CONTINUED INVESTIGATIONS ON THE AURORAL LUMINESCENCE AND THE UPPER ATMOSPHERE

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WITH 8 FIGURES IN THE TEXT AND 3 PLATES

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Introduction.

The present paper intends to give the results of observations made at the Auroral Observatory, Tromsø, during the autumn of 1938 with the assistance of Mr. O. Krogness (Jr.), and at Oslo during the years 1938—39, where I was ably assisted by Mr. G. Kvifte and O. Krogness.

The general plan followed by these observations was, in short, the following:

1. It was intended to obtain spectrograms of short exposure from various auroral forms and under various conditions in order to study the possible variations of the intensity distribution within the auroral spectrum. In particular, our attention was directed to the study of some altitude effects, described in previous papers (1, 2, 3, 4), and towards obtaining material for a more quantitative determination of the relation between intensity distribution and sunspot frequency. Such spectrograms were taken both at Tromsø and at Oslo by means of spectrographs of about identical optical properties. By comparing the spectra taken at Oslo with those from Tromsø, possible variations of the intensity distribution with *latitude* might be detected and measured. Some of these spectrograms obtained at Oslo were of an unusual type, indicating that occasionally hydrogen entered into the auroral region from outer space.
2. Already some years ago the writer together with Dr. L. Harang published results of precision measurements of the red *OI*-line 6300, by means of an interferometer method. The material from Oslo gave the wavelength 6300,286 Å while that of Tromsø led to the value 6300,308 Å.

   In order to increase the accuracy, we have continued to take interferometer pictures of the red line both at Oslo and Tromsø with improved experimental arrangements. The Tromsø instrument was reconstructed in order to secure the highest possible stability and precision of focussing.
3. The measurements of the temperature within the auroral region previously carried out by the writer partly in collaboration with Mr. E. Tønsberg, were based on spectrograms which were taken with a large glass spectrograph (A), and which gave the band 4278 with suitable photographic density and fairly good separation of the R- and P-branch. These spectrograms were obtained by directing the collimator towards the strongest parts of the auroral display during the exposure which usually lasted for several weeks.

   As the greatest intensity is found near the lower limit, the temperature derived in this way corresponds to an altitude interval of say 100—130 Km. In order to explain the slow rate with which the density of the atmosphere decreases upwards in the auroral region, some authorities have supposed that the temperature increases rapidly upwards and in altitudes of say 200 km it should reach values of more than 1000° K. The writer has shown that the existence of a temperature increase upwards of this magnitude may be studied in two different ways. One consists in taking interferometer pictures of the atomic *OI*-lines corresponding to varying altitudes of the auroral ray streamers. A number of interferometer pictures, obtained in this way, however, did not show any indication of a temperature-increase upwards (4, 5).

   The other way proposed was to take ordinary spectrograms of the nitrogen bands corresponding to the lower and the upper limit of auroral streamers. In order to carry out such measurements we should have to use a spectrograph of greater light power than the large glass spectrograph (A) previously used for the temperature measurements.

It was found, however, that if we base the temperature determination on the R-branch of the band 3914, the big quartz spectrograph (Q) which we have at Tromsø might be used for studying the temperature at various altitudes within the auroral region. With this instrument, the band 3914 may be obtained with suitable density with an exposure of a few hours. Some spectrograms for temperature measurements obtained with the quartz spectrograph (Q) during the autumn of 1938 will be dealt with in this paper.

PART I.

Spectrograms from Oslo and Tromsø Taken with Small Almost Identical Glass Spectrographs.

§ 2. The Enhancement of the Red OI-line (6300) with Altitude.

After the enhancement of the red *OI*-line with increasing altitude was detected by means of a spectroscope (2), observations were continued at Oslo with the object of obtaining spectrograms suitable for a photometric determination of the magnitude of this altitude effect. It was also of importance to continue these observations for longer periods in order to see how far the enhancement was a common occurrence or whether it might be connected with some particular situation.

The procedure followed by these investigations was similar to that used by the writer at Tromsø in 1923, and which led to the discovery of the enhancement upwards of the negative nitrogen bands relative to the green line (5577).

The method consists in taking on the same photographic plate a series of spectrograms some of which are obtained by pointing the collimator towards the upper part of auroral streamers, while others are obtained from regions near the lower limit. By these exposures we have to use a lens which forms a picture of the aurora on the slit. Usually we only take one pair of pictures, one corresponding to the upper, one to the lower, limit.

Some such pair of spectrograms were obtained during the years 1936 and 1937. The results, given in previous publications (3, 4), showed for all such pairs of spectrograms a considerable enhancement of the red *OI*-line with altitude. The relative intensity of the red *OI*-line relative to that of the green one, was on an average more than twice as large for spectrograms from the upper limit as compared with that obtained for the lower limit. During the two last years a considerable number of such pairs of spectrograms have been obtained at Oslo.

By taking on the same photographic plates spectrograms of a light source of known intensity distribution, it was possible — in a way previously described (8) — to obtain true relative intensities. The average elevation angle (height h) of the collimator, was estimated for each spectrogram, and in that way we were able to make corrections for atmospheric extinction.

The results of the Oslo-observations as regards the enhancement of the red line are given in Table I. The first and second columns give date and time of exposure. The third column indicates the auroral form which has dominated during the exposure. A means arc, DA = diffuse arc, R = ray streamers. $R = I_{6300}/I_{5577}$ indicates the ratio between the intensity of the red and green *OI*-line. The quantity R_u/R_1 gives the ratio of the values of R corresponding to the upper limit and that corresponding to the lower limit.

Table I.

Date	Time Exposure	Auroral Form	$R = I_{6300}/I_{5577}$		Ru/R_1
			upper	lower	
1938					
8 Nov.	21^{00}—24^{00}	A		51	1,4
9 »	00^{00}—01^{30}	R	70		
14 »	19^{00} –22^{00}	A	190		2,9
14-15 »	22^{00}—01^{00}	A		66	
24 »	18^{30}—22^{00}	A&D	123		2,7
24 »	22^{00}—23^{30}	A&D		45	
18 Dec.	18^{15}—20^{15}	R&D	93		1,8
18 »	20^{15}– 21^{00}	R&D		52	
		Mean 1938	119	53,5	2,2
1939					
19 Nov.	20^{50}—22^{20}	R	130		2,55
» »	22^{20}—23^{20}	A + R		51	
7 Oct.	20^{55}—22^{15}	R	114		3,35
» »	22^{15}—23^{00}	A		31	
17 »	19^{15}–20^{05}	A + R	90		3,30
	20^{30}—21^{30}	D.A.		24	
	21^{30}—23^{15}	R	69		
18 »	19^{15}—20^{13}	A		17	4,25
» »	20^{13}—20^{47}	A		23	
» »	20^{47}—21^{55}	R	85		
		Mean 1939	97,6	29,2	3,34
		Mean of all	108,3	41,3	2,62

For 1938 this ratio is, on an average, equal to 2,2 and for 1939, equal to 3,3. The mean of all observations is equal to *2,6*. This result is in very good agreement with that obtained from earlier observations (4). From the spectrograms obtained in 1937 we found for R_u/R_l the mean value 2,25.

The average altitude of the upper and lower limit may be estimated to 180 and 110 Km respectively. The measured enhancement of the red *OI*-line 6300 should then correspond to an increase of altitude of about 70 km.

§ 3. Altitude Effects of Nitrogen Bands.

On a number of pairs of spectrograms obtained at Oslo Oct. 11—12. 1937, it was found that the intensity of the 1st. positive group increases downwards (4); while the typical red bands of this group appeared with considerable density on the spectrograms corresponding to the lower limit, they were too weak to be observed on spectrograms from the upper limit.

This effect is closely related to the red aurorae of type B, which usually appear in the form of drapery-shaped arcs with red lower border. The redness of this type was shown to be due to the enhancement of the red bands of the 1st. positive group taking place near the lower limit, where the pressure is highest and the average velocity of the electric rays is smaller (6, 7, 8).

It was supposed that the redness of the lower border increased when its altitude decreased, and this was verified by height measurements of Harang and Bauer (9) of a typical red aurorae of type B, which reached down to altitudes between 68—70 Km. This explanation of the red aurorae of type B thus involves the existence of an altitude effect of the red bands of the 1st. positive group consisting in an enhancement of these bands with increasing altitude.

It was, however, a matter of great importance that the existence of this altitude effect was shown by direct observations on the spectrograms from Oct. 11—12. 1937. But although they showed the effect they gave no possibility of a quantitative determination of its magnitude.

From an aurora occurring Sept. 19th this year, we obtained at Oslo a pair of spectrograms where the red bands of the 1st. positive group also appeared on the spectrogram corresponding to the upper limit, and from which it was possible to obtain a quantitative determination of the effect.

Table II.

Oslo 19. Sept. 1939.

Wavelength	I. Corrected for extinction		I_u/I_l
	Exp. upper limit 20^{50}—22^{20}	Exp. lower limit 22^{20}—23^{20}	
1. P. G. Max 6500	23,1	32,3	0,71
6300	100	51,5	1,94
5577	76,8	101	0,76
4708	weak	3,6	
4278	10	10	1,0
3914	14	14	1,0

The two spectrograms are reproduced on Plate II, Nos. 18 and 19, and still more enlarged on Plate III, Nos. 1 and 2. The results of the intensity measurements are given in Table II. The negative bands are used as a standard of comparison. The last column which gives the ratio I_u/I_l clearly shows the following three altitude effects:

As the altitude increases, the relative intensity of the 1st. positive group decreases; that of the red *OI*-line increases in the way already dealt with, and the relative intensity of the green line decreases upwards. The latter altitude effect was first detected by the writer in 1923 (1).

§ 4. Variations with Latitude of the Auroral Spectrum.

A comparison between spectra previously obtained by means of similar instruments and plates at Oslo and Tromsø, has indicated that the red *OI*-line 6300 is relatively enhanced towards lower latitudes. This also means that the red aurorae of type A, which is due to the enhancement of the red *OI*-line (or rather triplet), are more frequent and more intensively red at Oslo than at Tromsø.

In January 1926 when spectrograms of red aurorae, showing the remarkable enhancement of the red line, were first secured (10), spectrograms were at the same time obtained at Tromsø with almost identical equipment.

Althought the red line also at Tromsø appeared relatively strong, its intensity relative to that of the green line was much smaller than found at Oslo for the same time interval. It therefore became a matter of importance to undertake more systematic studies of the possible variation of the auroral spectrum with latitude. For this purpose a number of spectrograms were taken at Oslo and at Tromsø. At both places

Table III.

Spectrograms from Tromsø.

Date 1938		26/10	''	''	''	28/10	''	''	''	''
Exp.	begin	18^{30}	19^{00}	19^{40}	21^{30}	17^{15}	17^{40}	18^{55}	19^{25}	20^{00}
	ends	19^{00}	19^{30}	21^{30}	23^{05}	17^{40}	18^{50}	19^{25}	20^{00}	20^{50}
Auroral Form		D&R	D&R	A	A&R	A sunlit	A&R sunlit	A, D&R	A, D&R	A&D
Relative Intensily corrected for extinction.	λ									
	6300	15	11	31	46	32	47	25	31	36
	5990	14	10	12	11	16	17	11	10	16
	5577	108	83	102	117	136	185	191	172	119
	5238	5,4	3,2	4,5						6,4
	4708	6,9	4,9	5,5	5,2	5,1	7,9	7,1	6,2	6,9
	4650	2,5	2,2	2,8	2,2					
	4278	24,4	24,4	24,4	24,4	24,4	24,4	24,4	24,4	24,4
	4058	2,9	1,9	1,8						
	3998	3,9	2,8	3,5						
	3914	55	60	63	70	63	56	63	65	54

(Continued).

Date 1938		28/10	''	''	''	8/11	21/11	''	''	''
Exp.	begin	20^{50}	22^{25}	23^{00}	00^{15}	17^{00}	18^{00}	18^{30}	20^{35}	21^{15}
	ends	21^{50}	23^{00}	00^{15}	01^{05}	18^{30}	18^{30}	19^{30}	21^{15}	22^{15}
Auroral Form		A	A	A	A	R&D	A&D	A&D	A&D	A
Rel. Int. corrected for ext.	6300	25	33	40	26	37	31	24	35	29
	5990	12	16	14	12	19				14
	5577	139	92	98	118	96	120	90	108	81
	4708	6,7		10	7,0					
	4278	24,4	24,4	24,4	24,4	24,4	24,4	24,4	24,4	24,4
	3914	65	71	70	70	52	62	66	70	70

(Continued).

Date 1938		26/11	3/12	''	16/12	''	''	20/12	''	''
Exp.	begin	17^{15}	16^{00}	17^{35}	18^{15}	19^{20}	20^{00}	16^{50}	17^{50}	22^{00}
	ends	18^{00}	16^{45}	18^{30}	19^{20}	20^{00}	21^{00}	17^{50}	18^{45}	23^{45}
Auroral From		A, D&R	A&D	A&R	A, D&R	D	A	A&R	A&D	D
Rel. Int. corrected for ext.	6300	20	58	52	34	20	16	28	17	31
	5990	9,2			14,4	7,8	9,5			
	5577	87	124	97	115	53	59	99	63	93
	5238					3,1	3,6			
	4708	11				4,5	5,1			
	4278	24,4	24,4	24,4	24,4	24,4	24,4	24,4	24,4	24,4
	3919	67	58	58	62	70	70	75	81	77

we used spectrographs of almost identical construction and optical properties.

Each instrument had a Rutherford prism, a camera lens: Erneman Kinostigmat f: 2 with aperture 3.0 cm. The collimator lens had the same aperture, but a focus distance of 20 cm. In front of the slit was placed a condensor lens. A more complete description of the instrument will be found in a previous paper (11) where fig. 3 and 4 give an illustration of the two instruments.

An intensity scale consisting of spectra from a standard lamp of known intensity distribution, was photographed on plates of the sort used for the auroral spectrograms. In this way it was possible to find the true relative intensity distribution which is independent of the apparatus used.

The spectrograms to be dealt with in this paper were obtained at Tromsø during the autumn of 1938 and those from Oslo during the winter, 1938—39 and the autumn 1939. Reproductions of most of the Tromsø spectrograms are given on Pl. I, Nos. 1—24; those from Oslo on Plate II. The most important data relating to each spectrogram are given in an explanation to the plates to be found at the end of the paper. The intensity distribution for the Tromsø spectrograms are collected in Table III, those derived from the Oslo spectrograms, in Table IV.

The average intensity distributions at Oslo and Tromsø are given in Table V for some of the most prominent bands and lines. The first column gives the wavelength, the second, the relative intensities found from the Tromsø observations from 1938 given in Table III. The third, gives the average intensity distribution taken from earlier publications. The fourth, contains the mean of the intensities given in columns (2) and (3). The fifth, contains the average distribution derived from the Oslo spectrograms from 1938—39 for which data are given in Table IV. The last column contains the ratio between the intensities found from the Oslo spectrograms and those from Tromsø. The intensity of the negative band 4278 has been used as a standard of comparison, because ordinarily it appears very distinctly on the spectrograms so its intensity may be accurately measured.

A comparison between the columns (2) and (3) of Table V is of considerable interest when we take into account the different ways in which the average densities are found in the two cases. While the numbers of column (2) are derived as the mean of

Table IV.

Spectrograms from Oslo.

Data of spectrograms						I corrected for extinction				
Date	Exp.	Direct.	Height	Form	Character	6550	6300	5577	4278	3914
25 Jan. 38	23^{10}—23^{15}	S. E.	30°	A + red. S			75	100	18,6	29,5
25 » »		Zenith	90°	cor.			55	100	17,6	25,7
6 Febr. 39	19^{45}—20^{45}	N & W	15°	D. A + R	L. lim.	25,1	36	100	16,8	36,6
6 » »	20^{45}—21^{45}	N	30°	D. S.	(U. lim.?)		73	100		
30 Mars »	20^{54}—21^{35}	W	20°	D. A.			129	100		
30 » »	21^{36}—22^{35}	N	20°	D. A.		63	68	100		
24 April »	22^{45}—23^{45}	Zenith	90°	cor.		30	61	100	18,7	25,4
24 » »	23^{45}— 0^{05}		45°	red. S		(44)	90	100	19,4	26,1
25 » »	0^{05}— 1^{00}	N. E.	20°	A + D. S.		27	41	100	17,6	38,7
25 » »	1^{00}— 1^{35}	E	70°	A + cor.		26	43	100	16,8	24,4
25 » »	1^{35}— 2^{28}	Zenith	90°	D + cor.		30	57	100	19,3	29,1
28 » »	23^{40}— 0^{20}	N	10°	A		39	61	100		
19 Sept. »	20^{50}—22^{20}	N	40°	R	U. lim.	30,2	130	100	13,0	18,2
19 » »	22^{20}—23^{20}	N	25°	A + R	L. lim.	31,8	51	100	9,9	13,9
3 Oct. »	20^{55}—21^{25}	N.W.	17°	D.S.		26	59	100	17,1	
3 » »	21^{25}—22^{10}	W	74°	A		32	45	100	8,5	12,0
5 » »	19^{55}—21^{15}	N	10°	A	L. lim.	22	39	100		
7 » »	20^{55}—22^{15}	W	40°	R	U. lim.		114	100		
7 » »	22^{15}—23^{00}	N	15°	A	L. lim.	23,4	31	100	9,9	
16 » »	21^{05}—22^{05}	W & N	28°	PS, DS, R	U. lim.	53,3	96,5	100		
17 » »	19^{15}—20^{05}	N	37°	HA & R	U. lim.	36,4	89,6	100		
17 » »	20^{30}—21^{30}	N	16°	D.A.	L. lim.	18,5	24,1	100	6,1	11 3
17 » »	22^{30}—23^{15}	N	32°	R	U. lim.		69,2	100		
18 » »	19^{15}—20^{13}	N	28°	A	L. lim.		17,1	100	5,1	7,8
18 » »	20^{13}—20^{47}	N	15°	A	L. lim.	21,6	22,6	100	9,2	16,5
18 » »	20^{47}—21^{55}	N W	39°	R	U. lim.	16,7	84,8	100	9,3	13,0

intensity measurements from a large number of spectrograms taken with small dispersion and short exposures, the numbers of column (3) are derived from a fairly small number of spectrograms obtained with spectrographs of much larger dispersion, but by using much larger times of exposure.

The table shows that in both these different ways we obtain very nearly the same typical intensity distribution showing that for the lines and bands here considered, the measured relative intensity is within certain limits nearly independent of the dispersion used.

The main interest is attached to the last column, which shows the remarkable fact that the intensity distribution within the auroral spectrum varies considerably with latitude. The most remarkable and prominent latitude effects expressed in Table V are the following:

1. The average intensity of the red *OI*-line (6300) relative to the negative band 4378 increases very considerably as we pass towards lower latitudes.
2. The relative intensity of the green *OI*-line (5577) also increases towards lower latitudes, but not so rapidly as the red *OI*-line. This involves that.
3. The intensity of the red *OI*-line relative to the strong green line increases towards lower latitudes. The enormous enhancement of the red line (6300) towards lower latitudes involves that the red aurorae of type (A) become more frequent and more pronounced as regards colour as we pass towards lower latitudes.

Table V.

λ	Tromsø 1938	Tromsø previously measured	Tromsø mean values	Oslo 1938—39	$I_{\mathrm{Oslo}} / I_{\mathrm{Troms\o}}$
b 6300	30,7	28	29,4	103	3,4
5990	12,8	15	14	(28)	(2,2)
a 5577	108,2	100	104	178	1,7
5238	4,0	6,0	5,0		
c 4708	6,7	7,8	7,3	10	1,5
4650	2,4	4 6	3,5		
d 4278	24,4	24,4	24,4	24,4	1,0
4058	2,2	3,4	2,8		
3998	3,4	3,7	3,5		
e 3914	66,0	47,4	56,7	39,2	0,59

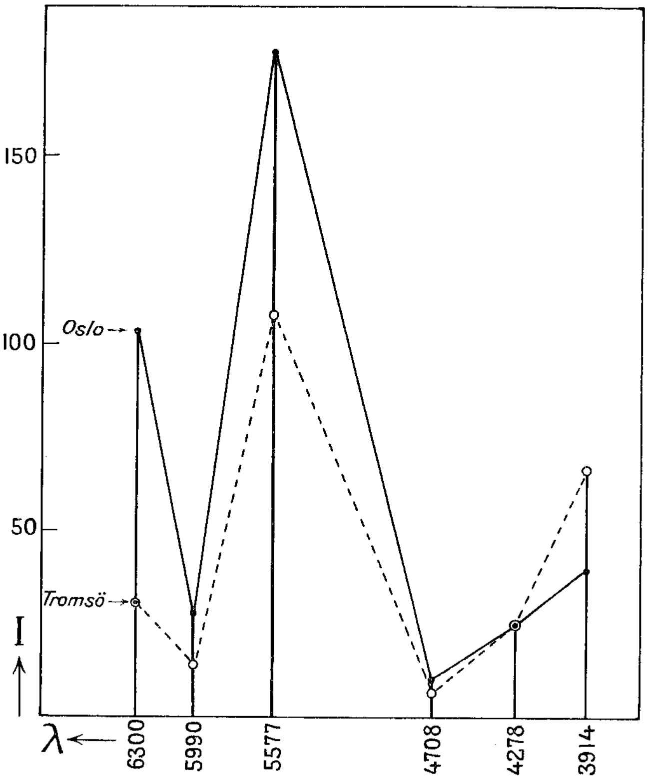

Fig. 1.

4. Table V indicates that the negative bands of the series N. G. (o,n) decreases less rapidly with increasing (n) as we pass towards lower latitudes. There are also indications that the bands of the same sequence decrease less rapidly with increasing quant number when we proceed towards lower latitudes.

   The latitude effects here mentioned are also clearly seen from Fig. 1 giving the intensity distribution at Oslo and Tromsø for some of the lines and bands here considered.

The latitude of Oslo is 59°55′ and that of the Auroral Observatory at Tromsø 69° 40′. The change of intensity distribution expressed in the last column of Table V and in Fig. 1 thus should correspond to a change of latitude of about 10°. Remembering that at Oslo the aurorae are, on an average, observed much lower in the northern sky than at Tromsø, the average difference of latitude is considerably smaller, and if we put the average latitude difference equal to about 8°, we are not far from the true value.

These latitude effects have an important bearing on the question as to the way in which the various lines and bands in the auroral luminescence are excited.

§ 5. Considerations regarding the Interpretation of the Latitude and Altitude Effects.

As we know, the green line is due to the transition of the neutral oxygen atom from the electronic state $^1S_0$ to the lower one $^1D_2$. We also know that the auroral luminescence is primarily produced by electric rays coming in from space (from the sun). The latitude effect then indicates that in order that the collision between the solar electron ray and atmospheric matter shall give oxygen atoms in the $^1S_0$ state, it is essential that atmospheric matter is brought into some abnormal state throught the effect of the ultra-violet radiation from the sun. This change may consist in the formation of ozone or in the dissociation of oxygen or nitrogen molecules into free atoms.

In order to see the significance of the latitude effects of the OI-lines, we may recall to memory some theoretical results given in previous papers (3,4).

The red line 6300 is the strongest component of the triplet $OI(^1D_2 - ^3P_{0,1,2})$. The intensity of the red line is proportional to $(n_d \varepsilon_d)$ where n_d is the number of oxygen atoms which in unit time is brought to the $^1D_2$-electronic state. ε_d is the fraction of these excited atoms which performs the transition $(^1D_2 - ^3P_{0,1,2})$.

The number (n_d) may be devided into two parts, the number $(n_s \varepsilon_s)$ which arrives at the $^1D_2$-state through the transition $(^1S_0 - ^1D_2)$ resulting in the emission of the green line, and the number $\triangle_d$ which in unit time is brought to the $^1D_2$-state in any other way either throught direct transitions from OI-levels higher than $^1S_0$ or through excitation processes which bring the atom directly to the $^1D_2$-state without the passing of any higher levels.

Denoting the intensities of the green and red line by G and R respectively we have:

$$G = h\nu_g n_s \varepsilon_s \tag{1a}$$

$$R = h\nu_r \frac{n_d \varepsilon_d}{1+\alpha+\beta} \tag{1b}$$

ν_g and ν_r are the frequencies of the two lines, h is Planck's constant and $\alpha = \frac{R_1}{R}$, $\beta = \frac{R_0}{R}$.

R_1 and R_0 are the two weakest components of the red triplet. The quantities α and β have not yet been accurately measured, but preliminary measurements (12,13) have given $\alpha = 0{,}58$. The right value is to be found in the interval $0{,}45 < \alpha < 0{,}6$.

With the third component — being usually too weak to be observed — the quantity β is not greater than 0,2.

Thus we may put:

$$1{,}5 < 1 + \alpha + \beta < 1{,}8$$

Putting:

$n_d = n_s \varepsilon_s + \triangle_d$, we get:

$$\frac{R}{G} = \varkappa\, \varepsilon_d \left(1 + \frac{\triangle_d}{n_s \varepsilon_s}\right) \tag{2}$$

where:

$$\varkappa = \frac{\lambda_g}{\lambda_y} \frac{1}{1 + \alpha + \beta}$$

Taking into account the interval found for $1 + \alpha + \beta$, we find:

$$0{,}59 > \varkappa > 0{,}49$$

Thus $\varkappa$ is smaller than 0,6. If now $\triangle_d$ was equal to zero, which means that the $^1D_2$-state was only reached through the transition from the $^1S_0$-state, and as $\varepsilon_d \overset{=}{<} 1$, then we should have:

$$\frac{R}{G} < 0{,}6$$

As stated in previous papers (3, 4), from aurorae exposed to sunlight or from red aurorae of type A which usually appear during periods of great sunspot frequency, we find the ratio $\frac{R}{G}$ to be much larger than 0,6, in fact it may exceed 2,5. This means that in these cases when the quantity R/G is large, the greater part of the intensity of the red *OI*-triplet is due to the quantity $\triangle_d$ or, in other words, to an excitation process which does not involve the transition $^1S_0 - {}^1D_2$.

The very considerable increase of R/G towards lower latitudes, in a sunlit atmosphere and during periods of high sunspot frequency and solar activity, thus shows that the excitation processes which are responsible for the quantity $\triangle_d$, if not due to variations in the properties of the solar electric rays, must be essentially connected with certain changes in the composition of the atmosphere resulting from some radiation of short wave-length, the production of which is due to some process on the sun which is closely related to the solar activity made visible through the appearance of sunspots, flocule and the typical variations of the solar corona.

The existence of such a radiation belonging to the type of soft X-rays forms the basis of the theory of the upper atmosphere given by the writer in 1923 in order to explain the most peculiar distribution of matter, which auroral studies had shown to exist in the auroral region above say 80—100 Km. As the large values of the ratio B/G may be observed in the middle of the night, the atmospheric changes responsible for them must at any rate partly be of such a kind that the new state may last for several hours.

The most important changes of this kind are:

1. The dissociation of molecules into atoms.
2. The formation of complex molecules like ozone (O_3).
3. The formation of molecular and atomic ions.

As mentioned in a previous paper (14), the enhancement in the auroral spectrum of certain *OII*-lines during periods of high sunspot frequency, is probably connected with the 3rd process, because we have to assume that the *OII*-lines result from the collision of the solar electron rays with oxygen atoms which in these regions already exist in the ionised state.

For the enhancement of the green and red *OI*-lines, it is the processes 1) and 2) which have to be considered. A number of excitation processes the occurrence of which might be promoted by the changes (1) and (2), have been dealt with in previous papers (7, 1). We may here mention the following:

1. Excitation of the S_0-state through the action of active nitrogen (N_A) on oxygen molecule in accordance with the equation:

$$N_A + O_2 = OI(^3P_2) + OI(^1S_0) + N_2 \tag{3}$$

It was shown (7) that by this reaction the available energy of "active nitrogen" (9,55 volts) is just sufficient for the process requiring 9,3 electr. volt, and the probability of it will be increased by resonance.

Now the formation of active nitrogen may result from a single collision between a nitrogen particle and the primary electric ray provided that a certain amount of nitrogen already exists in the form of free atoms.

Thus the excitation process expressed in equation (3) would account for the enhancement of the green line towards lower latitude, if we suppose that the effective soft *X*-rays from the sun increase the concentration of free nitrogen atoms.

2. The direct excitation of the $^1D_2$-state through collisions between ozone molecules and excited nitrogen molecules, i. e. molecules in the metastable $A\,(^3\Sigma)$-state. This process might be written (7,3):

$$N_2{}^A + O_3 = O_2\,(A^1\Sigma u) + OI\,(D_2) + N_2 \qquad (4)$$

Instead of $N_2{}^A$, oxygen molecules in some excited state might also come into consideration but the absence of oxygen bands in the auroral spectrum indicates that the concentration of excited O_2-molecules is rather small so their effect to give OI-atoms in the $^1D_2$-state by collision with O_3, ought to be rather insignificant.

A process of the type given in equation (4) would account for the enhancement of the red triplet in a sunlit atmosphere at high sunspot frecuency and towards lower latitudes, when we assume that ozone is formed in the auroral region by the action of soft X-rays, the formation of which is essentially connected with solar activity.

3. Transfer of normal O-atoms to the $^1S_0$ or to the $^1D_2$-state. These tranfers might first of all be produced by collisions between normal O-atoms and the primary electric rays. These processes probably occur, but it is not probable that they are the only ones. The electric rays from the sun have, on an average, energies of the order of several thousand electron volts, and it is to be expected that the other OI-lines corresponding to higher electron levels should appear with considerable intensity.

It has been found (14) that some of these other OI-lines probably appear, but they are very weak. Their appearance, however, would indicate that light is excited by collissions between normal O-atoms and electrons, and, if so, it should follow that some of the O-atoms — which during an auroral display are brought into the $^1S_0$- or $^1D_2$-state — have been transferred to this state directly or indirectly by the collision between normal O-atoms and the primary electric rays.

We have also to consider the possibility that molecules excited directly by impacts with the primary electric rays, may act on the normal O-atoms present in the atmosphere and bring them to the $^1S_0$ or $^1D_2$-states. Thus O-atoms might be excited by collisions of the second kind between normal O-atoms and nitrogen molecules in the metastable A-state.

Through the detection and interpretation of the ε-system which corresponds to the transition $N_2(A^3\Sigma - X^1\Sigma)$, we know that the excitation energy of $N_2{}^A$ is 6,19 electron volts. The energy necessary to excite the $^1D_2$ and $^1S_0$-states from normal O-atoms is 1,8 and 4,1 electron volts respectively.

We should therefore expect that a collision between O-atoms and $N_2{}^A$-molecules would first of all bring the O-atoms to the $^1S_0$-state. This process might be written:

$$N_{2A} + OI\,(^3P_2) = OI\,(S_0) + N_2 \qquad (5\text{ a})$$

According to the conditions under which the collision takes place, the two following processes might also occur:

$$N_2{}^A + OI\,(^3P_2) = OI\,(D_2) + N_2 \qquad (5\text{ b})$$

$$N_2{}^A + 2OI\,(^3P_2) = OI\,(S_0) + OI\,(D_2) + N_2 \qquad (5\text{ c})$$

The $N_2{}^A$ molecule would have sufficient energy for the process (5 c), but the probability of simultaneous collisions with two O-atoms is very small.

We have here drawn attention to a number of processes which might possibly account for the variation of the green and red OI-lines with altitude, sunlight and with latitude. The observed altitude effects may give some further information which will to a certain extent restrict the number of possible processes.

§ 6. Discussion of the Altitude Effects.

The explanation of the altitude effects of the green and red OI-lines and of the first positive group, has been discussed in previous papers (3,15). The enhancement of the 1st. positive group with decreasing altitude is simply explained when we take into account the results of experimental studies of the excitation functions of the 1st. positive group as compared with that of the negative one. It is found that the intensity of the 1st. positive, compared with that of the negative group increases with increase of pressure (7, 16, 17) and diminution of velocity, and that it therefore must increase downwards because the pressure increases and the average velocity diminishes. This explanation has been confirmed by a more accurate determination of the excitation functions of the nitrogen bands recently made at our institute (18).

In this case the interpretation is fairly simple because the bands in question are excited by direct collision between the primary electron and the nitrogen molecules.

The intensity of a band of the negative group may thus be expressed by the equation:

$$I_n = h\nu_n f_n(v\varrho)\, N_2 P \ldots\ldots \qquad (6)$$

$f_n(v\varrho)$ is the excitation function of the negative group, v is velocity and ϱ density, ν_n the frequency of the band considered, N_2 number of nitrogen molecules per cc and P the intensity of electric rays.

For a band of the first positive group, the intensity I_p^I is given by the equation:

$$I_p^I = h\,\nu_p^I f_p^I(v)\, N_2 P \qquad (7)$$

These two equations give:

$$\frac{I_p^I}{I_n} = \frac{\nu_p^I f_p^I(v, \varrho)}{\nu_n f_n(v, \varrho)} \qquad (8\text{ a})$$

For two given bands, ν_p^I/ν_n is a constant and the intensity of the 1st. positive, relative to that of the negative group, essentially depends on the excitation functions. When the density ϱ falls below a certain value, the excitation functions are nearly independent of ϱ.

Now the average velocity of the rays usually increases upwards. The experimental determination of the excitation functions (18) has shown that the ratio I_p^I/I_n increases very largely when the velocity gets smaller. In an interval between the excitation potential 11 volts of the 1st. positive and that of the negative group 16,4 volts, the ratio becomes infinitely large, because the negative bands do not appear at all.

In the auroral region we are not dealing with exactly homogeneous ray bundles, and at a certain altitude, the velocities will vary between certain limits. At each height the intensity ratio is determined by the average ray velocity, and, therefore, the emission of the negative group will not suddenly stop when the average ray energy is equal to the excitation energy, but we get a somewhat gradual diminution to zero.

Thus the equation (8 a) shows that the enhancement of the 1st. positive group towards lower latitudes is essentially determined by the excitation functions together with the fact that the average velocity of the ray-corpuscles diminish, and the density increases downwards along the auroral streamers.

If we have several groups of electric rays, the intensity ratio may be written:

$$\frac{I_p^I}{I_n} = \frac{\nu_p^I \sum\limits_i \left(f_p^I(v, \varrho)\, P\right)_i}{\nu_n \sum\limits_t \left(f_n(v, \varrho)\, P\right)_i} \qquad (8\text{ b})$$

In order to study the variation with altitude we should have to know the excitation functions for each group of electric rays, the relative intensity of the various groups as a function of altitude. The assumption that the solar electric rays consist of electrons mixed with positive rays composed of different corpuscles, would give new possibilities for variabilities within the auroral spectrum, and it greatly complicates the interpretattion of the observed variability effects.

As shown in previous papers (7), the nitrogen spectrum of the auroral spectrum is essentially of the same type as that we obtained by bombarding nitrogen with cathode rays, and differs essentially from that produced by positive rays (canal rays).

In the following discussion we will therefore assume that the auroral luminescence is primarily produced by electron rays. The excitation of the green and red OI-lines may be produced in essentially two different ways:

1. An O-atom in the ${}^1S_0$ or ${}^1D_2$-state may be formed from the very particle which has been brought to an excited state by collision with an electron ray.
2. The O-atom in the ${}^1S_0$ or ${}^1D_2$-state may result from a collision of the second kind between several particles (at least two) one of which has been excited by collision with an electron ray.

Let us first treat the 1st. posibility. The oxygen particles which by collision with an electron may give an O-atom in the ${}^1S_0$-state, are supposed to be present with concentrations $\omega_1, \omega_2 \ldots\ldots \omega_n$.

Those particles which by collision with an electron produce O-atoms in the ${}^1D_2$-state will be: $\omega_1', \omega_2' \ldots\ldots \omega_n'$.

Then the intensities of the green and red OI-lines may be written:

$$G = h\,\nu_g\,\varepsilon_s\,P\,\varepsilon_s\,\Sigma_j f_j(v)\,\omega_j \qquad (9)$$

$$R = h\,\nu_r\,\varepsilon_d\,P\left(\varepsilon_s\,\Sigma_j f_j(v)\,\omega_j + \Sigma_i\,\varphi_i(v)\,\omega_i'\right) \qquad (10)$$

$$G/I_n = \frac{\nu_g}{\nu_n}\,\frac{\varepsilon_s\,\Sigma f_j\,\omega_j}{f_n N_2} \qquad (11)$$

In equation (11) expressing the intensity of the green line relative to that of the negative bands, ν_g/ν_n is constant. The fraction ε_s is zero below an altitude H_0, above which it increases to 1. It is possible that in the region above say 100 km, ε_s is nearly equal to 1. At any rate, the variation of ε_s cannot explain the diminution of the ratio G/I_n with increasing altitude. On account of the rapid motions in the auroral region, the ratios of ω/N_2 may be supposed to vary little with altitude. Therefore, if the ratio G/I_n is expressed by an equation of the form (11), then the diminution of G/I_n with altitude might be explained in a similar way as the altitude effect of the 1st. positive group by means of the different form of the excitation functions.

From equation (9) and (10) we get:

$$\frac{R}{G} = \varkappa\, \varepsilon_d \left(1 + \frac{\Sigma\, \varphi_j\, \omega'_j}{\varepsilon_s\, \Sigma\, f_i\, \omega_i}\right) \qquad (12)$$

Even if the expression in the bracket is essentially independent of altitude, the quantity R/G might increase with altitude on account of ε_d which increases upwards from 0—1. If an essential increase of ε_d takes place in an interval say between 100 and 200 km, then this variation might explain the observed enhancement of the red line towards greater altitudes.

In order to see whether the explanation is correct, we should know the exact average lifetime of the $^1D_2$-state, the smallest average time (τ_m) between two collisions (the smallest average time of free path) which may just give noticeable emission of the red line. If we further knew how ε_d varied with the mean free path of the O-atom, we should be able to find approximately how ε_d varied with altitude.

Part of the enhancement, however, may be due to the increase with altitude of the expression in the bracket. As the concentrations O_i and O_j at any height are probably of the same order of magnitude, the form of the excitation functions would have a great influence on the variation of the ratio R/G.

The oxygen particles which may come into consideration are O, O_2, O_3 and eventually clusters of atmospheric matter containing oxygen. The first possibility treated and which leads to equations (9, 10, 11, and 12) involves that O-atoms in the $^1S_0$ and $^1D_2$-state result from a single collision between one of these oxygen particles and an electron.

In our laboratory we have recently made extensive investigations in order to see whether O_2-molecules can give $O(^1S_0)$ or $O(^1D_2)$-atoms by collision with an electron. In order to obtain observable light intensity at the smallest possible pressure, the tube was put into a strong magnetic field produced in a solenoid. The electron rays thus make numerous turns round the magnetic lines of force and in this way we increase enormously the number of collisions made by each ray before it strikes the wall.

We worked at pressures down to 10^{-4} mm, which corresponds to that existing in the atmosphere at an altitude of 100 km where we know that the green auroral line appears with great intensity. One result of our experiments *was that no trace of the green or red OI-line was observed under these conditions.*

It thus seems legitimate to conclude that *O-atoms in the $^1S_0$ or $^1D_2$-states are not produced in noticeable quantities, when an electron ray collides with an ordinary oxygen molecule. (O_2).*

It is, however, to be expected that the O-atom in the $^1S_0$ and $^1D_2$-state are produced by collisions between electrons and normal oxygen atoms. As the electron rays, however, have an energy which is large compared with the excitation energy we must expect that the relative probability for obtaining the O-atom in a certain excited state should be fairly constant. In other words the excitation of free O-atoms with swift electrons should give a line spectrum of definite intensity distribution.

The number of O-atoms (n_d) which in unit time is brought to the $^1D_2$-state is then:

$$n_d = \varepsilon_s\, n_s + k\, n_s = n_s\, (\varepsilon_s + k)$$

and

$$\frac{R}{G} = \varkappa\, \varepsilon_d \left(1 + \frac{k}{\varepsilon_s}\right) \ldots\ldots \qquad (13)$$

The quantity (k) may perhaps vary somewhat with the velocity of the rays and consequently with altitude, but the equation (13) *cannot explain that the ratio R/G varies largely with latitude, with solar activity, and that it is increased in a sunlit atmosphere, — because ε_d and k must essentially be constant for a given altitude.*

The explanation of the effects therefore require an excitation process which produces $OI(^1D_2)$ atoms independently of the production of O-atoms in the $^1S_0$-state, and this process must *be connected with a substance, the concentration of which is increased by the action of sunrays of short wavelength.*

Such a substance is ozone. The question is now whether a bombardment of ozone molecules with electron rays gives O-atoms preferably in the ($^1D_2$)-state. The experimental data available do not yet permit any answer to be given to this question.

If oxygen were contained in clusters consisting of various components of the atmosphere, the secondary processes might be operating within the particle. *In that case, also a number of secondary processes might occur although the intensities are still given by the equation (9) and (10).*

We shall then consider the second type of excitation process. In this case the light is not emitted from the excited particle itself, but first after this particle has made a collision of the second kind with at least one other particle.

It is evident that the intensity obtained by a process of this type will essentially depend on the relation between the average life time (τ) of the excited state, and the mean time (l/u) between successive collisions, (l) is the mean free path and (u) the average velocity.

Let the number of excited particles be N_o, then the number N, which may have a chance of making a collision of the second kind with its proper partner may be approximately given by the equation:

$$N = N_o e^{-\frac{l}{u\tau}}$$

The number of oxygen particles which is brought to some definite electron level may be given by an equation of the form:

$$N_o = k P f(v)\, C e^{-\frac{l}{u\tau}}$$

and

$$I = h\nu\varepsilon\cdot k\cdot P f(v)\, C e^{-\frac{l}{u\tau}} \tag{14}$$

(C) is the concentration of the particles directly excited by collisions with electric rays and (τ) the mean life-time of the excited state. (k) expresses the probability that a collision of the excited particles will result in the formation of an O-atom in the excited state considered, and ε is the fraction of the O-atoms brought into this state which performs the transition corresponding to the line considered.

As long as the mean free path (l) is small as compared with the distance ($u\tau$) which the particle on an average moves during the mean life-time (τ), the factor $e^{-\frac{l}{ut}}$ will be nearly equal to unity, and the intensity resulting from collisions of the second kind may be of the same order of magnitude as that produced, when the excited state of the line considered results directly from a collision with a ray particle.

In the auroral region, where the density is small, the mean free path is large, and in this case only processes can come into considerations for which (τ) is of the same order of magnitude as, or larger than, (l/u).

The average velocity (u) is equal to 14550 $\sqrt{\frac{M}{T}}$ cm/sec where (M) is the molecular weight of the particle, (T) the absolute temperature. According to our measurements $T = 240°\ K$ (approx.), and for atoms or molecules the velocity will be of the order of magnitude 50000 cm/sec.

At an altitude of 100 km the pressure is of the order of $2\cdot 10^{-4}$ mm which corresponds to a mean free path of the order $l = 100$ cm. In order that collisions of the second kind may give noticeable intensity at this altitude, the mean life-time (τ) of the primarily excited state must be larger than $2\cdot 10^{-3}$ sec.

When we proceed to altitudes of say 500 km, the pressure is probably not higher than 2.10^{-8} mm corresponding to a mean free path of 10^6 cm. At this altitude only excited states with an average lifetime of the order of 20 sec. or greater can give noticeable intensity.

Previous considerations show that a knowledge of the average lifetime of the metastable states of atmospheric matter may give us valuable information with regard to the question whether collisions of the second kind may account for the great intensity and the pronounced variations shown by the green and red lines in the oxygen spectrum.

We have previously considered a number of processes consisting of collisions of the second kind, between some type of activated nitrogen and oxygen either in the form of molecules or atoms. In all these cases the equation (14 a) expressing the intensity of the line considered takes the form:

$$I = h\nu_g \varepsilon k P f_n(v)\, N_2 e^{-\frac{l}{u\tau}} \tag{14 b}$$

$f_n(v)$ is the excitation function for the metastable state considered. In this way the intensity of the strong oxygen lines is proportional to the concentration (N_2) of the nitrogen molecules which form the dominant component of the atmosphere. If then $e^{-\frac{l}{u\tau}}$ does not differ much from unity, we may understand — as pointed out previously — that lines from oxygen may appear with such a dominating intensity.

In order to illustrate the consequences of processes of this kind, we suppose that the two strong oxygen lines are produced by a secondary process leading to equation (14 b). For the sake of simplicity we assume that the ${}^1S_o$-state is only reached through one such process, which only gives $O({}^1D_2)$ atoms through the transition(${}^1S_o$—${}^1D_2$). The quantity indicating the number of O-atoms which in unit time is brought to the ${}^1D_2$-state without passing the ${}^1S_o$-state, is supposed to be produced by another process of the type (14 b), then:

$$\frac{R}{G} = \varkappa\, \varepsilon_d \left(1 + \frac{k_d f_d(v)}{\varepsilon_s k_s f_s(v)}\, \varepsilon^{\alpha}\right) \tag{15}$$

where:

$$a = \frac{1}{u}\left(\frac{l_s}{\tau_s} \div \frac{l_d}{\tau_d}\right)$$

The indexes (s) and (d) refer to the processes leading to the $^1S_0$- and $^1D_2$-state respectively.

In order that processes of this type explain the variation of R/G with altitude, a must be a fairly small quantity, so for altitudes within the auroral region e^a does not differ very much from unity. If a is slightly positive and increases with altitude, then the increase of R/G upwards might be essentially due to the variation of e^a.

We see from equation (15), however, that a variation of R/G with altitude may also be due to differences of the excitation functions f_s and f_d, corresponding to the activated states of nitrogen, which by collisions give the $^1S_0$- and the $^1D_2$-state respectively.

PART II.

Showers of Hydrogen in the Auroral Region.

§ 7. Introductory Remarks.

Investigations on the auroral spectrum (1, 2, 3, 7, 11) have given the result that, as a rule, the lines from hydrogen like those of the Balmer series, are absent from the auroral spectrum. A large number of spectrograms have been obtained on which the stronger lines are much over-exposed and where even very weak lines appear in the region near the Balmer lines, but where no trace of hydrogen lines was to be seen. A number of spectrograms taken with fairly large dispersion, giving the stronger lines with large density and even the red bands of the 1st positive group quite distinctly, do not show any trace of (H_α), (7,13).

On a few spectrograms taken with one of the small glass spectrographs, we obtained a line with a wavelength 4860, which within the limit of error coincides with that of H_β. It was found, however, that this line equally well coincides with a *NII*-line and with one from *OII*. (7, 11, 15.)

This does not mean that the weak line 4860, which is found on a few spectrograms may not be identical with H_β, and that hydrogen may not occasionally appear in the upper atmosphere with sufficient concentration to show its lines in the auroral spectrum. On the contrary, the writer some years ago (7) proposed an explanation of the luminous night clouds — according to which these clouds — situated at an altitude of about 80 km. — were due to showers of hydrogen coming in from space. This precipitated hydrogen — probably coming from the sun — and appearing in the form of atoms — will combine with atmospheric oxygen in its various states to form water vapour. At the altitude of 80 km., the pressure in the atmosphere may be sufficiently large for the water vapour to condense to form clouds consisting of ice needles or supersaturated water drops. The condensation process must be facilitated by the presence of nuclei.

As suggested by Bernard (19) and by Cabannes and collaborators (20), the yellow line (5893) which appears in the night sky luminescence and in twilight, should originate from sodium, and possibly sodium or sodium oxyde might form very effective nuclei for the condensation of the water vapour which results from the hydrogen showers.

The sodium oxyde would dissolve in the water and in that way reduce the vapour pressure of the condensed particles.

Such a reduction of vapour pressure seems to be necessary to explain the fact that the luminous night clouds are situated at an altitude of about 80 km. (21). The total atmospheric pressure at this altitude should be about 0,004 mm. Hg. Taking the temperature at this altitude to be as low as ÷ 50°C., the vapour pressure of pure ice at this temperature is 0,03 mm, or about eight times the total pressure. Thus very effective nuclei like those of sodium oxyde should be wanted in order that condensation of water vapour might take place at an altitude of 80 km. If such nuclei are not present we should want a much lower temperature to explain the formation of the luminous night clouds provided they consist of condensed water vapour.

§ 8. Auroral Spectra Indicating Precipitations of Hydrogen.

During an auroral display occurring Oct. 18th 1939, we obtained at Oslo early in the evening from quiet auroral arcs, spectrograms of a peculiar type, which indeed indicates the existence of such hydrogen precipitations. We took three spectrograms that evening with the small glass spectrograph and they are reproduced on Plate II, Nos. 29—31, and in a still

Table VI.

λ	6563	6300	5577	4861	4708	4278	3914
Interpretation	$H\alpha$	$OI(^1D_2—^3P_2)$	$OI(^1So—^1D_2)$	$H\beta$	NG (0—2)	NG (0—1)	NG (0—0)
Intensity	(42)	34	196	7	3,6	10	15

greater magnification on Plate III B, Nos. 1, 2, 3. Nos 1 and 2 correspond to lower limit, No. 3 to the upper auroral limit.

The first spectrum (exposure 19^{15}—20^{18}) showed the green and red *OI*-lines with large density and the strongest negative bands appeared also quite distinctly. The bands of the first positive group, however, are faint although they usually appear quite strong from the lower border of arcs. But far in the red part a strong line now appeared. Wavelength measurements showed that this line within the limit of error coincides with H_α ($\lambda = 6562{,}8$). The dispersion being small especially in this part of the spectrum, the error may be several Å-units and, therefore, the coincidence might be accidental and not conclusive.

The spectrogram, however, showed in the blue part another line which is also usually absent in the auroral spectrum, and it was found that this line, within the limit of error, coincides with H_β ($\lambda = 4861$); though this line showed small photographic density on the plate, it still appeared quite distinctly. In fact, it was much stronger than the socalled second green line, which could not be seen at all, and it was considerably stronger than the negative band 4708.

From an intensity scale taken by means of a light source of known intensity distribution, the relative intensities of the bands and lines appearing on the Spectrogram No. 1 on Pl. III B were measured. The results are given in Table VI.

The simultaneous enhancement of two lines, one of which coincides with H_α, the other with H_β, can hardly be accidental, and our spectrograms thus would give evidence of a *situation where considerable quantities of hydrogen are present in the auroral region.*

The numerous strongly exposed spectrograms which were obtained during recent years and where the hydrogen lines are absent, show that noticeable concentrations of hydrogen are only found in the upper atmosphere on rare occasions. Thus the occurrence of *H*-lines should be *due to showers of hydrogen or to a kind of "hydrogen radiation" occasionally coming from the sun with an unusual intensity.*

It is therefore most probable that the line 4860 occasionally observed in spectrograms from previous years is to be identified with H_β and that the occurrence of this line indicates the occurrence of hydrogen showers.

A second spectrogram (Pl. III B, No. 2) showed the H_α-maximum; but as it was weaker, neither H_β nor the negative band 4708 was to be seen.

The third spectrogram (Pl. III B, No. 3) corresponding to the upper limit (exposure 20^{47}—21^{55}) showed the red *OI*-line considerably enhanced, but no trace of the H_α and H_β-maxima. This might indicate that the "Hydrogen effect" is mostly restricted to the lower part of the auroral region. The light from the lower limit of arcs usually corresponds to an altitude of about 100 km.

It is of interest to notice that a spectrogram obtained about a month earlier (Sept. 19th) also showed the H_α and H_β-maxima, but not so pronounced as the spectrogram from Oct. 18th. This spectrogram is shown on Plate II, No. 19, and on Plate III A, No. 1. Also this evening the hydrogen effect was restricted to the spectrogram corresponding to the lower limit (exposure 22^{20}—23^{20}), while that corresponding to the upper limit (No. 2, Pl. III A), which was exposed from 20^{50}—22^{20}, does not show any indication of the hydrogen lines.

In this case the spectrogram showing the "Hydrogen effect" was taken late in the evening, and, therefore, it does not seem to be essential for the appearance of hydrogen lines that the spectrum is taken soon after sunset.

Auroral displays appearing at Oslo Dec. 6th 1939 and January 3rd this year also gave spectra of an unusual type, as will be seen from the reproductions Pl. III C and D. The lines which probably correspond to H_α and H_β appear with considerable density and certain bands or lines in the region red

Table VI b.

λ	Possible Interpretation
6564	H_α
6185	1 P. G. (4—0) (or 12-9)
6135	1 P. G. (5—1)
5993	1 P. G. (15—12)
5890	1 P. G. (9—5) Na.
5772	
5680	
5472	
5235	1 P. G (16—11)
5007	Nebulium (*OIII*)
4859	H_β
4650	N. G. (1—3)
4357	*OI*, *NI*
4347	
4339	H_γ (?)

to green, usually weak or absent, now appear greatly enhanced. Some of the enhanced bands or lines are given in Table VI b.

It is quite remarkable that particularly on the spectrogram Pl. III D. 3, the yellow natrium-doublet seems to appear with considerable intensity, and that the negative band 4652 (N. G. 1—3) seems to appear with nearly the same intensity as the band N. G. (0—2).

If the enhanced red and blue lines originate from hydrogen, then we have to face another problem regarding the origin of these hydrogen showers. The hypothesis which naturally suggests itself is that the hydrogen originates from the sun, and that the increase of the hydrogen transport to the upper atmosphere is in some way connected with solar activity.

Emission of hydrogen may be connected with violent protuberances or closely connected with the coronal rays. According to the coronal theory proposed by the writer (22), the coronal rays are primarily due to the emission from the sun of electrons of fairly large kinetic energy. In order to compensate for the loss of negative charge, positively charged matter will follow in the track of the rays.

The ray bundles producing aurora and polar magnetic storms are constituted in a similar way. In any case, hydrogen may follow in the track of the electric ray bundles from the sun and thus increase the hydrogen concentration in the upper atmosphere to such an extent that the hydrogen lines may be strong enough to be observable in the auroral spectrum.

Also neutral atoms or molecules of hydrogen might be carried to the earth by the light pressure, but on this assumption we would rather expect that hydrogen was carried to the earth at a fairly constant rate. It is therefore most likely that the hydrogen transport to the earth — if it occurs — is connected with the electric radiations, the existence of which is proved by their production of aurora and magnetic disturbances.

We have also to consider the possibility that the sodium, whose presence in the atmosphere manifests itself through the appearance of the yellow Na-doublet in twilight and less marked in the night sky luminiscence, may be transferred from the sun into the higher strata of the atmosphere.

PART III.

Determination of the Temperature at Different Altitudes from the Intensity Distribution of Rotational Bands.

§ 9. Aim, Method, and Observations.

As shown in previous papers (11, 23, 24), the temperature existing in the auroral region can be fairly accurately measured by means of the intensity distribution within the *R*-branch of one of the strong negative nitrogen bands appearing in the auroral spectrum. The measurements previously described were based on spectrograms taken with a fairly big glass spectrograph which gave the band 4278 with a density suitable for photometric measurements.

For this wavelength the instrument gave the fairly large dispersion of 27 Å/mm. In order to obtain suitable spectrograms with this spectrograph, we had, even at Tromsø, to continue the exposure for weeks, and during that time the collimator was directed towards those parts of the sky where the auroral luminescence was brightest.

From the study of the intensity distribution along the auroral streamers (25, 26) we know that the intensity maximum on an average is situated about 10 km above the lower limit which at Tromsø has an average height of about 108 km. Thus the temperature measured from these bands of long exposure from the brightest spots corresponds to an average altitude of about 120 km.

The existence of long auroral rays in connection with the fact that the negative nitrogen bands are enhanced towards larger altitudes, showed that the density of matter within the auroral region decreases much more slowly than can be accounted for by the barometric height formula, provided we assume the temperature to be essentially constant (1). The same result has later been obtained through radio echo observations (27).

The barometric height formula could only give an approximate representation of the density distribution provided the temperature increased very rapidly upwards and at such a rate that at 200 km it should have obtained values of 1200°—1500° K. And in order to account for the fact that auroral rays may reach altitudes of 1000 km, we should probably at this altitude have to assume temperatures of the order of 10000°. Instead of assuming such improbable increases of temperature the writer assumed that matter was brought towards greater altitudes through the emission of electrons produced by soft X-rays from the sun (1, 4, 15).

It is evident that fundamental questions relating to the physics of the upper atmosphere are connected with the determination of the temperature for altitudes greater than 120 km.

One method of estimating the possibility of a rapid increase of temperature upwards is based on the broadening of atomic lines with increase of temperature (28). Under favourable conditions we may obtain interferometer pictures of the green or red *OI*-lines corresponding to aurora at different altitudes, and from the sharpness of the fringes we may draw certain conclusions regarding the magnitude of the possible temperature variations upwards (4, 15, 28).

A considerable number of interferometer pictures suitable for this purpose were obtained, but they showed no indication of an increase of temperature upwards.

Now the intensity distribution within the R-branch of the negative bands is more sensitive to temperature variations than the broadening of spectral-lines. It was therefore a matter of great importance to obtain spectrograms of the negative bands corresponding to different altitudes and which were suitable for temperature measurements.

As the intensity of the auroral luminescence decreases rapidly upwards, we cannot hope to obtain suitable spectra of the upper auroral border with the large glass spectrograph previously used for the temperature measurements.

With the large quartz spectrograph at the Auroral Observatory, we may obtain band 3914 with an exposure considerably smaller than that which is necessary to obtain band 4278 with the largest glass spectrograph.

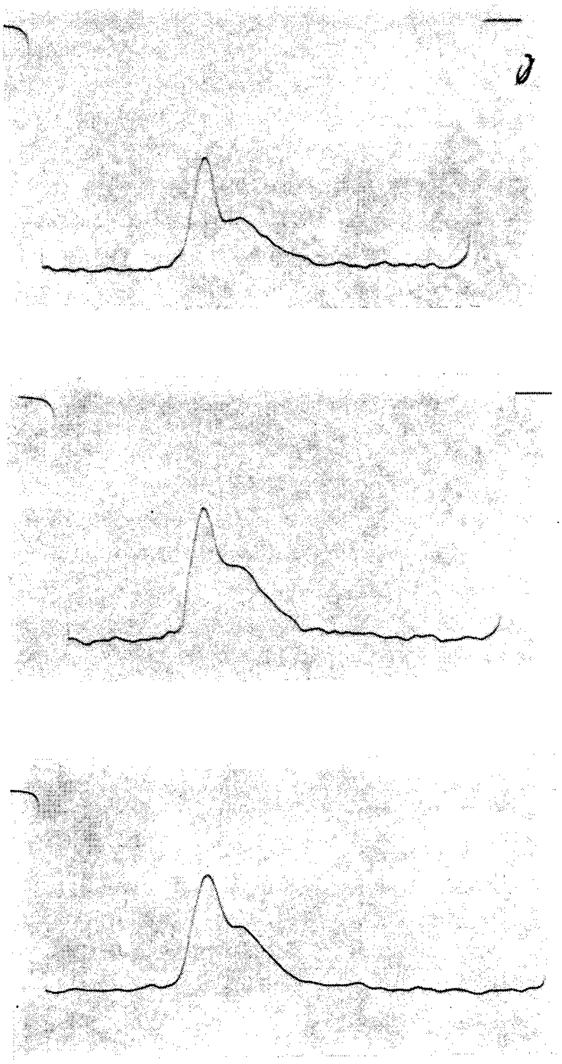

Fig. 2.

Near band 3914, the quartz spectrograph gives a dispersion 34,7 Å/mm which is not much smaller than that of the large glass spectrograph at band 4278. Band 3914 taken with the quartz spectrograph, should therefore give good conditions for fairly accurate determination of the temperature, and, on account of the shorter exposures, we might also obtain bands corresponding to the upper limit of the auroral ray streamers. During the autumn of 1938 we obtained with the quartz spectrograph three spectrograms which gave the 3914 band with a density suitable for intensity measurements. Two of these correspond to the lower limit; but one was obtained by systematically directing the instrument towards the upper limit. From the experience we have from the study of the altitude effects previously treated in this paper, we should have reason to conclude that the latter spectrum corresponds to an altitude of say 160—170 km.

Enlarged copies of the three spectrograms are given on Pl. I, No. 26, 27 and 28, the last corresponding to the upper limit. The photometer curves for the 3914 band are given in Fig. 2. The curve 1 (Fig. 2) corresponds to the upper limit. (Spectrogr. — No. 28 — obtained 16—28 Oct. 1938), curve 2 to the lower limit from spectrogr. No. 27, obtained 16—28 Oct. 1938. Curve 3 corresponds to lower limit from spectrogr. No. 26 taken 5 Nov. 1938—5 Jan. 1939.

§ 10. Temperatures Derived from the Three Spectrograms.

The procedure to be followed by the determination of temperature from the negative nitrogen bands, has been dealt with in previous papers (11, 23, 24, 29). In this connection we shall only for the sake of convenience record some of most important formulae which have to be used. Let I_K be the intensity within the R-branch corresponding to the rotational quant number K.

Then

$$\log_{10}(I_K/K) = -\varkappa_1 K(K+1) \ldots \qquad (16\text{ a})$$

where

$$\varkappa_1 = \frac{h^2 \log_{10} \varepsilon}{8\pi^2 J \cdot kT} \ldots\ldots\ldots\ldots\ldots \qquad (16\text{ b})$$

(h) is Planck's constant, ε the transcendental number 2,718 . . ., k is Bolsmann's constant and J the moment of inertia of the N_2^+=molecule in the upper state is equal to $13{,}4 \cdot 10^{-14}$ (gr.×cm^2).

This gives:

$$T_\varkappa = \frac{1{,}2855}{\varkappa_1} \ldots\ldots\ldots\ldots\ldots\ldots \qquad (17)$$

The value of $\varkappa$ is found from equation (16 a). Actually we construct a diagram giving the relation between $\log_{10}(I_K/K)$ and $K(K+1)$ ($\varkappa$-curve). We draw the straight line which best fits the observed points and the slope of this line gives the value of $\varkappa_1$. If we are able to observe the point where the intensity within the R-branch is a maximum, we may determine the temperature (T_m) from the rotational quant-number K_m which corresponds to maximum intensity from the following equation:

$$T_m = 2{,}96\, K_m(2K_m+1) \ldots\ldots \qquad (18)$$

The formulæ (16, 17, 18) are based on the assumption that the dispersion is so large that the intensity of each individual rotational line can be measured. The auroral spectrograms do not fulfil this condition. The individual lines will overlap to a certain extent with the result that the R-branch takes the form of a continuous striation. As stated in previous papers, we can find an upper limit to the effect of overlapping in the following way. We calculate a kind of corrected relative intensity I'_K by means of the following equation:

$$I'_K = d_K I_m \ldots\ldots\ldots \qquad (19)$$

where d_K is the distance between successive rotational lines corresponding to the quant number K.

In the case of the negative nitrogen bands we have

$$d_K = d_0 + aK \ldots\ldots \qquad (20)$$

The values of d_0 and a are:

for 4278 $d_0 = 0{,}725$, $a = 0{,}0615$ Å
for 3914 $d_0 = 0{,}613$, $a = 0{,}0455$ »

From the curve (I'_K, K) we find the value K'_m for which I'_K is a maximum and the corresponding corrected temperature T'_m from equation (18).

Further, we construct a $\varkappa'$ curve where I_K is replaced by I'_K. The slope of this curve gives a new value $\varkappa'_1$ and a corresponding temperature $T'_\varkappa$, from equation (17).

In order to find the true correction for overlapping, we have made a considerable number of temperature measurements from negative nitrogen bands which correspond to known temperatures of the light source (11 30, 31).

From one series of such measurements we derived the following formula:

$$T_{m(\text{corr.})} = 1{,}057\, T_m + 38{,}3 \ldots\ldots \qquad (21)$$

In a number of measurements we compared the temperatures derived from $\varkappa$-curves obtained from spectrograms with a dispersion about equal to that used for the auroral measurements with values corresponding to a dispersion sufficiently large to give separation of the individual lines. It was found that the temperature derived directly from the uncorrected $\varkappa$-curve $\left[\log_{10}\left(\frac{H_K}{K}\right) \rightarrow K(K+1)\right]$ within the limit of error was equal to the true temperature of the source.

It should be noticed that the determination of the quant-number K_m corresponding to maximum intensity, is uncertain, especially when the dispersion is so small that the P and R branches are not well separated. In the present case when the dispersion at the band measured (3914) is only $\frac{1}{34{,}7}$ mm/Å, we must consider the value derived from the $\varkappa$-curves as the most correct one.

Although some error may be attached to the absolute values, relative changes ought to be measured quite accurately as long as we compare bands of about the same photographic density and taken with the same instrument.

The results of the intensity measurements and temperature determinations for the three spectrograms mentioned, are given in Tables VII (A, B, and C). The first column of each table gives the quant-number K corresponding to selected points on the R-branch, the second, the directly measured intensity I, the third, the intensities I' corrected for overlapping. The following three columns give the numbers for the construction of the $\varkappa$-curves. Below each table we have put up the values of K_m, T_m, K'_m, T'_m, $\varkappa$, $\varkappa'$, and $T_\varkappa$ and $T'_\varkappa$.

For each spectrogram the curves (I, K), (I', K), $\varkappa$, and $\varkappa'$ have been drawn and are given in Fig. 3 (A, B, and C) and Fig. 4 (A, B, and C) respectively. On each diagram the curve (a) corresponds to uncorrected intensities, curve (b) to those corrected for overlapping.

The results are summarized in Table VIII.

Table VII (A).

Upper limit. Band 3914.

Quartz spectrograph (Q), Plate I, 28 (16—28 Oct. 1938).

K	I	I'	$2+\log {}^{I}/_{K}$	$1+\log {}^{I'}/_{K}$	$K(K+1)$
1,15	1,520	1,000	2,1213	0,9394	2,47
2,95	1,545	1,154	1,7191	0,5924	11,65
4,58	1,585	1,304	1,5392	0,4545	25,56
6,05	1,520	1,353	1,4000	0,3495	42,65
7,42	1,420	1,352	1,2819	0,2606	62,48
8,75	1,295	1,305	1,1703	0,1738	85,31
10,00	1,193	1,271	1,0766	0,1038	111,00
11,15	1,143	1,280	1,0107	0,0600	135,47
12,22	1,064	1,248	0,9400	0,0095	161,55
$K_m=4{,}56$ $T_m=193°\,K$			$\varkappa=6{,}12\cdot10^{-3}$ $T_\varkappa=210°\,K$		
$K'_m=6{,}75$ $T'_m=288°\,K$			$\varkappa'=4{,}9\cdot10^{-3}$ $T'_\varkappa=262°\,K$		
Mean $T_m=240°\,K$			Mean $T_\varkappa=236°\,K$		

Table VII (B).

Lower limit. Band 3914.

Quartz spectrograph (Q), Plate I, 27 (16—28 Oct. 1938).

K	I	I'	$2+\log {}^{I}/_{K}$	$1+\log {}^{I'}/_{K}$	$K(K+1)$
1,15	1,895	1,247	2,2170	1,0350	2,47
2,95	1,945	1,453	1,8191	0,6924	11,65
4,58	1,945	1,601	1,6281	0,5436	25,56
6,05	1,895	1,687	1,4958	0,4451	42,65
7,42	1,815	1,728	1,3885	0,3672	62,48
8,75	1.695	1,709	1,2871	0,2904	85,31
10,00	1,570	1,672	1,1959	0,2232	111,00
11,15	1,445	1,618	1,1126	0,1620	135,47
12,22	1,314	1,541	1,0314	0,1007	161,55
$K_m=4{,}0$ $T_m=108°\,K$			$\varkappa=6{,}12$ 10^{-3} $T_\varkappa=210°\,K$		
$K'_m=7{,}0$ $T'_m=311°\,K$			$\varkappa'=4{,}8$ 10^{-3} $T'_\varkappa=267°\,K$		
Mean $T_m=209°\,K$			Mean $T_\varkappa=239°\,K$		

Table VII (C).

Lower limit. Band 3914.

Quartz spectrograph (Q) Plate I, 26 5 Nov. 1938—5 Jan. 1939.

K	I	I'	$2+\log ({}^{I}/_{K})$	$1+\log {}^{I'}/_{K}$	$K(K+1)$
1,15	1,898	1,249	2,2175	1,0358	2,47
2,95	1,990	1,487	1,8291	0,7034	11,65
4,58	1,990	1,638	1,6380	0,5534	25,56
6,05	1,866	1,661	1,4892	0,4386	42,65
7,42	1,714	1,532	1,3636	0,3422	62,48
8,75	1,573	1,586	1,2549	0,2582	85,31
10,00	1,445	1,539	1,1600	0,1873	111.00
11,15	1,315	1,473	1,0715	0,1206	135,47
$K_m=4$ $T_m=108°\,K$			$\varkappa=5{,}48\cdot10^{-3}$ $T_\varkappa=235°\,K$		
$K_m=5{,}75$ $T'_m=225°\,K$			$\varkappa'=4{,}4\cdot10^{-3}$ $T'_\varkappa=292°\,K$		
Mean $T_m=172°\,K$			Mean $T_\varkappa=263°\,K$		

Comparing the temperatures corresponding to the upper limit with those corresponding to the lower one, we notice *that there is no indication of an increase of temperature with increase of altitude.*

It is of interest to remember that the very considerable changes of spectral intensity distribution with altitude previously dealt with, were obtained in

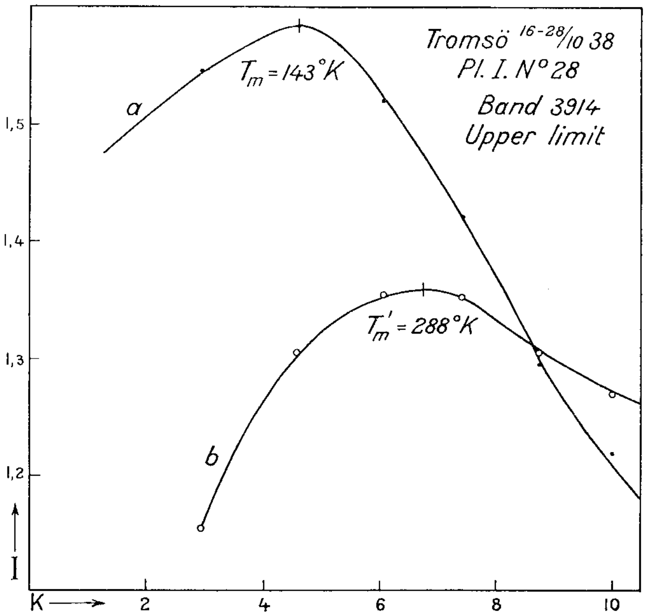

Fig. 3 (A).

a similar way by comparing spectrograms from the upper and lower limit of auroral rays. In this way we may therefore obtain spectra corresponding to considerable differences of altitude. At present, we have only obtained one spectrogram from the upper limit suitable for temperature measurements. Although this spectrogram gives no indication of a temperature increase upwards, we cannot conclude from the measurements of one single spectrogram that such an effect does not exist. Observations in this direction will be continued and we may hope to get spectrograms mainly corresponding to the upper limit of very long streamers. At any rate, these measurements of the temperature at different altitudes by means of the negative nitrogen band (3914), have confirmed previous results obtained by the interferometer method referred to already.

Table VIII.

	Lower border			Upper border
Date	16—28 Oct. 1938	5 Nov. 1938—5 Jan. 1939	Mean (lower)	16—28 Oct. 1938
K_m	4,0	4,0		4,65
T_m	108° K	108° K	108° K	193° K
K'_m	7,0	5,75		6,75
T'_m	311° K	225° K	268° K	288° K
$\varkappa$	$6{,}12 \cdot 10^{-3}$	$5{,}48 \cdot 10^{-3}$		$6{,}12 \cdot 10^{-3}$
$T_\varkappa$	210° K	235° K	223° K	210° K
$\varkappa'$	$4{,}8 \cdot 10^{-3}$	$4{,}4 \cdot 10^{-3}$		$4{,}9 \cdot 10^{-3}$
$T'_\varkappa$	267° K	292	280° K	262
		Mean	220° K	238° K
		Mean $T_\varkappa$	252° K	236° K

PART IV.

Interferometric Wavelength Measurements of the Red Auroral Line *OI* ($^1D_2$—$^3P_2$).

§ 11. Purpose and Procedure.

By means of the ordinary spectral apparatus used for the analysis of the auroral luminescence, we may measure the wavelength of a sharp line with such an accuracy that the error will be of the order of 1 Å unit. When the line is strong and isolated, or situated in the short wave part the error may be smaller, when it is weak or situated in the region of long waves, and when other lines or bands appear close to the line, the error may amount to a few Å-units.

When we have such an approximate knowledge of the wavelength the accuracy may be increased very considerably by means of interferometric methods.

Precision measurements of this kind were previously carried out at Oslo and at Tromsø for the

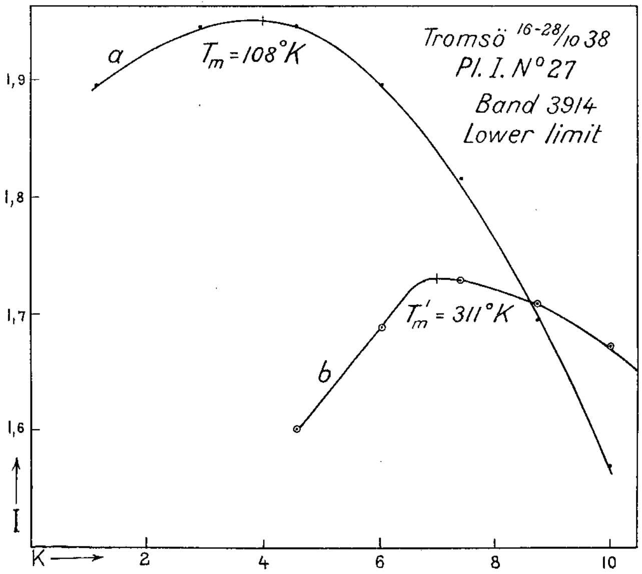

Fig. 3 (B).

strong green line (32, 33) and for the strongest component of the red *OI* triplet (13). The procedure was similar to that used by Babcock (34) for the green line of the night sky luminescence. We used a Fabry-Perot interferometer essentially consisting of a plane parallel quartz plate with metallic deposit on both surfaces placed in front of the lens of a camera. The line to be measured was partly isolated and the effect of the other part of the spectrum was reduced by means of suitable filters and sensitivity of the photographic plates.

Details regarding the method, the experimental arrangements, and the construction of the instruments were given in the papers already referred to (13, 32, 33). For the green line, 28 interferometer pictures were obtained and utilized for wavelength measurements. Some of these were obtained with a 2,5 mm etalon and another series was taken with an etalon of thickness about 5 mm. The values obtained with the two etalons and from pictures taken at various times showed good agreement with each other, and the most probable value for the wavelength of the green line was found to be

$$\lambda = 5577{,}3445\ \text{Å}\ (I.U).$$

In the case of the red *OI*-line we obtained at Tromsø 15 interferometer pictures with the 2,5 mm, and 7 pictures with the 5 mm etalon.

From ordinary spectrograms the red line was previously measured with an accuracy of about 3 Å. This accuracy did not suffice for the determination of the order number by means of pictures taken with

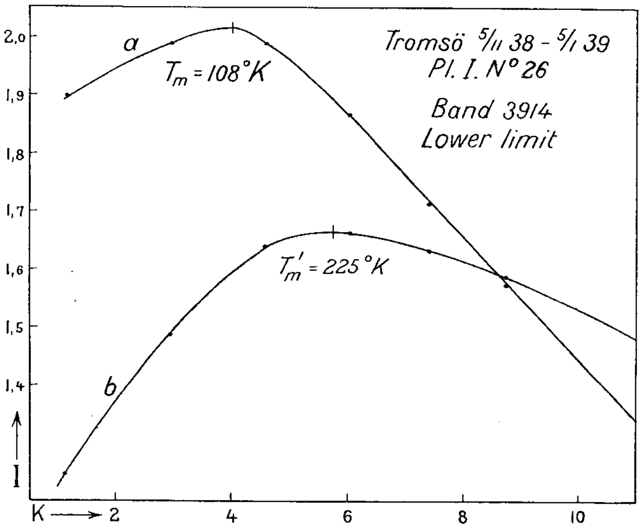

Fig. 3 (C).

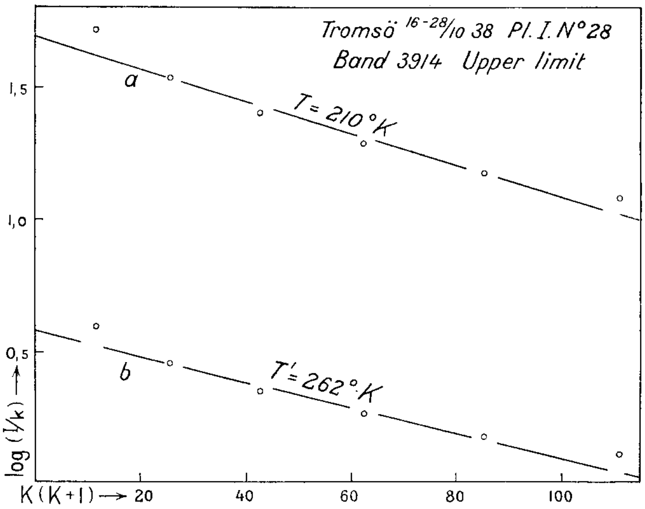

Fig. 4 (A).

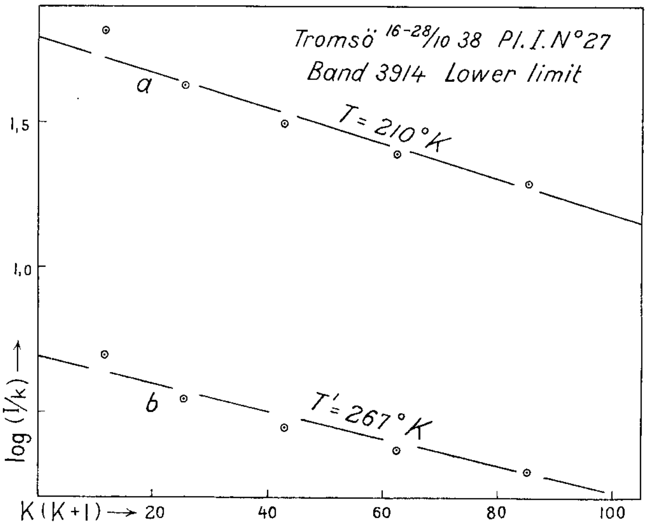

Fig. 4 (B).

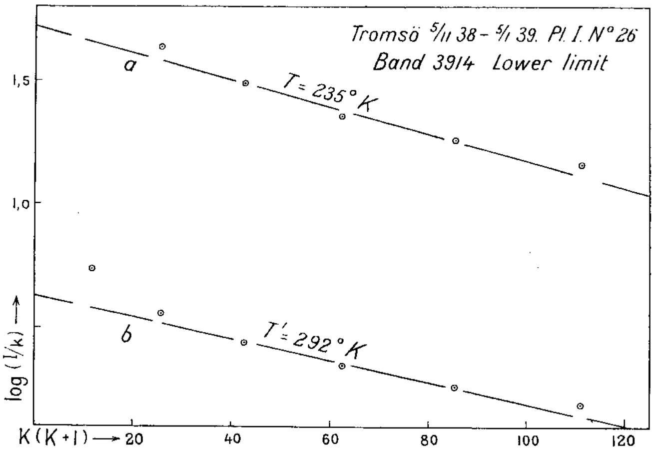

Fig. 4 (C).

a single etalon. For the 5 mm etalon there were 12 different order numbers which gave wavelength values within the interval of uncertainty. By means of the pictures taken with the 2,5 mm etalon, the number of possible wavelength values was reduced to 6 or 7.

A number of interferometer pictures taken at Oslo with a 1,5 mm etalon enabled us to determine the interference order and the wavelength without ambiguity.

The pictures obtained with the three different etalons led to the following results:

The 5 mm etalon gave $\lambda = 6300{,}312$ Å
The 2,5 —»— $\lambda = 6300{,}308$ Å
The 1,5 —»— $\lambda = 6300{,}286$ Å

Putting equal weight to the three determinations we obtain the following mean value:

$$\lambda = 6300{,}302 \text{ Å}$$

As the value obtained with the 1,5 mm etalon differs somewhat from those obtained with the two other etalons, we have of recent years made some more measurements in order to improve the accuracy.

The procedure was essentially the same as described in previous papers. The interferometer used at Oslo was the one used there for the earlier measurements of the red line (13). The Tromsø instrument was reconstructed and improved in various ways, so as to give a greater mechanical stability and better conditions for keeping the temperature constant during the time required for taking the series of pictures which form a complete set of observations. We used as a standard for comparison the yellow neon line.

$$\lambda = 5852{,}488 \text{ Å } (I.U)$$

An interferometer picture on this standard line was taken just before and immediately after the exposure of the auroral line.

The interference order (P) at the centre of the fringe system is put in the form:

$$P = n + \varepsilon$$

where (n) is a whole number and (ε) the excess fraction. The whole number (n) must be determined by means of the approximate knowledge we already have of the wavelength and from the thickness of the etalon.

Let λ_ν be the wavelength in vacuum for a certain spectral line, then:

$$n + \varepsilon = \frac{2 e_t}{\lambda_\nu} \mu_\lambda \ldots . \tag{22}$$

(e_t) is the thickness of the etalon at the temperature it had by the exposure. μ_λ is the refractive index of quartz at the wavelength and temperature considered. The excess fraction (ε) is found from the fringe system by means of the formula:

$$\varepsilon = \frac{(i+l)\, d_k^2 - (k-l)\, d_i^2}{d_i^2 - d_k^2} \ldots \tag{23}$$

(d_k) and (d_i) are the diameters of the ring-numbers (k) and (i) respectively.

Having determined (n) and (ε) for the auroral line and the comparison standard line, the wavelength of the auroral line in vacuum is found by means of the equation.

$$\lambda_\nu = \lambda_\nu' \frac{\mu_0}{\mu_0'} \frac{n' + \varepsilon'}{n + \varepsilon} (1 + \triangle \gamma t \ldots \tag{24}$$

λ_ν', n', ε', μ_0' correspond to the standard line, the other set to the auroral line. (μ_0) and (μ_0') are the refractive indexes of quartz at 0°C. for the auroral line and the standard line respectively.

($\triangle\gamma$) is equal to the ($\gamma_\lambda - \gamma_{\lambda_1}$) between the temperature coefficients of the refractive index of quartz for the auroral line and the standard line respectively.

The optical thicknesses of the etalons used were measured at the National Physical Laboratory, England. A complete account of the results of these measurements was given in the papers referred to (13, 33).

The thickness of the 2,5 mm etalon at the temperature of 20,06° C. was found to be:

$$e = 2{,}512690 \text{ mm},$$

that of the 1,5 mm etalon at 19,85° C.:

$$e = 1{,}511147 \text{ mm}.$$

The values of μ_0 and γ for the two lines considered are the following:

λ	μ_0	$\gamma \cdot 10^6$	$\Delta \gamma = \gamma_{6300} - \gamma_{5852}$
6300,3	1,54325133	$-3{,}904$	$-4{,}410^{-8}$
5852,5	1,54491952	$-3{,}860$	

§ 12. Observations and Results.

In November and December 1938 we obtained at Tromsø six sets of successful interferometer pictures of the red auroral line. The pictures were taken by my assistant Mr. O. Krogness (Jr.) with the new interferometer. Each plate contained besides the fringe system of the red line, two similar pictures of the standard neon line, one taken just before and one just after that of the auroral line.

Table IX.

Tromsø. 2,5 mm etalon.

$P_{Ne} = 13257 + \varepsilon_{Ne}$, $P_{Au} = 12301 + \varepsilon_{Au}$.

Plate	ε_{Ne}	ε_{Au}	λ_{Au}
I. $^{27}/_{11}$—38	0,591	1,018	6200,284
II. $^{27}/_{11}$—38	0,522	0,987	,282
III. $^{3}/_{12}$—38	0,626	1,044	,287
IV. $^{16}/_{12}$—38	0,580	0,992	,293
V. $^{16}/_{12}$—38	0,593	0,990	,299
VI. $^{20}/_{12}$—38	0,634	1,014	,308
		Mean	6300,292

Table X.

Interferometer measurements at Oslo of the red auroral line, with etalon 1,5 mm.

$n_{Ne} = 7974$. $n_{Au} = 7399$.

Date	Time of exposure	ε_{Ne}	ε_{Au}	λ_{Au}
$^{18}/_{12}$—38	19^{00}—20^{15}	0,20	0,41	6300,305
—»—	21^{00}—21^{30}	0,24	0,44	,312
$^{28}/_{4}$—39	23^{44}—00^{17}	0,50	0,70	,296
$^{7}/_{10}$—39	21^{30}—22^{15} 22^{15}—22^{45}	0,63	0,81	,305
$^{16}/_{10}$—39	21^{08}—22^{05}	0,60	0,76	,323
$^{17}/_{10}$—39	19^{30}—20^{20} 22^{00}—22^{45} 22^{46}—22^{15}	0,47	0,66	,306
$^{18}/_{10}$—39	19^{37}—20^{45} 20^{45}—21^{35}	0,53	0,73	,294
—»—	21^{38}—23^{00}	0,46	0,66	,298
			Mean	6300,305

Table XI.

Wavelength measurements of the red auroral line OI ($^1D_2$—$^3P_2$)

Place	Year	Thickness of etalon	Number of pictures	Wavelength
Oslo	1936	1,5 mm	5	6300,286
Oslo	1938—39	1,5 »	12	6300,305
Tromsø	1935—36	2,5 »	16	6300,308
Tromsø	1936	5,0 »	7	6300,312
Tromsø	1938	2,5 »	6	6300,292
Mean for Oslo (1,5 mm etalon)				6300,299
» » Tromsø (2,5 and 5,0 mm. etalon)				6300,305
» » Tromsø (2,5 mm etalon)				6300,304
» » All				6300,303

During last year twelve sets of interferometer pictures of the red auroral line were obtained at Oslo where I have been ably assisted by Mr. G. Kvifte.

The results of the Tromsø observations are given in Table IX, those from the Oslo material in Table X. The Tromsø material gives for the red auroral line the mean wavelength 6300,292, that of Oslo the mean wavelength 6300,305. Thus the values obtained with the 1,5 mm etalon are now somewhat larger than those found with the 2,5 mm etalon, contrary to our previous results.

All our interferometric measurements of the red auroral line are collected in Table XI.

We notice that the mean values obtained with etalons of different thicknesses, and at Oslo and Tromsø, now agree to within a few thousands of an Ångstrøm unit.

Attaching equal weight to all our measurements we obtain the following mean wavelength.

$$\lambda = 6300{,}303 \pm 0{,}010 \text{ Å (I.U)}$$

In conclusion I wish to thank Mr. G. Kvifte for most able assistance in connection with the observations and their further treatment, and Mr. O. Krogness (Jr.) for valuable assistance in connection with the observational work.

I am also greatly indebtet to "Det Vitenskapelige Forskningsfond" and "Nansenfondet" for giving me the grants necessary for the investigations dealt with in this paper.

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PLATES

Explanation to Pl. I.

Spectrograms taken at Tromsø.

Spectrograms 1—24 taken with small glass spectrograph on Ilford-hypersens. pan. plates. (Cfr. specification.)

Spectrogram 25 taken on Ilf. Double X-press plates with large glass spectrograph.

Exposure from 7 Oct.—8 Nov. 1938 (23 effective hours).

Spectrograms 26, 27, 28 taken with large quartz spectrograph (Q) in order to obtain the band 3914 with a density suitable for temperature determination.

No. 26 from 5 Nov. 1938—5 Jan. 1939, lower limit.

Nos. 27 and 28 from 16—28 Oct. 1938. No. 27 corresponds to lower limit, No. 28 to upper limit of aurorae.

Specification for the spectrograms Nos. 1—24 taken with the small glass spectrograph

Spect. No.	Date	Time of exposure	Auroral Form
1	26 Oct. 1938	18^{30}—19^{00}	D + R
2	— »	19^{00}—19^{30}	D + R
3	— »	19^{40}—21^{30}	A
4	— »	21^{30}—23^{05}	A + R
5	28 Oct. »	17^{15}—17^{40}	A (sunlit)
6	— »	17^{40}—18^{50}	A + R (sunlit)
7	— »	18^{55}—19^{25}	A + D + R
8	— »	19^{25}—20^{00}	A + D + R
9	— »	20^{00}—20^{50}	A + D
10	— »	20^{50}—21^{50}	A
11	8 Nov. »	17^{00}—18^{30}	R + D (sunlit)
12	21 Nov. »	18^{00}—18^{30}	A + D
13	— »	18^{30}—19^{30}	A + D
14	— »	20^{35}—21^{15}	A + D
15	— »	21^{15}—22^{15}	A
16	26 Nov. »	17^{15}—18^{00}	A + D + R
17	3 Dec. »	16^{00}—16^{45}	A + D (sunlit)
18	— »	17^{35}—18^{30}	A + R
19	16 Dec. »	18^{15}—19^{20}	A + D + R
20	— »	19^{20}—20^{00}	D
21	— »	20^{00}—21^{00}	A
22	20 Dec. »	16^{50}—17^{50}	A + R
23	— »	17^{50}—18^{45}	A + D
24	— »	22^{00}—23^{45}	D

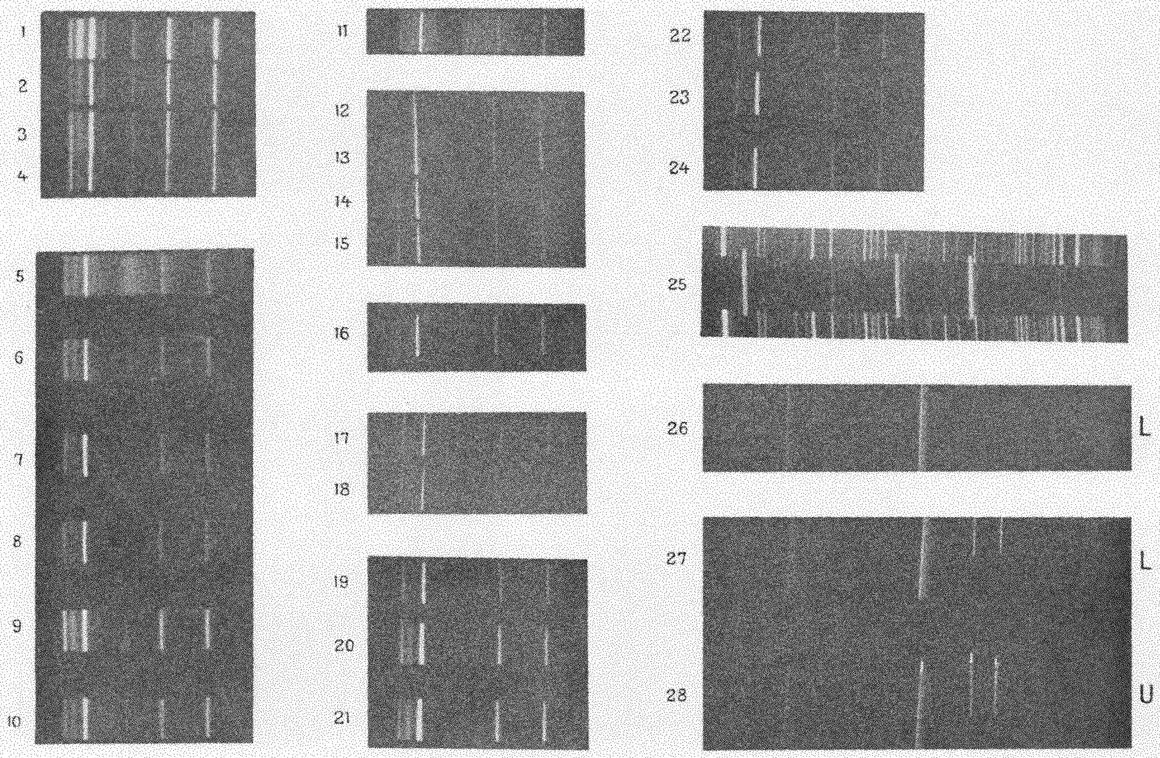
Explanation to Pl. II.

Spectrograms taken at Oslo with a small glass spectrograph.

Nos. 1—3, on Agfa Isopan. Plates Nos. 4—31 on Agfa Isopan ISS plates.

Spectr. No.	Date	Time of exposure	Auroral Form
1	14—15 Sept. 1938	23^{20}—00^{25}	A + R (L. limit.)
2	15—16 Sept. 1938	20^{00}—20^{45}	D.S.
3	— »	20^{45}—24^{00}	A + R.
4	8 Nov. »	21^{00}—24^{00}	A. (L. limit.)
5	9 Nov. »	00^{00}—01^{30}	R. (U. —
6	24—25 Nov. »	18^{30}—22^{00}	A + D (U. limit.)
7	— »	22^{00}—23^{30}	A + D (L. —
8	6 Febr. 1939	19^{45}—20^{45}	D.A. + R (L. limit.)
9	— »	20^{45}—21^{45}	D.S.
10	12—14 March »		Night sky
11	14—17 March »		Night sky
12	24—25 April »	00^{05}—01^{01}	A + D.S.
13	— »	01^{00}—01^{35}	Corona
14	— »	22^{45}—23^{45}	Corona
15	— »	23^{45}—00^{05}	D.S.
16	— »	01^{35}—02^{28}	Zenith
17	28 April »	23^{40}—00^{20}	A
18	19 Sept. »	20^{50}—22^{20}	R. (U. limit.)
19	— »	22^{20}—23^{20}	A + R (L. limit.)
20	3 Oct. »	20^{55}—21^{25}	D.S.
21	— »	21^{25}—22^{10}	A
22	5 Oct. »	19^{55}—21^{15}	A. (L. limit.)
23	7 Oct. »	20^{55}—22^{15}	R. (U. —
24	— »	22^{15}—23^{00}	A. (L. —
25	16 Oct. »	21^{05}—22^{05}	PS + DS + R (U. limit.)
26	17 Oct. »	19^{15}—20^{05}	D + R (U. —
27	— »	20^{30}—21^{30}	D.A. (L. —
28	— »	22^{30}—23^{15}	R. (U. —
29	18 Oct. »	19^{16}—20^{13}	A. (L. —
30	— »	20^{13}—20^{47}	A. (L. —
31	— »	20^{47}—21^{55}	R. (U. —

Pl. I.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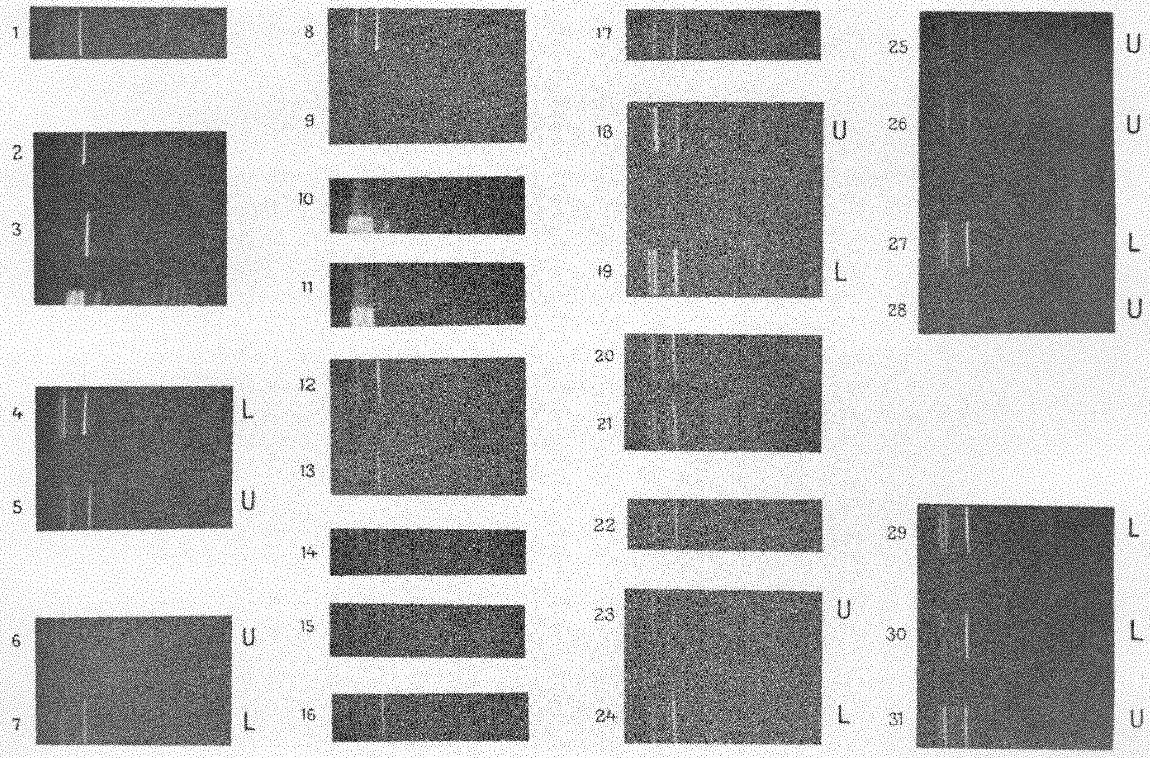
Pl. II.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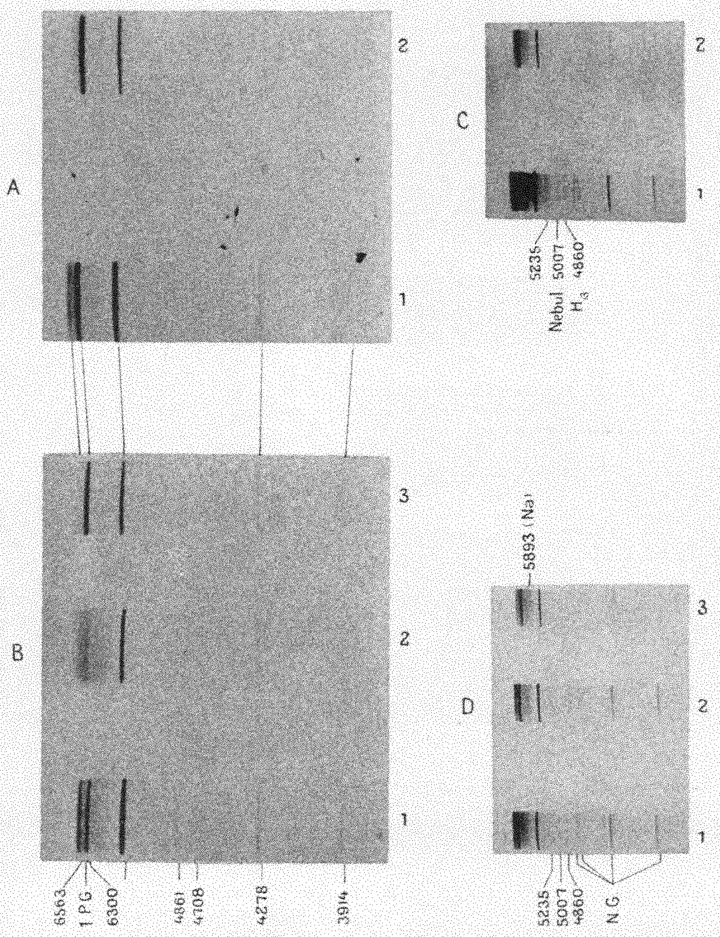

A. Spectrograms Nos. 18 and 19 of pl. II (19 Sept.) reproduced as negatives with a still greater enlargement. A. No. 1 corresponds to lower, No. 2 to upper limit. On No. 1 a line 4861 may just be seen.

B. Spectrograms corresponding to Nos. 29, 30, 31 on pl. II (18 Oct.) reproduced as negatives with a greater enlargement. Nos. 1 and 2 lower limit, No. 3 upper limit. On No. 1 the H_β-line is distinctly seen.

C. Spectrograms taken at Oslo Dec. 6—7, 1939 on Agfa Isopan plates ISS sensibilised with NH_3: No. 1 exposure on arcs and draperies from 22^{05}—24^{05} towards N. ($h = 15°$).

No. 2 exposure 00^{05}—02^{05} on upper limit of arc towards N. ($h = 30°$).

D. Spectrograms taken at Oslo Jan. 3—4, 1940 on Agfa Isopan. ISS plates (sens. with NH_3).

No. 1 Exposure 18^{35}—20^{35}, A & D towards N. ($h = 23°$).

No. 2 Exposure 20^{35}—22^{00}, lower limit of arc towards N. ($h = 12°$).

No. 3 Exposure 22^{00}—01^{00}, upper limit of diffuse arc towards N. ($h = 28°$).

temperature to be essentially constant (1). The same result has later been obtained through radio echo observations (27).

The barometric height formula could only give an approximate representation of the density distribution provided the temperature increased very rapidly upwards and at such a rate that at 200 km it should have obtained values of 1200°—1500° K. And in order to account for the fact that auroral rays may reach altitudes of 1000 km, we should probably at this altitude have to assume temperatures of the order of 10000°. Instead of assuming such improbable increases of temperature the writer assumed that matter was brought towards greater altitudes through the emission of electrons produced by soft X-rays from the sun (1, 4, 15).

It is evident that fundamental questions relating to the physics of the upper atmosphere are connected with the determination of the temperature for altitudes greater than 120 km.

One method of estimating the possibility of a rapid increase of temperature upwards is based on the broadening of atomic lines with increase of temperature (28). Under favourable conditions we may obtain interferometer pictures of the green or red *OI*-lines corresponding to aurora at different altitudes, and from the sharpness of the fringes we may draw certain conclusions regarding the magnitude of the possible temperature variations upwards (4, 15, 28).

A considerable number of interferometer pictures suitable for this purpose were obtained, but they showed no indication of an increase of temperature upwards.

Now the intensity distribution within the R-branch of the negative bands is more sensitive to temperature variations than the broadening of spectral-lines. It was therefore a matter of great importance to obtain spectrograms of the negative bands corresponding to different altitudes and which were suitable for temperature measurements.

As the intensity of the auroral luminescence decreases rapidly upwards, we cannot hope to obtain suitable spectra of the upper auroral border with the large glass spectrograph previously used for the temperature measurements.

With the large quartz spectrograph at the Auroral Observatory, we may obtain band 3914 with an exposure considerably smaller than that which is necessary to obtain band 4278 with the largest glass spectrograph.

Near band 3914, the quartz spectrograph gives a dispersion 34,7 Å/mm which is not much smaller than that of the large glass spectrograph at band 4278. Band 3914 taken with the quartz spectrograph, should therefore give good conditions for fairly accurate determination of the temperature, and, on account of the shorter exposures, we might also obtain bands corresponding to the upper limit of the auroral ray streamers. During the autumn of 1938 we obtained with the quartz spectrograph three spectrograms which gave the 3914 band with a density suitable for intensity measurements. Two of these correspond to the lower limit; but one was obtained by systematically directing the instrument towards the upper limit. From the experience we have from the study of the altitude effects previously treated in this paper, we should have reason to conclude that the latter spectrum corresponds to an altitude of say 160—170 km.

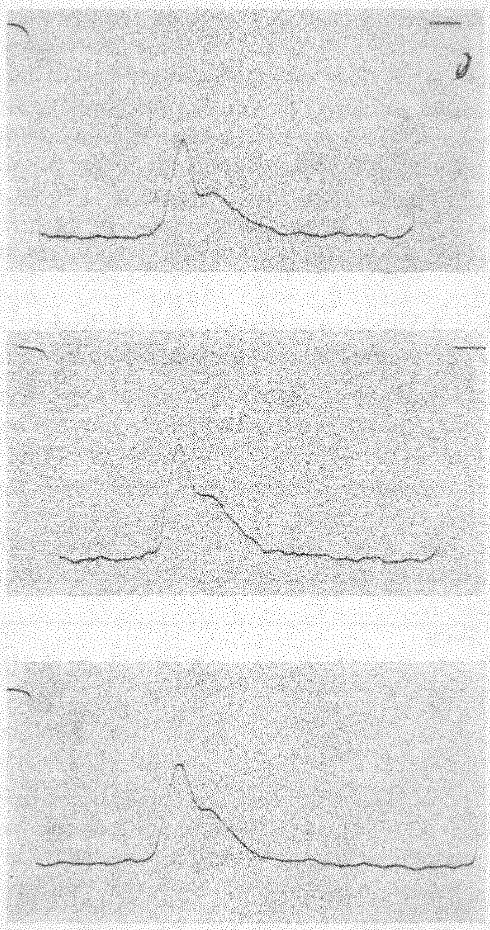

Fig. 2.