NOTES

COMPARISON OF THE *Na* AND N_2^+ FLASHES AT TWILIGHT AND DAWN*

I. INTRODUCTION

The material on twilight and dawn spectra available at the McDonald Observatory has been investigated for the N_2^+ flash, which is compared with the D emission of *Na*. The N_2^+ flash is a general phenomenon. The intensity gradients and variations of N_2^+ and *Na* are compared. The *Na* emission varies from point to point and from twilight to dawn much more than does N_2^+.

During the period from January, 1939, to April, 1941, C. T. Elvey, Miss A. H. Farnsworth, and W. Linke obtained about fifty series of excellent twilight and dawn spectra covering the region λλ 3800–6600 by using the fast spectrographs of the McDonald Observatory. On account of the importance of the N_2^+ flash for upper-atmosphere physics, it has appeared desirable to re-examine these spectra which have hitherto not been studied for the N_2^+ emission. In France, M. and J. Dufay[1] have recently discussed their observations of the N_2^+ flash. These authors considered only the twilight and pointed their spectrographs west. The material considered here comprises dawn, as well as twilight, spectra; phenomena at twilight and dawn may thus be compared. For each series considered in this paper, night-sky spectrograms are available which were taken during the same night as a check on the presence of auroral activity. The spectra were obtained during a period of low magnetic activity and hence are not well suited to an investigation of the relation between the N_2^+ intensity and magnetic or auroral activity, such as was suggested by M. and J. Dufay.

II. SPECTRA OBTAINED WITH THE NIGHT-SKY SPECTROGRAPH,[2] NOVEMBER 22–DECEMBER 11, 1939

Twelve series of spectrograms of good quality are available, seven taken at twilight and five at dawn. Each series consists of from four to seven successive exposures.

a) Let h be the height of the grazing solar ray in the direction of observation. In ten of the twelve series the negative intensity gradient, $-dI/dh$, of the *Na* line is definitely larger than that of N_2^+—in some cases conspicuously so. In one case (twilight, December 7, 1939) the *Na* and N_2^+ gradients are about the same; on this plate *Na* is extremely weak. In another case (dawn, November 22, 1939) the observational data are inconclusive.

b) A steady intensity increase of the N_2^+ emission is observed when h decreases. However, at $h \sim 40$ km the scattered solar spectrum becomes too strong for a normal N_2^+ emission at λ 3914[3] to appear; the visibility of the emission is uncertain on two plates for which $h = 42$ and $h = 48$ km, respectively. The scattered solar spectrum constitutes the only limitation.

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[1] *C.R.*, **224**, 1834, 1947.

[2] For a description of the spectrograph used see C. T. Elvey and Alice H. Farnsworth, *Ap. J.*, **96**, 451, 1942; the spectrograph is quite transparent at λ 3914. The exposures were of 10 minutes, except at the beginning of twilight (4, 5, or 7 min.) and at the end of dawn (5 or 2 min.). The spectrograph was pointed west or east at well-defined azimuth and zenith distances.

[3] The lower limit of h at which λ 3914 can still be observed is, of course, smaller than that at which λ 4278 is lost in the solar spectrum.

c) A comparison between the intensities of Na and of N_2^+ on successive nights or at twilight and dawn has a physical meaning only if h is approximately the same and if there is no trace of auroral display. Such a comparison has been made for the lowest h, corresponding to the highest intensities of N_2^+ and Na. The intensity ratio of Na and N_2^+ for the same h shows striking variations from day to day.

d) The N_2^+ emission is unobservable (with the present equipment and exposures) for $h > 130$ km.

e) For a comparison between twilight and dawn, excellent sets of spectrograms for twilight, night sky, and dawn are available for December 7, 8, and 11. In all three cases the intensity ratio Na/N_2^+ is much larger at dawn than at twilight. Relative intensities are clearly more easily determined than are absolute intensities; but it appears safe to say

TABLE 1

OBSERVATIONS DATA FOR N_2^+ ON NOVEMBER 22–DECEMBER 11, 1939

Date	Twilight				Dawn			
	Minimum h where N_2^+ Observed (Km)	Maximum Estimated Absolute Intensity of N_2^+	Data on Maximum h of N_2^+ Emission (Km)	Relative Intensity of Na and N_2^+ at Lowest h	Minimum h where N_2^+ Observed (Km)	Maximum Estimated Absolute Intensity of N_2^+	Data on Maximum h and N_2^+ Emission (Km)	Relative Intensity of Na and N_2^+ at Lowest h
Nov. 22...	70	......	Weak at 120	$Na>N_2^+$	86–82	4	Weak at 115	$Na>N_2^+$*
Dec. 3...	70	3	Faintly visible at 120; absent at 160	$Na>N_2^+$	......	......	....	....
Dec. 7...	70	1	Weak at 87	$Na\geq N_2^+$	70	3	Weak at 92; hardly visible at 100	$Na>>>N_2^+$
Dec. 8...	65	4	Very weak at 120; absent at 125	$Na>N_2^+$	62–67	4	Very weak at 81	$Na>>N_2^+$
Dec. 9...	42†	4†	Weak at 102; faint trace at 130	$Na>N_2^+$	55–64	2	Weaker at 73; absent at 92‡	$Na>N_2^+$
Dec. 10...	48–64†	4	Absent at 92	$Na<N_2^+$	......	......	....	....
Dec. 11...	58–68	3	Absent at 83	$Na\leq N_2^+$	61–73	2	Very weak at 95	$Na>>>N_2^+$

* Observations rather poor. † Uncertain because of intense solar spectrum. ‡ Rather weak spectra.

that N_2^+ was not noticeably weaker at dawn than at twilight, while, for a given h, Na was more intense at dawn. On November 22, 1939, the intensity ratio Na/N_2^+ seemed to remain the same for twilight and dawn; on that day Na was rather weak (so also was N_2^+). The results are summarized in Table 1.

III. DAWN SPECTRA OBTAINED WITH THE NEBULAR SPECTROGRAPH[4]

Eight series of spectrograms are available for a study of N_2^+ (Table 2). In addition, two series obtained on January 20 and 23, 1939, revealed intense Na lines, with practically

[4] For description see O. Struve, G. Van Biesbroeck, and C. T. Elvey, *Ap. J.*, **87**, 559, 1938. Only the dawn (at well-determined azimuths and zenith distances) can be observed with this instrument. Usual zenith distances ~85°. All exposures of 10 minutes except at beginning of twilight (≃5 min.) and end of dawn (≃5 min.).

no trace of N_2^+. Table 2 shows that on five dawns the intensity gradient of Na was much steeper than that of N_2^+, while in three cases (April 21 and 22, September 10) the gradients were about the same; in these three cases the intensity ratio Na/N_2^+ was definitely smaller than on the other dawns. Since N_2^+ did not change appreciably, a strong decrease in Na activity appears to have been present on these three days.

A careful examination of the relative intensities of the green (night-sky) line of [O I] and of the Na line on the series of night-sky and dawn spectra from April 18 to April 23 and around September 10 indicates that on April 21 and 22 and on September 10, the D line at dawn had approximately the same intensity as in the night-sky spectrum, so that there was no Na flash. In other words, when the D line at dawn is very weak, its intensity is simply due to night-sky emission. This result may be related to the "patchy" character of Na emission in the upper atmosphere.

From Table 2 it also appears that an increase of height h by 10 km reduces the N_2^+ intensity by a factor of about 2, while the Na flash is reduced by a factor of about 10.

TABLE 2

DAWN OBSERVATIONS MADE WITH THE NEBULAR SPECTROGRAPH

Date 1939	Minimum h where N_2^+ Observed (Km)	Estimated N_2^+ Gradient	Relative Intensity of Na and N_2^+ at Lowest h	Estimated Na Gradient	Relative Value of N_2^+ and Na Gradient	Estimated Intensity of N_2^+ at Lowest h
Feb. 24....	69–74	*	$Na>>N_2^+$	$I_{85}\simeq 0.1\, I_{74}$	Grad. $(N_2^+)<<<$ Grad. (Na)	4
Apr. 18....	84–90	$I_{102}\sim 0.5\, I_{90}$	$Na\simeq N_2^+$	$I_{102}\simeq 0.1\, II_{90}$	Grad. $(N_2^+)<<<$ Grad. (Na)	5
Apr. 19....	80–85	$I_{96}\sim 0.35\, I_{85}$	$Na\simeq N_2^+$	$I_{96}\simeq 0.1\, I_{85}$	Grad. $(N_2^+)<<<$ Grad. (Na)	4
Apr. 20....	80–85	$I_{96}\sim 0.4\, I_{85}$	$Na\simeq N_2^+$	$I_{96}\simeq 0.1\, I_{85}$	Grad. $(N_2^+)<<<$ Grad. (Na)	5
Apr. 21....	85–90	$I_{102}\sim 0.5\, I_{90}$	$Na<N_2^+$	About same as N_2^+	Grad. $(N_2^+)\leq$ Grad. (Na)	3–4
Apr. 22....	84–89	$I_{100}\sim 0.5\, I_{89}$	$Na<N_2^+$	About same as N_2^+	Grad. $(N_2^+)\leq$ Grad. (Na)	5
Apr. 23....	83–88	$I_{99}\sim 0.5\, I_{88}$	$Na\leq N_2^+$	$I_{99}\simeq 0.2\, I_{88}$	Grad. $(N_2^+)<<$ Grad. (Na)	6
Sept. 10....	83–88	$I_{99}\sim 0.7\, I_{88}$	$Na<<<N_2^+$	About same as N_2^+	Grad. $(N_2^+)\simeq$ Grad. (Na)	5

* Defect on plate.

Similar estimations are more difficult on the spectrograms listed in Table 1 (which have lower dispersion), which, however, give similar results.

The distribution of Na atoms within the atmosphere does not conform to the fairly uniform distribution of the normal constituents of the atmosphere; this may be due to the particular origin of atmospheric sodium. The patchy character affects twilight and dawn spectra as well as night-sky spectra.

IV. TWILIGHT AND DAWN SPECTRA OBTAINED AT YERKES OBSERVATORY AND AT VARIOUS OTHER LOCATIONS, WITH A NIGHT-SKY SPECTROGRAPH[5]

A series of spectrograms obtained at dawn, July 13, 1940, at the Yerkes Observatory, at zenith distances 0°, 60°, 70°, 80°, and 85° shows that (a) the Na line increases steeply in intensity when h decreases from $h = 100$ to $h = 68$ km (the Na emission is extremely weak for $h = 100$ and is not seen for $h > 100$); and (b) the N_2^+ bands increase more slowly in intensity but are still visible at $h = 134$ km. They seem unusually intense (more than on McDonald plates). One may estimate that N_2^+ would appear to approximately

[5] All these spectrograms were obtained by Miss Farnsworth.

160 km. The (0, 0) and (0, 1) bands behave exactly alike; the (0, 1) band is at least one-third as strong as the (0, 0) band. The intensity distribution among the vibrational transitions of N_2^+ is more closely related to sunlit aurorae or high-altitude aurorae than to ordinary aurorae. This point has been mentioned by M. and J. Dufay.

A set of 27 series of good spectrograms—11 at twilight and 16 at dawn—cover the period July 13, 1940, to spring, 1941, and the latitudes from 42°15′ N. to 31°36′ S. The following general results are obtained: (*a*) The intensities of N_2^+ and *Na* increase regularly with decreasing *h*. (*b*) The gradient of *Na* is much steeper than that of N_2^+, except when the *Na* line is very weak (night-sky emission). (*c*) Generally, *Na* is stronger at dawn than at twilight of the same night, while N_2^+ does not differ appreciably. (*d*) One finds many different intensity ratios for N_2^+ and *Na* at their maximum intensity (i.e., at the lowest height *h* compatible with scattered solar radiation). In the course of the observations of twilight and dawn made in New England during the spring of 1941, N_2^+ was almost always much more intense than *Na*, and the *Na* gradient was not much steeper than that of N_2^+. On the other hand, observations of the dawn in Argentina in November and December, 1940, revealed almost always *Na* definitely stronger than N_2^+.

V. CONCLUSIONS

a) The N_2^+ flash is observed on almost every series of good spectrograms taken at either twilight or dawn. Among about fifty good series, only two were found (dawns of January 20 and 23, 1939, at McDonald) in which N_2^+ was practically absent.

b) The intensity gradient of N_2^+ remains fairly constant. An increase of *h* by 10 km around 80–90 km reduces the intensity of the N_2^+ flash by a factor of approximately 2.

c) The intensity gradient of *Na* varies considerably. The *Na* emission is the sum of two terms, that of the night sky and that of the twilight flash, the relative importance of which varies considerably. The twilight flash has a very steep intensity gradient. When *Na* is very weak, the gradient is mainly due to the night-sky emission. When *Na* is very strong, the gradient is mainly due to the twilight (steeper than N_2^+). In the latter case an increase of *h* by about 10 km (around 80–90 km) reduces the *Na* flash by a factor of about 10.

d) The intensities of N_2^+ and *Na* increase with decreasing *h*. When *h* decreases, the background of the solar spectrum sets the limit of visibility.

e) For the same *h* the relative intensities of N_2^+ and *Na* vary considerably, even in a short interval of time. This is probably related to the patchiness of any upper-atmosphere emission. It seems that N_2^+ is "less patchy" than *Na*. Over long periods seasonal effects may also appear. In the night sky the *Na* line is known to be about five times stronger in November than in June or July. A similar effect seems to be present for the twilight.

f) Under "normal conditions" (no auroral display; N_2^+ and *Na* neither abnormally intense nor abnormally weak), N_2^+ has about the same intensity in the dawn flash as in the twilight flash, but *Na* is stronger at dawn than at twilight.

g) N_2^+ has been observed to $h \simeq 134$ km and could probably appear to $h \simeq 160$ km. On the other hand, our spectrograms do not reveal "twilight *Na*" for $h > 100$.

h) The relative intensities of the (0, 0) and (0, 1) bands of N_2^+ are similar to those in sunlit aurorae or in high-altitude aurorae (not to those in ordinary, low-altitude aurorae).

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P. Swings
M. Nicolet

McDonald Observatory
and
Royal Meteorological Institute, Brussels
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