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SPECTROPHOTOMETRY OF REPRESENTATIVE PLANETARY NEBULAE

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ABSTRACT

This investigation completes a spectrophotometric study of planetary nebulae initiated some years ago at the Lick Observatory. Special attention is paid to nebulae observed in the λλ 3700–6500 A region by Wyse, to objects with interesting structural features, and to certain stellar nebulae. The observed Balmer decrement agrees with the theoretical predictions by Menzel and Baker for their model *B*, in which all Lyman radiation is assumed degraded into Lyman-α, which alone escapes from the nebula. With the low dispersion employed, most of the central stars show continuous spectra with little evidence of absorption or emission lines. The nuclei of NGC 7026, 6751, and 6905, which show broad Wolf-Rayet emission lines of oxygen, helium, and carbon, are discussed in detail, and relative line intensities are derived.

I. INTRODUCTION

A basic requisite for the understanding of the planetary nebulae is a knowledge of the intensities of the emission lines that comprise their spectra. The brightness of the lines of a given ion differ from nebula to nebula or even within the same nebula in such a way as to reveal important clues to the prevalent conditions of excitation and ionization.

The meaning of the intensity of a nebular emission line merits a moment's attention. First, we would like to have the total intensity of the nebular line—i.e., the total amount of monochromatic energy received from the whole nebula per second by a unit area just outside the earth's atmosphere perpendicular to the line drawn to the nebula. This information should be supplemented by measurements of the distribution of energy throughout the nebular images—the results may be expressed very well by means of isophotic contours such as those published by Berman.[1] Although the total intensity and the isophotic contour give a complete description of the observational data, the emission per unit volume is the item of greatest theoretical interest. An estimation of this quantity requires some knowledge of the spatial structure of the nebula, as well as of its distance. In general, both of these are poorly known.

A number of observers have published measurements of nebular line intensities. Berman observed with the Crossley reflector and quartz spectrograph of the Lick Observatory. Plaskett[2] obtained slit spectra of a number of the brighter objects at the Dominion Astrophysical Observatory. More recently, Bowen and Wyse[3] used the Lick 36-inch refractor and spectrographs equipped with the image slicer. They estimated the intensities of the lines with the aid of scale plates. T. L. Page[4] secured excellent photometric material for a large number of nebulae. He employed the Cassegrain spectrograph of the 82-inch McDonald reflector and a wide slit. A report on the continuous spectra of the planetaries has been published, but an account of the line intensities has not yet appeared.

Some years ago at the Lick Observatory the writer measured the relative total intensities of the nebular lines (and, when possible, the Balmer continuum) in eleven planetary nebulae.[5] In addition to this list, a few objects observed by Stoy were also discussed. The

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* The reductions described in this paper were carried out primarily while the writer was at Indiana University.

[1] *Lick Obs. Bull.*, **15**, 86, 1930.

[2] *Pub. Dom. Ap. Obs. Victoria*, **4**, 187, 1928.

[3] *Lick Obs. Bull.*, **19**, 1, 1939.

[4] *Ap. J.*, **96**, 78, 1942.

[5] *Ap. J.*, **93**, 236, 1941.

present investigation comprises a completion of this program. In the present instance, however, the relative total intensities are given for only the stellar planetaries. For the other objects the intensities measured at a particular point (or sometimes two or more points) in the nebula are tabulated, although in a number of instances the total intensities also have been measured.

Section II discusses the selection of the nebulae observed; Section III describes the techniques of observation and reduction; Section IV gives the results, mostly in the form of tables; and Section V treats of the Balmer decrement. A final portion of the paper is devoted to some remarks on the nuclei of the nebulae.

II. SELECTION OF OBJECTS

The observational program was planned in conjunction with quantum-mechanical calculations of the target areas for the collisional excitation of certain of the stronger forbidden lines. Since the transition probabilities are known, it should be possible to utilize such target areas in connection with the observed intensities to get information on the state of ionization and excitation, the electron temperature, and ultimately the composition of the radiating gases.

Particular emphasis was placed on the nebulae studied by Wyse[6]—NGC 2165, 2440, 6741, and IC 5217, which had not been observed in the earlier program. The idea was to supplement the extensive line-intensity measurements in the visual and photographic regions with data for the ultraviolet. Second, there has been included a number of objects of moderate surface brightness that show interesting structural details, e.g., NGC 1535, 2392, 3242, 4361, 6720, 6751, 6778, 6818, 6905, and 7026. Finally, observations were secured of certain stellar nebulae of interest because of their high densities, central stars, and the problem of the Balmer decrement.

In all, 170 spectrograms of 45 planetary nebulae and their nuclei were secured in the 1943–1945 program. Of these objects, 27 have been previously observed by Page and 33 by Wright,[7] and a few have been studied by Minkowski[8] and by Stoy.

For many nebular problems wide-slit spectrograms of the type obtained by Page are probably more useful than slitless plates. Sky fog is greatly cut down, and there is no interference from overlapping stellar spectra. Slitless plates of the larger nebulae are useful only for the stronger, well-separated lines and are capable of giving us no reliable data on the weaker lines or those that fall close to one another. On the other hand, slitless spectrograms often yield more complete information about the structural features of the planetaries and permit the determination of the integrated intensities of the nebular images. The latter data are needed, for example, for the determination of the temperatures of the central stars. A comparison of the line intensities from Page's plates with those obtained in the present series will be of considerable interest, however.

The structural features of a number of planetary nebulae—in particular NGC 1535, 2022, 2392, 2440, 3242, 6309, 6445, 6720, 6751, 6778, 6905, 7026—have been studied on the Crossley slitless spectrograms, and some results have already been published elsewhere.[9] Since these reductions were completed, however, it has become evident that an adequate treatment of the spatial structures of planetary nebulae requires plates taken with a much larger scale, e.g., the slitless spectrograms secured by Olin Wilson at the coudé focus of the 100-inch reflector.[10] Accordingly, reference is made only to the Crossley results for a few of the fainter objects, which cannot be observed at the coudé focus.

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[6] *Ap. J.*, **95**, 356, 1942.

[7] *Pub. Lick Obs.*, **13**, 193, 1918.

[8] *Ap. J.*, **95**, 243, 1942.

[9] Cf. the author's *Astrophysics* (Philadelphia: Blakiston Co., in press), chap. xiv.

[10] Cf., for example, the discussion of NGC 6572 and NGC 7662 by Olin Wilson and L. H. Aller, *Pub. A.A.S.*, **55**, 70, 1950.

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Limitations imposed by uncertainties in the physical theory.—Recent discussions by Bates, Massey, Fundaminsky, and Leech[11] have shown that the predicted cross-sections for the collisional excitation of the forbidden lines are grossly in error. At the present time it is possible to calculate only a lower limit to the abundances of the ions responsible for the forbidden lines—with no assurance that the real values lie close to this lower limit. For the same reason, electron temperatures derived from a comparison of the 4363 and green nebular lines are open to question, and a precise specification of this parameter is not possible. It is possible, however, that the relative cross-sections are less affected than the absolute values, and for the present we may retain the electron temperatures heretofore assigned. The general character of the excitation in the nebulae, as well as the energy distribution in the continuous spectrum as observed by Page, strongly indicates that T_ϵ must lie in the neighborhood of 10,000° K for most nebulae.

In view of these uncertainties, estimates of ionic densities and the level of excitation and ionization from a study of the emission of [*O* II], [*O* III], [*Ne* V], [*Ne* III], etc., would be insecure. Accordingly, no such discussion is attempted here.

III. OBSERVATIONS AND REDUCTIONS

Photometric procedures.—The observational technique is similar to that employed in the 1938–1939 series.[5] All the plates were secured with the quartz slitless spectrograph at the Crossley reflector of the Lick Observatory. Laboratory standardizations were secured with a spot sensitometer and were supplemented with exposures of the comparison star taken with diaphragms. In the earlier series, π^1 Cygni was employed as the comparison star; in the present investigation the stars observed by Barbier and Chalonge have been utilized.[12] Their list contains objects well distributed over the sky, carefully observed with painstaking spectrophotometric techniques.

Tracings of the plates were made with the Moll microphotometer at the Lick Observatory and with the Beals-type microphotometer at the Yerkes Observatory. Each plate was traced parallel to the dispersion. One trace usually sufficed for the smaller objects; extended objects frequently required several traces through different parts of the nebula. Tracings perpendicular to the dispersion and, in some instances, along the lines of symmetry of the nebula have also been run, in order to study the structural features of certain images in the larger objects.

The construction of deflection log *I*-curves involved both the sensitometer spots and the widened spectra of the comparison stars. Observations of the comparison star consisted of a series of equal exposures, between each of which the effective aperture of the telescope was varied in a known fashion by means of a diaphragm with circular holes. In the region of low densities the *D* log *I*-curves usually coincided; the variations with wave length appeared in the slopes of the straight-line portions. The plates secured on a single night's observations were developed together, and a single set of *D* log *I*-curves used was derived. Since development conditions were standardized and plates of a single emulsion number were used, the reduction-curves were very similar from one set of observations to the next.

Vignetting.—In the slitless spectrograph, vignetting is dependent upon wave length. Hence it is necessary that the nebula and comparison star be photographed in the same part of the field. Since the adjustment is made visually and the spectrum of the star appears continuous, slight errors are sometimes made. The position of the bright-line nebula can be adjusted accurately. The plateholder can be slid perpendicular to the direction of dispersion, so that several spectra of the comparison star or of the comparison star and

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[11] *Trans. R. Soc. London, A* (in press). For a discussion of possible effects of the revision of the cross-sections on ionic densities, etc., derived from nebular line intensities see L. H. Aller, *Ap. J.*, **111**, 609, 1950.

[12] *Ann. d'ap.*, **4**, 30, 1941.

the nebula can be photographed upon the same plate. Thus the error in the centering of the comparison star can be found. The effect of vignetting was measured as a function of difference in centering upon a series of the plates taken especially for the purpose. In all instances the error in the observations from that cause would appear to be small, amounting to about $\Delta \log I = 0.01$ in the limit. After August, 1944, the corrections have been determined and applied to each night's observations of the comparison stars whenever necessary.

Effect of background continuum.—As previously mentioned, in extended objects the intensity is measured at some particular point or points—usually the brightest portions. In stellar objects the total area under the reduced intensity-curve of the monochromatic image has been measured. Usually, the intensities so derived are in good agreement with those found simply from the heights of the profile on the tracings. In each instance the contribution of the background continuum of the star or nebula must be estimated and subtracted from the measured intensity. This correction is especially serious for the weaker lines and for the Balmer continuum. With respect to the latter, Page's procedure of extrapolating the observed continuum longward of the Balmer limit to shorter wave lengths has been followed. As in the 1938–1939 observations, the tabulated intensity of the 20 A interval of the Balmer continuum is corrected for this underlying continuum. In general, the slitless plates are unsatisfactory for the determination of the energy distribution in the continuum. Slit spectra are required for this purpose.

Type of plates.—Until September, 1944, Eastman 103*a*-O plates were employed. Thereafter, Eastman II*a*-O plates were used. The gain in quality more than offsets the loss in speed. For photometric purposes the plates are less satisfactory than the standard Eastman 33's or Eastman 40's, in that they often show larger random errors.

Sources of error.—Among the sources of error we may mention, first of all, the limitations imposed by the nonuniformity of the photographic emulsion. Second, the calibration-curves are likely to be in error, particularly in the far ultraviolet. Laboratory and comparison-star data may be utilized in the region from about λ 3600 to λ 5000, but farther in the ultraviolet no satisfactory standards are available, and a mean curve has been employed throughout the ultraviolet. The exposure times on the comparison stars and laboratory standards are shorter than those on the nebulae, so that the deflection log I-curves are appropriate to a shorter time interval than the nebular exposures. To correct for the atmospheric extinction, use has been made of Popper's determination of the absorption as a function of wave length. These mean absorption coefficients are reliable for the summer and fall months, but at other times the fluctuations, particularly in the ultraviolet, may become serious. A troublesome feature of photometry on long-exposure slitless spectrograms is the effect of sky fog. At a given point in the spectrum of a nebula, sky light of many different colors is incident. One has to subtract this sky fog from the monochromatic nebular image, and a precise reduction is not possible. Finally, there are practical difficulties in estimating the position of the background continuum and in correcting for the effects of overlapping images.

Precision of the measures.—Perhaps some idea of the precision of the observations may be gained from the internal agreement of the intensities in a given nebula, measured upon different plates and nights. The computed probable error of the intensity of a line depends upon its position in the spectrum and upon its strength. In the region $\lambda\lambda$ 3700–5000 the probable error of a single measurement of a line stronger than 1.0 (on the scale $H\beta = 10$) is about 10 per cent. Weaker lines show somewhat larger probable errors, partly because of greater accidental errors and partly because of the difficulty in locating the position of the continuum. Ultraviolet lines, such as λ 3341 or λ 3428, also show larger probable errors, of the order of 14–17 per cent. These are the accidental errors; systematic effects are not included.

A detailed comparison with Wyse's intensities for the four nebulae common to our lists shows reasonably good agreement. The fainter lines are systematically measured slightly weaker in the present set of observations. The differences, however, are much smaller than in the earlier series, in which total intensities were measured and the fainter lines (referred to results obtained with the slit spectrograms) seemed systematically too weak. Perhaps sky fog is responsible for some of these troubles.

IV. THE OBSERVED LINE INTENSITIES

Table 1 gives the designation of the nebula, the α and δ for 1945, the plate number, the exposure time, and, finally, the secant of the zenith distance at midexposure. Tables 2, 3, and 4 give the relative intensities of the principal nebular lines on the scale $H\beta = 10$. Table 2 gives the data for low-excitation objects; Table 3 the results for certain high-excitation nebulae (i.e., objects that show the ultraviolet lines of [*Ne* v] and the Bowen fluorescent mechanism); while Table 4 gives the results for a number of nebulae of low surface brightness or extended surface. For these objects, only the intensity of the strongest lines could be measured. Frequently, the overlapping of images prevented any reliable estimate of the intensities for N1 and N2.

The intensity of the Balmer continuum is expressed in terms of 20 A intervals at the Balmer limit, also on the scale $H\beta = 10$. The tabulated value is corrected for the underlying continuum.

The high-excitation nebulae NGC 2022 and 2392 have recently been the subjects of a detailed spectrophotometric study by Minkowski and the writer. We shall discuss the Lick observations in conjunction with the Mount Wilson data at a later date.

Binuclear nebulae.—NGC 6778 resembles NGC 2440 or 7026, except that its surface brightness is much lower. The *He* II image is small and concentrated perhaps in the nucleus, and the other lines show a binuclear formation. There is no evidence of the spectrum of a central star.

Table 5 gives the intensity distribution along the line joining the two lobes for the [*O* III] λλ 4959–5007, $H(H\beta, H\gamma, H\delta)$, and λ 3727 images of NGC 6778, and the corresponding data (plus that for the [*Ne* III] image in NGC 7026). I have averaged the intensities for the two lobes, since the nebulae possess (very nearly) bilateral symmetry. In NGC 7026, $I(H\beta)$ is taken as 10 at the brightest portion of the condensation—3″ from the center, whereas $I(H\beta)$ is chosen as 10 at 5″ from the center of NGC 6778. I have also calculated the distribution of the emission per unit volume on the assumption that the emitting lobes are roughly spherically symmetrical. It now appears that such a hypothesis is inadequate in even the first approximation. In NGC 7026 the λ 4686 emission is strongly concentrated toward the center, as Wright pointed out many years ago, but I have been unable to find marked differences between the other images. On the other hand, the table shows that the maximum of the image of λ 3727 falls some 2″ or 3″ farther from the center than that of the [*O* III] image. Similar studies have also been carried out for NGC 2440.

Ring nebula.—The high-excitation lines of the Bowen fluorescent mechanism and λ 3203 of *He* II appear in NGC 6905 and 6720, for example, although they are not much above the level of sky fog on the plates. Slitless spectra are not well suited for NGC 6720; I have, however, measured the intensities of the ultraviolet lines with respect to $H\beta$, with the following results:

λ.........	3133	3203	3341	3445
I.........	1.8	1.4	0.7	1.0

If the assumption is made that, to a first approximation, the emitting material in the shell in NGC 6720 is distributed in a spherically symmetrical fashion, one may deduce the emission per unit volume, $E(\rho)$, from the intensity distribution across the monochro-

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TABLE 1

OBSERVATIONS OF PLANETARY NEBULAE

Nebula	α	δ	Plate	Date	Exposure (Minutes)	Secant Zenith Distance
Anon.	$0^h25^m.3$	+55°36′	416	Oct. 14, 1944	120	1.07
			423	Oct. 15, 1944	30	1.06
IC 351.	3 44	+34 53	417	Oct. 14, 1944	90	1.10
			424	Oct. 15, 1944	20	1.22
II 2003.	3 52.8	+33 43	418	Oct. 14, 1944	93	1.01
			425	Oct. 15, 1944	75	1.10
			426	Oct. 15, 1944	14	1.03
NGC 1535. . . .	4 11.7	−12 53	454	Nov. 18, 1944	120	1.58
J 320.	5 2.5	+10 39	472	Mar. 9, 1945	60	1.41
			473	Mar. 9, 1945	21	1.65
NGC 2022. . . .	5 36.6	+ 9 2	450	Oct. 17, 1944	232	1.21
II 2149.	5 43.5	+46 7	448	Oct. 17, 1944	5, 11	1.41
			449	Oct. 17, 1944	22	1.31
			474	Mar. 9, 1945	5, 12	1.45
			475	Mar. 9, 1945	30	1.58
NGC 2165. . . .	6 19.2	−12 57	427	Oct. 15, 1944	5	2.58
			428	Oct. 15, 1944	20	2.35
			429	Oct. 15, 1944	85	1.89
			464	Nov. 19, 1944	150	1.54
J 900.	6 22.8	+17 50	462	Nov. 19, 1944	100	1.30
			463	Nov. 19, 1944	20	1.32
			468	Jan. 12, 1945	172	1.08
			469	Jan. 12, 1945	20	1.24
NGC 2392. . . .	7 26.0	+21 2	324	Mar. 19, 1944	120	1.34
			325	Mar. 19, 1944	20	2.44
			430	Oct. 15, 1944	87	1.10
			465	Nov. 19, 1944	90	. . . .
			470	Jan. 13, 1945	150	1.36
			471	Jan. 13, 1945	20	1.93
NGC 2440. . . .	7 39.5	−18 5	419	Oct. 14, 1944	20	2.46
			420	Oct. 14, 1944	77	2.06
			439	Oct. 16, 1944	5	2.92
			440	Oct. 16, 1944	10	2.79
			441	Oct. 16, 1944	19	2.58
			442	Oct. 16, 1944	90	2.02
			455	Nov. 18, 1944	180	1.82
NGC 3242. . . .	10 22.1	−18 21	313	Mar. 18, 1944	70	1.84
			314	Mar. 18, 1944	60	2.40
			326	Mar. 19, 1944	60	2.10
			327	Mar. 19, 1944	15	2.31
			333	May 20, 1944	10	2.33
			334	May 20, 1944	60	2.54
			456	Nov. 18, 1944	55	1.90
			482	Mar. 11, 1945	30	1.83
NGC 4361. . . .	12 21.7	−18 28	477	Mar. 9, 1945	195	1.93
			483	Mar. 10, 1945	170	1.79
II 3568.	12 31	+82 53	488	May 8, 1945	50	1.62
			489	May 8, 1945	10	1.66
II 4593.	16 9.2	+12 13	336	May 20, 1944	17	1.13
			337	May 20, 1944	45	1.11
			345	May 21, 1944	10	1.29
			346	May 21, 1944	18	1.25
			347	May 21, 1944	43	1.18
			478	Mar. 9, 1945	15	1.10
			479	Mar. 9, 1945	20	1.11
II 4634.	16 58.3	−21 43	340	May 20, 1944	18	2.10
			349	May 21, 1944	18	2.00
			350	May 21, 1944	60	1.97
			491	May 8, 1945	55	2.54

TABLE 1—*Continued*

Nebula	α	δ	Plate	Date	Exposure (Minutes)	Secant Zenith Distance
NGC 6309....	$17^{h}10^{m}.9$	−12°51′	351	May 21, 1944	87	1.57
			352	May 21, 1944	20	1.93
			358	June 22, 1944	120	1.62
			484	Mar. 11, 1945	17	1.91
			485	Mar. 11, 1945	105	1.64
NGC 6445....	17 46	−20 1	506	June 10, 1945	140	1.85
NGC 6567....	18 10.6	−19 5	353	June 18, 1944	47	1.80
			354	June 18, 1944	24	1.79
			492	May 8, 1945	50	2.37
Anon.........	18 15	+10 6	497	June 9, 1945	65	1.46
			515	June 15, 1945	60	1.34
II 4732.......	18 30	−22 42	399	July 22, 1944	120	2.00
			516	June 15, 1945	60	2.13
			517	June 15, 1945	15	2.28
Anon.........	18 47.3	+20 45	498	June 9, 1945	110	1.12
			502	June 10, 1945	20	2.00
			503	June 10, 1945	63	1.62
NGC 6720....	18 52	+32 57	288	Sept. 18, 1943	....	1.13
			289	Sept. 18, 1943	....	1.25
			509	June 14, 1945	....	1.20
NGC 6741....	19 0	− 0 31	291	Sept. 18, 1943	120	1.36
			292	Sept. 18, 1943	30	1.65
			304	Sept. 21, 1943	105	1.44
			431	Oct. 16, 1944	90	1.61
			432	Oct. 16, 1944	20	2.05
NGC 6751....	19 2.9	− 6 3.1	486	May 7, 1945	115	1.47
			518	June 16, 1945	160	1.39
II 4846.......	19 13	− 9 10	355	June 18, 1944	62	1.66
			355	June 18, 1944	20	1.66
			499	June 9, 1945	60	1.66
NGC 6778....	19 15.5	− 1 42	495	June 8, 1945	110	1.29
			526	July 1, 1945	130	1.38
NGC 6790....	19 20	+ 1 23	381	July 16, 1944	90	1.85
			511	June 14, 1945	60	1.29
			512	June 14, 1945	10	1.35
NGC 6803....	19 29	+ 9 57	385	July 17, 1944	30	1.13
			500	June 9, 1945	60	1.14
			501	June 9, 1945	6	1.17
NGC 6807....	19 32	+ 5 21	400	July 22, 1944	40	1.25
			507	June 10, 1945	15	1.20
Anon.........	19 36.5	+15 48	533	July 2, 1945	90	1.64
			534	July 2, 1945	8	1.30
NGC 6818....	19 40.0	−14 18	297	Sept. 20, 1943	115	1.68
			298	Sept. 20, 1943	30	2.08
			375	July 15, 1944	59	1.81
			379	July 16, 1944	180	1.62
			523	June 16, 1945	60	2.22
NGC 6833....	19 48	+48 49	389	July 18, 1944	83	1.10
			410	Aug. 20, 1944	113	1.03
NGC 6884....	20 9	+46 19	361	June 24, 1944	40	1.61
			362	June 24, 1944	20	1.46
			363	June 24, 1944	119	1.21
NGC 6886....	20 11	+19 50	293	Sept. 19, 1943	60	1.30
			294	Sept. 19, 1943	20	1.39
			299	Sept. 20, 1943	105	1.47
			386	July 17, 1944	170	1.08
			387	July 17, 1944	60	1.33
			443	Oct. 17, 1944	147	1.11
NGC 6891....	20 12	+12 33	401	Aug. 22, 1944	80	1.38
			402	Aug. 22, 1944	25	1.62
			433	Oct. 16, 1944	30	1.47
			434	Oct. 16, 1944	70	1.58

TABLE 1—*Continued*

Nebula	α	δ	Plate	Date	Exposure (Minutes)	Secant Zenith Distance
NGC 6905....	20^{h}20^m	+19°56′	493	May 8, 1945	138	1.31
			524	June 16, 1945	115	1.07
NGC 7026....	21 5	+47 46	295	Sept. 19, 1943	65	1.37
			365	June 24, 1944	115	1.04
			366	June 24, 1944	25	1.02
			406	Aug. 19, 1944	190	1.03
			422	Oct. 15, 1944	120	1.04
IC 5117......	21 30	+44 20	390	Aug. 19, 1944	90	1.06
			391	Aug. 19, 1944	30	1.02
			412	Aug. 20, 1944	90	1.37
			413	Aug. 20, 1944	15	1.62
			460	Nov. 19, 1944	120	1.26
Anon.........	21 31	+39 22	368	June 26, 1944	195	1.32
			392	July 18, 1944	70	1.02
			397	July 22, 1944	20	1.10
			411	Aug. 20, 1944	188	1.01
			435	Oct. 16, 1944	60	1.26
II 5217.......	22 22	+50 42	296	Sept. 17, 1943	45	1.74
			370	June 25, 1944	70	1.07
			371	June 25, 1944	10	1.04
			407	Aug. 19, 1944	120	1.07
			408	Aug. 19, 1944	40	1.25
			452	Nov. 18, 1944	120	1.12
Anon.........	22 29.2	+47 28	528	July 1, 1945	110	1.10
			535	July 2, 1945	90	1.35
			536	July 2, 1945	20	1.21
NGC 7354....	22 38.2	+61 0	510	June 14, 1945	120	1.47
Anon.........	23 24.1	+57 54	538	July 2, 1945	75	1.16
			539	July 2, 1945	20	1.11

TABLE 2

LOWER-EXCITATION NEBULAE

λ	Ion	Anon 0^{h}25^m	J 320	II 2149	II 3568	II 4593	II 4634	Anon 19^{h}36^m
Bac 20 A....	....	....	....	....	0.88	0.73	0.70	....
3703.9......	*H* I	....	....	....	....	....	....	....
3712.0......	*H* I	....	....	....	....	....	....	....
3727........	[*O* II]	26	2.1	11	0.95	5.9	3.1	3.7
3750.2......	*H* I	....	....	0.73	....	....	....	....
3770.6......	*H* I	....	....	0.9	....	....	....	0.36
3797.9......	*H* I	0.33	0.52	0.92	....	....	....	0.53
3835.4......	*H* I	1.20	0.75	1.2	0.62	....	....	0.51
3868.7......	[*Ne* III]	11	11	2.4	6.6	3.4	6.0	8.9
3889.1......	*H* I	3.1	2.6	1.5	2.2	1.9	2.0	1.10
3967.4......	[*Ne* III]	5.5	5.5	2.3	3.0	2.3	4.0	3.3
4026.2......	*He* I	....	....	....	0.56	....	....	0.46
4069+76....	[*S* II]	0.78	....	....	0.39	....	....	1.1
4101.8......	*H*δ	3.3	3.0	3.0	2.5	2.6	2.3	2.0
4340.5......	*H*γ	4.7	5.0	5.2	4.2	5.0	3.9	3.4
4363.2......	[*O* III]	1.6	1.8	0.60	0.88	....	0.52	1.0
4471.5......	*He* I	2.1	0.8	0.76	0.43	0.64	0.46	0.65
4634+40....	*N* III	....	....	....	....	....	....	0.26
4685.8......	*He* II	2.6	....	....	....	....	....	0.52
4711.4......	[*A* IV]	....	....	....	....	....	....	0.58
4740.3......	[*A* IV]	....	....	....	....	....	....	0.77
4861.3......	*H* I	10.0	10.0	10.0	10.0	10.0	10.0	10
4959.5......	[*O* III]	35	34	14	50	18	28	52
5007.6......	[*O* III]	88	89	41	140	57	78	19.7
C..........	....	....	0.27	0	0.27	0.28	0.0	0.36

TABLE 2—*Continued*

λ	Ion	NGC 6567	Anon 18$^{\mathrm{h}}$15$^{\mathrm{m}}$	II 4732	Anon 18$^{\mathrm{h}}$47$^{\mathrm{m}}$	II 4846	NGC 6790	NGC 6803	NGC 6807
Bac 20 A ...	....	......	0.92	....	1.30	0.58	0.60	2.4	....
3703.9......	*H* I	......	0.22	....	0.19	....	....	....	....
3712.0......	*H* I	......	0.26	....	0.25	....	0.21	....	....
3727........	[*O* II]	2.3	16	1.6	7.8	4.0	1.3	4.0	2.9
3750.2......	*H* I	......	0.47	....	0.37	0.49	0.15	0.33	0.38
3770.6......	*H* I	......	0.47	....	0.41	0.41	0.24	0.47	0.42
3797.9......	*H* I	......	0.50	....	0.54	0.75	0.31	0.91	0.56
3835.4......	*H* I	0.98	0.81	0.91	0.77	0.88	0.40	1.4	0.72
3868.7......	[*Ne* III]	5.6	....	10	1.07	8.7	8.6	9.6	8.4
3889.1......	*H* I	2.1	1.1	1.6	1.4	2.1	1.0	2.1	1.4
3967.4......	[*Ne* III]	2.7	1.6	3.4	2.0	4.2	3.2	4.8	3.8
4026.2......	*He* I	0.53	0.20	....	0.22	0.43	0.16	0.30	0.4
4069+76....	[*S* II]	0.57	0.51	....	0.19	0.47	0.14	0.56	0.42
4101.8......	*Hδ*	2.50	2.6	2.3	2.5	2.7	1.8	2.3	2.7
4340.5......	*Hγ*	4.40	5.1	4.3	4.6	4.9	4.1	4.6	4.9
4363.2......	[*O* III]	0.57	....	2.4	0.22	1.4	1.4	0.98	1.1
4471.5......	*He* I	0.60	0.27	0.91	0.48	0.94	0.56	0.96	0.65
4634+40....	*N* III	......	....	....	0.11	....	0.21	0.32	....
4685.8......	*He* II	......	....	....	....	....	....	0.78	....
4711.4......	[*A* IV]	......	....	....	0.12	....	0.21	0.62	....
4740.3......	[*A* IV]	......	....	....	....	....	0.29	0.71	....
4861.3......	*H* I	10.0	10.0	10	10	10	10	10	10
4959.5......	[*O* III]	32	0.48	47	13	36	56	38	40
5007.6......	[*O* III]	79	1.61	....	38	97	147	107	....
C..........	....	0.06	0.14	0.14	0.17	0.04	0.68	0.23	0.17

TABLE 2—*Continued*

λ	Ion	NGC 6833	NGC 6884	NGC 6891	NGC 7026 Center	NGC 7026 Lobes	II 5117	Anon 22$^{\mathrm{h}}$29$^{\mathrm{m}}$	Anon 23$^{\mathrm{h}}$24$^{\mathrm{m}}$
Bac 20 A ...	....	0.54	....	1.34	0.51	....	....	1.63	....
3712.0......	*H* I	......	....	....	....	....	0.17	0.39	....
3727........	[*O* II]	1.1	1.1	1.9	3.1	4.7	2.0	4.0	1.0
3734........	....	......	....	....	....	....	....	0.55	0.48
3750.2......	*H* I	0.17	0.11	....	....	....	0.22	0.54	0.40
3770.6......	*H* I	0.26	0.12	....	....	....	0.35	0.62	0.41
3797.9......	*H* I	0.41	0.20	0.22	....	....	0.38	0.90	0.49
3835.4......	*H* I	0.54	0.42	0.52	....	....	0.51	1.0	0.60
3868.7......	[*Ne* III]	6.4	6.0	7.3	6.6	7.4	9.3	7.5	4.5
3889.1......	*H* I	1.3	0.78	2.3	1.9	2.1	1.2	2.5	1.1
3967.4......	[*Ne* III]	2.9	2.6	3.5	3.1	3.6	4.1	4.1	2.8
4026.2......	*He* I	0.18	0.07	0.64	....	....	0.30	0.61	....
4069+76....	[*S* II]	0.22	0.06	....	0.58	0.41	0.60	0.23	....
4101.8......	*Hδ*	2.0	0.98	2.5	2.2	2.2	2.3	3.5	1.7
4340.5......	*Hγ*	3.4	2.23	5.10	3.7	4.4	4.2	5.2	3.6
4363.2......	[*O* III]	1.1	0.52	....	0.18	....	1.9	0.83	2.2
4471.5......	*He* I	0.38	0.40	0.66	0.44	0.56	0.63	1.22	0.74
4634+40....	*N* III	......	0.26	0.25	0.60	0.46	0.54	0.36	....
4685.8......	*He* II	......	1.24	0.20	2.8	1.3	1.38	....	....
4711.4......	[*A* IV]	......	0.42	....	0.27	0.38	0.50	0.30	....
4740.3......	[*A* IV]	......	0.49	....	....	....	0.75	....	....
4861.3......	*H* I	10	10	10	10.0	10	10	10	10
4959.5......	[*O* III]	22	60	3.0	42	40	61	20	13
5007.6......	[*O* III]	54	170	8.3	96	84	160	....	31
C..........	....	0.46	0.84	0.66	0.37	....	0.46	0.0	0.33

matic image, $I(x)$. At a given point x_0 from the center of the projected nebular image, the intensity $I(x_0)$ in the cross-section is given by the integral equation

$$I(x_0) = 2\int_{x_0}^{\infty} \frac{E(\rho)\,\rho\,d\rho}{\sqrt{\rho^2 - x_0^2}}.$$

Solutions of this equation have been given by Von Zeipel, Plummer, and others.[13] Convenient tables for the numerical solution are given by Wallenquist.[14] Chandrasekhar and Münch[15] have shown that the accuracy attainable in the solution for $E(\rho)$ cannot be high. Probably only the general character of the emission function can be derived.

Measurements of the intensity distribution along the major axis of the images of λλ 4686, 3869, 3727, and 4340 are published elsewhere.[9] Whereas the cross-sections of the *H* and *He* II images may be interpreted in terms of a spherically symmetrical emis-

TABLE 3

HIGH-EXCITATION NEBULAE

λ	Ion	IC 351	IC 2003		NGC 1535 Bright Ring	NGC 2165	J 900
			(*a*)	(*b*)			
3133	*O* III	10	8.5	....	....	8.8	3.1
3178	*He* I	....	....	....	....	0.81	....
3203	*He* II	3.4	2.7	....	2.3	1.9	1.4
3299	*O* III	....	....	....	....	0.74	....
3312	*O* III	1.7	0.84	....	....	0.97	0.57
3346	*Ne* V+*O* III	2.1	1.35	1.56	0.8	2.2	1.05
3425	*Ne* V+*O* III	....	0.70	0.71	....	6.0	1.8
3444	*O* III	3.0	2.8	3.0	0.95	2.2	1.7
3650(20 A)	*H*	....	....	....	(1.9)	0.7	0.25
3727	[*O* II]	0.87	4.2	5.0	0.80	3.13	5.2
3750.2	*H*	....	0.5	....	....	0.56	0.55
3770.6	*H*	....	....	....	....	0.40	0.42
3797.9	*H*	0.62	0.48	....	....	0.48	0.50
3819	*He* I	....	....	....	....	....	....
3835.4	*H*	0.61	0.81	....	....	0.53	0.74
3868.7	[*Ne* III]	9.0	9.0	7.5	7.4	8.7	7.4
3889.1	*H*	1.7	2.0	2.0	2.1	1.8	1.6
3967.4	[*Ne* III]+*H*	3.8	5.0	4.2	3.0	4.3	3.4
4026.2	*He*	....	0.28	....	....	0.18	0.33
4069+76	[*S* II]	....	0.25	....	....	0.20	0.30
4101.8	*H*	2.3	3.0	3.0	2.1	2.65	2.1
4200	*He* II	....	....	....	....	0.12	....
4340.5	*H*	5.8	5.0	6.2	4.9	4.6	4.2
4363.2	[*O* III]	1.6	1.2	....	1.9	2.1	1.3
4471.5	*He* I	2.8	0.37	....	0.60	0.34	0.40
4542	*He* II	0.32	0.43	....	....	0.18	0.27
4634–40	*N* III	0.37	0.34	....	....	0.47	0.32
4685.8	*He* II	6.0	5.6	7.5	2.4	6.0	4.7
4711.4	[*A* IV]	0.85	0.49	....	....	0.72	....
4740.3	[*A* IV]	0.77	0.44	....	....	0.65	0.40
4861.3	*H*	10.0	10	10.0	10	10	10
4959.5	[*O* III]	44	40	30	....	53	39
5007.6	[*O* III]	176	136	98	....	128	126
C	....	0.12	0.0		....	0.0	0.17

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[13] See, e.g., Smart, *Stellar Dynamics* (Cambridge: At the University Press, 1938), pp. 297–304.

[14] *Upsala Medd.*, No. 65, p. 42, 1936.

[15] *Ap. J.*, **111**, 144, 1950, esp. secs. 2 and 3.

TABLE 3—*Continued*

λ	Ion	NGC 2440	NGC 3242 Bright Ring	NGC 6309	NGC 6741	NGC 6886	Anon 21^h31^m	II 5217
3133........	*O* III	4.4	7.0	....	....	....	3.5	
3178........	*He* I	....	....	....	....	....	....	....
3203........	*He* II	2.0	2.0	....	1.3	....	3.0	....
3299........	*O* III	....	....	....	....	....	....	....
3312........	*O* III	0.73	1.1	....	....	0.07	....	....
3346........	*Ne* v+*O* III	6.7	1.6	....	1.9	2.0	5.6	....
3425........	*Ne* v+*O* III	16	0.55	4.7	4.1	4.4	18.0	....
3444........	*O* III	1.6	3.3	....	1.7	0.9	1.0	0.6
3650(20 A)...	*H*	0.20	0.80	....	....	....	0.48	0.75
3727........	[*O* II]	8.3	1.7	4.7	8.2	9.3	4.5	2.0
3750.2......	*H*	....	....	....	....	0.19	0.25	0.29
3770.6......	*H*	....	....	....	....	0.17	0.37	0.32
3797.9......	*H*	....	....	....	....	0.20	0.47	0.52
3819......	*He* I	....	....	....	....	....	....	....
3835.4......	*H*	....	....	....	0.74	0.60	0.69	0.60
3868.7......	[*Ne* III]	8.3	11.7	9.5	8.6	9.7	6.2	9.8
3889.1......	*H*	....	....	....	1.2	1.1	1.7	2.0
3967.4......	[*Ne* III]+*H*	3.7	5.0	4.5	3.2	3.3	3.4	4.2
4026.2......	*He*	....	....	....	0.62	0.12	0.26	0.20
4069+76....	[*S* II]	....	....	....	0.60	0.44	0.28	0.16
4101.8......	*H*	2.6	3.2	2.6	3.0	1.7	2.25	2.8
4200........	*He* II	....	....	....	0.36	....	....	....
4340.5......	*H*	5.2	6.3	4.2	3.7	4.0	4.6	5.5
4363.2......	[*O* III]	2.9	....	....	1.3	1.5	2.0	1.3
4471.5......	*He* I	0.27	0.52	....	0.50	0.22	0.53	0.62
4542........	*He* II	0.30	....	....	....	....	0.82	....
4634–40.....	*N* III	1.0	0.66	....	0.62	0.42	0.20	0.34
4685.8......	*He* II	7.6	5.1	7.7	3.4	4.0	9.0	1.30
4711.4......	[*A* IV]	1.6	....	....	0.81	0.4	1.0	0.70
4740.3......	[*A* IV]		....	....	1.32	0.4	0.5	0.74
4861.3......	*H*	10	10	10	10.0	10.0	10	10
4959.5......	[*O* III]	75	59	40	58	65	29	55
5007.6......	[*O* III]	....	135	101	141	160	75	150
C..........	....	....	....	....	0.16	0.49	0.21	....

sion per unit volume, the [*Ne* III] and [*O* II] images clearly show that the emission departs far from spherical symmetry. In fact, negative values of $E(\rho)$ are required for the region just inside the edge of the ring, in order to represent the observed data. Therefore, departures from spherical symmetry are severe. In view of the filamentary character of this object this result is hardly surprising.

Comments on other nebulae are given in the notes to Table 4.

The structural features of a number of planetary nebulae are being studied in collaboration with Olin C. Wilson, who has obtained slitless spectra with the 100-inch coudé. The present measures may be of value in relating the intensity measures in one monochromatic image with those in another.

V. THE BALMER DECREMENT

Because of the uncertainties in the collisional cross-sections, we are unable to derive ionic abundances and electron temperatures from the nebular line intensities, nor does it seem worth while to calculate electron densities, since the nebular surface brightnesses and distances are so poorly known. Accordingly, our discussion is restricted here to a single problem—the Balmer decrement.

The most detailed observational discussion of the Balmer decrement is that by Ber-

TABLE 4

NEBULAE WITH EXTENDED SURFACES

λ	ION	NGC 4361*	NGC 6445†	NGC 6571‡	NGC 6778§	NGC 6818		NGC 6905‖	NGC 7354#
						West Side	East Side		
3133	*O* III	....	....	....	....	....	....	2.2	....
3203	*He* II	....	....	....	....	....	....	2.8	....
3346	[*Ne* V]	5.4	....	....	....	2.6	4.8	....	....
3428	[*Ne* V]	....	....	....	....	6.7	8.6	....	....
3444	*O* III	20	....	....	....	....	3.2	....	....
3650(20 A) ..	*H*	....	....	1.2	0.19	1.0	....	....	....
3727	[*O* II]	....	20	17	5.8	4.7	6.8	0.87	....
3868	[*Ne* III]	5	12	7.5	4.6	11	14	5.2	5.5
3889	*H*	....	....	....	2.2	....	2.0	....	....
3967.4	[*Ne* III]	3.7	....	3.8	2.2	4.5	4.5	2.2	2.6
4101.8	*H*δ	4.2	....	3.2	2.8	3.0	2.6	1.6	2.8
4340.5	*H*γ	9.7	4.1	5.4	4.3	5.9	6.6	2.4	3.6
4363.2	[*O* III]	....	....	....	1.3	....	2.1	....	....
4471.5	*He* I	....	....	....	1.1	....	....	....	....
4634–40	*N* III	....	....	....	0.8	....	....	....	....
4686	*He* II	25	5.6	3.2	1.62	8.2	9.3	3.9	6.2
4740	[*A* IV]	....	....	....	....	....	1.3	....	....
4861	*H*β	60	10	10	10	10	10	10	10
4959	[*O* III]		110	160	24	....	170	78	140
5007	[*O* III]		....	....	65	....	....	....	....

* High excitation. Overlapping of irregular monochromatic images prevents accurate measurements.

† The monochromatic images resemble one another closely. The appearance of NGC 6445 recalls a coral atoll and inclosed lagoon.

‡ Tabulated values are means of two sides of nebulae.

§ Both lobes have the same excitation. Mean values are tabulated.

‖ Mean of measures in three parts of nebula.

The monocromatic images resemble one another closely.

TABLE 5

STRUCTURE OF NGC 7026

Distance	*O* III	*O* II	*Ne* III	Hydrogen	Distance	*O* III	*O* II	*Ne* III	Hydrogen
x..........	....	....	....	....	4.........	81	3.62	4.66	6.51
0.........	71	2.32	3.31	4.25	5.........	53.5	2.29	2.33	3.86
1″........	70	2.6	4.41	5.85	6.........	23.8	1.33	0.98	2.3
2.........	77	3.51	6.62	8.60	7.........	9.15	0.64	0.417	1.0
3.........	82	4.72	7.35	10.0	8.........	4.88	0.29	0.07	0.13

STRUCTURE OF NGC 6778

Distance	*O* II	*O* III	Hydrogen	Distance	*O* II	*O* III	Hydrogen
0..........	3.7	57.5	8.2	8........	3.86	29.4	4.7
1″.........	3.8	58.5	8.5	9........	3.11	20	3.1
2..........	3.9	62.7	9.2	10..... .	2.2	12	1.8
3..........	4.0	64.5	9.8	11........	1.3	6.3	1.0
4..........	4.3	63	10.0	12........	0.81	3.0	0.36
5..........	4.8	60	10.0	13........	0.49	1.15	....
6..........	4.87	53	9.0	14........	0.26	....	....
7..........	4.48	42	7.1				

man,[16] who calibrated Wright's intensity estimates with the aid of photometric measurements of his own. He divided the nebulae into three classes, depending on the ratio of N2 to $H\beta$. In order to correct for space absorption, he assumed the interstellar material to be uniformly distributed in galactic longitude and to fall off uniformly with height above the galactic plane. The distance of each nebula had been derived from studies of galactic rotation.[17] With the aid of the distances, line intensities, and galactic latitudes, he made a least-squares solution for the coefficient of absorption per kiloparsec, the exponent n in the assumed law of selective absorption λ^{-n}, and the Balmer decrement for each group. We summarize his results for the Balmer decrement in Table 6. The difficulty with Berman's procedure is that the absorbing material is so unevenly distributed throughout the galaxy that the basic assumptions are not even approximately fulfilled.

TABLE 6

THE BALMER DECREMENT
(After Berman)

λ	I	II	III	λ	I	II	III
4861......	10.0	10.0	10.0	3969.....	1.25	1.37	1.79
4340......	4.45	4.80	5.00	3889.....	1.15	1.00	1.24
4101......	2.13	2.4	2.63	3835.....	0.77	0.52	0.89

In an attempt to overcome some of these difficulties, the nebulae have been divided into three classes: S, stellar low-excitation objects; L, low-excitation objects with extended surfaces; and H, high-excitation objects (those showing ultraviolet *He* II [*Ne* V], or *O* III lines). Smoothed Balmer decrements are derived for each of these objects. If the true decrements are the same for each group, the smoothed intensities should differ from one another only because of differential space absorption. In particular, the nebulae with the slowest decrements should be the least affected by space absorption. Accordingly, the Balmer decrements for each group have been reduced on the assumption that the one with the slowest decrement is essentially unaffected. In this way a set of tentative, observed Balmer decrements may be found.

With observations of this precision, it suffices to take the absorption proportional to $1/\lambda$. Hence one may write

$$\log \frac{I_n}{I_4} = \log \left(\frac{I_n}{I_4}\right)_0 - C\left[\frac{1}{\lambda_n} - \frac{1}{0.4861}\right],$$

where I_n/I_4 is the intensity of the nth line referred to $H\beta$ as 1.0; the subscript "0" refers to the value that this ratio would have if corrected for space absorption; and C is a constant to be determined for each nebula, whose value, computed by least squares, is listed in Tables 2 and 3 for several nebulae. The wave lengths, λ_n, are assumed expressed in microns. With the aid of these C's, it is possible to correct the intensities of the nebular lines for the effects of space absorption.

The mean Balmer decrements, calculated for groups S, L, and H, are compared with the theoretical calculations by Menzel and his colleagues.[18] Models A and B assume a nebula in which the central star radiates no energy in the Lyman lines. Model A is transparent in the lines, so that all the Lyman radiation produced in the nebula by cyclic processes escapes. In model B, all Lyman radiation is assumed degraded into Lyman-α,

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[16] *M.N.*, **96**, 890, 1936.

[17] L. Berman, *Lick Obs. Bull.*, **18**, 57, 1937.

[18] See J. G. Baker and D. N. Menzel, *Ap. J.*, **88**, 52, 1938; Baker, Menzel, and Aller, **88**, 423, 1938; **89**, 587, 1939.

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which alone escapes from the nebula. The Balmer decrement is rather insensitive to the electron temperature; I have chosen a value of 10,000° as representative of typical planetary nebulae. Model *C* refers to a thin nebula (similar to *A*), whose central star radiates like a black body in the Lyman lines. The stellar radiation steepens the theoretical decrement markedly; it would have little influence in a thick nebula.

The Balmer decrement is quite similar for the three groups of nebulae, and there is no clear-cut indication that the high-excitation objects have a systematically different decrement than do the low-excitation objects. The decrements I have found are less steep than those published by Berman but are in substantial agreement with the calculations for theoretical model *B*. This result comes as no surprise, since both models *A* and *C* correspond to thin shells, which should be much fainter than the objects studied in the present survey. It is, of course, possible that slight variations will be found in the Balmer decrements for objects of comparable density and excitation; but, until such differences have been established, it would appear that space absorption remains the chief cause of the variation in the observed decrements, an opinion expressed by Berman some years ago.

VI. THE SPECTRA OF THE CENTRAL STARS

The spectra of the central stars of the planetary nebulae are difficult to observe. Absorption lines originating in the nucleus are often smothered under strong nebular emission, and nuclear emission lines can be observed only when they do not coincide in position with nebular lines.[16]

Stars with continuous spectra.—Most of the central stars showed continuous spectra. Thus Anon $0^{h}25^{m}$, NGC 6807, II 4732, and probably also NGC 6309 and 6567 showed weak continua probably of stellar origin, with no trace of any stellar emission lines. The well-exposed spectrum of the central star of Anon $18^{h}15^{m}$ showed no trace of any emission lines. A number of central stars, those of IC 351, Anon $18^{h}47^{m}$, NGC 6790, NGC 6803, Anon $19^{h}36^{m}.5$, NGC 6884, and NGC 5217 show λ 4686 *He* II, λλ 4712–4740 [*A* IV], and the λ 4640 group. Probably the λ 4640 lines, as well as the others, originate in the inner portion of the nebula rather than in the star. The central stars of Anon $22^{h}29^{m}$ and $23^{h}24^{m}$ seem to show the λ 4640 group, but not λ 4686. These lines may

TABLE 7

THE BALMER DECREMENT: COMPARISON BETWEEN THEORY AND OBSERVATION

λ	*n*	OBSERVED			THEORETICAL		
		Low Excitation		High Excitation *H*			
		Stellar *S*	Nonstellar *L*		*A*	*B*	*C*
4861......	4	....	....	....	....	....	....
4340......	5	5.25	5.66	5.65	5.76	5.1	3.5
4101......	6	2.97	3.31	3.13	3.74	3.1	1.6
3969......	7	1.93	2.20	1.99	2.55	2.06	0.89
3889......	8	1.44	1.50	1.32	1.82	1.43	0.55
3835......	9	1.00	1.03	0.93	1.36	1.05	0.36
3797......	10	0.74	0.85	0.66	1.05	0.79	0.25
3770......	11	0.57	0.56	0.49	0.81	0.59	....
3750......	12	0.45	0.46	0.36	0.65	0.46	....
3734......	13	0.42	....	....	0.52	0.37	....
3722......	14	0.38	....	....	0.42	0.30	....
3712......	15	0.30	....	....	0.35	0.25	....
3707......	....	0.26	....	....	....	....	....

originate in the star itself. On the other hand, J 320 shows λ 4686 but no λ 4640; presumably the emission here is of nebular origin.

The intensity distribution in the continuous spectra of some of the brighter stars has been measured. Table 8 gives the results for NGC 1535, NGC 6891, and II 4593. No correction has been made for space absorption. Preferably, such studies should be made with carefully guided wide-slit spectrograms (to eliminate sky fog) and with somewhat higher dispersion than I have employed.

TABLE 8

INTENSITY DISTRIBUTION IN THE CONTINUOUS SPECTRA OF CENTRAL STARS OF NGC 1535, NGC 6891, AND II 4593

λ	IC 4593	LOG (I_λ/I_{4800})		λ	IC 4593	LOG (I_λ/I_{4800})	
		NGC 6891	NGC 1535			NGC 6891	NGC 1535
3300......	0.67	....	0.68	4100.....	0.21	0.26	0.15
3400......	.59	0.74	.59	4200.....	.19	.21	.11
3500......	.53	.67	.51	4300.....	.16	.16	.09
3600......	.47	.58	.43	4400.....	.13	.12	.07
3700......	.41	.49	.36	4500.....	.11	.09	.06
3800......	.35	.42	.30	4600.....	.08	.06	.04
3900......	.30	.36	.24	4700.....	.05	.03	.02
4000......	0.25	0.31	0.19	4800.....	0.00	0.00	0.00

TABLE 9

THE SPECTRA OF THE NUCLEI OF NGC 6751 AND NGC 6905

NGC 6751		NGC 6905		IDENTIFICATION
λ	*I*	λ	*I*	
3203.........	0.36	3203(prob.neb.)	5	3203 *He* II
3276.........	0.25	....	....	3275 *O* V
3338–3357....	0.63	....	....	3360 *N* III
~3380.......	0.39	....	....	3381 *O* III+*O* IV
3397–3429....	1.3	....	....	3411 *O* IV
~3430.......	0.49	3420–3437	2.9	3429–3445 *O* III
3469–3489....	0.55	....	....	3483 *N* IV
3696–3722....	1.2	3672–3710	2	3708–3750 *O* III, *O* IV, *O* V
3808–3837....	0.42	3794–3854	22	3811–3834 *O* VI
3947–3987....	0.33	3920–3982	2.3	3965 *O* III
4082–4125....	0.55	4096–4141	....	4070 *O* III 4100 *N* III, *He* II 4123 *O* V
~4200.......	0.19	....	....	4200 *N* III, *He* II
	0.18	....	....	....
4427–4470....	0.26	4410–4470	0.76	4441 *C* IV
4492–4572....	0.13 0.17	4490–4565	1.2	4512–4540 *N* III? 4542 *He* II 4515 *C* III
4616–4714....	10.0	4640–4702	10	4650 *C* III, *C* IV 4686 *He* II

The central stars of NGC 7026, 6751, and 6905 show broad emission lines. In the nucleus of NGC 7026 no lines are found in addition to those near λ 3800 and λ 4650, although there is some suggestion of weak diffuse features in the ultraviolet. The spectrum of the central star of NGC 6751 is of the carbon-sequence, Wolf-Rayet type, with high-excitation lines of carbon, helium, and oxygen in various stages of ionization. Nitrogen, represented by the λ 3483 *N* III group, may be present also. The spectrum of the nucleus of NGC 6905 is similar, although there is no suggestion of any nitrogen. Presumably it and the nucleus of NGC 7026 are typical stars of the carbon sequence, in which the stronger features are the *C* IV λ 4650 and *O* VI λ 3811 groups. Table 9 gives the intensities for the nuclear emission lines of NGC 6751 and 6905. Measures are difficult because of the overlapping nebular spectrum and the faint diffuse character of the stellar lines.

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