1941ApJ....93..337E

THE SPECTRUM OF THE NIGHT SKY*

C. T. ELVEY, P. SWINGS, AND WALTER LINKE

ABSTRACT

A conservative list of lines in the spectrum of the night sky is given, using spectrograms obtained at the McDonald Observatory with the nebular spectrograph. The identifications are discussed, and the attention of the laboratory spectroscopists is called to the various experimental problems connected with this question. The main features of the spectrum of the night sky are represented by the atomic lines of *Na* I and [*O* I] and the band spectrum of N_2, particularly the Vegard-Kaplan and the First Positive systems.

Estimates of the relative intensities of some of the lines in the spectrum of the night sky show that the sodium line is weak during the summer. Also, it was found that the sodium line was enhanced in a luminous area of the night sky. The estimates of intensities of the forbidden oxygen lines show that the red line, λ 6300, is very strong at the end of twilight and decreases to a more or less constant value around midnight, while the green auroral line shows the tendency to reach a maximum shortly after midnight, as many others have observed.

Many descriptions of the spectrum of the night sky have been published in recent years and also, many lists of lines and identifications. Some of these lists contain a large proportion of uncertain lines, and a careful examination of our material has convinced us that many of the announced lines do not actually exist on our spectrograms. This may be due to the fact that the spectrum of the night sky may be accidentally richer at certain locations and at certain times; or, it is possible that techniques in observing, measuring, and reducing the material have given erroneous results. Because of this uncertainty in part of the collected materials, tentative identifications and discussions have appeared which are without sound bases.

It has seemed to us that it would be useful to publish a conservative list of lines in the spectrum of the night sky (table 5) which could be a basis for future discussion of the fundamental features. The table is preceded by a discussion of the identifications. The main purpose of this attempt is to call the attention of the spectroscopists to the various experimental problems connected with this question. Our identifications will be based exclusively on our list and on one by H. W. Babcock[1] for the wave lengths greater than 5000 A. No attempt will be made to give a critical discussion of the previous publications or to give a complete bibliography,[2] as this would require too much space.

We will also give some preliminary results of intensity variations in the spectrum of the night sky obtained from spectrograms taken with the nebular spectrograph in the survey for emission nebulosities in the Milky Way.

The spectrograms under discussion were obtained with the nebular spectrograph of the McDonald Observatory, a description of which has been given by Struve, Van Biesbroeck, and Elvey.[3] The light from the sky is picked up by the narrow mirror which acts as the slit of the spectrograph and which is on an equatorial mounting and is reflected to a stationary mirror located 75 feet along the polar axis, which, in turn, sends the beam of light back to an objective-prism camera mounted on the polar axis with the slit. The long distance of the slit, 150 feet, makes a collimating lens unnecessary. Two quartz prisms and an f/1 Schmidt camera are used, thus making an instrument especial-

---

* *Contributions from the McDonald Observatory, University of Texas*, No. 29.

[1] *Pub. A.S.P.*, **51**, 47, 1939.

[2] For references earlier than 1935 see G. Dejardin, *Rev. Mod. Phys.*, **8**, 1, 1936. For more recent work see J. Gauzit, *Ann. d'Ap.*, **1**, 334, 1938, and M. Nicolet, *Mémoires de l'Institut royal météorologique de Belgique*, Vol. **9**, 1939, and *Bull. Acad. R. Belgique*, **25**, 81, 1939.

[3] *Ap. J.*, **87**, 559, 1938.

ly useful in the near ultraviolet. The correcting plate of the Schmidt camera is of ultraviolet glass which begins to lose transparency around λ 3200; thus the far ultraviolet regions are rather weak on our spectrograms.

The linear dispersion varies from 115 A per millimeter at λ 3200 to 500 A per millimeter at λ 5000. The slit as imaged on the spectrogram has a width of 0.04 mm, and thus, considering the dispersion, the effective width of the slit is about 5 A at λ 3200 to 20 A at λ 5000. Band structure or close lines cannot be resolved, and consequently the identification of some of the lines cannot be made with very great certainty.

Five spectrograms of the night sky with exposures ranging up to 9 hours have been used for the determinations of wave lengths. A comparison spectrum of mercury was impressed on the spectrograms by placing a mercury tube in the center of the slit of the nebular spectrograph.

The spectrograms were measured on a Gaertner measuring-machine, and the wave lengths were determined by a graphical method, inasmuch as the diffuse character of the lines did not warrant a more refined method. To help construct a standard dispersion curve, we used spectra of the iron arc, the Balmer lines of hydrogen in stellar spectra, and the ozone spectrum found on spectrograms of stars exposed for the far ultraviolet region. One of the spectrograms of the night sky is shown in Plate XIV. Two prints of the same spectrogram are placed side by side in order to help separate the faint detail from defects of the plate. In the reproduction processes two or three of the faint lines at the violet end of the spectrum have been lost. We have measured only details which we feel reasonably certain to represent lines. No attempt has been made to measure the lines from microphotometric tracing, for it has been our experience that a line cannot be detected with any certainty on a tracing unless it can be seen by a visual inspection of the spectrogram.

The measured wave lengths of the lines observed on our spectrograms are in the first column of Table 5, along with the mean errors of the wave length whenever a line has been measured on two or more plates. In case it has been measured on only one spectrogram, a mean error is not shown; and in those cases where the wave length is quite uncertain, owing to the faintness of a line being measured on only one spectrogram, it is inclosed in parentheses.

Two good spectrograms were obtained with the nebular spectrograph, using glass prisms, thus resulting in a linear dispersion about twice that of the quartz prisms. These were measured from λ 3900 to the red end of the spectrum and are included in Table 5.

The wave lengths of the three principal lines in the red-green region of the spectrum—λλ 6300, 5893, and 5577—have been assumed, since so much more accurate values exist.

In the second column of Table 5 are listed the estimated intensities of the lines and a brief description of their character. The remainder of the table is devoted to the identifications, which are being discussed in the following sections.

ATOMIC LINES

Besides the forbidden transitions of [*O* I], λλ 5577, 6300, and 6364, and the D lines of *Na* I, there is also some evidence, though not quite conclusive, in favor of the second line of the principal series of *Na* I, λ 3303, $3s^2S - 4p^2P^o$.

The line measured by H. W. Babcock[1] near λ 6401 is certainly not the component $^3P_0 - {}^1D_2$ of the nebular transition of [*O* I] at λ 6392, which should be extremely weak compared with λ 6364 of the same transition.

Many discussions have been published recently concerning the presence in the spectrum of the night sky of the forbidden line[4] $^4S_{3/2} - {}^2P_{3/2,\,1/2}$ of [*N* I] at λ 3466.5. That

---

[4] This is actually a doublet, but the separation of the two components of ^2P is only of the order of 0.5 cm^{-1}. A search for the transition, of auroral type λ 10,407, in the spectrum of the night sky would be interesting.

there is no line of appreciable intensity at that wave length is certain, as our line λ 3460 ± 1 A is narrow, and an error of measurement of 6 A is excluded in that region.

A systematic discussion of all forbidden and permitted atomic transitions has revealed no other reliable identification.[5] This is similar to the results of M. Nicolet[6] concerning the spectrum of the aurora borealis.

MOLECULAR BANDS

The main role in the spectrum of the night sky is played by the molecules, and especially by N_2; however, the identifications are in many cases still very uncertain. The first reason is observational, owing to the low dispersion and the low resolving-power available; however, in this regard we feel that our material is among the best collected so far. A second reason is our ignorance concerning the mechanism of excitation; even if we suppose that we know the general type of excitation, it does not seem safe to assume a priori any distribution on the rotational and vibrational levels. It seems that the rotational distribution corresponds to a low temperature, from 200° to 300° K; but different systems may be excited by different mechanisms or at various altitudes, and the distribution on the excited levels may differ widely from the thermodynamic equilibrium at the low kinetic temperature of the emitting regions. We also know that the excitation process may give rise to a strong selectivity among the vibrational transitions.

It would be interesting to compute systematically all the intensity distributions in the bands, assuming a low temperature—say 250° K. This could be done according to the general procedure followed by Swings and Nicolet,[7] or by Dufay,[8] for the spectra of comets. For the following discussion these complete calculations have not been made, and the effect has only been roughly estimated.

N_2 molecules.—All of the band systems of N_2 have been examined in order of increasing electronic excitation.

The Vegard-Kaplan system, $A^3\Sigma \rightarrow X^1\Sigma$, is similar to the atmospheric absorption bands of O_2, the upper level being metastable in both cases. The Vegard-Kaplan bands are degraded to the red in the laboratory, but in our present knowledge of the excitation processes in the high atmosphere it would be dangerous to assume that those in the spectrum of the night sky should show a sharp violet head. According to reliable identifications, the Vegard-Kaplan bands do not show any conspicuous structure on our spectrograms. This may be expected on a very low dispersion spectrogram of a low temperature emission.

The presence of the Vegard-Kaplan bands in the spectrum of the night sky seems quite certain, but some of the identifications still remain doubtful, owing partly to the fact that we had to use mostly calculated wave lengths. It is very desirable to obtain more laboratory information concerning these bands, particularly the relative intensities of those transitions observed in the spectrum of the night sky.

A first attempt in that direction has been made recently by R. Bernard,[9] who was able to excite the Vegard-Kaplan bands by electronic collisions. The bands are especially strong in the presence of a great excess of argon, and the sequences $v'' - v' = 10, 11, 12, 13$, are then as prominent as they are in the spectrum of the night sky. Bernard has given preliminary intensity estimates of the various vibrational transitions. Considering

---

[5] Our spectrograms exclude emissions such as *He* I, *Fe* II, etc., in interstellar space as well.

[6] *Ann. d'Ap.*, **1**, 381, 1938.

[7] *Ap. J.*, **88**, 173, 1938.

[8] *Ap. J.*, **91**, 91, 1940.

[9] *Ann. d. Phys.*, **13**, 1, 1940. O. R. Wulf and E. H. Melvin (*Phys. Rev.*, **55**, 687, 1939) have recently succeeded in exciting the Vegard-Kaplan bands in N_2 at atmospheric pressure and at a temperature which is practically that of the walls. The (0-5), (0-6), (1-4), and (1-5) transitions show a rotational structure which has been measured.

the laboratory and the observational techniques, the agreement with our observations is rather satisfactory.

If we introduce our identifications in a vibrational diagram, we obtain Figure 1. The Condon parabola is quite displaced, as compared with the theoretical curve computed by J. Gauzit;[10] but on the other hand, it agrees with Gauzit's observations. The shift is due to the fact that we are already dealing with fairly high vibrational levels, *v*.

The First Positive system, $B^3\Pi \rightarrow A^3\Sigma$, is especially difficult to detect with certainty, owing to the fact that the intensity distribution depends so very much on the type of excitation among the vibrational transitions. The probable identifications in the list of the McDonald Observatory are indicated in Table 5. Among them, λ 5442 (10, 5) and λ 5755 (12, 8) are present in active nitrogen. For the identifications the wave lengths of the heads have been considered, which seems plausible on low-dispersion spectrograms, owing to the prominence of the *Q* branch. Eleven bands observed by H. W. Babcock[1] are in good agreement with the wave lengths of the bands of this system. They are collected together in Table 1; however, some of these attributions are obviously uncertain. It is seen that the observed bands (except λ 5060) belong to the three sequences $\Delta v = 3$, 4, and 5.

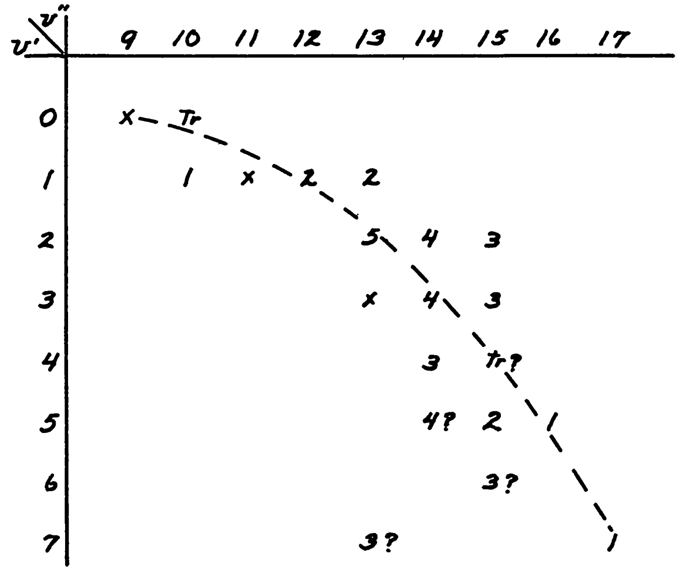


FIG. 1.—Vibrational diagram of Vegard-Kaplan bands of N_2 in the night sky. Crosses indicate bands which have not with certainty been observed in the night sky but which may be present.

The largest excitation potential observed is a little higher than 10 volts. The system is very weak, compared to the Vegard-Kaplan system, which requires only about 7 volts. It seems to us that, although there may still be some doubt concerning the identifications, the presence of the First Positive system may be accepted.

The Lyman-Birge-Hopfield system, $a\,^1\Pi \rightleftharpoons X^1\Sigma$, has been observed only in the region 1200–2500 A; but as the excitation energy is close to the higher level of the First Positive system, its extension toward the longer wave lengths should be considered, just as has been the case for the Vegard-Kaplan system. As far as we know, its possible presence in the night-sky spectrum has not been discussed previously. For identification purposes we shall use the wave lengths of the band heads, which again seems to be safe; the Lyman-Birge-Hopfield bands are degraded toward the red. We have computed the

---

[10] *Op. cit.*, p. 334.

wave lengths of the band heads of the series, $v' = 0, 1, \ldots, 10$,[11] but actually we should start the present discussion by examining the series of lowest excitation, $v' = 0$ (Table 2).

Many other suggestions have been introduced in Table 5. As in most of the identifications, we again cannot be certain with regard to the presence of the Lyman-Birge-Hopfield system; but at least there seems to be a fairly strong probability in favor of it, especially since two strong bands observed in the spectrum of the night sky, 3378 A and 3834 A, are degraded toward the red, as would be expected.

The main purpose of the present suggestion is to call the attention of the laboratory spectroscopists to this system of N_2, which should be reinvestigated and whose extension toward longer wave lengths should be attempted experimentally.

TABLE 1

N_2 BANDS OF THE $B^3\Pi \rightarrow A^3\Sigma$ SYSTEM IN BABCOCK'S LIST

λ (Obs.)	Transition	λ (Obs.)	Transition
5060 (1)	(11–5)+(10–4)*	6166 (1)	(4–0)
5242 (1)	(16–11)	6258 (3)	(11–8)*
5317 (1)	(14–9)	6401 (1)	(9–6)
5374 (0)	(12–7)*	6464 (2)	(8–5)
5709 (1)	(13–9)	6560 (3bb)	(7–4)
5965 (0)	(8–4)		

* Observed in active nitrogen.

TABLE 2

$v'=0$ SERIES OF THE LYMAN-BIRGE-HOPFIELD SYSTEM

Transition	λ (Calc.)	λ (Sky)	Intensity (Sky)
0–19	3375.2	3378 ± 2	5; wide, violet edge sharp
0–20	3591.3	Absent	....
0–21	3832.6	3834 ± 1	4; wide, violet edge sharp
0–22	4103.7	(4107)	Weak, uncertain
0–23	4410.8	4420 ± 3	5; wide (blended with other bands)

The excitation potential of the excited level $v' = 0$ is 8.5 volts.

The Second Positive system, $C^3\Pi \rightarrow B^3\Pi$, if present, must be of extreme weakness. The (0, 0) transition, which is the strongest in the system, has its head at λ 3371 and is degraded toward the violet. It seems very improbable that even this band plays any role as a blend in the strong band λ 3378, which has a sharp violet edge.

N_2^+ molecule.—The Negative system, $B^2\Sigma \rightarrow X^2\Sigma$, of the N_2^+ molecule has its strongest band at λ 3914.4, and it gives a partial identification of the narrow band observed at 3912 ± 2 A.

NO molecule.—The spectrum of the *NO* molecules has usually been considered to be absent from the night sky.

The β bands, $B^2\Pi \rightleftarrows X^2\Pi$, have double heads with an interval $\Delta\nu = 91.5$ cm^{-1}, and the bands are degraded toward the violet. Each band consists of a *P*, an *R*, and a weak *Q* branch. In this case it seems safe to use the origins for the identifications, but with the understanding that a systematic $\Delta\nu$ may appear. The origins of the three strongest

---

[11] The extension has been limited at $v' = 10$, owing to the hypothetic character of the identification; evidently it could be extended to higher vibrational levels.

double bands of the observable region are transition (0, 9), 3386.38 and 3376.43; transition (0, 10), 3583.48 and 3572.39; transition (0, 11), 3800.91 and 3788.48, each group having laboratory intensity 10.

It may be noticed that the (0–9) bands fall in the region of the strong, wide observed line λ 3378 ± 2, intensity 5. The absence of the (0–10) transitions may be due to their proximity to the very strong band at λ 3556. Finally, the (0–11) transition may play some role in the wide band λ 3789, whose measured wave length is too great to assume a pure identification with a Vegard-Kaplan band, (2–12), λ 3769.

The presence of the β bands of NO is not ascertained, nor has it been excluded. The excitation potential required is 5.6 volts.

The γ bands, $A^2\Sigma \rightleftharpoons X^2\Pi$, the Third Positive group of Deslandres, give coincidences as listed in Table 3. These identifications do not fit too well in the Condon parabola,[12] and we should not give too much weight to the coincidences indicated here. The excitation potential required is 5.5 volts.

TABLE 3

COINCIDENCES OF NIGHT-SKY LINES WITH γ BANDS OF NO

λ Laboratory	λ Night Sky
(1–8), 3112	(3110)
(3–12), 3303	3298±3, (3) wide, diffuse
(0–8), 3375	3378±2, (5) wide, violet edge sharp
(1–10), 3458	3460±1, (2) narrow

NH molecules.—The remarkable structure of the β bands, $B^3\Pi \rightarrow A^3\Sigma$, λ 3360 (0–0) and λ 3371 (1–1), is well known. On low-dispersion spectrograms with short exposures they appear like lines, although λ 3360 is wider than λ 3371. These bands may quite possibly play some role in the wide band observed at λ 3378, but the fact that the measured wave length is so different from 3360–3371 indicates that at least the contribution from NH must be small.

Other nitrogen compounds.—The molecules NO_2, N_2O_4, N_2O, N_2O_3, ... , seem to be absent from the spectrum of the night sky.

CH molecules.—J. Cabannes, J. Dufay, and J. Gauzit[13] have observed that the Vegard-Kaplan bands vary from the zenith to the horizon, whereas a group of lines near λ 4300 does not vary and would thus seem to be of interplanetary or interstellar origin.[14] They assume that these lines of constant intensity are due to the $A^2\Delta \rightarrow X^2\Pi$ system of CH.

If we assume a terrestrial (or near interplanetary) origin of the bands, the discussion of the CH violet system is easy, when using the theoretical intensity distribution in the spectra of comets, as indicated by P. Swings and M. Nicolet[7] and as actually used by M. Nicolet[15] to identify CH in comets, or when using the similar but more elaborate procedure of J. Dufay.[8] These theoretical diagrams show that the Q branch near λ 4313 may play a role in the observed line at 4316 A, together with a Vegard-Kaplan band.

On the other hand, the $B^2\Sigma \rightarrow X^2\Pi$ system near λ 3900 seems to be absent on our spectrograms.

The system $C^2\Sigma \rightarrow X^2\Pi$ is characterized by two bands: (0, 0) at λ 3143 and (1, 1) at λ 3157. It seems probable that these two bands are identical with our observed lines at λ 3145 ± 2 (intensity 1) and λ 3157.

---

[12] Schmidt, *Z.f. Phys.*, **64**, 119, 1930.

[13] *Nature*, **142**, 718, 1938.

[14] If the origin is interstellar, we should expect only the first rotational lines to appear, namely, λ 4300.2 and λ 4303.9, and these are not seen on our spectrograms. As far as our observations indicate, an interstellar emission is thus excluded. This does not apply to interplanetary origin.

[15] *Z.f. Ap.*, **15**, 154, 1938.

CN molecules.—According to Cabannes, Dufay, and Gauzit,[16] the *CN* bands are present in the spectrum of the night sky, and they belong to a group similar to the *CH* bands which do not vary from the zenith to the horizon, whereas the Vegard-Kaplan bands weaken at the zenith.

In the violet system, $B^2\Sigma \rightarrow X^2\Sigma$, the $\Delta v = 0$ group near λ 3883 should be considered essentially, but this band is absent from our spectra. Similarly, the $\Delta v = -1$ group near λ 4216 and the $\Delta v = +1$ group near λ 3590 are absent.

The agreement of some observed wave lengths with the tail bands (corresponding to $v' = 9, 10, \ldots, 15$) are pure chance coincidences.

Other carbon compounds.—The molecular bands of C_2, CO, CO^+, CO_2, are all absent from our spectrograms.

TABLE 4

SERIES $v'=0$ AND 1 OF THE SCHUMANN-RUNGE SYSTEM OF O_2

v''	Series $v'=0$		Series $v'=1$	
	λ Lab.	λ Sky	λ Lab.	λ Sky
12	3104.3	(3110)	. . . .	. . . .
13	3232.9	3233	3162.5	(3157)
14	3370.0	3378±2	3293.7	3298±3
15	3516.5	. . . .	3433.4	3425±3
16	3673.3	. . . .	3583.0	. . . .
17	3841.1	3834±1	3742.1	3742±1
18	4021.1	4016±2	3912.8	3912±2

O_2 molecules.—The Schumann-Runge system, $B^3\Sigma \rightleftharpoons X^3\Sigma$, of O_2 for transitions from $v' = 0$ and 1, corresponding to the lowest excitation, has been observed in the laboratory up to the visible region. The origins of the Schumann-Runge bands of the $v' = 0$ and 1 series are given in Table 4, along with lines observed in the spectrum of the night sky. Owing to the rotational structure of these bands, the observed centers of gravity should lie to the red of the origins by, say, about 5 A. Obviously, the coincidences do not all give reliable identifications, but there is some suspicion in favor of the presence of the Schumann-Runge bands. As Table 5 shows, they are the most probable blends of the observed lines listed in Table 4.

There is very little evidence for the presence of the atmospheric bands of O_2, $A^1\Sigma \rightarrow X^3\Sigma$, in the spectrum of the night sky measured by Babcock,[1] except possibly the α' band ($v' = 3$, $v'' = 0$), which could possibly explain λ 5775 and λ 5816.

OH molecule.—There is no definite evidence showing the presence of the *OH* system, $B^2\Sigma \rightleftharpoons A^2\Pi$, in the night sky except for some possible blending of the (1, 1) transition at λ 3122 to form a very weak and uncertain line measured at λ 3110.

H_2O molecule.—The so-called "*C* band" (transition from 1, 3, 1 to 0, 0, 0) may play some role in the broad band observed by Babcock at λ 6560 (3bb?). The weak ζ band (3, 2, 0) coincides practically with λ 5453 (2), observed by Babcock, but this may be merely a chance effect. The whole problem of the emission of bands of H_2O should be considered still unsettled.

INTENSITY VARIATIONS

The intensity variations in the spectrum, and of the integrated light, of the night sky have been the subject of many investigations, and again we will not attempt to give a bibliography of the work. G. Dejardin[2] has summarized much of the work prior to

---

[16] *Op. cit.*, p. 755.

TABLE 5

SPECTRUM OF THE NIGHT SKY

WAVE LENGTH AND MEAN ERROR	INTENSITY	IDENTIFICATION				
		Atom or Molecule	System*		Transition	Wave Length
(3110)	…	O_2	SR	0–12	$B^3\Sigma \rightarrow X^3\Sigma$	3104
		N_2	LBH	7–24	$a^1\Pi \rightarrow X^1\Sigma$	3116
		NO	γ	1–8	$A^2\Sigma \rightarrow X^2\Pi$	3112
		OH		1–1	$B^2\Sigma \rightarrow A^2\Pi$	3122
3145 ± 2	1	*CH*		0–0	$C^2\Sigma \rightarrow X^2\Pi$	3143
		N_2	LBH	9–26	$a^1\Pi \rightarrow X^1\Sigma$	3148
(3157)	…	*CH*		1–1	$C^2\Sigma \rightarrow X^2\Pi$	3157
		N_2	LBH	10–27	$a^1\Pi \rightarrow X^1\Sigma$	3164
		O_2	SR	1–13	$B^3\Sigma \rightarrow X^3\Sigma$	3162
		N_2	2d Pos.	1–0	$C^3\Pi \rightarrow B^3\Pi$	3159
3211 ± 1	3, narrow	N_2	LBH	2–20	$a^1\Pi \rightarrow X^1\Sigma$	3210
		N_2	VK	7–13	$a^3\Sigma \rightarrow X^1\Sigma$	3209
3233	…	O_2	SR	0–13	$B^3\Sigma \rightarrow X^3\Sigma$	3233
3263 ± ½	1, narrow	…	…	…	…	…
3298 ± 3	3, wide, diffuse	N_2	LBH	8–26	$a^1\Pi \rightarrow X^1\Sigma$	3298
		Na	…	…	$3s^2S \rightarrow 4p^2P^0$	3303
3321 ± 2	2, wide, diffuse	…	…	…	…	…
3378 ± 2	5, wide, violet edge sharp, red edge diffuse	N_2	LBH	0–19	$a^1\Pi \rightarrow X^1\Sigma$	3375
		N_2	LBH	1–20	$a^1\Pi \rightarrow X^1\Sigma$	3388
		O_2	SR	0–14	$B^3\Sigma \rightarrow X^3\Sigma$	3370
		NO	β	0–9	$B^2\Pi \rightarrow X^2\Pi$	3386–3376
		NH	β	0–0	$B^3\Pi \rightarrow A^3\Sigma$	3360
		NH	β	1–1	$B^3\Pi \rightarrow A^3\Sigma$	3371
		N_2	VK	0–9	$a^3\Sigma \rightarrow X^1\Sigma$	3353
		N_2	2d Pos.	0–0	$C^3\Pi \rightarrow B^3\Pi$	3371
3425 ± 3	1, diffuse	N_2	VK	1–10	$a^3\Sigma \rightarrow X^1\Sigma$	3425
		N_2	VK	4–12	$a^3\Sigma \rightarrow X^1\Sigma$	3417
		N_2	VK	7–14	$a^3\Sigma \rightarrow X^1\Sigma$	3424
		N_2	LBH	4–23	$a^1\Pi \rightarrow X^1\Sigma$	3428
3460 ± 1	2, narrow	*NO*	γ	1–10	$A^2\Sigma \rightleftarrows X^2\Pi$	3458
3488 ± 1	3, narrow	N_2	LBH	9–28	$a^1\Pi \rightarrow X^1\Sigma$	3492
3556	10†	…	…	…	…	…
(3598)	…	N_2	VK	0–10	$a^3\Sigma \rightarrow X^1\Sigma$	3603
		N_2	LBH	1–21	$a^1\Pi \rightarrow X^1\Sigma$	3602
3623	1, very narrow	N_2	LBH	3–23	$a^1\Pi \rightarrow X^1\Sigma$	3625

---

* The abbreviations for the names of the systems are: SR, Schumann-Runge; LBH, Lyman-Birge-Hopfield; VK, Vegard-Kaplan.

† This is a very wide line and it is the strongest in the ultraviolet region. Its violet edge is sharper than the red edge. On one plate the wide line appeared to be separated into two lines with the wave lengths 3549 A and 3558 A.

TABLE 5—*Continued*

Wave Length and Mean Error	Intensity	Identification				
		Atom or Molecule	System*		Transition	Wave Length
3636.........	2, narrow	N_2	LBH	4–24	$a^1\Pi \rightarrow X^1\Sigma$	3635
3664±1......	1, narrow	N_2 N_2	VK LBH	4–13 7–27	$a^3\Sigma \rightarrow X^1\Sigma$ $a^1\Pi \rightarrow X^1\Sigma$	3666 3667
3707±3......	3, wide	N_2	VK	1–11	$a^3\Sigma \rightarrow X^1\Sigma$	3685
3742±1......	4, wide	N_2 O_2	VK SR	5–14 1–17	$a^3\Sigma \rightarrow X^1\Sigma$ $B^3\Sigma \rightarrow X^3\Sigma$	3753 3742
3787.........	1, wide	N_2	VK	2–12	$a^3\Sigma \rightarrow X^1\Sigma$	3769
3817.........	1, very narrow	....	....	....	....	....
3834±1......	4, wide, violet edge sharp, red edge diffuse	N_2 N_2 O_2	VK LBH SR	6–15 0–21 0–17	$a^3\Sigma \rightarrow X^1\Sigma$ $a^1\Pi \rightarrow X^1\Sigma$ $B^3\Sigma \rightarrow X^3\Sigma$	3845 3833 3841
3912±2......	5, narrow	N_2^+ N_2 O_2	Neg. LBH SR	0–0 10–31 1–18	$B^2\Sigma \rightarrow X^2\Sigma$ $a^1\Pi \rightarrow X^1\Sigma$ $B^3\Sigma \rightarrow X^3\Sigma$	3914 3910 3913
3948±3......	3, narrow	N_2	VK	4–14	$a^3\Sigma \rightarrow X^1\Sigma$	3949
3984±2......	2	N_2	VK	1–12	$a^3\Sigma \rightarrow X^1\Sigma$	3979
4016±2......	2, wide	O_2	SR	0–18	$B^3\Sigma \rightarrow X^3\Sigma$	4021
4048±1......	2	N_2	VK	5–15	$a^3\Sigma \rightarrow X^1\Sigma$	4046
4072±2......	5, wide	N_2	VK	2–13	$a^3\Sigma \rightarrow X^1\Sigma$	4073
(4107)	....	N_2	LBH	0–22	$a^1\Pi \rightarrow X^1\Sigma$	4104
4134±2......	3, narrow	N_2	LBH	7–29	$a^1\Pi \rightarrow X^1\Sigma$	4133
4174±2......	5, wide	N_2	VK	3–14	$a^3\Sigma \rightarrow X^1\Sigma$	4171
4259.........	1, wide.................	N_2	VK	7–17	$a^3\Sigma \rightarrow X^1\Sigma$	4254
(4268)	....	N_2	VK	4–15	$a^3\Sigma \rightarrow X^1\Sigma$	4270
4316.........	2	N_2 CH	VK	1–13 0–0	$a^3\Sigma \rightarrow X^1\Sigma$ $A^2\Delta \rightarrow X^2\Pi$	4321 4313
4379.........	1, narrow	N_2	VK	5–16	$a^3\Sigma \rightarrow X^1\Sigma$	4383
4420±3......	5, wide	N_2 N_2	VK LBH	2–14 0–23	$a^3\Sigma \rightarrow X^1\Sigma$ $a^1\Pi \rightarrow X^1\Sigma$	4425 4411
4543±1......	3, wide	N_2	VK	3–15	$a^3\Sigma \rightarrow X^1\Sigma$	4536
4587±3......	1, narrow	....	....	....	....	....
4669±1......	1, wide	....	....	....	....	....

TABLE 5—*Continued*

Wave Length and Mean Error	Intensity	Identification			
		Atom or Molecule	System*	Transition	Wave Length
4827±3	3	N_2	VK 2–15	$a^3\Sigma \rightarrow X^1\Sigma$	4838
4878±1	1, narrow	....	....	....	....
(4994)	....	....	....	....	....
5213	....	N_2	1st Pos. 17–12	$B^3\Pi \rightarrow A^3\Sigma$	....
(5352)	....	N_2 O_2	1st Pos. 13–8 Atm. 4–0	$B^3\Pi \rightarrow A^3\Sigma$ $A^1\Sigma \rightarrow X^3\Sigma$	5339 5360
(5441)	....	N_2	1st Pos. 10–5	$B^3\Pi \rightarrow A^3\Sigma$	5442
5577	500, narrow	[*O* I]	....	$[2p^1D - 2p^1S]$	5577
(5750)	....	N_2	1st Pos. 12–8	$B^3\Pi \rightarrow A^3\Sigma$	5755
5893	25, narrow	*Na* I	....	$3s^2S - 3p^2P^o$	5893
6235	5, narrow	N_2	1st Pos.	Blend	....
6300	25, narrow	[*O* I]	....	$[2p^3P_2 - 2p^1D_2]$	6300
6364	3, narrow	[*O* I]	....	$[2p^3P_1 - 2p^1D_2]$	6364
6580	1, wide	N_2	1st Pos.	Blend	....

1936, while some of the more recent investigations have been reported by Dufay.[17] We will give only some preliminary observations of the variations in the intensities of some of the lines we have observed in the spectrum of the night sky.

Many exposures were made with the nebular spectrograph of the McDonald Observatory in the survey by Struve and Elvey[18] for emission nebulosities in the Milky Way. These exposures are all long enough to show a fairly intense spectrum of the night sky, and although many of them are not calibrated for photometric purposes they are satisfactory for making estimates of the relative intensities of the spectral lines. We have 280 spectrograms well distributed over the sky and taken throughout the year, and we believe that the estimated intensities will suffice to bring out the macroscopic character of the changes and will point the way for more detailed photometric investigations.

All the spectrograms were examined indiscriminately, and the estimates of the relative intensities of the green auroral line to that of the sodium line and the oxygen line at λ 6300 were recorded. The estimates are on an arbitrary scale and have not been calibrated. In order to smooth over the diurnal and the irregular variations, the estimated ratios for a given lunation were grouped together, and average values were obtained. These are plotted in Figure 2. The upper curve gives the relative intensities for λ 5577/λ 5892, and the lower curve those for λ 5577/λ 6300. It is seen from the curves that the relative intensities of the two oxygen lines (lower curve) are reasonably constant throughout the year. On the other hand, the relative intensities of oxygen to sodium (upper curve) show a definite maximum in the summer. The point marked with an arrow

---

[17] *Trans. I.A.U.*, **6**, 164, 1938.

[18] *Ap. J.*, **89**, 119 and 517, 1939; **90**, 301, 1939.

is indeterminate because the sodium line was so weak that an estimate could not be made. The curves, being plots of a ratio, do not indicate which of the two lines involved is variable. However, an inspection of the plates shows that the sodium lines are weak, relative to the rest of the spectrum. This is confirmed by observations by H. W. Babcock[1], in which he found that spectrograms taken during the same summer showed very weak sodium lines, while those taken during the following October showed sodium lines approximately fivefold stronger.

Unfortunately, our observations were not carried through the summer of 1939. A few observations were obtained in August and September and are shown on the diagram. Those for September are rather discordant, but this seems definitely to be due to an enhancement of the green auroral line relative to the remainder of the spectrum at that time.

An explanation of the observed phenomenon would be rather hazardous at present, since we have no sound theory to explain the origin of the sodium atoms in the atmosphere, and it would be rather difficult to tell whether the variation is a matter of abundance or of excitation. The increase in the intensity of the sodium line does correspond with the time of the year when the meteors are most abundant (one of the suggested origins for the sodium atoms), but this meager evidence cannot be taken to confirm the meteoric origin of the sodium atoms.

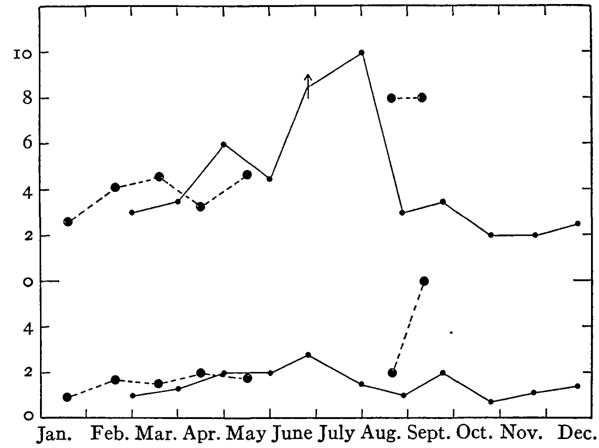


FIG. 2.—Estimated relative intensities of λ 5577/λ 5892 (*upper curves*) and λ 5577/λ 6300 (*lower curves*). The dots are observations for 1938, and the dot with circle for 1939.

Another phenomenon exhibited by the sodium atoms is the great enhancement of the sodium D lines in the spectrum of dawn and of twilight. This is, no doubt, a direct resonance phenomenon which is caused by the illumination of sunlight and which must be quite different from the nocturnal excitation of the sodium atoms. S. Chapman[19] has discussed the excitation of sodium in the upper atmosphere and has suggested that it is a result of a collisional process whereby excited oxygen atoms give up energy to the sodium atoms.

These two mechanisms of excitation of the sodium atoms in the upper atmosphere should help to throw some light upon the question of the variability of the sodium observed, for if both the night-sky spectra and the dawn or twilight spectra had weak sodium lines at the same time, we could reasonably well interpret the decreased intensity of the sodium lines as an abundance phenomenon rather than one of excitation. Unfortunately, we have only two spectra of dawn at the time of the observed minimum of the sodium lines in the night sky, and although they do not show a trace of the sodium lines, we cannot draw any conclusions, for the spectrograms were taken when the illuminated atmosphere at the end of the exposure was 85 km above the surface of the earth. To obtain the best dawn spectra of the sodium lines, the illuminated atmosphere should be as low as 60 km.

With respect to the sodium line, we have one lone observation which is of interest. During the night of February 11/12, 1939, while we were making an exposure with the nebular spectrograph of a region of BD − 3°1643, we observed in the eastern part of

[19] *Ap. J.*, **90**, 309, 1939.

the sky a diffuse luminous area extending from the southeast to the northeast along the horizon and reaching an altitude of about 10° in the east. We completed the exposure and then made a similar one on the luminous area, the area having decreased somewhat in luminosity before the end of the exposure. A reproduction of the green-red region of the two spectrograms is shown in Plate XV. The sodium line, λ 5893, is distinctly enhanced in the luminous area, showing either an excess of sodium atoms in that region or a condition of excitation more favorable to the production of the sodium line. There was no ionospheric storm, and the magnetic character figure at the time was 0.0.

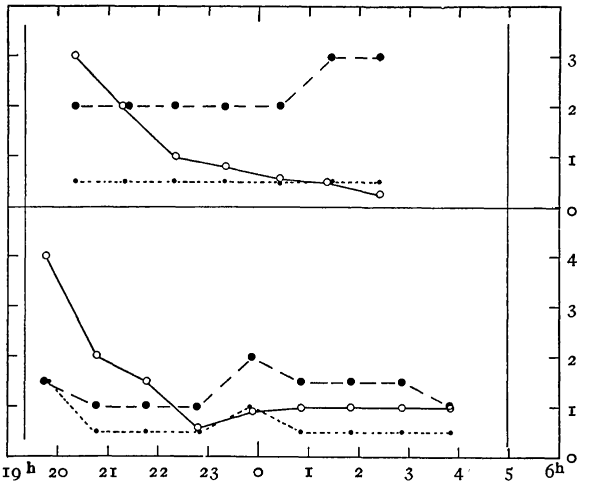


FIG. 3.—Diurnal variations of λλ 5577 (large dots), 5892 (small dots), and 6300 (circles) for the nights of November 16/17 (*upper curve*) and 19/20, 1938. The abscissae are Central Standard Times, and the ordinates are estimates of intensities on an arbitrary scale.

On several nights during November, 1938, the nebular spectrograph was used to obtain a series of exposures of one-hour duration, each to show the diurnal variations of the principal radiations in the visual region of the spectrum of the night sky. Since the slit of the spectrograph is quite long, it was possible, with the aid of a specially constructed set of apertures, to make a series of five exposures on each film. When more than one film was taken on a night, all were developed together. For the purposes of the present investigation, estimates of intensities have been made for the lines λλ 5577, 5892, and 6300 A on two nights: November 16/17 and 19/20, 1938. The results are plotted in Figure 3, the abscissae being the hours of the night in Central Standard Time, and the ordinates the estimated intensities in arbitrary units.

The data for the two nights show similar results, with the exception that the line λ 5577 is consistently stronger on November 16/17. The striking feature of the curves is the high intensity of λ 6300 at the beginning of the night and its gradual decrease to a more or less steady value around midnight.[20] The tendency of λ 5577 to reach a maximum after midnight, as noted by many observers, is indicated but is not very pronounced. Apparently, the sodium line is quite constant throughout the nights in question.

The oxygen line λ 5577 originates from the metastable state ^{1}S and terminates in the ^{1}D state, which is metastable and is at the same time the origin of λ 6300. Our observations show that the oxygen atoms can reach the ^{1}D state independently of the transition from the ^{1}S state. The processes of excitation must be considered in order to explain the differences in the behavior of the two lines of oxygen throughout the night, but we shall postpone such considerations until our spectrophotometric observations are complete.

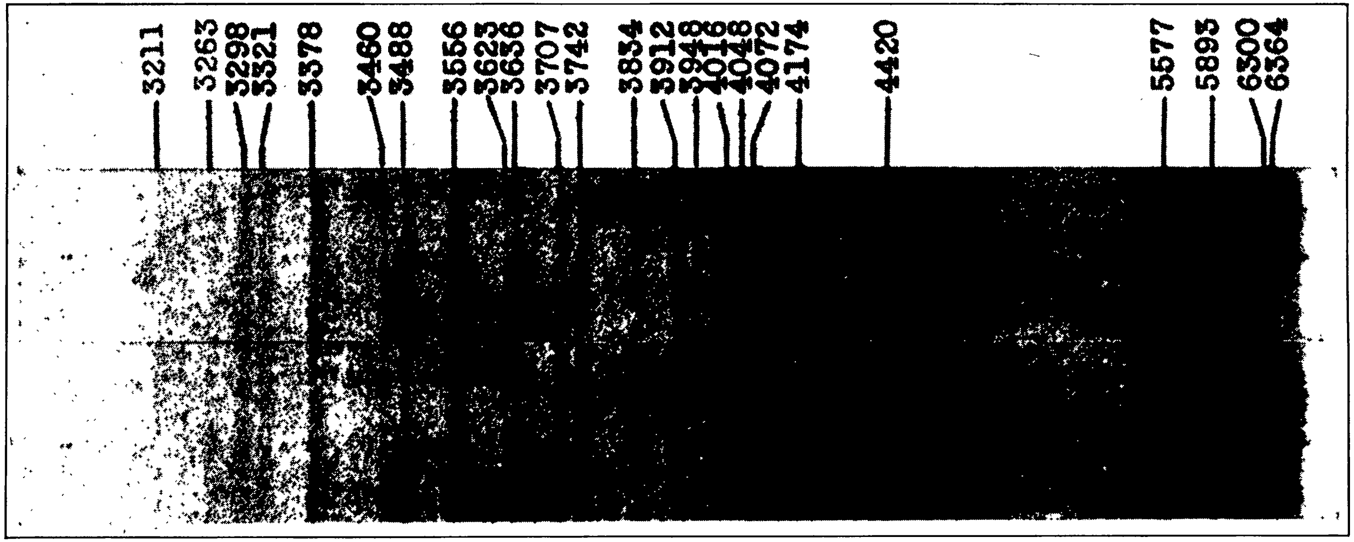
This work was in part supported by a grant from the American Association for the Advancement of Science, for which grateful acknowledgment is made.

McDONALD OBSERVATORY
August 1940

---

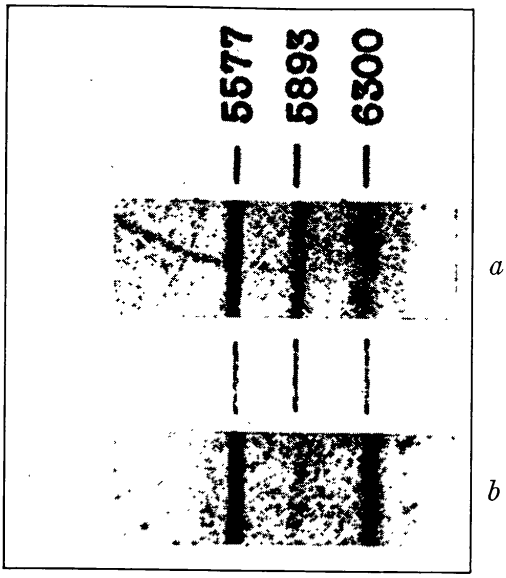
[20] This phenomenon has been observed by H. Garrigue, *C.R.*, **202**, 1807, 1936; **205**, 491, 1937.

PLATE XIV



The Spectrum of the Night Sky

PLATE XV



a) SPECTRUM OF LUMINOUS AREA OF NIGHT SKY OBSERVED ON FEB. 11/12, 1939 5^h20^m TO 8^h25^m U.T.

b) NORMAL SPECTRUM OF NIGHT SKY OBSERVED DURING THE SAME NIGHT 2^h10^m—5^h10^m U.T.