The Light of the Night Sky

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I. INTRODUCTION

THE light of the night sky is of complex origin but for this discussion we are interested only in one part of it, that which originates in the upper atmosphere. This part has been called the "permanent aurora" by V. M. Slipher[1] who found that the green auroral line was ever present in the light of the night sky. It is also frequently referred to as the "non-polar aurora," a term which we shall use in this paper. Since Slipher's discovery, there have been a large number of investigations of the light originating in the upper atmosphere, both spectroscopically and photometrically. With the exception of the three principal radiations in the visual portion of the spectrum, the extreme faintness of the light has presented many difficulties to spectroscopic investigations. The most powerful light gathering spectrographs must be used in order to record them and this has resulted in poor wave-length determinations and uncertainties of identifications owing to inaccuracies and the low resolving power. A large number of lines and bands have been announced for all regions of the spectrum accessible to astronomical observations, λ3000 to λ8600. Owing to limited space no attempt will be made to give a critical discussion of the published[2] announcements of lines and their identifications, but I would like to summarize the more probable identifications which will be helpful in discussing the physics of the upper atmosphere, and then to discuss some of the more recent photometric observations. References have been made to a few of the spectroscopic and photometric investigations of the light of the night sky and from them additional references can be had to most of the other published works.

II. GENERAL SPECTRAL FEATURES

A spectrogram of the night sky taken with the nebular spectrograph of the McDonald Observatory is shown in Fig. 1.

[1] V. M. Slipher, Astrophys. J. **49**, 266 (1919).
[2] See Georges Dejardin, Rev. Mod. Phys. **8**, 1 (1936) for references to early papers and Jean Dufay, Trans. I. A. U. **6**, 164 (1938) for later papers. Elvey, Swings, and Linke, Astrophys. J. **93**, 337 (1941).

The strongest feature in the spectrum of the night sky is the green auroral line, whose wave-length has been accurately measured by H. D. Babcock[3] employing interference methods, the resulting value being 5577.35A. This radiation was identified by McLennan and Schrum[4] as a transition from the metastable state of oxygen. The next strongest feature is also a forbidden transition in the oxygen atom, the upper state being the lower state in the transition which produces the green auroral line. The line is really a triplet, but the third member is so faint that it has not been definitely recorded in the night sky spectrum. The strongest member is λ6300 and the second is λ6364. These lines are present in the auroral spectrum and Vegard and Harang[5] have measured the wave-length of the stronger by interference methods thus definitely proving its identity. In the normal night sky spectrum the two "red nebular" lines of oxygen, as they are sometimes called, are frequently blended and are somewhat fainter than the green auroral line. However, at certain parts of the night these lines develop into the strongest feature of the spectrum, but we shall discuss this later in detail. The third prominent feature of the spectrum of the night sky is a yellow line which is enhanced greatly during twilight. This resonance phenomenon has led Bernard[6] to identify the line as due to sodium, it being a blend of the two sodium *D* lines. Subsequent observations[7] with interferometers have definitely proven its identification. The resonance effect is very pronounced when the sun is illuminating a layer of the atmosphere 60 to 80 km above the surface at twilight.

The above three strongest features of the spectrum of the night sky are the only ones definitely assigned to radiation from atoms. Most of the remaining emission is of molecular origin.

[3] H. D. Babcock, Astrophys. J. **57**, 209 (1923).
[4] J. C. McLennan and G. M. Schrum, Proc. Roy. Soc. **A106**, 138 (1924).
[5] L. Vegard and L. Harang, Geofysiske Publ. **11**, No. 15 (1937).
[6] R. Bernard, Comptes rendus **206**, 448 (1938).
[7] J. Cabannis, J. Dufay, and J. Gauzit, Astrophys. J. **88**, 164 (1938); R. Bernard. *ibid.*, **89**, 133 (1939).

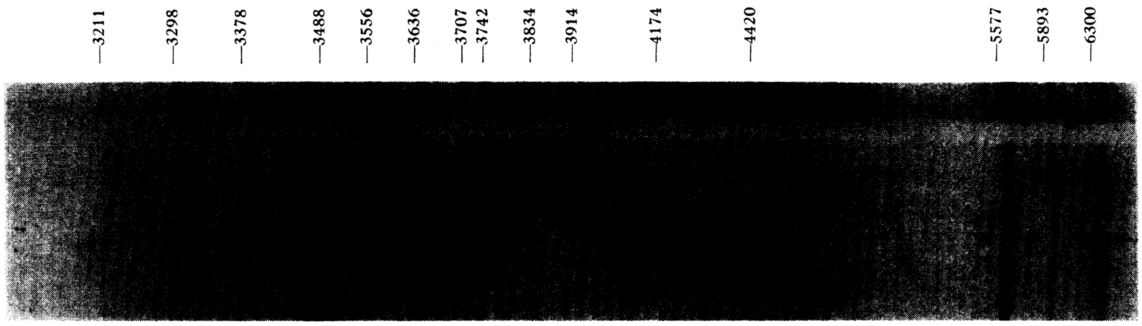

FIG. 1. The spectrum of the night sky.

III. LONG WAVE-LENGTH REGION

The investigation of the long wave-length region in the spectrum of the night sky is the most troublesome owing to the low sensitivity of the photographic emulsions and the low dispersion that must be employed. The wide slits that are used with the low linear dispersion gives very low resolving power and of course the wave-length determinations are also very uncertain. In order to give a better picture of the difficulties encountered, the wave-length determinations for the region to the long wave-length of λ5000 are plotted in Fig. 2, for several observers along with the more important suggestions for identifications. The well-determined wave-lengths in the green-red region are shown by the long lines in the spectra in which they are observed. Some 70 lines have been measured by Cabannes[8] in the region λ5000–8000; however, many of these are parts of maxima of wider features. I have indicated in the diagram the limits of the wider features for it seems quite obvious that the resolving power of the equipment makes the maxima rather uncertain, particularly when one investigates the region of the red oxygen triplet for which the wave-lengths are quite accurately known. In the next row are plotted the wave-lengths determined by V. M. Slipher;[9] those in the far red are very uncertain, of course, since the dispersion was very low. He has given the positions of three strong features as 7500A, 8250A, and 8600A. In another communication he reports radiations out to λ10,000 but does not give the wave-lengths. In the third row are the observations of H. W. Babcock[10] who used a grating spectrograph with a linear dispersion of 385A/mm. An inspection of the reproduction of the spectrogram shows the high quality; however, it does not extend to the long wave side of λ6600. Since it is generally reported that the infra-red spectrum of the night sky and the aurora are similar, the wave-lengths of the auroral spectrum are plotted. The principal band heads of the first positive system of the nitrogen molecule are also shown since the auroral spectrum has been attributed to it. The night sky spectrum in the infra-red region has been identified with the absorption bands of oxygen and water vapor in the atmosphere and these have been added for comparison.

The principal conclusion to be drawn is that more accurate wave-lengths are needed for the infra-red portion of the night sky spectrum.

IV. SHORT WAVE-LENGTH REGION

On the other hand the knowledge of the shorter wave-length regions of the spectrum of the night sky is very much better than that of the infra-red. The photographic emulsions are many times faster and the linear dispersion improves greatly with shorter wave-lengths. Most of the radiations have been accounted for except for the strongest band in the ultraviolet region which is still somewhat uncertain. They are all associated with molecules and none with atoms, the nitrogen molecule being the principal contributor. Beginning with the lowest electronic excitation, we find the bands of the Vegard-Kaplan system play a prominent part in the spectrum of the blue and violet regions, accounting for nearly all the

[8] J. Cabannes, Comptes rendus **198**, 2132 (1934).
[9] V. M. Slipher, J. Roy. Astronom. Soc. Canada **27**, 365 (1933).
[10] H. W. Babcock, Pub. Astronom. Soc. Pac. **51**, 47 (1939).

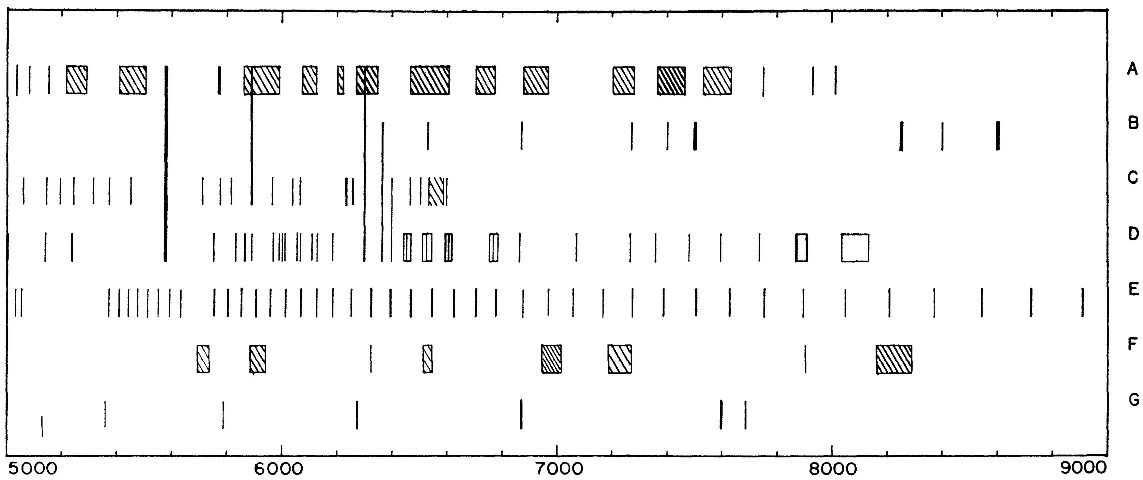

FIG. 2. Diagram of wave-lengths and identifications of radiations in the long wave portion of the spectrum of the night sky. A = Cabannes; B = Slipher; C = H. W. Babcock; D = Aurora; E = N_2 — 1st pos.; F = H_2O (absorp.); G = O_2 (atmos.).

radiations, three of which are fairly strong. This system is a transition from the $A^3\Sigma$ metastable state to the ground state. The excitation potential is 6.2 volts. The next system of bands is the first positive system and it is found that eleven of the fainter bands observed by Babcock in the red-green region are in good agreement with the wave-length of the bands of this system. The excitation potential is of the order of 10 volts for the highest excitation observed. The Lyman-Birge-Hopfield system has an excitation energy close to the higher levels of the first positive system and although it has been observed only in the far ultraviolet region beyond the transmission of the earth's atmosphere, a computation of the wave-lengths of band heads in the more accessible regions show many coincidences with bands in the spectrum of the night sky. There is a fairly strong probability that this system is present in the spectrum of the night sky. The excitation potentials observed are 8.5 volts. The second positive system and all others seem to be absent from the spectrum of the night sky.

From the ionized molecule, the strongest group is the negative system, λ3914, and it is very weak or absent from the spectrum of the normal night sky. However, it appears with the slightest trace of polar aurora.

Looking at other compounds of nitrogen such as NO, NH, NO_2, etc., only one, NO, seems to have any probability of being represented in the spectrum of the non-polar aurora: There are

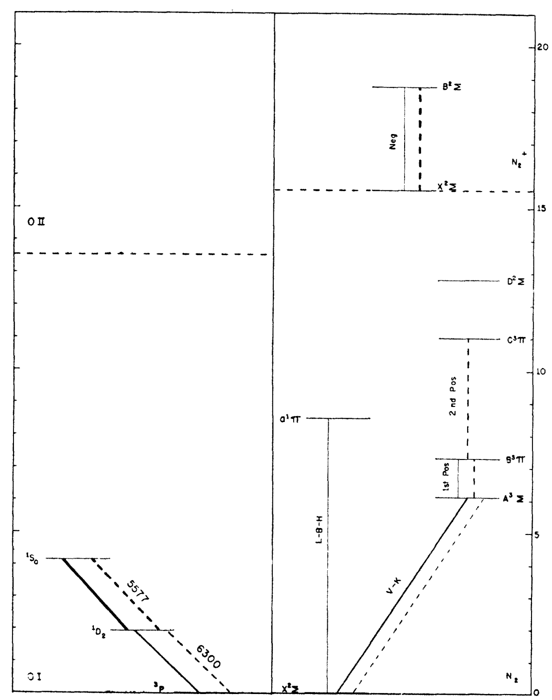

FIG. 3. Schematic energy level diagrams for the nitrogen molecule and the oxygen atom showing the relative importance of radiations in the spectrum of the non-polar aurora (continuous lines) and the polar aurora (dashed lines).

coincidences indicating that the β-bands and the γ-bands of NO may both be present. Their excitation potentials are 5.6 and 5.5 volts, respectively.

Other molecules such as CH and CN have been

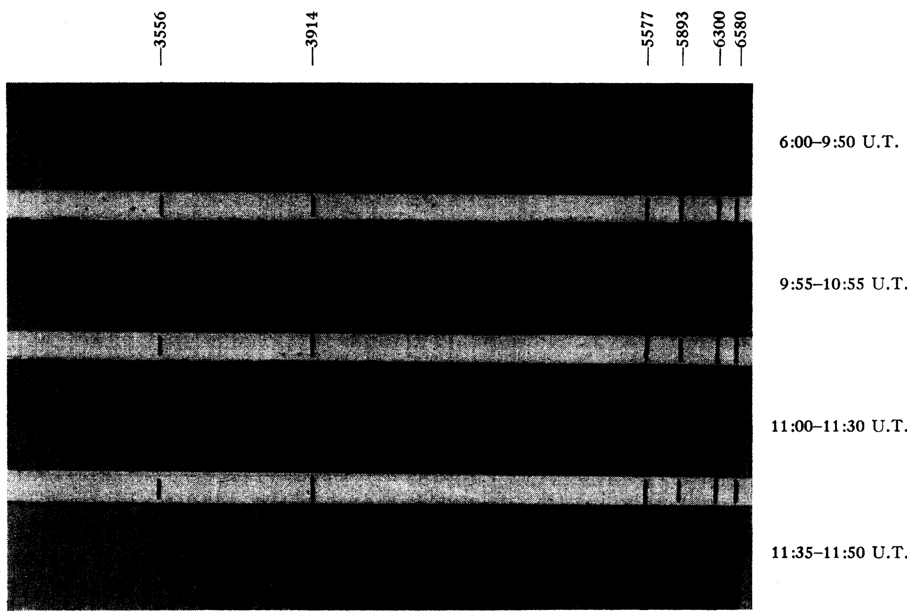

FIG. 4. Spectra of the night sky (October 1, 1938) showing the development of the strong auroral band, 3914.

suggested as contributors to the spectrum of the night sky but the evidence is rather weak, and further if they do exist they are probably of interplanetary or interstellar origin.

For the oxygen molecule, the atmospheric bands are in the infra-red region and the observational data are very meager. Many of the Schumann-Runge bands have been observed in the laboratory for the blue and ultraviolet regions of the spectrum and many coincidences are found with bands of the non-polar aurora. There is fair probability that this system of bands is present. Its excitation potential is 6.1 volts, for the lower excitations.

V. POLAR AND NON-POLAR AURORAS

In making a comparison of the non-polar and the polar auroras we find that the forbidden transitions of the oxygen atom are prominent in both; in the non-polar aurora they are by far the most important radiations. The sodium line is strong in the non-polar aurora and appears to be absent from the spectrum of the polar aurora. Among the transitions in the nitrogen molecule we find that the Vegard-Kaplan bands are the most prominent in the non-polar aurora while in the polar aurora the negative system of the ionized molecule vies with the green auroral line for importance, and the Vegard-Kaplan bands are relatively unimportant. The first positive system is present in the spectrum of both but the second positive system is absent from the non-polar aurora and fairly strong in the polar.

We can illustrate the difference between the two spectra by means of Fig. 3 which is a schematic energy level diagram of the nitrogen molecule and of the oxygen atom and on which are drawn the relative importance of the various radiations in the polar and non-polar aurora, the non-polar auroral bands being indicated by continuous lines and those of the polar aurora by the dashed lines. The widths of the lines indicate the relative importance.

This shows that the excitations for the two kinds of aurora are of different magnitude. The non-polar aurora is of low excitation while the polar is of the order of 19 volts. The excitation of the polar aurora is due most probably to charged particles from the sun striking the atmosphere, whereas the source of energy for the non-polar aurora probably comes from the energy resulting from the recombination of oxygen atoms as suggested by S. Chapman.[11]

[11] S. Chapman, Phil. Mag. **23**, 657 (1937).

V. M. Slipher[12] of the Lowell Observatory made the interesting discovery that a polar auroral spectrum is present during the twilight, and since it lasts for only a short time he has termed it the "auroral flash." The principal feature noted is the presence of the negative bands of ionized nitrogen which are so prominent in the polar aurora. This development of the "auroral flash" is shown in a series of spectrograms taken at the McDonald Observatory and illustrated in Fig. 4. The spectra were taken with the nebular spectrograph pointed toward the eastern horizon, the first two exposures of three hours and fifty minutes and of one hour, respectively, show the usual spectrum of the night sky. The next exposure of half an hour duration just preceding astronomical dawn shows the enhancement of the red oxygen lines and the appearance of the negative system of ionized nitrogen. The last exposure, fifteen minutes during dawn, shows the increased strength of the negative system, λ3914. This is no doubt an effect of the ionizing action of the ultraviolet light of the sun which produces the N_2^+ in the upper atmosphere. The increased strength of the oxygen line, λ6300, relative to the green auroral line is striking but we will discuss this feature later.

VI. PHOTOMETRIC OBSERVATIONS

There have been a large number of photometric investigations of the light of the night sky, particularly with regard to that part which originates in the upper atmosphere. Again we shall not attempt to discuss each in detail but will mention only a few of the investigations which illustrate the general run of data.[2]

(a) Methods of Observation

The photometric observations may be discussed under two headings, photometry with filters to isolate given regions of the spectrum and spectrophotometric investigations. The spectrophotometric observations are rather difficult owing to the long exposures that must be made with the spectrographs, but when used for the brighter emission lines it is possible to separate the line both from adjoining radiations and also from the continuous spectrum. The latter becomes especially troublesome at twilight.

[12] V. M. Slipher, Trans. Am. Geophys. Union, p. 125 (1933).

We shall note that by the proper choice of filters and photometric devices it is possible to measure the brightness variations of given emission lines or band systems. Lord Rayleigh,[13] for example, has used visual photometers with red, green, and blue filters for measuring the brightness of the night sky, the green filter isolating the green auroral line while the most effective emission for the red filter is the red oxygen lines, and for the blue filter the Vegard-Kaplan system of emissions from the nitrogen molecule. The visual method is not especially accurate, but it does give a large amount of observational material with a small amount of equipment. The photographic method has been used to some extent as well as the photoelectric photometer. The latter is the most accurate and is extremely useful in studying the short period variations of intensity of the light of the night sky. The K–H photo-cell is sensitive to the blue-violet region and consequently records the variations of the Vegard-Kaplan bands. Most of the Cs–O cells have good sensitivity in the infra-red region and excellent photometric studies can be made of that region but we are still somewhat uncertain of the identifications of the radiations that are being measured. D. N. Barber[14] has successfully used a K–O cell with filters to measure the green auroral line.

(b) Variations of Intensity

Lord Rayleigh[15] and his collaborators have obtained quite long series of visual observations with color filters and these have been discussed by H. Spencer Jones,[16] particularly with regard to the long period and the seasonal variations. The data were obtained during the interval from 1925 to 1933 at Terling, England; Cape Town, South Africa; and Canberra, Australia. They find that the brightness of the night sky for the three spectral regions correlate very well with the sunspot areas for the Cape Town data but for the other two stations it is not so good, especially the red region of the spectrum. For the auroral light the correlation coefficients are 0.99, 0.79, and 0.60, respectively, for Cape Town, Canberra, and Terling. A discussion of the annual variations

[13] Lord Rayleigh, Proc. Roy. Soc. **A106**, 117 (1924).
[14] D. N. Barber, private communication.
[15] Lord Rayleigh, Proc. Roy. Soc. **A119**, 11 (1928).
[16] H. S. Jones, Proc. Roy. Soc. **A151**, 22 (1935).

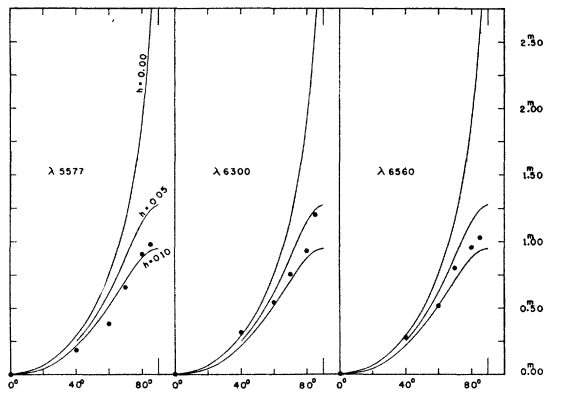

FIG. 5. Observed variations of intensity with zenith distance for λ5577, 6300, and 6560. The curves indicate theoretical variations for values of the heights to the layer in terms of the earth's radius.

shows that the data are represented by both a six-month and a 12-month period. Furthermore it is noted that there is a marked difference of the seasonal variations with the three stations, being much larger at Terling which is in the highest magnetic latitude.

Another interesting observation of the seasonal variation of radiations of the night sky is that of Cabannes and Dufay[17] who measured the brightness of two of the Vegard-Kaplan bands. They found large variations from night to night, but by taking monthly averages they find a double maximum, a rather narrow one in March and a broad one in July and August. This variation resembles the variation in the frequency of auroras as observed in New York.

The green auroral line has been the subject of a number of investigations for its nocturnal variation of intensity and there are many reports that it reaches maximum intensity around midnight or shortly afterward. Garrigue[18] observing at Pic du Midi did not verify the maximum of the green line. Likewise, spectrophotometric observations by Miss Farnsworth and myself[19] do not show that the green line reaches a maximum in the middle of the night. On occasions we have found such and at other times the line is relatively constant throughout the night. It appears that the apparent maximum which has been observed for this line may be a result of the irregular variations that are present in the light of the night sky.

A remarkable phenomenon, the great intensity of λ6300 at twilight compared to λ5577 and its decrease in intensity for several hours after the end of twilight, has been observed by Cabannes and Garrigue.[20] It is an effect of direct excitation by the light of the sun, possibly resonance, and the effect has been traced to an altitude of 800 to 1000 km in the atmosphere.

During the last two years we have been carrying on several investigations of the variation of the light of the night sky at the McDonald Observatory, both by spectrophotometric methods and with photoelectric photometers. Since these investigations add considerable information to that now available I would like to mention some of the results even prior to publication. The following spectrophotometric observations have been made in collaboration with Dr. Alice H. Farnsworth of Mt. Holyoke College, South Hadley, Massachusetts, and will soon appear in detail in the *Astrophysical Journal.*

Dr. Farnsworth and I have attempted to determine the following through photometric observations of the strong lines in the red-green portion of the spectrum: 1. the height of the non-polar auroral layer by a determination of the variation of intensity with zenith distance; 2. the nocturnal variations of intensity; and 3. to obtain whatever information possible as to the geographical distribution of the intensity of the various radiations. The latter was possible by a trip which Dr. Farnsworth made to South America on a sabbatical leave from college teaching.

The method of determining the height of the non-polar auroral layer is based on the assumption that the luminous layer is uniform over large geographical distances and that its thickness is not large compared to the radius of the earth. We have used a graphical method since the accuracy does not warrant more exact procedure and have computed the theoretical variations of intensity with zenith distance for several values of "*h*" the height to the auroral layer. The observational material was obtained by using a set of six prisms which were placed on a decker in front of the slit

[17] J. Cabannes and J. Dufay, Comptes rendus **200**, 878 (1935).
[18] H. Garrigue, Comptes rendus **202**, 807 (1936); **205**, 491 (1937).
[19] C. T. Elvey, in preparation.
[20] J. Cabannes and H. Garrigue, Comptes rendus **203**, 484 (1936).

FIG. 6. Spectra of the dawn and the night sky showing the enhancement of the sodium line.

of the spectrograph and thus simultaneous exposures could be obtained for the following zenith distances: 0°, 40°, 60°, 70°, 80°, and 85°. Calibrations were determined for any vignetting for the various prisms, and corrections were made for extinction.

It was found on reducing the observations that the assumption of a uniform distribution of light in the auroral layer was erroneous and this is confirmed by observations with the photoelectric photometers, hence we have combined all the observations to obtain a mean value rather than to try studying the height at each station, or at different times. The results obtained for the two oxygen lines λλ5577 and 6300 and the band of uncertain origin at λ6560 are illustrated in Fig. 5. It can be seen that the order of the height is between $h = 0.05$ and 0.10, probably being near to 0.08 or around 500 km. This is in disagreement with a preliminary value determined by some observations with a photoelectric photometer[21] which was of the order of 125 km. However, it is pointed out that the origin of the radiations in the infra-red region to which the photoelectric photometer is sensitive is rather uncertain. Garrigue[22] found that the ratio of light at the zenith to the horizon was of the same order of magnitude as determined by Elvey and Farnsworth for both λλ5577 and 6300. It seems that the evidence points toward a height of around 500 km for the layer producing the green and red auroral lines.

Nocturnal variations of intensity for both of the oxygen lines, λλ5577 and 6300, the sodium line λ5893, and the band at λ6560 of uncertain origin were determined with the spectrograph pointed at a zenith distance of 70°. During the time and for the places for which the observations were made, December, 1940 in Bosque Alegre, Argentina, January, 1941 in Potrerillos, Chile, and each March to June in the southern New England states, there were no marked differences of intensities during the night nor from place to place. Investigations showed that the magnetic activity for the nights when observations were made was in general low. The observations indicated that when the magnetic activity is low, there is no major difference of intensity of the various radiations for different geographical positions; however, the observations were too meager for generalizations.

A more interesting phase of the investigations of Elvey and Farnsworth is the nocturnal variations of intensity when the instrument is pointed nearer the horizon and toward the setting or rising sun. At this position the enhancement of the sodium line is pronounced in twilight and also in the dawn spectra. Series of exposures taken with the instrument toward the setting sun and left in that position through the night show that the sodium line is very strong during twilight and fades rapidly to a rather constant value which remains throughout the night. The reverse is found when the instrument is pointed eastward. (See Fig. 6.) All of the observations of the intensity of the sodium line were combined to show the variation during twilight and a mean curve was obtained.

Since the sodium line is enhanced through resonance its intensity should be a function of the number of atoms being illuminated. The heights to the illuminated portion of the atmosphere were computed and the logarithm of the intensity was

[21] Dedication of National Astrophysical Observatory at Tonanzintla, Pueblo, Mexico, February 17, 1942.
[22] H. Garrigue, Comptes rendus **202**, 807 (1936).

plotted against the heights and it was found that the mean curve is a straight line. This line is parallel with that representing the theoretical decrease in the number of molecules, thus showing that the distribution of sodium atoms over the interval from 75 km to 115 km follows the exponential law. Because of the sudden appearance or disappearance of the sodium line as the sun illuminates the region of 60 to 80 km above the surface Bernard assumed that the sodium atoms occupied a rather definite layer in the upper atmosphere. It appears, however, that this is a result of the exponential decrease in the number of atoms and that above 80 km the total number of atoms of sodium is too small to make a noticeable effect.

The transition in the oxygen atoms which produces the green auroral line leaves the atoms in a suitable state to produce the red auroral line, λ6300; hence, one might expect that their relative intensities would be a rather definite thing. The observed curves of nocturnal variations when the instrument is pointed toward the setting sun shows a high intensity of λ6300 in twilight which decreases rapidly at the end of twilight and then more slowly for the next three or four hours after the end of twilight. For the remainder of the night the intensity decreases slowly. The green auroral line on the other hand remains relatively constant throughout twilight and the night. With the spectrograph pointed toward the rising sun there was no special twilight effect and the intensity decreased through the night until two hours before the beginning of dawn when it began increasing, slowly at first and then more rapidly. This is apparently an effect of the sun illuminating the upper atmosphere. The difference between the evening and the morning effects is no doubt due to the fact that in the former case the atmosphere had been illuminated all day by the sun while in the latter it had been in the shadow all night. As in the case for the sodium lines the increase in the intensity due to the sun illuminating the upper atmosphere is compared with the theoretical numbers of molecules being illuminated and it was found that the intensity does not increase exponentially. The illumination from the upper layers of the atmosphere is too great thus indicating an excess of oxygen atoms in the $^1D_2$ state.

Some preliminary results of the nocturnal variations made with a photoelectric photometer were presented at the dedication[21] of the National Astrophysical Observatory at Tonanzintla, Pueblo, Mexico. The observations with a photoelectric photometer can be made much more rapidly than by the photographic method, and consequently, the resolution on the time scale is much greater. Also, the accuracy is greater. It was found that the curves of nocturnal variations were rarely smooth and on the so-called "quiet" nights there is a gradual drop in intensity through the night. This has been termed the background and apparently superimposed upon this are irregular fluctuations. It was found that the irregular fluctuations were not the same in different directions and it was concluded that these irregular fluctuations were caused by small clouds of light; further, that they were caused by some exciting agency other than that which produced the background, perhaps in the same manner as auroras or possibly by meteors. The irregular fluctuations are related to magnetic activity and on more active nights the irregular fluctuations may be large and overlap thus raising the general brightness of the night sky.

To summarize briefly the observational data we find that the spectrum of the non-polar aurora tells us that the following excited atoms and molecules are present in the upper atmosphere: ^1S and $^1D_2$ states of oxygen, ^2P state of sodium, the $A^3\Sigma$, $B^3\Pi$, $a^1\Pi$ states of the nitrogen molecule, probably the $A^2\Sigma$ and the $B^2\Pi$ states of the NO molecule, the $B^3\Sigma$ state of the oxygen molecule, and certain excited states of the water molecule. High in the upper atmosphere near the times of twilight there are present the $B^2\Sigma$ state of the ionized nitrogen molecule and an excess of oxygen atoms in the $^1D_2$ state. All of the states represented are of low excitation potentials except for the ionized nitrogen molecule during twilight when the sunlight no doubt produces the ionization and the excitation.

(c) Magnetic Influences

D. N. Barber[23] working at the Lick Observatory has measured the brightness of the green auroral line of the night sky and has found an excellent

[23] D. N. Barber, Lick Obs. Bull. **19**, 105 (1941).

correlation of its variability with that of magnetic activity as measured at the Mount Wilson Observatory on the preceding day. Since the measures of brightness of the sky were made in the vicinity of the pole and hence the volume of atmosphere where the activity in the illumination was concerned, lies to the north, it would be very interesting to know what the correlation would have been had the magnetic observations been made directly under the main source of light.

Observations indicate that on a night when there is little or no magnetic activity there is a fairly steady but slowly decreasing supply of excited atoms and molecules in all the states, listed in the preceding section except as noted for the twilight phenomena. As magnetic activity increases there are areas or patches in the upper atmosphere in which there are greater numbers of atoms and molecules in the excited states. The number of excited atoms is widely variable from night to night but when studied through the year their numbers seem to depend upon two periods, one of six months and the other 12 months. The numbers are also dependent upon the distance from the magnetic equator, increasing toward the poles. The measures of height indicate that during the night the oxygen atoms in the two metastable states are around 500 km above the surface. The twilight phenomena indicate that the excess of oxygen atoms in the $^1D_2$ extend from 100 km to perhaps 1000 km. The ionized nitrogen molecules are in the same regions, but this is only an estimate based on the general appearance of the emission in comparison with $\lambda 6300$.

VII. THEORETICAL CONSIDERATIONS

Any theory which tries to account for the above observations is apt to have a difficult time. S. Chapman,[11] however, has presented a theory which can account for the amount of energy required through the night and has shown how it is possible to account for the various radiations which are present. His theory has been based on theoretical discussions of atmospheric ozone. He first assumes in the upper atmosphere, say above 100 km, that the main constituents are molecular nitrogen and atomic oxygen. Secondly, he maintains that the energy represented by the light of the night sky is originally derived from sunlight; it is stored up by the dissociation of oxygen molecules and is regained through the recombination of the atoms which then liberate the energy of dissociation. The process, however, requires the participation of a third particle in order that the conservation of energy and momentum may be fulfilled. This third particle will in general be either a nitrogen molecule or an oxygen atom. Since the nitrogen molecules are more numerous than the oxygen atoms there will be more triple collisions with them but since the first excited state of the molecule is 6.2 ev, the energy derived from the possible recombination is insufficient and consequently the reaction does not occur. When the third particle is another oxygen atom, the energy of recombination, 5.1 ev, can raise the atoms to the ^1S state which requires 4.2 ev and the remainder of the energy will either excite the vibrational or rotational levels of the oxygen molecule or go to kinetic energy. By descent to the ^1D state the green auroral line is emitted, and if no further collisions are experienced by the atom it will descend to the ^3P state with the emission of the red auroral line. If such were the case the number of quanta of $\lambda 5577$ would equal those of $\lambda 6300$. However, some of the ^1D atoms will collide with oxygen atoms in the ^3P state in the presence of the third particle and the sum of the energy derived from recombination and from the excited state will be available for excitation of the third particle, 5.1, 1.96, or 7.1 ev, which will excite the lowest state of the nitrogen molecule, $A^3\Sigma$, or if the kinetic energy of the triple collision is sufficient, the molecule may be excited to the $B^3\Pi$ state. We thus see that a steady supply of excited oxygen atoms and nitrogen molecules is provided by the recombination of oxygen atoms to form molecules.

Although this theory can account for a steady supply of excited atoms and molecules throughout the night and also account roughly for the proportions of each, it runs into some difficulties. It is a little hard to see how this theory can explain the sporadic changes in the intensity of the light of the night sky, its spotted or irregular distribution, its strong dependence upon the terrestrial magnetic activity, its dependence upon magnetic latitude, and the nature of the seasonal or annual variations. Also, we should include the abnormal behavior of the red oxygen lines, $\lambda 6300$ at evening and morning twilight, and the appearance at twilight of the negative system of ionized nitrogen which is one of the characteristics of the auroral spectrum. The enhancement of the sodium line at twilight is adequately explained as a resonance phenomenon as the sun illuminates the sodium atoms in the region of 60 to 80 km.

In checking over the discrepancies between Chapman's theory and the observational facts, we find that most of them are phenomena which are characteristic of the polar aurora rather than the non-polar aurora. The obvious question to ask is whether there might be some influence from the polar aurora on the light of the night sky. The observations made with the photoelectric photometer suggested that the light of the night sky might be made up of two components and this has been adopted as a working hypothesis. The background illumination of the night sky might be more properly called the non-polar aurora. This light originates in the upper atmosphere in accordance with Chapman's theory and superimposed upon this are the irregular fluctuations in brightness which are patches of light and have another origin.

If the background illumination of the night sky is produced in a manner as suggested by Chapman we should be able to arrive at some idea of the magnitude of the effect and its relationship to the various layers in the atmosphere. Since the recombination process is a triple collision in an atmosphere that is decreasing upward in an exponential fashion, the decreasing density will set an upper limit to the level above the surface where the collisions become so infrequent that they are no longer effective in producing the light of the night sky. Since it is primarily a three-body collision of oxygen atoms we can make use of the theoretical investigation of the chemistry of the upper atmosphere of O. R. Wulf and Lola S. Deming[24] in which they have discussed the recombination coefficient and the theoretical distribution of oxygen molecules and atoms, and we can compute the number of transitions which will be expected from this process. Of course, this is a bold extrapolation of the problem which was originated to explain the ozone content of the atmosphere but it is hoped that it will give us some ideas with which to work. A crude measure of the number of transitions of the oxygen atoms required to produce the green auroral line in the spectrum of the night sky is around 10^9 per second per square centimeter. It is computed that the number of collisions under the above assumptions required to produce these transitions would be furnished by the atmosphere above the level of 160 km. Also, that the rate has decreased so that the recombinations above 175 km are ineffective, which would thus establish an upper limit for the layer producing the non-polar aurora. Since the auroral lines are transitions from metastable states it is possible to make some estimate of the lower limit of the layer by computing the frequency that an atom makes a two-body collision and de-exciting it before it has time to radiate. The mean lifetimes of the two metastable states of oxygen are different, being 0.5 and 100 seconds. Computations indicate that the transition from the ^1S state which produces the green auroral line will be unhindered for heights greater than 120 km while that from the ^1D state producing the red oxygen lines will be unhindered above 160 km. This crude calculation indicates that the auroral layer should be in neighborhood of 120 to 180 km. All the observations for the height of the layer producing the red and green auroral lines give greater values, 300 to 500 km, thus indicating that either or both the recombination coefficient or the density is incorrect. As pointed out earlier, the determinations of height by means of observations with a photoelectric photometer indicated that the layer was around 125 km; however, we are not so very certain of the origin of the radiations which were being measured. Since the observations do not satisfy the theoretical quantities we should satisfy ourselves that the data are correct and then proceed to determine the recombination coefficient and the density, if possible.

If the origin of the irregular fluctuations is the same as that of the polar aurora, that is, by the bombardment of the upper atmosphere from ions emitted from the sun, then most of the above questions can be explained. When there are no ions coming from the sun then the light of the night sky will be very uniform in character and will show a slow decrease in brightness through the night as has been observed with the photoelectric photometers on a few occasions. Small

[24] O. R. Wulf and L. S. Deming, Terr. Mag. **41**, 299 (1936).

clouds or streams of ions striking the atmosphere will produce the small irregular patches of luminosity which are observed. With greater activity on the sun the ions are sent off in greater numbers, there will be more and more patches of light which eventually will overlap and tend to produce a considerable portion of the light of the night sky. This will readily explain the dependence upon magnetic activity, the greater intensity at higher latitudes, and the annual and long period effects which are closely related to auroral activity. As the streams and clouds of ions increase in numbers and intensity the patches of light will become distinguishable to the eye above the general background illumination and we have the normal polar aurora.

Of the observational facts there are two which still require an explanation, namely, the appearance of the negative system of the ionized nitrogen molecule at twilight and the abnormal intensities of the red oxygen line, λ6300 at the beginning and the end of the night.

O. R. Wulf and Lola S. Deming[25] have suggested that, in the high atmosphere where the gas pressure is very low, there are ionized molecules of nitrogen produced by sunlight and that they absorb and re-emit the 0−0 band of the negative system, λ3914. There are no measures of the height at which the bands of the negative system occur in the atmosphere of the evening or morning sky but all evidence points toward the origin being quite high.

The remarkable behavior of the red oxygen line, λ6300, at the end of twilight and before dawn should give considerable information concerning the upper atmosphere. This shows that, during twilight and for nearly four hours afterward and for the two hours preceding dawn and during dawn, there are excessive numbers of oxygen atoms in the ^1D state. These must get into that state by some means other than by a downward transition for there is no evidence for such changes in the intensity of the green auroral line. The energy required to place the atom in this state is 1.96 ev. Since the sun is illuminating the upper atmosphere at the time it is very tempting to attribute the increased number of atoms in the ^1D state to the dissociations of oxygen molecules which can leave one in the ground state and one in this metastable state. However, the intensity of the red oxygen line is greater when the number of molecules should be the smaller, that is, when they have been in the sunlight all day. It has also been suggested that the effect may be a resonance one but it again is difficult to account for the evening twilight and the dawn effects, for it would seem that in the high atmosphere the dissociation of the oxygen molecules would take place very soon after the sun illuminated them. For the present we will have to say that the upper atmosphere contains many more oxygen atoms in the ^1D state than can be accounted for, at least until adequate investigations can be made to determine the effects, for example, of the heating of the atmosphere during the day and its consequent expansion by day and contraction by night, and the effect of the electron liberated by the ionization of the nitrogen molecule. It is known that the oxygen atom has a great affinity for electrons to produce the negative oxygen ion, thus liberating a small amount of energy.

[25] O. R. Wulf and L. S. Deming, Terr. Mag. **43**, 283 (1938).

DISCUSSION

J. Franck and P. Pringsheim, *University of Chicago*, referred to the hypothesis that the *D* lines may be emitted by a NaCl molecule dissociating under the influence of ultraviolet light into a chlorine atom and an excited sodium atom. Since by that process the sodium atoms would get kinetic energies surpassing the translation energy of temperature motion, the *D* lines would be broadened.

A simple measure of the breadth of the lines is possible by a study of the absorption of the *D* lines by sodium vapor contained in a suitably arranged absorption cell.

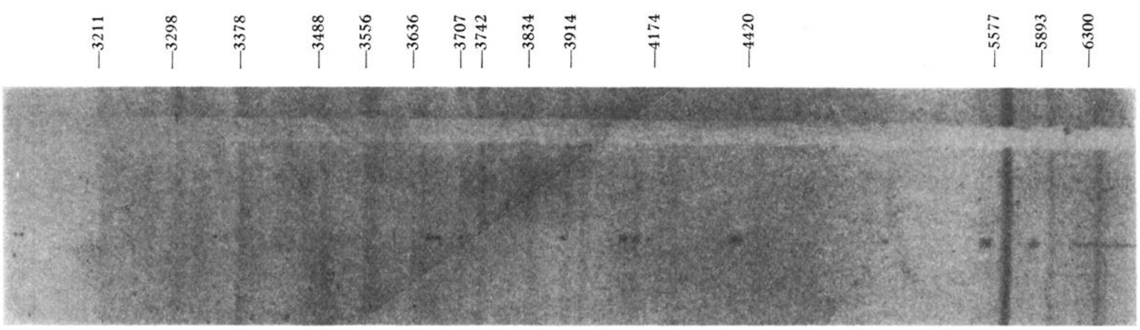

FIG. 1. The spectrum of the night sky.

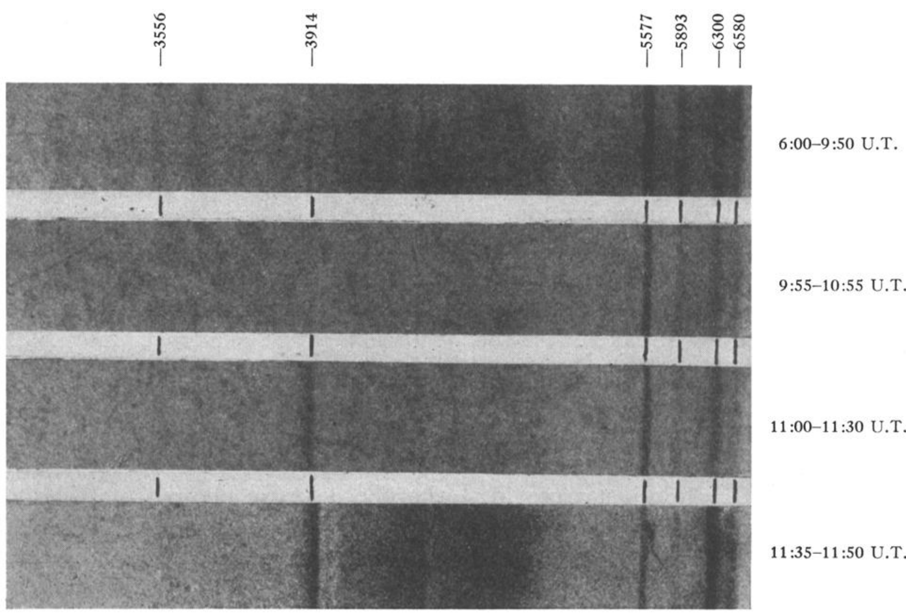

FIG. 4. Spectra of the night sky (October 1, 1938) showing the development of the strong auroral band, 3914.

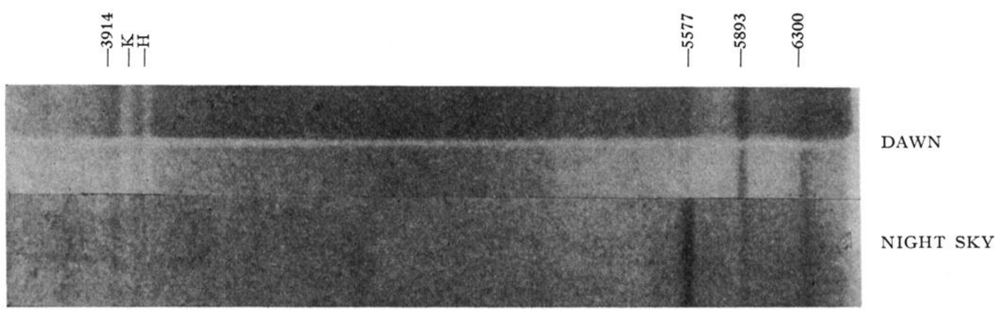

FIG. 6. Spectra of the dawn and the night sky showing the enhancement of the sodium line.