H\gamma$
3561	3564	4377 broad	4368
3609	3611		4385
3690	....	(4412)	4416
3759	3760	4442	4441
3889	3889	(4474)	4472
3925 broad	3920	4514	4517
3963	3962	4545	4543
4028	4027	4653	4652
4069	4070	4687	4687
4102	$H\delta$	4786	4786
4123	4122	4859	$H\beta$
4156	4155	4920	4923

I.C. 1747. $\alpha = 1^{h}\ 50^{m}3$; $\delta = +60° 49'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 Nov. 24.80	800	g (slitless)	$2^{h}\ 0^{m}$
1917 Sept. 16.90	865	g (slitless)	4 0

A small elliptical ring with a very faint nucleus. The object is too faint to furnish intensity measurements of much value, the line $H\delta$, for instance, being barely discernible on the stronger plate.

NEBULAR LINES

line	I_q	line	I_q
N_1	200	$H\delta$	trace
N_2	110	3967	(40)
$H\beta$	50	3869	(60)
$H\gamma$	(50)	3727	trace

The nucleus gives a faint continuous spectrum with a broad emission band estimated roughly to extend from 4640 to 4700A.

I.C. 351. $\alpha = 3^{h}\ 41^{m}1$; $\delta = +34° 45'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 Sept. 5.99	765	g (slitless)	$1^{h}\ 38^{m}$
Sept. 24.93	771	g (slitless)	4 10
1917 Oct. 23.89	876	g (slitless)	3 0
Dec. 12.70	897	g (slitless)	3 0

A small slightly elliptical nebula. Direct photographs show an apparently uniform disc, but, as sometimes happens, this is due to the fitting together of component images of different forms and sizes. 4686A gives a small, almost stellar pattern not more than $2''5$ in diameter at most, while the remaining images are ellipses showing condensations at the ends of the major axis. The distance between these condensations is about 5″. In an integrated image, such as is secured by a direct photograph, the 4686 image fills in between these condensations and gives the general appearance of a uniform disc. The following are the lines with their relative photometric intensities:

NEBULAR LINES

line	I_q	line	I_q
N_1	182	(3967+ Hϵ)	35
N_2	110	Hζ	(15)
Hβ	53	3868	55
4686	58	Hη	(10)
4363	18	Hθ	(5)
Hγ	47	3445	(17)
Hδ	26		

There is a very faint continuous nucleus spectrum which affords a suggestion of broad emission bands.

N.G.C. 1535. $\alpha = 4^{h}\ 9^{m}6$; $\delta = -13^\circ\ 0'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time	Region of Spectrum
1914 Dec. 7.83	683	a	4^h 30^m	blue-violet
Dec. 22.76	684	i	5 0	blue-violet
1916 Sept. 26.98	777	g (slitless)	2 50	ultra-violet

A slightly elliptical ring lying on a uniformly illuminated circular disc. The outer diameter of the ring is about 18½″ and that of the background 40″. There is a very strong central star.

4686A gives an image about 10 or 15 per cent smaller than the hydrogen set, and, judging from the appearance of the lines 4363, 4712, and 4741 on the small scale slit spectrograms, these images are also small, though this is not so certain. The three last mentioned lines are faint and hardly record on the slitless spectrogram. The other images are of about the same size as those due to hydrogen.

NEBULAR LINES

line	I_q	line	I_q
N_1	155±	4471	(5±)
N_2	109±	4363	(20±)
Hβ	52±	Hγ	48±
4741	(10±)	Hδ	25±
4712	(5±)	(3967+ Hϵ)	31±
4686	(25±)	3889	(20±)
		3869	63±

The above measurements were made on a single plate and the results are therefore only approximate.

The nucleus gives a continuous spectrum. The hydrogen lines are dark.

I.C. 418. $\alpha = 5^{h}\ 22^{m}8$; $\delta = -12^\circ\ 46'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time	Region of Spectrum
1913 Feb. 18.75	439	f	1^h 27^m	ultra-violet
Mar. 14.68	444	a	1 40	blue-violet
1914 Oct. 21-22	654	a	6 10	blue-violet
Nov. 10.94	665	a	4 10	blue-violet
1916 Oct. 25.94	788C	g (slitless)	0 5	ultra-violet
Oct. 25.94	788D	g (slitless)	0 15	ultra-violet
Oct. 25.97	789	g (slitless)	1 0	ultra-violet
1917 Oct. 27.00	877	g (slitless)*	2 10	ultra-violet

* Photographed on a lantern slide plate.

This is a slightly elliptical nebula with a bright central star. In the telescope its appearance, except for the star, is that of a uniformly illuminated disc.

The spectrum is shown in plates XLV and XLIX, figure 4. It is comparatively simple, the principal lines being 3727A, N_1, N_2, and those of hydrogen. The hydrogen image and the one at 3727 are not discs, but small rings, a fact which is not readily perceived, however, unless the photographic density is just right, because the images are traversed by the strong continuous spectrum of the nucleus. 3727A gives the largest image and the best defined ring. It is uniform and does not exhibit any mottling or curdling such as is sometimes found in the corresponding images of other nebulae. It is more elliptical than the other rings.

At first glance the hydrogen images appear to decrease in size from line to line with decreasing wave-length, but the difference is, I believe, only apparent, and due to difference in intensity. On comparing plates of unequal exposure so as to match, in intensity, the different images of the series, one with another, the apparent inequality disappears.

The images N_{1-2} were discovered by Dr. Campbell, who observed the nebula in 1893,[5] to be smaller than the image at $H\beta$. His measures of the three diameters are:

$$N_1 = 11'', \ N_2 = 9'', \ H\beta = 14''.$$

The present investigation confirms this early observation with respect to the smaller size of the two nebular images as compared with that of $H\beta$, but not the difference in size of the first two images. While there is apparently such a difference on all of the plates, I am nevertheless inclined to think that the discs are actually equal in diameter, and that the seeming difference is due to the character of the images. These lines do not give ring-shaped patterns, such as the hydrogen lines and 3727A do, but nebulous discs which fade in intensity from the center outward. On account of this fact, the measured diameter will depend on the brightness, and N_1 being the brighter line will appear to give the larger image. However that may be, the diameters on the photographs certainly vary with the exposure time. On plate No. 789, which was exposed for an hour, N_2 is more intense and larger than N_1 is on 788 D, exposed for 15 minutes. The diameters as measured approximately on these two plates are as follows:

Line	Diameter (E and W)*	
	1 hr. exp.	15 m. exp.
N_1	11″.5	9″
N_2	10.5	8
$H\beta$†	13 (over-exposed)	12

* The difference in intensity between N_1 and N_2 is less photographically than it is visually, and one would expect less difference in the apparent diameters, when measured on a single plate than when determined directly by the eye. This seems to be the case. Photographic diameters from the same plate differ by only 1″, while visually the difference appears to be about 2″.

† Outside diameter of the ring.

The measures are inexact, but they serve to show the effect of increased density on diameter. From the appearance of the images I am inclined to think that with equal density N_2 would appear equal in size to N_1, and that the two discs are equal. The matter is of some importance, as the inequality, if proved, would establish a difference in the behavior of these two lines which appear to belong together.

The three discs due to N_1, N_2, and $H\beta$ have been described by Campbell as being brightest at the center and fading gradually as the edges are approached, but that $H\beta$ is more uniform than the others. My own observations confirm this with respect to the first two discs, but the third shows the ring structure quite unmistakably.

A comparison of all of the plates indicates the following order in size of the images:

$$3727 > \text{Hydrogen} > 4471 \text{ (Helium)} > N_{1-2}.$$

The inequality in the last two members is uncertain on account of the difference in the character of the images. 4471A appears to have a definitely defined edge, while the N images are nebulous.

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[5] *Astron. and Astrophysics*, **13**, 494, 1894.

The relative size will therefore vary with exposure time. The N discs are sensibly round, the hydrogen rings slightly elliptical, and the 3727 ring more elliptical still.

The integrated image of the nebula as viewed in a telescope is a disc for the reason that the N_{1-2} images fill in the $H\beta$ ring. The same is true, in a less degree, of the nebula as photographed. The different images tend to nest one within another, but plates, insensitive to N_{1-2}, such as the lantern slide, may give indications of a hollow interior.

NEBULAR LINES

line	I_q	line	I_q
N_1	33	4068	(10)
N_2	22	4026	(7)
$H\beta$	51	$H\epsilon$	20
4471	10	$H\zeta$	18
4388	(1)	$H\eta$	17
4363	(1)	$H\theta$	12
$H\gamma$	49	$H\iota$	(9)
$H\delta$	29	$H\chi$	(8)
4076	(2)	3727	85*

* The relative intensity of the components of the doublet, as estimated on slit spectrograms, is about 2 : 1, 3726 being brighter than 3729A.

The intensities of the lines according to the system established by the slitless quartz spectrograph are given in the usual table. Wave-lengths as measured on the slit spectrograms are given in table 3. There are so many faint and uncertain lines among them that it seems preferable to give the measures for each plate, rather than the means. There are included some lines which do not appear in the intensity table. These are so faint that their strength cannot well be estimated.

TABLE 3

I.C. 418. WAVE-LENGTHS

1914 Oct. 21-22 No. 654	Nov. 10.94 No. 665	Remarks
3726.11	3726.30	long, strong
3728.85	3729.04	long, fairly strong
3835.56	3835.54	very faint
....	3869.0±	v. v. ft. extends out into nebula
3889.13	3889.02	long, strong, probably compound helium and hydrogen
3965.6±	3964.4±	v. v. ft.
3970.25	3970.17	long, strong
4026.23	4026.57	v. ft.
(4062.4)	....	suspected v. v. ft. line
4068.74	4068.61	ft., long
4076.43	4076.0	v. ft., long
4101.91	4101.93	long, v. strong
4122.3±	....	v. v. ft., v. short
4200.5±	....	v. difficult dark line
4267.9	....	v. v. ft., length uncertain
(4325)	....	suspected v. v. ft. nucleus band
4340.55	4340.65	long, v. strong
4363.4	....	v. v. ft.
4388.5	4387.5	v. v. ft., extends out
4471.76	4471.71	fairly strong, medium length
4483.0	....	dark line
4541.7	4541.2±	strong dark line
4571.4±	4572.6±	v. v. ft., only certain in nucleus
(4640.4±)	....	suspected v. ft. nucleus band
4649.0±	4649.9±	ft., nucleus only
4685	4686.8±	nucleus line, v. ft. and difficult
4861.2	4861.5	long, v. strong
4922.8	4921.5	v. ft.
4959.0	4959.1	medium length, strong
(4972.6±)	(4971.9±)	suspected v. ft. nucleus band
5007.0	5007.0	medium length, strong

The spectrum of the nucleus is strong and continuous, with bright and dark bands, as indicated in table 3.

Orion Nebula. $\alpha = 5^h\ 30^m4$; $\delta = -5°\ 27'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time	Region of Spectrum
1908 Dec. 17.81	1	c	$7^h\ 0^m$	blue-violet
1912 Jan. 12.78	348	h	4 0	$H\beta$-N_1
Jan. 30.76	350	h	4 0	$H\beta$-N_1
Jan. 31.77	351	h	5 50	$H\beta$-N_1
Nov. 22.95	424	f	2 15	ultra-violet
1913 Feb. 14.78	438	a	2 30	blue-violet
Mar. 9.69	443	a	3 2	blue-violet
Feb. 25.77	597	i	4 36	blue-violet
Mar. 15.66	601	a	3 25	blue-violet

The spectrum has been observed only for the purpose of measuring the wave-lengths of lines, no attempt having been made to study the line distribution through the nebula. That the nebula is not homogeneous is well known. Campbell was the first to prove it with respect to $H\beta$ on the one hand and the two chief nebular lines on the other. Since then it has been found by Hartmann and others that the line at 3727A has a distribution peculiar to itself. The object affords an interesting subject for study, but the apparatus available in the present investigation is not suitable for the observation of anything so large. No attempt has been made, therefore, to extend the results of previous investigators with respect to the homogeniety of the nebula.

Wave-lengths of the lines, measured except as noted, with a single-prism spectrograph attached to the 36-inch refractor, are given in table 11.

N.G.C. 2022. $\alpha = 5^h\ 36^m6$; $\delta = +9°\ 2'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 Dec. 13.86	898	g (slitless)	$4^h\ 0^m$

An elliptical ring nebula resembling, somewhat, in general appearance N.G.C. 7009 and N.G.C. 7662. Direct photographs show condensations at the extremities of the major axis of the ellipse. In the slitless spectrograms these condensations occur in the N_1, N_2, and 3869 images, being particularly strong in the first two. The other lines hardly appear to show them. The line 3727A, which usually surpasses all others in the depiction of these outlying condensations, is not present.

There is little difference in the size or shape of the images, except that the one at 4686 is noticeably less elliptical than the others, and the illumination within the space enclosed by this ring is relatively strong. The ultra-violet line at 3426 is rather faint, and it is not possible to form an accurate estimate of its relative size nor of the intensity distribution within it.

The spectrum of the nucleus is continuous, and, as is the case with the spectra of all of these nuclei, it extends with almost undiminished intensity far into the ultra-violet. Although faint throughout its length, it can readily be traced to 3450A.

The spectrogram is hardly suitable for measurement with the photometer. The lines in the order of their estimated intensities are:

$$N_1,\ 4686,\ H\gamma,\ H\beta = N_2 = 3869,\ H\delta = (H\epsilon + 3967),\ 3426.$$

I.C. 2149. $\alpha = 5^h\ 48^m9$; $\delta = +46°\ 6'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 Oct. 26.90	791	g (slitless)	$3^h\ 0^m$
Oct. 27.00	792	g (slitless)	1 0

A small, very much elongated elliptical nebula. The nucleus is a comparatively bright star. The hydrogen series is relatively strong and can be followed to Hχ (3750A). Two more lines would probably be visible were it not for the strong nebular line at 3727A.

NEBULAR LINES

line	I_q	line	I_q
N_1	79	(3967+ Hϵ)	29
N_2	49	Hζ	22
Hβ	50	3869	26
4471	16±	Hη	10
Hγ	50	Hθ	(8)
Hδ	37	Hι	(6)
4069	trace	Hχ	(4)
4026	trace	3727	55

The monochromatic images are fairly uniform elliptical discs. They appear at the first glance to differ in size, but a comparison of the two plates, which were made with different exposures, shows that this is, in nearly every case, an effect of relative intensity. 3727 is quite certainly the largest, but it is doubtful whether there is much difference among the other images.

The central star records a continuous spectrum. It is very bright, quite bright enough for observation with a slit spectrograph. It should be observed with such an instrument for the purpose of determining more precisely the character of its spectrum.

I.C. 2165. $\alpha = 6^{h}\ 17^{m}.1$; $\delta = -12^{\circ}\ 56'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 Dec. 19.88	899	g (slitless)	1^{h} 0^{m}
Dec. 20.85	901	g (slitless)	1 40

Photographed directly the nebula appears as a nearly circular uniform disc about 8″ or 10″ in diameter. The images recorded on the spectrograms show some differences among themselves. 3426A gives the smallest image and 4686 the one next in size. 3727, though faint, gives the largest image, and both the 3967 and 3869 discs are larger than those due to hydrogen. The N_1 and N_2 discs also appear larger than the latter, but they are more intense, and the effect may be due to this fact. The 3727A image is a ring, that is, it is hollow. The others are discs, though some of them are perhaps relatively a little weak in the center; in other words, there are indications of a tendency toward a ring structure in all of the images.

NEBULAR LINES

line	I_q	line	I_q
N_1	194	Hδ	26
N_2	108	(3967+ Hϵ)	34
Hβ	53	Hζ	15
4740	(8)	3869	51
4712	(8)	Hη	(5)
4686	55	Hθ	(4)
4640	(10)	3727	19
4471	10	3445	(4)
4363	27	3426	10
Hγ	47		

N.G.C. 2392. $\alpha = 7^{h}\ 23^{m}3$; $\delta = +21^{\circ}\ 7'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time	Region of Spectrum
1914 Nov. 7.85	663	a	1^{h} 4^{m}	blue-violet
1915 Mar. 2.78	686	a	4 6	blue-violet
Mar. 3.78	688	i	4 10	blue-violet
1916 Mar. 28.78	711	i	2 0	blue-violet
Mar. 29.73	712	i	4 0	blue-violet
Apr. 2-3	713	a	8 20	blue-violet
Nov. 24.96	801	g (slitless)	1 30	ultra-violet
Nov. 24.94	803	g (slitless)	6 5	ultra-violet
Dec. 20-29	804	a	14 50	blue-violet
1917 Jan. 9-10-12-13	806	e	18 0	blue-green

This is the double-ring planetary in *Gemini*. It consists of a bright nucleus, surrounded by a strong continuous and nearly circular ring. The nucleus is a little eccentric with respect to the ring. Outside of this bright ring is a second and much fainter ring, circular in general outline but badly broken or curdled. These rings appear to lie on a faint uniform disc of nebulosity almost exactly circular and having a diameter slightly greater than that of the larger ring.

The general features of the spectrum are shown in the illustrations better than they can be described. Figure 1 of plate XLVII is a reproduction of spectrogram No. 803. The dimensions of the system seem to be about the same for all wave-lengths, but there are pronounced differences in intensity distribution. One of the most striking features is the intensity of the outstanding lobe in the image at 3727A and its absence from the image at 3426. In 4686A the lobe is relatively weak. The same may be said, in fact, of the whole outer ring, of which this lobe is a part; it is relatively intense in the 3727 image, of, let us say, normal intensity in the hydrogen and N images, a trace in 4686, and absent in 3426. 3445A is too faint to permit of a judgment as to the presence or absence of the outer ring. All of the images of sufficient intensity show the faint circular background except 3727A, from which it appears to be absent. It is particularly easy to see in 4686 and 3426, where its visibility is not interfered with by the outer ring. All of the images of the inner ring resemble each other very closely.

NEBULAR LINES

(Intensities in bright ring)

line	I_q	line	I_q
N_1	(170±)	$H\gamma$	50
N_2	85	$H\delta$	29
$H\beta$	50	(3967+ $H\epsilon$)	28
4740	trace	3869	60
4712	trace	3727	34
4686	70	3426	35
4363	37	3346	11

Observed with a slit spectrograph the spectrum is a remarkably interesting one. Unfortunately the observations are not so extensive as one could wish. This has resulted from the comparative faintness of the nebula as well as from the fact that it is a winter object, and it is therefore difficult, with the uncertain weather of that season, to arrange for exposures extending over several nights, such as are essential to the adequate investigation of the spectrum.

The best of the slit spectrograms is No. 713 (plate XLIII), which was taken on the evenings of April 2 and 3, 1916. It was made on a Seed No. 23 plate. These plates, while comparatively slow for faint astronomical subjects, possess advantages in the way of fineness of grain and contrast which are particularly valuable in depicting the spectrum of this object. The following description of the spectrum is based on an examination of all of the plates.

The line 4686A on crossing the nucleus is broadened into a band about 2A wide. There are two similar bands in the spectrum of the nucleus at 4634 and 4641, but they do not appear to extend out into the nebula. None of the lines except 4686A is intensified or broadened on crossing the nucleus spectrum. A very remarkable feature of N_1 and N_2, which is perhaps shared by Hβ and other hydrogen lines, is their strong curvature. They are roughly in the form of a bow, the convex side of the bow lying toward the red. On the low dispersion plates the line 4686A does not appear to share the curvature. This line differs so in its general habits from most of the other nebular lines that it has seemed to me of interest to inquire whether it is subject to the same peculiar distortion as they. In the laboratory the line is particularly resistant to resolution by the Stark effect,[6] which has been suggested as a contributing cause of the disturbance of the nebular lines. An attempt was made to photograph the line with three prisms, devoting to this purpose an exposure of 18 hours on four successive nights, but observing conditions were poor and the observation is inconclusive. It is quite certain, however, that the line is subject to disturbance as it enters the dark area within the ring, but whether this disturbance corresponds exactly with that of N_1 and N_2 is not determined. The observation should be repeated under more favorable conditions. A somewhat similar observation of the line in N.G.C. 7662 was more successful and is of interest in this connection.

The hydrogen lines are reversed in the nucleus, that is, they occur there as dark lines. These dark lines do not appear to share the displacement of the bright curved nebular lines in the immediate vicinity of the nucleus, but, within error of observation, correspond in wave-length with the lines in the ansa. An explanation of the curvature of the nebular lines as the result of velocity in the line of sight would have to take account of this fact. The reversal in the nucleus of the Hβ line is not so certain as that of the members above it. The spectrum of the nucleus is under-exposed here, which partly accounts for that fact, but there is the additional complication introduced by the greater strength of the emission line as well and the comparative weakness of absorption. On those plates which show the details of the nucleus spectrum the nebular hydrogen lines, with the exception of Hβ, which is the strongest, are visible only in the bright ansa. They are not recorded in the comparatively dark area within. The bright Hβ line can be followed close up to the nucleus, where it becomes somewhat confused with a dark line in measured position 4959, which I assume to be that part of the dark Hβ line left by the displaced bright line. The dark Hβ being weaker than Hγ, which in turn is less intense than Hδ, shows progressive strength of these absorption lines with decreasing wave-length. The contrary is true with respect to the nebular emission lines; they increase in intensity with wave-length. There seems to be a significant parallel between this nebular nucleus and those Class B stars which have dark hydrogen lines with bright borders, usually on the red edge, and the observations furnish the suggestion that the red edge in these Class B stars may be the same phenomenon which is exemplified in the displacement of the middle of the nebular bright line.

Besides those due to hydrogen, there are numerous dark lines in the spectrum of the nucleus. These are recorded in table 4. One of the strongest is 4471A, due to helium, but perhaps the most significant are the members of Pickering's ζ *Puppis* series, with the primed subscripts, and 4097A. The spectrum conforms quite closely to the Harvard Class Oe, the main difference lying in the relatively greater strength of the helium lines.[7] Table 4 affords a basis for comparison with the spectrum of 29 *Canis Majoris,* the typical Class Oe star. The data for this star are taken from Miss Cannon's table[8] of lines in the Class O stars, and the estimates of intensity of the nucleus lines were made so as to conform as well as possible to those adopted for the star.

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[6] Evans and Croxson, *Phil. Mag. VI,* 32, 327, 1916.

[7] 4712A is the only one of the reasonably strong helium lines not represented. It may be masked by the presence of the weak nebular line at 4711A.

[8] *Annals H. C. O.,* **28**, 233.

TABLE 4

Nucleus N.G.C. 2392		29 Canis Maj. (Oe)		
λ	i	λ	i	
(3933)	....	3933.8	2	
(3964)	....	....	....	He
(3970)	....	3970.2	25	
4026	20	4026.4	20	He–Hε′
(4083)	5±	....	....	
(4089)	5±	4089.2	6	
4097.4	20	4096.9	18	
4101.9	30	4101.8	25	
(4113)	5±	4116.2	3	
(4120)	5±	4120.5	2	He
(4124)	5±	....	....	
4143.3	8	4144.0	3	He
....		4186.2	1	
4200.5	10	4200.7	5	Hδ′
4340.6	25	4340.7	25	
....		4367.3	2	
4387.4	8	4387.8	3	He
4471.3	25	4471.8	15	He
(4480.2)	8	4481.4	1	
....		4514.5	5	
4542.4	10	4542.4	5	Hγ′
4634.2	*15*	*4633*	*3*	
4641.0	*15*			
4685.9	*30*	*4688*	*8*	
....		4712.8	4	He
4859±	15±	4861.5	15	

Enclosure by parentheses indicates that the line is only suspected.
Italics indicate emission bands, Roman type dark lines.

As indicated in the text, some of the lines in this nebula are sensibly distorted in such a manner as to give them the appearance of a bow with the convex side toward the red. Since the wave-lengths in the nucleus must be corrected to normal by means of measures of the nebular lines of known wave-length, it is a matter of choice as to which part of the line to use for the purpose. In reducing the observations for this table the wave-lengths in the ansa were assumed to be normal and it is significant that on this bases the dark nucleus lines Hγ, Hδ and 4471 assume their normal values. A reference to the wave-length of Hβ is made in the text.

N.G.C. 2440. $\alpha = 7^h\ 37^m5$; $\delta = -17°\ 58'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 Dec. 20.94	902G	g (slitless)	1^h 15^m
1918 Feb. 9.78	902A	g (slitless)	2 45

A small dumbbell nebula with faint exterior nebulosity. In appearance it strongly suggests N.G.C. 7026, and the spectra of the two objects are somewhat alike, though with the important difference that the ultra-violet lines at 3346, 3426, and 3445A are present in N.G.C. 2440 and have not been observed in the other. 4363 is also somewhat stronger.

There is a very pronounced difference in size in the images, 3727A being as usual the largest and 3426 the smallest of the brighter ones. 3346A is probably of the same size as 3426, but it is too faint to permit of an accurate estimate. The relative dimensions are indicated by the following measured separations of the two chief condensations in the nebula. As stated elsewhere, these measurements are merely approximate and are subject to small errors due to distortion of field which have not been fully determined. I believe, however, that they are competent to decide the question of relative size, the only cases in doubt being the extreme lines N_1 and N_2, which are farthest from the center of the field and from minimum deviation.

line	distance center to center
3426	3.″1
4686	5.3
Hβ–Hδ	5.7
N_1–N_2	6.4
(3967+ Hε)	6.3
3869	6.5
3727	8.3

The third image from the last is a composite of two which are probably of different size, the Hϵ component being presumably equal to the other hydrogen impressions while 3967 is perhaps comparable with 3869.

NEBULAR LINES

line	I_q	line	I_q
N_1	280	(3967+ Hϵ)	24
N_2	175	3869	62
Hβ	49	3727	52
4686	62	3445	(4±)
4363	(20)	3426	(50±)
Hγ	51	3346	(5)
Hδ	20		

In both plates Hγ appears to be unduly bright. This may be due to partial overlapping of the images at 4363A, but this hardly seems sufficient to account for the increase. As shown by the measurements, Hγ is about equal in strength to Hβ, while Hδ is relatively faint.

There is no trace of a nucleus spectrum.

N.G.C. 3242. $\alpha = 10^h\ 19^m9$; $\delta = -18°\ 8'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 Apr. 5-6	809	a	$9^h\ 30^m$
Apr. 27.75	816	g (slitless)	0 45
Apr. 28.72	819	g (slitless)	2 0
Dec. 20.01	900	g (slitless)	3 48

The nebula is a somewhat irregular elliptical ring lying on a background of comparatively uniform nebulosity. In appearance and in size it bears a striking resemblance to N.G.C. 7662, and the likeness extends in an even more remarkable degree to the spectra of the two objects. Except for the fact that the line 3426 is relatively faint in N.G.C. 3242, and that the image at 3727 is a little less complicated, the spectra appear to be identical. While the nebulous background on which the ring rests is more uniform in N.G.C. 3242 than in 7662, the spectrum of the latter object, as shown in plate XLVI, will serve to illustrate the appearance of that of the former.

The nebulous background is missing for the image at 4686A, and probably for the faint neighboring images and the far ultra-violet images as well. As not infrequently happens, the image at 4686 is rounder, that is, less elliptical, than the other images. The far ultra-violet rings present the same appearance, but here it is, in a measure at least, due to the fact that the light traverses the prisms out of minimum deviation, and therefore elongates the image in the direction of the spectrum. The major axis of the 4686 ring is slightly shorter and the minor axis somewhat longer than is the case of the hydrogen, N, and other images. 3727A is somewhat indistinct, but is pretty much concentrated in nuclei at the extremities of the major axis of the ellipse. These outlying condensations occur to a less marked degree in the other images, except those of the 4686 group and the ultra-violet group. The hydrogen images can be followed to the line 3727A.

The intensity measurements refer to the ring. They are uncertain on account of the variation of the background from line to line, and also because the relative intensities of the several lines are not the same in different parts of the ring. Most of the lines are strongest at the extremities of the major axis, while 4686A is at its best at the ends of the shorter diameter. Subject to more than the usual uncertainty, the intensities are as follows:

NEBULAR LINES

line	I_q	line	I_q
N_1	184	Hδ	34
N_2	123	4026	(5)
Hβ	50	(3967+ Hε)	40†
4740	(6)	Hζ	*
4712	(5)	3869	71
4686	49	Hη	*
4640	(5)	Hθ	(5)
4542	(5)	3727	16‡
4471	(8)	3445	23
4363	(15)	3426	(4)
Hγ	51	3342	(5)
4200	(5)	3313	(2)

† These lines are not separated on the slitless spectrograms from which these intensity estimates were derived. They are, however, resolved on plate 809, on which their relative intensity appears to be about 1 : 4, 3967 being the stronger.

* Too close to 3869A for complete separation in this object.

‡ The measurements for this line refer to the condensations at the extremities of the ellipse.

The continuous spectrum, found in so many of the planetary nebulae, which begins at about the limit of the Balmer hydrogen series and extends into the ultra-violet, is relatively quite strong. In breadth it extends to the limits of the bright ring. The nucleus has the characteristic spectrum. It extends far into the ultra-violet, reaching well above 3300A, or practically to the silver transparency band. It is apparently continuous.

N.G.C. 4361. $\alpha = 12^{h}\,19^{m}.3$; $\delta = -18^{\circ}\,13'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 Apr. 12.80	714	i	5^h 0^m

This is a large oval nebula with a strong central star and two spiral extensions or streamers, giving it the appearance of a spiral nebula. It can hardly be classed as such, however, as the spectrum is gaseous. It is unfortunately too large to be observed advantageously with the slitless spectrograph, and the spectrum has accordingly been photographed only with the slit instrument, using a single prism and a very short camera. The linear dispersion of the spectrogram is very low.

The spectrum is different from that of any nebula that I have observed in that it presents the line 4686A as a strong, long line in conjunction with what might otherwise be called a hydrogen type of spectrum. This line is the most intense in the spectrum, being fully twice as strong as any of the others. It also appears to be quite as long as any of them. The two nebular lines N_1 and N_2 are relatively faint, the former being scarcely as bright as Hβ. Usually 4686A appears as a nebular line only in objects in which these two lines are strong. The order of intensity is as follows: 4686, Hβ = Hγ, N_1, Hδ, N_2, Hε, 4363.

The spectrum of the nucleus is continuous, at least no bright or dark bands are visible with the comparatively low dispersion used in this observation.

I.C. 3568. $\alpha = 12^{h}\,30^{m}.4$; $\delta = +83^{\circ}\,7'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 May 11.76	821	g (slitless)	2^h 0^m
June 18.76	824	g (slitless)	1 0
June 18.78	825	g (slitless)	0 15

A small, slightly elliptical nebula lying on a faint circular background of nebulosity. The nucleus is stellar. There is little to remark about the spectrum. The nebulous background, or halo, shows about the brighter monochromatic images. 4686A is absent from both nebula and nucleus. The different images appear to be of about the same size, though it is difficult to judge accurately in such a matter when the object is so small and the image intensities different. The following lines are the only ones recorded.

NEBULAR LINES

line	I_q	line	I_q
N_1	160±	Hδ	34
N_2	92	(3967+ Hε)	34
Hβ	46	Hζ	10±
Hγ	53	3869	48

The spectrum of the nucleus is continuous. It reaches with scarcely diminished intensity far into the ultra-violet, terminating above 3300A.

N.G.C. 6058. $\alpha = 16^h\ 1^m0$; $\delta = +40°\ 57'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 June 22.79	828	g (slitless)	2^h 0^m

This is a small, very faint ring nebula with a comparatively strong nucleus. The nebula itself is too faint to record with the exposure of two hours given to the single plate secured, but there is a very fair record of the spectrum of the nucleus. This spectrum, which is to all appearances strictly continuous, can readily be distinguished from the other stellar spectra on the plate by its great length and uniformity. It has about twice the linear extent of spectra of stars which are several magnitudes brighter. The variation in intensity along the spectrum is very gradual.

I.C. 4593. $\alpha = 16^h\ 7^m0$; $\delta = +12°\ 20'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 July 6.78	732	g (slitless)	0^h 30^m
July 6.83	733	g (slitless)	1 25
1917 Apr. 27.91	817	g (slitless)	1 0
Apr. 27.95	818	g (slitless)	0 15
Apr. 27.85	820	g (slitless)	3 0

A very small bright nebula with a short faint extension which carries at its extremity a condensation or satellite. As seems to be invariably the case with these outlying condensations, it is much more pronounced in the image at 3727 than in the others, though it is indicated more or less certainly in all of them. The images appear to be about equal in size.

The nebula is so small and the continuous spectrum of the nucleus so bright that measurements of intensity are made with difficulty, and the results given are subject to considerable uncertainty.

NEBULAR LINES

line	I_q	line	I_q
N_1	107	Hδ	30
N_2	74	Hε	20
Hβ	53	Hζ	20
4471	trace	3869	20
Hγ	47	3727	45

The spectrum of the nucleus is continuous. It is very uniform and extends beyond 3300A.

N.G.C. 6210. $\alpha = 16^h\ 40^m3$; $\delta = +23°\ 59'$

DETAILS OF OBSERVATION

Date		Plate No.	Instrument	Exposure time	
1913	Apr. 24.90	454	f	3^h	0^m
1914	Oct. 14.66	653	a	2	0
1916	June 22.73	724	g (slitless)	0	7
	June 22.74	725	g (slitless)	0	35
	June 22.81	726	g (slitless)	2	30
1917	Aug. 10.68	840	g (slitless)	0	11
	Aug. 10.72	841	g (slitless)	1	30
	Aug. 10.77	842	g (slitless)	0	30

A small bright nebula about 10″ in diameter with faint complicated outlying nebulosity. The brighter part of the nebula is all that shows on the spectrograms. The monochromatic images indicate considerable structure within this bright area which is not visible in a direct photograph. A narrow dark lane running nearly east and west divides it into two parts of unequal brightness. The northern section is the larger as well as the brighter and contains the nucleus. The southern has the appearance of a piece cut off from the main nebula, except in the image due to 3727A, where it is made up of two separated condensations in positions corresponding to the east and west extremities of the section.

NEBULAR LINES

line	I_q	line	I_q
N_1	*	$H\epsilon$	(10)
N_2	*	3967	(30)
$H\beta$	50	3889 $(He+H\zeta)$	20
4471	9	3869	55
4363	10	$H\eta$	7
$H\gamma$	50	$H\theta$	5
$H\delta$	28	$H\iota$	(4)
4069	(3)	$H\chi$	(3)
4026	(3)	3727	30

* The measures of these lines agree so poorly among themselves that the average results would have little meaning. The color curves of the plates used probably differ greatly at this point even among plates of the same brand. Observations made with Seed No. 27 plates are fairly consistent and give the following intensities for this nebula:

N_1	N_2	N_1/N_2
90±	64	1.4
90	64	1.4
112	76	1.5

The Seed No. 23 plates give higher and less accordant values of all of these quantities, including the ratio.

There is a group of very faint lines, or bands, between 463 and 474$\mu\mu$, composed undoubtedly of the known nebular lines of this region, but it is difficult to determine whether they are confined to the nucleus or extend out into the envelope. The continuous spectrum noted in other nebulae as beginning at about 3890 and extending in the direction of shorter wave-lengths is comparatively strong in this object.

The spectrum of the nucleus is continuous, with the possibility of superposed bright bands, as mentioned above. It is not recorded on the slit spectrogram, but is shown on the plates made with the slitless instrument. On the strongest of these plates there are indications of dark lines at 464 and 468$\mu\mu$, corresponding in position with the strong bordering lines in B.D. +30° 3639. While the observation should be confirmed by a long exposure with a slit spectrograph, I am inclined to the opinion, on the showing of these plates, that the nucleus is a Class O star.

I.C. 4634. $\alpha = 16^h\ 55^m6$; $\delta = -21° 40'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 June 19.81	827	g (slitless)	$3^h\ 0^m$
July 23.75	830	g (slitless)	2 0
July 24.75	832	g (slitless)	0 30

A nebulous disc about 5″ in diameter. There is nothing noteworthy about the spectrum except that the image at 3727 appears to be double, the components lying north and south of each other. The disc is very small and the "seeing" was poor when the photographs were made, so that not much can be said with respect to the relative sizes of the images. One gets the impression that 4471A is confined pretty closely to the region of the nucleus. Otherwise the images cannot differ greatly in size.

NEBULAR LINES

line	I_q	line	I_q
N_1	190±	(3967+ Hε)	31
N_2	82±	Hζ	14
Hβ	50	3869	46
4471	9	Hη	(6)
4363	8	Hθ	(5)
Hγ	50	Hι	(4)
Hδ	27	3727	13

The nucleus shows a uniform continuous spectrum with the characteristic persistence in the ultra-violet.

N.G.C. 6309. $\alpha = 17^h\ 8^m4$; $\delta = -12° 48'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 June 25	829	g (slitless)	$2^h\ 0^m$

An irregularly elliptical ring nebula. The image at 4686A is smaller than the others and is apparently not weakened in the center. The order of intensity of the lines is N_1, N_2, 4686, 3869, Hβ = Hγ, 3967, Hδ.

N.G.C. 6543. $\alpha = 17^h\ 58^m6$; $\delta = +66° 38'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time	Region of Spectrum
1910 June 25.93	245	a	$3^h\ 32^m$	visible
1914 June 26.93	609	f	2 35	ultra-violet
June 28.86	610	f	6 0	ultra-violet
Sept. 16.70	649	a	1 55	blue-violet
Oct. 1.77	651	a	5 0	blue-violet
1916 May 4.78	716	b	2 0	visible
May 11-12	717	b	13 0	visible
June 28.81	728	g (slitless)	1 0	ultra-violet
Aug. 18.72	737	g (slitless)	1 0	ultra-violet
Aug. 19.70	738	g (slitless)	0 4	ultra-violet
Aug. 19.71	739	g (slitless)	0 15	ultra-violet
Aug. 19.76	740	g (slitless)	1 0	ultra-violet

This is the bright planetary nebula in *Draco*. It is interesting historically as being the one in which bright lines were discovered by Sir William Huggins. The spectrum is shown in plate XLIII, figure 2, and XLIX, figures 1, 2, and 3.

The structure of the nebula is quite complex, and varies somewhat from image to image on the slitless spectrograms. 3727A gives the largest of the images, and, as not infrequently happens, is relatively bright in the outer parts. In fact, the two outlying lobes are by far the brightest parts of this image. Projecting outward from about the middle of each one of these lobes is a minute excrescence suggesting a projecting pin. None of the other images exhibits this appendage, except that there is perhaps a trace of it on the over-exposed N_1 image. The 3727 image shows much more definite detail than the others, which rather baffle any attempt to make out their structure, though the definition of the plates is excellent. All of the images are, approximately at least, of the same size. The curious detached continuous spectrum in the ultra-violet is relatively strong.

4686A is concentrated in the nucleus as a strong emission band about 9A wide, and there are a number of other hazy lines, or bands, in the nucleus. In the following list they are compared with some of the so-called Wolf-Rayet radiations measured in B.D. +30° 3639.

N.G.C. 6543 nucleus	Wolf–Rayet (B.D. +30° 3639)	N.G.C. 6543 nucleus	Wolf–Rayet (B.D. +30° 3639)
(340)	340	4122.0	4121.4
341	341	4267.2	4266.9
348		4632.0	4634
356	356	4650.7	4651.6
4057.4	4056.7	4687.4	4687.1
4079		5804	5801 5812
4088.6	4088.9		

This spectrum has been observed by Professor Max Wolf, who measured many of its lines and who reports two previously unobserved at 3653 and 3639A.[9] I have not been able to confirm these two, but it is possible that my apparatus is not well adapted to this particular observation. These lines would be near the beginning of the ultra-violet continuous spectrum, and if very faint might be masked by it on the slitless spectrograms. In his description of the nucleus spectrum Professor Wolf speaks of it as presenting two maxima, one at 4390A and the other at 3640, and describes the ascent to these maxima as gradual on both sides. The plates which furnish the basis of the present description do not indicate such a distribution, but show the characteristic nucleus spectrum, very even and uniform, running out into the ultra-violet and fading to invisibility at 3270A, which is the limit of silver reflectivity. The nebula itself is quite free from continuous spectrum to a point in the violet at about 365$\mu\mu$, above which it is relatively strong. It appears to me not unlikely that the appearance referred to by Professor Wolf is due to his apparatus being incompetent to distinguish between the continuous spectrum of the nucleus and that of the nebula as a whole. The blending of the two would cause some such appearance as he describes.

NEBULAR LINES

line	I_q	line	I_q
N_1	92±	4097	(4)
N_2	58	4026	(7)
$H\beta$	51	(3967+ $H\epsilon$)*	30
4713	(3)	3965	(2)
4641	(3)	$H\zeta$	(18)
4471	11	3869	37
4388	(2)	$H\eta$	(11)
4363	(3)	$H\theta$	(8)
$H\gamma$	49	$H\iota$	(6)
$H\delta$	30	3727	40

* On slit spectrograms the two components are almost equal in intensity, $H\epsilon$ being perhaps a shade the brighter.

Measurements of wave-length and notes are given in table 5. The notes were made before I had the advantage afforded by the slitless spectrograms for judging the lengths of lines, but they are left as originally made.

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[9] *Sitz. Heidel. Akad.*, 35 Abh., 1911.

TABLE 5

N.G.C. 6543. Wave-Lengths

Plate No. 651

3725.97	v. ft., long
3835.48	v. ft., long
3868.83	v. strong, long
3888.88	strong, long
3964.37	v. ft., length uncertain
3968.84	doublet, components of equal length and intensity
(4008.0)	suspected v. ft., long
4026.10	fairly strong, long
(4033.6)	suspected v. ft. line, long, strengthened in nucleus
(4043.2)	suspected v. ft. nucleus emission band
4057.45	hazy, fairly strong, occurs in nucleus only
(4068.5)	suspected v. ft. hazy nucleus emission band
4078.8	v. ft., hazy, seen only in nucleus
4088.6	hazy nucleus line, rather ft.
4097.19	v. ft., extends out into nebula but length uncertain, strengthened in nucleus
4101.86	v. strong, long
4122.0	v. ft., occurs in nucleus only
4267.17	v. ft., seen only in nucleus
4340.67	v. strong, long
4363.31	ft., extends out into nebula, but comparatively short
4388.6	v. ft., extends out, length uncertain
4471.65	long, fairly strong
4632.0	v. ft., hazy, occurs in nucleus only
4640.96	v. ft., extends out into nebula, but comparatively short
4650.7	v. ft., hazy, occurs in nucleus only
4657.9	hazy, occurs in nucleus only
4683	edge
4687.4	max. } broad strong nucleus band, broadest in spectrum
4692	edge
4713	v. ft., extends out into nebula, but comparatively short
4861.5	v. strong
4959.0	v. strong
5007.1	v. strong

Plate No. 717

5802	ft., occurs in nucleus only
5875	D_3, rather ft., long
6562	$H\alpha$, strong, long
6582	ft., long

N.G.C. 6572. $\alpha = 18^h\ 7^m2$; $\delta = +6°\ 50'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time	Region of Spectrum
1910 June 12.95	244	a	$2^h\ 35^m$	visible
1912 Aug. 21.75	404	e	3 0	$H\beta$-N_1
Aug. 30.74	406	e	3 50	$H\beta$-N_1
1914 June 1.85	606	a	6 50	blue-violet
June 10-11	607	a	13 37	blue-violet
June 24.85	608	b	2 15	visible
June 29-30	611	b	14 5	visible
1915 June 20-21	696	a	12 45	blue-violet
1916 Aug. 30.68	748	g (slitless)	0 1	ultra-violet
Aug. 30.69	749	g (slitless)	0 4	ultra-violet
Aug. 30.69	750	g (slitless)	0 15	ultra-violet
Aug. 30.74	751	g (slitless)	1 0	ultra-violet

A small very brilliant planetary and one that has been studied extensively by spectroscopic observers. There is a faint nucleus which, according to Keeler, who made a careful study of the telescopic appearance of the object as well as of its spectrum, is not stellar, but apparently due to a general increase in the density of the nebulous material. Reproductions of the spectra are given in figures 3 of plate XLIII and 3 of plate XLVII.

Reference has already been made to the fact that several of the bands characteristic of the spectra of the Wolf-Rayet stars occur in the spectrum of the nucleus. The line 4686A does not occur in the outer regions of the nebula, but is localized in the spectrum of the nucleus as a band about 15 Angstroms wide. Other broad bands similarly restricted are 4057 and 5807A, while the lines 4634, 4641, 4650, and 4658A are hazy and also confined to the nucleus. Most of these bands are Wolf-Rayet radiations, and it was their detection in the nucleus of this object which led to a fuller investigation of the spectra of nebular nuclei.

In addition to those mentioned above, there are other short lines scattered throughout the spectrum. By a short line is meant one which does not extend beyond, or very far beyond, the spectrum of the nucleus. In a nebula, like this one, in which the intensity falls off gradually in passing from the center outward it is difficult to judge of the length of a line, since by making the photographic exposure long enough one can lengthen any line unless it is entirely absent from the outer parts of the nebula. Nevertheless the question of the relative lengths of lines is of such interest that I have, with a realization of these difficulties, ventured to describe many of the lines as short, medium, and long. Such a classification must, in the nature of things, be tentative, but I am inclined to believe, on account of the distinctive appearance of many of the lines, that the assignments are, on the whole, not far from correct. The estimates are given in table 6.

TABLE 6

N.G.C. 6572. DESCRIPTION OF LINES

3726	long	
3729	long	
3798	long	
3835	long	
3869	long	
3889	long	
(3956)	suspected v. ft. broad nucleus emission band	
3967	long	
3970	long	
4009	v. ft., short, possibly confined to nucleus	
4026	medium length	
4052	edge	
4057.6	center	ft. nucleus emission band
4063	edge	
4069	medium length	
4076	medium length	
(4087)	suspect v. ft. broad nucleus emission band	
4097	short, faint	
4102	long	
4120	ft., medium length	
4145	short, diffuse, probably broadened in the nucleus	
4267	short	
4341	long	
4363	medium length	
4388	medium length	
4416	v. ft.	
4471	length about same as 4363	
(4489)	suspect nucleus emission band	
(4537)	suspect dark band in nucleus	
(4542)	suspect v. ft. nucleus emission band	
4571	v. ft., medium or long, appears stronger in nucleus	
4634	hazy, short	
4641	hazy, short	
4650	hazy, short	
4658	hazy, short	
(4678)	suspect dark line in nucleus	
4681	edge	
4686.8	center	nucleus emission band
4695	edge	
4713	medium to short	
(4735)	suspect dark line in nucleus	
4740	short	
4861	long	
4922	short	
4959	long	
5007	long	
5807	hazy band in nucleus	
6548	long	
6563	long	
6583	long	

In his comments on the spectrum of this nebula Professor Wolf states that the longest line is Hγ, which he finds to extend 27″ from the center. It seems probable that his result is affected by instrumental irregularities, or unfavorable observing conditions, since the radius of the nebula is only 5″ or 6″.[10] It is therefore doubtful whether this observation can be regarded as sufficiently delicate to settle the somewhat difficult question of the relative lengths of the lines in this nebula.

The wave-lengths and intensities of the lines are given in tables 11 and 13.

In addition to the emission bands already mentioned, the nucleus gives a continuous spectrum. As photographed with the slitless spectrograph this spectrum fades gradually toward the violet until the image at 3727A is reached. On the less refrangible side of the image it appears to increase in intensity, but that is, I believe, an effect due to the crowding together of the images formed by the hydrogen series, which are very close together. There is a further apparent increase at about 3650A, which is undoubtedly due to the peculiar ultra-violet continuous spectrum found in many nebulae. This would probably be as good an object as any in which to study that ultra-violet spectrum.

N.G.C. 6629. $\alpha = 18^h\ 19^m6$; $\delta = -23^\circ\ 16'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 July 25.80	834	g (slitless)	$2^h\ 20^m$

Photographed directly this nebula appears as a disc about 15″ in diameter, with a bright nucleus. The spectroscope serves to disperse the light of the nucleus and shows the nebula proper to be a hazy ring.

The intensity measurements of the images are of doubtful accuracy and are not given here. The lines present, arranged in order of intensity, are: N_1, N_2, Hβ, Hγ, Hδ, 3869, Hϵ, 3727.

The nucleus spectrum is continuous.

N.G.C. 6644. $\alpha = 18^h\ 26^m4$; $\delta = -25^\circ\ 13'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 Aug. 7.68	835	g (slitless)	$0^h\ 15^m$
Aug. 7.72	836	g (slitless)	1 10

A beautiful example of a stellar nebula. All of the images appear as points except 3727A, which has a suggestion of haziness about it. There is no record of a continuous spectrum.

The intensity measurements are not accordant, and are not recorded. The system of measurement is hardly applicable to images as small as these. The lines arranged in order of intensity are: N_1, N_2, 3869 = Hβ, Hγ, 3967, 4363, 4686 = Hδ, 3727. N_1 and N_2 are very bright, relatively twice as bright perhaps with respect to Hβ as they are in N.G.C. 7027, where they are in fact exceptionally strong in this same sense.

I.C. 4732. $\alpha = 18^h\ 27^m9$; $\delta = -22^\circ\ 43'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 June 18.93	826	g (slitless)	$2^h\ 0^m$

This is an exceedingly small nebula. The monochromatic images of correct intensity have a diameter of about 3″, and as the "seeing" was very poor when the exposure was made it may

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[10] *Sitz. Heidel. Akad. Wiss.,* 35 Abh., 1911.

be that the object is stellar. N_1 and N_2 are very bright relatively to $H\beta$. The photometric observations are uncertain on account of the small size of the image, the great range in intensity and the position of these lines in the spectrum. Subject to these sources of error, the ratios of the intensity of $N_1 : N_2 : H\beta$ are as 380 : 230 : 50. The nebular lines in order of intensity are: N_1, N_2, $H\beta = 3869$, $H\gamma$, $(3967 + H\epsilon)$, $H\delta$, 4363. There is no continuous spectrum.

I.C. 4776. $\alpha = 18^h\ 39^m3$; $\delta = -33°\ 27'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 July 24	833	g (slitless)	$1^h\ 11^m$
Aug. 8	837	g (slitless)	2 0

A small bright irregularly elliptical nebula. The images are all of about the same size except that at 3727A, which is somewhat larger than the others and very diffuse and hazy.

NEBULAR LINES

line	I_q	line	I_q
N_1	overexposed	$(3967 + H\epsilon)$	33
N_2	77	$H\zeta$	15
$H\beta$	53	3869	47
4471	10	$H\eta$	8
4363	14	3820	(3)
$H\gamma$	47	$H\theta$	6
$H\delta$	26	$H\iota$	(5)
4069	(6)	$H\chi$	(4)
4026	(6)	3727	28

The spectrum of the nucleus is continuous, except that an emission band is suspected on the stronger plate (No. 837) at or near 4650A.

N.G.C. 6720 (*Ring Nebula in Lyra*). $\alpha = 18^h\ 49^m9$; $\delta = +32°\ 54'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 April 24.90	715	i	$5^h\ 50^m$
June 2.78	721	g (slitless)	2 0
June 2.83	722	g (slitless)	0 20
June 15-16	723	i‡	13 32
June 27.86	727	g (slitless)	5 34

‡ Position of slit 30° west of north.

Reproductions of spectrograms numbers 723 and 727 are given in plates[11] XLII and XLVIII.

Spectroscopic observations of this nebula are numerous. It appears to have attracted an amount of attention rather out of proportion to its interest or importance. At any rate, it has been studied to the exclusion of brigher and more interesting objects. The fact that it is comparatively large and suitable for general observation with small telescopes has probably contributed to this.

The nebula is really quite faint, and an unusually long exposure is necessary for a good record. Spectrograms have been secured with both the slitless spectrograph and the low-dispersion slit instrument. It is too large for effective observation with the present slitless spectrograph and it is hoped that a more suitable optical combination will be available for its study at some future time. It has therefore not been attempted to make the present series of plates in any sense complete.

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[11] The continuous spectrum in figure 4 of plate XLII comes from the moonlit sky.

The most interesting of the older observations from the point of view of the present work are those of Max Wolf[12] and Burns.[13] To the former we owe the discovery of the non-homogeneity of the nebula. He found the 4686 ring to be the smallest, that at 3727 to be the largest, and assigned two intermediate sizes to the others. He observed in addition that the area enclosed by the ring is relatively weak in 3727 light and strong in that of 4686A. Wolf's observations were made chiefly by the laborious process of securing successive exposures of great length with the slit of his spectrograph in different position angles, though he appears to have made some use of the slitless spectrograph. Burns' investigation was undertaken with a small slitless spectrograph attached to the Crossley reflecting telescope, and is in many respects similar to mine. His dispersion was, however, less than a fifth that of the present instrument, which is itself, as I have indicated, too low for the best observation of this object.

The image at 4686A differs from the others in the following particulars:

1. It is smaller.
2. It is almost circular.
3. It is a nearly uniform disc with those edges corresponding to the flat sides of the nebula slightly reinforced. That is, the edge of the disc is slightly brightened on the sectors corresponding to the brightest parts of the nebula.

The image at 3727A differs markedly from the others in that it shows vastly more detail. It is doubtless due in a great measure to this fact that a photograph of the nebula exhibits much more structure than is visible in the telescope. The other images are very nebulous or hazy, while this one is made up of what appears to be a complicated system of interlacing filaments, suggesting the great detail in the network nebulae in *Cygnus*. Wolf and Burns have found this image to be larger than the others, and while this is undoubtedly the case it is difficult to compare the sizes quantitatively on account of the unequal distribution of the light in the different images. The difference in length of the major axes, for images of normal intensity, is not very great, but the difference in length of the minor axes is considerable. The following are the measures of plate No. 727 for inner and outer diameters of three of the rings.

MAJOR AXIS

λ	Inner diameter	Outer diameter
N_1–N_2	34″	86″
4686	....	46″
3727	43″	90″

Measurements of the shorter diameter (along the length of the spectrum) can not be directly compared with one another in view of certain small field distortions inherent in this type of instrument which have not yet been quantitatively determined, and these diameters are therefore not given, though it is doubtless in that direction that the image 3727A has its greatest excess over the others. I am inclined to think that with the two exceptions mentioned the images are all essentially of the same size and shape. There appear to be two very faint hazy protuberances on the outside edge of the 3727 image just to the north of the northeastern end and to the south of the southwestern end of the major axis.

Dr. Burns extended his observations to the red end of the spectrum, and reports that the Hα image differs from the other hydrogen images and bears a close resemblance to the one at 3727A. As we should not expect Hα to give an image differing greatly from those of the other hydrogen lines, it seems probable that the reported Hα image is in reality due chiefly to one or both of the nebular lines 6548 and 6583, which, together, are quite as strong as Hα in some nebulae.

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[12] *Vierteljahrschrift Astron. Gesell.* **43**, 283, 1908.

[13] *Lick Obs. Bull.*, **6**, 92, 1910.

The spectrum of the nucleus or central star has at one time or another been the subject of considerable speculation. As Burns has pointed out, it is apparently continuous, there being no visible dark lines or bright bands to mar the uniformity of its course. It does not differ in any respect from the nucleus of any other planetary nebula which gives a continuous spectrum. The record is a long faint line of uniform intensity fading out at about 3400A. Spectra of stars in the vicinity several magnitudes brighter do not extend that far. The spectrograms have not been measured photometrically. Arranged in the order of their intensities the lines are: 3727, N_1, N_2, 3869, $H\beta = H\gamma$, $(3967 + H\epsilon)$, 4686, $H\delta$, 4363, 4471, 3889, $4069 = 4026$.

N.G.C. 6741. $\alpha = 18^h\ 57^m5$; $\delta = -0°\ 35'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 Aug. 24.69	742	g (slitless)	$0^h\ 30^m$
Aug. 24.75	743	g (slitless)	1 0
1917 Aug. 9.69	838	g (slitless)	0 30
Aug. 9.77	839	g (slitless)	3 0

A small nearly round nebula slightly elliptical in an east and west direction. The monochromatic images are all discs, except that at 3426A, which might better be described as a point. A comparison of all the plates leads to the conclusion that there is quite a range in the sizes of the different discs, that at 3727A being the largest, with a major axis of about 6″, while the one at 3426A is the least. The 4686A image is small, but perceptibly larger than the latter. The images are so small and they differ so in brightness that it is difficult to estimate their relative sizes. The following are in their estimated order of size: 3727, 3869, 4686, 3426A. The remaining images are probably intermediate in size between the second and third.

NEBULAR LINES

line	I_q	line	I_q
N_1	370±	$H\gamma$	37
N_2	170±	$H\delta$	20
$H\beta$	63	$(3967 + H\epsilon)$	22
4740	(5)	3889	(5)
4712	(5)	3869	62
4686	46	3727	46
4641	(5)	3426	24†
4363	20		

† This image is a stellar point, but contains about as much light as 3889A, which has a sensible area.

There is no continuous spectrum.

N.G.C. 6751. $\alpha = 19^h\ 0^m5$; $\delta = -6°\ 8'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 Aug. 23.78	741	g (slitless)	$1^h\ 30^m$
Aug. 29.76	744	g (slitless)	3 0
1917 Aug. 12.75	844	g (slitless)	4 30

In a direct photograph the object presents the appearance of a faint irregularly round disc with a bright nucleus. The spectrograms show monochromatic ring-shaped images. The brightest of these are N_1 and N_2, and they furnish most of the photographic as well as the visible light of the nebula. $H\beta$, $H\gamma$, $H\delta$, and 3727A are present, though faint. These four lines give very much larger rings than N_1 and N_2, the diameters being about 30 per cent greater. 3869A also appears to be present, but it is so faint that its diameter can not very well be estimated.

Most of the light of the nucleus comes from a very broad composite band, evidently the result of the combination of the Wolf-Rayet bands at 4650 and 4686A, the former being much the stronger. There is a fainter band at about 4090A, also very broad, and there are probably others of a similar character scattered along the spectrum. The continuous spectrum of the nucleus is very faint and has a lumpy look. It may be composed of bands such as the two referred to.

The reason that this ring nebula presents, in a direct photograph, the appearance of a disc is that the rings of different size fit one within the other, while the nucleus serves to fill the vacant place in the center of the smallest ring. The same thing happens in other objects.

No photometric measurements were made.

I.C. 4868. $\alpha = 19^{h}\ 11^{m}0$; $\delta = -9^{\circ}\ 14'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 Sept. 26.68	774	g (slitless)	$1^{h}\ 35^{m}$

An exceedingly small nebula. All of the images except N_1, N_2, and $H\beta$, which are slightly out of focus, are practically stellar. 3727A is as small as the others, but there is a suggestion of haziness around its edge that is lacking in them.

NEBULAR LINES

line	I_q	line	I_q
N_1	126	$H\delta$	30
N_2	78	$(3967 + H\epsilon)$	40
$H\beta$	49	3889	22
4363	(7)	3869	59
$H\gamma$	51	3727	21

The photometric measurements are uncertain, as the nebula is small and there is only a single observation.

N.G.C. 6790. $\alpha = 19^{h}\ 17^{m}9$; $\delta = +1^{\circ}\ 19'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 Oct. 25.67	786	g (slitless)	$2^{h}\ 0^{m}$
Aug. 10.81	843	g (slitless)	0 30
Aug. 14.68	846	g (slitless)	0 10

A very bright, practically stellar, nebula.

NEBULAR LINES

line	I_q	line	I_q
N_1	360±	3889 $(He + H\zeta)$	25
N_2	180±	3869	68
$H\beta$	53	$H\eta$	9
4471	13	$H\theta$	6
4363	26	$H\iota$	(4)
$H\gamma$	47	$H\chi$	(3)
$H\delta$	28	$H\lambda$	(3)
4069	(3)	3727	11
4026	(5)	$H\xi$	(2)
$(3967 + H\epsilon)$	34		

In addition to the lines listed above, the following are probably present, though very faint: 4740, 4712, and 4686A. They are of about the same intensity as $H\lambda$.

The continuous spectrum is very faint.

N.G.C. 6803. $\alpha = 19^{h}\ 26^{m}6$; $\delta = +9^\circ\ 52'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 July 23.91	831	g (slitless)	$3^{h}\ 0^{m}$

This is a very small object, practically stellar. The monochromatic images on the spectrogram show discs a few seconds in diameter, but this may be due to the "seeing," which was bad when the photograph was made.

NEBULAR LINES

line	I_q	line	I_q
N_1	130±	Hδ	24
N_2	100±	4076	(10)
Hβ	52	(3967 + Hε)	37
4471	(10)	Hζ	15
4363	(12)	3869	59
Hγ	48	3727	20

There appears to be a trace of continuous spectrum.

N.G.C. 6807. $\alpha = 19^{h}\ 29^{m}6$; $\delta = +5^\circ\ 29'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 Aug. 14.88	847D	g (slitless)	$4^{h}\ 0^{m}$

The nebula is stellar. Only the over-exposed images show appreciable discs.

NEBULAR LINES

line	I_q	line	I_q
N_1	overexposed	(3967 + Hε)	30
N_2	77	Hζ	12
Hβ	55	3869	43
4471	(6)	Hη	(5)
4363	17	Hθ	(3)
Hγ	45	Hι	(2)
Hδ	22	3727	12
4026	trace		

The measurements are uncertain.

Continuous spectrum is not present, except possibly on the more refrangible side of 3727A.

B.D. +30° 3639. $\alpha = 19^{h}\ 30^{m}8$; $\delta = +30^\circ\ 18'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time	Region of Spectrum
1914 July 8.86	618	b*	$1^{h}\ 13^{m}$	visible
July 13-14	623	b	13 0	visible
July 22-23	624	a‡	11 0	blue-violet
Aug. 11.84	632	f	6 18	ultra-violet
1916 Sept. 5.73	757	g (slitless)	0 4	ultra-violet
Sept. 5.74	758	g (slitless)	0 4	ultra-violet
Sept. 5.75	759	g (slitless)	0 15	ultra-violet
Sept. 5.80	760	g (slitless)	1 0	ultra-violet
Oct. 20.7	780	g (slitless)	0 4	ultra-violet
Oct. 20.7	781	g (slitless)	0 4	ultra-violet
Oct. 20.7	782	g (slitless)	0 4	ultra-violet
Oct. 20.7	783	g (slitless)	0 4	ultra-violet
Oct. 31.67	794	g (slitless)	1 26	ultra-violet
1917 June 4.03	823	k*†	3 0	red
Aug. 15.79	847	g (slitless)	3 0	ultra-violet

* Slit of spectrograph in focus for Hα light coming from refractor.

† This photographic exposure was kindly made by Mr. C. D. Shane, with a spectrograph designed by the writer for this purpose.

‡ Slit slightly out of focus of 36-inch refractor.

The bright-band character of the spectrum of this star was discovered by Mrs. Fleming in 1890.[14] It was included by Pickering in his list of spectra of the fifth type.[15] Campbell in an investigation of stars of this class found object to be surrounded by an envelope of hydrogen gas.[16] Later observers detected a few nebular radiations in the integrated spectrum of the system,[17] and Adams found the line 4069A to be present in the envelope.[18] In 1914 these and numerous other nebular lines were found to have their origins in the star's gaseous surroundings. The so-called hydrogen envelope may therefore be said to be a planetary nebula. A preliminary account of the spectrum has been given in an earlier paper.[19]

An excellent plate secured with the slitless spectrograph shows that the envelope, or nebula, is not a disc, but an exceedingly minute ring, irregularly elliptical in shape and somewhat eccentrically placed with respect to the bright star. The axes of the $H\beta$ ring, in the sense mean of inner and outer diameters, are about $2''$ and $3''$ respectively. The spectrogram in question probably represents the limit of definition obtainable with this apparatus. It is reproduced in plate L, magnified about seventeen diameters from the original negative. The outer diameter of the image as measured on this plate is about $5''$. An increase in exposure extends the borders slightly.

The lines in the spectrum of the nebula as measured with the slit spectrograph attached to the 36-inch refractor are given in table 7. The lengths of the brighter ones correspond to a diameter of about $7''$. This slight excess over the diameter given above is probably due to instrumental imperfections (including chromatic aberration) and circumstances of observation. The faint lines N_1 and N_2 impress one as being shorter than the hydrogen lines, but this may be the result of their faintness.

TABLE 7

B.D. +30° 3639. NEBULAR OR ENVELOPE LINES

λ (R)	I_g*	λ (R)	I_g*
3726.47	15	4861.2	110
3729.24	7	4959	8
3835.6	10	5007.2	10
3840.4	5	(5593)†	8
3889.3	30	5755.2	20
(3935.1)	10	(5776)†	10
3970.3	50	6303.6±	10
4068.8	60	6548.5‡	70
4076.6	20	6563	100
4101.9	70	6583.2‡	110
4340.6	90	6729§	15

In addition to the lines listed, the fainter ones of the hydrogen series are recorded on the slit spectrograms as far as H_o (3697A).

* Lines below 10 in intensity are very faint.

† These are faint bands in the nucleus which possibly extend out into the nebula as narrow lines.

‡ Measured with a dispersion of 3 prisms (plate No. 823). Assumed wave-length of $H\alpha = 6563.01$.

§ This line is diffuse on its more refrangible edge, presenting the appearance of having a close companion. The measured position of the suspected companion is 6718A.

The spectrum of the nucleus, or central star, which is by far the brighter part of the system, is continuous with many superposed bright bands and a few dark ones, while the surrounding nebula emits only narrow bright lines. These features are well shown in the illustrations (pl. XLIV). A number of considerations make the study of the spectrum of the nucleus desirable, not the least of which is the fact that as compared with other stars of its spectral class it exhibits comparatively narrow bands, which renders a fairly accurate determination of their wavelengths possible. This is particularly true in the cases of those bands which are sufficiently close to encroach upon one another in the spectra of other stars. Instances in point are the triplet at 5801–28 and the numerous bands in the vicinity of 4650A.

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[14] *Astr. Nach.*, **125**, 155, 1890.

[15] *Astr. Nach.*, **127**, 1, 1891.

[16] The Wolf-Rayet stars, *Ast. and Ast.-Phys.*, **13**, 461, 1894.

[17] Palmer, *Lick Obs. Bull.*, **2**, 53, 1902; Wolf, *Sitz. Heidelberger Akad. Wiss.*, 14 Abhl., 1913; Merrill, *Lick Obs. Bull.*, **7**, 129, 1913.

[18] *Science*, **32**, 882, 1910.

[19] *Ap. Jour.*, **40**, 466, 1914.

The bands vary considerably in width. In some cases this is undoubtedly due to the overlapping of close bands, which thus blend to form an apparently single one of greater width, and in others to photographic spreading through over-exposure, but after allowing as well as possible for such effects they appear to fall into two groups having widths of about 10 and 2½A respectively. The former is the larger group and includes such lines as 4686A and the helium lines. The so-called ζ *Puppis* bands (bright in this object) fall in the narrow group.

The measurements of the nucleus spectrum are recorded in table 8. Except as indicated to the contrary in footnotes, they were made with slit spectrographs attached to the 36-inch refractor. The intensity scale is made to correspond more or less with that adopted for the lines of the surrounding nebula on the Ig system explained on page 242. On account of their diffuse character, intensities 5 or 10 represent bands at about the limit of visibility. Anything rated at 40 or higher may be considered comparatively bright.

TABLE 8

B.D. +30° 3639. SPECTRUM OF NUCLEUS

			Laboratory		Stellar dark lines	
λ (R)	Ig[1]	Description[10]	λ	element	Class O	Class B
3342[2]	....	ft.	....	....	....	....
3404[2]	....	ft.	....	....	....	....
3414[2]	....	ft.	....	....	....	....
3429[2]	....	ft., narrow	....	....	....	....
3447[2]	....	ft.	....	....	....	....
3564[2]	....	ft., v. broad	....	....	....	....
3611[3]	....	v. strong	....	....	....	....
3640[3]	....	ft., v. broad	....	....	....	....
3705[2]	....	fairly strong	05.2	He	05.	05.
3760[3]	....	narrow, strong	60.09	O (III)	....	60.1
3794[3]	....	fairly strong	91.47	O (III)	....	92.
3883.0	....	dark line	....	....	....	....
3884 3894	20	edge edge	88.78	He	89.1	89.1
3915 3920.2 3925	30	edge center edge	20.8	C	....	20.8
3962	15	....	61.75	O (III)	....	62.
4022	....	dark line	....	....	....	....
4027	40	....	26.0 26.40	Hε′ He	26.8	26.4
4050.9	....	dark line	....	....	....	....
4056.7	55	....	....	....	59	....
4063.8	....	strong dark line	....	....	....	....
4070[4]	55	....	....	....	69.4 72.0	69.4 72.0
4084.7	....	dark line	....	....	....	....
4088.9	45	....	89.09	Si (IV)	89.1	89.1
4113		edge				
4115.1	20	max.	16.51	Si (IV)	16.2	16.2
4121.4 [11]	40	max.	21.0	He	20.8	20.8
4129.6	20	max.	28.29	Si (II)	....	....
4133		edge	31.04	Si (II)	....	....
4155.4	50	....	....	....	....	54.2
4163.8	50	....	....	....		
4187.7	60	....	....	....	86.2	85.7 90.1
4200.5	15	....	00.3	Hδ′	00.6	00.6
4229.6	15	....	....	....	....	....
4239	10	....	....	....	....	....
4247	5	....	....	....	....	....
4266.9	70	....	67.30	C	....	67.3
4316.7[5]	30	....	....	....	17.3 19.8	17.3 19.8
4320.6	....	dark line	....	....	....	....
4325.8[5]	50	....	....	....	....	25.9
4347[4]	30	....	....	....	....	49.6
4368.1	40	....	....	....	67.2	67.2
4385	40	v. broad, prob. composite	88.10	Par He	88.1	79.8 88.1
4416.2	40	....	....	....	15.1 17.0	15.1 17.0

TABLE 8—(*Continued*)

λ (R)	I_g	Description[10]	Laboratory		Stellar dark lines	
			λ	element	Class O	Class B
4441.4	40	....	....	....	....	....
4457	20	....	....	....	....	....
4465.8	....	strong dark line	....	....	....	....
4472.4	40	....	71.7	He	71.7	71.7
4516.6	50	....	....	....	....	....
(4533)[6]	10	....	....	....	....	....
4538.0	....	dark line	....	....	....	....
4542.7	20	....	41.3	Hγ′	42.4	42.4
4555.0	20	....	52.64	Si (III)	....	53.0
4569	10	....	67.90 74.79	Si (III) Si (III)	....	68.3
4593.9	20	....	....	....	....	91 97
4619[12]	10	....	....	....	....	20
4634[12]	10	....	34.2	(?) H (II)	....	....
4641.8	....	strong dark line	....	....	....	....
4651.6	100	....	47.6 50.4 51.6	C	50	50
4666.0	40	....	....	....	....	....
4675.4	20	....	....	....	....	76
4681.0	....	dark line	....	....	....	....
4687.1	50	....	....	....	....	86.0
4695.7	....	dark line	....	....	....	....
4702.2	10	....	....	....	....	99 05
(4713)	10	....	13.2	He	....	13.2
4738	5	....	....	....	....	....
4786.4	20	....	....	....	....	....
4799.2	10	....	....	....	....	....
4923	10	....	22.1	Par He	no record	22.1
4940	10	....	....	....	“ “	41.6
5017[8]	10	....	15.7	Par He	“ “	15.7
5091.5	10	....	....	....	“ “	....
5130.9[9]	25	....	....	....	“ “	....
5251.1	20	....	....	....	“ “	....
5272.6	15	....	....	....	“ “	....
5305.0	15	....	....	....	“ “	....
5412.2	15	....	....	....	“ “	13.6
5470.2	10	....	....	....	“ “	....
(5576)	5	....	....	....	“ “	....
5593	8	....	92.57	O (III)	“ “	....
(5660)	5	....	....	....	“ “	....
5691		edge				
5696.0	60	center	96.0	C	“ “	97.8
5703		edge				
5773	10	....	....	....	“ “	73
5801	15	....	01.4	C	“ “	....
5812.3	30	....	12.0	C	“ “	....
5828	20	....	26.7	C	“ “	....
5876.8	30	....	75.9	He	“ “	76
5893.5	15	....	90.2 96.2	D_2 D_1	“ “	90 96
6154	10	....	....	....	“ “	no record
(6206)	5	....	....	....	“ “	“ “
(6309)	5	....	....	....	“ “	“ “
6459	5	....	....	....	“ “	“ “
6676[8]	5	....	78.4	Par He	“ “	“ “

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[1] For explanation of this intensity system see p. 242.

[2] Bands observed with slitless spectrograph. The wave-lengths are extrapolated and are uncertain. Intensities cannot be given on the I_g scale.

[3] Wave-lengths measured with quartz slit spectrograph. Intensities cannot be given on the I_g scale.

[4] Difficult to measure accurately on account of close bright lines in nebula.

[5] These two bands practically blend. Separated by only a comparatively narrow dark line.

[6] The apparent presence of a band here may be an effect of contrast due to a dark line at 4538.

[8] On account of the chromatic aberration of the telescope in this region it is not possible to say whether this band is confined strictly to the nucleus.

[9] There seems to be a group of two or more faint emission bands below this one extending to about 5162A.

[10] Unless otherwise specified the wave-lengths are the centers of emission bands.

[11] A composite band with three maxima, the middle one of which is the strongest.

[12] These bands are incompletely resolved.

The principal helium lines are represented. The brightest ones certainly, and probably the faint ones as well, are bordered on the more refrangible edge by dark bands. The lines of parhelium are comparatively faint, only the strongest being certainly present. The extra hydrogen, or *ζ Puppis* lines, are bright, but narrower than the helium bands. They appear to have, like the latter, dark companions on the violet edges. The centers of all of the emission bands referred to in this paragraph appear to be displaced slightly toward the red. Taking only those which for one reason or another seem to be most suitable for measurement, we have:

λ star	λ laboratory	origin	Δ star-lab.
4027.0	4026.4	principally He	+0.6
4200.5	4200.3	$H\delta'$	+0.2
4472.4	4471.7	He	+0.7
4542.7	4541.3	$H\gamma'$	+1.4
4687.1	4686.0	......	+1.1

As will be seen later, other stellar bands (under reasonable assumptions as to their origin) do not exhibit this shift. It seems not unlikely that the displacement may be associated with the fact that the members of these particular groups of bands have absorption on the violet edge, which may encroach upon, and disturb, the position of that boundary.

TABLE 9

Comparison of Stellar and Carbon Wave-Lengths

λ star	I_g	laboratory	I
3920.2	30	3920.8*	5±
4266.9	70	4267.3	10
4651.6	100	4647.6	10
		4650.4	8
		4651.6	8
5593	8	5592.1†	8
5696.0	60	5696.0	10
5801	15	5801.4	7
5812.3	30	5812.0	5
5828	20	5826.7	3
5893.5	15	5893	....
....	....	6578	9
....	....	6583	8

* This line is not reported by Merton, whose observations do not appear to have extended so far into the violet. It has been inserted as a characteristic carbon line found associated with 4267A. Its laboratory wave-length appears to be somewhat uncertain. The value given is quoted from Lunt (*Ann. Cape Obs.*, **10**, II, 37, 1906). The intensity represents the mean of the estimates of a number of observers. See Kayser *Handbuch der Spectroscopie*, **5**.

† This line has since been ascribed by Fowler and Brooksbank to the third line spectrum of oxygen. *Mon. Not. R. A. S. Lond.* **77**, 511, 1917.

There appears to be little doubt that carbon is represented in the spectrum. Several observers, particularly Mr. T. R. Merton, have called attention to the probable occurrence of this element in the Class O stars.[20] Mr. Merton has been able to excite a spectrum, probably due to carbon, whose lines correspond closely in position with many of the bands characteristic of these stars. His measurements are given in column 3 of table 9. Merton identifies the last pair of lines with the nebular line at 6583, which occurs in the envelope, but this is hardly permissible, as the envelope line is narrow while the others are in the form of broad bands localized in the nucleus. It is quite possible that there is a nucleus band in this position, and that it is completely obliterated by the over-exposed envelope line referred to. In fact, the envelope lines 6548, 6563, and 6583 are run together through over-exposure on the plate which shows the fainter nucleus bands to advantage, so there is essentially no evidence against the

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[20] Lockyer, Baxandall, and Butler, *Proc. Roy. Soc. Lond.*, **A**, **82**, 543, 1909; Merton, *ibid.*, **A**, **91**, 498, 1915; Wright, *Proc. Nat. Acad. Sci. Am.*, **1**, 596, 1915.

presence of a nucleus band of moderate intensity at this place.[21] Except with respect to some of the relative intensities the correspondence may be said to be excellent, and it is doubtful whether that irregularity is in any degree critical, as the relative strength of many of the lines vary in the laboratory spectrum with conditions of observation. The comparison certainly seems to indicate the presence of carbon in the star.

The possible identity of the other bands is indicated in table 8. Silicon appears to be represented by members of Lockyer's group IV, and possibly groups II and III.[22] The agreement is not in all respects so good as one might wish. The two lines 5042 and 5057 in Lockyer's group II have not been observed, but this may be due to lack of sensitiveness of the plate in this region. The discrepancy of over 2A in the group III line at 4552.6 is rather large. The bands of Fowler's extension to the fourth group have not been found.[23] Fowler and Brooksbank[24] have recently discovered a new line spectrum of oxygen which is excited by very intense electrical discharges. They have identified certain bands in the spectrum of this nucleus with lines in that spectrum, which they designate the third spectrum of oxygen, O (III). The identities referred to are indicated in table 11. Their work renders exceedingly probable the presence of oxygen in this and other celestial objects.

Some of the stronger groups of lines in the elementary line spectrum of oxygen correspond fairly well in position with bands observed in the nucleus. Lines in this spectrum are so numerous, and the nucleus lines so broad that it is difficult to compare the two and little assistance is rendered by a mere table of wave-lengths of the oxygen spectrum. A glance at a chart of the spectrum of oxygen, as photographed by Lunt,[25] however, shows a number of prominent groups of lines, the strongest of which are approximately in the following positions: 4072, 4119, 4349, 4416, 4593, 4650, 4942. There are nucleus bands close to all of these positions, which are, however, in a number of cases undoubtedly due, partially at least, to other elements. Perhaps it may be said that while the evidence in favor of the presence of the elementary spectrum is not by any means convincing that against it is equally weak.

It is to be remarked that all of the elements here referred to are prominently represented in the Class B stars by the very lines, occurring there as dark, through which their presence in B.D. +30° 3639 is indicated. It has been noted by other observers that there appears to be a significant correspondence between the bright band spectra of the Wolf-Rayet stars and the dark line record of the Class B stars, though many of the prominent features of each are lacking in the other. In columns 6 and 7 of table 8 are inserted lists of stellar lines lying close to the bright bands. The stellar wave-lengths are taken from the tables of Miss Cannon[26] and Mr. Baxandall.[27] Lines in Class B spectra are fairly numerous, and this fact must be considered in judging of the significance of approximate coincidences.

Reference has already been made to the fact that some of the emission bands are bordered on the more refrangible edge by broad dark lines. In a spectrum such as this, containing numerous emission bands, some of which are grouped closely together, it is not always possible to distinguish between absorption bands and minima due to other causes. The following list of bordered bands is therefore doubtless incomplete. The distance of the dark band from the

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[21] Huggins (*Phil. Trans.*, 154, II, 139, 1864) found that the red carbon doublet is suppressed in an atmosphere of hydrogen, and this has been confirmed by Herbert (*Phil. Mag.*, 6th series, 4, 202, 1902), who has investigated the effect quantitatively. Herbert finds that the lines are practically extinguished by a 50 per cent mixture of hydrogen. The violet carbon line at 4267 is, on the other hand, hardly affected. In view of the great strength of hydrogen in this object the conditions would appear to be favorable for the elimination from the spectrum of the lines in question. It would be a matter of interest to learn whether the spectrum observed by Merton can be excited jointly with that of hydrogen.

[22] *Proc. Roy. Soc.*, 67, 403, 1900.

[23] *Mon. Not. R. A. S. Lond.*, 76, 196, 1916.

[24] *Mon. Not. R. A. S.*, 77, 511, 1917.

[25] *Ann. Cape Obs.*, 10, pt. II, pl. II.

[26] *Ann. H. C. O.*, 28, II, 233-237, 1901.

[27] Comparison of the spectra of Rigelian, Crucian, and Alnitamian Stars, *Publ. Solar Physics Committee*, 1914.

center of the bright one appears to be in the neighborhood of 5A, except in the case of 4642A, in which it is considerably larger. There is no evidence of a relationship between displacement and wave-length, such as is found to exist in the novae, and in view of the great range in the width of the emission bands such a dependence is hardly to be expected. The outstanding discrepancy just alluded to is somewhat disconcerting. Surmising that it might be a photographic effect due to the great strength of the bright band, I have measured the line on a more suitably exposed plate and find that it is hardly possible that the tabular position is in error more than half an Angstrom. One might be inclined to think that in this instance the bright and dark bands are not physically related, were it not for the fact that each is, of its kind, the strongest feature of the spectrum. A possible explanation is suggested by the probability that the bright band is due to the carbon triplet, 4647.5 —50.9 —51.6, and it may be that only the more refrangible member of such a composite line would be effective in producing the bordering dark band. In that case the dark line is exactly in the required position. If there is any such law as the one suggested, it would appear to indicate that the absorption lines are produced at a lower level than the bright bands, and that consequently they may be obliterated when covered by bright emanations of sufficient strength.

λ dark	λ emission	Δ	λ laboratory	element
3883.0	3889.0	6.0	3888.78	He
4022.1	4027.0	4.9	4026.40	He
4050.9	4056.7	5.8	....	......
4063.8	4070.0	6.2	....	......
4084.7	4088.9	4.2	....	......
4320.5	4325.8	5.3	....	......
4465.8	4472.4	5.6	4471.66	He
4538.0	4542.7	4.7	4541.3	......
4641.8	4651.6	9.8	....	......
4681.0	4687.2	6.2	4685.98	......
4695.7	4702.2	4.5	....	......

In two instances there are nebular lines and nucleus bands which correspond closely in wave-length. In one of these it is quite certain that the band and line are of independent origin, while in the other we cannot say whether or not there is a physical relation between the two. The hydrogen line at 3889.20A crosses the broad helium band at 3888.78. These two lines are so close together that, were it not for their difference in character, it would be impossible to separate them with the low dispersion used. The other case referred to is 4070A. There is a band 9A wide centering at this point. As this band has a dark companion its normal wave-length is probably a trifle less than the figure given, let us say 4069.2, which corresponds closely with the line 4069.5A in the Class B stars. Crossing the band is the nebular line 4068.8A. Whether the line is due to an element common to these three classes of objects it is at present impossible to say.

The continuous spectrum of the nucleus is so strong that it does not seem practicable to measure intensities either of the nebula or nucleus spectrum with the photometer.

The continuous spectrum possessed by so many nebulae, which begins near the limit of the hydrogen series and extends toward the ultra-violet, does not appear to be present.

N.G.C. 6818. $\alpha = 19^h\ 38^m 3$; $\delta = -14^\circ\ 24'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 Sept. 25.68	772	g (slitless)	$1^h\ 20^m$
1917 Aug. 13.77	845	g (slitless)	4 0

Direct photographs show a disc about 20″ in diameter which exhibits much structure. Plate No. 845 is shown in figure 1 of plate XLVIII. The spectrograms record images of a variety of shapes and sizes. Most of them have the appearance of a horseshoe, the open end of the shoe lying to the north. Some of the images show mottlings, or condensations, scattered along the shoe, or ring. The hydrogen images are free from these, or nearly so. N_1 and N_2 are not completely separated, so that it is not possible to state whether this is the pattern which they record. 3967A shows the condensations fairly well, 3869A better still, while 3727A is composed of condensations and not much else. It seems to be a rule that outlying condensations such as these, and detail in general, are greatly strengthened in images given by the last line.

The images at 3426 and 4686A do not show the mottlings. These images are noticeably smaller than the others and the first is itself smaller than the second. The line 3426A is not recorded in a great many nebulae, but when it does occur the image which it gives is either the smallest, as in the present instance, or as small as any in the spectrum. On a previous occasion the writer made a similar statement[28] with respect to the line at 4686A, but that was before the ultra-violet region had been systematically studied.

NEBULAR LINES

line	I_q	line	I_q
N_1	overexposed	$H\delta$	22
N_2	112	$(3967 + H\epsilon)$	24
$H\beta$	51	3869	47
4686	60	3727	34
4363	(15)	3445	trace
$H\gamma$	49	3426	16

The intensities depend on the measurement of a single plate, and are uncertain.

N.G.C. 6826. $\alpha = 19^h\ 42^m.1$; $\delta = +50°\ 17'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time		Region of Spectrum
1914 Aug. 27.85	641	a	5^h	0^m	blue-violet
Sept. 8-9	648	a	11	25	blue-violet
1916 May 19.78	718	i	0	20	blue-violet
May 19.92	719	i	5	0	blue-violet
June 28.91	729	g (slitless)	2	0	ultra-violet
June 28.97	730	g (slitless)	0	20	ultra-violet
June 28.98	731	g (slitless)	0	5	ultra-violet
1917 Sept. 10.74	858	g (slitless)	2	25	ultra-violet
Sept. 10.82	859	g (slitless)	0	52	ultra-violet
Sept. 10.84	860	g (slitless)	0	17	ultra-violet

In the telescope this nebula appears as a round uniform disc with a very bright nucleus.

There is an excellent reproduction of the spectrum as photographed with the slitless spectrograph in plate L. The most striking features are probably the two star-like condensations on the periphery of the 3727 image. There are faint condensations in corresponding positions in the other images, but they are inconspicuous and must be looked for carefully to be recognized.

The condensations appear at first glance to be isolated features of the images, but a more careful examination discloses in most of the images a delicately traced ellipse, and the condensations mark the extremities of its major axis. The ellipse is not visible in the 3727 image. The phenomenon appears analogous, in some respects, to that observed in N.G.C. 7009, where most of the light of the elliptical image at 3727A is concentrated near the ends. The condensations are farther apart in 3727A than in the other images, one of them lying partly beyond the edge of the disc. The measured distances here and in two of the hydrogen lines are:

3727A	22″8
$H\gamma$	19.2
$H\beta$	19.8

These measures are only approximate.

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[28] *Proc. Nat. Acad. Sci. Am.*, I, 266, 1915.

The images are of about the same size except with respect to the separation of the two outlying bright points. It would be difficult to make a more definite estimate of the relative dimensions because the edge of the nebula is ill-defined, and consequently the diameter varies with the intensity in a manner that it is hard to allow for even with plates of long and short exposure.

The line intensities were measured in the body of the nebula. In the case of 3727A the intensity was also measured in the condensations.

NEBULAR LINES

line	I_q	line	I_q
N_1	not measured	Hγ	51
N_2	not measured	Hδ	30
Hβ	49	4097	(5)
4712	(2)	4026	(8)
4471	10	(3967 + Hε)*	31
4388	(3)	3869	40
4363	(8)	3727	22 (38 in condensations)

* The components are equal in intensity.

In addition to the above lines, the hydrogen lines from Hζ to Hχ and the following due to helium, 4009, 4120, and 4144A, are recorded on one of the small scale plates (No. 719), but their intensity on the adopted scale cannot very well be estimated.

The nucleus has the characteristics of a Wolf-Rayet or Class O star. The following bright bands occur, or, where indicated by parentheses, are suspected, in its spectrum:

Nucleus	Wolf-Rayet
4057	4057
4089	4089
(4109)	....
(4116)	4115
(4122)	4121
4635 edge ⎫	4634
4661 edge ⎭	4650
4686	4687

The Pickering series is represented by dark lines at Hγ′ and Hδ′ (4541 and 4199A). The lines of the Balmer series are also dark and are recorded from Hβ to Hχ (3750A). I may remark that the slitless spectrograph appears to be a relatively efficient form of instrument for recording dark nucleus lines in the presence of bright lines of the same wave-length in the spectrum of the nebula. The absorption lines of hydrogen are much more readily seen on the slitless plates of this and other nebulae than on the slit spectrograms. This seems a little surprising at first, but the reason is very simple. On a slit spectrogram the bright nebular line crosses the dark line and tends to neutralize or obliterate it. The contrast between the center of the line and the adjoining continuous spectrum is absolutely reduced, or may perhaps be reversed. In using the slitless spectrograph we in effect place over the dark line a bright disc, which illuminates not only the center of the line but the adjacent continuous spectrum as well. The absolute contrast remains the same, and, in particular, it cannot be reversed, though of course the proportional illumination is modified.

Table 10 is based on measures of one of the slit spectrograms.

TABLE 10

N.G.C. 6826. WAVE-LENGTHS

Plate No. 648	I_g	
3868.85	40	
3889.01	20	
3933.18	....	fine dark line in nucleus
(3959.1)	....	susp. fine dark line in nucleus
3967.57	30	
3970.17	30	
4026.7	10	
4057.5	15	ft. hazy emission band*
4089.0	10	hazy emission band*
4097.8	10	short line
4101.90	50	
(4109)	5	suspect nucleus band
(4116)	5	suspect nucleus band
(4122)	5	suspect nucleus band
4199.1	....	hazy dark line in nucleus
4340.62	60	
4363.55	12	
4471.4	15	
4541	....	v. broad dark band in nucleus
4635± 4661±	....	v. ft. hazy emission band, difficult*
4682.7	....	dark line in nucleus bordering emission band
4686.2	20	max. of emission band*
4690±	....	end of band
4861.7	60	
4959.3	70	
5006.9	100	

* Confined to nucleus.

N.G.C. 6833. $\alpha = 19^{h}\ 46^{m}.9$; $\delta = +48^{\circ}\ 42'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 Aug. 19.71	848	g (slitless)	1^{h} 0^{m}
Aug. 19.75	849	g (slitless)	0 28
Aug. 19.83	850	g (slitless)	3 0

This is a stellar nebula, the largest image of normal intensity being not more than 3″ in diameter, which is a very good star pattern. The intensity measurements are uncertain, as is always the case with small images.

NEBULAR LINES

line	I_q	line	I_q
N_1	116	(3967 + $H\epsilon$)	27
N_2	53	$H\zeta$	15
$H\beta$	49	3869	45
4471	10	$H\eta$	(5)
4363	16	$H\theta$	(4)
$H\gamma$	51	3727	trace
$H\delta$	26		

There is an exceedingly faint continuous spectrum.

N.G.C. 6879. $\alpha = 20^{h}\ 5^{m}.9$; $\delta = +16^{\circ}\ 38'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 Sept. 16.72	864	g (slitless)	2^{h} 35^{m}

A very small nebula, almost stellar, but apparently elongated slightly east and west. The object is faint and there are not many lines recorded on the single plate secured. Small though it is, it evidently possesses a nucleus, for there is a faint continuous spectrum threading the centers of the discs.

NEBULAR LINES

line	I_q	line	I_q
N_1	125	$H\gamma$	44
N_2	77	$H\delta$	(20)
$H\beta$	56	(3967 + $H\epsilon$)	28
4363	(10)	3869	38

The object being small and only one plate available, the intensity measures are uncertain.

N.G.C. 6884. $\alpha = 20^h\ 7^m2$; $\delta = +46^\circ\ 10'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 Nov. 16.68	797	g (slitless)	3^h 0^m
Nov. 24.67	799	g (slitless)	1 0
Nov. 26.66	802	g (slitless)	0 15
1917 Sept. 17.76	867	g (slitless)	1 0

The nebula presents, both in a direct photograph and on a spectrogram, a perfectly round disc 4″ or 5″ in diameter. It is difficult to say whether or not there is much difference in size in the monochromatic images, since the faint images naturally appear smaller than the bright ones. In larger objects it is possible to eliminate this effect, to a certain extent, by comparing plates of different exposures, but with a very small image this cannot be done unless we know that the plates are exactly the same with respect to focus, seeing, and other conditions of observation. Concerning two of the discs, however, there is no question that a difference in size exists. The disc at 3727 is larger than that at 4686, since the former is both larger and fainter than the latter.

NEBULAR LINES

line	I_q	line	I_q
N_1	286	$H\gamma$	44
N_2	160	$H\delta$	28
$H\beta$	56	4026	(4)
4740	(6)	(3967 + $H\epsilon$)	32
4712	(6)	$H\zeta$	14
4686	22	3869	62
4640	(6)	$H\eta$	(6)
4471	(10)	$H\theta$	(4)
4363	22	3727	17

There is little if any continuous spectrum.

N.G.C. 6886. $\alpha = 20^h\ 8^m3$; $\delta = +19^\circ\ 41'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 Sept. 13.74	863	g (slitless)	3^h 0^m
Sept. 17.69	866	g (slitless)	0 55
Sept. 18.72	869	g (slitless)	0 16

A small disc about 5″ in diameter. Allowing for differences in intensity, 3426A appears to give the smallest image, 4686A that next in size, while the largest are perhaps furnished by 3869 and 3727A. The latter is hazy on the edges, and with prolonged exposure would probably spread out into the largest image. The two last named images appear to have minute excrescences on the southeast and northwest edges which serve to give them an elongated appearance. Some of the other images have tendencies in this direction. Otherwise they appear to be perfectly round. N_1 and N_2 are intensely bright relatively to $H\beta$.

NEBULAR LINES

line	I_q	line	I_q
N_1	330	$H\gamma$	43
N_2	180	$H\delta$	21
$H\beta$	57	$(3967 + H\epsilon)$	30
4740	(10)	$H\zeta$	15
4712	10	3869	57
4686	49	$H\eta$	(10)
4640	(5)	3727	40
4471	(7)	3445	(4)
4363	26	3426	17

There is no record of a continuous spectrum.

N.G.C. 6891. $\alpha = 20^h\ 10^m.4$; $\delta = +12°\ 24'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 Sept. 25.77	773	g (slitless)	$1^h\ 30^m$
1917 Aug. 21.84	853	g (slitless)	4 10

The nebula is a hazy disc about 12″ in diameter, somewhat elongated north and south. There is a very bright nucleus. The monochromatic images present the same appearance as the nebula, except of course with respect to the nucleus, the spectrum of which is continuous. They are strong in the center and fade out to a nebulous edge. The size of an image of this sort is naturally a function of the intensity and exposure time, and probably most of the small apparent differences in diameter that are exhibited by these spectrograms are due to this cause. It seems likely, however, that the 3727 image is larger than the others. It appears to have a greater length in the direction of the spectrum than hydrogen images of less exposure but equal photographic density.

The intensity measurements are rendered very difficult by the strong continuous spectrum of the nucleus. In making them it was necessary to set the photometer near the hazy edges of the nebula, and even here somewhat arbitrary corrections are necessary for the intensity of the background. The results are therefore uncertain.

NEBULAR LINES

line	I_q	line	I_q
N_1	194	$H\delta$	23
N_2	86	$(3967 + H\epsilon)$	20
$H\beta$	59	$3889\ (He + H\zeta)$	17
4686	trace	3869	30
4471	(5)	3727	25
$H\gamma$	41		

The nucleus gives the characteristic continuous spectrum. It is of very uniform intensity and can be followed to above 3300A. There is no indication of either bright or dark lines.

I.C. 4997. $\alpha = 20^h\ 15^m.6$; $\delta = +16°\ 25'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 Sept. 26.77	775	g (slitless)	$2^h\ 0^m$
Sept. 26.83	776	g (slitless)	0 30

This is an exceedingly bright stellar nebula. The weaker of the two spectrograms has some overexposed images and a still shorter exposure would be of value. All of the lines form neat, clean, circular discs of stellar dimensions, except 3727A which, though faint, gives a decidedly hazy image. It may be noted that 4363A is extremely bright, perceptibly brighter than the neighboring line Hγ; in fact the measurements indicate it to be second in strength in the spectrum. This observation serves to isolate it from all other strong lines within the limits of the ordinary photographic region of the spectrum (3000 to 5000A).

NEBULAR LINES

line	I_q	line	I_q
N_1	47	Hζ	17
N_2	30	3869	62
Hβ	48	Hη	10
4471	16	3820	(5)
4363	57	Hθ	9
Hγ	52	Hι	8
Hδ	30	Hχ	7
4076	(6)	Hλ	6
4069	9	3727	20
4026	6	Hν	(3)
(3967+ Hε)	37	3705 (He + Hξ)	(3)

The continuous spectrum is weak until it reaches the vicinity of Hξ (3704A), from which point on into the ultra-violet it is stronger. It is undoubtedly reinforced by the detached continuous spectrum observed in this region in other nebulae. On the stronger of the two plates (No. 775) there appears to be a dark band on the more refrangible edge of 3727. This may, however, be a subjective effect due to contrast with the bright line on one side and the head of the continuous spectrum just referred to, combined with Hν and Hζ, on the other.

N.G.C. 6905. $\alpha = 20^h\ 17^m9$; $\delta = +19° 47'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 Aug. 22.80	854	g (slitless)	$3^h\ 30^m$

This is a large faint planetary, almost the duplicate in appearance of N.G.C. 40. That object has an exceedingly interesting spectrum, and the present one was added to the list for the purpose of determining whether the resemblance extends to the two spectra. It is so faint that it would otherwise hardly have been considered as a subject for observation.

The lines present in the nebula proper are N_1, N_2, 3869, 4686, and Hγ.

The images are all faint, but there is a record sufficient to show that there is little resemblance between the spectra of the two nebulae. 3727A is relatively strong in N.G.C. 40, while 3869 is the brightest ultra-violet line in 6905. N_1 and N_2 are practically absent from No. 40, but are the most intense lines in the spectrum of 6905. 4686A is absent from the nebular spectrum of the former, but present in that of the latter. The hydrogen series appears to be present in both.

The nucleus gives a continuous spectrum, with two very broad emission bands at wave-lengths 3795–3835 and 464–471±±μμ. These figures are merely approximate. The second band is apparently composite and is doubtless due to the Wolf-Rayet radiations at 4650 and 4686A, much broadened, with the first the stronger of the two. The spectrum appears to be identical with that of the nucleus of N.G.C. 7026, except that in the latter object the 4686 component of the band just discussed is weak or missing.

This appears to be one of those rare objects in which 4686A is present both as a nebular and as a nucleus line.

N.G.C. 7009. $\alpha = 20^h\ 58^m.7$; $\delta = -11°\ 46'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time	Region of Spectrum
1914 Sept. 21-22	650	a*	$10^h\ 0^m$	blue-violet
Nov. 4.64	657	a*	0 15	blue-violet
Nov. 4.67	658	a*	1 0	blue-violet
1916 July 6.94	734	g (slitless)	1 0	ultra-violet
July 6.97	736	g (slitless)	0 20	ultra-violet
Sept. 24.72	770	g (slitless)	3 0	ultra-violet

* Position angle of slit 346° (about perpendicular to the general direction of the ellipse).

A brilliant elliptical ring with outlying lobes beyond the extremities of its minor axis. There are two straight threads of light running outward from the nebula in the direction of the major axis, which terminate in minute knobs, or condensations. The object suggests the appearance of Saturn when viewed with the rings "edge on."

The spectrum is shown to fair advantage in plates XLII and XLVIII.[29] It will be seen by a glance at the photographs made with the slitless spectrograph that most of the light of wavelength 3727A is concentrated in two small areas at the extremities of the ellipse. This is just the place where the other lines are weak. The weakness is most pronounced in the 4686 image, from which the ends of the ellipse are practically gone. The small condensations mentioned as terminating the faint extensions of the major axis are relatively strong in the image at 3727A, though the extensions themselves hardly show. These extensions are, however, visible on the brighter images. The short diameter of 4686A is less than that of the other images, measuring 7″.1 as compared with 8″.5 for Hβ and Hγ.

In appearance the nebula strongly resembles N.G.C. 7662, and the spectra of the two objects are almost identical in the part of the photographic region covered by glass instruments. Helium (4471) is relatively stronger in No. 7009, while the Pickering series is more pronounced in No. 7662. Some of the ultra-violet lines are apparently missing in 7009, but allowance must be made for the fact that this object, on account of its southern declination, is observable only at a great zenith distance, and the lines in question are therefore much weakened by absorption. Another point of difference brought out by the slit spectrograms is that in N.G.C. 7009 the line 4363A terminates at the bright ring. In N.G.C. 7662 it extends beyond. Otherwise the spectra are remarkably alike. The similarity in form and spectrum of the three nebulae N.G.C. Nos. 3242, 7009, and 7662 is striking.

NEBULAR LINES

line	I_q*	line	I_q*
N_1	130±	4267	(3)
N_2	85±	Hδ	30
Hβ	50	4097	(5)
4740	(8)	4026	(4)
4712	(8)	(3967 + Hϵ)	42†
4686	28	3889	(15)
4640	(8)	3869	70
4634	(2)	Hη	(6)
4471	10	Hθ	(5)
4363	(15)	3727	24–16*
Hγ	50	3445	10

*The intensity measurements are on the side of the bright ellipse except for 3727A, in which case the two condensations at the ends are measured. These two condensations are of unequal brightness and measurements of both are given.

† On a slit spectrogram which resolves these lines 3967A appears to be about 3 times as strong as Hϵ.

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[29] The faint hazy patch above Hγ in fig. 5, pl. XLVIII, is probably a photographic defect.

The detached ultra-violet continuous spectrum is quite strong. This is rather a good spectrum in which to measure its lower limit, because the nebula itself is quite narrow and roughly serves the purpose of a slit. An estimate of the position, which is after all necessarily an approximate one, places the limit at about 3650A.

The spectrum of the nucleus is continuous, and has the usual uniform appearance characteristic of the spectra of nebular nuclei.

N.G.C. 7026. $\alpha = 21^h\ 2^m.9$; $\delta = +47° 27'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 Oct. 26.72	790	g (slitless)	3^h 0^m
1917 Sept. 11.79	862	g (slitless)	6 0

The nebula consists of two slightly elongated lobes lying parallel to each other and separated by a comparatively dark lane not quite equal to their width. Faint filaments of nebulosity surround and connect the lobes. One of the spectrograms is reproduced in plate XLVII, figure 2.

The image at 4686, although maintaining the general shape of the nebula, is very much smaller than the others, while 3727A is larger. There is no evidence of a difference in size or separation among the remaining images. The separation of the two lobes, measured center to center, is as follows:

N_1	image overexposed
N_2	$6''.3$
$H\beta$-$H\gamma$-$H\delta$	6.0
4686	3.7
3869	6.1
3727	7.3

The slight range in the measured separations of intermediate size is probably not significant. It has been suggested that the separating lane in this nebula is due to absorption. If that is true, it is evident that the absorption must be selective and within the nebula itself, and not beyond the luminous part, because the width of the lane varies with the size of the image, that is, it is different for different wave-lengths. It is exceedingly narrow for 4686A, and very wide for 3727. This fact is incompatible with the idea of its being caused by a generally opaque medium.

NEBULAR LINES

line	I_q	line	I_q
N_1	overexposed	$H\gamma$	43
N_2	115±	$H\delta$	28
$H\beta$	57	(3967 + $H\epsilon$)	33
4686	20	3869	55
4471	10	3727	28

There is a very faint nucleus situated just to the east of the center of the lane. The light of this is concentrated in two broad bands, one extending from 3795 to 3835A, and the other from 4640–4690A. These estimates are only approximate. The second band is doubtless the Wolf-Rayet band 4650A. The nucleus of the nebula N.G.C. 6905 has an almost identical spectrum.

N.G.C. 7027. $\alpha = 21^h\ 3^m.3$; $\delta = +41°\ 50'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time	Region of Spectrum
1909 Oct. 13.80	31	a	4^h 0^m	visible
1910 June 26.85	246	a	5 11	visible
Sept. 8.88	254	a	5 13	visible
Sept. 27.83	258	c	5 55	visible
Oct. 25.79	271	f	2 20	ultra-violet
Oct. 26.83	272	f	3 15	ultra-violet
Oct. 27.77	273	a	6 5	visible
1912 Aug. 16.74	403	e*	3 40	blue-green
Aug. 21.86	405	e*	1 50	blue-green
Aug. 30.87	407	e*	1 45	blue-green
Oct. 30.75	418	f	2 5	ultra-violet
Nov. 26.76	426	f	2 20	ultra-violet
1913 Aug. 5.77	540	d	3 45	blue
Aug. 14.78	542	b	7 0	visible
Aug. 17.85	543	b	7 28	visible
Aug. 31.87	549	d	4 10	blue
Sept. 4.80	551	a	7 25	blue-violet
1914 Nov. 4.74	659	a†	0 17	blue-violet
Nov. 4.78	660	a†	1 0	blue-violet
Nov. 9-10	664	a*	10 15	blue-violet
1916 Sept. 4.74	754	g (slitless)	0 15	ultra-violet
Sept. 4.85	755	g (slitless)	4 0	ultra-violet
Oct. 31.73	795	g (slitless)	0 22	ultra-violet
Oct. 31.76	796	g (slitless)	1 0	ultra-violet

† Position angle of slit 321°.
* Position angle of slit 141°.

This is a rather small but exceedingly bright nebula, perhaps the brightest in the sky. It has two condensations or nucleii of unequal intensity. In any one of the slitless spectrograms the different monochromatic images appear to be of unequal size, but this is almost entirely an effect of image intensity. Properly timed images are nearly of the same dimensions, though the one at 4686 may be a little smaller than the others.[30] There is not, however, the difference in this respect that one finds in many objects.

It is an excellent nebula for wave-length determinations, not only on account of its brilliancy but also because its spectrum includes a very great percentage of the known nebular lines. This is the reason for the large number of observations which have been made.

The spectrum shown in plate XLII was secured with the slit placed in the line of the two nuclei. Photographs taken with the slitless spectrograph are reproduced in plate XLVI.

The wave-lengths as measured in this and other nebulae are given in table 11. The mean results for all the measurements of a single spectrum are recorded there. It has seemed preferable not to publish the determinations from individual plates *in extenso.* The observations were made with instruments of many kinds and under a great variety of conditions, and a complete account of the reductions would be very long, and probably serve no useful purpose. There are some details of the measurement of particular lines, however, which seem to call for some explanation, and these are discussed here.

The line 3426.4A was measured twice with the quartz spectrograph (f). This is the only one of the ultra-violet group 3313 to 3445A which I have measured with a slit spectrograph in any nebula, the others being too faint for the present instrumental equipment. It is one of the ultra-violet lines discovered by Palmer, the other being 3346A. Dr. Palmer observed with a very small slitless quartz spectrograph, and was unable to more than indicate the positions of his lines, since they are far to the violet of any other nebular lines known at that time, and he was obliged to extrapolate about 300 units beyond his nearest standard, 3727A. The wave-lengths

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[30] In a previous paper I stated that the nebula appeared to be perfectly homogeneous. That view was based on observations with a slit spectroscope. It may be necessary to modify the assertion upon further investigation with more efficient apparatus.

given by Palmer differ considerably from my determinations. They are 337 and 345$\mu\mu$. The second of these should not be confused with 3445A of the present system. That is a line which happens to fall near his estimated position, but it was not observed by him.

The other lines in the ultra-violet group just mentioned were measured in this and other nebulae on slitless spectrograms, using the line 3426.4 and other known nebular lines as a basis for inter- and extrapolation. They are probably not more than a unit or two in error.

The line 4686A was measured on four plates, secured with a battery of three prisms. The single determinations are as follows:

4686.00
85.90
85.93
85.92

Mean 4685.94

4363A is recorded on one of these plates. The wave-length as measured is:

4363.39

A discussion of the wave-lengths of N_1 and N_2 is given in another paper and need not be repeated here.

A word may not be out of place concerning the suggestion by Fowler* that a search be made in the spectrum of this nebula for the line at 3203A, observed by him in the laboratory and designated as the first line in the second principal series of hydrogen. The so-called principal series is comparatively strong in this nebula, the leading line, at 4686A, being among the brighter lines of the spectrum, and this fact led Professor Fowler to suggest that the least refrangible line of the second series, which he found associated in laboratory spectra with the principal one, be searched for in the spectrum of this nebula. The line is not recorded on any of my plates, but that fact furnishes little evidence that it is not present in the spectrum. A silvered mirror is transparent for light of that wave-length, and its reflectivity is therefore, unfortunately for this purpose, very low, so that a line of considerable strength at this particular point might well fail to record. The observation should be attempted with a metallic or nickel-plated mirror.

There is a very faint continuous spectrum due to the whole of the brighter part of the nebula. Following it in the direction red to violet, it fades out to vanishing intensity at about 4000A. Another continuous spectrum begins abruptly at about 3700 and continues far into the ultra-violet.

I.C. 5117. $\alpha = 21^h\ 28^m7$; $\delta = +44°\ 10'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1917 May 30.97	822	g (slitless)	$0^h\ 57^m$
Aug. 20.95	852	g (slitless)	3 0

This is a stellar nebula. Monochromatic images of proper exposure are about 2½″ in diameter, which is about as small as can be expected for any star. N_1 is intense even on the shorter exposure and gives a 4″ disc. It is probable that the increased diameter is due to circumstances of observation. As is the case with all stellar nebulae, the intensity measurements are rather uncertain.

NEBULAR LINES

line	I_q	line	I_q
N_1	overexposed	$H\gamma$	39
N_2	140	$H\delta$	17
$H\beta$	60	(3967 + $H\epsilon$)	25
4363	26	$H\zeta$	(6)
		3869	48

No continuous spectrum is recorded.

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* *Mon. Not. R.A.S.*, 73, 68, 1912.

I.C. 5217. $\alpha = 22^h\ 19^m.9$; $\delta = +50^\circ\ 28'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time
1916 Oct. 20.83	784	g (slitless)	3^h 0^m
Oct. 25.78	787	g (slitless)	1 0

A small elliptical nebula with the major axis lying north and south. The definition is not of the best on either of the spectrograms, but as far as one can judge the intensity of the images falls off from the center outwards. The strongest discs therefore appear to be the largest. Most of the apparent differences in size can be ascribed to this cause, but 4686 is quite certainly confined closely to the nucleus, and the image at 4471 impresses one as being small. The images given by the lines 4740, 4712, and 4640, which usually conform to the behavior of 4686A, are too faint to permit of an estimate of their sizes. 3727A gives a faint image of the same general size as the others, but more nebulous.

NEBULAR LINES

line	I_q	line	I_q
N_1	overexposed	Hδ	30
N_2	75	(3967 + Hϵ)	39
Hβ	53	3889 (He + Hζ)	21
4740	(6)	3869	55
4712	(6)	Hη	10
4686	12	Hθ	(7)
4640	(5)	Hι	(5)
4471	13	Hχ	(5)
4363	16	3727	15
Hγ	47	3445	trace

There is a faint continuous spectrum due to the center of the nebula which, as noted above, appears to include 4686A, and possibly other lines, as localized radiations.

N.G.C. 7662. $\alpha = 23^h\ 21^m.1$; $\delta = +41^\circ\ 59'$

DETAILS OF OBSERVATION

Date	Plate No.	Instrument	Exposure time	Region of Spectrum
1914 Oct. 12-13	652	a	17^h 4^m	blue-violet
1916 Aug. 29.90	745	g (slitless)	0 15	ultra-violet
Aug. 29.95	746	g (slitless)	1 0	ultra-violet
Aug. 29.99	747	g (slitless)	0 5	ultra-violet
Aug. 30.88	752	g (slitless)	3 16	ultra-violet
Nov. 2.73	798	g (slitless)	4 30	ultra-violet
1917 Sept. 5-6-7	855	e′	24 0	blue-green

This is a beautiful nebula, consisting of an oval ring lying on a more or less circular disc of nebulosity. Distributed around the edge of this disc are a number of bright lobes which give the impression of detached portions of an outer ring system.

A number of spectrograms are reproduced in plates XLII and XLVI. They show at a glance the variety in the forms of the monochromatic images. The most striking image is that at 3727A, rather inadequately depicted. Here the light is almost all in the outer broken ring, and is distributed in a string of stellar points, most of which are resolved on the original photograph but are run together in the reproduction. The outstanding point shown in plate XLVI, figure 5, above and to the right of this image lies on a faint thread of nebulosity following the general form of the outer ring. Little more than a trace of the inner ring is shown.

The absence of exterior nebulosity from 4686A is very noticeable. The ring itself is rounder than the others, due to the fact that its minor axis is slightly greater and its major axis slightly less than those of, say, the hydrogen rings. The measured diameters of the principal rings are given herewith. They are subject to certain small sources of error, such as field distortion and effects of departure from minimum deviation, which have not yet been quantitatively investigated but which probably do not seriously affect the measurements.

	diameter			diameter	
line	major	minor	line	major	minor
N_1	14″9	9″8	3967	15″6	9″4
N_2	14.7	10	3869	15.7	9.6
Hβ	14.6	8.7	3727	14	13±
4686	13.7	9.1	3445	14.2	10.2
4542	12	8	3426	9	7
Hγ	14.8	8.7	3342	13.4	9.8
Hδ	14.4	8.8			

Collecting the images which appear to have about equal dimensions, the following tentative grouping results:

line 3426	9″ × 7″	line Hβ Hγ Hδ	14″6 × 8″7
4542	12 × 8	N_1 N_2	14.8 ×10
3342 3445 4686	13.8×10	3869 3967	15.6 × 9.5

The inner ring of 3727A is so faint as to be scarcely measurable.

The ring at 4686A, when viewed on the original negative, impresses one as being smaller than many of the others. This is doubtless a subjective effect due to the fact that the interior is relatively intense. The various monochromatic images differ in several respects. In some there are very pronounced gaps in the flat sides of the oval. Among the images which show these gaps are N_1, N_2, 3869, 3967, 3727, and to a less extent the hydrogen images. There are no gaps in the images of the ultra-violet group 3313 to 3445A, while the 4686 image is especially strong at these places.

The orientation is not the same for all of the rings. The major axis of the nebula lies approximately NE and SW. With respect to this mean position the axis of 4686A inclines perceptibly towards the east and west, while 3869 and 3967 appear, though not certainly, to favor the north and south direction. The difference in inclination of the 4686A and Hβ ovals is very apparent in figure 4 of plate XLVI. A greater effect of this sort is indicated in the case of 4471A. That oval appears in figure 5 to slope the wrong way. This reversal of direction may be more apparent than real, and perhaps due to a difference in the relative intensity of some of the outlying parts of the image. The record is rather faint and the observation should be confirmed.

NEBULAR LINES

line	I_q	line	I_q
N_1	360	4026	(3)
N_2	145	(3967 + Hε)*	37
Hβ	48	Hζ	(25)
4740	(6)	3869	65
4712	(6)	Hη	(5)
4686	59	Hθ	(4)
4641	(4)	3759†	(4)
4634	(1)	3727	13
4541	(4)	3445	13
4471	(4)	3426	6
4363	(15±)	3346	(2)
Hγ	52	3342	5
4200	(3)	3313	(2)
Hδ	29		

* On a slit spectrogram 3967A is estimated to be about three or four times as strong as Hε.

† This line probably present, but too close to other images to be completely separated.

The spectrum as photographed with the single-prism slit spectrograph is shown in figure 2 of plate XLII. The restricted occurrence of 4686A and neighboring lines is shown by their comparative shortness. 4363A seems to be of intermediate length. This spectrum has been observed with high dispersion by Director Campbell and Dr. Moore, who have found that the lines N_1 and N_2 are split and distorted in a remarkable manner (pl. XXXIX, fig. 65*c*). The line at 4686A differs in its behavior in so many respects from many of the other lines that it seemed worth while to observe it under high dispersion for the purpose of determining whether it is affected in the same manner and degree. An observation was therefore made with the dispersion of three prisms and an exposure of 24 hours, using a Seed No. 23 plate (spectrogram No. 855). The line is divided in much the same manner as the two nebular lines referred to but differs from them in that, with respect to the pattern they exhibit, it is reversed in the sense right and left. The observation would appear to indicate that the distortion is not the result of velocity in the line of sight, because, if it were, the gases responsible for the respective lines would have to be moving in opposite directions to produce the observed effect.

The wave-lengths measured in this nebula are given in table 11. The spectrum of the nucleus appears to be continuous.

DATA REFERRING TO ILLUSTRATIONS

The data in these tables refer to the illustrations which follow. Probably the only part requiring explanation is the last column in the second table. The orientation of the image on a slitless spectrogram is determined by conditions of observation which are generally imperative, so that it is impossible to have it uniform in any series of plates. It is therefore necessary that it be specified in each case. When the image is properly oriented its disposition on the plate corresponds with that in the sky.

The scale of plates XLVI to L is approximately uniform except with respect to two subjects. Its value is 1 mm. = 4″.3. The two exceptions noted are XLVIII, figure 2, which is about half the normal scale, and L, figure 2, in which the scale is double, one millimeter being equivalent to about 2″.2 of arc. This plate is enlarged about seventeen times from the original negative.

SLIT SPECTROGRAMS

Plate	Figure	Object	Obsn. No.	Exposure	Pos. angle of slit	Remarks
XLII	1	N.G.C. 7027	664	10¼^{h}	141°	Slit in line of nuclei
	2	N.G.C. 7662	652	17	0	
	3	N.G.C. 7009	650	10	346	Slit approx. along minor axis
	4	N.G.C. 6720	723	13½	150	Slit approx. along minor axis. The background of continuous spectrum is from moonlit sky
XLIII	1	N.G.C. 2392	713	8⅓	90	
	2	N.G.C. 6543	649	2	90	
	3	N.G.C. 6572	607	13½	90	
	4	Orion	1	7	90	Region just north of Trapezium
XLIV	1	B.D. +30°3639	624	11	90	Slightly out of focus of 36-inch objective
	2	B.D. +30°3639	623	13	......	Visible region of spectrum
	3	N.G.C. 40	685	6	90	No comparison spectrum
	4	N.G.C. 40	689	3	......	Nucleus only
	5	N.G.C. 40	......	....	......	Reproduction 689 with cylindrical lens. Principal Wolf-Rayet bands marked at top
	6	Vega	......	....	......	Showing general absorption above limit of hydrogen series; not seen in Class K spectrum shown below
XLV	....	....	......	....	......	Comparison of nebular spectra

SLITLESS SPECTROGRAMS

Plate	Figure	Object	Obsn. No.	Exposure	Orientation right end cut
XLVI	1	N.G.C. 7027	795	22^{m}	South
	2	N.G.C. 7027	796	1^{h}	South
	3	N.G.C. 7662	745	15^{m}	South
	4	N.G.C. 7662	746	1^{h}	South
	5	N.G.C. 7662	752	4¼^{h}	South
XLVII	1	N.G.C. 2392	803	6^{h}	West
	2	N.G.C. 7026	790	3^{h}	North
	3	N.G.C. 6572	751	1^{h}	South
XLVIII	1	N.G.C. 6818	845	4^{h}	South
	2	N.G.C. 6720	727	5½^{h}	20° east of south; Ring nebula in Lyra
	3	N.G.C. 7009	736	7^{m}	South
	4	N.G.C. 7009	734	1^{h}	South
	5	N.G.C. 7009	770	3^{h}	South
XLIX	1	N.G.C. 6543	740	1^{h}	East
	2	N.G.C. 6543	739	15^{m}	East
	3	N.G.C. 6543	740	....	East. Same as figure 1
	4	I.C. 418	789	1^{h}	South
L	1	N.G.C. 6826	858	2½^{h}	North
	2	B.D. +30°3639	757	4^{m}	South
	3	N.G.C. 40	753	4^{h}	North

1918PLicO..13..191W

PLATE XLII

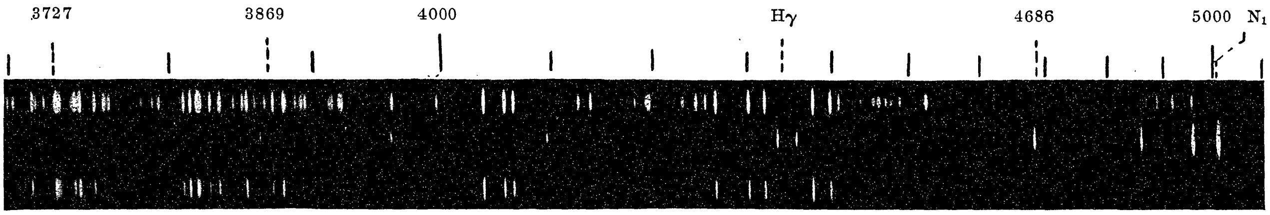


Figure 1. N.G.C. 7027.

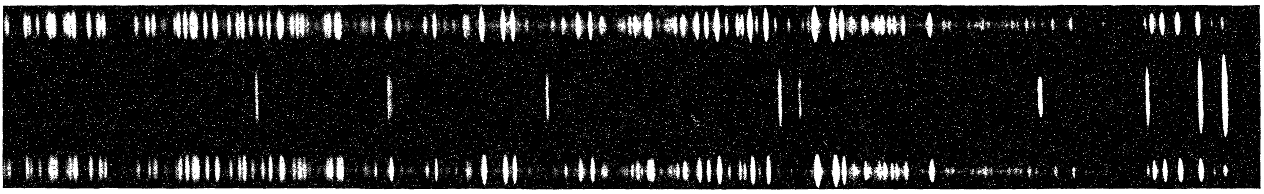


Figure 2. N.G.C. 7662.

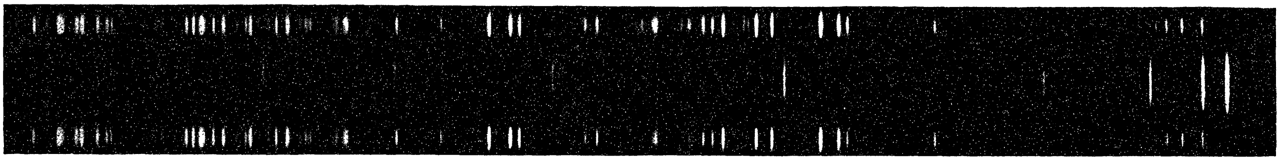


Figure 3. N.G.C. 7009.

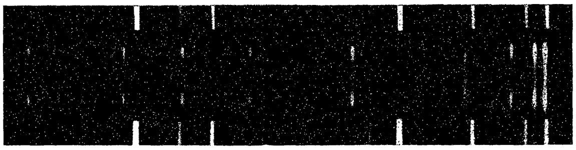


Figure 4. Ring nebula in Lyra.

PLATE XLIII

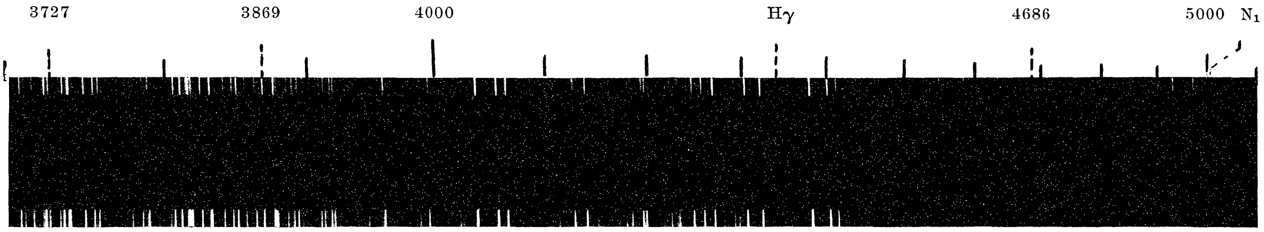


Figure 1. N.G.C. 2392.

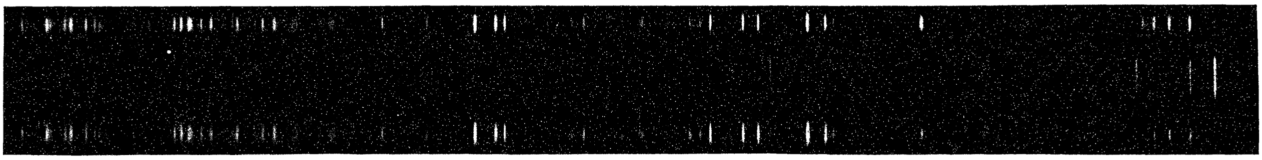


Figure 2. N.G.C. 6543.

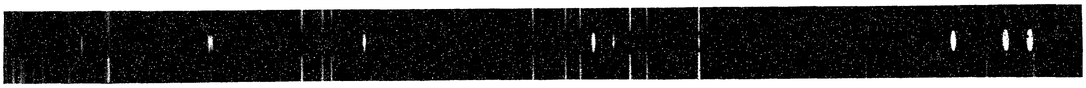


Figure 3. N.G.C. 6572.

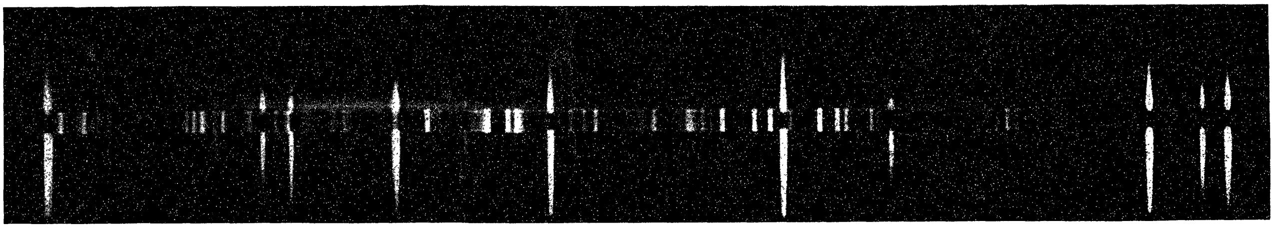


Figure 4. Orion Nebula. (Comparison spectrum at center.)

PLATE XLIV

Figure 1. B.D. +30°3639.

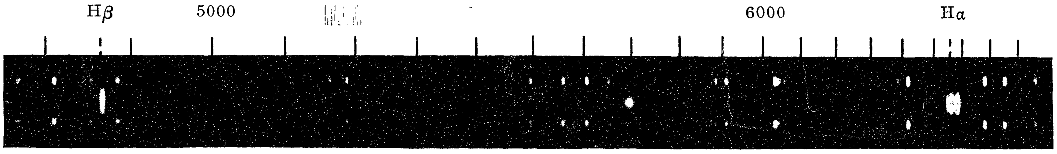


Figure 2. B.D. +30°3639 (visible region).

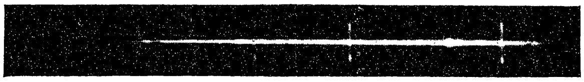


Figure 3. N.G.C. 40.

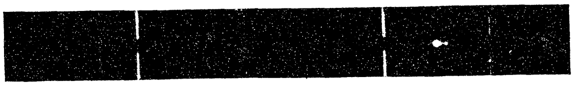


Figure 4. Nucleus of N.G.C. 40.

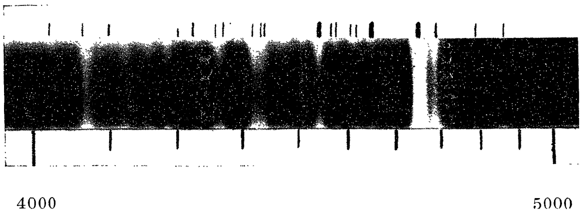


Figure 5. Nucleus of N.G.C. 40.

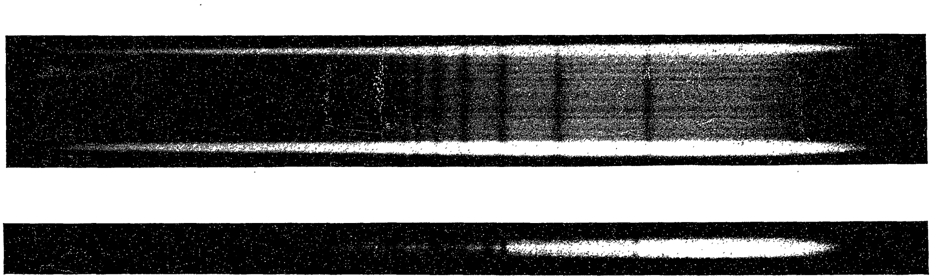
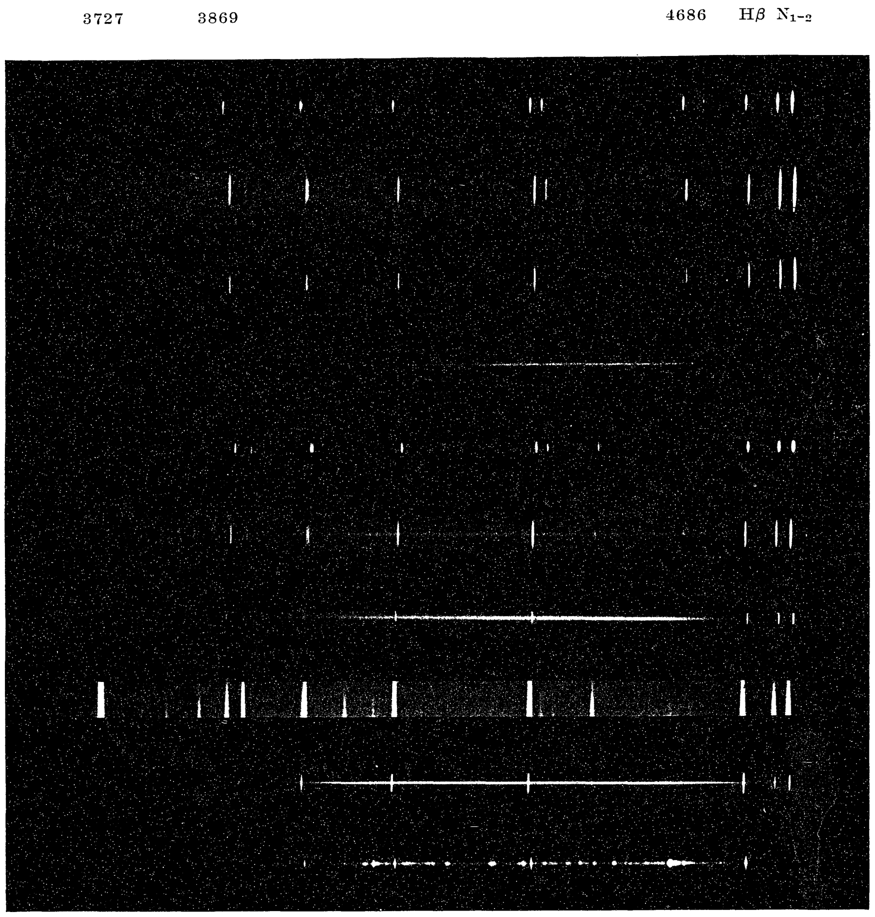


Figure 6. Above α Lyrae, below β Aquilae.



4686A long. N. G. C. 7027

4686A shorter. 7662

4686A shorter. 7009

4686A long but partially condensed in nucleus. 4634 and 4641 in nucleus. 2392

4686A completely condensed in nucleus. 6572

4686, 4650, 4634, 4267A condensed in nucleus. 6543

4686 bordered by dark line on violet edge. 6826

Orion

4650 stronger than 4686A. N_1 N_2 and 4471 (helium) short. I. C. 418

4650 stronger than 4686A. Helium in nucleus. B.D.+30°3639

Comparison of Nebular Spectra.

PLATE XLVI

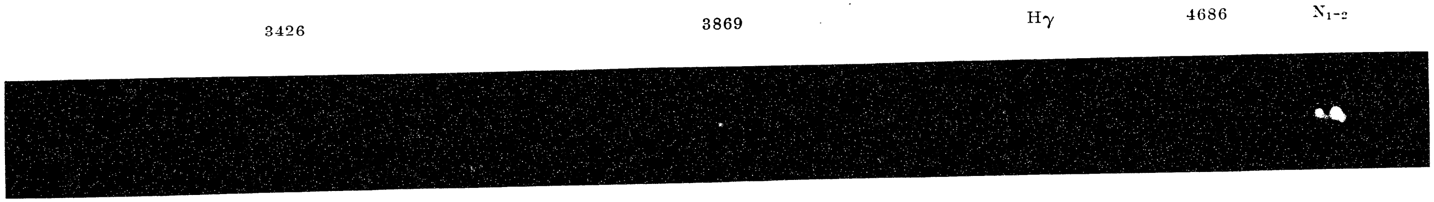
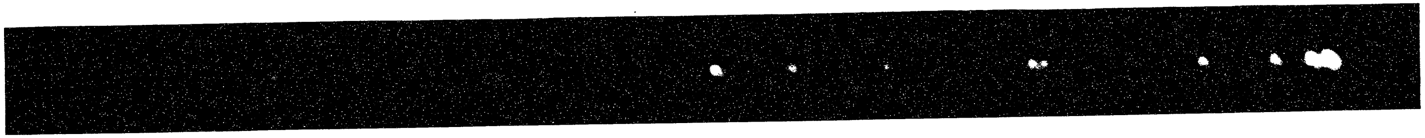


Figure 1.



N.G.C. 7027.

Figure 2.

N.G.C. 7662

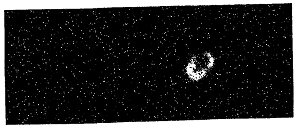


Figure 3.

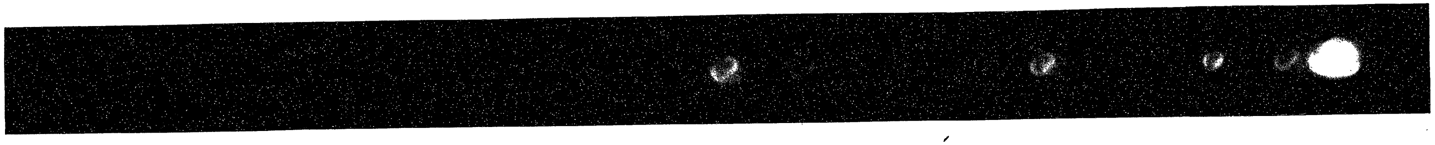


Figure 4.

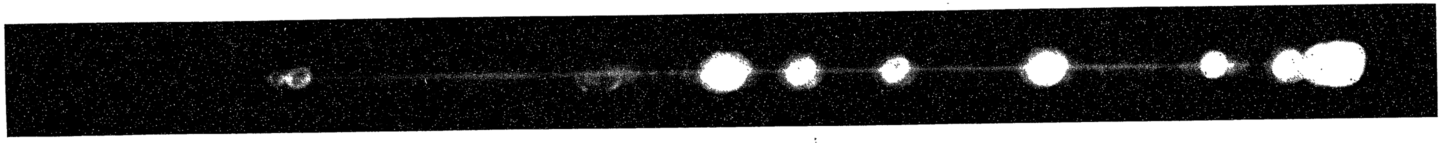


Figure 5.

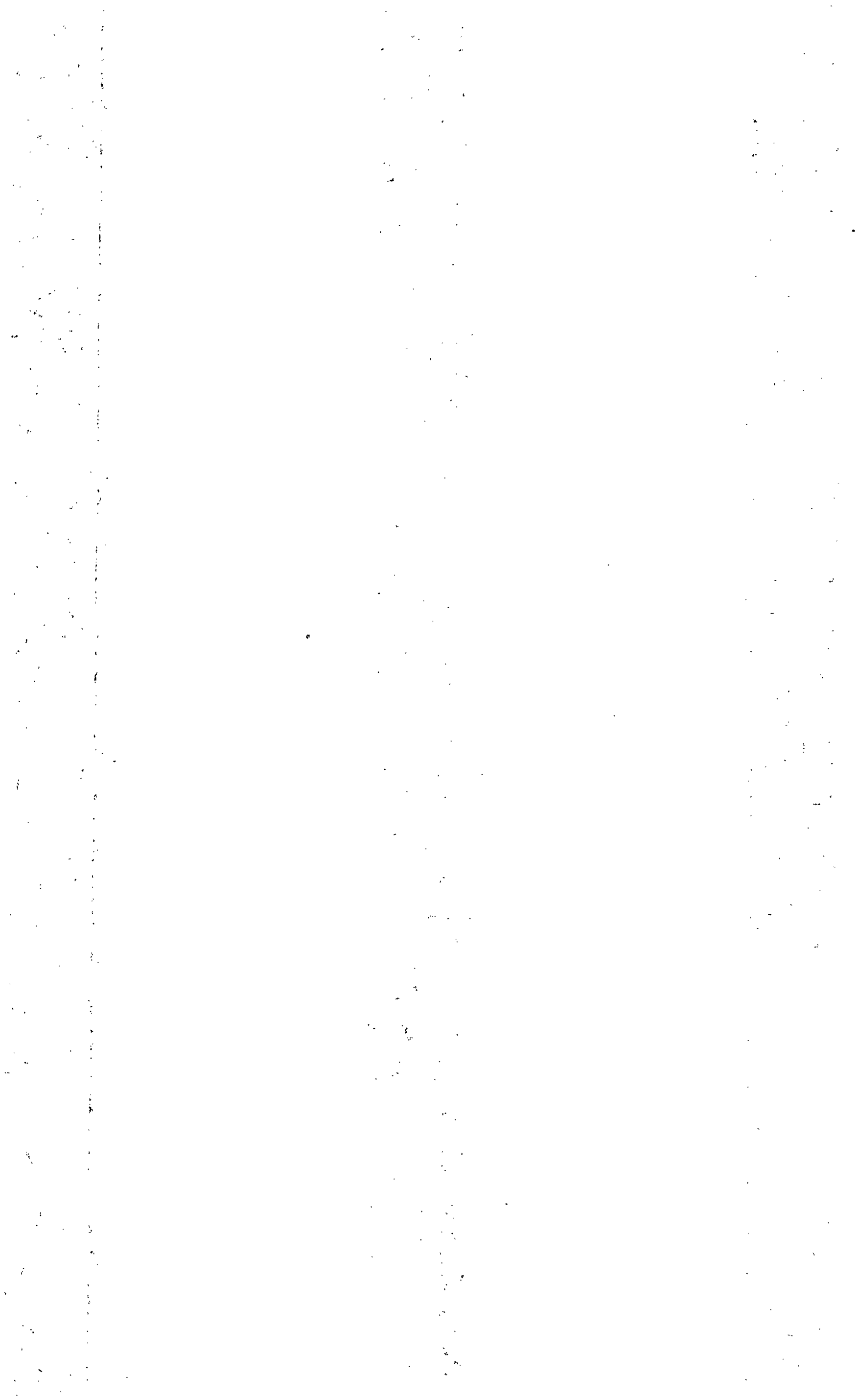


PLATE XLVII

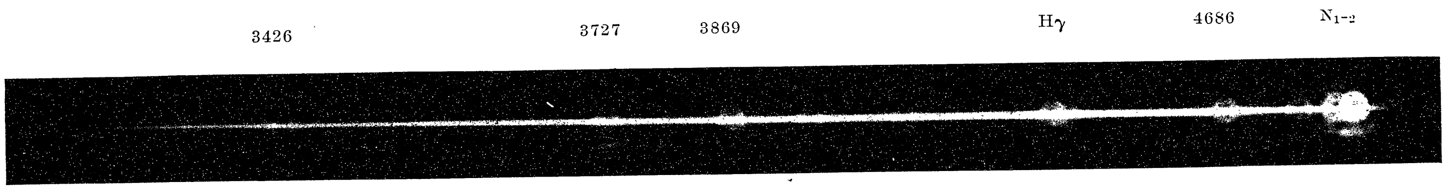


Figure 1. N.G.C. 2392.

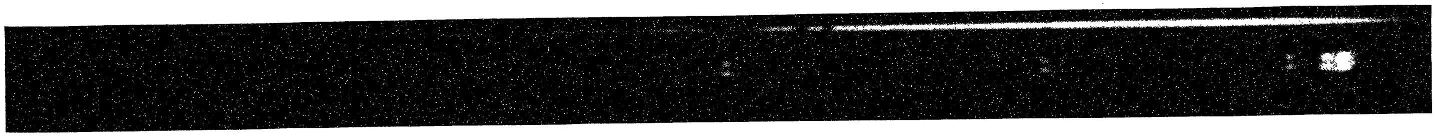


Figure 2. N.G.C. 7026.

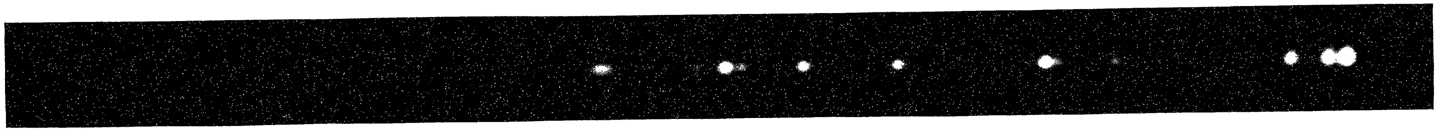


Figure 3. N.G.C. 6572.

PLATE XLVIII

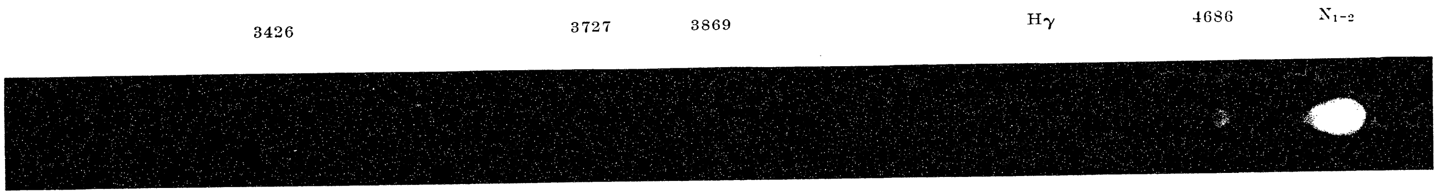


Figure 1. N.G.C. 6818.

Figure 2. Ring nebula in Lyra.

N.G.C. 7009

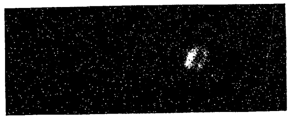


Figure 3.

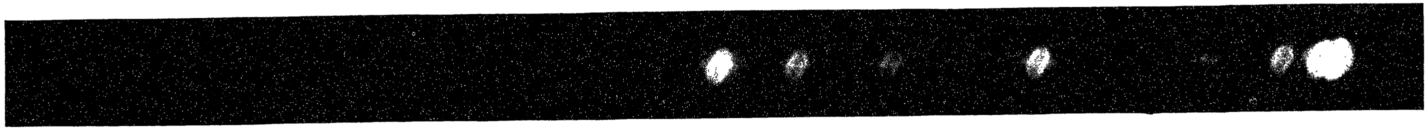


Figure 4.

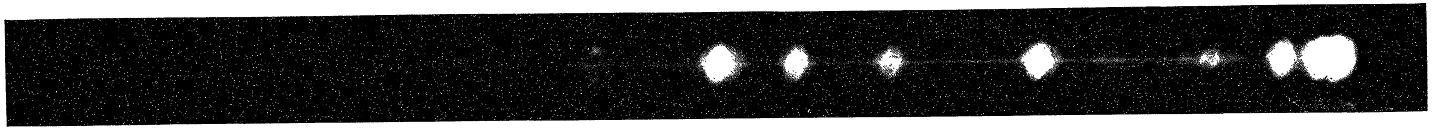


Figure 5.

PLATE XLIX

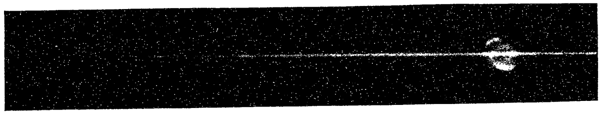


Figure 1.

N.G.C. 6543.

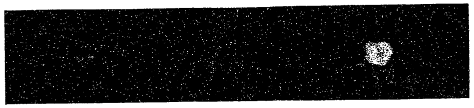


Figure 2.

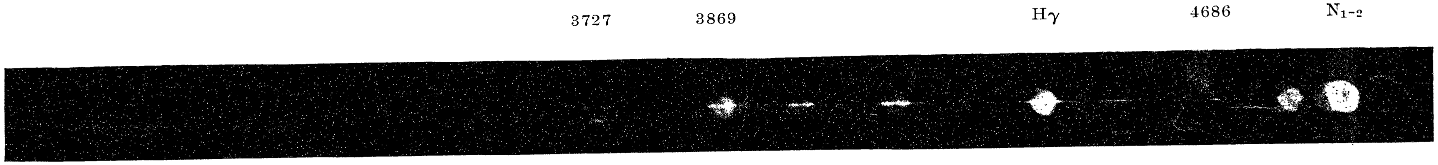


Figure 3.

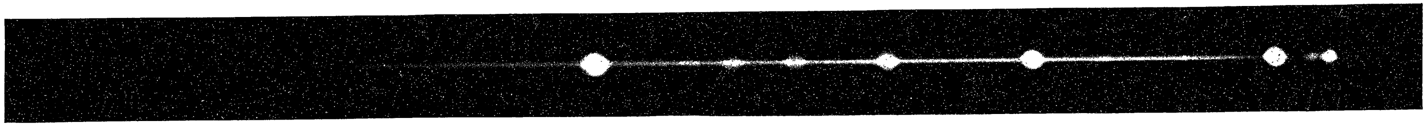


Figure 4. I.C. 418.

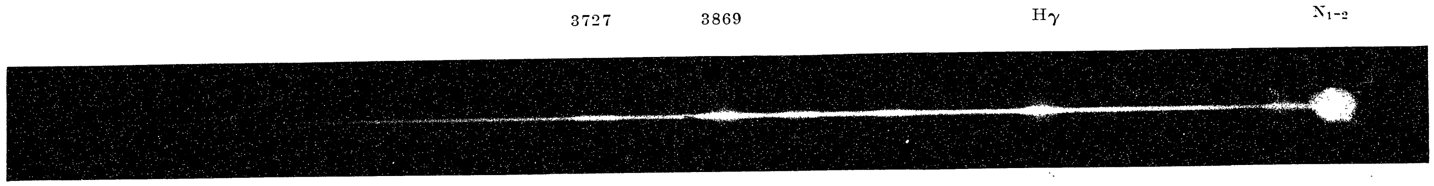


Figure 1. N.G.C. 6826.

Figure 2. B.D. +30°3639. (Double scale.)

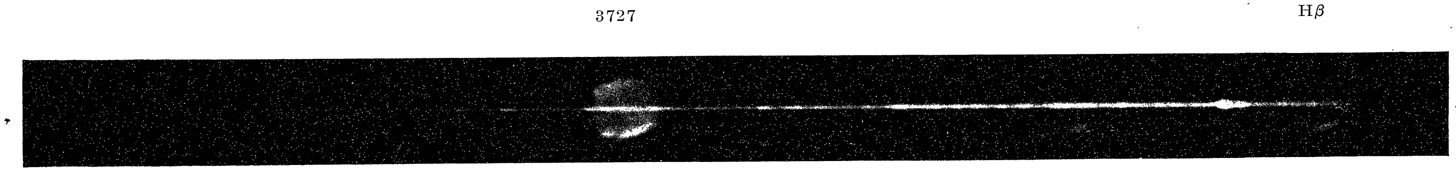


Figure 3. N.G.C. 40.

CHAPTER II

WAVE-LENGTHS AND INTENSITIES OF THE NEBULAR LINES

The Wave-Lengths of the Nebular Lines.—The most extensive observations of nebular wave-lengths heretofore available have been those of Campbell,[31] who investigated the spectra of the *Orion* and six planetary nebulae. Measurements of the spectrum of the *Orion* nebula have also been published by Lockyer,[32] and two bright planetaries have been the subjects of investigation by Max Wolf.[33] These observers measured a comparatively large number of lines with the use of low dispersion. Accurate observations have been made of a few of the brighter lines. Of these the earliest are those of Keeler,[34] who in 1891 determined by visual methods, and with a high degree of precision, the wave-lengths of the two green lines now generally designated as N_1 and N_2. These lines have been remeasured photographically by Hartmann,[35] Campbell and Moore,[36] and the writer.

A very beautiful application of the methods of interference measurement to an astronomical problem was made by Buisson, Fabry, and Bourget in their observations of the doublet near 3727A in the spectrum of the *Orion* nebula.[37] They not only determined the positions of these lines with the greatest accuracy, but detected differences of wave-length in various parts of the nebula due to differential radial velocity.

The present determinations depend upon the measurement of the spectra of nine bright nebulae. The results are given in table 11. The table includes, with a few exceptions, all of the well authenticated lines announced by previous observers and a number in addition to these. Two of the exceptions are the very faint green lines at 518 and 531$\mu\mu$, discovered respectively by Vogel and Campbell. They lie in a region of the spectrum to which it is difficult to sensitize plates and do not appear on any of my photographs. Should it ever become necessary to determine their places photographically plates can probably be specially sensitized for the green which will record them in a reasonable exposure time. Besides these lines the only others not measured are two reported by Max Wolf at 3629 and 3652A in the spectrum of N.G.C. 6543. There is a reference to them in the description of the spectrum of that object.

While quite a variety of spectrographs have been used, each observation being accomplished with the instrument which seemed best adapted to the particular purpose, most of the spectrograms have been made with the single-prism spectrograph (a) attached to the 36-inch refractor. Some of the brighter lines were, however, photographed with a battery of three prisms and with a grating, while in the ultra-violet it was necessary to depend very largely on the slitless quartz spectrograph. I regret that it has not been practicable to secure satisfactory photographs of all of the ultra-violet lines with the quartz slit spectrograph. The reason for the failure lies in the strong curvature of the field given by the simple quartz lenses. This curvature corresponds to a radius of six inches, and is too great to be accommodated by bending, even with the most flexible glass plates procurable. The use of films is unsatisfactory on account of certain changes in length which they have been found to undergo even in the comparatively short interval of time required for an exposure. It is not uncommon for a film to alter its dimensions by a half of 1 per cent in less than two hours, a degree of instability not to be tolerated in any photographic operation where accuracy is required. We have been attempting for several years to secure achromatic lenses which will give a better field and thus allow the use of glass plates, but disturbed commercial conditions have prevented the accomplishment of this purpose.

The instruments used are all described in the appendix under the head of the letters by which they are indicated in the text.

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[31] *Astron. and Astrophys.*, **13**, 384 and 494, 1894.

[32] *Phil. Trans.*, **186A**, 73, 1894.

[33] *Sitz. Heidel. Akad. Wiss.*, **35** Ab., 1911.

[34] *Publ. Lick Obs.*, **3**, 165, 1894.

[35] *Ap. Jour.*, **15**, 291, 1902.

[36] *Lick Obs. Bull.*, **9**, 6, 1915.

[37] *Ap. Jour.*, **40**, 241, 1914.

It is believed that the observations are practically free from systematic error, a fact which is indicated by the agreement with lines of known origin where they are available for comparison. Certain of these known lines, particularly the brighter ones of the hydrogen series, have been used to reduce the nebular wave-lengths to normal, and a fair agreement with laboratory values follows as a necessity; but the fainter lines above Hε have, as a rule, not been used for this purpose, and here the degree of correspondence between the nebular and laboratory values may be taken as an indication of the accuracy of the measures. In the near ultra-violet there is a check furnished by the interferometer determinations of Buisson, Fabry, and Bourget of the wave-length of the doublet at 3727A. The comparison appears to indicate a systematic error at this point of +.06A, which I should hardly have expected. This quantity is, however, within the limits of accuracy of the measurements of any other lines in the vicinity, and is therefore a matter of little consequence. The error does not persist below Hε.

The observations published in the previous paper[40] are included, with the more recent ones, in table 11.

Wave-lengths of the nucleus bands are collected in table 12. In the case of B.D. +30° 3639 and a few other objects the measurements were made chiefly with a slit spectrograph and the positions may be regarded as reliable. In most instances, however, the wave-lengths have been estimated on slitless spectrograms and are therefore subject to considerable uncertainty. Where a band is very broad and apparently composite the wave-lengths of the probable components are inserted and covered by a brace. For further particulars the observations recorded in Chapter I should be referred to.

The photographs on which these wave-lengths depend were made on Seed No. 27 and Seed No. 30 plates, for the photographic region, and for the "visible" region of the spectrum, on Seed No. 27 plates bathed in Pinacyanol, Pinaverdol, and Homocol in the proportions recommended by Wallace[39].

Intensities of the Nebular Lines.—There are two systems of intensity used in this discussion, one of which refers to the intensity as photographed with the glass spectroscope (a) attached to the 36-inch refractor with correcting lens. This scale is designated by Ig. The other indicates the intensity as observed with the slitless quartz spectrograph used in conjunction with the Crossley reflecting telescope. This has been termed the Iq scale. It might appear at first that the use of the two scales would lead to confusion, and that the glass system should be discarded in favor of that determined by quartz, which is of course the more uniform of the two. In view, however, of the fact that a great deal of work in this field still lies ahead of the glass spectrograph, it seems better to preserve the older scale for the convenience of observers who may desire to compare observations made with this, or similar apparatus, with the present ones.

Ig System.—In the earlier paper[40] the intensities of the bright nebular lines were indicated on an arbitrary scale running from 1 to 80, 1 indicating the faintest line photographed. In extending the work to the fainter lines all of these naturally fell within the unit, and desiring not to alter the original intensity assignments fundamentally, and at the same time to avoid the use of decimals, the intensities were all multiplied by ten, which allowed plenty of latitude for the estimates of the fainter lines. This scale as originally adopted was, as has been said, quite arbitrary, and was described as follows: "The relative brightness of the lines as photographed is indicated in a way by the numbers opposite the wave-lengths. About all that can be said of the system is that, for any one object, the larger the number the brighter the line. Such estimates must of course be used with caution, as the apparent brightness of a line is greatly influenced by photographic and instrumental conditions." These considerations apply to the present extension of the scale to the fainter lines.

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[39] *Lick Obs. Bull.*, 5, 151, 1909.

[40] *Lick Obs. Bull.*, 1, 153, 1902.

	N.G.C. 7027			N.G.C. 7662				Mean λ		Probable origin, etc.
	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	R	I A	(λ in I A)
	1	----	1	3313 [2]	1	----	2	3313	3313 [1]	
	----	----	----	3342 [2]	1	----	5	3342	3342 [1]	
	1	----	8	(3347) [2]	1	----	2	3346	3346	Palmer 337μμ
	1	----	20	3426.4 [4]	----	----	6	3426.4	3426.2	Palmer 345μμ
	1	----	8	3444 [2]	1	----	13	3445	3445 [1]	
	----	----	----	------------	----	----	----	3704	3704	Hξ 3703.9; He 3705
	----	----	----	------------	----	----	----	3712	3712	Hν 3712.0
	----	----	----	------------	----	----	----	3722	3722	Hμ 3721.9
	----	----	----	3727.4 [4]	----	----	----	3726.30	3726.16	Buisson, Fabry & Bourget 3726.100
	----	----	12		----	----	13			
	----	----	----		----	----	----	3729.05	3728.91[1]	Buisson, Fabry & Bourget 3728.838
	----	----	----	------------	----	----	----	3734	3734	Hλ 3734.4
2	1	----	3	------------[6]	----	----	----	3750	3750	Hχ 3750.2
2	1	----	4	------------[7]	----	----	----	3759	3759 [1]	
2	1	----	4	------------[7]	----	----	----	3771	3771	Hι 3770.6
2	1	----	5	------------[7]	----	----	4	3798	3798	Hθ 3797.9
2	1	----	1	------------[7]	----	----	----	3820	3820	He 3819.6
2	1	----	8	------------[7]	----	----	5	3835.6	3835.5	Hη 3835.42
	----	----	----	------------	----	----	----	3840.4	3840.2 [1]	
)	3	70	55	3868.84	3	45	65	3868.89	3868.74	
5	2	10	13	3888.9	1	10	25	3889.11	3888.96	Hζ 3889.05; He 3888.64
	----	----	----	------------	----	----	----	(3935)	(3935)	
	----	----	----	------------	----	----	----	3965.0	3964.8 [1]	Par He 3964.7
3	3	70	28	3967.57	2	40	37	3967.66	3967.51[1]	
3	1	30		3970.08	2	20		3970.23	3970.08	Hε 3970.07
	----	----	----	------------	----	----	----	4009	4009 [1]	Par He 4009.3
	2	1	3	4026.3	1	2	3	4026.4	4026.2	Hε′ 4026; He 4026.2
)	1	1—	1	------------	----	----	----	(4064)	(4064)[1]	
8	3	20	9	------------	----	----	----	4068.77	4068.62	
	2	2	4	------------	----	----	----	4076.37	4076.22[1]	
±	2	1	2	------------	----	----	----	4097.5	4097.3 [1]	N 4097.30
8	3	70	24	4101.87	3	40	29	4101.89	4101.74	Hδ 4101.74
	----	----	----	------------	----	----	----	4120.7	4120.6	He 4120.8
	----	----	----	------------	----	----	----	4144.2	4144.0	Par He 4143.7
	1	1	3	4200.5 [2]	1	3	3	4200	4200 [1]	Hδ′ 4200.1
	----	----	----	------------	----	----	----	4267.2	4267.1	C 4267.14
1	3	90	43	4340.67	3	60	52	4340.62	4340.46	Hγ 4340.47
	----	----	----	------------	----	----	----	(4353)	(4353)[1]	
9[3]	1	80	30	4363.4	3	20	15±	4363.37	4363.21	
	----	----	----	------------	----	----	----	4388.1	4388.0	Par He 4388.0
	----	----	----	------------	----	----	----	(4416)	(4416)[1]	
0	3	8	9	4472.0	1	3	4	4471.71	4471.54	He 4471.49
	2	2	7	4541.6	1	5	4	4541.6	4541.4 [1]	Hγ′ 4544.1
	1	1—	5	------------	----	----	----	4571.7	4571.5	
5	2	2	6	4634.8	1	1	1	4634.3	4634.1 [1]	H II 4634.4[11]
1	2	8	10	4641.7	1	3	4	4641.1	4640.9	
	1	1	5	------------	----	----	----	4649.4	4649.2 [1]	C (4647.4, 4650.7, 4651.6)
	2	1	5	------------	----	----	----	4658.4	4658.2	
4[3]	4	90	43	4685.80	3	60	59	4685.94	4685.76	Fowler 4685.80
	----	----	----	4711.6 [5]	1	10	6	4711.6	4711.4 [1]	
)[5]	3	8	9	------------	----	----	----	4712.8	4712.6	He 4713.2
7	4	4	5	------------	----	----	----	4725.7	4725.5 [1]	
16	5	20	15	4740.5	1	3	6	4740.4	4740.2	
50[4]	----	80	57	4861.50	3	40	48	4861.50[4]	4861.32	Hβ 4861.33
	----	----	----	------------	----	----	----	4922.4	4922.2	Par He 4921.9
06[3]	4	200	150	4959.2	2	80	145	4959.09[10]	4958.91	
97[3]	4	800	300	5007.1	2	200	360	5007.02[10]	5006.84	
	1	1—	----	------------	----	----	----	5017	5017 [1]	Par He 5015.7
5	2	4	----	------------	----	----	----	5411.5	5411.3	Hβ′ 5410.3
	----	----	----	------------	----	----	----	(5655)	(5655)[1]	
	2	1	----	------------	----	----	----	5737	5737 [1]	
4	2	4	----	------------	----	----	----	5755.0	5754.8	
8	2	8	----	------------	----	----	----	5875.9	5875.7	He 5875.6
1	2	5	----	------------	----	----	----	6302	6302 [1]	
	2	2	----	------------	----	----	----	6313	6313 [1]	
	2	2	----	------------	----	----	----	6364	6364 [1]	
	1	10	----	------------	----	----	----	6548.3	6548.1 [1]	
	2	100	----	------------	----	----	----	6563.01[4]	6562.79[4]	Hα 6562.80
	2	30	----	------------	----	----	----	6583.8	6583.6 [1]	
	2	1	----	------------	----	----	----	6677	6677 [1]	Par He 6678.2
	2	1—	----	------------	----	----	----	6730	6730 [1]	

I.C.
5217

686

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it exists, and that the nebular line is actually D_3. This measurement has not been used in striking
ean.

I_q not measured.

The final values of N_1 and N_2 are the means, struck by Campbell and Moore, of the results of several
vers. *L. O. Bull.*, **9**, 9, 1915.

This is close to the strongest line in the secondary spectrum of hydrogen observed by Dufour. It
shes the only case of coincidence with a line of that spectrum, however, and too great significance should
e attached to this single correspondence in wave-length.

TABLE 11

Nebular Wave-Lengths

Orion Nebula				I.C. 418				N.G.C. 6543				N.G.C. 6572				B.D. +30° 3639				N.G.C. 6826				
λ (R)	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	λ (R)
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...........[6]
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...........[6]
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...........[7]
3704	1	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
3712.4	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
3722	1	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
3726.38	3	40	....	3726.22	3	50		3726.0	1	1	40	3726.22	3	3		3726.47	1	15	....	....	....	....		....
							85	....	....	....	....	....			21	....	....	....	....	...........[7]	....	....	22	...........[7]
3729.10	3	30	....	3728.94	2	30		....	....	....	....	3728.9	1	1+		3729.24	1	7	....	....	....	....		....
3734.1	1	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
3749.8	1	3	....	....	....	....	....	....	....	....	....	...........[7]	....	....	5	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
3770.7	1	6	....	....	....	....	....	...........[7]	....	....	6	...........[7]	....	....	8	....	....	....	....	....	....	....	....	....
3798.1	1	10	....	....	....	....	....	...........[7]	....	....	8	3798.1	1	1	10	....	....	....	....	....	....	....	....	...........[7]
3820	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
3835.7	3	15	....	3835.55	2	10	17	3835.5	1	1	11	3835.5	2	3	14	3835.6	1	10	....	....	....	....	....	...........[7]
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3840.4	1	5	....	....	....	....	....	....
3868.85	4	40	....	3869	1	5	....	3868.83	1	40	37	3868.91	5	50	50	....	....	....	....	3868.85	1	40	40	3868.84
3889.17	4	40	....	3889.07	2	40	18	3888.88	1	20	18	3889.17	5	15	20	3889.3	1	30	....	3889.01	1	20	....	3889.0
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(3935)	1	10	....	....	....	....	....	....
3965.1	2	10	....	3965	2	5	....	3964.4	1	5	2	3965.1	1	2	2	....	....	....	....	....	....	....	....	....
3967.62	2	30	....	....	....	....	....			30		3967.64	3	50		....	....	....	....	3967.57	1	25		
							....	3968.8	1		30	....			38	....	....	....	....				31	3968.9
3970.27	4	40	....	3970.21	2	60	20			30		3970.24	3	40		3970.3	1	50	....	3970.17	1	30		
....	....	....	....	....	....	....	....	(4008)	....	1	....	4009.2	2	1—	1	....	....	....	....	....	....	....	....	....
4026.5	2	10	....	4026.4	2	10	7	4026.1	1	10	7	4026.36	3	10	10	....	....	....	....	4026.7	1	10	8	4026.2
....	....	....	....	....	....	....	....	....	....	....	....	(4065)	1	1—	....	....	....	....	....	....	....	....	....	....
4068.7	2	5	....	4068.67	2	20	10	....	....	....	....	4068.83	3	6	5	4068.8	1	60	....	....	....	....	....	....
4076.6	1	2	....	4076.2	2	5	2	....	....	....	....	4076.3	3	3	2+	4076.6	1	20	....	....	....	....	....	....
....	....	....	....	....	....	....	....	4097.2	1	2	4	4097.6	3	1	2	....	....	....	....	4097.8	1	10	5	4097.3
4101.93	4	60	....	4101.92	2	80	29	4101.86	1	50	30	4101.87	5	60	31	4101.9	1	70	....	4101.90	1	50	30	4101.8
4121	1	1	....	....	....	....	....	....	....	....	....	4120.7	3	1	2	....	....	....	....	....	....	....	....	....
4144	1	1	....	....	....	....	....	....	....	....	....	4144.2	3	1	2	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
4268	1	1	....	4267.9	1	5	1	....	....	....	....	4267.22	3	2	3	....	....	....	....	....	....	....	....	4266.6
4340.62	4	100	....	4340.60	2	90	49	4340.67	1	60	49	4340.62	5	70	50	4340.6	1	90	....	4340.62	1	60	51	4340.6
(4353)	1	1—	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
4363	1	6	....	....	....	....	....	4363.31	1	5	3	4363.29	5	20	14	....	....	....	....	4363.55	1	12	8	4363.4
4388	1	4	....	4388.0	2	5	1	4388.6	1	2	2	4388.1	3	2	2	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	(4416)	1	1—	....	....	....	....	....	....	....	....	....	....
4471.8	3	20	....	4471.73	2	25	10	4471.65	1	20	11	4471.62	5	20	12	....	....	....	....	4471.42	1	15	10	4471.9
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	4572	1	3	1	4572.6	1	1	....	4571.29±	3	1	1	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	4634.6	3	1	1	....	....	....	....	....	....	....	....	4634.3
....	....	....	....	....	....	....	....	4641.0	1	5	3	4640.8	3	3	2+	....	....	....	....	....	....	....	....	4641.2
....	....	....	....	....	....	....	....	....	....	....	....	4649.5	3	2	2	....	....	....	....	....	....	....	....	....
4659	1	2	....	....	....	....	....	....	....	....	....	4658.4	3	1	1	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4686.1
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4711.5
4714 [5]	1	1	....	....	....	....	....	4712.8	1	5	3	4712.7 [5]	4	5	3	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	4740.17	3	5	3	....	....	....	....	....	....	....	....	4740.5
4861.50[4]	....	70	....	4861.3	2	100	51	4861.52	2	65	51	4861.50[4]	....	60	50	4861.2	1	110	....	4861.7	1	60	49	4861.4
4921	1	1—	....	....	....	....	....	....	....	....	....	4922.4	4	2	2	....	....	....	....	....	....	....	....	....
4959.09[3]	2	50	....	4959.1	2	60	22	4959.09	2	80	58	4959.15[3]	2	80	75	4959	1	8	....	4959.3	1	70	....[9]	4958.5
5007.01[3]	3	70	....	5007.0	2	80	33	5007.0	2	100	92±	5007.04[3]	2	250	120	5007.2±	1	10	....	5006.9	1	100	....[9]	5006.4
....	....	....	....	....	....	....	....	....	....	....	....	5017	1	2	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	(5655)	1	1—	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	5740	1	1—	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	5755.2	1	2	....	5755.2	1	20	....	....	....	....	....	....
...........[7]	....	....	....	....	....	....	....	5876.0	1	20	....	5876.6 [8]	1	20	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	6301.4	1	3	....	6303.6	1	10	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	6367	1	1—	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	6548.3	1	10	....	6548.33±[3]	1	70	....	....	....	....	....	....
...........[7]	....	....	....	....	....	....	....	6563.0	1	65	....	6563.1	1	60	....	6563.01 [4]	1	100	....	....	....	....	....	....
....	....	....	....	....	....	....	....	6583.4	1	10	....	6583.2	1	30	....	6583.86 [3]	1	110	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	6679±	1	1	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	6731	1	1—	....	....	....	....	....	....	....	....	....	....

Bracketed lines: *suspected only.*

[1] These lines are believed to have been observed for the first time in the present investigation.

[2] Observations with large slitless spectrograph.

[3] Observations with high dispersion (3 prisms).

[4] Assumed wave-length.

[5] As helium is very weak in both N.G.C. 7009 and 7662, this line cannot be ascribed, in these two objects, entirely to the comparatively faint helium line at 4713.3A. There is evidently a distinct nebular line at 4711.5A. This is too close to the helium line to be separated from it in those nebulae in occur. The measured position of the blend therefore varies from one nebula to another relative strengths of the components.

[6] Probably present.

[7] Present, but not measured.

[8] The measured position of the line on the one plate of N.G.C. 6572 which covers th .7 A greater than that of D_3. This discrepancy corresponds to an error of measuremen .006 mm. While an error of that size is hardly to be looked for, I am inclined for the

TABLE 11

AR WAVE-LENGTHS

.G.C. 6826			N.G.C. 7009				N.G.C. 7027				N.G.C. 7662				Mean λ		Probable origin, etc.
No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	R	I A	(λ in I A)
....	....	....	....	....	....	....	3312[2]	1	....	1	3313[2]	1	....	2	3313	3313[1]	
....	....	....	............[6]	....	....	....	....	....	....	....	3342[2]	1	....	5	3342	3342[1]	
....	....	....	....	....	....	....	3346[2]	1	....	8	(3347)[2]	1	....	2	3346	3346	Palmer 337$\mu\mu$
....	....	....	............[6]	....	....	....	3426.4	1	....	20	3426.4[4]	....	....	6	3426.4	3426.2	Palmer 345$\mu\mu$
....	....	....	............[7]	....	....	10	3445[2]	1	....	8	3444[2]	1	....	13	3445	3445[1]	
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3704	3704	Hξ 3703.9; He 3705
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3712	3712	Hν 3712.0
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3722	3722	Hμ 3721.9
....	....		....	....	....	....		....	....	....		....	....	....	3726.30	3726.16	Buisson, Fabry & Bourget 3726.100
....	....	22	............[7]	....	....	20	3727.4[4]	....	....	12	3727.4[4]	....	....	13			
....	....		....	....	....	....		....	....	....		....	....	....	3729.05	3728.91[1]	Buisson, Fabry & Bourget 3728.838
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3734	3734	Hλ 3734.4
....	....	....	....	....	....	....	3750[2]	1	....	3	............[6]	....	....	....	3750	3750	Hχ 3750.2
....	....	....	....	....	....	....	3759[2]	1	....	4	............[7]	....	....	....	3759	3759[1]	
....	....	....	....	....	....	....	3771[2]	1	....	4	............[7]	....	....	....	3771	3771	Hι 3770.6
....	....	....	............[7]	....	....	5	3798[2]	1	....	5	............[7]	....	....	4	3798	3798	Hθ 3797.9
....	....	....	....	....	....	....	3819[2]	1	....	1	............[7]	....	....	....	3820	3820	He 3819.6
....	....	....	............[7]	....	....	6	3836[2]	1	....	8	............[7]	....	....	5	3835.6	3835.5	Hη 3835.42
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3840.4	3840.2[1]	
1	40	40	3868.84	1	45	70	3869.00	3	70	55	3868.84	3	45	65	3868.89	3868.74	
1	20	....	3889.00	1	20	15	3889.15	2	10	13	3888.9	1	10	25	3889.11	3888.96	Hζ 3889.05; He 3888.64
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(3935)	(3935)	
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3965.0	3964.8[1]	Par He 3964.7
1	25			....	40		3967.78	3	70		3967.57	2	40		3967.66	3967.51[1]	
		31	3968.9	....	....	42				28				37			
1	30			....	20		3970.33	1	30		3970.08	2	20		3970.23	3970.08	Hε 3970.07
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4009	4009[1]	Par He 4009.3
1	10	8	4026.2	1	5	4	4026.3	2	1	3	4026.3	1	2	3	4026.4	4026.2	Hε′ 4026; He 4026.2
....	....	....	....	....	....	....	(4063.)	1	1—	1	....	....	....	....	(4064)	(4064)[1]	
....	....	....	....	....	....	....	4068.78	3	20	9	....	....	....	....	4068.77	4068.62	
....	....	....	....	....	....	....	4076.4	2	2	4	....	....	....	....	4076.37	4076.22[1]	
1	10	5	4097.3	1	10	5	4097.5±	2	1	2	....	....	....	....	4097.5	4097.3[1]	N 4097.30
1	50	30	4101.85	1	30	30	4101.88	3	70	24	4101.87	3	40	29	4101.89	4101.74	Hδ 4101.74
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4120.7	4120.6	He 4120.8
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4144.2	4144.0	Par He 4143.7
....	....	....	....	....	....	....	4200	1	1	3	4200.5[2]	1	3	3	4200	4200[1]	Hδ′ 4200.1
....	....	....	4266.6	1	2	3	....	....	....	....	....	....	....	....	4267.2	4267.1	C 4267.14
1	60	51	4340.60	1	60	50	4340.61	3	90	43	4340.67	3	60	52	4340.62	4340.46	Hγ 4340.47
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(4353)	(4353)[1]	
1	12	8	4363.40	1	20	15	4363.39[3]	1	80	30	4363.4	3	20	15±	4363.37	4363.21	
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4388.1	4388.0	Par He 4388.0
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(4416)	(4416)[1]	
1	15	10	4471.9	1	10	10	4471.70	3	8	9	4472.0	1	3	4	4471.71	4471.54	He 4471.49
....	....	....	....	....	....	....	4541.6	2	2	7	4541.6	1	5	4	4541.6	4541.4[1]	Hγ′ 4544.1
....	....	....	....	....	....	....	4571.6	1	1—	5	....	....	....	....	4571.7	4571.5	
....	....	....	4634.3	1	2	2	4633.5	2	2	6	4634.8	1	1	1	4634.3	4634.1[1]	H II 4634.4[11]
....	....	....	4641.2	1	10	8	4641.1	2	8	10	4641.7	1	3	4	4641.1	4640.9	
....	....	....	....	....	....	....	4649.1	1	1	5	....	....	....	....	4649.4	4649.2[1]	C (4647.4, 4650.7, 4651.6)
....	....	....	....	....	....	....	4658.2	2	1	5	....	....	....	....	4658.4	4658.2	
....	....	....	4686.1	1	40	28	4685.94[3]	4	90	43	4685.80	3	60	59	4685.94	4685.76	Fowler 4685.80
....	....	....	4711.5[5]	1	10	8	....	....	....	....	4711.6[5]	1	10	6	4711.6	4711.4[1]	
....	....	....	....	....	....	....	4713.0[5]	3	8	9	....	....	....	....	4712.8	4712.6	He 4713.2
....	....	....	....	....	....	....	4725.7	4	4	5	....	....	....	....	4725.7	4725.5[1]	
....	....	....	4740.5	1	10	8	4740.46	5	20	15	4740.5	1	3	6	4740.4	4740.2	
1	60	49	4861.4±	1	65	50	4861.50[4]	....	80	57	4861.50	3	40	48	4861.50[4]	4861.32	Hβ 4861.33
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4922.4	4922.2	Par He 4921.9
1	70	....[9]	4958.5±	1	80	85±	4959.06[3]	4	200	150	4959.2	2	80	145	4959.09[10]	4958.91	
1	100	....[9]	5006.4±±	1	100	130±	5006.97[3]	4	800	300	5007.1	2	200	360	5007.02[10]	5006.84	
....	....	....	....	....	....	....	5018.	1	1—	....	....	....	....	....	5017	5017[1]	Par He 5015.7
....	....	....	....	....	....	....	5411.5	2	4	....	....	....	....	....	5411.5	5411.3	Hβ′ 5410.3
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(5655)	(5655)[1]	
....	....	....	....	....	....	....	5736	2	1	....	....	....	....	....	5737	5737[1]	
....	....	....	....	....	....	....	5754.4	2	4	....	....	....	....	....	5755.0	5754.8	
....	....	....	....	....	....	....	5875.8	2	8	....	....	....	....	....	5875.9	5875.7	He 5875.6
....	....	....	....	....	....	....	6300.1	2	5	....	....	....	....	....	6302	6302[1]	
....	....	....	....	....	....	....	6313	2	2	....	....	....	....	....	6313	6313[1]	
....	....	....	....	....	....	....	6363	2	2	....	....	....	....	....	6364	6364[1]	
....	....	....	....	....	....	....	6548	1	10	....	....	....	....	....	6548.3	6548.1[1]	
....	....	....	....	....	....	....	6563	2	100	....	....	....	....	....	6563.01[4]	6562.79[4]	Hα 6562.80
....	....	....	....	....	....	....	6583	2	30	....	....	....	....	....	6583.8	6583.6[1]	
....	....	....	....	....	....	....	6676	2	1	....	....	....	....	....	6677	6677[1]	Par He 6678.2
....	....	....	....	....	....	....	6729	2	1—	....	....	....	....	....	6730	6730[1]	

---

separated from it in those nebulae in which both lines
varies from one nebula to another according to the

late of N.G.C. 6572 which covers this region is about
esponds to an error of measurement on the plate of
e looked for, I am inclined for the present, to assume

that it exists, and that the nebular line is actually D_3. This measurement has not been used in striking the mean.

[9] I_q not measured.

[10] The final values of N_1 and N_2 are the means, struck by Campbell and Moore, of the results of several observers. *L. O. Bull.*, 9, 9, 1915.

[11] This is close to the strongest line in the secondary spectrum of hydrogen observed by Dufour. It furnishes the only case of coincidence with a line of that spectrum, however, and too great significance should not be attached to this single correspondence in wave-length.

TABLE 11

NEBULAR WAVE-LENGTHS

Orion Nebula				I.C. 418				N.G.C. 6543				N.G.C. 6572				B.D. +30° 3639				N.G.C. 6826				N.G.C. 7009				N.G.C. 7027				N.G.C. 7662				Mean λ		Probable origin, etc.
λ (R)	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	λ (R)	No. obs.	I_g	I_q	R	I A	(λ in I A)
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3312 [2]	1	....	1	3313 [2]	1	....	2	3313	3313 [1]	
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....[6]	....	....	....	....	....	....	....	3342 [2]	1	....	5	3342	3342 [1]	
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3346 [2]	1	....	8	(3347) [2]	1	....	2	3346	3346	Palmer 337μμ
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....[6]	....	....	....	3426.4	1	....	20	3426.4[4]	....	....	6	3426.4	3426.2	Palmer 345μμ
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....[7]	....	....	10	3445 [2]	1	....	8	3444 [2]	1	....	13	3445	3445 [1]	
3704	1	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3704	3704	Hξ 3703.9; He 3705
3712.4	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3712	3712	Hν 3712.0
3722	1	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3722	3722	Hμ 3721.9
3726.38	3	40	....	3726.22	3	50	85	3726.0	1	1	40	3726.22	3	3	21	3726.47	1	15	....	....[7]	....	....	22	....[7]	....	....	20	3727.4[4]	....	....	12	3727.4[4]	....	....	13	3726.30	3726.16	Buisson, Fabry & Bourget 3726.100
3729.10	3	30	....	3728.94	2	30		....	....	....	....	3728.9	1	1+		3729.24	1	7	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3729.05	3728.91[1]	Buisson, Fabry & Bourget 3728.838
3734.1	1	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3734	3734	Hλ 3734.4
3749.8	1	3	....	....	....	....	....	....	....	....	....	....[7]	....	....	5	....	....	....	....	....	....	....	....	....	....	....	....	3750 [2]	1	....	3	....[6]	....	....	....	3750	3750	Hχ 3750.2
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3759 [2]	1	....	4	....[7]	....	....	....	3759	3759 [1]	
3770.7	1	6	....	....	....	....	....	....[7]	....	....	6	....[7]	....	....	8	....	....	....	....	....	....	....	....	....	....	....	....	3771 [2]	1	....	4	....[7]	....	....	....	3771	3771	Hι 3770.6
3798.1	1	10	....	....	....	....	....	....[7]	....	....	8	3798.1	1	1	10	....	....	....	....	....	....	....	....	....[7]	....	....	5	3798 [2]	1	....	5	....[7]	....	....	4	3798	3798	Hθ 3797.9
3820	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3819 [2]	1	....	1	....[7]	....	....	....	3820	3820	He 3819.6
3835.7	3	15	....	3835.55	2	10	17	3835.5	1	1	11	3835.5	2	3	14	3835.6	1	10	....	....	....	....	....	....[7]	....	....	6	3836 [2]	1	....	8	....[7]	....	....	5	3835.6	3835.5	Hη 3835.42
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3840.4	1	5	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3840.4	3840.2 [1]	
3868.85	4	40	....	3869	1	5	....	3868.83	1	40	37	3868.91	5	50	50	....	....	....	....	3868.85	1	40	40	3868.84	1	45	70	3869.00	3	70	55	3868.84	3	45	65	3868.89	3868.74	
3889.17	4	40	....	3889.07	2	40	18	3888.88	1	20	18	3889.17	5	15	20	3889.3	1	30	....	3889.01	1	20	....	3889.00	1	20	15	3889.15	2	10	13	3888.9	1	10	25	3889.11	3888.96	Hζ 3889.05; He 3888.64
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(3935)	1	10	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(3935)	(3935)	
3965.1	2	10	....	3965	2	5	....	3964.4	1	5	2	3965.1	1	2	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3965.0	3964.8 [1]	Par He 3964.7
3967.62	2	30	....	....	....	....	....	3968.8	1	30	30	3967.64	3	50	38	....	....	....	....	3967.57	1	25	31	3968.9	....	40	42	3967.78	3	70	28	3967.57	2	40	37	3967.66	3967.51[1]	
3970.27	4	40	....	3970.21	2	60	20			30		3970.24	3	40		3970.3	1	50	....	3970.17	1	30			....	20		3970.33	1	30		3970.08	2	20		3970.23	3970.08	Hε 3970.07
....	....	....	....	....	....	....	....	(4008)	....	1	....	4009.2	2	1—	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4009	4009 [1]	Par He 4009.3
4026.5	2	10	....	4026.4	2	10	7	4026.1	1	10	7	4026.36	3	10	10	....	....	....	....	4026.7	1	10	8	4026.2	1	5	4	4026.3	2	1	3	4026.3	1	2	3	4026.4	4026.2	Hε′ 4026; He 4026.2
....	....	....	....	....	....	....	....	....	....	....	....	(4065)	1	1—	....	....	....	....	....	....	....	....	....	....	....	....	....	(4063.)	1	1—	1	....	....	....	....	(4064)	(4064)[1]	
4068.7	2	5	....	4068.67	2	20	10	....	....	....	....	4068.83	3	6	5	4068.8	1	60	....	....	....	....	....	....	....	....	....	4068.78	3	20	9	....	....	....	....	4068.77	4068.62	
4076.6	1	2	....	4076.2	2	5	2	....	....	....	....	4076.3	3	3	2+	4076.6	1	20	....	....	....	....	....	....	....	....	....	4076.4	2	2	4	....	....	....	....	4076.37	4076.22[1]	
....	....	....	....	....	....	....	....	4097.2	1	2	4	4097.6	3	1	2	....	....	....	....	4097.8	1	10	5	4097.3	1	10	5	4097.5±	2	1	2	....	....	....	....	4097.5	4097.3 [1]	N 4097.30
4101.93	4	60	....	4101.92	2	80	29	4101.86	1	50	30	4101.87	5	60	31	4101.9	1	70	....	4101.90	1	50	30	4101.85	1	30	30	4101.88	3	70	24	4101.87	3	40	29	4101.89	4101.74	Hδ 4101.74
4121	1	1	....	....	....	....	....	....	....	....	....	4120.7	3	1	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4120.7	4120.6	He 4120.8
4144	1	1	....	....	....	....	....	....	....	....	....	4144.2	3	1	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4144.2	4144.0	Par He 4143.7
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4200	1	1	3	4200.5 [2]	1	3	3	4200	4200 [1]	Hδ′ 4200.1
4268	1	1	....	4267.9	1	5	1	....	....	....	....	4267.22	3	2	3	....	....	....	....	....	....	....	....	4266.6	1	2	3	....	....	....	....	....	....	....	....	4267.2	4267.1	C 4267.14
4340.62	4	100	....	4340.60	2	90	49	4340.67	1	60	49	4340.62	5	70	50	4340.6	1	90	....	4340.62	1	60	51	4340.60	1	60	50	4340.61	3	90	43	4340.67	3	60	52	4340.62	4340.46	Hγ 4340.47
(4353)	1	1—	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(4353)	(4353)[1]	
4363	1	6	....	....	....	....	....	4363.31	1	5	3	4363.29	5	20	14	....	....	....	....	4363.55	1	12	8	4363.40	1	20	15	4363.39[3]	1	80	30	4363.4	3	20	15±	4363.37	4363.21	
4388	1	4	....	4388.0	2	5	1	4388.6	1	2	2	4388.1	3	2	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4388.1	4388.0	Par He 4388.0
....	....	....	....	....	....	....	....	....	....	....	....	(4416)	1	1—	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(4416)	(4416)[1]	
4471.8	3	20	....	4471.73	2	25	10	4471.65	1	20	11	4471.62	5	20	12	....	....	....	....	4471.42	1	15	10	4471.9	1	10	10	4471.70	3	8	9	4472.0	1	3	4	4471.71	4471.54	He 4471.49
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4541.6	2	2	7	4541.6	1	5	4	4541.6	4541.4 [1]	Hγ′ 4544.1
....	....	....	....	4572	1	3	1	4572.6	1	1	....	4571.29±	3	1	1	....	....	....	....	....	....	....	....	....	....	....	....	4571.6	1	1—	5	....	....	....	....	4571.7	4571.5	
....	....	....	....	....	....	....	....	....	....	....	....	4634.6	3	1	1	....	....	....	....	....	....	....	....	4634.3	1	2	2	4633.5	2	2	6	4634.8	1	1	1	4634.3	4634.1 [1]	H II 4634.4[11]
....	....	....	....	....	....	....	....	4641.0	1	5	3	4640.8	3	3	2+	....	....	....	....	....	....	....	....	4641.2	1	10	8	4641.1	2	8	10	4641.7	1	3	4	4641.1	4640.9	
....	....	....	....	....	....	....	....	....	....	....	....	4649.5	3	2	2	....	....	....	....	....	....	....	....	....	....	....	....	4649.1	1	1	5	....	....	....	....	4649.4	4649.2 [1]	C (4647.4, 4650.7, 4651.6)
4659	1	2	....	....	....	....	....	....	....	....	....	4658.4	3	1	1	....	....	....	....	....	....	....	....	....	....	....	....	4658.2	2	1	5	....	....	....	....	4658.4	4658.2	
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4686.1	1	40	28	4685.94[3]	4	90	43	4685.80	3	60	59	4685.94	4685.76	Fowler 4685.80
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4711.5 [5]	1	10	8	....	....	....	....	4711.6 [5]	1	10	6	4711.6	4711.4 [1]	
4714 [5]	1	1	....	....	....	....	....	4712.8	1	5	3	4712.7 [5]	4	5	3	....	....	....	....	....	....	....	....	....	....	....	....	4713.0 [5]	3	8	9	....	....	....	....	4712.8	4712.6	He 4713.2
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4725.7	4	4	5	....	....	....	....	4725.7	4725.5 [1]	
....	....	....	....	....	....	....	....	....	....	....	....	4740.17	3	5	3	....	....	....	....	....	....	....	....	4740.5	1	10	8	4740.46	5	20	15	4740.5	1	3	6	4740.4	4740.2	
4861.50[4]	....	70	....	4861.3	2	100	51	4861.52	2	65	51	4861.50[4]	....	60	50	4861.2	1	110	....	4861.7	1	60	49	4861.4±	1	65	50	4861.50[4]	....	80	57	4861.50	3	40	48	4861.50[4]	4861.32	Hβ 4861.33
4921	1	1—	....	....	....	....	....	....	....	....	....	4922.4	4	2	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4922.4	4922.2	Par He 4921.9
4959.09[3]	2	50	....	4959.1	2	60	22	4959.09	2	80	58	4959.15[3]	2	80	75	4959	1	8	....	4959.3	1	70	....[9]	4958.5±	1	80	85±	4959.06[3]	4	200	150	4959.2	2	80	145	4959.09[10]	4958.91	
5007.01[3]	3	70	....	5007.0	2	80	33	5007.0	2	100	92±	5007.04[3]	2	250	120	5007.2±	1	10	....	5006.9	1	100	....[9]	5006.4±±	1	100	130±	5006.97[3]	4	800	300	5007.1	2	200	360	5007.02[10]	5006.84	
....	....	....	....	....	....	....	....	....	....	....	....	5017	1	2	....	....	....	....	....	....	....	....	....	....	....	....	....	5018.	1	1—	....	....	....	....	....	5017	5017 [1]	Par He 5015.7
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	5411.5	2	4	....	....	....	....	....	5411.5	5411.3	Hβ′ 5410.3
....	....	....	....	....	....	....	....	....	....	....	....	(5655)	1	1—	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(5655)	(5655)[1]	
....	....	....	....	....	....	....	....	....	....	....	....	5740	1	1—	....	....	....	....	....	....	....	....	....	....	....	....	....	5736	2	1	....	....	....	....	....	5737	5737 [1]	
....	....	....	....	....	....	....	....	....	....	....	....	5755.2	1	2	....	5755.2	1	20	....	....	....	....	....	....	....	....	....	5754.4	2	4	....	....	....	....	....	5755.0	5754.8	
....[7]	....	....	....	....	....	....	....	5876.0	1	20	....	5876.6 [8]	1	20	....	....	....	....	....	....	....	....	....	....	....	....	....	5875.8	2	8	....	....	....	....	....	5875.9	5875.7	He 5875.6
....	....	....	....	....	....	....	....	....	....	....	....	6301.4	1	3	....	6303.6	1	10	....	....	....	....	....	....	....	....	....	6300.1	2	5	....	....	....	....	....	6302	6302 [1]	
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	6313	2	2	....	....	....	....	....	6313	6313 [1]	
....	....	....	....	....	....	....	....	....	....	....	....	6367	1	1—	....	....	....	....	....	....	....	....	....	....	....	....	....	6363	2	2	....	....	....	....	....	6364	6364 [1]	
....	....	....	....	....	....	....	....	....	....	....	....	6548.3	1	10	....	6548.33±[3]	1	70	....	....	....	....	....	....	....	....	....	6548	1	10	....	....	....	....	....	6548.3	6548.1 [1]	
....[7]	....	....	....	....	....	....	....	6563.0	1	65	....	6563.1	1	60	....	6563.01 [4]	1	100	....	....	....	....	....	....	....	....	....	6563	2	100	....	....	....	....	....	6563.01[4]	6562.79[4]	Hα 6562.80
....	....	....	....	....	....	....	....	6583.4	1	10	....	6583.2	1	30	....	6583.86 [3]	1	110	....	....	....	....	....	....	....	....	....	6583	2	30	....	....	....	....	....	6583.8	6583.6 [1]	
....	....	....	....	....	....	....	....	....	....	....	....	6679±	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	6676	2	1	....	....	....	....	....	6677	6677 [1]	Par He 6678.2
....	....	....	....	....	....	....	....	....	....	....	....	6731	1	1—	....	....	....	....	....	....	....	....	....	....	....	....	....	6729	2	1—	....	....	....	....	....	6730	6730 [1]	

Bracketed lines: *suspected only.*

[1] These lines are believed to have been observed for the first time in the present investigation.

[2] Observations with large slitless spectrograph.

[3] Observations with high dispersion (3 prisms).

[4] Assumed wave-length.

[5] As helium is very weak in both N.G.C. 7009 and 7662, this line cannot be ascribed, in these two objects, entirely to the comparatively faint helium line at 4713.3A. There is evidently a distinct nebular line at 4711.5A. This is too close to the helium line to be separated from it in those nebulae in which both lines occur. The measured position of the blend therefore varies from one nebula to another according to the relative strengths of the components.

[6] Probably present.

[7] Present, but not measured.

[8] The measured position of the line on the one plate of N.G.C. 6572 which covers this region is about .7 A greater than that of D_3. This discrepancy corresponds to an error of measurement on the plate of .006 mm. While an error of that size is hardly to be looked for, I am inclined for the present, to assume that it exists, and that the nebular line is actually D_3. This measurement has not been used in striking the mean.

[9] I_q not measured.

[10] The final values of N_1 and N_2 are the means, struck by Campbell and Moore, of the results of several observers. *L. O. Bull.*, **9**, 9, 1915.

[11] This is close to the strongest line in the secondary spectrum of hydrogen observed by Dufour. It furnishes the only case of coincidence with a line of that spectrum, however, and too great significance should not be attached to this single correspondence in wave-length.

TABLE 12

NUCLEAR BANDS

N.G.C. 40	I.C. 1747	I.C. 418	N.G.C. 2392	N.G.C. 6543	N.G.C. 6572	I.C. 4776	N.G.C. 6751	B.D.+30° 3639	N.G.C. 6826	N.G.C. 6905	N.G.C. 7026	I.C. 5217
(335)	....	....	....	....	....	....	....	3342	....	....	....	....
3385±	....	....	....	....	....	....	....	....	....	....	....	....
3403	....	....	....	(340)	....	....	....	3404	....	....	....	....
3412	....	....	....	341	....	....	....	3414	....	....	....	....
....	....	....	....	....	....	....	....	3429	....	....	....	....
3449	....	....	....	....	....	....	....	3447	....	....	....	....
(3493)	....	....	....	348	....	....	....	....	....	....	....	....
3561	....	....	....	356	....	....	....	3564	....	....	....	....
3609	....	....	....	....	....	....	....	3611	....	....	....	....
....	....	....	....	....	....	....	....	3640	....	....	....	....
3690	....	....	....	....	....	....	....	....	....	....	....	....
3759	....	....	....	....	....	....	....	3760	....	....	....	....
....	....	....	....	....	....	....	....	3794	....	....	....	....
....	....	....	....	....	....	....	....	....	....	3815	3815	....
3889	....	....	....	....	....	....	....	3889	....	....	....	....
....	....	....	....	....	....	....	....	3920.2	....	....	....	....
3925	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	(3956)	....	....	....	....	....	....	....
3963	....	....	....	....	....	....	....	3962	....	....	....	....
4028	....	....	....	....	....	....	....	4027	....	....	....	....
....	....	....	....	4057.4	4057.6	....	....	4056.7	4057	....	....	....
4069	....	....	....	....	....	....	....	4070	....	....	....	....
....	....	....	....	4079	....	....	....	....	....	....	....	....
....	....	....	....	4088.6	(4087)	....	4090	4088.9	4089	....	....	....
4102	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	(4109)	....	....	....
....	....	....	....	....	....	....	....	4115.1	(4116)	....	....	....
4122	....	....	....	4122.0	....	....	....	4121.4	(4122)	....	....	....
....	....	....	....	....	....	....	....	4129.6	....	....	....	....
4156	....	....	....	....	....	....	....	4155.4	....	....	....	....
....	....	....	....	....	....	....	....	4163.8	....	....	....	....
4185	....	....	....	....	....	....	....	4187.7	....	....	....	....
....	....	....	....	....	....	....	....	4200.5	....	....	....	....
4230	....	....	....	....	....	....	....	4229.6	....	....	....	....
....	....	....	....	....	....	....	....	4239	....	....	....	....
....	....	....	....	....	....	....	....	4247	....	....	....	....
4268	....	....	....	4267.2	....	....	....	4266.9	....	....	....	....
....	....	....	....	....	....	....	....	4316.7	....	....	....	....
4323	....	(4325)	....	....	....	....	....	4325.8	....	....	....	....
4336	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	4347.4	....	....	....	....
....	....	....	....	....	....	....	....	4368.1	....	....	....	....
4377	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	4385	....	....	....	....
(4412)	....	....	....	....	....	....	....	4416.2	....	....	....	....
4442	....	....	....	....	....	....	....	4441.4	....	....	....	....
....	....	....	....	....	....	....	....	4457	....	....	....	....
(4474)	....	....	....	....	....	....	....	4472.4	....	....	....	....
....	....	....	....	....	(4489)	....	....	....	....	....	....	....
4514	....	....	....	....	....	....	....	4516.6	....	....	....	....
....	....	....	....	....	....	....	....	(4533)	....	....	....	....
4545	....	....	....	....	(4542)	....	....	4542.7	....	....	....	....
....	....	....	....	....	....	....	....	4555.0	....	....	....	....
....	....	4572	....	....	4571	....	....	4569	....	....	....	....
....	....	....	....	....	....	....	....	4593.9	....	....	....	....
....	....	....	....	....	....	....	....	4619	....	....	....	....
....	....	....	4634	4632.0	....	....	....	4634	....	....	....	....
....	....	....	4641	....	....	....	....	....	....	....	....	....
4653	4651	4649	....	4650.7	....	(4650)	4650	4651.6	4651	4651	4651	....
	....	....	....	....	....	....	....	4666.0	....	....	....	....
	....	....	....	....	....	....	....	4675.4	....	....	....	....
4687	4686	4686	4686	4687.4	4686.8	....	4686	4687	4686	4686	....	4686
....	....	....	....	....	....	....	....	4702.2	....	....	....	....
....	....	....	....	....	....	....	....	(4713)	....	....	....	....
....	....	....	....	....	....	....	....	4738	....	....	....	....
4786	....	....	....	....	....	....	....	4786.4	....	....	....	....
....	....	....	....	....	....	....	....	4799.2	....	....	....	....
4859	....	....	....	....	....	....	....	....	....	....	....	....
4920	....	....	....	....	....	....	....	4923	....	....	....	....
....	....	....	....	....	....	....	....	4940	....	....	....	....

TABLE 12—(*Continued*)

N.G.C. 40	I.C. 1747	I.C. 418	N.G.C. 2392	N.G.C. 6543	N.G.C. 6572	I.C. 4776	N.G.C. 6751	B.D.+30° 3639	N.G.C. 6826	N.G.C. 6905	N.G.C. 7026	I.C. 5217
....	....	(4972)	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	5017	....	....	....	....
....	....	....	....	....	....	....	....	5091.5	....	....	....	....
....	....	....	....	....	....	....	....	5130.9	....	....	....	....
....	....	....	....	....	....	....	....	5251.1	....	....	....	....
....	....	....	....	....	....	....	....	5272.6	....	....	....	....
....	....	....	....	....	....	....	....	5305.0	....	....	....	....
....	....	....	....	....	....	....	....	5412.2	....	....	....	....
....	....	....	....	....	....	....	....	5470.2	....	....	....	....
....	....	....	....	....	....	....	....	(5576)	....	....	....	....
....	....	....	....	....	....	....	....	5593	....	....	....	....
....	....	....	....	....	....	....	....	(5660)	....	....	....	....
....	....	....	....	....	....	....	....	5696.0	....	....	....	....
....	....	....	....	....	....	....	....	5773	....	....	....	....
....	....	....	....	5804	....	....	....	5801	....	....	....	....
....	....	....	....	....	5807	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	5812.3	....	....	....	....
....	....	....	....	....	....	....	....	5828	....	....	....	....
....	....	....	....	....	....	....	....	5876.8	....	....	....	....
....	....	....	....	....	....	....	....	5893.5	....	....	....	....
....	....	....	....	....	....	....	....	6154	....	....	....	....
....	....	....	....	....	....	....	....	(6206)	....	....	....	....
....	....	....	....	....	....	....	....	(6309)	....	....	....	....
....	....	....	....	....	....	....	....	6459	....	....	....	....
....	....	....	....	....	....	....	....	6676	....	....	....	....

Iq System.—In this system I have endeavored to indicate the relative photographic intensity of the lines of a nebular spectrum as they would be observed at the zenith with the slitless quartz spectrograph (g) attached to the Crossley reflecting telescope and with the use of Seed 23 or 27 plates. In pursuance of this plan the following procedure was adopted:

(1) The image densities were measured against a calibrated wedge on the Hartmann Microphotometer.

(2) The relative intensities thus determined were corrected for the difference in the atmospheric absorption between the mean position of observation and the zenith. The correction depends, of course, on the wave-length. In making these corrections use has been made of the formula developed by Fowle.[41] For the Crossley telescope I have assumed an elevation of 1200 meters, a water vapor pressure of .45 cm., and a barometric height of 654 mm. as representing summer observing conditions.

(3) The intensities measured on strong and weak plates of each nebula were combined. This is in general necessary for a complete observation, because very bright and very faint lines can not be measured on the same plate on account of the great range in intensity. The results from two or more plates were combined by means of the measures common to both. After the relative intensities of all of the lines had been determined, the whole system of numbers representing them was multiplied by a factor calculated to bring the mean of intensities Hβ and Hγ to the value 50.

There has emerged from this process a set of numbers (see table 13) which undoubtedly leave much to be desired in the way of accuracy. Still the result of the attempt probably represents an advance on any system of intensities that has heretofore been used for nebular lines. The uncertainties referred to arise from a number of causes. The measurement of irregular nebular images, some of which are stellar, others of which present extended surfaces, images impressed by light of different wave-lengths on different photographic emulsions, such measurements involve difficulties not to be met with in ordinary stellar photometry. The bright continuous spectrum of the nucleus is sometimes troublesome, particularly where the nebula is small. In objects exhibiting images of different sizes and shapes there usually arises a question as to what part of this or

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[41] *Smithsonian Physical Tables*, 6th ed., 182, 1914. Fowle's constants have been extended to 3300A with the aid of Abbot's results on p. 181 of the same publication.

that image is to be selected for observation. In reducing to the zenith, a great deal of uncertainty arises in the cases of the ultra-violet lines from ignorance as to the amount of water vapor in the atmosphere above the observer.

The identifications of lines for the purpose of intensity measurements have been made by inspection and, in cases of very faint lines, there may be instances of misidentification.

The quantities in brackets under Iq in table 13 do not rest on photometric measurements, but merely on eye estimates in the established system. Only fairly well impressed and separated images are measurable with the photometer, so it would be necessary in many cases to omit lines if approximate eye estimation were not resorted to.

With all the sources of error and uncertainty which have been mentioned, and others which have not been referred to, it might seem as though the intensity measurements were really of little value. It is rather a difficult matter to estimate their accuracy, but I have sought to obtain some light on the subject by comparing the values of Iq for Hδ in the different nebulae. If we assume the intensity gradient of the Balmer series, that is, the fall in intensity from one line to another, to be invariable from nebula to nebula, then the true values of Iq for Hδ should be the same in all nebulae, since the mean of Hβ and Hγ is assumed to be 50 in every instance. As a matter of fact, the gradient is not by any means invariable, but if we attempt to eliminate extreme cases by excluding nebulae having outside values for Hβ and Hγ, taking only those in which Iq for Hβ lies between 50 and 55, we have twenty spectra in which the gradient may be considered to be more uniform. In these twenty objects the mean of the values of Iq for Hδ is 28. The residuals from this mean are due to three causes:

1. Errors of observation of Hδ;
2. Errors of observation of mean of Hβ and Hγ;
3. Variations from uniformity in the gradient from Hβ-γ to Hδ.

Now, if we assume that the gradient is invariable and that the residuals are due entirely to the first two causes, we will evidently get the maximum possible value of the probable error. Computing the probable error of a single observation on the basis of this assumption, we have

$$e = \pm 2.3;$$

that is, the probable error is equal to or less than 8 per cent of the value of Iq for Hδ. This is probably a conservative estimate of the percentage of error for all intensities except those that are small, or bracketed. The likelihood of error is also greater above 3500A because of uncertainty in the correction for atmospheric absorption.

In using this table it is necessary to bear in mind that the values of Iq are relative, and have nothing to do with the actual intensity of the image on a plate. The absence of a line from the table does not necessarily mean that it is not in the spectrum of the nebula, unless other fainter lines are recorded. Take, for instance, the line 4471, which has a pretty uniform intensity through the table. It is not recorded in the faint nebula I.C. 1747, but it would probably be brought out by long exposure. The faintest line estimated in that object has an intensity 40, while Hδ, with a probable intensity of 30, shows only a trace. In judging of the presence or absence of a line from the spectrum of a given nebula, or of the significance of the word trace (tr), account should be taken of the strength of the faintest lines actually noted in that spectrum.

Should a sensibility curve become available for the Seed 23 plates approximate energy ratios can be determined for the lines.[42]

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[42] A provisional sensibility curve for Seed 23 plates has been furnished by the manufacturers (The Eastman Kodak Co.), which is perhaps sufficiently accurate in the blue-green to permit of approximate relative energy determinations for the three principal lines. The factors by which the values of Iq are to be multiplied for the lines Hβ, N_2, and N_1 are 1, 1.6, and 2.2. The mean values of Iq (from about 30 nebulae) for these three lines are 52, 102, and 185. The corresponding energies are as 5 : 16 : 40.

TABLE 13

RELATIVE INTENSITIES OF NEBULAR LINES AS OBSERVED WITH QUARTZ SPECTROGRAPH

N.G.C. No.	40	I.C. 1747	I.C. 351	1535	I.C. 418	I.C. 2149	I.C. 2165	2392	2440	3242	I.C. 3568	I.C. 4593	6210	I.C. 4634	6543	6572	I.C. 4776	6741
Class	III	IIa	Ib	Ic	III	IIb	Ib	Ia	Ia	Ib	IIa	IIb	IIa	IIa	IIa	IIa	IIa	Ia
3313	......	......	......	......	......	......	......	......	......	(2)	......	......	......	......	......	......	......	......
3342	......	......	......	......	......	......	......	......	......	(5)	......	......	......	......	......	......	......	......
3346	......	......	......	......	......	......	......	11	(5)	......	......	......	......	......	......	......	......	......
3426	......	......	......	......	......	......	10	35	(50±)	(4)	......	......	......	......	......	......	......	24
3445	......	......	(17)	......	......	......	(4)	......	(4)	23	......	......	......	......	......	......	......	......
Hξ 3704	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Hν 3712	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
3727d	97	tr	......	......	85	55	19	34	52	16	......	45	30	13	40	21	28	46
Hλ 3734	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Hχ 3750	......	......	......	......	(8)	(4)	......	......	......	......	......	......	(3)	......	......	(5)	(4)	......
3759	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Hι 3771	......	......	......	......	9	(6)	......	......	......	......	......	......	(4)	(4)	(6)	(8)	(5)	......
Hθ 3798	......	......	(5)	......	12	(8)	(4)	......	......	(5)	......	......	5	(5)	(8)	(10)	6	......
3820	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(3)	(3)	......
Hη 3835	......	......	(10)	......	17	10	(5)	......	......	......	......	......	7	(6)	(11)	14	8	......
3869	......	(60)	55	63±	......	26	51	60	62	71	48	20	55	46	37	50	47	62
(He+Hζ) 3889	(10)	......	(15)	(20±)	18	22	15	......	......	......	10±	20	20	14	(18)	20	15	(5)
3965	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(2)	(2)	......	......
3967		(40)	35	31±		29	34	28	24	40	34	20	(30)	31	30	38	33	22
Hε 3970	(15)				20								(10)					
4009	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(1)	......	......
4026	......	......	......	......	(7)	tr	......	......	......	(5)	......	......	(3)	......	(7)	10	(6)	......
4064	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(1)	......	......
4069	......	......	......	......	(10)	tr	......	......	......	......	......	......	(3)	......	......	5	(6)	......
4076	......	......	......	......	(2)	......	......	......	......	......	......	......	......	......	......	(2+)	......	......
4097	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(4)	(2)	......	......
Hδ 4102	25	tr	26	25±	29	37	26	29	20	34	34	30	28	27	30	31	26	20
4121	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(2)	......	......
4144	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(2)	......	......
4200	......	......	......	......	......	......	......	......	......	(5)	......	......	......	......	......	......	......	......
4267	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(3)	......	......
Hγ 4340	49	(50)	47	48±	49	50	47	50	51	51	53	47	50	50	49	50	47	37
4363	......	......	18	(20±)	(1)	......	27	37	(20)	(15)	tr	......	10	8	(3)	14	14	20
4388	......	......	......	......	(1)	......	......	......	......	......	......	......	......	......	(2)	(2)	......	......
He 4471	......	......	......	(5±)	10	16±	10	......	......	(8)	......	tr	9	9	11	12	10	......
4541	......	......	......	......	......	......	......	......	......	(5)	......	......	......	......	......	......	......	......
4571	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(1)	......	......
4634	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(1)	......	......
4641	......	......	......	......	......	......	(10)	......	......	(5)	......	......	......	......	(3)	(2+)	......	(5)
4649	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(2)	......	......
4658	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(1)	......	......
4686	......	......	58	(25±)	......	......	55	70	62	49	......	......	......	......	......	......	......	46
4712	......	......	......	(5±)	......	......	(8)	tr	......	(5)	......	......	......	......	(3)	(3)	......	(5)
4725	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
4740	......	......	......	(10±)	......	......	(8)	tr	......	(6)	......	......	......	......	......	(3)	......	(5)
Hβ 4861	51	50	53	52±	51	50	53	50	49	50	46	53	50	50	51	50	53	63
4922	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(2)	......	......
4959	tr	110	110	109±	22	49	108	85	175	123	92	74	......	82±	58	75	77	170±
5007	tr	200	182	155±	33	79	194	(170±)	280	184	160±	107	......	190±	92±	120	......	370±

Blank spaces opposite 4959 and 5007A do not indicate weakness or absence of the lines from the nebula. They are strong in nearly all objects but are, in instances, difficult to measure because of mutual interference of the images or by reason of overexposure.

TABLE 13—(*Continued*)

RELATIVE INTENSITIES OF NEBULAR LINES AS OBSERVED WITH QUARTZ SPECTROGRAPH

N.G.C. No.	I.C. 4846	6790	6803	6807	6818	6826	6833	6879	6884	6886	6891	I.C. 4997	7009	7026	7027	I.C. 5117	I.C. 5217	7662
Class	IIa	IIa	IIa	IIa	Ia	IIa	IIa	IIa	Ic	Ia	IIb	IIa	Ib	Ic	Ia	IIa	Ib	Ib
3313	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(1)	......	......	(2)
3342	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	5
3346	......	......	......	......	......	......	......	......	......	......	......	......	......	......	8	......	......	(2)
3426	......	......	......	......	16	......	......	......	......	17	......	......	......	......	20	......	......	6
3445	......	......	......	......	tr	......	......	......	......	(4)	......	......	10	......	8	......	tr	13
Hξ 3704	......	(2)	......	......	......	......	......	......	......	......	......	(3)	......	......	......	......	......	......
Hν 3712	......	......	......	......	......	......	......	......	......	......	......	(3)	......	......	......	......	......	......
3727d	21±	11	20	12	34	22§	tr	......	17	40	25	20	20*	28	12	......	15	13
Hλ 3734	......	(3)	......	......	......	......	......	......	......	......	......	6	......	......	......	......	......	......
Hχ 3750	......	(3)	......	......	......	......	......	......	......	......	......	7	......	......	(3)	......	(5)	......
3759	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(4)	......	......	......‡
Hι 3771	......	(4)	......	(2)	......	......	......	......	......	......	......	8	......	......	4	......	(5)	......
Hθ 3798	......	6	......	(3)	......	......	(4)	......	(4)	......	......	9	(5)	......	5	......	(7)	(4)
3820	......	......	......	......	......	......	......	......	......	......	......	(5)	......	......	(1)	......	......	......
Hη 3835	......	9	......	(5)	......	......	(5)	......	(6)	(10)	......	10	(6)	......	8	......	10	(5)
3869	59±	68	59	43	47	40	45	38±	62	57	30	62	70	55	55	48	55	65
(He+Hζ) 3889	22±	25	15	12	......	......	15	......	14	15	17	17	(15)	......	13	(6)	21	(25)
3965	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
3967	40	34	37	30	24	31	27	28±	32	30	20	37	42	33	28	25	39	37
He 3970																		
4009	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
4026	......	(5)	......	tr	......	(8)	......	......	(4)	......	......	(6)	(4)	......	3	......	......	(3)
4064	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(1)	......	......	......
4069	......	(3)	......	......	......	......	......	......	......	tr	......	9	......	......	9	......	......	......
4076	......	......	tr	......	......	......	......	......	......	......	......	(6)	......	......	(4)	......	......	......
4097	......	......	......	......	......	(5)	......	......	......	......	......	......	(5)	......	(2)	......	......	......
Hδ 4102	30±	28	24	22	22	30	26	(20±)	28	21	23	30	30	28	24	17	30	29
4121	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
4144	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
4200	......	......	......	......	......	......	......	......	......	......	......	......	......	......	3	......	......	(3)
4267	......	......	......	......	......	......	......	......	......	......	......	......	(3)	......	......	......	......	......
Hγ 4340	51±	47	48	45	49	51	51	44±	44	43	41	52	50	43	43	39	47	52
4363	(7)	26	(12)	17	(15)	(8)	16	(10±)	22	26	......	57	(15)	......	30	26	16	(15±)
4388	......	......	......	......	......	(3)	......	......	......	......	......	......	......	......	......	......	......	......
He 4471	......	13	(10)	(6)	......	10	10	......	(10)	(7)	(5)	16	10	10	9	......	13	(4)
4541	......	......	......	......	......	......	......	......	......	......	......	......	......	......	7	......	......	(4)
4571	......	......	......	......	......	......	......	......	......	......	......	......	......	......	5	......	......	......
4634	......	......	......	......	......	......	......	......	......	......	......	......	(2)	......	(6)	......	......	(1)
4641	......	......‡	......	......	......	......	......	......	(6)	(5)	......	......	(8)	......	(10)	......	(5)	(4)
4649	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(5)	......	......	......
4658	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(5)	......	......	......
4686	......	(3)†	......	......	60	......	......	......	22	49	tr	......	28	20	43	......	12	59
4712	......	(3)	......	......	......	(2)	......	......	(6)	10	......	......	(8)	......	(9)	......	(6)	(6)
4725	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(5)	......	......	......
4740	......	(3)	......	......	......	......	......	......	(6)	(10)	......	......	(8)	......	15	......	(6)	(6)
Hβ 4861	49±	53	52	55	51	49	49	56±	56	57	59	48	50	57	57	60	53	48
4922	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
4959	78±	180±	100±	77	112	......	53	77±	160	180	86	30	85±	115	151	140	75	145
5007	126±	360±	130±	......	......	......	116	125±	286	330	194	47	130±	......	300	......	......	360

§ Intensity of this line in the condensations is 38.
* See footnote, p. 233.
‡ Probably present.
† The line is probably localized in the nucleus.

CHAPTER III

THE SPECTRA OF THE NUCLEI OF THE PLANETARY NEBULAE

The present chapter concerns itself in part with the relationship between the planetary nebulae and the Wolf-Rayet, or class O stars. So much has been written on this subject, both in a conservative scientific spirit and in a speculative vein, that it has seemed to me fitting to give a brief review of some of the principal observations of stars of this class.

The Wolf-Rayet stars, so named in honor of the discovery of the first three known members of the group by MM. Wolf and Rayet at the Paris Observatory in 1867, comprise a comparatively small group of objects giving spectra characterized by bright bands of considerable width usually superposed on continuous spectrum. Besides those bright radiations, the spectra sometimes show dark bands, and in instances fairly narrow dark lines, but the bright bands have generally been regarded as the characteristic spectral features of the group.

These spectra appear ever since their discovery to have attracted an unusual amount of interest, and their position in the various schemes of stellar classification has been the subject of speculation by astronomers. In 1890 and again in 1891 Pickering drew attention to certain points of resemblance between their spectra and those of the planetary nebulae, and classified both as belonging to a fifth type of stellar spectrum.[43] Pickering's association of the two classes of objects appears to have been based partly on certain correspondences in wave-length and partly on the similarity of their distribution in the sky. He drew attention to the very significant fact that the Wolf-Rayet stars follow closely the central line of the Galaxy, and as the gaseous nebulae favor the same region, though less strikingly, the circumstance favored the presumption that the two classes of objects are related. The spectral correspondences alluded to by Pickering refer to approximate coincidences in wave-length among lines that are now recognized as due to hydrogen and helium. To what extent these are significant it is somewhat difficult to judge, since we are familiar with the occurrence in both the nebulae and certain red stars of the bright lines of hydrogen, a circumstance which is not generally held to indicate spectral relationship. The very important question of breadth of line was not dealt with, probably because the slitless spectroscope with which the observations were made is incompetent to distinguish between the breadth of a line due to the extent of the source in the case of a nebula and breadth as a spectral peculiarity of the bands in the Class O stars.[‡]

At about the same time that Pickering suggested this classification Keeler, who was then engaged in his visual investigation of nebular spectra, independently announced his conviction that the nuclei of the planetary nebulae are closely related to the Wolf-Rayet stars.[44] Keeler's conclusion seems to have been based on the observation of lines near the limit of visibility, notably in the spectrum of the nebula N.G.C. 6572 (Σ6), with respect to which he says:[45]

> Besides the usual lines 5007, 4959, Hβ, and Hγ, several others were seen in the spectrum of the nucleus. A line near D was quite bright, and a comparison with the sodium line from a spirit lamp showed that it was probably D_3. . . . The principal lines were fine and sharp in the spectrum of the nebula, but fuzzy and considerably broadened in that of the nucleus. It would evidently be a matter of considerable interest to note whether the bright lines D_3, Hα, and other of the less conspicuous lines appear only in the nucleus, where the substances in which they have their origin are doubtless subjected to greater temperature and pressure, or whether the lines do not appear in the spectrum of the more diffuse parts of the nebula, simply on account of their faintness. It was very hard to determine this point. The lines were very short—mere knots on the spectrum of the nucleus—but they certainly seemed to fade outward from the nucleus much more rapidly than the ordinary nebular lines.

* * * * * * * * * * * * * * * * * * * *

> The D_3 line is barely visible in the diffuse part of the nebula and is brighter and broader near the nucleus.

* * * * * * * * * * * * * * * * * * * *

> In my preliminary paper I pointed out the great resemblance between the spectra of the nuclei of planetary nebulae and the spectra of stars of the Wolf-Rayet class. At the time I had not noticed that Professor

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[43] *Ast. Nach.*, **127**, 1, 1891.

[‡] Footnote p. 197.

[44] *Publ. Lick Obs.*, 3, 227.

[45] *Loc. cit.*, pp. 209, 226, 227.

Pickering had called attention to the same fact in the then recently published fourth report of the Henry Draper Memorial. It is interesting to note that the similarity is apparent in both the visual and the photographic spectra. Professor Pickering has since classified both objects together as forming a fifth type of stellar spectrum.

Keeler's observation with respect to increased breadth and haziness of D_3 and other nebular lines on crossing the spectrum of the nucleus appears to be uncertain, and has not in all respects been confirmed by later observers. It seems necessary to call attention to this because the phenomenon which Keeler suspected, and which he apparently believed to be a normal one, that is, the broadening out of a line in passing from a nebula to its nucleus, is as a matter of fact quite rare. As will be seen later, the occurrence of a given radiation as a nebular line and as a nucleus band in the same object, while it occasionally happens, is uncommon. In particular it has not been confirmed in the objects especially referred to by Keeler. Campbell's[46] description of the appearance of D_3 in Σ6 is as follows:

> The line D_3 is sufficiently bright for its form to be observed. When it is in focus it does not reduce to a point: it extends out a perceptible distance from the continuous spectrum of the nucleus; and, as is the case with the principal visual lines, belongs to the nebula proper.

The writer's observations, made later by photography, confirm in a way those of both Keeler and Campbell. D_3, like 4471A and the other helium lines, is of medium length, not so long as the hydrogen and the N_{1-2} lines, but still extending into the nebula. There is no indication of increased breadth in the nucleus.

Four years after Keeler's observations Campbell published the most exhaustive account of the spectra of the Wolf-Rayet stars that has appeared. He observed all of the then known stars of this type which are within the reach of the instruments at Mount Hamilton. His observations were both photographic and visual, and covered the spectrum from λ4100 to $H\alpha$. He added numerous lines to the list of known ones, and, as most of these are of unknown origin, left the spectra even more enigmatic than he had found them. At about this time the same investigator made an equally comprehensive study of the spectra of the bright-line nebulae. His conclusions as to a relationship between these two classes of spectra are therefore of the highest interest and are as follows:

> Aside from the hydrogen, D_3, and 4472 lines, the nebular spectrum presents a few interesting coincidences with the Wolf-Rayet spectrum. The lines at 5412 and 4687 observed in several nebulae were found with more or less prominence in nearly all the Wolf-Rayet stars; but the lines at 4389, 4067, and 4026 were found in only a few of the stars, and it is not certain that the last two lines occupy the same positions in the nebulae and stars, though they probably do. The prominent star lines 5813, 5693, 5593, 5472, 4652, 4636, 4541, 4509, 4442 were specially searched for in the nebulae and not found. Likewise the nebular lines 5751, 5007, 4959, 4715, 4364 were most carefully looked for in the stars, and no trace of them is visible. I think we must say that if any relation exists between these spectra, it is not clearly established and its nature is not apparent. . . .
>
> In conclusion, I think we can say, from the foregoing observations, that the spectra of the Wolf-Rayet stars are not closely related to any other known type. They appear to have several points in common with the nebular and *Orion*-type spectra; but the last two appear to be much more closely related to each other than to the Wolf-Rayet spectra. It is therefore difficult to place these stars between the nebulae and *Orion* stars. They certainly do not come *after* the *Orion* stars, and one does not like to place them *before* the nebulae. We can probably say that the bright lines are chromospheric, owing their origin to very extensive and highly heated atmospheres, but showing very little relation, in constitution and physical condition, to that of our own Sun. For the present, at least, this type of spectrum must be considered as distinct from every other known type, just as the nebular spectrum is distinct, and, like the nebular spectrum, containing lines whose origin cannot be assigned.

It should be stated that Campbell's investigation did not include the systematic observation of the nuclei of the planetary nebulae. With Keeler he realized the importance of the study of these nuclei, but the Lick Observatory did not at the time possess the instrumental equipment requisite for the work. Campbell's position with respect to the distinctiveness of the two classes of spectra appears to the writer as having been properly taken. A further reference to this subject is made on page 253. The observations seemed to set at rest the earlier notion that the relation between the Wolf-Rayet stars and the nebulae is a close one.

In 1899 Sir William and Lady Huggins[47] were concommittal with respect to the position of the Wolf-Rayet stars:

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[46] *Astron. and Astrophys.*, 13, 497, 1894.

[47] An Atlas of Representative Stellar Spectra, p. 77

> The question before us is: Which class of stars, from the evidence we at present possess, should be placed first, as being in the stage of least condensation, and therefore in the youngest condition?
>
> Leaving out of consideration, for the present, as we have them still under investigation, the Wolf-Rayet stars, the evidence we possess points distinctly to some of the white stars as being the most diffuse, and still in the earliest condition.

In their general work on stellar classification the astronomers of the Harvard College Observatory, notably Miss Cannon,[48] have quite definitely established a relationship between the Class O, or Wolf-Rayet, and the Class B stars.

In 1907 Hartmann[49] made certain observations of the spectrum of *Nova Persei* which he believed indicated that it had been transformed into a Wolf-Rayet star, and Adams and Pease[50] have reported similar changes in the spectra of five novae.

Other observations of interest have been published of the spectra of these stars and they have been made the subject of a purely theoretical inquiry by Nicholson. The appended list of references[51] is probably incomplete, but it covers important contributions to the literature of the subject.

It should be remarked that while some observers have sought to attach the Class O stars to the nebulae, and to those related objects, the temporary stars, this has not invariably been the case. At least two of these stars, γ *Argus* and ζ *Puppis,* have been assumed by Lockyer to be in mid-development, and therefore presumably far removed from the primordial condition which the nebular stage is supposed to mark.[52] The theory espoused by several astronomers, notably Sir Norman Lockyer, that the course of stellar evolution runs through an ascending and subsequently a descending temperature curve, has received, in recent years, considerable support from considerations of a general nature which indicate a very low density for some of the red stars. The Class O stars, being of a very high temperature, must, if they represent a stage in normal stellar development, be placed at the peak of the temperature curve, that is, according to this theory, somewhere in middle life. On the other hand, under the hypothesis of a continuously falling temperature, these stars, under the same assumption as to their normality, must be regarded as representing one of the initial stages of stellar existence. The proof of a close relationship between the Class O stars and the nebulae would therefore strongly substantiate the latter hypothesis as against the former, and it is perhaps in this connection that the general question of such a relationship has, at present, its greatest significance.

In the year 1913 the writer's attention was drawn by Dr. P. W. Merrill to the occurrence of 4686A as a hazy line, or band, in the stellar nucleus of N.G.C. 6826, and shortly afterward Dr. G. F. Paddock observed the Wolf-Rayet band at 4650A in the central star of the large dim planetary N.G.C. 40.[53] These observations were casual, and incidental to the photography of nebular spectra for the purpose of measuring velocities in the line of sight in the prosecution of a research under the direction of Director Campbell. The writer became interested in the problem during the following year through the detection in the bright central region of N.G.C. 6572 of five bands characteristic of the Wolf-Rayet spectra. A preliminary account of these and other observations was published at the time[54] in the belief that they strongly indicated a close connection between the nebulae and the Wolf-Rayet stars. The following discussion deals with the phase of the investigation suggested by these observations.

The presence of the bands just referred to in the spectrum of N.G.C. 6572 was strongly indicative of a relation between the nebulae and the Wolf-Rayet stars, not so much because some of them do not correspond in wave-length with known nebular lines, since "new" nebular

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[48] *Ann. H. C. O.*, **28**, 141, 1901.

[49] *Astron. Nach.*, **177**, 113, 1908.

[50] *Ap. Jour.*, **40**, 294, 1914; *Proc. Nat. Acad. Sci. Am.*, **1**, 391, 1915.

[51] Miss Cannon, *Ann. H. C. O.*, **28**, 146 and 243, 1901; Palmer, *Lick Obs. Bull.*, **2**, 53, 1902; Pickering, *H. C. O. Circular* No. 98, 1905; Duncan, *Lick Obs. Bull.*, **6**, 58, 1910; Max Wolf, *Sitz. Heidel. Akad. Wiss. Ab.*, **14** and **22**, 1913; Merrill, *Lick Obs. Bull.*, **7**, 129, 1913; Adams, *Science*, **32**, 882, 1910; Nicholson, *Mon. Not. R. A. S. London*, **74**, 118, 1913; Bosler, *C. R.*, **160**, 124, 1915.

[52] *Proc. Roy. Soc. Lond.*, **73**, 277, 1904.

[53] *Lick Obs. Bull.*, **9**, 29, 1916.

[54] *Astrophys. Jour.*, **40**, 466, 1914.

lines are discovered from time to time, but because their breadth, which in 4686A amounts to 15A, gives them the character of the stellar radiations. Furthermore, the nucleus here is apparently not a star but a general thickening of the nebulous material. The observation led, as has been stated in the introduction, to the second division of this work, that is, to the observation of the nuclei of the planetary nebulae. The results are described in detail in Chapter I, and a very considerable amount of information that it would be difficult to convey in a description can be gathered from the illustrations. There are, however, certain general considerations which may appropriately be discussed here.

In a few of the nuclei bright bands only are recorded, but in the greater number the continuous spectrum predominates. In many cases bright bands are superposed on this continuous spectrum, and in some instances dark lines are also found.

The Continuous Spectrum of the Planetary Nuclei.—The most striking feature of the continuous spectrum is its very uniform extension into the ultra-violet. I have observed no exception to this rule. While there may be slight variations in the character of the intensity curves, speaking generally, any one of them may be taken as a type of all. In order to give some precision to the description, the nucleus of N.G.C. 6543 has been selected, quite at random, for measurement with the microphotometer. The results are platted in figure 1, where (*a*) represents the observations of intensity made with the photometer, (*b*) the same observations corrected to normal dispersion, and also adjusted for the reflectivity of the silvered mirror. Losses within the spectroscope have been neglected. Curve (*c*) represents (*b*) corrected approximately for the absorption of the atmosphere. If we assume the photographic plate used to have been of uniform sensibility throughout the violet and ultra-violet[55] (*c*) may be taken as a rough approximation to a section of the energy curve. Where the maximum lies can not be conjectured.

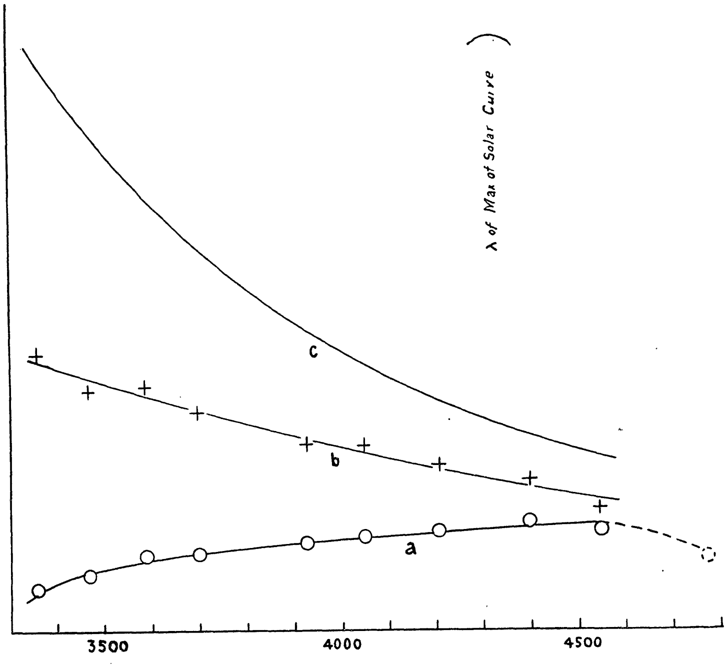

Figure 1

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[55] "The chromatic sensibility of ordinary plates . . . is sensibly uniform throughout the ultra-violet and down through the violet and blue to about wave-length 0.5μ)," P. G. Nutting, *Outlines of Applied Optics*, p. 224. The manufacturers of the Seed 23 plates used in these observations are unable at present to furnish an accurate sensibility curve. A provisional curve, which they kindly supplied, shows a rapid falling off toward the ultra-violet. Such a characteristic would mean greater strength in the ultra-violet spectrum of the nucleus than that indicated in the figure.

The characteristic appearance of these spectra can best be appreciated by comparing the records on plates XLVI to L with spectrograms of *α Lyrae* and *β Aquilae* made with the same apparatus (pl. XLIV, fig. 6) or with an excellent set of photographs of the ultra-violet spectra of stars published by Sir Norman Lockyer.[56]

One might be inclined to suspect that the richness in the ultra-violet is due to the peculiar *detached* ultra-violet spectrum of the outstanding nebulosity, which is visible in some of these illustrations, and is referred to in Chapter IV, but this I am convinced is not the case. It persists beyond the point where that spectrum is recorded, and exists in spectra where the outstanding spectrum is faint or invisible.

Nuclear Bright Bands.—The relative strength of the bright bands with respect to the continuous spectrum is very different in different objects. In some, such as N.G.C. 7026 and 6751, they occur almost without it, while in others they are barely visible against the strong continuous background. It is possible that faint bands exist in many of the spectra in which they have not been detected by reason of lack of sufficient contrast with the continuous spectrum. The following nebulae have nuclei sufficiently bright for observation. They are divided into two groups, the nuclei of the first group present bright bands, those of the second give continuous spectra only.

NUCLEI OF PLANETRY NEBULAE

Bright bands	Continuous spectrum only
N.G.C. 40	N.G.C. 1535
I.C. 1747	N.G.C. 2022
I.C. 351 (?)	I.C. 2149
I.C. 418	N.G.C. 3242
N.G.C. 2392	N.G.C. 4361
N.G.C. 6210 (?)	I.C. 3568
N.G.C. 6543	N.G.C. 6058
N.G.C. 6572	I.C. 4593
I.C. 4776 (?)	I.C. 4634
N.G.C. 6751	N.G.C. 6629
B.D. +30° 3639	N.G.C. 6720
N.G.C. 6826	N.G.C. 6879
N.G.C. 6905	N.G.C. 6891
N.G.C. 7026	N.G.C. 7009
I.C. 5217 (?)	N.G.C. 7662

The interrogation mark indicates that the presence of bright bands is merely suspected.

We are here confronted with the interesting fact that out of thirty nebular nuclei about one-half are Class O stars. The number of the Class O stars heretofore known, including those of the 10th magnitude, is 107. The total number of stars brighter than magnitude 10 is of the order of a million. There is, therefore, in general, about one Class O star to every 10,000 stars. This is, however, for obvious reasons not a fair statement of the proportion. It may justly be argued that the percentage of Class O stars is greater in the Milky Way, near which these objects lie, than in other parts of the sky, but if we shift the decimal once and call the ratio 1 to 1000, there still remains a safe margin over the proportion of 1 to 2 determined for the nebular nuclei. But the showing is, I believe, very much better than that. As we have already seen, the invariable characteristic of the nucleus spectra is the remarkable extension into the ultra-violet. The Class O spectra show this peculiarity in only a slightly less marked degree, some of them matching up perfectly in this respect with the nebular nuclei. I can not but believe that this wonderful richness in ultra-violet light which gives to the spectra of nebular nuclei their characteristic appearance, in spite of the great differences which they exhibit in the matter of bright bands, is the dominating peculiarity which must be regarded as the distinguishing mark of this group of objects. As it is also characteristic of the Class O stars, and since half of the nuclei are undoubtedly stars of that class, I have no hesitancy in advancing the opinion that the nebular nuclei belong to the same general division as the Class O stars, irrespective of whether they exhibit bright bands or not. But, however we label them, the really significant thing seems to

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[56] *Proc. Roy. Soc. Lond.*, **73**, 238, 1904.

be that these objects present a type of energy curve, which, if we interpret it in the usual way as a heat phenomenon, marks them as bodies of very high temperature, higher probably than that of any other class of stars.*

These remarks concerning temperature refer of course only to the nucleus, and not to the surrounding nebula. Whether the temperature of the nebula itself is high is a question touched only indirectly by these observations. The fact that the continuous ultra-violet radiations from the nucleus can pass through the enormous atmosphere of the nebula without extinction by molecular scattering proves the highly rarefied state of the latter. If the gas is rare and its luminosity is due to incandescence, a high temperature is indicated. This is in general accord with the results of Buisson, Fabry, and Bourget,[57] who assign a high temperature to the *Orion* nebula on the basis of their observations with the interferometer.

A striking fact brought out by the observations is that there is very little resemblance between the spectrum of a nebula and that of its nucleus. The two spectra are quite distinct, as will be readily appreciated by a glance at the plates or by the comparison of measurements. It is due to this fact that the relation between the nebulae and the Class O stars has been obscure. Campbell's observation that the spectra of the Wolf-Rayet stars, while presenting points of similarity with those of the nebulae, are quite distinct applies with equal truth to the spectra of the nuclei, but we have here incontrovertible proof of physical association to bridge the gap in spectral similarity. The spectral difference between a nebula and its own nucleus is likely to be more pronounced than that between it and the nucleus of some other object, because it is uncommon for a line which occurs in both classes of spectra to occur both as a nebular line and a nucleus band in the same object. 4686A appears in both places in N.G.C. 2392 and 6905, and Paddock[58] has observed the hydrogen lines to widen into bands in the nucleus of N.G.C. 40, but the phenomenon is apparently a rare one. It has been assumed by some observers that the nucleus spectrum represents in a sense an intensification of the nebula spectrum in which the nebular lines are broadened out, but this does not, in general, appear to be the case.

It is a matter of interest to know which of the lines or bands are common to the nebulae and the Wolf-Rayet stars. An absolutely reliable answer may never be possible, since it is difficult to measure the wave-lengths of many of the stellar bands with sufficient accuracy, and in any

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* If we measure the ordinates at the extremities of the arc (*c*), figure 1, and endeavor to match them by computations on the basis of the Wien-Planck radiation formula, it is necessary to assume a temperature which seems absurdly high—of the order of 50,000° Cent. I am not disposed to place much reliance on the accuracy of the curve, nor any on this method of determining stellar temperature, that is by the calculation of the absolute temperature from the ratio of intensities at two points in the spectrum, though the procedure has had the sanction of some use in astronomical practice, for there is little ground for the belief that any of the radiation formulae afford exact mathematical expressions of the energy distribution at the higher stellar temperatures. It is doubtless more permissible to assume generally, as is usually done, that increased richness in the shorter wave-lengths of stellar spectra is indicative of higher temperature, and on the basis of this assumption the nebular nuclei are undoubtedly to be considered among the hottest of the stars. Even this assumption, however, is not in keeping with the opinion of Burns (*Publ. Ast. Soc. Pac.*, 27, 113, 1915), who, from a very suggestive discussion of Coblentz's measures of the total radiation of the stars, concludes that the Class B stars have an excess of infra-red radiation ($\lambda > 1.4\mu$) and are not, therefore, certainly hotter than the A5 stars, though, magnitude for magnitude, they are relatively richer in the violet rays. Unfortunately the deduction hinges on the observation of only two stars, one—the most critical—of which appears to have been observed under somewhat unfavorable conditions and besides is an unsuitable object because it is a spectroscopic binary (*Lick Obs. Bull.*, 8, 116, 1914). It is to be hoped that future development of the work so successfully initiated by Dr. Coblentz will contribute further to our knowledge of the radiation curves of stars, but until more progress has been made in that direction, and the interpretation of the observations has become more certain, I question whether we can afford to discard the evidence of temperature afforded by observations in the photographic region of the spectrum.

Dr. Burns calls attention to the fact that if we accept the original Draper Catalogue system of photographic magnitudes, that is, if we arbitrarily assume the photographic brightness to be determined by the intensity of the spectrum at λ4320, the Class A stars are relatively as bright "photographically" as those of Class B, while on the basis of the total amount of photographic light they are fainter. A discrepancy of this nature is to be expected as a result of the heavy absorption beyond the hydrogen series in the spectra of the Class A stars (fig. 2). The latter are doubtless hotter than their total actinic intensity would lead one to suppose.

[57] *Ap. Jour.*, 40, 258, 1914.

[58] *Loc. cit.*

event a further investigation of the Class O stars will be necessary. A partial answer can, however, be obtained by a comparison of the nebular and nuclear lines of the present measurements. In addition to the lines of hydrogen and helium, including 4686A and those of the *ζ Puppis* series, which are generally recognized as occurring both in the nebulae and the Class O stars, there are possible coincidences as follows:

nebula	nucleus	nebula	nucleus
3342}	3342±	4416	4416
3345{	....	....	....
3426	3429±	4571.7	4570
3445	3449±	4634.3	4634
4068.8	4070	4641.1	4641
4267.2	4266.9	4649.4	4651

Probably the most interesting and important phase of the nebular problem is that which concerns the relationship of the nucleus to the nebula. If we make the rather arbitrary assumption that the nucleus is a star in the process of formation out of the surrounding material, the question reduces to speculation as to the nature of the changes that take place during the process of development. The present observations do not appear to afford a very broad basis for speculations of this character. In the preliminary note referred to, the suggestion was made that a process of development might be indicated by the relative lengths of certain lines. The idea was not new, but appeared to receive some support from the observations then available. Later, in attempting to classify the nebulae with respect to the lengths of 4686A and certain other lines, a sequence of spectra was secured which seemed rather in harmony with the notion of an orderly development. The sequence is indicated in plate XLV, reproduced from the original paper.[59] It seemed plausible that the last nebula represented in that plate had passed through the stages typified by those in the scale above. But if this be true, what of the nucleus of N.G.C. 2392, which is a typical Class Oe star, equipped with dark lines and presumably in a more advanced stage than B.D. +30° 3639 or N.G.C. 40? Does this represent some sort of celestial shortcut to early maturity, or is there in fact no normal course of evolution, but rather a process of development determined by conditions peculiar to each object? As a result of the observation of a great variety of nebulae, associated with equally diversified nuclei, I am able to come to no conclusion in the matter. The observations are recorded as faithfully as possible, and await the divining power of some subtler mind. The sequence indicated in plate XLV is therefore not regarded as being of special significance with respect to any theory of nebular development. It has, however, suggested a tentative system of classification which has been of convenience in this work, and the plate is reproduced to indicate the basis on which that classification rests.

In concluding the discussion of the nebular nuclei I may be permitted to emphasize the nature of the link which appears to connect the gaseous nebulae and the Class O stars. All of these objects can be grouped under the three following heads:

1. Nebulae without nuclei.
2. Nebulae with nuclei. The nuclei are in all instances stars of very high temperature, and in half the cases show Class O bands.
3. Class O stars, with no (observed) nebulous surroundings. Temperature high.

As astrophysical evidence goes, the link appears to be fairly strong and the chain complete. It would be interesting to find some of the previously known Class O stars to be surrounded by nebulae. This has already been done in the case of B.D. +30° 3639, Campbell's hydrogen envelope star, in which the principal nebular lines have been found, as recorded elsewhere, and it appears not unlikely that other observations of a similar character will be made in the future, but such discoveries are scarcely necessary to add to the strength of the link. The only effect would be to remove one or more objects from group 3 and place them in group 2.

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[59] *Proc. Nat. Acad. Am.*, 1, 590, 1915.

CHAPTER IV

THE DISTRIBUTION OF RADIATION THROUGH THE NEBULAE

The observations referred to in this section were made with the slitless quartz spectrograph attached to the Crossley reflecting telescope.[60] They were undertaken for the purpose of investigating the distribution of material in the nebulae, with the hope that some light might be shed on the general question of the relation between a nebula and its nucleus. A very short period of observation sufficed to develop a number of interesting facts with respect to line distribution, but the significance of these in their bearing on the original problem is not clear. The early observations made with slit spectrographs having indicated a decided tendency of the line 4686A to localize near the center, and of the line 3727A to occur in the outer regions, it seemed possible that we were dealing with gases of different densities, and that the observed distribution is the result of gravitational action. The fuller evidence furnished by the complete monochromatic images lends little weight to this view. While the peculiar tendency of 3727A to favor the outer regions of the nebula is exhibited in numerous objects, a fact which taken alone might indicate it to be emitted by a comparatively rare gas, it is also equally true that the line tends more strongly than any other line to concentrate in the exterior condensations, or knots, a thing that is hardly to be expected if the gas is peculiarly unresponsive to gravitational action.

These outlying knots are well shown in N.G.C. 7662, 6543, and many other objects. In elliptical ring nebulae there appears to be a tendency on the part of this line to favor the ends of the ellipse, as in N.G.C. 7009 and 6826, though the phenomenon is not exhibited by the *Lyrae* nebula. See plates XLVI to L.

Quite aside from these characteristics, however, the general appearance of the images does not suggest the symmetry which we should expect as the result of gravitational action. The very decided difference in the distribution of helium, as indicated by 4471A on the one hand and the line 4686A on the other, in such objects as N.G.C. 7662 and 6572, taken in connection with the remarkable behavior of the latter line in the laboratory, is strongly suggestive that it is a physical condition that is localized, rather than actual material.

Fowler,[61] in his account of the discovery of 4686A in the laboratory, has called attention to the manner in which it is isolated in a vacuum tube, the lines of the series to which it belongs being "readily distinguished from the lines of helium, and from most other lines, by their localization." He also refers to Wolf's observation of the local occurrence of the line in the *Lyra* nebula. We have, then, in a vacuum tube essentially the same phenomenon as that observed in many nebulae, the restriction of 4686A to a certain part of the source.

Another factor which perhaps modifies the size and appearance of the images is selective absorption. The intensity of a line emitted by a great thickness of gas is, of course, a function of both its emissive and absorptive powers, and with changing physical conditions throughout the region of distribution it is not at all unlikely that the appearance of a nebula is modified accordingly, and that the modification is different for different lines.

It is not impossible that all three of the factors mentioned, unhomogeneity in composition, variation in physical state, and selective absorption, combine to produce the differences in the images of a nebula as recorded by different lines.

The fact noticed by Max Wolf in the *Lyra* nebula that 4686A is comparatively strong within the ring and that 3727A is faint there has been found to be characteristic of ring nebulae, and his remark that the two lines tend to avoid each other appears in general to be true. The image at 3727 frequently shows much more detail than any of the others.

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[60] See Appendix, under (g).

[61] *Mon. Not. R. A. S.,* 73, 63, 1912.

With respect to the sizes of the images, where a difference exists, which is not always the case, 3727A when present is always at least as large as, and usually larger than, any other image,[62] and 3426 is, in a corresponding sense, equal to, or smaller than, any other. The order of size appears to be 3426, 4686, the H lines, 3869, and 3727A. The N_{1-2} lines appear, as a rule, to give slightly larger images than hydrogen, though in certain well-known instances, such as the *Orion* nebula and I.C. 418, they are smaller. Unfortunately these lines are quite far from the center of the plate and are a little more subject to field and prismatic distortion than $H\beta$, so that the most accurate comparison in size can not be made, but in N.G.C. 2440 and some other objects the greater size of the N_{1-2} images is certain.

N.G.C. 40 appears to be somewhat exceptional in that the hydrogen images are as large as that at 3727A, though 4686A and numerous other bands are localized in the nucleus.

The line at 4686A is of peculiar interest, in view not only of its remarkable behavior in the nebulae but also because in the laboratory it is peculiarly sensitive to physical conditions obtaining in the source. It seems not unlikely that experiments with this line may eventually define some of the conditions existing in the nebulae. In this connection it seems pertinent to refer to 3426A. This nebular line has the characteristics of 4686A with respect to localization developed in a still higher degree than has that line itself. It would be interesting to know whether a line in this position can be excited in the laboratory. Some sort of superspark condition would appear to be indicated for the experiment.

A very remarkable feature of many of the nebular spectra is an apparently continuous spectrum which commences quite abruptly at about $365\mu\mu$ and extends with great uniformity far into the ultra-violet. The spectrum should be investigated with a slit spectrograph for the purpose of determining its character and limit with greater certainty. On account of the well understood limitations of the slitless spectrograph in the matter of resolving power, when applied to the study of a body having a sensible diameter, one cannot be certain that the spectrum is, in fact, continuous, though its extent and great uniformity favor the assumption that it is. The point of beginning of the spectrum as measured in N.G.C. 6543 and 7009 is about 3650A, but in other objects the wave-length may be greater. The spectrum is shown in plates XLIX, figure 1, in XLVI, figure 5, and in several other illustrations. It suggests to the unbridled imagination the feather of an arrow, the spectrum of the nucleus being the shaft. The peculiarity of this spectrum is not its continuity, since many nebulae present more or less continuous radiation, but the fact that it comes to an abrupt end, and, furthermore, that end is very close to the theoretical limit of the Balmer hydrogen series at 3647A. From this position the continuous spectrum extends in the direction of shorter wave-lengths, while the lines of the Balmer series reach toward the red. Evershed has observed a similar spectrum in the solar prominences and lower chromosphere, which begins suddenly at 3668A, and suggests a hydrogen origin for it.[63] He refers to an observation by Sir William and Lady Huggins[64] to the effect that in such stars as *Vega* the continuous spectrum suffers a sudden fall in intensity at the end of the series of dark hydrogen lines, beyond which it continues without further enfeeblement far into the ultra-violet. The phenomenon with respect to *Vega* is well shown in plate XLIV, figure 6, the upper part of which is the spectrum of *Vega* and the lower that of *β Aquilae,* a star of Class K introduced for the purpose of showing that in later stars the peculiarity is absent. In figure 2, of the text illustrations, are curves based on direct photometric measurements of these two plates. We have, then, in *Vega* an *absorption* spectrum corresponding closely with the *emission* spectrum in the chromosphere and in the nebulae. In the stellar spectrum the absorption appears to begin at about $\lambda 3700$.[65] Evershed's limit for the chromosphere emission is 3668, while in the

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[62] There may be a few exceptions in cases of those stellar nebulae in which 3727 is faint.

[63] *Phil. Trans.*, **197A**, 399, 1901.

[64] *An Atlas of Representative Stellar Spectra*, p. 85.

[65] The darkening in this vicinity is doubtless largely due to the crowding together of the hydrogen lines, which are very broad.

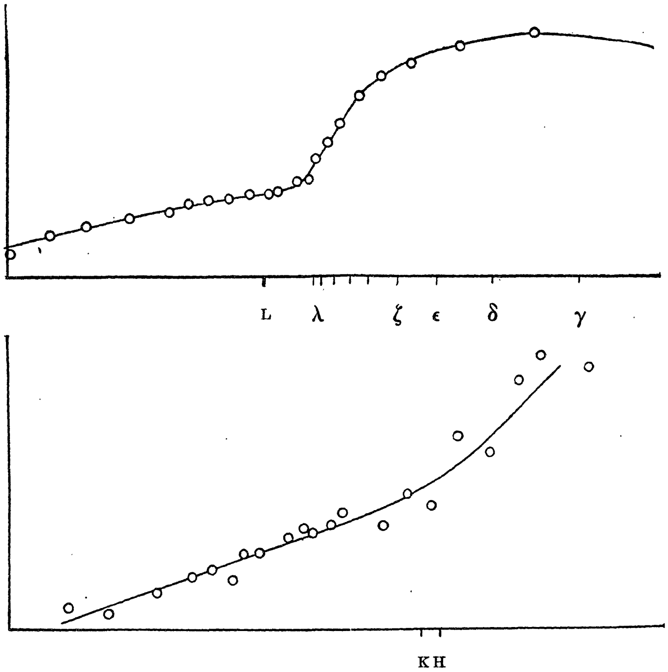

Figure 2. Intensity curve (prismatic dispersion). Upper α Lyrae, Lower β Aquilae. L indicates the limit of the Bulmer series.

nebulae the measured position is roughly 3650. The limit for the Balmer series is about 3647, so there is apparently some overlapping of the two spectra, the amount probably depending on the conditions in the source. A corresponding continuous spectrum appears to have been actually observed by Dufour[66] in the laboratory, during the course of his investigation of the spectrum of hydrogen, though he seems not to have associated it with the Balmer series, but rather with the secondary spectrum of hydrogen.

In this connection it will be recalled that Wood,[67] in his investigation of the absorption of sodium vapor, noticed a continuous absorption spectrum beginning just where the Balmer series for sodium leaves off, and extending far into the ultra-violet. That is, the sodium spectrum presents a phenomenon closely paralleling the apparent behavior of hydrogen in the early stars.

All of these facts seem to lend plausibility to the idea that the spectrum here discussed belongs to the Balmer series, and that its production is in some way involved in the mechanics of line series radiation. Bohr,[68] in the development of his theory of radiation, has attempted to account for the continuous sodium absorption observed by Wood, but whether continuous radiation is also to be accounted for is not stated.

Professor Millikan has drawn my attention to the fact that the Balmer hydrogen series is almost certainly to be regarded as the L radiation of the Roentgen ray spectrum of hydrogen, since its limit at 3646A is very close to the position of one of the L lines as computed by Moseley's law.[69] He also points out that the absorption observed in the spectrum of *Sirius* corresponds exactly with the characteristic absorption bands found by Barkla and Sadler, and also De Broglie, to border the K and L lines in the Roentgen ray spectrum. An emission spectrum corresponding to that in the nebulae seems not to have been observed for Roentgen rays.

Laboratory experiments undertaken in this connection might lead to interesting results. To any one contemplating them the writer would suggest the use, for purposes of preliminary investigation, of comparatively low dispersion.

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[66] *Ann. Chim. et Phys.*, (8), **9**, 361, 1906.
[67] *Ap. Jour.*, 29, 100, 1909.
[68] *Phil. Mag.*, 26, 17, 1913.
[69] R. A. Millikan, *The Electron*, 195 and 202.

CHAPTER V

The present chapter is devoted to miscellaneous topics which form no definite part of the three divisions covered by the preceding three chapters.

On the Presence of Carbon and Nitrogen in the Nebulae.—Coincidences among nebular lines and lines in the spectra of stars and terrestrial sources are usually regarded as limited to radiations of hydrogen and helium, including 4686A and the related series of *ζ Puppis* lines. Attention was drawn in a previous paper to indications of the presence in the nebulae of nitrogen and carbon. There is in the nebulae a very faint line close to Hδ which became pronounced enough in the spectrum of *Nova Geminorum* No. 2 to modify very perceptibly the form of the Hδ band. In fact, it was first suspected in the *nova* from this circumstance, and afterward found, with prolonged exposure, in a number of nebulae. Its wave-length is uncertain on account of its faintness and the overpowering strength of the Hδ line, which, with the low dispersion used, is very close. The mean of eight measures gives 4097.3A. There is a characteristic dark line in the spectra of certain of the Class O stars, the wave-length of which, as measured in the spectrum of *ϵ Orionis* by R. H. Curtiss,[70] is 4097.3A. The stellar line has been the subject of much discussion in studies of spectral classification. It has its maximum, according to Miss Cannon, in Class Oe stars. It has been assigned by various observers to as many elements, but the best case seems to have been made out by Lockyer, Baxendall, and Butler, who identify it with a line of abnormal behavior in the spectrum of nitrogen.[71] Whatever its chemical source, its strength in Class O stars argues for its common origin in these and in the nebulae. A line which plays an equally or perhaps more important part in stars a little further along in their development is 4267.14A. This is universally ascribed to carbon, and the wave-length quoted is Hartmann's laboratory determination made with a tube containing a highly rarefied gaseous hydrocarbon compound. A faint nebular line has been photographed in this vicinity by several observers, but only rough determinations of its position have been published. The mean of five of my measures places it at 4267.1A. The line is very faint, and this value may be in error, say, 0.2 of an Angstrom. The South Kensington and other observers have found[72] the carbon line 4267.14 to be accompanied by a composite line at 4647.4, 4650.7, 4651.6. If this line were in the nebulae it would not be resolved, but would be represented by a hazy line at 4649.3±. There is such a line at 4649.2. The presence of carbon and nitrogen in the nebulae seems probable.

Recently Detected Lines Common to the Spectra of the Gaseous Nebula and the Temporary Stars.—A line to which some interest attaches is that at 4725.5A, observed in N.G.C. 7027. This line was unknown until recently and has been observed only in this nebula. However, in an analysis made many years ago of a complex bright band[73] in the spectrum of *Nova Persei* it was found that, after allowing for numerous maxima and minima in a certain compound bright band, due to the known nebular lines in the vicinity, there were outstanding certain others which could be accounted for by a hypothetical nebular line near wave-length 4724. The detection of this line at measured wave-length 4726 may be taken as a confirmation of the correctness of this conclusion. It will be remembered that the bright nebular line at 3967 was detected in the same way, and the same is true with respect to the line 4097A just referred to. Still another instance may be mentioned in 4711A, the detection of which as a nebular line independent of 4713 (helium) explains what were previously regarded as peculiarities in the behavior of this helium line in *Nova Persei* No. 2. The finding of lines in this way, first by inference based upon apparent irregularities in the *nova* bands, with subsequent confirmation in the nebulae, tends to strengthen our confidence in the rigorous correspondence between the spectra of the novae during the so-called nebular stage and the spectra of the nebulae.

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[70] *Pub. Ast. Obs. Univ. Mich.*, 1, 120, 1915.

[71] *London, Proc. R. Soc., A*, 82, 534, 1909.

[72] *Ibid.*

[73] *Lick Obs. Bull.*, 1, 54, 1901.

Lines Apparently Associated in the Spectra of the Nebulae.—The question of association or linkage of lines in the spectra of the nebulae has, from the time of the first spectroscopic observations of these objects, claimed the interest of astronomers. The N_{1-2} lines, for instance, appear to vary one with the other, and are generally regarded as belonging together.[74] The same is, of course, true with respect to the members of the Balmer series and the various helium series of lines, the relationship of some of the latter having been inferred before the actual discovery of helium.

I have attempted to determine whether there are any other groups of lines of common behavior, but have not been able to arrive at very certain conclusions. The isolation of certain lines seems perhaps more certain than the association of others. There are two characteristics which may be made the basis of segregation; these are relative intensity and distribution. To what extent behavior in either of these respects is a safe guide to the grouping of lines is a matter of doubt. The relative intensity of lines in the same spectrum is, of course, in many instances subject to great variation under change of condition in laboratory experimentation, and it is not impossible that certain gases may occur in equal proportions in practically all the nebulae, so that a uniform line relation is, strictly speaking, neither the necessary nor sufficient condition for identity of origin of the lines concerned; still, it seems worth while to examine the available data to see what lines appear to have a common behavior.

The two lines near $H\alpha$, 6548, and 6584A occur in such very unlike spectra as N.G.C. 7027 and B.D. +30° 3639, being particularly strong in the latter object. They have not been observed in the *Orion* nebula. We have therefore to search out the lines common to the spectra of the first two objects, which are very dissimilar, and select any of undue intensity in the second spectrum which do not occur, or are faint, in the *Orion* nebula. 5755, 4069, and possibly 4076A are the only lines that meet these requirements. 3727A is out of the question because, while it is in the first two nebulae, it is the strongest line in the *Orion* spectrum. There is therefore the possibility that 6548 and 6584A, which seem to occur together, are linked with 5755, 4069, and less certainly with 4076A, but with no other strong lines. The observation of the two red lines are comparatively few, and further investigation may, of course, tend to divide the suggested group. These lines appear to show no particular regard to the class of nebula they favor with their presence.

The N lines probably have a common behavior, but do not appear to be associated with any other strong lines.[75] It is true that the measured values of Iq are not relatively the same in the nebulae listed in table 13, but that is, I think, due to the fact that the green is a region of the spectrum unfavorable for measurement of intensity. It is close to the end of the sensibility curve, and different plates give different intensity ratios even in the same object. The fact that they are isolated from other lines is indicated by their faintness in I.C. 4997, a nebula in which all of the other lines maintain a good strength.

There is an interesting group of lines in the neighborhood of 4686A, which are characteristically short in such objects as N.G.C. 7662 and 7009 (pl. XLII). One would expect to find some evidence of relationship, but there appears to be none, as is indicated by the following comparison:

Object	Relative intensity of lines					
N.G.C. 7662	4741	=	4711	>	4641	
7009	4741	=	4711	=	4641	
6543	absent		probably absent		4641	fairly strong, 4632 and 4651 in nucleus
7027	4741	>	4711	=	4641	

Although the five lines mentioned here undoubtedly have characteristics in common, they are not to be definitely connected together.

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[74] A difference in behavior of these two lines in the spectrum of *Nova Geminorum* No. 2 is reported by Adams and Pease. *Proc. Nat. Acad. Sci.*, **1**, 392, 1915.

[75] *Loc. cit.*

4363A probably does not belong with any other line in the photographic spectrum, judging by its remarkable strength in I.C. 4997.

3869 and 3967 are probably linked. When Hϵ, which is close to the latter, is sufficiently faint the two images given by these lines are alike, and the relative intensities appear to be uniform.

Of the pair at 3727, the one of greater wave-length is the fainter; but, so far as I have been able to observe, always accompanies the other if the strength of the photograph is sufficient. They appear to be companions.

3426 and 3346A maintain approximately the same relative intensity. Furthermore, the former line, and probably the latter, give nebular images of the smallest size. For example, in N.G.C. 7662 (pl. XLVI, fig. 5) 3426 gives a small image, while the small 3346 ring can be seen eccentrically situated within the bright image due to 3342A.

3445, 3342, and 3313A give normal sized images in the nebula just referred to. They seem to belong to a group.

Recapitulating, the following lines as arranged in vertical columns appear, with more or less certainty, to be linked:

3313	3346	3726	3869	4069	4363	4959 (N_2)
3342	3426	3729	3967	4076 (?)	....	5007 (N_1)
3445	....	....	....	5755	....	....
....	....	....	....	6548	....	....
....	....	....	....	6584	....	....

Classification of the Gaseous Nebulae.—The only serious attempt of which I am aware that has been made to classify the gaseous nebulae is that of Miss Cannon.[76] The arrangement in that classification is based on the relative intensity of certain lines of the spectrum, the most critical of which is 4686A. With respect to this line Miss Cannon says: "The presence of the bright band 4686 in both gaseous nebulae and spectra of Class O certainly indicates a connection between the two. Accordingly, gaseous nebulae characterized by this band have been placed in the later divisions, presumably near Class O." Admitting the existence of a close relationship between the two classes of spectra, and the importance of 4686A as an index of the position of one with respect to the other, I can not entirely agree with the deduction in the second sentence of the quotation. In general I should be disposed to assign a nebula in which 4686A is strong to the class farthest removed from the stellar stage. The basis for this view is touched in two earlier papers,[77] to which frequent references have already been made.

A difficulty encountered at the outset in any attempt to classify the nebulae lies in the fact of their unhomogeneity, and their differences, one from another, in structure. Objects like I.C. 418 and B.D. +30°3639 consist of two definite parts, a nucleus and an envelope. Which of these is to be made the basis of the classification? Other objects show no nucleus whatever, and among them some exhibit the line 4686A and some do not. At first sight the lines 4686 and 3727A would appear to be competent to serve as indices, since they predominate as a rule at opposite ends of any system that can reasonably be suggested, but a difficulty here is that one or the other may be made to predominate in the spectrum of a single object by selecting a suitable part of it for observation. A striking thing brought out by the present observations is the apparent relation in certain instances between spectrum and form. Many of the ring nebulae, for example, N.G.C. 7662, 7009, and 3242, are almost identical in form and spectrum, and the ring nebula in *Lyra* is somewhat like them in both respects. Of the six objects designated as belonging to Class Ib in the system shortly to be indicated five are ring nebulae, and the sixth (I.C. 5217) is on the border line of its class. These considerations lead me to believe that the question of form may eventually enter as a factor in the classification of nebulae. The compli-

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[76] *Annals of Harvard College Observatory*, **76**, 19, 1916.

[77] *Proc. Nat. Acad. Sci. Am.*, **1**, 269 and 590, 1915.

cations referred to here arise from the great extent of these objects. In the case of a star which is a much more concentrated body conditions are presumably more homogeneous over its entire radiating surface, and some more uniform law of radiation would naturally be expected.

The foregoing considerations are conformable with the opinion expressed elsewhere that we have at present insufficient data to serve as a basis for a satisfactory theory of nebular development, and therefore that any system of classification of the nebulae by means of their spectra must be regarded as merely descriptive. I have for my own convenience adopted such a system on the basis of the general arrangement of nebular spectra indicated in plate XLV and more fully described in one of the papers just referred to, and as it has been found to serve very well in segregating the spectra into comparatively homogeneous groups I venture to present some account of it.

Having arranged the objects in the order indicated in the illustration, it was found that some of the principal lines showed a fairly steady progression in intensity from one end of the series to the other. The following prominent lines experience a general decrease in intensity as we pass from the beginning to the end of the sequence, 3869, 3967, 4363A, and the N lines. The line 3727A appears, on the other hand, to become stronger, though the variation is so irregular that it can hardly be deemed a critical line. For instance, while it is the strongest line in B.D. +30° 3639, N.G.C. 40, and in other objects near the end of the sequence, and is generally weak in those at the beginning, there are exceptional cases such as the *Lyra* nebula, which belongs well up in the scale, in which it is photographically the brightest line. It also occurs in undue strength in N.G.C. 6886, the spectrum of which, except for this fact, is practically identical with that of N.G.C. 7027, the first nebula in the sequence. In addition to these facts, the line has such a spotted distribution that its relation to the rest of the spectrum is necessarily a matter of doubt, and while it is perhaps the most interesting of all the lines, by reason of its erratic behavior, its significance in the suggested scheme of arrangement appears to be obscure, and its use as a criterion is hardly justifiable.

Of the lines mentioned as decreasing in intensity, 3869A appears to be the most suitable to use as a guide. It is, generally speaking, strong, and therefore easily photographed in nearly all nebulae in which it appears at all. It gives a clear uniform image, and is well separated from its nearest neighbor at 3889A. 3967A probably follows the behavior of 3869, but is unsuitable on account of its proximity to Hϵ. 4363A conforms in a general way with the intensity variations of 3869, though the relative intensities are not by any means uniform. The line is apparently not of such general occurrence as 3869, and it is too close to Hγ for complete separation in the larger planetaries when a slitless spectrograph is used. N_1 and N_2 are apparently not critical in their behavior, and, in addition, there is the practical consideration that they lie near the end of the sensibility curve of most photographic plates, and their apparent strength varies greatly from one commercial brand of plates to another. For example, a "Cramer Crown" or a "Lumiere Σ" plate may record these lines as faint, where a "Seed No. 27" or "30" will show them well. Some such difference doubtless exists in a less degree among different emulsions of the same commercial brand of plates. In view of all of these facts, 3869A has tentatively been adopted as a guide line when 4686A is absent.

The procedure has been to place in one group all those spectra which contain 4686A as a nebular line, in a second those from which this line is absent but in which 3869 occurs, and in the third those from which both of these lines are absent.

It will be noticed that the lines in the ultra-violet lying above 3500A occur only in those nebulae which emit 4686A, but that they do not always accompany that line. This suggests a subdivision within the first group. The ultra-violet lines appear to belong to two subgroups, of which the leading lines are 3426 and 3445A. From general considerations referred to elsewhere, it seems fair to infer that the remarkable characteristics of 4686A are even more pronounced in 3426, so that it has been assumed that the nebulae in which this line is the stronger belong in the earliest subdivision. Those in which 3445A is stronger are assigned to the second, while the occurrence of 4686A without either of these lines determines the third subdivision of the first class.

The second class is subdivided on the basis of the intensity of 3869A, the first division consisting of those nebulae in which Iq for this line is greater than 30, the second, of those in which it is equal to or less than that intensity. The selection of Iq = 30 (which is close to the mean value for Hδ) as the intensity marking the dividing point is not entirely an arbitrary one, as, in so far as the present list is concerned, it places in the first subdivision those spectra which contain 4363A and excludes them from the second. Whether the criterion will continue to function in this manner under the strain of a further accumulation of data can not of course be predicted. It is hardly to be expected that it will, since the intensity of 4363A with respect to 3869 varies from object to object, the two being almost equally strong in I.C. 4997. It might seem the better plan to make the presence of 4363A the test, but this line is sometimes not visible through under-exposure, or, when using a slitless spectrograph, on account of its proximity to Hγ.

Class III contains only three objects: N.G.C. 40, Index 418, and B.D. +30° 3639. It requires subdivision, probably with respect to the occurrence of helium or the brightness of the N lines, but observations of more objects should be available before proceeding further.

To sum up, the basis of classification is as follows:

		Typical Nebula
Class I	4686A present in the *nebula*	
	(a) 3426A stronger than 3445A	N.G.C. 7027
	(b) 3445 stronger than 3426	N.G.C. 7009
	(c) 3445 and 3426 absent	N.G.C. 6884
Class II	4686A absent from *nebula,* 3869A present.	
	(a) Iq for 3869A$>$30	N.G.C. 6572
	(b) Iq for 3869A$\leqq$30	Index 2149
Class III	4686 and 3869A absent	....

A Comparison of the Spectrum of the Orion and Planetary Nebulae.—The suggestion has been made that there is a fundamental difference between the extensive nebulae, such as the *Orion* nebula, and the planetaries. This point of view is based largely on observations of velocity in the line of sight. It has been found by Kapteyn and Campbell that there is a progressive increase in speed with advancing stellar type, and Campbell has called attention to the fact that the velocities of the planetary nebulae exceed those of Class M, the final group of stars. The space velocity of the *Orion* nebula is, as was pointed out by Keeler, approximately zero. Some astronomers have been inclined to infer from this that while the *Orion* nebula represents an initial stage in stellar evolution the planetaries represent a final one.

The question as to whether the spectrum of the *Orion* nebula differs fundamentally from those of the planetaries is therefore an important one. In plate XLV the spectra are compared. Making allowance for the fact that the plate of the *Orion* spectrum was taken with apparatus more transparent to violet and ultra-violet light than that used for the others, it will be observed that there is little difference between the spectrum it records and others placed close to it in the illustration. The spectra of the planetary nebulae differ much more among themselves than some of them do from the spectrum of the *Orion* nebula. Whether or not the spectral similarity which exists between certain of the planetaries on one hand and the *Orion* nebula on the other indicates approximate equality of physical constitution depends upon the sensitiveness of the nebular spectrum as an index of the state of its source. That the spectrum is responsive to changes in the physical condition of the radiating gas is rendered almost certain by the great variety of spectra that are found, not only in different nebulae but also in different parts of the same object. This subject has been discussed in the preceding chapter with particular reference to the line 4686A, which, judging from the way it reacts in the laboratory, is very responsive to changes of physical condition. This line is due to helium, and its occurrence proves the existence of some peculiar physical state at the seat of radiation. The presence of helium in I.C. 418, the *Orion* and other nebulae, without the presence of this line, indicates that a condition present in other nebulae does not exist here. There are doubtless other lines that are equally sensitive, for instance, 3727A. This line behaves so erratically that it is difficult to credit its distribution to the local occurrence of any particular gas. Other lines are perhaps equally critical, so that it may fairly be assumed that the nebular spectrum is an index of the condition of the gas that radiates it. Since the spectrum of the *Orion* nebula is practically identical with that of a certain class of planetary spectra, it appears probable that its physical state is not sensibly different from theirs.

In the matter of structure the planetary nebulae present points of difference from the extended nebulae, and the symmetry of arrangement which they so often exhibit suggests that with them the relation of nebula to included star is more fundamental than with the larger and more irregular gaseous masses. It is this undoubted intimacy between nebula and nucleus that gives special interest to the spectral characteristics of the nuclei. In the cases of stars involved in extended nebulosity there is greater latitude for the assumption of a casual relationship. However that may be, it appears to be noteworthy that the spectrum itself affords no basis for distinguishing between the *Orion* nebula and planetary nebulae of the corresponding class; on the contrary, identity of physical constitution in these objects is indicated. This view is strengthened by the fact that the stars involved in the *Orion* and the planetary nebulae are all of high temperature and have points of spectral similarity.

In closing this section devoted to miscellaneous results of observation I wish to draw attention to the importance of observing the line 4686A under high dispersion in those objects, such as N.G.C. 2392 and 7662, which exhibit N_{1-2} lines of peculiar shape. The matter is referred to at some length in the description of the observations of those two nebulae, and need not be dwelt on here. It will be recalled that in the spectrum of N.G.C. 7662 the pattern of 4686A is reversed, in a right and left sense, with respect to that of the principal nebular lines, as observed by Campbell and Moore. This result depends on a single observation, and while it appears quite definite it should be confirmed, because it must be taken into consideration in any explanation of the remarkable structure of the nebular lines, a structure which might otherwise be accounted for on the basis of comparatively simple assumptions.

SUMMARY OF RESULTS AND CONCLUSIONS

In the following paragraphs an attempt is made to summarize the results and conclusions arrived at in this investigation. Certain definite results can very easily be specified, but I have felt some hesitancy in drawing definite conclusions for the reason that I regard the value of the work to lie in the observations themselves rather than in any construction that I might feel disposed to put upon them. In fact, the interpretation of observations of this character is a problem lying rather within the domain of physics than of astronomy, and more particularly within that subdivision of the field of molecular and submolecular physics which includes the theory of radiation. This is generally true with respect to the more complicated phenomena of celestial spectroscopy for the very apparent reason that the astronomer can not, in his experiments, vary the condition of the radiating source. The best he can do is to go from one object to another in the hope of encountering differences in condition, the nature of which can only be conjectured. The result, therefore, of even the most successful of such efforts, is usually a fragmentary collection of observations which the laboratory worker, with his control of conditions of observation, may hope to bring into some sort of mutual relation. This truism of astrophysics applies with particular force to the results of the present investigation, and it is hoped that much of the material, particularly that relating to the distribution of lines in the nebulae, will eventually be unified and have its significance made clear by experimental work in the laboratory.

With respect to some of the simpler phenomena presented through the medium of these observations, there are inferences which, in the present state of our knowledge, may tentatively be drawn. Some of these depend on the assumption that the energy curve of the spectrum is an index of the temperature of the body which emits it. This is ordinarily assumed in estimating the temperature of a celestial object, and there appears to be no special reason to question the application, in this manner, of a fairly well established law of physics; still, it is well in these days when, as Professor Millikan so well expresses it, "new viewpoints and, indeed, wholly new phenomena, follow one another so rapidly across the stage of physics that the actors themselves scarcely know what is happening," to adopt a conservative view, and to bear in mind that other agencies besides heat may be competent to produce an energy curve rich in the shorter wave-lengths. The detection of such a thing as a continuous spectrum of appreciable strength, beginning suddenly at a certain point and extending out into the ultra-violet, suggests caution in the interpretation of the energy curve in terms of temperature alone. But adopting the usual point of view, that an increase in the relative strength of the shorter wave-lengths is indicative of increased temperature, the conclusions with respect to the temperature of the nebular nuclei follow as a matter of necessity.

Subject to the foregoing reservations, the general results and conclusions may be summarized as follows:

1. The wave-lengths of the nebular lines, including some not previously reported, have been measured.

2. The nuclei of the planetary nebulae have been found to give a continuous spectrum strong in ultra-violet light, indicating that they are at a very high temperature.

3. Half of the observed nuclei have been observed to exhibit the characteristic bands of the Wolf-Rayet or Class O stars, and they are probably all to be classed as belonging to the same general group as these stars. A definite connection is therefore established between the planetary nebulae and the Class O stars.

4. There is no essential spectral difference between the *Orion* nebula and the planetary nebulae of the same spectral class. As the nebular spectrum appears to be sensitive to changes of physical condition in the nebulae, this justifies the presumption that the conditions in both the *Orion* and planetary nebulae are comparable, a point of view that is supported by the fact that the stars involved in both have a high temperature and possess points of spectral similarity. Spectroscopic evidence does not, therefore, of itself, justify the separation of the planetary from the more extended nebulae, and the placing of one class at the beginning of stellar evolution and the other at the middle or end of it. If we were obliged to assign them a position it would seem necessarily to be that at the beginning, unless we are prepared to accord some other to the system of the *Orion* nebula. The alternative would be to assume that practically identical conditions for nebular radiation can arise under very different circumstances of development.

5. I refer with a great deal of diffidence to the rôle played by the gaseous nebulae in the drama of cosmical development. The subject of stellar evolution, like many others in astronomy, should be approached with a full sense of the limitations of our ordinary experience as a basis for appraising probability in the interpretation of celestial phenomena. We know little of the physical constitution of the nebulae, and nothing whatever of the stimulus which excites them to luminescence. It is of interest to recall in this connection that the dark side of the Earth would undoubtedly exhibit to a celestial observer a bright line (auroral) spectrum, faint, it is true, but of sufficient strength to be seen or photographed.[78] In this case the luminosity is probably due to the influence of the Sun, an explanation which holds out the suggestion that that of the nebulae may be stimulated by their nuclei. The very obvious objection to such a notion is that some of the nebulae have no visible nucleus, nor is it reasonable to suppose that in these instances a nucleus exists and is hidden in the nebula, because the readiness with which ultra-violet light is transmitted when the nucleus is visible at all shows the planetary nebulae to be exceedingly transparent, and the uniformly high temperature of the known nuclei is unfavorable to the assumption that a nucleus may be dark. The inference is that if we can not photograph a nucleus it is not there. These reflections point to the probability that the involved star is not the cause of a nebula, nor of its light, and that the latter, whatever the mechanics of its origin, finds its stimulus in the body of the nebula.* If one were compelled to choose either the star or the nebula as the cause or antecedent of the other it would again, as in paragraph 4, seem more consistent with the scattered evidence at present available to place the nebula first, though in making such a choice I should be obliged to regard it as a forced decision, and not the expression of a definite conviction, for I do not feel fully assured that we are close to an understanding of the real significance of the gaseous nebulae. However, the present observations have a bearing on those theories of evolution that assume the nebulae to occupy a place prior to that of the stars. There are at present two general conceptions as to the nature of stellar evolution, one of which assumes a falling temperature throughout the period of a star's development while the other predicates a rise to maximum and a subsequent decline; both of these assume the nebula as the primordial state. As between these two hypotheses the present observations undoubtedly favor the first, since they add to the proof that the gaseous nebulae are associated only with the hot stars.

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[78] Campbell, *Astrophys. Journ.*, 2, 162, 1895; also Slipher, *Lowell Obs. Bull.*, 3, 1, 1916.

* Since the above was written I find myself to have been anticipated in this observation to the extent of a century and a quarter by Sir William Herschel, even in the matter of the reference to the aurora. "But what a field of novelty is here opened to our conceptions! A shining fluid, of a brightness sufficient to reach us from the remote regions of a star . . . and of extent so considerable to take up 3, 4, 5, or 6 minutes in diameter. Can we compare it to the coruscation of the electric fluid in the aurora borealis? . . . It has been said above that in the nebulous stars the shining fluid does not seem to be so essentially connected with the central points that it might not also exist without them. . . . If therefore this matter is self-luminous, it seems more fit to produce a star by its condensation than to depend on the star for its existence." (*Abridged Phil. Trans.*, 17, pp. 25–26.) Herchel's conclusions were of course drawn without the advantage of the spectroscopic evidence we now possess, and it seems well worth pointing out that that evidence, so far as it goes, is confirmatory of the forecast of his sagacious mind.

6. Many of the planetary nebulae, when photographed with the prismatic camera (slitless spectroscope), present a remarkable variety of forms corresponding to different nebular lines. The significance of the variation is not understood. It may be due in part to differences in distribution of the component gases of the nebula; in the case of the 4686A and some other lines it appears to be almost certainly due to a localization of peculiar physical conditions. Other causes may also be effective in altering the apparent form of a nebula; for instance, selective absorption of the nebular lines themselves. Whatever the cause, it is quite apparent that the image of a nebula as it appears in the telescope, or on a direct photograph, is an integrated one due to the superposition of many which are liable to be quite unlike. It follows that there is a limit to the value of simple telescopic or photographic observations in the study of nebular structure.

7. A spectrum, apparently continuous, which begins abruptly at about the limit of the Balmer series and extends into the ultra-violet, has been found in the nebulae. It is undoubtedly the same spectrum as that observed by Evershed in the spectra of the solar chromosphere and prominences, and, as noted by him, corresponds with the ultra-violet absorption first observed by Huggins in the spectrum of *Vega*. It is probably part of the Balmer hydrogen series, and is of possible significance in the theory of radiation.

8. The probable existence of carbon and nitrogen in the nebulae is indicated.

9. A system of nebular classification is suggested.

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