NEW IMPORTANT RESULTS RELATING TO THE AURORAL SPECTRUM AND THE STATE OF THE UPPER ATMOSPHERE

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§ 1. Introductory Remarks.

The present paper deals with auroral and some twilight spectrograms obtained partly at the Auroral Observatory at Tromsø, partly at the Physical Institute at Oslo. The spectrograms, with the exception of one, were taken during the winter season 1940—41. Taking into account the aim and purpose of the observations we may conveniently divide them into the following groups:

a. It is of particular importance to obtain spectrograms which enable us to measure as accurately as possible the weaker auroral lines, which appear *e. g.* in the green and blue part of the spectrum. Great interest is attached to the possible appearance of the hydrogen lines and lines originating from oxygen and nitrogen atoms in various states of ionisation. As regards hydrogen, one of us (1.2, 24) recently found that lines coinciding with the Balmer-lines (H_α and H_β) occasionally appear with considerable strength in the auroral spectrum, while as a rule they are absent or too weak to be observed. This result would mean that occasionally showers of hydrogen were falling into the atmosphere.

In order to test the correctness of our interpretation of the weak lines, it is of importance to obtain as many as possible of the weaker lines on spectrograms having a fairly great dispersion. In order to get the weaker lines the spectrograph must also have a great light power; but even then we have to continue the exposure for several nights with aurorae.

One of the big glass spectrographs at Tromsø (spectrograph B) was constructed by one of us to meet these requirements. With regard to its construction we may refer to a detailed description given in a previous paper (3).

With this spectrograph we have obtained five most interesting spectrograms (Pl. I) giving a large number of weak lines which may be measured with fairly great accuracy and some of which are new lines not previously measured.

b. The great interest which is attached to the appearance in the auroral spectrum of the red oxygen triplet *OI* ($^1D_2$—$^3P_{0\,12}$) makes it a matter of importance to determine as accurately as possible the relative intensity of its components. Some attempts in this direction have already been made (4), but the spectra were not quite suitable and the previous results cannot claim any great accuracy.

In order to obtain an observational material suitable for this purpose, it was essential to use a spectrograph of large dispersion so as to get the components well separated, and to reduce the background density near the lines. For this purpose a number of successful spectrograms were taken during the winter-season 1940—41 with the great glass spectrograph (A) from 1921 previously described by one of us (compare paper (5) Pl. IV, Fig. 1). Reproductions of these spectrograms are shown on plate II, series A.

c. As is well known, the auroral spectrum is subject to great variations, which are particularly pronounced in the red part. Some very interesting and pronounced variations were found from a series of spectrograms taken with a small glass spectrograph (*a*) during the two successive evenings March 1 and 2, 1941. Reproductions are given on Pl. II series (*a*) and (*b*).

d. As shown in previous papers (5, 6, 7, 8), the temperature in the auroral region may be measured by means of the intensity distribution within one of the rotational bands appearing in the auroral spectrum. As a rule the temperature corresponds to the night side of the earth and to an interval of altitude between say 100 and 140 km.

As pointed out in previous publications (2,9) the temperature may increase with altitude and may be greater on the day side than on the night side of the earth.

The possible variation with altitude was studied by one of us (2,9) by observing the light emitted from very long rays, but no marked increase of temperature was to be observed. The possible influence of direct sunlight on the temperature of the ionosphere might be detected by taking spectra from light emitted from aurorae exposed to sunlight.

By means of the large quartz spectrograph (Q) previously described (paper 3, Fig. 4), we obtained last winter from aurorae exposed to sunlight a spectrogram, which gave some of the negative bands with a density suitable for temperature measurements (Plate II, No. 13).

e. In order to study the fairly rapid variations of the auroral spectrum, it is essential that the time of exposure necessary to obtain a suitable spectrogram should be as short as possible, but at the same time it is very desirable that the dispersion is so great, that lines may appear fairly well separated. For this purpose one of us (Vegard) recently built two spectrographs one of which had the camera lens replaced by a concave mirror.

These instruments will be described in a subsequent paper, but some results obtained with one of them from spectrograms taken at Oslo will be dealt with here.

CHAPTER I

Results derived from Spectrograms Taken with the Large Glass Spectrograph (B), Particularly Concerning the Appearance and Interpretation of Weak Lines.

§ 2. Some Remarks Regarding the Spectrograms.

The spectrograms to be dealt with in this chapter are those reproduced on Plate I. The necessary data such as time of exposure and type of plate are given in the explanations to the plates printed at the end of this paper. All of them have been subject to a long exposure.

In addition to the strong bands and lines which usually appear on auroral spectrograms, the spectrograms contain many weak lines and bands, and a considerable number of these have not previously been observed and measured.

In addition to the auroral spectrogram each plate contained an intensity scale from a light source with known spectral intensity distribution, by means of which it was possible to determine the relative intensity of the lines appearing on the auroral spectrogram. A spectrum of helium mixed with some hydrogen was used for comparison.

The first spectrogram (Pl. I, No. 1) was obtained during the winter season 1939—40 and on account of its particular importance some results derived from it have already been published (10).

A closer examination of the five spectrograms on Plate I shows that they differ considerably with regard to intensity distribution, and show the appearance or absence of certain weak bands and lines. These differences are partly due to differences as regards the relative sensitivity of the plates in the various spectral regions; but, as we shall see later on, some of these differences are real and due to variations in the composition of the auroral luminescence.

The spectrograms Nos, 1, 3, and 4 were taken on the same sort of plates (Ilford Selo Chrom). Spectrogram No. 2 is taken on Ilf. doubl. *X*-press and No. 5 on Ilf. Hyp. Pan. 2. The spectral sensitivity curves for the three plates, when used in connection with the spectrograph (B) are represented in Fig. 1. The sensitivity is measured by the quantity (Q) which has been introduced and explained in previous papers. (Cf. *e. g.* paper 11.) It is highly important that the spectral sensitivity distribution of the plates is taken into account when we are comparing spectra not taken on plates of the same sort.

The auroral spectrum on plate No. 5 has a displacement relative to the comparison spectrum, and its lines are not sharp. For some unknown reason the instrument had suffered some mechanical or thermal change during the exposure. The weaker lines on the auroral spectrogram, however, can be measured by means of the stronger auroral lines, for which the wavelength has been accurately determined.

On spectrogram No. 2 the auroral luminescence is mixed with some reflected sunlight (twilight) which produces a continuous background and is intercepted by absorption lines, which are particularly well seen in the short wave region.

The spectrograms Nos. 1, 3, and 4 which should correspond to fairly pure auroral luminescence have remarkably sharp lines, but in certain spectral regions *e. g.* between 4200 and 4700 they appear in such a number as to give the spectrogram at many places the appearance of continuous bands.

The background of weak lines may differ very considerably in structure and relative intensity from

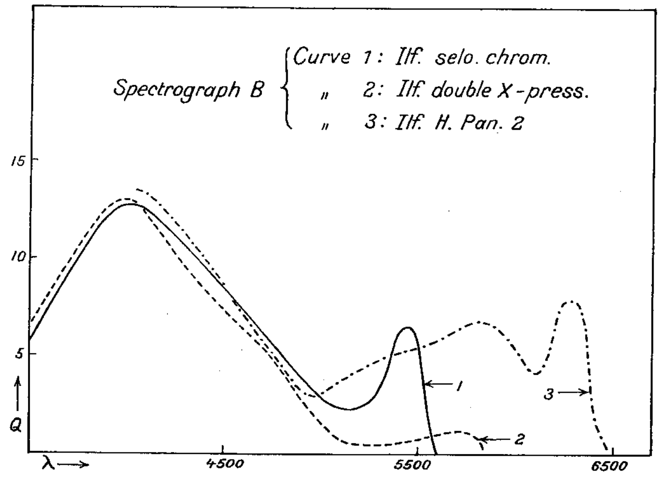

Fig. 1.

time to time according to the auroral types which have been subject to exposure. It has been previously pointed out by one of us (5) that certain weak lines in the blue part are enhanced with increasing altitude. It has also been found previously (3), that gray diffuse surfaces emit large numbers of weak lines or bands in this spectral region, while distinct and strong auroral forms only give a comparatively small number of lines and bands in the same region.

§ 3. Lines and Bands in the Region 4700—5400.

A most remarkable and important feature of these spectrograms is the appearance of some lines and bands in the region 4700—5400. *One of these lines which appears on spectrograms Nos. 1, 2, and 3 is seen to coincide exactly with the* H_β *line of the comparison spectrum.*

Taking into account the fairly large dispersion and the distinctness of the line, no doubt can be left with regard to the correctness of this interpretation.

Another line which appears quite distinctly near the strong He-line 5015 was found to have the wavelength 5006.8 which within the limit of error is equal to that of the famous nebulium line (5006.9) originating from the ground states of an oxygen ion which have lost two electrons.

The spectrogram No. 1 from the winter 1939—40 showed very clearly two broad bands, one with its maximum at 5374, which appears to be nearly continuous perhaps with some structure, and one with its maximum at 5287 which appears to be continuous towards longer waves. In the direction of shorter waves it has a structure consisting of a sharp edge at 5255, then follow two sharp lines with wavelengths 5231 and 5202. This second band is no doubt identical with the so-called "second green line" which on spectrograms of small dispersion appears as a somewhat broad line with a wavelength 5238.

The bands and lines in the green do not appear on spectrogram No. 2. As will be apparent from the sensitivity curves (Fig. 1) this is due to the small sensitivity in green of the Ilf. doubl. X-press plates.

The absence of the band 5374 on the spectrogram No. 5 is perhaps partly due to the fact that the panchromatic plate used, has a very different spectral sensitivity distribution in the green region (cf. the curves Fig. 1).

§ 4. Results of the Wavelength Measurements.

For the five spectrograms on Plate I all lines (or bands) which could be clearly seen, were measured. The results are given in Table I.

In the last column, giving for each line the weighted mean of its wavelength, the new lines not previously measured are marked with an (x). It will be seen that the table contains no less than thirty new lines not previously detected.

The first column of Table II contains the previously known lines, the second column contains the lines measured from the spectrograms on Plate I, which are given in the last column of Table I.

In the third column we have set up the relative intensities resulting from earlier measurements and representing a kind of typical intensity distribution.

The last column contains the interpretation proposed for the various bands and lines.

In those cases where the values previously found for the wavelength of a weak line, differ essentially from the one deduced from the present spectrograms (second column), the latter must as a rule be taken as representing the most accurate value.

§ 5. The Appearance of Hydrogen and Sodium Lines.

We have already called attention to the important fact, that the new spectrograms give definite proof of the appearance of the H_β-line from hydrogen. It appears from Table II that three of our spectrograms give a line 4339,7 which within the limit of error coincides with the H_γ-line 4340 from hydrogen.

Table I.

Wavelengt of Lines and Bands from Spectrograph B.

Ilf. Selo Chrom. Pl. I, No. 1	Ilf. Double X-press Pl. I, No. 2 Some sunlight	Ilf. Selo Chrom. Pl. I, No. 3	Ilf. Selo Chrom. Pl. I, No. 4	Ilf. H P. 2 Pl. I, No. 5	Weighted Mean	Ilf. Selo Chrom. Pl. I, No. 1	Ilf. Double X-press Pl. I, No. 2 Some sunlight	Ilf. Selo Chrom. Pl. I, No. 3	Ilf. Selo Chrom. Pl. I, No. 4	Ilf. H. P. 2 Pl. I, No. 5	Weighted Mean
-	-	-	-	6368.3	6368.3	4387.0	-	-	-	-	4387.0
-	-	-	-	6300.3 st	6300.3	4377.0	(4380.3)	4376.7	4378.6	4375	4376.8
-	-	-	-	6175 7	6175.7^{x}	4368.3	4369.4	4368.3	4368.3	4367.5	4368.4
-	-	-	-	6138.5	6138.5^{x}	4348.5	4349.2	4349.8	4347.5	(4351.8)	4349.2
-	-	-	-	6110.2	6110.2	4340.0	4339 2	4339.8	-	-	4339.7
-	-	-	-	6008.9	6008.9	4332.0	4334 6	-	4333.4	(4335.2)	4333.3^{x}
-	-	-	-	5977.0	5977.0^{x}	4317.0	4320.1	4318.3	4318	4319.9	4318.7
-	-	-	-	5948.2	5948.2^{x}	4302.5	4307.5	-	-	-	4305.0^{x}
-	-	-	-	5890.4	5890.4	4292 8	4296.5	-	4294.5	4296.5	4295.1
-	-	-	-	5836.6	5836.6	4277.6 st	4279.8	4277.5	4277.6	4279.6	Standard
-	-	-	-	5742.5	5742.5^{x}	4236.0	4237.2	4236.4	4236.0 st	4236.0 st	Standard
-	5678 0	-	-	5675.2	5676.6	-	4224.1	-	4222	-	4223.0
-	5620.0	-	-	5619.0	5619.5^{x}	4200.0	4199.7	4198.4	4199.8	4199.5	4199.5
5577.35 st	5577.35	5577.35 st	5577.35 st	5577.35	Standard	-	-	4185.9	-	-	4185.9^{x}
-	5456.5	-	-	-	5456.5	4174.0	-	4172.6	-	-	4173.3
5416	-	5417.0	5414	-	5415.8^{x}	-	-	4153.3	-	-	4153.3^{x}
5375	-	-	5372.5	-	5373.8^{x}	4141.5	4140.1	-	4140.0	-	4140.5
-	-	5353.0	5349	-	5351.0^{x}	4116.0	-	4112.0	-	4114	4114
5331	-	-	5330	-	5330.5^{x}	4097.0	-	4094.0	-	4092.0	4094.3
-	-	-	5307	-	5307^{x}	4073.3	-	4071.5	-	4073.2	4072.7
5295	5285	5285.5	5282	-	5287.0	4059 5	4059.2	4057.8	4049.8	(4055.2)	4059.1
5253	-	5251.4	5254	5260	5255.0^{x}	-	4049.9	-		-	4049.9
5230	-	5231.3	5231.5	5230.5	5230.8	4042.5	4041.3	4041.7	4042.8	4041	4042.1^{x}
5203	5203.2	5207.3	5196	5200	5202	4027.0	4028.7	-	4026.7	-	4027.5^{x}
-	5155.4	-	-	(5159)	5155.4^{x}	4012.0	-	-	4010.5	-	4011.3
-	-	-	5031	-	5031	3997.8	3997.3	3996.8	3997.0	3998.0	3997.4
5006.8	5007.4	5007.1	5005.5	5007	5006.8	3962.3	-	-	-	-	3962.3^{x}
-	(4935 2)	-	-	-	(4935.2)	3957.5	-	-	-	3957.0	3957.3^{x}
-	(4916 1)	-	-	-	(4916.1)^{x}	3941.0	3942.0	3941.7	3942.6	3943.0	3942.0
-	(4901 2)	-	-	-	(4901.2)^{x}	3915.0	3916.4	3914 5	3915.0	3916.0	3915.4
4861.3	4861.6	4861.6	-	-	4861.5	3884.5	3884.7	3883.8	3884.0	3884.5 st	3884.3
-	4784.1	-	-	-	4784 1^{x}	3877.0	-	3874.3	-	-	3875.6
-	4749.9	-	-	-	4749.9^{x}	3857.5	-	3857.5	-	-	3857.5^{x}
4710.-	4712.3	4708.7	4708.7	4708.7	4708.7	3821.8	-	-	-	-	3821.8^{x}
4652.1	4654.9	4652.2 st	4652.2 st	4652.2 st	4652.2	3805.4	3804.7	3804.7	3805.1	3805.6	3805.1
4595.5	-	4598.5	-	-	4597.0	3771.4	-	3771.9	-	-	3771.6
		4572 1			4572.1	3755.5	3754.8	3755.3	3755.2	3757.2	3755.2
4564.5	-		-	-	4564.5	3728.5	-	3728.1	-	-	3728.3
		4554.2			4554.2	3710.0	-	3711 0	3713.2	3712.0	3711.5
4534.5	-	4534.3	-	-	4534.4	3688.0	-	3687.9	-	-	3688.0
4511.0	-	4510.4	-	-	4510.7	-	-	3670.3	-	-	3670.3
4488.0	-	4486.9	-	-	4487.5	-	-	3602.8	-	-	3602.8
-	4475.8	-	-	-	4475.8^{x}	3580	3577.6	3577.2	3578.5	(3582.3)	3578.3
4467.0	-	-	-	-	4467.0	3570	-	-	-	-	3570
4452 0	4453.3	-	-	-	4452.5^{x}	3535	3536.2	3535.0	3536.8	(3542.4)	3535.7
-	-	4434.2	-	-	4434.2	-	3503.7	-	-	-	3503.7
4428	-	4427.5	-	-	4427.8	-	3467.7	-	-	-	3467.7
4415.1	4415.3	4415.2	4415 3	4415.5	4415.3	-	3432.2	-	-	-	3432.2
-	(4400.5)	-	-	(4406)	4403.2^{x}	-	3373.5	-	-	-	3373.5
4396.0	4391.6	-	4393.6	4397	4394.5						

On the spectrograms Nos. 4 and 5 of Plate I no trace of H_β is to be observed, although spectrogram No. 4 is taken on the same sort of plates as No. 1 and 3, and in the case of spectrogram No. 5 the sensitivity of the plate for H_β is equally large as that of the Selo Chrom plates.

The H_α-line, however, cannot appear on Plate No. 5 on account of the small sensitiveness of the Ilf. H. P. 2 plate at the wavelength of H_α.

In this connection it is interesting to notice that four of the new lines appearing on our spectrograms (Pl. I) coincide with strong lines of the band spectrum of hydrogen. These lines are indicated by H_2 in Table II. This indicates that during the period of our observations not only the spectrum of atomic hydrogen, but also that of molecular hydrogen appear in the auroral luminescence.

Spectrogram No. 5 taken on a panchromatic plate shows the yellow sodium *D*-line quite distinctly. It is well known from earlier observations that the yellow sodium line appears in the auroral luminescence, and also that its relative intensity is subject to variations. These facts show that even in the auroral region, above say 100 km, the relative concentration of sodium may be quite considerable and of the same order of magnitude as that of oxygen or nitrogen, although at other times it may be quite insignificant.

The spectrograms thus confirm the discovery recently announced by one of us (2) that hydrogen lines occasionally appear with considerable density in the auroral luminescence, while at other periods they are too weak to be observed. This fact was explained by assuming that showers of hydrogen — probably coming from the sun — were penetrating into the atmosphere.

§ 6. Remarks Regarding the Bands in Green.

The spectrograms gave the spectrum of the "second green auroral line" with such a dispersion that its structure can be more closely analysed.

It was suggested by one of us in previous papers (cf. *e. g.* paper No. 3) that the "second green line" might be an aspect of the band called N_2 which is emitted from solid nitrogen. This band was found to have a structure, and when traces of nitrogen are contained in solid neon, we actually observed in the N_2-band two fairly sharp components with wavelength 5229.4 and 5202.9, which within the limit of error coincide with the two auroral lines mentioned.

This interpretation which has been supported by these spectrograms of greater dispersion, does not, however, involve that "the second auroral line" with its structure should originate from nitrogen in the solid state.

The investigations carried out by one of us on the luminescence from solidified gases, have shown that the bands emitted from the nitrogen molecules, when surrounded by solid neon, differ very little from those emitted from nitrogen molecules in the free gaseous state. (Cf. *e. g.* paper (12).)

As the N_2-band — no doubt — originates from nitrogen molecules, it is likely that the N_2-band like the ε-system[1] may be emitted under the conditions of extremely low pressure existing in the auroral region, although it has not yet been observed in laboratory experiments.

We have also tried to interpret the two sharp lines 5231 and 5202 as atomic lines, but as yet without success.

The group of lines (or bands) which constitute the "second green line" shows considerable variations with regard to the relative intensity, with which it appears in the auroral luminescence. Thus it is very weak (or hardly to be observed) on spectrogram No. 4 taken on the same sort of plates as Nos. 1 and 3, where it appears quite distinctly. It also appears quite distinctly, however, on spectrogram No. 5.

In the case of the other green band with its maximum at 5374, we also notice some indication of a structure. The wavelength values of some maxima are given in Tables I and II. We have, however, not yet been able to suggest any possible origin of this band.

§ 7. On the Appearance of Atomic O-Lines.

In previous papers one of us has shown (13, 14) that a considerable number of weak auroral lines nearly coincide with lines from atoms of oxygen and nitrogen, either neutral or in various states of ionisation. These interpretations are most strikingly confirmed by the more accurate wavelength values derived from the new spectrograms here dealt with, and by a number of new lines which also coincide with atomic *O*- or *N*-lines.

It appears from Table II that 5 lines including the strong green and red lines may be referred to neutral *O*-atoms. One of these 4368.3, appears with appreciable intensity and coincides exactly with the strong *OI*-line 4368.3. We have found in our laboratory at Oslo that this line appears with particularly great relative intensity under such conditions as are favorable for the emission of the green line 5577.

No less than 16—18 lines are found to coincide with conspicuous lines of the *OII*-spectrum originating from oxygen atoms which have lost one electron. Most of these lines are fairly accurately measured.

In Table II, 3 lines have been referred to the *OIII*-spectrum. One of these, the nebulium-line, 5006.8, appears sharp and isolated and is therefore accurately

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[1] In the literature usually called Vegard-Kaplan bands.

Table II.

Auroral Lines and Bands.

From earlier observations	From present spectrograms	I	Interpretation
8132 8035	-	-	1. P. G. $\left\{\begin{matrix}5—4\\6—5\end{matrix}\right\}$
7906 7867	-	(47)	1. P. G. 7—6
7734	-	-	1. P. G. 8—7, (2—0)
7594	-	-	1. P. G. 9—8, (3—1)
7479	-	-	1. P. G. (10—9), 4—3
7368	-	-	1. P. G. (11—10), 5—3
7264	-	-	1. P. G. 6—4
7068	-	-	1. P. G. 8—6
6861	-	-	1. P. G. 3—0, 10—8
6784 6768 6753	-	-	1. P. G. 4—1, 11—9
6696 6682 6669	-	-	1. P. G. 5—2, 12—10
6619 6605 6592	-	-	1, P. G. 6—3, 13—11
6564			*H*α
6543 6526 6512	-	-	*NII* ($^1D_2—^3P_1$) (6547) 1. P. G. 7—4, 14—12, *NII* ($^1D_2—^3P_0$) (6525 6) Nebul.
6469 6454 6441	-	-	1. P. G. 8—5 *OI* (6454.6) *OI* (6439.1)
6398	-	-	1. P. G. 9—6
6363.7	6368.3	-	*OI* ($^1D_2—^3P_1$)
6300.30	6300.3	10—600	*OI* ($^1D_2—^3P_2$)
6185	-	-	1. P. G. 12—9
-	6175.7	-	1. P. G. 18—16
-	6138.5	-	
6129	-	-	1. P. G. 5—1
6108	6110.2	-	1. P. G. 13—10, 19—17
6068	-	-	1. P. G. 6—2 (ε 3—18)
6058	-	-	
6011.1	6008.9	-	1. P. G. 7—3
6001	-	-	*NI* (6000)
5990.8	-	15	1. P. G. 15—12
-	5977.0	-	H_2 (7975.4)
			1. P. G. 8—4
5966.4	-	-	
-	5948.2	-	H_2 (5947.9)
5891	5890.4	-	*Na. I* (D_1, D_2)
5867	-	13	1. P. G. 17—14
5833	5836.6	-	1. P. G. 18—15 (10—6)
5772	-	-	
5751	-	-	*NII* ($^1S_0—^1D_2$) Nebul. (5754.8) (ε, 1—16) *OI* (5750.4)
-	5742.5	-	
5680	5676.6	-	*NII* (5676.0, 5679.5)
-	5619.5	-	1. P. G. 15—11
5577,3445	5577.35	100	*OI* ($^1S_0—^1D_2$)
5472	-	-	1. P. G. 9—4
-	(5456.5)	-	*NII* (5454.3)
- - - - -	5415.8 5373.8 5351.0 5330.5 5307.0	-	Band with structure
5238	5287.0 5255.0	- 6.0	Band with sharp edge at 5255, H_2 (5256.6)
-	5230.8 5202.0	- -	The sharp lines 5230.8 and 5202.0 approximately coincide with the lines 5229.4 and 5202.9 from solid Nitrogen mixed with Neon (N_2 band)
-	5155.4	-	
5139	-	-	
-	5031	-	H_2 (5030.4)
5002	5006.8	-	*OIII* ($^1D_2—^3P_2$) = 5006.9 = Nebulium
-	4935.2	-	*NI* (5935.0)
-	4916.1	-	*NI* 4914.9
-	4901.2	-	
(4858)	4861.5	.	*H*β (4861.3)
4780	4784.1	-	ε, 5—17, *NII* or *OII*
4709.7	4708.7	7.8	N. G. 0—2
4652.2	4652.2	4.6	N. G. 1—3
4596.1	4597.0	3.4	N. G. 2—4
-	4572.1	-	H_2 (4572.7)
4566.0	4564 5	-	*NII*, *j* ($3d\ ^3F_2—3p\ ^1D_2$) = 4565
-	4554.2	2.0	N. G. 3—5
4535	4534.4	1.6	ε, 3—15, H_2 (4534.6) *NIII* 2 *s* 2 *p* ($3p\ ^4D_{3/2}—3s\ ^4P_{5/2}$)
4507	4510.7	1.2	*NIII* (4510.9) 2 *s* 2 *p* ($3p\ ^4D_{3/2}—3s\ ^4P_{1/2}$)
4484	4487.5	1.6	N. G. 5—7 *NI j'* 4 *d*. $^4P_3—2s\ 2p^4\ ^4P_3$, H_2
-	(4475.8)	-	*Ne* (4475.7)?
-	4467.0	-	*OII* (4467.8)
-	4452 5	-	*OII* (4452.4)
4437	4434.3	1.6	*NII* (4432.7)
4424	4427.8	3.0	ε, 2—14

Table II (Continued).

From earlier observations	From present spectrograms	I	Interpretation	From earlier observations	From present spectrograms	I	Interpretation
4415.1	4415.3	2.5	*OII* $\left\{\begin{array}{l} j' \ (3\,\mathrm{s}\ {}^2P_{1/2}-3\,p\ {}^2D_{3/2})=4416.97 \\ j' \ (3\,s\ {}^2P_{3/2}-3\,p\ {}^2D_{3/2})=4414.89 \end{array}\right\}$ Nebul.	-	3962.3	-	*OIII* (3961.6)
				-	3957.3	-	*NII* (3956), *OI*, *OII* (3954.4, 3954.6)
-	4403.2	-		3942.8	3942.0	2.2	2. P. G. 2—5
4396.0	4394.5	-	*OII*, j' $(3\,p\ {}^2P_{3/2}-3\,d\ {}^2D_{5/2})=4396.0$	3914 4	3915.4	47.4	N. G. 0—0
-	4387.0	-	*O* (4386.3)	3884.5	3884.3	2.2	N. G. 1—1
4375.6	4376.8	1.6	*OII* (4378.3), (ε, 6—15, 4380)	3872 0	3875.6	1.0	*OII* $\left\{\begin{array}{l} j' \ (3\,p\ {}^4D_{3/2}-3\,d\ {}^4P_{1/2})=3872.5 \\ j' \ (3\,p\ {}^4D_{7/2}-3\,d\ {}^4D_{5/2})=3875.8 \end{array}\right\}$ Nebul.
4368.2	4368.4	2.4	*OI*, K' $(4\,p\ {}^3P_{0,1,2}-3\,s\ {}^3S_1^0)=4368.3$				
4362.0	-	1.2	*OIII* $({}^1S_0-{}^1D_2)=4363=$ Nebul.	-	3857.5	-	*OII*, j' $(3\,p\ {}^4D_{5/2}-3\,d\ {}^4D_{5/2})=3857.2$
4345.6	4349.2	3.0	2. P. G. 0—4	-	3821.8	·	*OII*, j' $(3\,p\ {}^2P_{1/2}-4\,s\ {}^2P_{1/2})=3821.7$
-	4339.7	-	H_γ (4340)	3805.4	3805.1	4.9	2. P. G. 0—2
-	4333.3	-	*NI* (4336.5) *Ne* (4334.1)	3769	3771.6	1.0	ε, 2—12, *NIII* (3771)
4319.5	4318.7	1.6	ε, 1—13, *OII* (4319.6)	3755.2	3755.2	4.2	2. P. G. 1—3
-	4305.0	-	*OII* (4304) *NI* (4305.5)	3728.6	3728.3	1.0	*OII* $\left\{\begin{array}{l} k \ ({}^4S_{3/2}-{}^2D_{5/2})=3728.9 \\ k \ ({}^4S_{3/2}-{}^2D_{3/2})=3726.2 \end{array}\right\}$ Nebul.
-	4295.1	-	*OII* (4294.8)				
4277.6	4278	24.4	N. G. 0—1	3711.1	3711.5	2.4	2. P. G. 2—4
4236.0	4236	5.9	N. G. 1—2	3685.3	3688.0	1.6	ε, 1—11
4226 3	-	4.0	*NII* (4227.4)	3671.8	3670.3	-	2. P. G. 3—5
-	4223	-	*NI* (4223.0)	3603.0	3602.8	1.0	ε, 0—10
4218	-	3.0	ε, 0—12 (4218)	3583	-	1.6	N. G. 1—0
4200.0	4199.5	2.0	N. G. 2—3	3577.6	3578.3	9.8	2. P. G. 0—1
-	4185.9	-	*OII* (4185.5)	3663.5	-	1.6	N. G. 2—1
4176.2	4173.3	1.4	ε, 3—14, H_2 (4175.2)	3536 8	3535.7	4.9	2. P. G. 1—2
4142.6	4140.5	1.4	2. P. G. 3—7	3503.2	3503.7	2.2	2. P. G. 2—3
4119.7	(4114)	1.6	*OII*, j' $(3\,p\ {}^4P_{5/2}-3\,d\ {}^4D_{7/2})=4119$	3484	-	1.0	2. P. G. 7—8
4092.0	4094.3	1.6	2 P. G. 4—8, *OII* $\left\{\begin{array}{l} j' \ (3\,p\ {}^4D_{7/2}-3\,d\ {}^4F_{7/2})=4092.9 \\ j' \ (3\,p\ {}^4D_{5/2}-3\,d\ {}^4F_{3/2})=4094.2 \end{array}\right.$	3467.4	3467.7	3.0	2. P. G. 3—4, *NI* k $({}^2P_{1,2}-{}^4S_2^0)=3466.5$
				3429.0	(3432.2)	2.0	ε, 1—10
4076.0	4072.7	-	ε, 2—13 *OII*, j' $(3\,d\ {}^4F_5-3\,p\ {}^4D_4)=4075.9=$ Nebul. *OII* (4072)	3371.3	(3373.5)	9.0	2. P. G. 0—0
				3339.3	-	1.2	2. P. G. 1—1
4058	4059.1	3.4	2. P. G. 0—3	3285.3	-	1.8	2. P. G. 3—3
4048.5	4049.9	-	*OII*, j' $(3\,d\ {}^4F_{7/2}-4\,f\ {}^4F_{7/2})=4048.2$	3202.7	-	2.2	ε, 1—9, ε, 7—13
-	4042.1	-	*N* (4043.5, 4041.3), H_2 (4043.6)	3192.4	-	-	ε, 4—11, *OII* (3194)
-	4027.5	-	*N* (4026), *HeI* (4026.4)	3168.7	-	-	2. P. G. 9—7
-	4011.3	-	*He* (4009.3)	3159.3	-	5.8	2. P. G. 1—0
3997.7	3997.4	3.7	2. P. G. 1—4	3125.7	-	3.6	2. P. G. 2—1
3981	-	1.0	ε, 1—12, *OII* (3982.7)	3114.0	-	-	2. P. G. 3—2.

For the sake of brevity we have put:

$2\,s^2\,2p^2=j$, $2\,s^2\,2\,p^3=k$, $2\,s^2\,2p^2\,({}^3P)=j'$ and $2\,s^2\,2\,p^3\,({}^4S)=k'$

measured. The second *OIII* line 4362 appears close to a stronger *OI*-line, 6368.3, and has only been observed and measured on one spectrogram. The third line referred to *OIII* (3962), has only been measured on spectrogram No. 1 on Plate I.

As already mentioned weak lines appear in large numbers and close to each other in various parts of the auroral spectrum. We have therefore not been able to mark out and measure all the lines which actually appear. Some of the lines, which appear indistinctly in a crowd of others, may be not so accurately measured as more isolated and sharp lines. Our interpretations of the oxygen lines, may not be correct in all details, but taking into account the considerable number of lines now referred to *OII*, and the fairly high degree of accuracy now obtained of the wavelength values, *we are justified in believing that our interpretation as regards O-lines is essentially correct and that not only OI-lines, but also OII and OIII lines appear with observable intensity in the auroral luminescence.*

This result probably means that a considerable fraction of the oxygen in the upper atmosphere exists in the form of atoms, some of which are neutral while a considerable fraction has lost one or two electrons.

§ 8. The Appearance of Atomic Nitrogen Lines.

In papers published by one of us in 1923 (21) and later years (5.2), it was stated that some of the weak lines appearing in the auroral spectrum might possibly be referred to the line spectra of nitrogen. The weak lines dealt with in these earlier papers were mostly obtained from spectrograms of very small dispersion and the identification therefore uncertain. In this respect the present observational material represents a great advancement, because a number of weak lines are observed with the large glass spectrograph (B) of considerable dispersion.

After the atomic nitrogen spectra had been analysed, and the energy states had been determined for the neutral and ionised nitrogen atoms, and after it had been proved that the strong green and red auroral lines were to be referred to the lowest energy states of the neutral oxygen atom, it became a matter of importance to look for the corresponding nitrogen lines in the auroral spectrum. Table III contains the wavelength values for the forbidden lines resulting from the lowest ground states of the neutral (*NI*) and singly ionised nitrogen atom (*NII*).

Table III.

NI		*NII*	
Transition	λ	Transition	λ
$^4S—^2D_{5/2}$	5200.1	$^1D—^3P_0$	6525.6
$^4S—^2D_{3/2}$	5197.8	$^1D—^3P_1$	6547
		$^1D—^3P_2$	6583
$^4S—^2P$	3466.5	$^1S—^1D$	5754.8

The wavelength values of *NI* in Table III are taken from a paper by Nicolet (17) who deduces them from Edlèns measurements of the energy states. The wavelength values of *NII* are calculated from the energy states of *NII* given by Bacher and Goudsmit (22).

The ground states of the neutral nitrogen atom should give a doublet at about 5200 and a line in the ultraviolet. The doublet would not be separated by our spectrograph (B). Its average wavelength should be 5199. This wavelength only differs by 3 Å from the auroral line 5202.0. This difference, however, is considerably larger than the possible error of our measurements, further theoretical calculations of the intensity of the *NI* doublet carried out by Nicolet (17) indicate that it cannot be expected to appear with observable intensity on an auroral spectrogram.

As first pointed out by Bernard, the *NI*-line 3466.5 nearly coincided with a line in the auroral spectrum. This line has been observed by one of us in 1922, and since then obtained on a number of spectrograms of considerable dispersion. The wavelength values obtained from those of our spectrograms which should give the best conditions for accurate results are given in Table IV.

Table IV.

No.	Time for Exposure	Wavelength
1............	Winter 1930—31[1]	3467.2
2............	Winter 1934—35[2]	3467.9
3............	Winter 1936—37	3467.2
4............	Winter 1940—41	3467.7
	Mean	3467.5

The values Nos. 1, 2, 3 were derived from spectrograms taken with a large quartz spectrograph, whose dispersion at 3467 is about 23 Å/mm. The last value (No. 4) is found from spectrogram No. 2 on Plate I.

The dispersion of the spectrograph (B) at the wavelength considered is about 46 Å/mm. It appears from these data that the values given in Table IV should be correct to within a small fraction of an Å-unit.

From discharges in nitrogen, Kaplan (15, 16) observed a line with a wavelength 3471, which he identifies with the forbidden nitrogen line *NI* (^2P—^4S) for which the lower energy states gave the wavelength 3470.

In 1938 Bernard obtained spectrograms at the Tromsø Observatory which showed the same line as previously observed and measured by us. His first measurements gave the wavelength 3470. This value was very close to that which at that time was accepted for the wavelength of the *NI* (^2P—^4S) line, and he proposed to identify the auroral line with this nitrogen line.

Later on Nicolet (18) pointed out that Edlén's more accurate measurements of the ^2D and ^2P states of neutral nitrogen atoms led to a wavelength of 3466.5 Å. Later on also Bernard by repeated measurements on his auroral spectrograms finds the wavelength 3466.5. From this apparently perfect agreement between Bernard's value and that derived from Edlén's measurements, Nicolet (17) will find conclusive proof for the appearance of the *NI*-(^2P—^4S) line in the auroral spectrum.

It must be remembered, however, that the dispersion of the spectrograph used by Bernard was extremely small, and the possible error of the wavelength values will amount to several Å-units. In fact the various values given by Bernard himself differ by 3—4 Å units.

From Bernard's measurements we cannot draw any definite conclusion with regard to the origin of the line situated near the *NI* (^2P—^4S) line. The most reliable values of this auroral line as yet obtained are those found by us and given in Table III. Our value (3467.5) differs from that derived from Edlén's measurements for the *NI* (^2P—^4S) line (3466.5) by 1 Å unit. This difference, however, is not greater than might perhaps be accounted for by inaccuracies either in the determination of the energy states of *NI* or through an inaccuracy in the measurements of the auroral line resulting from the presence of the band 3469 of the 2nd positive group of nitrogen. The somewhat larger wavelength of this band might produce an apparent displacement of the line towards longer waves.

Although the presence of the line *NI* (^4S—^2P) in the auroral luminescence cannot yet be regarded as settled, it may be regarded as a possibility, and this possibility has been supported by the fact that Table II contains 8 lines which within the limit of error coincide with *NI*-lines some of which are new lines for the first time observed on the spectrograms on Plate I.

With regard to the *NII* lines connected with the lowest electronic states, the three red lines given in Table III may be more or less masked by the bands of the 1st positive group of nitrogen. In the auroral spectrum a weak line (5751) has been observed near the *NII*-line 5754.8. As the 5751 line has only been observed on rare occasions and on spectrograms with small dispersion, the possible error may be so large that its identity with the *NII*-line is by no means excluded. It is of interest to notice in this connection that Table II contains 8 lines which nearly coincide with *NII* lines and 2 nearly coinciding with *NIII* lines.

The new data given by the spectrograms on Pl. I have shown that *OI*, *OII*, and *OIII* lines appear with measurable intensity in the auroral luminescence, and that probably also lines appear which belong to the *NI*, *NII*, and *NIII* spectra. Finally Table II contains a few bands and lines for which we have not yet ventured to suggest any interpretation.

§ 9. Measurements of Relative Intensities of Some Weak Lines and Bands.

As already mentioned, the spectrograms on Pl. I apparently show considerable differences as regards the relative intensities of lines and bands. Some of these differences are due to the use of different sorts of plates. We have therefore found it to be of interest to determine the true intensities relative to one of the negative bands for some of the weak bands and lines which appeared on the spectrograms of Pl. I.

The measurements were made by means of a registering photometer of the Moll type in a way which has been described in previous papers (cf. paper No. 5).

The results are given in Table V.

The intensity of a particular line or band is compared with that of the negative band 4708 whose intensity is put equal to 10.

On the spectrograms Pl. I, Nos. 1, 3, and 4 taken on Ilf. Selo Chrom plates the green line 5577 is not

Table V.

Relative Intensities from B-Spectrograph.

	Pl. I No. 1	Pl. I No. 2	Pl. I No. 3	Pl. I No. 4	Pl. I No. 5	
5417 5373 5353	2.8	The plate very insensitive	2.5	10.4	0	
5285 5251	4.4		3.3	10.9	0	
5251	1.9		1.5	1.7	0.9	4.3
5231	2.1		2.4	2.0	2.4	
5202	2.1		2.3	3.8	2.7	
5160	-	-	-	-	1.9	
5007	1.6	1.9	2.3	(2.1)	2.6	
4861	1.6	1.5	1.5	0.7	0.6	
4708	10.0	10.0	10.0	10.0	10.0	
4650	4.2	4.2	3.6	4.4	3.4	
4415	1.2	1.6	1.2	0.9	1.0	
4368	1.3	2.2	1.3	0.9	1.0	
4345	1.1	1.3	1.3	1.1	0.8	
4319	0.7	1.0	0.7	1.2	0.5	
4236	7.0	7.1	7.3	6.6	7.4	
4200	1.4	1.0	1.5	0.9	1.9	

overexposed, but as the sensitivity curve for this wavelength (Fig. 1) falls rapidly with increasing wavelength, the relative intensity of the green line cannot be measured with sufficient accuracy. On spectrograms Nos. 2 and 5 the green line is overexposed and not suitable for quantitative intensity measurements. The same holds for the strongest bands of the negative nitrogen group. The absence on spectrogram 2 of the bands in green between 5200 and 5400 is due to the low sensitiveness of the plate in this region.

The green bands 5417—5353 and 5285—5251 are seen to vary in a similar manner from one spectrogram to another. They are both particularly strong on spectrogram No. 4 while both are either weak or absent on spectrogram No. 5. This indicates that there might be a close connection between the two bands as regards their origin.

The three lines 5251, 5231, and 5202 also vary in a similar way from one spectrogram to another, and their relative intensities have not changed essentially during the period of time covered by our spectrograms. In the case of spectrogram No. 5 a continuous band appears to fall in the region of these lines. The maximum relative intensity of this band is found to be 4.3. The slight variations shown by these lines may be due to inaccuracies of the measurements resulting mainly from the more or less continuous background.

The table indicates that for most of the weak lines measured, the relative intensity has kept fairly constant during the period considered. An exception is found for the two lines 4861, 4415 and 4368 which show a marked variability. Thus the intensity on Pl. 2 is about twice as large as that of Plate 4.

CHAPTER II

Relative Intensity and Wawelength of the Second Component of the Red Triplet $OI\ ({}^1D_2 - {}^3P_{012})$.

§ 10. The Spectrograms.

By means of a large glass spectrograph (A) constructed by one of us in 1922 (described in paper No. 5, Pl. IV, Fig. 1) four spectrograms were taken on red sensitive plates, all of which give the two strongest components of the red triplet with a density suitable for intensity measurements. They are reproduced on Pl. II, Nos. 1—4. In the case of Nos. 1 and 2 we used Agfa I. S. S. plates while Nos. 3 and 4 were taken on Ilf. Hyp. Pan. 2.

From the sensitivity curves Fig. 2 we notice that the second red component in the case of the H. P. 2 plates is situated in a region where the sensitiveness falls off rapidly with increasing wavelength. This will introduce some uncertainty in the intensity measurements, so the relative intensities derived from these spectrograms are less reliable than those obtained from spectrograms Nos. 1 and 2 taken on the Agfa I. S. S. plates.

A spectrum of helium mixed with hydrogen was used for comparison except in the case of spectrogram No. 1 where hydrogen mixed with sodium is used.

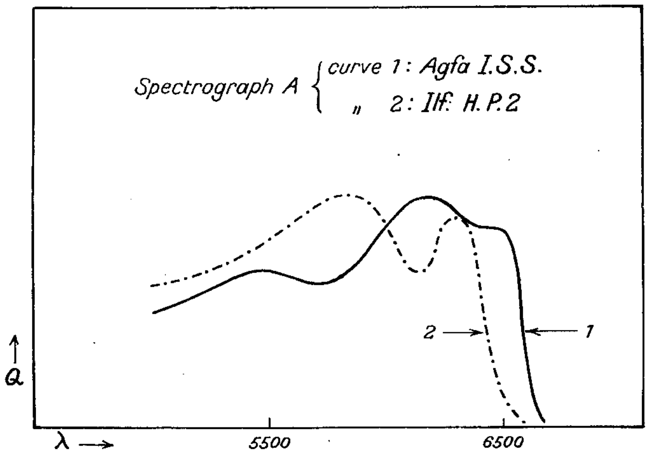

Fig. 2

Each plate was provided with an intensity scale consisting of a series of spectra from a constant light source with known spectral intensity distribution. The spectrograms were taken with times of exposure varying in the proportion 1 : 2 : 4 : 8.

The photographic densities were recorded by means of a Moll microphotometer.

§ 11. Results of Intensity Measurements within the Red Triplet.

Regarding the method used in the intensity measurements, we refer to previous publications (Nos. 5 and 19). The spectrograms only show the two strongest components of the red triplet while no trace of the third one, $OI\ ({}^1D_2 - {}^3P_0)$, is to be seen.

In the case of spectrograms Nos. 3 and 4 this might be due to the rapid fall of sensitiveness, but this cannot explain the absence of the third component in spectrograms Nos. 1 and 2. Our spectrograms thus show that the relative intensity $\frac{I_0}{I_2}$ of the third component relative to the strongest one is very small so that $\frac{I_0}{I_2}$ is approximately equal to zero.

In addition to the intensity measurements of the red lines, we have also measured that of the strong green line, although it is too much exposed for accurate intensity measurements. The results of the intensity measurements are given in Table VI.

Table VI.

λ	Intensities			
	Pl. II. No. 1	Pl. II. No. 2	Pl. II. No. 3	Pl. II. No. 4
5577......	3.42	5.16	6.70	3.13
6300......	1.00	1.00	1.00	1.00
6363......	0.385	0.375	(0.317)	(0.287)
Dates of exposure..	8/11—26/11 40	4/12—9/12 40	27/1—23/2 41	25/2—2/4 41
Effective exp. time..	20 hours	6 hours	12 hours	16 hours
Photogr. plate	Agfa I.S.S.	Agfa I.S.S.	Ilf. H.P. 2	Ilf. H.P. 2

In the last three lines of the table we have given the dates of exposure, effective time of exposure and the sort of photographic plate used.

For the reason already mentioned the intensities of the second red component have been put into brackets for spectrograms Nos. 3 and 4. The values derived from the two first spectrograms agree well with each other and taking the mean, we get:

$$\frac{I_1}{I_2} = 0.380$$

Putting equal weight to all four determinations the mean value will be:

$$\frac{I_1}{I_2} = 0.341$$

The observed intensity ratio (about 0.38) is somewhat larger than the value 1/3 found theoretically (17). The difference, however, is not very large.

In a previous paper one of us (20) has discussed the various ways in which the ${}^1D_2$-state of an oxygen atom may be reached. If it is reached only through the transition $({}^1s_0 - {}^1D_2)$ leading to the emission of the green line, then the intensity (I_b) of the strongest line of the red triplet relative to that of the green line (I_a) should be equal to:

$$\frac{I_b}{I_a} = \frac{\lambda_a}{\lambda_b} \cdot \frac{1}{1+\alpha+\beta} = \varkappa \ldots . \qquad (1)$$

λ_a and λ_b are the wavelength of the green line and that of the strongest red component respectively:

$$\alpha = \frac{I_1}{I_2} \text{ and } \beta = \frac{I_0}{I_2}$$

The values of α and β have previously only been roughly estimated from fairly inaccurate intensity measurements. As a result of our presents measurements, however, they can be fixed fairly accurately. Putting $\alpha = 0.38$ and $\beta = 0$, we get:

$$\varkappa = 0.64 \qquad (2)$$

Thus if we find that the intensity of the red line 6300 is more than 0.64 times that of the green line (5577) then we know that during the aurora dealt with, the ${}^1D_2$ *state has been reached in other ways than through the transition* $({}^1S_0 - {}^1D_2)$.

§ 12. The Wavelength of the Second Component of the Red Triplet.

On account of the fairly large dispersion of the spectrograph (A) used for the spectrograms Nos. 1—4 on Plate II, the wavelength of the red lines can be measured with considerable accuracy. As the wavelength of the strongest red component has previously been measured (2.4) very accurately by means of

Table VII.

Spectr. No.	λ_2	λ_1	Standard lines
1	6300.3	6364.1	$H\alpha$, 5895.9, 5577.35
1	-	6364.1	$H\alpha$, 6300.3, 5577.35
2	6300.9	6364.6	$H\alpha$, 5875.6, 5577.35
2	-	6364.1	$H\alpha$, 6300.3, 5577.35
3	-	6364.3	— — —
4	-	6364.8	— — —
Mean	6300.6	6364.3	

an interferometer method, we may with advantage use this line as one of the standard lines for the determination of the wavelength of the second red component.

From spectrograms Pl. II, Nos. 1 and 2 where lines of comparison appear beyond the red oxygen triplet, we can also measure the wavelength of the strongest component. Such measurements may be of interest as a test of the correctness of our previous results, and at the same time a comparison with previous values gives us means of estimating the correctness of our present measurements.

The results are given in Table VII.

We notice that the value found for the wavelength of the strongest component only differs by 0.3 Å from the more accurate value 6300.300 obtained by the interferometer method. From the energy states of the *OI*-spectrum, we find the following wavelength-values:

$$\lambda_2 = 6300.33$$
$$\lambda_1 = 6363.75$$
$$\lambda_0 = 6391.68$$

In the case of λ_2 the value derived from the energy states seen to agree well with the value found from the auroral luminescence. In the case of λ_1, however, there is a difference of about 0.5 Å units. This difference is probably somewhat larger than the possible errors of the mean value given in Table VII, which indicates that there is some error attached to the determination of the energy states of the neutral oxygen atom.

CHAPTER III.

Ionospheric Temperature Measured from Aurorae Exposed to Sunlight.

§ 13. Remarks Regarding the Procedure Employed in the Measurements.

The method of measuring the ionospheric temperatures by means of the nitrogen bands appearing in the auroral spectrum has been dealt with in previous papers (5, 6, 7, 8).

The temperature is deduced from the intensity distribution of the *R*-branch of one of the negative bands. The bands 4278 and 3914 are best suited for the purpose.

The temperature may be derived either by determining the rotational quant number (K_m) which corresponds to the intensity maximum of the *R*-branch, or by determining the way in which the intensity of the *R*-branch varies with the rotational quant number.

In the case of a Maxwellian distribution of the rotational energy of the emitting molecules, this relation between intensity (I) and rotational quant number (K) can be expressed by the formula:

$$\log_{10}\left(\frac{I_k}{K}\right) = -\varkappa\, K(K+1) \,.\,.\,.\,.\,. \qquad (3\text{ a})$$

where:

$$\varkappa = \frac{h^2 \log_{10} \varepsilon}{8\pi^2 J \cdot kT} \,.\,.\,.\,.\,.\,.\,. \qquad (3\text{ b})$$

The moment of inertia (J) of the N_2^+ molecular ion in the upper electronic state is equal to 13.4 10^{-14} (gr. cm^2), (h) and (k) are Planck's and Boltzmann's constants respectively. From equation (3 b) we deduce the temperature:

$$T_\varkappa = \frac{1.2855}{\varkappa} \qquad (4)$$

The value of $\varkappa$ is deduced from the slope of the line expressing the relation between $\log\left(\frac{I}{K}\right)$ and $K(K+1)$.

Having determined (K_m) the temperature (T_m) is found from the equation:

$$T_m = 2.96\, K_m\, (2\, K_m + 1) \qquad (5)$$

On account of the small dispersion to be used in auroral spectrography the individual rotational lines are not separated. Temperature determinations from light sources of known temperature carried out in the laboratory at Oslo with spectrographs of about the same dispersion as those used, have shown that the temperature $T_\varkappa$ deduced from the value of $\varkappa$ within the limit of error gives the correct temperature.

The determination of the temperature from the position of the maximum (K_m), however, is subject to some systematic error tending to make the temperature too low. By determining the temperature T_m from light sources of known temperature, and by using about the same dispersion of the band as that of the auroral spectrograms, we deduced the following empirical correction formulae:

$$T_{mc} = 1.06\ T_m + 38 \qquad (6)$$

Although this formula corresponds to a dispersion somewhat larger than that of the quartz spectrograph used for the spectrogram here to be dealt with, the correction formula will hold approximately.

The possible overlapping of the individual lines of a band may produce a change in the relation between I and K. In the previous papers referred to, we have shown how to find an upper limit to the effect of overlapping. From the curve (I—K) corrected for overlapping, we find new values (K_m'), $\varkappa'$ and the corresponding temperatutes T_m' and $T_\varkappa'$. Laboratory experiments have shown that these temperatures are higher than that of the light source, and may therefore be regarded as upper limits of the temperature.

§ 14. The Temperature of the Ionosphere Exposed to Sunlight.

The interpretation of certain phenomena connected with the reflection of radio waves from the ionised layers of the upper atmosphere has led to the assumption, that very high temperatures of more than 1000° may exist in the ionosphere. Measurements of the temperature in the ionosphere by means of the auroral spectrum, however, have shown conclusively that at any rate on the night side of the earth and in the region between 100 and 130 km, the temperature is quite low, and equal to about ÷ 45° C.

In previous papers (2.23) one of us has described some results of investigations on the possible increase of temperature with altitude. In the study of the temperature variations with altitudes two methods have been employed (2.23) both of which are based on observations of the upper part of very long auroral rays. Both methods led to the result that the increase of temperature upwards — if any — had to be quite insignificant.

Thus the temperature of the ionosphere as measured by the rotational energy of the molecules is about the same as in the stratosphere and we have as yet found no indication of such an increase upwards as to give temperatures of the order of say 1500° K in the F_2-region.

The temperature in the ionosphere, however, might be considerably higher during the day than on the night side of the earth. If so we should expect to find a higher temperature from auroral bands emitted from an atmosphere exposed to sunlight, than that we ordinarily find under night conditions.

During the period from Feb. 26 to April 4, 1941 the large quartz spectrograph at Tromsø was used for the exposure of such aurorae as occasionally appeared in an atmospheric layer exposed to sunlight. During the whole period, we had such aurorae for about 1.5 hours, which is thus to be regarded as the effective time of exposure.

The spectrogram which is reproduced on Pl. II, No. 13 gives the two bands 4278 and 3914 with suitable density for intensity measurements. The results of our measurements are given in Tables VIII and IX for the bands 4278 and 3914 respectively.

Table VIII.

Temperature of Sunlit Aurorae from Band 4278 Taken with Quartz Spectrograph (Q).

K	I	$\log {}^{I}/_{K} + 2$	I'	$\log {}^{I}/_{K} + 1.5$	$K(K+1)$
1.64	0.70	1.63	0.58	1.05	4.33
3.43	0.78	1.35	0.73	0.83	15.19
5.27	0.85	1.21	0.89	0.73	33.04
6.72	0.83	1.09	0.945	0.65	51.88
8.04	0.77	0.98	0.94	0.57	72.68
9.42	0.68	0.86	0.89	0.47	98.16
10.60	0.58	0.73	0.79	0.37	122.96
$K_m = 55$ $T_m = 195\ K^\circ$		$\varkappa = 5.5\ 10^{-3}$ $T_\varkappa = 234\ K^\circ$	$K_m' = 6.9$ $T_m' = 300\ K^\circ$		$\varkappa = 4.25\ 10^{-3}$ $T_\varkappa' = 303\ K^\circ$

Table IX.

Temperature of Sunlit Aurorae at Tromsø, from Band 3914 taken with Quartz Spectrograph (Q).

K	I	$\log {}^{I}/_{K} + 2$	I'	$\log {}^{I}/_{K} + 1{,}5$	$K(K+1)$
1.85	1.76	1.979	1.22	1.320	5.27
3.60	1.83	1.706	1.42	1.096	16.56
5.20	1.87	1.554	1.59	0.986	32.24
6.65	1.82	1.438	1.67	0.900	50.87
8.00	1.71	1.329	1.67	0.820	72.00
9.40	1.50	1.203	1.56	0.719	97.76
10.55	1.30	1.091	1.42	0.629	121.85
11.70	1.16	0.995	1.33	0.555	148.59
12.80	1.05	0.913	1.26	0.492	176.64
$K_m = 5.50$ $T_m = 195°\ K$		$\varkappa = 5.2\ 10^{-3}$ $T_\varkappa = 247°\ K$	$K_m' = 7.25$ $T_m' = 340°\ K$		$\varkappa' = 4.0\ 10^{-3}$ $T_\varkappa' = 322°\ K$

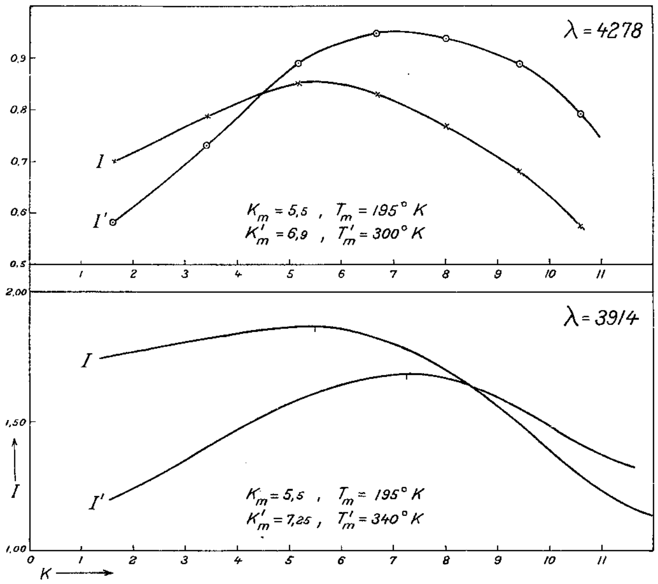

Fig. 3.

The $(I\text{—}K)$ curves are represented in Fig. 3. Those marked (I) correspond to the intensities directly measured, (I') to those corrected for overlapping. In Fig. 4 the quantities $\log\,(I/K)$ and $\log\,(I'/K)$ are represented as functions of $K(K+1)$.

In dealing with these observations we must take into account that the intensities for small quant numbers are too large, because here the R-branch approaches the P-branch. When for large quant numbers (K) the R-branch becomes weak the measured intensities are also likely to become too large on account of ground fog. We notice that the observed points on Fig. 4 with the exception of those of very small and very large quant numbers, nearly fall on a straight line, the slope of which gives us the value of $\varkappa$. The values of (K_m), $(\varkappa)$ (T_m) and $(T_\varkappa)$ corresponding to I and I' are given on the diagram Fig. 3 and 4 and at the bottom of Tables VIII and IX.

From the equation (6) we find for both bands $T_{mc} = 245°\ K$ which is seen to agree well with the mean value of $T_\varkappa$ for which we find $T_\varkappa = 241°\ K$.

The results show that the temperature derived from a sunlit aurora is probably a little higher than that obtained from aurora under night conditions. The effect, however, is not large.

Independent of the possible error attached to the determination of the absolute value of the temperature, temperature variations might be traced fairly accurately by comparing spectral bands obtained with the same spectrograph. As stated above the temperature $T_\varkappa$ should give nearly the true temperature of the source, and as $T_\varkappa$ can be fairly accurately determined, it may with advantage be used for the comparison. The results of temperature measurements which up to the present have been obtained with the large quartz spectrograph are collected in Table X.

The mean temperature found from aurorae exposed to sunlight thus comes out 20° higher than the average derived from aurorae under night conditions, and our results thus indicate a slight increase of temperature due to direct sunlight; but the effect is not larger than the differences we may find for temperatures all of which correspond to night conditions. It is also probable that the temperatures found with the quartz spectrograph and under night conditions are too low. In fact the mean temperature found with

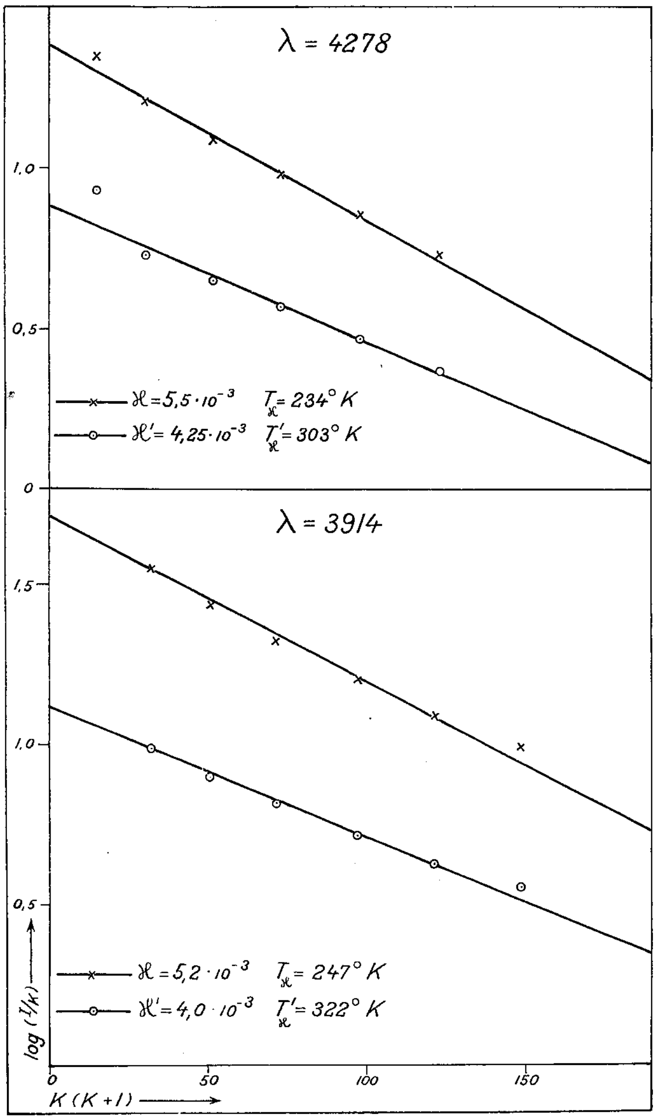

Fig. 4.

the quartz spectrograph at night (220° K) is 8° lower than the mean value (228° K) found from spectrograms taken with the large glass spectrograph under ordinary night conditions.

More observations will therefore be needed in order to settle the question as to the reality of this sunlight effect on the ionospheric temperature. At any rate the effect is too small to account for the high temperatures assumed by some authorities to account for certain effects connected with the reflection of electric waves from ionised layers.

Table X.

Results Obtained with the Large Quartz Spectrograph (Q).

Date and Time Interval of Exposure	T in $K°$	T in centigr.	Band	
18. Jan. — 8. Feb., 1938	230	—43	3914	Night conditions
7. March— 9. March, 1938 ..	216	—57	3914	— —
16. Oct. —28. Oct., 1938	210	—63	3914	Lower limit
16. Oct. —28. Oct., 1938	210	—63	3914	Upper —
5. Nov. 1938—5. Jan., 1939 ..	235	—38	3914	Lower —
Mean for night conditions	220	—53		
26. Feb.—2 April 1941	247	—26	3914	Sunlit atmosphere
	234	—39	4278	
Mean for sunlit atmosphere...	240	—33		

CHAPTER IV

Some Pronounced Variations in the Composition of the Auroral Luminescence.

§ 15. Variations in Spectral Intensity Distribution Observed at Tromsø.

On March 1 and 2 spectrograms were taken at Tromsø with the small glass spectrograph (α). Reproductions are given on Plate II, Nos. 5—12. We notice at a glance that the spectra from the first night differ essentially from those of the second, especially with regard to the relative intensity of the bands and lines in the red. On the spectrograms from March 1 the red OI-triplet appears with unusual intensity, while the red bands of the 1st positive group are too weak to be observed. On the following evening, however, the oxygen triplet is very weak indeed, while bands of the 1st positive group are quite strong.

The intensity of the red and of the green OI-line relative to that of the negative bands 4278 and 3914 were measured in the ordinary way earlier described (19). The results are collected in Table XI. At the top of the table we have for each spectrogram given some data of particular interest.

In the first part of Table XI denoted by (A), the intensities are given relative to that of the strong green line. We notice that on the spectrograms from the evening of March 1 the red OI-line 6300 is stronger than the green one. In two cases corresponding to red auroral surfaces *the intensity of the red line is more than 6 times that of the green one.*

In this case the $^1D_2$-state of the neutral oxygen atom has mainly been excited directly, without the atoms having had to pass through the $^1S_0$-state. During the following evening the intensity of the red line is only about 15% of that of the green one. In fact the intensity of the red line is probably in this case found too high, because the red OI-line is more or less masked by or superimposed on the bands of the 1st positive group.

This sudden and large variation of the relative intensity of the red OI-line which has also been observed on previous occasions is a most important fact which any explanation of the variability will have to account for.

In the lower part of Table XI (denoted by B) the intensities are given relative to that of the negative nitrogen group. The intensity of the band 3914 is put equal to 47.4, which happens to be the relative intensity previously given to this band for the "typical auroral spectrum", when the intensity of the green line is put equal to 100. This second part (B) of Table XI shows the most interesting fact, *that the intensity of the green line relative to that of the negative bands is reduced when the red OI-line is very strong, and it is unusually large when — as in the case of March 2 — the intensity of the red OI-line is particularly small.*

The conditions which are favorable for a direct excitation of the $^1D_2$-state seem to reduce the relative probability for the excitation of the $^1S_0$-state

Table XI.

	λ	Relative Intensities							
	Spectrum	Pl. II. No. 5	Pl. II. No. 6	Pl. II. No. 7	Pl. II. No. 8	Pl. II. No. 9	Pl. II. No. 10	Pl. II. No. 11	Pl. II. No. 12
	Date	1/3—41	1/3—41	1/3—41	2/3—41	2/3—41	2/3—41	2/3—41	2/3—41
	Time of Exp.	$18^{20-25}+18^{30-35}$	$18^{50}—19^{05}$	20^{08-18}	18^{31-47}	20^{17-30}	20^{33-46}	$21^{45}—22^{15}$	?
	Direction	S	SW	W	N	S	W	E	S
	Height	25°—30°	27°	20°	25°	28°	26°	27°	20°
	Auroral form	Red surfaces	Weak draperies and surfaces	Red surfaces	R. A.	R. A.	R. B.	Grey surfaces and bands	R. A. & D.
	Remarks	Sunlit	Sunlit						
A	6300	627.4	148.0	662.1	14.2	14.2	11.6	19.3	18.4
	5577	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	4278	54.8	29.4	28.0	17.1	17.9	13.6	15.2	18.7
	3914	96.6	65.5	59.2	31.2	39.7	33.9	34.2	40.1
B	6300	307.9	107.1	530.1	21.6	17.0	16.2	26.7	21.7
	5577	49.1	72.4	80.1	151.9	119.4	139.8	138.6	118.2
	4278	26.9	21.3	22.4	26.0	21.4	19.0	21.1	22.1
	3914	47.4	47.4	47.4	47.4	47.4	47.4	47.4	47.4

§ 16. Variations of Intensity Distribution from Auroral Spectrograms Taken at Oslo.

A new glass spectrograph (C) combining a very high light power with a fairly large dispersion has recently been built by one of us (Vegard) at Oslo. A more detailed description of the instrument will be given in a subsequent paper. In this connection we shall merely mention that the lens in front of the plate was an astro lens F: 0.95 with an aperture of 8 cm.

The curve Fig. 5 gives an idea of the dispersion.

With this instrument we obtained at Oslo a number of auroral spectrograms, and a series taken on April 24, 1941 call for considerable interest and will be briefly dealt with in this paper. Reproductions are given on plate III. These spectrograms were taken on two photographic plates (Agfa ISS).

The first plate contains in addition to three auroral spectrograms Pl. III, Nos. (5, 6, 7) also four twilight spectrograms (1, 2, 3, 4) which will be dealt with later on. We notice that the spectrograph gives quite good separation of the two red *OI*-lines and their intensity ratio may be determined.

The spectrogram No. 5 corresponds to a mixture of twilight and aurorae, and the stronger lines are too dense for intensity measurements. Relative intensities have therefore only been determined for the four spectrograms Nos. 6—9 and for some of the more conspicuous lines and bands. The results are set up in Table XII.

For each spectrogram we have given the intensities in two columns. The first column contains the intensity relative to that of the green line which is put equal to 100. In the second column the intensities are expressed relative to that of the negative band 4278 for which the intensity for all spectrograms is put equal to 24.4.

During the first part of the evening (Spectr. 6 and 7) the red *OI*-lines are comparatively weak while the bands of the 1st positive group are fairly strong. Then quite suddenly conditions have changed in such a way, that the red *OI*-lines are largely enhanced and the 1st positive group is weakened.

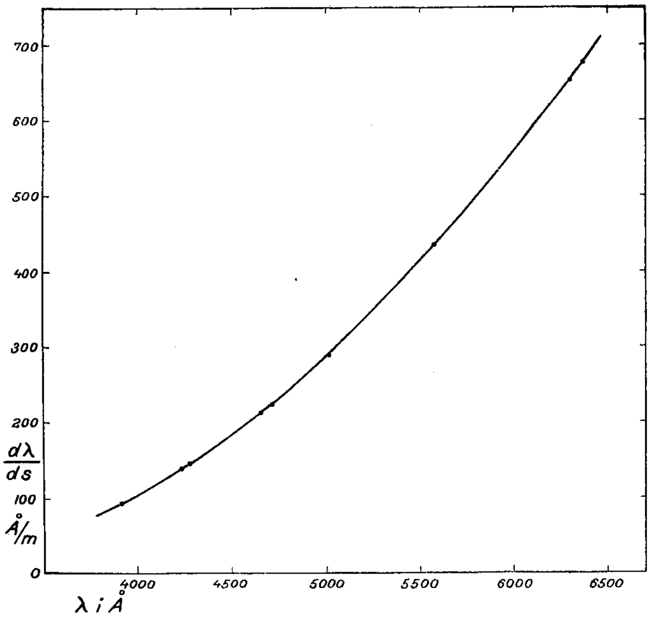

Fig. 5.

Table XII.

Relative Intensities from Spectrograms taken at Oslo with New Spectrograph (C).

λ	Pl. III. No. 6		Pl. III. No. 7		Pl. III. No. 8		Pl. III. No. 9	
	$I_{5577}=100$	$I_{4278}=24.4$	$I_{5577}=100$	$I_{4278}=24.4$	$I_{5577}=100$	$I_{4278}=24.4$	$I_{5577}=100$	$I_{4278}=24.4$
1. pos.	54.3	69.0	19.6	34.3	44.5	16.8	36.0	24.3
6363	-	-	10.8	19.0	68.8	25.4	37.9	25.6
6300	41.7	52.8	30.7	53.7	192.0	41.2	103.2	69.5
5577	100.0	126.6	100.0	175.0	100.0	36.8	100.0	67.4
4708	-	-	5.6	9.9	-	-	12.3	8.3
4650	-	-	3.8	6.6	-	-	9.4	6.3
4278	19.3	24.4	13.9	24.4	66.0	24.4	36.2	24.4
4236	-	-	5.2	9.1	27.9	9.2	16.5	11.1
3914	-	-	19.6	34.4	109.0	40.5	50.8	34.2
Exp.:	21^{53}—21^{58}		21^{58}—22^{45}		22^{50}—23^{55}		23^{55}—02^{10}	
Direction	N		N		N		N	
Height	6°		16°		37°.5		15°	
N. L. form	Yellow draperies		Red diffuse arc		Top of rays		A & D, dif. surf.	

Also in this case we notice that the intensity of the green *OI*-line relative to that of the negative group is unusually large (above the normal), when the red *OI*-line is weak, and that the intensity of of the green line is smaller (below normal) when the red *OI*-line appears with great intensity.

The enhancement of the red *OI*-line with altitude is shown by the spectrogram No. 8, which corresponds to the top of the rays, and which gives a higher relative intensity of the red line than the other spectrograms corresponding to the lower part of the auroral streamers.

§ 17. The Intensity Ratio of the Two Strongest Components of the Red *OI*-Triplet.

The dispersion of the new spectrograph (C) is sufficient for the separation of the components of the red *OI*-triplet. The intensities of the two strongest components 6300 and 6364 were measured, and the results are contained in Table XII.

The ratio $a = \frac{I_{6364}}{I_{6300}}$ calculated from the intensities given in Table XII are given in Table XIII.

The value here found for the intensity ratio a is a little smaller than that found from the spectrograms of much larger dispersion, the difference, however, is not large, and it seems possible with the new spectrograph to obtain fairly accurate results.

Table XIII.

Spectr.	$a = \frac{I_{6364}}{I_{6300}}$
Pl. III. No. 7	0.353
» » » 8	0.355
» » » 9	0.367
Mean	0.352

§ 18. The Absence of the Yellow Sodium Line in the Twilight Spectrum.

On the evening of April 24 we had commenced work with the intention of studying the twilight spectrum. For this purpose a series and spectrograms were taken from the north-western sky about 20° above the horizon. As the twilight faded, aurorae became visible and the exposure was continued on the auroral luminescence.

The twilight spectrograms are reproduced on Pl. III, Nos. 1—4. In spite of the short exposure of only a few minutes, suitable for the twilight spectrograms, the green auroral line appears with considerable intensity on spectrograms 2, 3, and 4, and spectrogram No. 5, which also shows some twilight, is dominated by the auroral luminescence.

In spite of the fact that the twilight spectrograms have a quite suitable density, *the yellow sodium line is not to be observed.* This shows that the sodium concentration in the effective region fluctuates considerably. This variability of the sodium contents in the effective twilight region is the subject of further investigations at Oslo. In this connection we may merely mention that the existence of such variations may help us to solve the problem as to the origin of the sodium, which is responsible for the appearance of the sodium line in the twilight spectrum.

Summary of Results.

1. A number of very successful auroral spectrograms have been obtained at Tromsø with a big glass spectrograph with considerable dispersion. These spectrograms contain a large number of weak lines and bands many of which have not previously been observed; and the wavelengths of these lines have been measured so accurately that as a rule the error is only a fraction of 1 Å unit.

2. These spectrograms have confirmed Vegard's recent discovery that occasionally the hydrogen spectrum appears in the auroral luminescence. The Balmer lines H_β and H_γ and some of the stronger lines of molecular hydrogen were observed.

3. One spectrogram taken on panchromatic plates showed the yellow sodium line quite distinctly, showing that even in the auroral region, the sodium concentration may be quite conspicuous.

4. The socalled "second green line" or band was shown by the larger dispersion to consist of a band and two distinct lines, which within the limit of error coincided with lines observed in the luminescence emitted from solid nitrogen mixed with neon.

5. Another nearly continuous band, perhaps with some structure, was observed in the green between 5307 and 5415.

6. About 25 lines have been found to originate from oxygen atoms in different states of ionisation. These lines also include lines originating from transitions from the metastable ground states. To these belong the famous nebulium line 5006.8 from the ground state of *OIII*, and the nebulium doublet 3728 belonging to the ground states of *OII*.

7. A considerable number of lines are found to coincide with lines of atomic nitrogen. A line for which the most accurate measurements as yet made lead to the wavelength 3476.5 may possibly be identified with the line *NI* (^2P—^4S) attached to the ground states of neutral nitrogen atoms.

8. Measurements of the relative intensities of the lines appearing on the spectrograms mentioned, have shown that the hydrogen spectrum and the green bands are subject to large variations, while the relativ intensities of the atomic oxygen lines seem to be fairly constant.

9. Spectrograms taken on panchromatic plates by means of a spectrograph of large dispersion have enabled us to measure the wavelength and relative intensity of the second component of the red *OI*-triplet. The wavelength was found to be 6364.3 Å, and the intensity ratio $\frac{I_{6364}}{I_{6300}}$ was found equal to 0.380, a value which is a little larger than the value 0.33 found theoretically.

10. By means of our large quartz spectrograph at Tromsø, we obtained a spectrogram of aurora exposed to sunlight. The spectrogram gave the bands 4278 and 3914 with densities suitable for temperature measurements. The temperature was found to be ÷ 33° C, which is about 20° higher than the average found for aurorae under night conditions by means of the same spectrograph.

The sunlight effect indicated is quite small, and the measurements give no indication of such high temperatures (above 1000°) as have been assumed in order to account for certain effects connected with the reflection of radio waves from the ionospheric layers.

11. Some observations obtained at Tromsø with a small spectrograph of high light power have shown that the intensity distribution in the region of long waves may change very largely from one night to another.

When the intensities are compared with that of the negative group, it is found that a large increase in the relative intensity of the red *OI*-triplet, is accompanied with a considerable decrease in the intensity of the strong green *OI*-line. *The processes and circumstances favorable for a direct excitation of the* $^1D_2$*-state seem to reduce the probability for the excitation of the* $^1S_0$*-state.*

12. Auroral spectrograms were obtained at Oslo with a new spectrograph having an extremely large light power and a fairly good dispersion. These spectrograms showed the enhancement of the red triplet with altitude, and in accordance with the results mentioned under point (11), we found that an increase of the relative intensity of the red doublet was accompanied by a decrease in the intensity of the green line relative to that of the negative group.

These spectrograms gave separation of the two components of the red *OI*-triplet. Intensity measurements gave for the ratio $\frac{I_{6364}}{I_{6300}}$ the mean value 0.352 in fairly good agreement with that obtained with the larger dispersion.

13. Some twilight spectrograms obtained with the new spectrograph at Oslo were quite remarkable, because the sodium line was absent although the exposure was quite favorable. This indicates very pronounced variations in the sodium concentrations in the atmospheric layers from which the sodium line in the twilight mainly originates. Investigations on these variations will be continued at Oslo.

In conclusion we wish to convey our sincere thanks to cand. mag. G. Kvifte for invaluable assistance in connection with the auroral observations at Oslo, and in the treatment of the experimental material dealt with in this paper. Our thanks are also due to "Det Videnskapelige Forskningsfond" and "Nansenfondet" for their invaluable economical support of these investigations.

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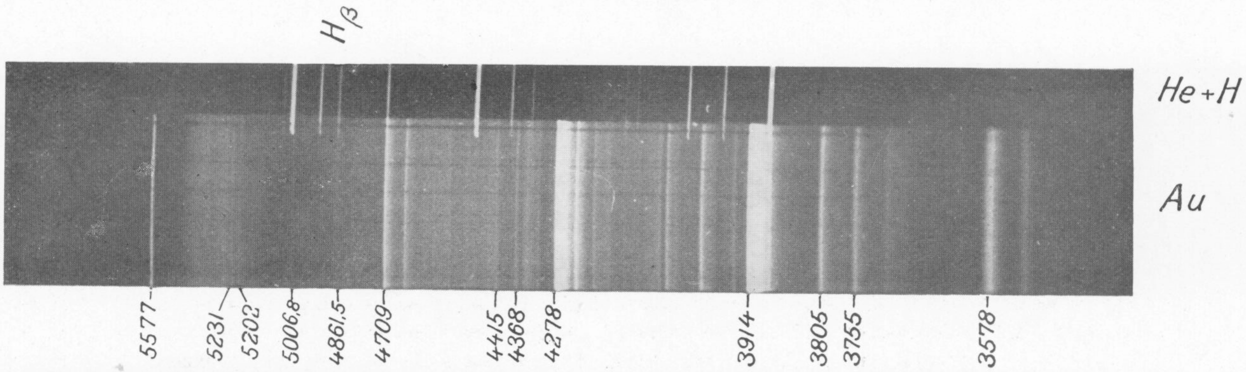
PLATES

Pl. I.

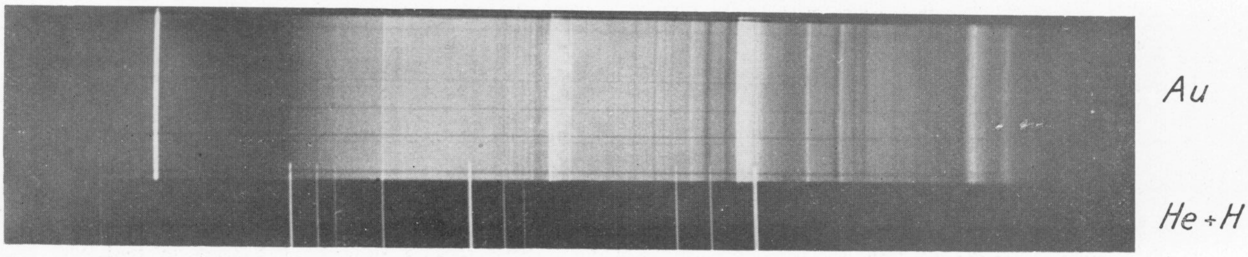
Spectrograms taken at Tromsø with the two-prism glass spectrograph (B).

No.	Year	Date	Effective exp. time	Sort of photogr. plates	Remarks
1	1940	Feb. 6.—March 10.	12—15 hours	Ilf. Selo. Chrom	Various auroral types
2	1940	Oct. 21.—Nov. 26.	30 »	Ilf. Double *X*-press.	Aurorae mixed with nightsky luminescence
3	1940—41	Nov. 28.—Jan. 16.	16 »	Ilf. Selo Chrom	Various auroral forms
4	1941	Jan. 21.—Feb. 20.	12 »	Ilf. Selo Chrom	Various auroral forms
5	1941	Feb. 20.—April 4.	21 »	Ilf. Hyp. Pan. 2	Some displacement of spectra

1


Hβ
He+H
Au
5577
5231
5202
5006,8
4861,5
4709
4415
4368
4278
3914
3805
3755
3578

2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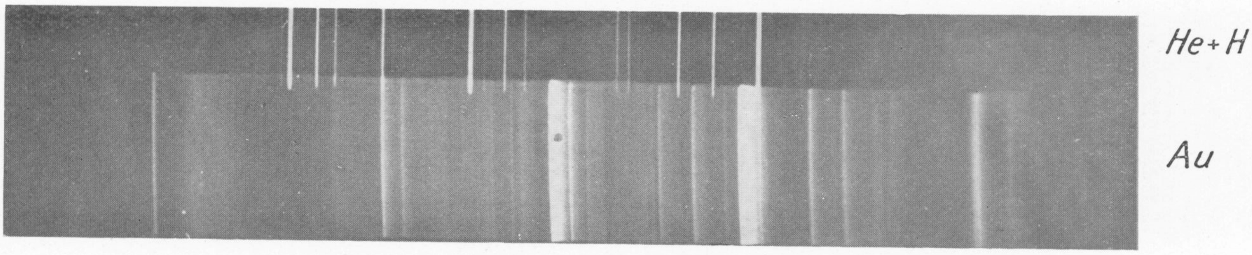
He+H

3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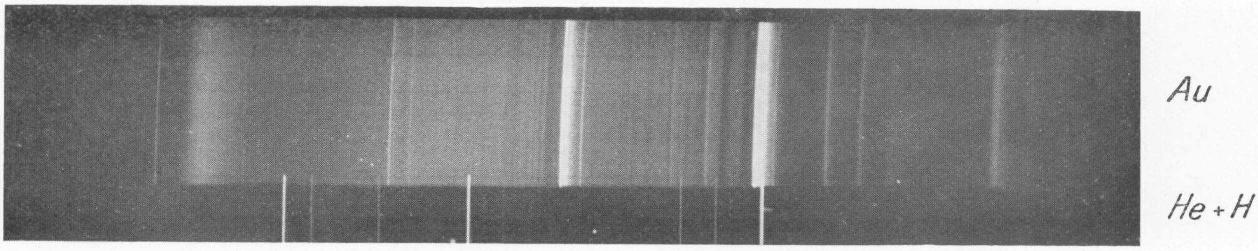
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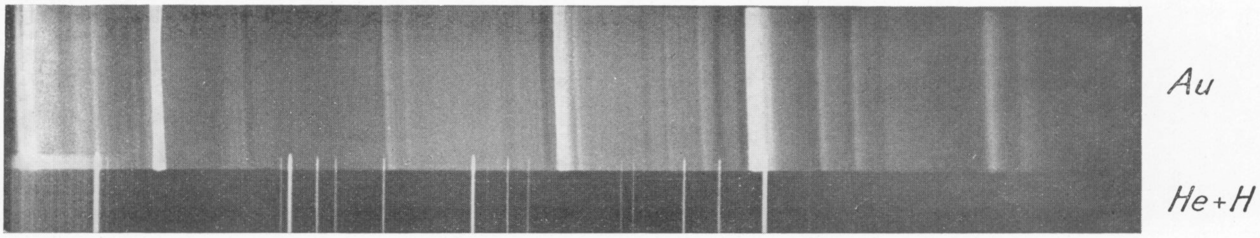
He+H

5

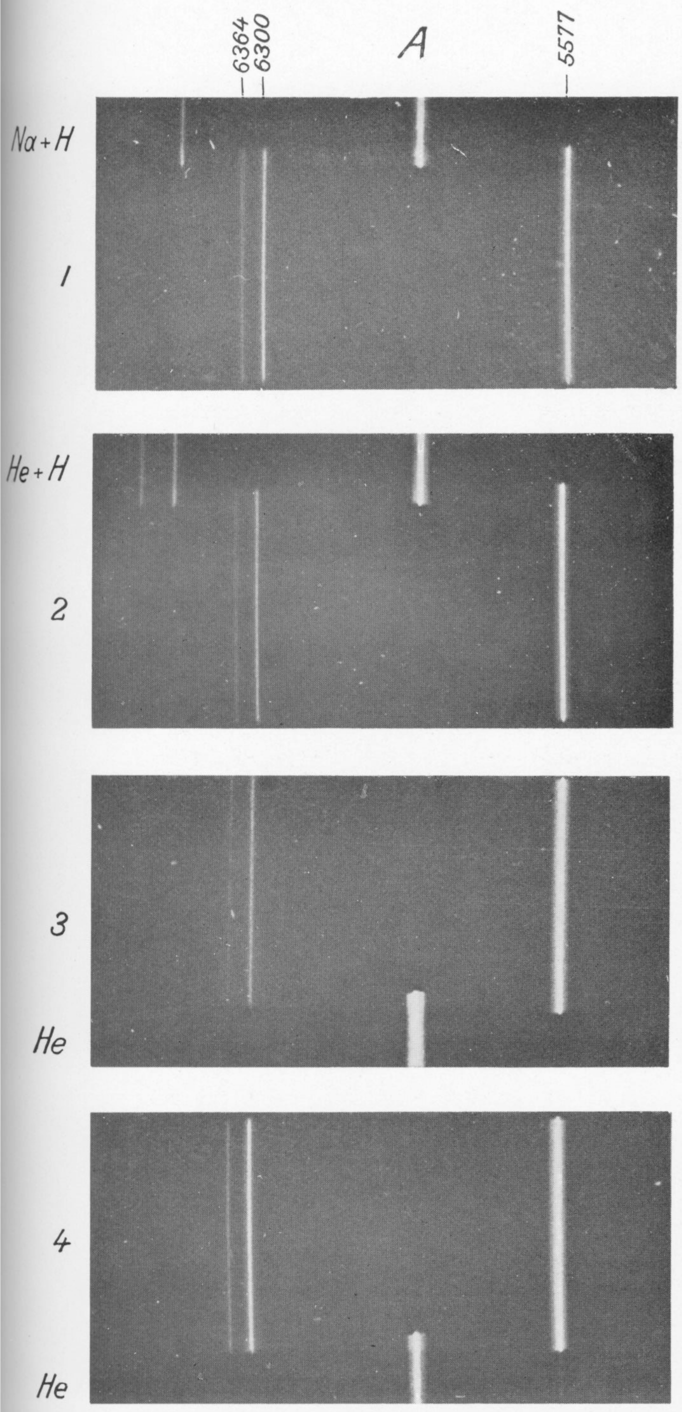

Au
He+H

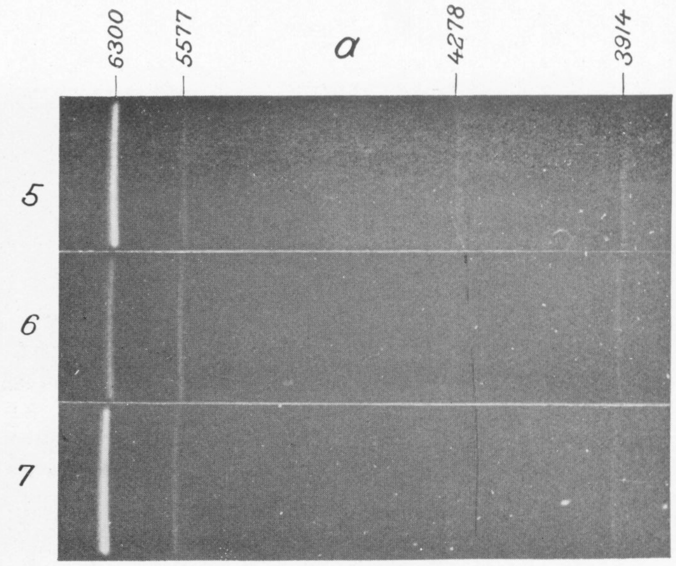
Pl. II.

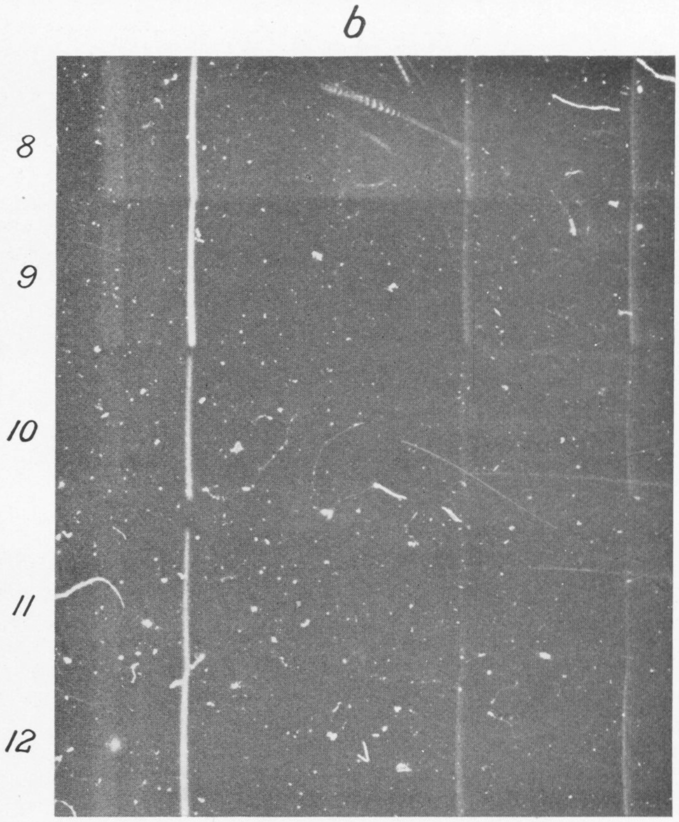
Spectrograms taken at the Tromsø Observatory. Series (A) taken with a large spectrograph (A) provided with a Rutherford Prism. The series (a) and (b) were taken with a small spectrograph provided with a Rutherford Prism. Each of the series (a) and (b) was taken on the same plate. No. 13 taken with the large quartz spectrograph.

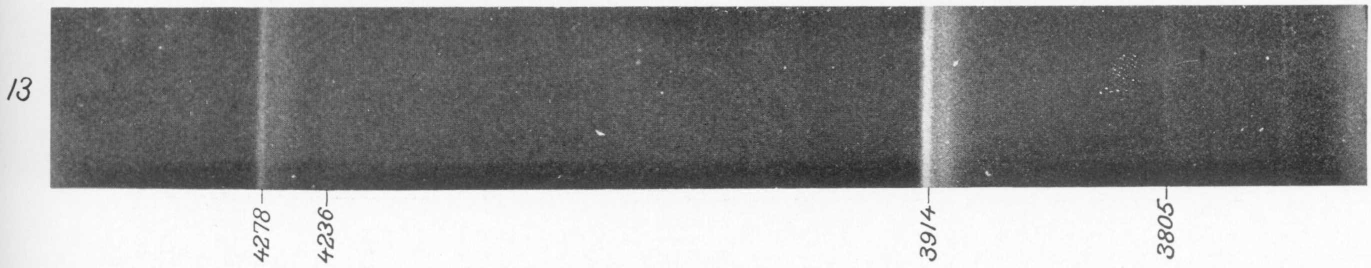
No.	Year	Date	Effective exp. time	Sort of plates	Remarks
A. 1.	1940	Nov. 8.—Nov. 26.	20 hours	Agfa I. S. S.	Various auroral types
A. 2.	1940	Dec. 4.—Dec. 9.	6 »	Agfa I. S. S. Sens. with NH_3	Towards arcs in the northern sky
A. 3.	1941	Jan. 27.—Feb. 23.	12 »	Ilf. H. P. 2	Various auroral types
A. 4.	1941	Feb. 25.—April 2.	16 »	Ilf. H. P. 2	Various auroral types

No.	Date	Time of exposure	Sort of plates	Remarks
a. 5.	March 1. 1941	18^{20}—^{25} and 18^{30}—^{35}	On the same plate Agfa *ISS.* sens. with NH_3	Sunlit red surface towards S. $h = 25°—30°$ above horizon.
a. 6.	—»—	18^{50}—19^{05}		Sunlit weak draperies and surfaces towards S. W. $h = 27°$.
a. 7.	—»—	20^{08}—20^{18}		Red surfaces towards S. W. $h = 20°$.
b. 8.	March 2. 1941	18^{31}—18^{47}	On the same plate Agfa *ISS.* sens. with NH_3.	R. A. towards N. $h = 25°$ occasionally red lower border.
b. 9.	—»—	20^{17}—20^{30}		R. A. towards S. $h = 28°$.
b. 10.	—»—	20^{33}—20^{46}		R. and Bands towards W. $h = 26°$.
b. 11.	—»—	21^{45}—22^{15}		Gray weak surfaces towards E. $h = 27°$.
b. 12.	—»—	(not given)		Brilliant R. A. and D in the S. $h = 20°$.
13	Exposure from Feb. 26—April 4, 1941 on aurorae in sunlight.			


A
6364
6300
5577
Na+H
1
He+H
2
3
He
4
He


a
6300
5577
4278
3914
5
6
7

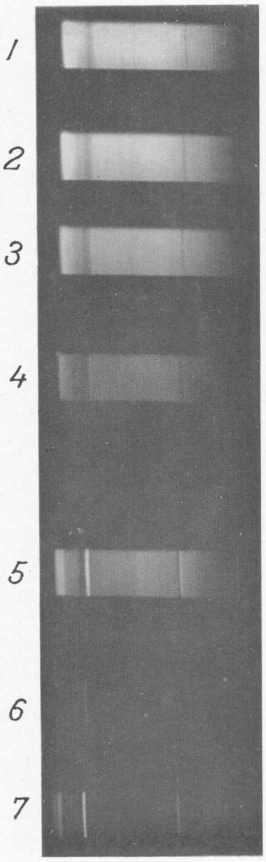

b
8
9
10
11
12

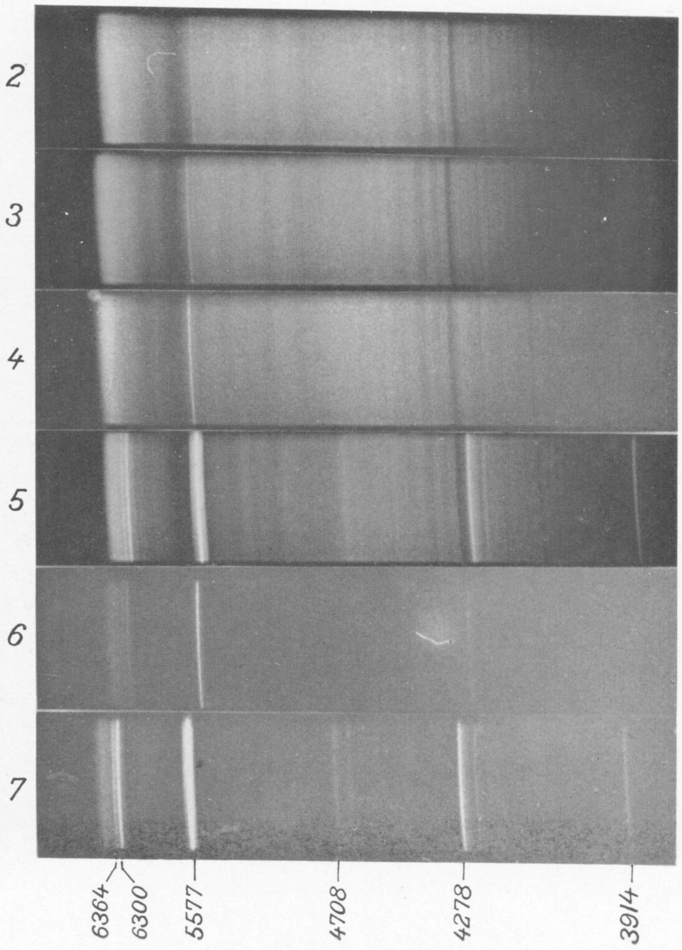

13
4278
4236
3914
3805

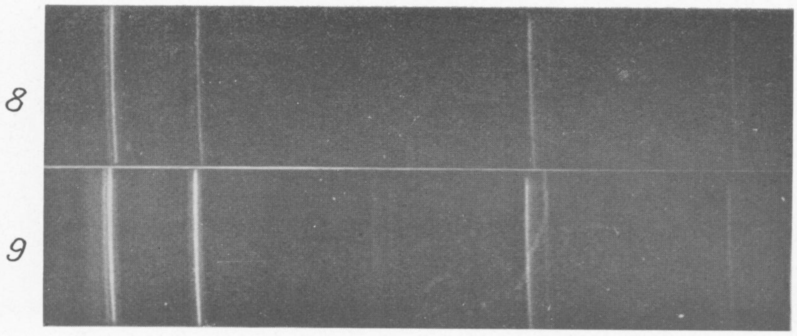
Pl. III.

Spectrograms taken at Oslo during the evening of April 24th with the new glass spectrograph (C), having an Astro Camera lens 1 : 0.95, on two Agfa *ISS* plates sensitized with NH_3. The series (1—7) gives a reproduction of the spectrograms as they appeared on the first of our plates. The two spectrograms (8—9) were obtained on our second plate.

No.	Time of exposure	Direction	h	Remarks	
1	21^{00}—21^{03}	N. W.	20°	Twilight	1st plate
2	21^{03}—21^{08}	»	»	Twilight	
3	21^{03}—21^{15}	»	»	Twilight	
4	21^{15}—21^{18}	»	»	Twilight	
5	21^{18}—21^{53}	N.	12°—24°	Yellow R. A. & D.	
6	21^{53}—21^{58}	»	6°	Yellow D.	
7	21^{58}—22^{45}	»	16°	Reddish, diffuse A.	
8	22^{50}—23^{55}	»	37.5°	Top of R.	2nd plate
9	23^{55}— 2^{10}	»	15°	R. A., D. surfaces	


1
2
3
4
5
6
7


2
3
4
5
6
7
6364
6300
5577
4708
4278
3914


8
9