I. CONTINUED INVESTIGATIONS ON THE AURORAL SPECTRUM

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1. Introductory Remarks.

Previous investigations on the auroral spectrum have shown that a considerable number of lines and bands appear in the red and infra red region (1, 2, 3, 4, 5).

Some lines and bands have been obtained on spectrograms with fairly large dispersion (3, 4, 5), but in previous publications a number of bands in red as well as the infra red bands (3, 4, 6) were only obtained and measured by means of spectrographs with very small dispersion. On such spectrograms, lines and bands are not well separated, and the accuracy with which the wave-length can be measured is small both on account of small dispersion and of unsatisfactory definition of the band or line.

Particular interest is attached to the red line near $\lambda = 6300$, and for two reasons. Primarily the identification of the green line with the oxygen line OI ($^1S_0$—$^1D_2$) suggests that the red oxygen triplet OI ($^1D_2$—$^3P_{012}$) should appear in the auroral spectrum and that the red line near 6300 should be the principal component OI ($^1D_2$—$^3P_2$) of this triplet.

Secondarily it has been shown (1) that red coloured aurorae of type *A* owe their redness to the enhancement of the red line 6300, perhaps accompanied by the other weaker components of the *OI* triplet. It is evident that it is a matter of great importance to obtain auroral spectrograms in the long wave region with spectrographs having as large dispersion as possible.

The result of some auroral spectrograms, covering the red region and obtained with spectrographs of fairly good dispersion, were given in some papers (3, 4, 5) already published. For this purpose we have been using a big glass spectrograph and a grating spectrograph. They were both constructed to meet the requirements of the auroral studies and combined a considerable dispersion with high light power. Regarding details of construction, we would refer to a description given in a previous paper (3). The big glass spectrograph is illustrated in Figs. 5—12 and the grating spectrograph in Figs. 13 and 14 of the paper (3) referred to.

During the autumn of 1932 we obtained on pan-cromatic plates two spectrograms with the big glass spectrograph and three with the grating spectrograph. The results were given in a paper published in 1933 (5). In the red part, these spectra showed two lines 6300 and 6367, which might possibly be identified as the strongest components of the *OI* triplet, and, further, some of the spectrograms showed some weak bands belonging to the first positive group of nitrogen.

It was our intention to continue our investigations of the long wave-region with the two spectrographs just mentioned, and we decided to use the big glass spectrograph for the red region. For this purpose we used Ilford hyper-sensitive pan-chromatic plates.

We further tried to obtain spectra in the infra red by means of the grating spectrograph, which had been specially intended for this purpose. We used a type of infra red sensitive plate denoted as Agfa 700—900 $\mu\mu$. They were hyper-sensitized according to the Schmiechek procedure.

Although the region of short waves has been fairly completely explored, we have also taken auroral spectrograms of long exposure with the large quartz spectrograph described by one of us in a previous paper (3).

2. The Infra Red Spectrum studied by means of the Grating Spectrograph.

Owing to the faintness of the luminescence, an exposure of a large number of effective north-light hours is wanted in order to obtain the infra red bands with the grating spectrograph. A hypersensitized infra red plate can only keep for a few days, and we cannot expose on the same plate more than a few days. Consequently we can only have any hope of obtaining a successful spectrogram when we have powerful aurora for several nights in succession.

Even at Tromsö with its high auroral frequency, such opportunities are fairly rare. On account of these difficulties, we have with the grating spectrograph as yet only obtained one spectrogram showing infra red bands with measurable intensity. The spectrogram was taken in 1933, when we were able to get an exposure of 13 hours of strong aurorae in the course of two successive nights, Febr. 23. and 24. A reproduction of the spectrum is shown on Plate I No. 4.

Eight bands could be distinctly seen and measured. The results of the wave-length measurements are given in Table I. The first column gives estimated intensities on an arbitrary scale where the intensity of the strongest band has been indicated by 10.

Table I.

Auroral spectrum		Interpretation	Nitrogen discharge	
I	λ		λ	I
2	8132	5—4, (10—10, 14—15)	8197 } 8144 8112 } 8144	2 3
		6—5	8011	5
4	7906	7—6, (12—12, 16—17)	7838	3
4	7734	8—7, (2— 0)	7722	10
		3—1	7613	7
3	7594	5—2, 9—8	7587	7
10	7479 {	4—2 10—9	7498 7465	3 2
7	7368	5—3		
5	7264	6—4		
4	7068	8—6		

By the small dispersion used, the individual rotational lines, of which the band is composed, are not separated and we only observe a somewhat broad and diffuse line.

The wave-length values given in the second column correspond to the mean position of the band and they do not correspond to the heads or to the zero line of the bands. This circumstance must be taken into account by the interpretation of the observed bands. The best procedure would be to compare the auroral bands with known band spectra obtained with about the same dispersion.

An infra red band spectrum of nitrogen, taken with a dispersion of the same order of magnitude as that of the grating spectrograph, is shown on Plate I No. 5.

As already shown in previous papers (3, 5), the auroral bands in infra red belong to the 1st positive group of nitrogen, this result having been confirmed by the present spectrogram of larger dispersion.

The third column contains the vibrational quant numbers n' and n'' of the upper and lower state for each band. Now there are several transitions which give bands with nearly the same position, and in such cases we have indicated those vibrational transitions which can come into consideration.

The last column contains the bands of spectrogram No. 5, which corresponds to the positive column of a nitrogen discharge. We notice that most of these bands are also present in the auroral spectrum, but, in addition, the latter has some bands not observed in the luminescence from the positive column. This may be partly due to the fact that the spectrograms Nos. 4 and 5 were taken with infra red plates Agfa 810, having a sensitivity curve in the infra red region different from that of the grating spectrogram here considered taken with Agfa 700—900 $\mu\mu$.

But the use of different plates and instruments cannot account for the great differences of intensity distribution within the 1st positive group of the auroral luminescence, and that of the positive column. Thus in the positive column the band $\lambda = 7722$ ($n' = 8$—$n = 7$) appears with dominating intensity, while this band is relatively weak in the auroral spectrum, where, on the other hand, the band $7479 \begin{Bmatrix} 4-2 \\ 10-9 \end{Bmatrix}$ is the strongest one.

It will be a matter for further investigation to find out under what conditions we may obtain an infra red spectrum of nitrogen with the intensity distribution shown by the auroral luminescence.

3. Auroral Spectrograms in the Red Region obtained with the big glass Spectrograph.

During the past Winter we obtained two spectrograms taken on Ilford hyper-sensitive pan-chromatic plates with the big glass spectrograph. One (No. 1 on the plate) was exposed for more than three months from Sept. 1935 to Jan. 1936, the other (No. 2 on the plate) was exposed for the rest of the Spring of 1936.

On the plate was also photographed a continuous spectrum from an incandescent lamp for which the intensity distribution of the spectrum for a given voltage is known. Further, an intensity scale was taken by means of a Zeiss "Stufenfilter".

The spectrogram No. 1 is very remarkable on account of the considerable number of bands and lines in the red part it contains, and for the distinctness with which they appear on the spectrogram. The line 6300 is particularly strong, but also a line which has the position of the *OI* ($^1D_2$—$^3P_1$) component appears quite distinctly. Besides, we notice a regular succession of bands belonging to the 1st positive group of nitrogen.

On the spectrogram No. 2 the green auroral line and the negative bands seem to appear equally dense as on the first spectrogram, but the red part is much weaker. We notice the two lines which have the position corresponding to the strongest components of the red oxygen triplet, but in this case the second component *OI* ($^1D_2$—$^3P_1$) is apparently not weaker, but even somewhat stronger than the component *OI* ($^1D_2$—$^3P_2$) with wave-length 6300.

The measurements of the wave-length values from spectrogram No. 1 by means of the neon comparison spectrum gave values for the two strong red lines $\lambda = 6291$ Å and $\lambda = 6352$ Å, which are about 10 Å too low.

From spectrograms previously measured (3, 4, 5) we know that the wave-length of these lines must be very near to 6300 and 6364. The wave-length of the strongest component has also been measured by an interferometer method (9), and the result of our first interferometer plate of the red line was given in a preliminary note (10). Recently, a considerable number of interferometer measurements have been undertaken, the results of which are given in the two following papers (II) and (III).

Table II.

Active Nitrogen No. 3 on Pl.	Nitrogen discharge pos.-column G. Publ. X No. 4	Interpretation		Aurora	
		1. P. G.	*OI*	Spectr. No. 1	Spectr. No. 2
		10— 8		6861	
6757	6781 6765 6748	11— 9		6784 6768 6753	
6699 6684 6670	6704 6682 6660	5— 2 12—10		6696 6682 6669	6680
6616 6604 6593	6630 6606 6582	(6— 3) 13—11		6619 6605 6592	6604
6539 6527 6515	6550 6525 6502	7— 4 14—12		6543 6526 6512	6524
6460	6472 6453 6433	8— 5 (15—13)		6469 6454 6441	
6380	6398 6380 6361	9— 6	$^1D_2$—$^3P_1$	6363	6363
6312 6304 6295	6327 6306 6285	10— 7 21—20	$^1D_2$—$^3P_2$	6300.3	6300.0
6246 6222	6235	11— 8 21—20			
6180	6181	12— 9			
	6114	13—10		6129	
6062	6070	6— 2		6068	
6006	6019 6003 5987	7— 3 15—12		6011 6001 5991	6010
5951	5963	8— 4		(5966)	
5900 5891 5882	5911 5901 5880	9— 5 (22—20)?		5891	
			$^1S_0$—$^1D_2$	5577.35	5577.35
		15—10 16—11 17—12	or N_2B	5238	

These measurements show that the strongest line has a wave-length 6300,30 Å. We can therefore regard the wave-length of the strongest red line as known and use it for the calculation of the displacement of the auroral spectrum relative to the neon comparison spectrum. In this way we obtain the wave-length

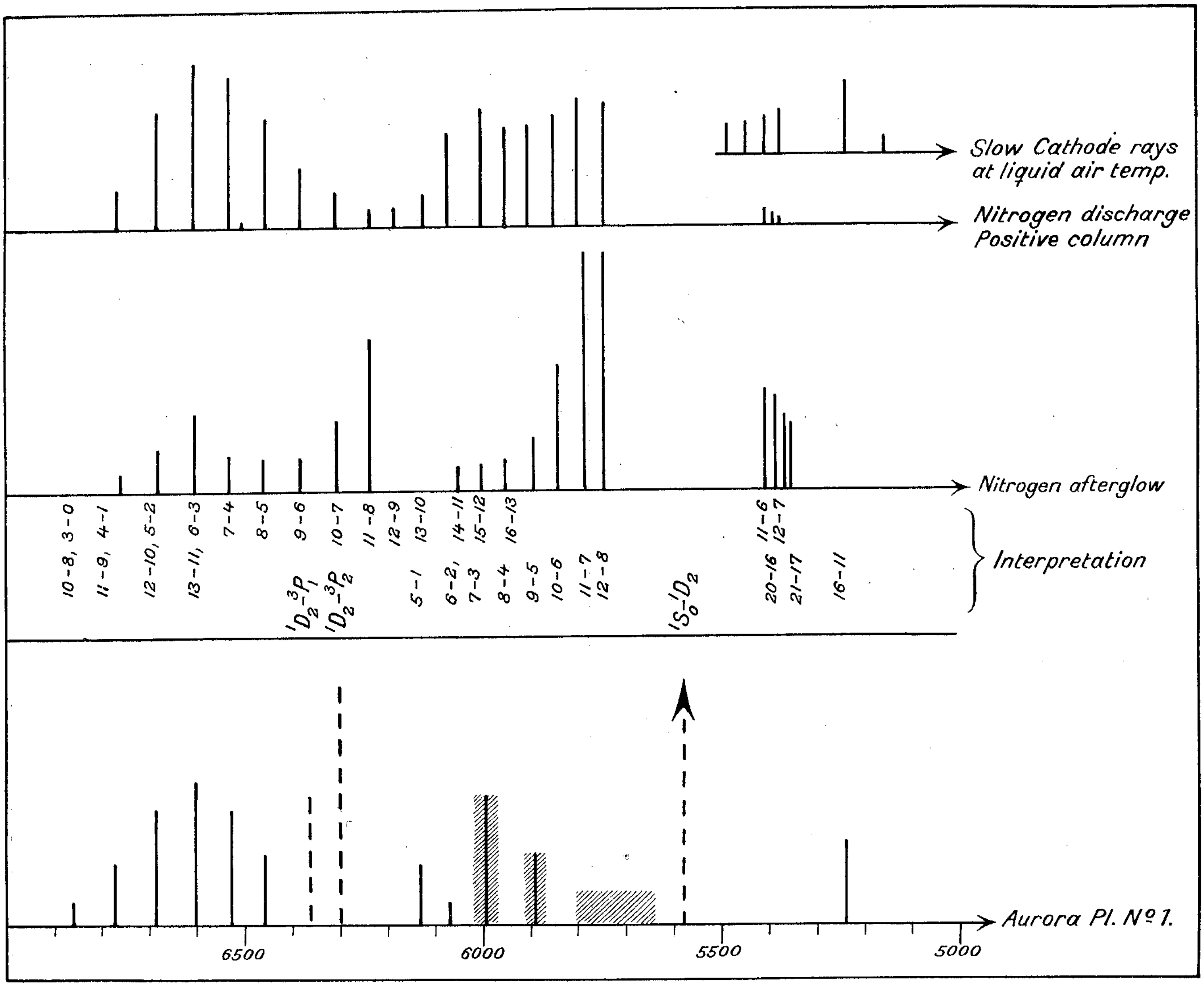

Fig. 1.

values of the other lines and bands free from the error due to the small displacement.

The results of the wave-length measurements from the two auroral spectrograms in the long-wave region are given in the two last columns of Table II.

The first column contains bands of the first positive group which appear on a spectrum of active nitrogen taken at the Physical Institute Oslo by Mr. Olaf Lund on pan-chromatic plates. (Spectrogram No. 3 on plate I.)

The second column gives the bands of the 1st positive group of a spectrogram obtained from the positive column of a nitrogen discharge. This spectrogram was reproduced in paper No. 2, Pl. II, Fig. 2 b. The column in the middle of the table gives the interpretation of the auroral spectra as well as of the two from nitrogen.

It is, first of all, of interest to notice that in agreement with previous results (2, 3) no trace of the red hydrogen line (H_α) or of the red helium lines are observed.

We further notice that all the bands of the 1st positive group appearing in the auroral spectrum are also observed in the spectra from nitrogen in laboratory experiments, but not all the bands which may appear strong in nitrogen afterglow or in the positive column of nitrogen discharge have been observed in the auroral spectrum. This is due to the fact that the intensity distribution within the 1st positive group is very variable and the auroral spectrum shows a peculiar distribution different from any as yet observed in laboratory experiments.

The intensity distribution within the red and yellow region, as it is estimated from the auroral spectrogram No. 1 on the plate I from the spectrogram of the nitrogen afterglow (No. 3 on plate I) and from the positive column (Paper No. 2, plate II, Fig. 2 b), is illustrated in Fig. 1. The figure also includes the intensity distribution of bands in the green part taken from a spectrogram reproduced in paper No. 2, Pl. III, Fig. 2, No. 1 corresponding to nitrogen excited with slow cathode rays (240 volts) at liquid air temperature. This spectrum is of particular interest because it shows the band (16—11) with large intensity and this band has a position which, within the limit of error, corresponds to that of the "second green auroral line" (5240).

We have to remember that the "intensity distribution" given, is merely an expression of the photographic density, and that, therefore, the true intensity distribution obtained by taking into account the variation of photographic sensitivity with wavelength, will be different. As the three spectra to be compared are taken with pan-chromatic plates, the apparent intensity distributions ought to be roughly comparable.

Comparing the auroral spectrum with that of active nitrogen, we see from Fig. 1 that the intensity distribution shows some very marked differences.

The red bands (10—7) and (11—8), the yellow ones (10—6), (11—7) and (12—8), and the green bands (11—6), (12—7), (20—16) and (21—17) which are so prominent in the spectrum of the nitrogen afterglow, are either absent or at any rate extremely weak in the auroral spectrum.

We notice, however, that the intensity distribution within the auroral spectrum of the bands of the 1st positive group is, on the whole, very similar to that emitted from nitrogen under the action of cathode rays.

This result is in agreement with conclusions drawn by one of us in earlier papers (2, 3), and it also confirms the view regarding the excitation of the auroral spectrum obtained by Vegard and Tönsberg from a comparison between the spectra of the aurorae and of the night sky luminescence (6, 7). It will be a matter of great importance to find the physical conditions of the excitation which give the 1st positive group with the same intensity distribution as we observe in the auroral spectrum.

4. The true Relative Intensity within the Auroral Spectrum.

In the case of the auroral spectrogram No. 1 on Plate Ia spectrogram from an incandescent lamp with known intensity distribution was photographed on the same plate, as well as some intensity scales obtained by means of a "Zeiss-Stufenfilter".

The method of determining the true intensity distribution when the apparent intensity distribution is known, has been described by one of us in a previous paper. (2)

The total emission of the standard lamp (I_T) may be expressed by the equation:

$$I_T = \int_0^\infty E_\lambda \, d\lambda \qquad (1)$$

where E_λ is known as a function of (λ) for the standard lamp employed.

We call the apparent intensity of a line $\varphi(u)$, where (u) is the deflection taken out of the microphotometer curve. $\varphi(u)$ is determined in the known way by means of the intensity scale.

The true relative intensity of a certain line (a) is then given by the expression:

$$I_a = \frac{\varphi(u_a)}{Q_a} \qquad (2)$$

Let $\varphi(u'_a)$ be the apparent intensity of the continuous spectrum from the standard lamp, and the wavelength considered, then we have:

$$Q_a = \frac{\varphi(u'_a)}{E_\lambda \frac{d\lambda}{ds}} \qquad (3)$$

where $\frac{d\lambda}{ds}$ is the dispersion of the instrument for the wave-length considered.

The value of (Q) as a function of wave-length was calculated for the photographic plate of spectrogram No. 1. The curve is shown in Fig. 2. It is to be remembered that the sensitivity factor (Q) does not only depend on the photographic sensitivity, but also on the spectograph used.

A registram of the auroral spectrum No. 1 is shown in Fig. 3 a. The relative intensities (I) derived from this registram by means of equation (2) are given in Table III.

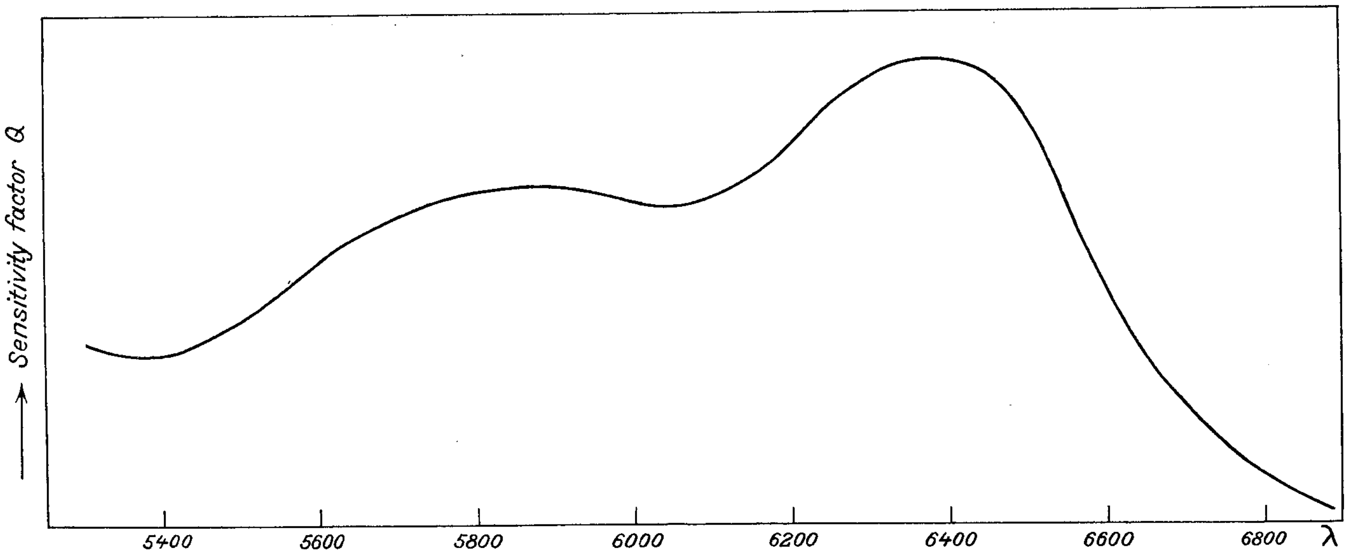

Fig. 2.

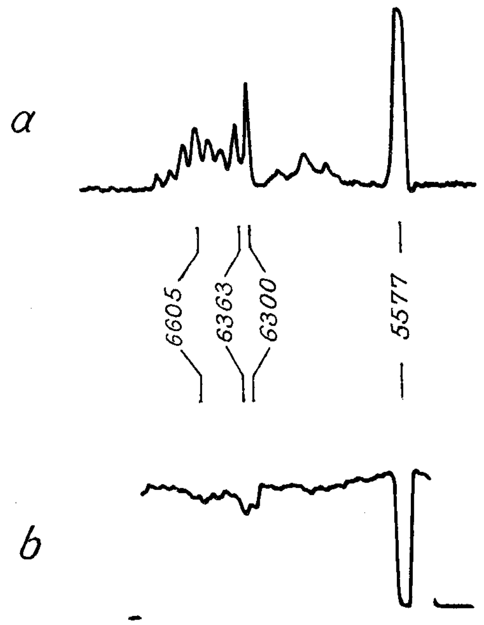

Fig. 3.

Table III.

λ	Interpretation	Intensity
5577	OI ($'S_0$—$'D_2$)	(1080)
5891	(9— 5), (22—20)	15
6001	(7— 3), (15—12)	20
6129	(13—10)	13
6300	OI ($'D_2$—$^3P_2$)	38
6363	OI ($'D_2$—$^3P_1$)	21
6454	(8— 5), (15—13)	16
6526	(7— 4), (14—12)	23
6605	(6— 3), (13—11)	42
6682	(5— 2), (12—10)	(60)
6768	(11— 9)	(88)
6861	(10— 8)	(120)

The relative intensity of the strong green line is uncertain because it is highly over-exposed.

The true relative intensity within the 1st positive group differs essentially from the apparent intensity on the plate. Thus the band 6605 which appears most intense on the plate, is not the strongest band, but the intensity increases considerably as we pass to the bands 6682, 6768, and 6861, due to the fact that the sensitivity of the plate (Q-value) falls rapidly with increasing wave-length in this region (cfr. Fig. 2). In fact, the apparently weak band 6861 (10—8) is the strongest red auroral band observed.

5. Comparison between the Intensity Distribution of the Spectrograms Nos. 1 and 2.

The auroral spectrograms Nos. 1 and 2 (Pl. I) being taken on the same kind of plate, may be regarded as approximately comparable, and we may treat them as if they were spectrograms on the same plate.

As already mentioned, particular interest is attached to the relative intensity of the two strongest components 6300, and 6363 of the *OI* triplet. We see from these curves that the second component 6363 appears to be much stronger on spectrogram No. 2. Cfr. fig. 3 b.

In order to see how far the intensity of the oxygen lines has changed relative to that of the nitrogen bands, we have also measured the intensity of the band 6605 which appears on both plates sufficiently dense to be measured.

The results of the measurements are given in Table IV.

The intensity of the strongest red *OI* line is put equal to 100 and we notice that the intensity of the second line in spectrogram No. 2 is almost twice that of the spectrogram 1. The latter spectrogram shows the relative intensity of the two lines as it is normally observed. The large intensity of the second component in spectrogram 2 is, however, abnormal, and, as we can hardly assume a real intensity change for the two components of the *OI*-triplet, the apparent enhancement of the second component must result from the enhancement of some other band or line of nearly the same wave-length.

From the wave-length Table II we see that the bands (9—6) and (10—7) of the 1st positive group nearly coincide with the oxygen lines 6363 and 6300 respectively. If in the auroral spectrum the bands (9—6) appear fairly strong relative to the bands (10—7) then the enhancement of the 1st positive group relative to the red oxygen lines would have the effect of producing an apparent enhancement of the oxygen triplet.

Table IV.

λ	Q	Spectrogr. 1		Spectrogr. 2	
		$\varphi(u)$	I	$\varphi(u)$	I
6300	11.3	100	100	100	100
6363	11,8	61,5	59,0	119,5	114,5
6605	5,8	60,5	118	81,5	159,0

From Table IV we see that the relative intensity of the band 6605 is considerably larger in spectrogram No. 2; but if the bands of the first positive group maintain a constant intensity distribution, this increase could not account for the large apparent enhancement of the line 6363.

Hence we conclude that the apparent increase of the intensity of the second component of the oxygen triplet in spectrogram No. 2 must be due to the enhancement of some band or line situated in the vicinity of this line. If it is due to the band (9—6) of the first positive group, this band must have been enhanced as compared with other bands of the same group.

6. Spectrogram in the Region of Short Waves.

During the Winter of 1934—35 a successful spectrogram was obtained at the Auroral Observatory Tromsø with the large new quartz spectrograph. (Cfr. paper No. 3.) We used Ilford Double X-press plates and the exposure lasted from Nov. 1933 to April 1934. A reproduction of the spectrogram is shown on plate II. No. 2. In the long wave part, the instrument was not in focus so the green line 5577 comes out very diffuse on the spectrogram. The results of the wave-length measurements are given in Table V.

Table V.

Measured from Plate II No. 2		λ from earlier measurements	$\Delta\lambda$	Interpretation
Intensity	λ measured			
m. d.	(4700,7)	4708,7		N. G. (0,2)
w. d.	(4643,8)	4652,2		N. G. (1,3)
w. d.	4346,9	4345,6	+ 1,3	2. P. G. (0,4)
w. d.	4324,5	4319,5	+ 5,0	b' 2, P. G. (5, 10)?
v. st.	4281,0	4277,6 P	+ 3,4	N. G. (0,1)
st. d.	4264,0	4267,6 R	÷ 3,6	
m.	4239,5	4236,0	+ 3,5	N. G. (1,2)
w.	4219,5	4218,0	+ 1,5	OI, N.
v. w.	4074,5	4076,0	÷ 1,5	OII
w.	4062,2	4058,0	+ 4,2	2. P. G. (0,3)
v. w. d.	*4048,5*			
m.	3998,8	3997,7	+ 1,1	2. P. G (1,4)
w. d.	3984,5	(3981,3)		b' ε (1,12)
v. w.	3946,7	3942,8	+ 3,9	2. P. G. (2,5)
v. st.	3918,9	3914,4 P	+ 4,4	N. G. (0,0)
st. d.	3905,5	3903,5 R	+ 2,0	
m.	3807,6	3805,4 P	+ 2,2	2. P. G. (0,2)
w.	3771,5	3769,0	+ 2,5	N. OII
m.	3757,7	3755,2	+ 2,5	2. P. G. (1,3)
w.	3712,6	3711,1	+ 1,5	2. P. G. (2,4)
v. w.	*3708,0*			
w.	3688,0	3685,3	+ 2,7	b' ε (1,11)
f.	*3671,8*			2. P. G. (3,5)
v. w.	3597,7	(3603,0)		ε (3,12)
v. st.	3580,1	3577,6	+ 2,5	2. P. G. (0,1)
m.	3538,2	3536,8	+ 1,4	2. P. G. (1,2)
br. w. d.	3502,5	3503,2	÷ 0,7	2. P. G. (2,3)
w.	3467,9	3468,7	÷ 0 8	2. P. G. (3,4)
br. w. d.	3427,0	3429,0	÷ 2'0	b' ε (1,10)
st.	3372,3	3371,3	+ 1'0	2. P. G. (0,0)
br. w. d.	3285,3	3285,3	0'	2. P. G. (3,3)
br. w. d.	3200,2	3202,7	÷ 2,5	b' ε (1,9)
v. w.	*3192,4*			
v. w.	*3168,7*			2. P. G. (9,7)
m.	3158,3	3159,3	÷ 1,0	2. P. G. (1,0)
w. d.	3133,4	3135,7	÷ 2,3	2. P. G. (2,1)
v. w. d.	*3115,2*	3114,0	+ 1,2	2. P. G. (3,2)

The apparent intensity, as it is estimated from the spectrogram, is given in the first column and indicated in the following way.

v. st.	means	very strong
st.	»	strong
m.	»	medium
w.	»	weak
v. w.	»	very weak
f.	»	faint
d.	»	diffuse
br.	»	broad.

The second column contains the wave-length values of those lines and bands which have appeared on our spectrogram sufficiently distinct for measurement.

The third column contains the corresponding wave-length values from earlier measurements. We notice that — probably owing to the very long exposure — four lines (or bands) appear, which have not been observed previously.

Two of these, 3168,7, and 3671,8, have been identified as bands belonging to the second positive group of nitrogen. For the other two, 3708, and 4048,5, we can at present give no definite interpretation.

The presence of the band 3169 identified as due to the transition (9—7) of the second positive group of nitrogen, suggests that also other transitions of the sequence $n'—n''=2$ corresponding to values of n'', smaller than 7 would also appear in the auroral luminescence, if we could observe in the auroral region. The bands for which $n''<7$, however, will be absorbed in the atmosphere and thus escape observation.

In conclusion, we wish to express our sincere thanks to Mr. S. Stensholt for his most valuable assistance in connection with the treatment of the observational material.

II. INTERFEROMETER MEASUREMENTS OF THE RED AURORAL LINE 6300

BY *LEIV HARANG* AND *L. VEGARD.*

(Manuscript received 12. December 1936.)

1. Introductory Remarks.

In a previous paper (9) we have given the results of our interferometer measurements of the green auroral line undertaken at the Auroral Observatory, Tromsø. For this purpose we used an interferometer of Fabry-Perot type consisting of a camera in front of which was put a plane-parallel quartz plate half-silvered on both sides.

By using ortho-chromatic plates not sensitive to red, and in front of the interferometer plate a yellow filter, it was secured that the part of the auroral luminescence which acted on the photographic plate, mainly consisted of the strong green line. The procedure is similar to that used by Babcock (12) for his measurements of the green line from the night sky luminiscence.

We used two interferometer quartz plates about 2,5 mm and 5 mm thick. With each of these plates we took a large number of interference pictures, which led to the wave-length:

$$\lambda = 5577{,}3445 \ (\pm\ 0{,}0027)$$

for the green auroral line. Within the limit of error, this value agrees with that found for the wave-length of the oxygen line *OI* ($^1S_0$—$^1D_2$).

This interpretation of the green line suggests that also the oxygen triplet *OI* ($^1D_2$—$^3P_{012}$) appears in the auroral spectrum. The strongest component of this triplet should have a wave-length of about 6300 and from the spectral analysis of the auroral luminiscence (1, 2, 3, 5), it is well known that a red line with about this wave-length appears in the auroral spectrum. Usually, this line is very weak, but as shown by one of us (1), it may in certain cases be as strong as the green line and give the aurora a deep red colour.

On account of the great intensity variations of this line and its possible relation to the green line, precision measurements of its wave-length became a matter of great importance. The method to be adopted for the interferometer measurements of the red line is essentially the same as that used for the green one. In the case of the red line we had to use photographic plates sensitive to red and in front of the interferometer plate we used a filter which absorbed all short waves down to about $\lambda = 5700$ Å.

With regard to the apparatus and the instrumental equipment, it is sufficient to refer to our previous paper (9). The optical thicknesses of the two interferometer plates were measured at The National Physical

Laboratory, England, and a complete account of the results is given in our first paper (9).

As the red aurora with the enhanced red line (6300) seems to be particularly frequent at lower latitudes, we decided to undertake similar measurements at Oslo, and for this purpose an interferometer provided with two new quartz plates was constructed. In the present paper we shall only deal with the results of the interference pictures taken at the Auroral Observatory, the results from Oslo will be given in the subsequent paper (III).

2. Remarks regarding the Wave-length from the Interference Pictures.

A more complete description of the method and the deduction of the formulae on which the wave-length measurements are based was given in our first paper already referred to. In this connection we shall now merely make a few remarks regarding our method of operation and give the formulae which are to be used in the present case.

A matter of great importance is to exclude errors due to temperature variations. In order to compensate for temperature variations, we followed the same procedure as that adopted by our determination of the green line.

Just before and immediately after the exposure of the auroral interference picture, similar pictures were taken of the fringes from the yellow Neon line $\lambda = 5852{,}488$. *I. U.* With these exposures we used another combination of filters, which gave transparency in a narrow interval surrounding the yellow Neon lines. Each plate thus ordinarily contained three pictures, one of the red auroral line in the middle with one neon picture on each side.

The interference rings of the neon line give us means of determining the effective thickness of the plate of the temperature present. Assuming that the temperature varies at a constant rate, the mean value of the effective thickness derived from the two neon pictures should give us the effective mean thickness of the interferometer plate during the exposure of the auroral red line.

The wave-length in vacuum λ_v is given by the relation[1]

$$\lambda_v = \frac{2e\mu}{n+\varepsilon} \quad \ldots\ldots\ldots\ldots \qquad (1)$$

e is the thickness, μ the refractive index of the plate at the temperature present. It must be taken into account that μ varies with the wave-length. $n + \varepsilon$ is the interference order number (P) at the centre of the picture, n is the whole number part, and ε — the fractional part of it.

Applying the equation (1) to the auroral and neon lines, and assuming that both pictures correspond to the same temperature and the same effective thickness (e), we obtain the following formula:

$$\lambda_v = \lambda_v' \frac{\mu_0}{\mu'_0} \frac{n' + \varepsilon}{n + \varepsilon} (1 + \Delta\gamma t) \qquad (2)$$

where λ_v, μ and $n + \varepsilon$ correspond to the auroral line and the quantities with dashes, to the neon line.

$$\Delta\gamma = \gamma_\lambda - \gamma_{\lambda_1}$$

where γ_λ and γ_{λ_1} are the temperature expansion-coefficients for the refractive index of quartz for the auroral line and the neon line respectively.

Putting:

$$\lambda'_v \cdot \frac{\mu_0}{\mu'_0} = a \qquad (4)$$

we have:

$$\lambda_v = a \frac{n' + \varepsilon}{n + \varepsilon} (1 + \Delta\gamma t) \qquad (5)$$

The quantity (a) is a constant for the whole series of pictures. We find:

$$a = 5854{,}1103 \frac{1{,}54325132}{1{,}54491940} = 5847{,}7895 \text{ Å}.$$

From equation (5) it is apparent that the determination of the wave-length requires the knowledge of the whole order numbers (n), and the fractional parts (ε) of the two lines. As described in our first paper (9) the fractional part (ε) is found from the diameters of the interference rings by means of the formula:

$$\varepsilon = \frac{(i-1)\, d_k^2 - (k-1)\, d_i^2}{d_i^2 - d_k^2} \qquad (6)$$

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

In order to determine n and n' it is necessary that, already at the start, we should have an approximate knowledge of the wave-length values of the lines we are dealing with, and that we should know the effective thickness of the interferometer plate to within a fraction of a wave-length.

As already mentioned, the thickness of the plates was measured at The National Physical Laboratory and knowing the thermal expansion of quartz, we

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[1] Cfr. Paper 9 equation (6).

can find the thickness e_0 at any temperature. In the case of neon, n' can be found directly from the known wave-length by means of equation (1).

As will appear from previous publications, the red auroral line has been obtained on a considerable number of spectrograms. Some of these have been taken with small spectrographs having a too small dispersion in the red part to give a sufficient accuracy for our purpose.

Of late years we have also obtained the red line by means of a big glass spectrograph and a grating spectrograph. These instruments have a dispersion so large that if we were working under ordinary laboratory conditions, we would easily determine the wave-length within an error less than 1 Å.

In 1932 we obtained with the large dispersion four spectrograms showing the red line quite distinctly for measurement. The results are given in a previous paper (5).

The red line was recently measured from a spectrogram obtained by the big glass spectrograph during the spring 1936. These spectrograms give the following wave-length values:

	Weight	λ	
1932	2	6300,6	Grating spectrograph
	1	6302,1	
	2	6300,2	Glass spectrograph
1936	1	6305,1	
	1	6300,0	
Weighted mean		6301,3	

The error should not exceed about 1,5 Å. As far as our present spectrographic measurements go, we can merely state that the wave-length of the red line must lie somewhere in the interval 6299,8—6302,6. This means that for each interferometer etalon there are several values of (n) which lead to wave-length values within the right interval.

3. Results from the Interference Pictures obtained at Tromsø Observatory.

The first picture showing a number of distinct interference rings of the red line was obtained on January 15. 1934 with the 2,5 mm etalon. The results of the measurements of this first plate were published in a letter to "Nature" (10). Among the wave-length values (about 6) situated in the interval of uncertainty, there was one which, within the limit of error, agreed with the wave-length found for the strongest component OI ($^1D_2$—$^3P_2$) of the red oxygen triplet.

The wave-length found from our first interference picture was:

$$\lambda = 6300{,}322 \; I.U.$$

By direct measurements of the red OI line with a dispersion of 29 Å/mm, Hopfield (11) finds:

$$\lambda = 6300{,}23 \text{ Å } (I.U.)$$

From the spectral terms, corresponding to the $^1S_0$, $^1D_2$ and $^3P_{012}$ levels, as determined by Hopfield, we find the value:

$$\lambda = 6300{,}328 \text{ Å } (I.U.)$$

Probably the latter value is the more correct because it is derived from spectra taken with an instrument of very large dispersion: 1,7 Å/mm. Putting equal weight on both determinations, we obtain the following mean wave-length value for the red OI ($^1D_2$—$^3P_2$) line:

$$\lambda = 6300{,}279 \text{ Å } (I.U.)$$

During the winter season 1935—36 a considerable material of interference pictures was obtained at Tromsø. It consisted of 7 plates with pictures taken with the 5 mm etalon and 16 plates with pictures taken with the 2,5 mm etalon.

In all cases the interference fringes of the red auroral line were quite distinct and consisted of a fairly large number of rings, the diameters of which could be measured fairly accurately. Some of the pictures showing the interference ring-systems obtained with the two etalons for the red auroral line, are reproduced on Plate III. A couple of pictures of the fringe-system for the yellow neon comparison line are also shown on the plate.

As already mentioned, the 2,5 mm etalon gave 6—7 wave-length values inside the interval of uncertainty, and an etalon of the double thickness gives about twice this number.

Owing to the fact that one etalon is almost exactly twice as thick as the other, the pictures obtained with the 5 mm etalon do not give any reduction in the number of possible wave-length values inside the interval of uncertainty given by the 2,5 mm etalon. This will be seen from Table I, which contains the results for two of our plates, one taken $^{20}/_{12}$ 1935 with 2,5 mm etalon, the other $^{19}/_{2}$ 1936 with 5 mm etalon.

Table I.

2,5 mm etalon $^{20}/_{12}$ 1935		5 mm etalon $^{19}/_{2}$ 1936	
$n = 12301 +$	$\lambda = 6300 +$	$\lambda = 6300 +$	$n = 24568 +$
— 3	+ 1,824	+ 1,847	— 6
		+ 1,590	— 5
— 2	+ 1,312	+ 1,333	— 4
		+ 1,076	— 3
— 1	+ 0,802	+ 0,819	— 2
		+ 0,563	— 1
0	+ 0,290	+ 0,306	0
		+ 0,050	+ 1
+ 1	— 0,221	— 0,207	+ 2
		— 0,464	+ 3
+ 2	— 0,736	— 0,721	+ 4
		— 0,978	+ 5
+ 3	— 1,246	— 1,235	+ 6

We notice from Table I that the wave-length obtained with the 2,5 mm etalon corresponding to $n = 12301 = N_I$ within the limit of error, coincides with the value which is obtained from the 5 mm etalon by putting for this etalon the whole part of the order number $n = 24568 = N_{II}$. We further notice that all the values for the 2,5 mm etalon equally well coincide with corresponding values for the 5 mm etalon.

Now there are good reasons for the assumption that the red auroral line here dealt with, is identical with the strongest component of the oxygen triplet (OI) $({}^1D_2$—${}^2P_{012})$. If so, only the values of (n) corresponding to $(n—N) = 0$ and which give a wave-length near to that of Hopfield can come into consideration. Then the two plates considered in Table I would lead to the wave-length value $\lambda = 6300{,}298$ Å *I.U.* in fairly good agreement with the value we published in our letter to "Nature" (10).

Taking $\lambda = 6300{,}3$ Å as an approximate value of the wave-length of the red line, the whole order number can be fixed without ambiguity. On this assumption the wave-length has been measured for all our interference pictures and the measurements and calculations were made independently at Tromsø Observatory and at Oslo. The results are given in Tables II and III for the 2,5 mm and the 5 mm etalon respectively.

Table II.

2,5 mm etalon. Tromsø 1935—36.

Date	Tromsø			Oslo		
	Aurora $P = 12301 +$	Neon $P = 13257 +$	Aurora $\lambda = 6300 +$	Aurora $P = 12301 +$	Neon $P = 13257 +$	Aurora $\lambda = 6300 +$
$^{16}/_{12}$	0,993	0,627	0,307	1,023	0,687	0,325
$^{19}/_{12}$	0,880	0,512	0,311	0,938	0,543	0,300
$^{20}/_{12}$	0,944	0,573	0,307	0,996	0,580	0,290
$^{20\text{-}21}/_{12}$	0,833	0,526	0,334	0,942	0,553	0,302
$^{20\text{-}21}/_{12}$	0,913	0,573	0,323	0,904	0,609	0,349
$^{21\text{-}22}/_{12}$	0,898	0,488	0,290	0,924	0,546	0.309
$^{26\text{-}27}/_{12}$	0,850	0,519	0,331	0,918	0,540	0,309
$^{27\text{-}28}/_{12}$	0,922	0,550	0,301	0,979	0,566	0,290
$^{31}/_{12}\text{-}^{1}/_{1}$	0,963	0,534	0,279	0,957	0,577	0,307
$^{8}/_{1}$	0,977	0,573	0,290	0,971	0,616	0,318
$^{13\text{-}14}/_{1}$	0,883	0,490	0,299	0,914	0,510	0,297
	0,891	0,517	0,308	0,897	0,551	0,325
$^{20}/_{1}$	0,856	0,481	0,309	0,907	0,499	0,295
$^{20}/_{1}$	0,871	0,502	0,311	0,936	0,542	0.301
$^{21}/_{1}$	0,864	0,507	0,317	0,908	0,535	0,312
$^{21}/_{1}$	0,850	0,477	0,310	0,931	0,548	0,306
		Mean:	0,308		Mean:	0,308

Table III.

5 mm etalon. Tromsø 1936.

Date	Tromsø			Oslo		
	Aurora $P = 24568 +$	Neon $P = 26477 +$	Aurora $\lambda = 6300 +$	Aurora $P = 24568 +$	Neon $P = 26477 +$	Aurora $\lambda = 6300 +$
27/1 1936	0,611	0,115	0,304	0,734	0,131	0,281
17/2	0,501	0,000	0,305	0,558	0,060	0,309
18/2	0,567	0,173	0,303	0,611	0,181	0,324
19/2	0,548	0,110	0,319	0,633	0,131	0,306
19/2	0,636	0,085	0,291	0,515	0,137	0,338
21/2	0,535	0,171	0,338	0,657	0,235	0,325
22/2	0,559	0,066	0,306	0,623	0,183	0,321
			Mean: 0,309			Mean: 0,315

The tables give for each plate the date of exposure, the order number $P = n + \varepsilon$ corresponding to the standard *Ne*-line and the red auroral line and, finally, the resulting wave-length of the red auroral line given in *I.U.* At Tromsø each plate was measured and calculated two or three times and in the table we have given the mean values of P and of λ.

The differences between corresponding values found at Tromsø and at Oslo are seen to be about as large as the differences between numbers within the same column. This shows that the error is mainly due to uncertainty in the determination of the excess fraction (ε), from the interference ring-system. Compared with this error, the possible inaccuracy due to incomplete temperature correction seems to be insignificant. The average values obtained at Tromsø and Oslo agree remarkably well.

The thickest plate ought to give the most accurate values, but as the pictures obtained by means of the 2,5 mm etalon give more distinct fringes with larger diameters, it seems reasonable to give the results for both etalons equal weight. On the assumption that the red auroral line is the strongest component of the oxygen triplet, we then find for its wave-length:

Mean from Tromsø mesurements:

$$\lambda = 6300{,}3083\ (\pm 0{,}0030)\ I.U.$$

Mean from Oslo measurements:

$$\lambda = 6300{,}3101\ (\pm 0{,}0033)\ I.U.$$

Mean: $\lambda = 6300{,}3092\ (\pm 0{,}003\ )\ I.U.$

Our thanks are due to Mr. S. Stensholt M. A., for valuable assistance in connection with the preparation of this paper.

III. INTERFERENCE MEASUREMENTS OF THE RED AURORAL LINE 6300 CARRIED OUT AT OSLO

BY *L. VEGARD* AND *LEIV HARANG*

(Manuscript received 12. December 1936.)

1. Introduction.

By the analysis of the auroral spectrum undertaken by means of ordinary spectrographs, the wave-length of a line or band may be measured with an accuracy varying from say 0,2 Å to several Ångström units according to the dispersion of the instrument and the definition and distinctness with which the line or band appear on the plate.

When in this way such an approximate knowledge of the wave-length has been acquired, the accuracy may be further increased by means of interferometer methods.

As stated in a previous paper (9) preparations for such measurements were commenced in 1921; but the first arrangements tried did not lead to any satisfactory results. On the basis of these preliminary tests, and the measurements carried out by Babcock (12) for the night sky luminescence, preparations for the building of a satisfactory interferometer were made in connection with the building of the New Observatory at Tromsø during the years 1926—29.

It was decided to use an interferometer of the Fabry-Perot type. The main part of this instrument consists of a quartz plate, half-silvered on both sides put up in front of the objective lens of a camera. In order to separate the light of the line to be measured, some kind of monochromating device has to be used.

We might use a prism-monochromator in front of the interferometer plate or we might let the picture formed by the camera lens fall on the slit of the ordinary spectrograph. When we use a wide slit, the interference fringes will be seen on the picture of each line as illustrated in paper No. 3, Pl. I f. An interferometer which utilises any type of prism-monochromator will have a very small light power, and would require long exposures in the case of the weak auroral luminescence.

We know that the auroral luminescence has a spectrum essentially composed of nitrogen bands, the strong green line and a red line (or perhaps triplet of lines) in the region 6300—6400, which in certain cases of red and sunlit aurorae may appear with considerable strength (1, 14).

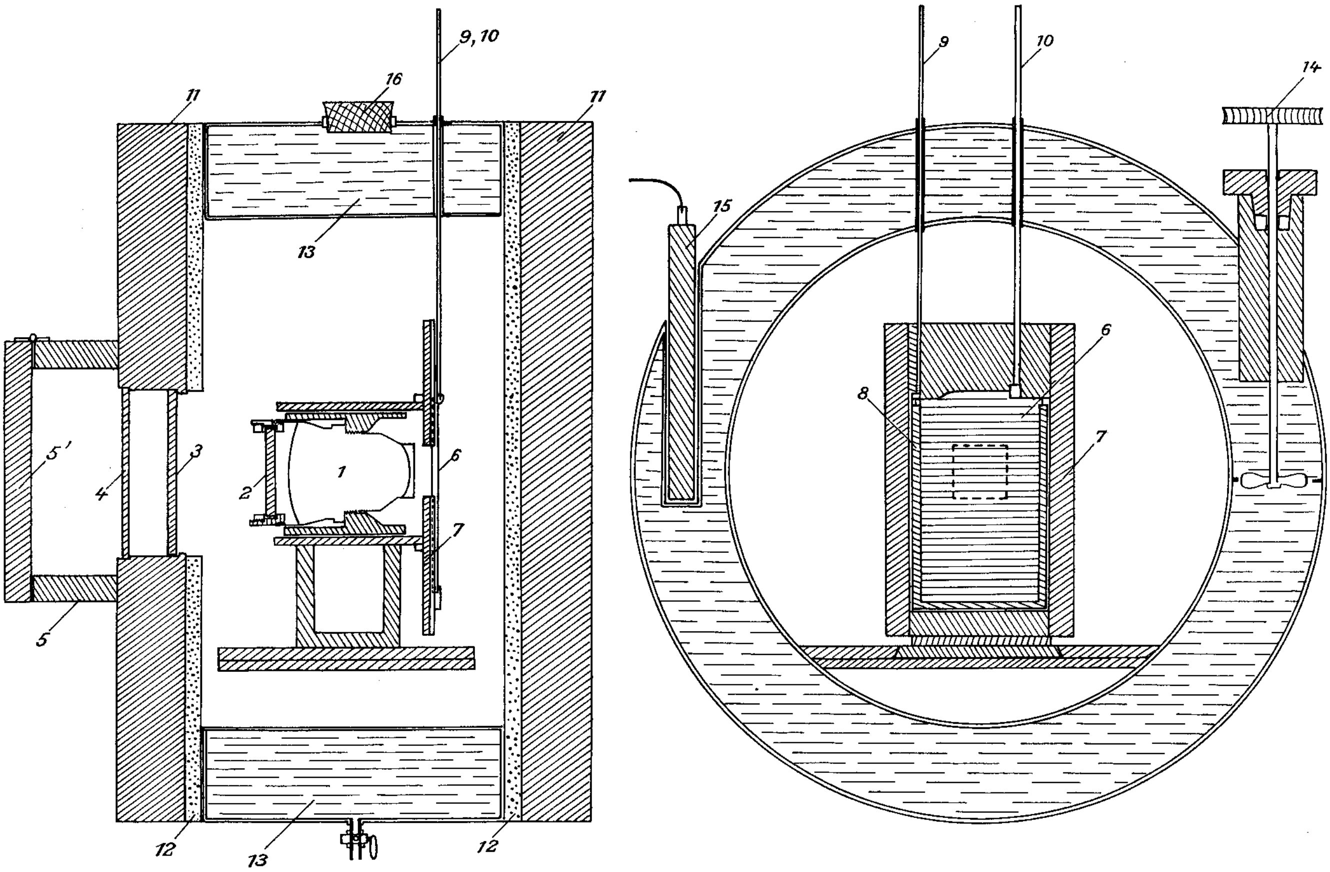
The problem which we first of all had to deal with, was an accurate determination of the wave-length of the green line and that of the strongest red line, with a wave-length near to 6300 Å.

Taking advantage of this special character of the auroral luminescence, it is possible to obtain a sufficient separation of the line to be measured, by using suitable coloured filters in front of the slit, eventually combined with photographic plates for which the sensitivity is restricted to certain parts of the spectrum. Thus in the case of the green auroral line, we used a yellow filter and orthochromatic plates not sensitive to red (8, 9), and, in the case of the red line, we had to use panchromatic plates and a suitably selected red filter. (Cfr. paper 10.)

As the strong green line appears with dominating strength, and as no other bands or lines appear in the region between 5250 and 5800, the filter method gives an almost perfect monochromating effect in the case of the green line.

In the case of the red line, conditions are not so favourable. First of all the intensity of the red line is comparatively small, and of the same order of magnitude as that of a number of red bands appearing in its vicinity. But also here we take advantage of the particular properties of the auroral luminescence which have been found from the previous spectral analysis (2, 3, 5).

The line near 6300, is considerably stronger than any other line appearing in the red region, and the bands which may pass through the red filter are composed of a large number of rotational components, so their interference fringes will overlap, and merely contribute to the general continuous ground-blackening of the picture. It might therefore seem possible with filter monochromator to obtain fringes from the strong red line although the background may be somewhat blackened.



a Fig. 4. b

As already mentioned (1, 14) the red line may in certain cases be largely enhanced, so the aurorae may even appear dark red. As red aurorae of this type (*A*) seem to be more frequent and pronounced at lower latitude, we decided to undertake measurements also at Oslo, and for this purpose a new interferometer was constructed and built in the workshop of the Physical Institute.

The results obtained at Tromsø for the green and red lines have been published in previous papers (8, 9, 10). In the present paper, we would give the results obtained at Oslo up to the present.

2. The Interferometer.

The interferometer arrangement used at Oslo is in principle the same as that which we used at Tromsø, and which has been described in previous publications (9). As the Oslo equipment, however, differs considerably in details of construction and in the specification of optical parts, a short description will therefore be given.

In order to secure the greatest possible accuracy, it is essential that the interferometer plate and the camera are kept in a thermostat where the temperature is kept as constant as possible during the exposure of each plate, or that eventual small variations are so regular that they may be compensated for by means of symmetrical observations.

The construction of the interferometer and the thermostat will be seen from Figs. 4 a and 4 b, showing sections along, and perpendicular to, the axis of the instrument.

For the interferometer, we used a lens (1) of high light power (1 : 1,25) and with a focus distance of 50 mm, supplied by Astro-Gesellschaft, Berlin. The Fabry-Perot etalon (2) was mounted in front of the lens. The plate-holder could be made to slide up and down and given any desired position by means of a long brass rod (9) passing through the thermostat and fixed to the frame 8. In a similar way the photographic plate could be uncovered by means of the rod (10) fixed to the casket-lid (6).

In a circular opening in front of the etalon was placed a filter (3) and a glass plate (4). This window was protected by the tube (5) with the lid (5′) which was turned up during exposures. The side walls of thermostat consisted of a receiver formed by two metal cylinders (13) which might be filled with water, preferably a mixture of ice and water. The ends of the thermostat were covered with thick boards (11) and layers of felt (12) to improve the isolation. The water could be kept in motion by a propeller (4) driven by a small electromotor. If necessary, the water could be heated by means of an electric heater (15) where the current could be suitably regulated. The apparatus was mounted in a frame arrangement on the roof of the Physical Laboratory building in such a way that the instrument could be pointed towards any part of the sky by rotating it on a horizontal and vertical axis.

When the air-temperature kept fairly constant, we preferred not to use the heater, but the apparatus was allowed to take up a nearly thermal equilibrium determined by the external conditions.

For the measurements of the red auroral line we intended to use the yellow neon line $\lambda = 5852{,}488$ Å *I.U.* The filter (3) had therefore to be selected in such a way that it absorbed practically completely the green auroral line 5577, while being transparent to the yellow neon line and the red auroral line.

We used a Wratten red filter No. 23 *A*, which fulfils the conditions mentioned. In making the exposures of the standard neon line, it was necessary to remove the strong red part of the neon light. This was done by placing a Wratten filter No. 61 *N* between the light source and the tube (5). The combination of the two filters only left a narrow interval of transparency on both sides of the yellow neon line.

In connection with the construction of the new nstrument, two new quartz plates were ordered from A. Hilger, London, with thicknesses of about 1,5 and 2,5 mm. It was intended to use for these plates an aluminium coating obtained by letting metallic vapour condense on the surface in a vacuum.

At first a thin layer was tried, but after some tests with auroral luminescence, the layer was found to be too thin to give distinct interference fringes. The thickness of the aluminium layer was therefore considerably increased and to such an amount that the plate with its coating on both sides reduced the intensity of light to about $^1/_6$ of its initial value. This denser coating appeared to be very satisfactory.

3. Remarks regarding the Method used.

The method used has been described fairly completely in a previous paper (9) dealing with the determination of the green line. For the sake of convenience we shall give also here the more important formula we are using.

Let the interference order number at the centre of the fringe system be *P*, the wave-length in vacuum (λ_v) and the thickness and refractive index of the plate at the temperature considered be *e* and then

$$\lambda = \frac{2\, e \mu \gamma}{P} \tag{1}$$

$$P = n + \varepsilon \tag{2}$$

where (n) is a whole number and (ε) the excess fraction of (P).

The wave-length would be determined from equation (1) by knowing the following quantities. The thickness (e) and the refractive index μ_λ at $0^0 C$, their temperature coefficients, the temperature of the interferometer plate, the whole number (n) and the fractional part (ε). The optical thickness of the plate was measured at the National Physical Laboratory, England. The refractive index μ_λ and the temperature coefficients of (e) and (μ) are known.

In order to determine (n) we must already at the start have an approximate knowledge of the wave-length which we are going to measure.

Previous measurements of the red auroral line by means of ordinary spectrographs have given for its wave-length:

$$\lambda = 6301{,}3 \text{ Å } I.U.$$

with an error which ought not to exceed 1,5 Å. With the plate thickness used, it means that the wave-length is not sufficiently accurately known to fix the value of n, for a number of n-values will give wave-length values within the interval of uncertainty. For a given uncertainty interval, the number of possible n-values is proportional to the plate thickness. This shows the advantage of using the thin 1,5 mm plate.

The value of (n) may now be fixed definitely by using two plates, provided the thickness of the plates does not stand in the simplest possible rational relation to one another.

As shown in a previous paper (9) the two plates used at Tromsø, of 2,5 mm and 5 mm thickness, cannot fix the n-value, but, as we shall see, *a combination of fringe-systems from the 1,5 mm etalon with those of the 2,5 mm etalon fixes the n-value without ambiguity and thus leads to a complete determination of the wave-length of the red auroral line.*

The excess fraction (ε) is determined from the diameters of the interference rings by means of the formula:

$$\varepsilon = \frac{(i-1)\,d_k^2 - (k-1)\,d_i^2}{d_i^2 - d_k^2} \tag{3}$$

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

The determination of (λ) from equation (1) would require a very accurate knowledge of the effective temperature and thickness of the etalon, and errors in these quantities would enter with their full force into the results.

In order to eliminate these errors the following procedure was adopted. Immediately before and after the exposure of the red auroral line, we take pictures of the ring-system corresponding to the yellow neon line mentioned.

For the neon line λ'_v we have:

$$\lambda'_v = \frac{2\,e\,\mu_{\lambda'}}{n' + \varepsilon} \tag{1'}$$

If the temperature varies at a constant rate, we can assume that the mean temperature of the neon pictures is equal to the mean temperature corresponding to the auroral ring-system. Combining equations (1) and (1') we get:

$$\lambda_v = \lambda'_v \frac{\mu_0}{\mu'_0} \frac{n' + \varepsilon'}{n + \varepsilon} (1 + \Delta\gamma\, t) \tag{4}$$

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

As $\Delta\gamma$ is a very small quantity, no accurate knowledge of the temperature is wanted by this procedure; but it is, of course, very essential that the temperature is kept nearly constant and that the possible variation during the exposure of a plate is linear so that the mean temperature of the neon exposures is equal to the mean temperature of the auroral picture.

The whole number n' for the standard neon line is determined from equation (1'). The thickness (e) and the refractive index (μ) are known for any known temperature, and only an approximate value of the temperature is wanted for the determination of (n'). The excess fraction (ε) is found from the two ring-systems of the neon line photographed on the plate.

The thickness of the two quartz plates which were ordered in 1935, was determined with the very thin aluminium coating which was first tried. The results of the measurements of the optical thickness will be found in the following report from the National Physical Laboratory, dated May 16th, 1935.

"Description: Each etalon consists of a natural quartz plate with optically plane and parallel faces, coated with very thin aluminium films. The nominal thicknesses of the two etalons are 1,5 mm and 2,5 mm respectively, and their diameters are approximately 5 cm."

Examination for Planeness and Parallelism.

The errors of flatness of the individual surfaces do not generally exceed 0,1 band in mercury green light, except for a local irregularity near the periphery of the 1.5 mm plate. Over a region extending about 2 cm along the periphery of this plate and about 1 cm towards the centre of the plate both surfaces have approximate complementary errors of flatness amounting to about 0,3 band. Owing to the complementary nature of these errors the thickness of the plate remains approximately constant over this region.

The plates were examined for optical parallelism by illuminating them in turn with a beam of cadmium light of limited aperture. The diameters of circular interference fringes were observed in light reflected from various regions of the plates, which were supported without strain on a horizontal flat surface during this test. On the accompanying diagram each dot represents the centre of a circle about 17 mm diameter on the actual plate, and the associated figure indicates the variation of the order of interference in cadmium green light, referred to the central region as zero. It will be seen that the 1,5 mm plate is constant in order of interference to 0,08 λ, corresponding to a maximum variation of thickness of 0,000020 mm, and that the 2,5 mm plate is constant in order of interference to 0,14 λ, corresponding to a maximum variation of thickness of 0,000036 mm.

The deposited aluminium films are extremely thin and have therefore low reflection coefficients. As a consequence, the interference fringes produced by the etalons have a low value of $I_{\max}/I_{\min}$ where

$I_{\max}$ is the intensity in the bright rings and $I_{\min}$ is the intensity in the dark rings. The etalons may be regarded as suitable for use with faint sources and were actually standardised under definitely faint source conditions.

Measurement of Thicknesses.

The thicknesses of the two etalons were measured in terms of four standard radiations whose accepted wave-lengths in dry air, at 15° C and 760 mm pressure, containing a normal amount of carbon dioxide, are:

Cadmium Red, λ_1 = 0,6438 4696 micron (Fundamental Standard).

Krypton λ_2 = 0,5870 9154 micron (Pérard, Rev. d'Optique) 7 p. 1.

Krypton Green Yellow λ_3 = 0,5570 2892 micron (Pérard, Rev. d'Optique 7, p. 1, 1928).

Cadmium Green λ_4 = 0,5085 8212 micron (Sears and Barrell, Roy. Sos. Proc. A, 139, p. 202, 1933).

In order to calculate the wave-lengths of these radiations in natural quartz at a particular temperature, it is first necessary to reduce the values in air to vacuum conditions, then, assuming a knowledge of the refractive index of natural quartz for the ordinary ray at that temperature, the wave-lengths in quartz may be calculated by means of the relation:

$$q = \frac{\lambda_{\text{vac}}}{\mu_q}$$

where λ_q = wave-length in quartz at t° C.,
μ_q = refractive index of quartz at t° C,
λ_{vac} = wave-length in *vacuo*.

The values of the wave-lengths in *vacuo* were calculated by means of the following formula for the refractive index of dry air, containing a normal amount of carbon dioxide:

$$(\mu_a - 1)\,10^6 = \left[288{,}069 + \frac{1{,}4787}{\lambda_a^2} + \frac{0{,}03161}{\lambda_a^4}\right]\frac{h}{760}\cdot\frac{1}{1 + 0{,}003716\,t}$$

where μ_a = refractive index of air,
λ_a = wave-length in air, expressed in microns,
h = barometric height in mm,
t = temperature in degrees in centigrade.

The relation quoted above is due to Pérard (Trav, et Mém. du B.I.P.M, 18, p. 42 (1929). From this, the wave-lengths *in vacuo* may be calculated, remembering that the standard values are for air at 15° C, and 760 mm pressure, and that $\lambda_{\text{vac}} = \mu_a \lambda_a$. Thus *in vacuo*:

λ_1 = 0,6440 2493 micron
λ_2 = 0,5872 5427 micron
λ_3 = 0,5571 8360 micron
λ_4 = 0,5087 2387 micron

Pérard has obtained accurate values for the refractive index of natural quartz etalons cut with their optical faces accurately normal (within 2 to 3 minutes of arc) to the optical axis (Jour. de Physique Série VI, 8, 344 (1927)). At 15° C, the weighted mean values for the four radiations are:

λ_1......... μ_q = 1,542,706,48
λ_2......... μ_q = 1,544,754,65
λ_3......... μ_q = 1,546,068,35
λ_4......... μ_q = 1,548,655,21

Pérard (loc. cit.) also gives the variation of the refractive index of natural quartz with temperature:

$$\mu_t = \mu_0 + h\,t$$

where

μ_t = refractive index of quartz at t° C
μ_0 = refractive index of quartz at 0° C

$$h = a + \frac{b}{\lambda_a}$$

in which

λ_a = wave-length in air, expressed in microns
a = —0,000,006,95
b = +0,000,000,58 micron

From these equations, the laws of variation of refractive index of quartz with temperature for the four radiations may be calculated:

λ_1...... μ_t = 1,542,797,08 —0,000,006,04 t
λ_2...... μ_t = 1,544,844,20 —0,000,005,97 t
λ_3...... μ_t = 1,546,157,00 —0,000,005,91 t
λ_4...... μ_t = 1,548,742,36 —0,000,005,81 t

The thickness of each etalon was measured by illuminating it with a convergent beam of radiations from a cadmium lamp and a krypton lamp, either source being directed on to the etalon as desired. The whole aperture of each etalon, up to about 2 mm from the edge, was utilised, and each etalon was supported in a vertical plane without strain during the measurements. A real image of the circular interference fringes, produced in light transmitted by each etalon, was focussed on the wide slit of a constant deviation spectroscope which was fitted with a micrometer eye-piece. The diameters of 5 bright rings in each radiation were measured and from these measurements the excess fractions were calculated by the method of least squares. With a knowledge of the approximate thicknesses of the two plates, which had been obtained by ordinary mechanical measurements before the plates were aluminized, and of the wave-lengths calculated according to the method already described, the orders of interference were derived by the method of exact fractions usually applied to Fabry-Perot etalons.

In Tables I and II are given the results of the measurements of the thicknesses of the two etalons.

Reference to the paper by Pérard (loc. cit.) shows that the refractive index for the ordinary ray in natural quartz, varies with different specimens by about three parts in one million. For this reason the probable errors associated with the values of the thicknesses are: ± 0,000,002 mm for the 1,5 mm etalon, and ± 0,000,004 mm for the 2,5 mm etalon. Taking into account the additional errors of observations, the total errors associated with the values in terms of millimeters are less than ± 0,000,01 mm for both etalons.

With regard to the values of the orders of interference quoted in the tables, since these are observed quantities and do not involve any assumptions concerning the refractive index of quartz, the errors are smaller, and are probably less than ± 0,02 in each case.

Table I.

1,5 mm etalon.

<table>
<tr><td colspan="5">Temperature of Standardisation = 19,85° C</td></tr>
<tr><td colspan="5">Approximate thickness, measured by mechanical means = $1{,}510_9$ mm</td></tr>
<tr><td></td><td>λ_1</td><td>λ_2</td><td>λ_3</td><td>λ_4</td></tr>
<tr><td>Observed orders of interference ...</td><td>7239,526</td><td>7949,868</td><td>8386,112</td><td>9200,268</td></tr>
<tr><td>Calculated wave-lengths at 19,85° C (Micron)........................</td><td>0,4174,7226</td><td>0,3801,6735</td><td>0,3603,9411</td><td>0,3284,9993</td></tr>
<tr><td>Thickness (mm)..................</td><td>1,511,151</td><td>1,511,140</td><td>1,511,153</td><td>1,511,144</td></tr>
<tr><td colspan="5">Mean value of thickness at 19,85° C = 1,511,147 mm</td></tr>
</table>

Table II.

2,5 mm etalon.

<table>
<tr><td colspan="5">Temperature of Standardisation = 20,06° C</td></tr>
<tr><td colspan="5">Approximate thickness, measured by mechanical means = $2{,}513_0$ mm</td></tr>
<tr><td></td><td>λ_1</td><td>λ_2</td><td>λ_3</td><td>λ_4</td></tr>
<tr><td>Observed orders of interference ...</td><td>12,037,622</td><td>13,318,882</td><td>13,944,104</td><td>15,297,938</td></tr>
<tr><td>Calculated wave-lengths at 20,06° C (Micron)........................</td><td>0,4174,7260</td><td>0,3801,6766</td><td>0,3603,9440</td><td>0,3285,0019</td></tr>
<tr><td>Thickness (mm)..................</td><td>2,512,689</td><td>2,512,696</td><td>2,512,688</td><td>2,512,688</td></tr>
<tr><td colspan="5">Mean value of thickness at 20,06° C = 2,512,690 mm</td></tr>
</table>

The law connecting temperature and length in a direction along the optical axis of quartz is given by Pérard (loc. cit.):

$$L_t = L_0 (1 + 7{,}124\, t \times 10^{-6} + 8{,}202\, t^2 \times 10^{-9})$$

Utilising this equation in addition to the data already quoted, it may be calculated that on raising the temperature of the 2,5 mm etalon from 15° C to 25° C, the order of interference for the cadmium red line (λ_1) increases by only 0,425 λ_1.

4. Observations and Results.

The apparatus was mounted during the summer of 1935. During some auroral displays which were observed at Oslo during the autumn of 1935, we tried to obtain interference pictures with our new quartz etalons, but with negative results. It was found, however, that the absence of the rings was due to the fact that the aluminium coating was too thin, and it was decided to increase the thickness of it. Meanwhile one of the old etalons was used at Oslo.

During an auroral display occurring during the night 20—21. April 1935, we obtained with the old silver-coated 5 mm etalon an auroral picture showing a faint ring-system from the red line.

As already mentioned, our previous spectrographic determinations of the red auroral line are not sufficiently accurate to fix the whole order number (n). Therefore, the interference picture from one etalon only gives a series of wave-length values among which the true value has to be selected.

The measurements carried out by means of the interference pictures obtained at Tromsø (Paper II) show that the interference pictures, taken with the 2,5 mm etalon, cut out half the number of wave-length values, which the 5 mm etalon places inside the interval of uncertainty; but still the 2,5 mm etalon gives about 7 possible values.

One of these values is found to be very near to that found for the strongest component of the red oxygen triplet OI ($^1D_2 - {}^3P_{0 \cdot 1 \cdot 2}$) in laboratory experiments. If, for other reasons, we *assume* this interpretation to be the right one, then we can determine the wave-length from a single interference picture of the red line. On this assumption, the weak interference ring-system we obtained with the 5 mm etalon led to the wave-length:

$$\lambda = 6300{,}330 \text{ Å } I.U.$$

A very prominent auroral display was observed in the northern sky at Oslo during the night of Oct. 16—17, 1936, and on that occasion we were able to take up work with the new etalons after they had got a much denser aluminium coating.

As a considerable number of successful interference pictures had already been obtained at Tromsø with the 5 mm and 2,5 mm etalons (Paper II), it was first of all important to obtain interference pictures with the 1,5 mm etalon, *because the ring-system of this etalon combined with those of the 2,5 mm etalon fixes the order number and the wave-length without ambiguity.*

In certain parts of the sky towards *N-E*, the aurorae at intervals took on a deep red colour. As stated by one of us in a letter to "Nature" (10), the red-coloured aurorae were of type (A) and due to enhancement of the red line. It was also stated that the intensity of the red line relative to that of the green one increased with altitude.

Although the aurorae as a rule have the ordinary greenish colour, the red line has no doubt been considerably enhanced, and, therefore, the conditions were very favorable for obtaining good interference pictures of the red line.

We took 5 successful plates showing the ring-systems of the red auroral line very distinctly. The photographic plate also contained the pictures of the fringes from the standard neon line. During the night, the air temperature only showed very small variations between + 1,6° to + 2° C. It was therefore not found advisable to use any artificial temperature regulation which would have disturbed the thermal equilibrium, which had been acquired under the existing natural conditions.

Reproductions of the five interference pictures of the red auroral line are given on Plate IV, Nos. 1— 5. No. 6 on plate IV is a picture of a ring-system from the standard neon line. The pictures are "negatives" copied from diapositive plates, so that the dark rings indicate maxima of light intensity. The time of exposure and a characterisation of the auroras exposed, are seen from the "Explanation" to Plate IV given at the end of this paper.

In order to fix the value of the whole part (n) of the order number for the red auroral line, we would compare the possible values obtained at Tromsø with the 2,5 mm etalon with those obtained at Oslo with the 1,5 mm etalon.

In Table III we have compared the results from picture No. 5 from Oslo with a plate taken at Tromsø 20/12 1935 with the 2,5 mm etalon. It appears from

Table III.

1,5 mm etalon		2,5 mm etalon	
Oslo $^{16-17}/_{10}$ 1936		Tromsø $^{20}/_{12}$ 1935	
$n = 7399 +$	$\lambda = 6300 +$	$\lambda = 6300 +$	$n = 12301 +$
− 3	+ 2,847	+ 1,824	− 3
− 2	+ 1,995	+ 1,312	− 2
− 1	+ 1,143	+ 0,802	− 1
0	**+ 0,291**	**+ 0,290**	0
+ 1	− 0,561	− 0,221	+ 1
+ 2	− 1,411	− 0,736	+ 2
+ 3	− 2,262	− 1,246	+ 3

the table that, *in the interval of uncertainty, there is only one wave-length which, within the limit of error, is the same for both etalons. This is in fact the value 6300,291 which, within the limit of possible error, is identical with that found for the strongest component of the oxygen triplet OI* ($^1D_2 - {}^3P_{012}$).

Having thus found that the whole part of the order number of the red line is equal to $n = 7399$, we can determine without ambiguity, the wave-length for all our plates. The results are given in Table IV.

Table IV.

Pl. No.	Neon	Aurora	
	$n' = 7974$ ε'	$n = 7399$ ε	$\lambda = 6300 +$
1	0,604	0,789	0,304
2	0,598	0,805	0,285
3	0,536	0,758	0,276
4	0,542	0,769	0,272
5	0,564	0,847	0 291
Mean $\lambda = 6300{,}286$ ($\pm 0{,}006$) Å *I.U.*			

It appears from the table that the values of the excess fraction ε' and ε keep practically constant throughout the night. This shows that the temperature of the etalon has possesed a high degree of constancy.

The value obtained at Oslo $\lambda = 6300{,}286$ is somewhat lower than that found from the Tromsø plates $\lambda = 6300{,}309$.

The red oxygen line ($^1D_2 - {}^3P_2$) was measured by Hopfield (11) from a spectrogram with a dispersion of 29 Å/mm. He finds in this way $\lambda = 6300{,}23$. From his determination of the position of the ($^1D_2$) level we derive the wave-length 6300,328 Å.

Putting equal weight on both determinations, the wave-length of the red oxygen line as found by laboratory experiments should be:

$$\lambda = 6300,\ 279 \text{ Å } I.U.$$

This value fits best with that found at Oslo for the red auroral line. We cannot, however, at the present time say which determination is the most accurate, or give any definite explanation of the difference of 0,023 Å between the result found from the Tromsø and the Oslo material. It is, however, our intention to increase the accuracy still further by continued observations and measurements.

As already mentioned, the red auroral line is enhanced in the luminescence from red aurorae of type (*A*) as well as from auroras exposed to sunlight (1, 14). Now, the identification of the red auroral line with the strongest component of the oxygen triplet ($^1D_2 - {}^3P_2$) would involve that also the two components ($^1D_2 - {}^3P_1$) and ($^1D_2 - {}^3P_0$) should be enhanced because we cannot assume any essential change in the relative intensities within the triplet.

Up to the present, spectrograms with a largely enhanced red line have only been obtained with spectrographs of such small dispersion and such a broad slit that the second component does not appear separated from the strongest one.

On the morning of Oct. 17th just before sunrise, a spectrogram of aurorae exposed to sunlight was taken at Oslo with a small glass spectrograph. As already mentioned by one of us in a note in "Nature" (13) the red line 6300 appeared on this spectrogram with even larger photographic density than the strong green line (5577), showing that the red line was enormously enhanced. In this case, however, the slit was sufficiently narrow to give separation and the second component was clearly visible.

This shows that also the line 6364 takes part in the enhancement and this result, together with the interference measurements of the strongest red line, shows conclusively *that the red auroral lines 6300 and 6364 are the two strongest components of the OI triplet* ($^1D_2 - {}^3P_{012}$).

Grateful acknowledgements are due to Mr. S. Stensholt M. A. Oslo, for his valuable assistance in connection with this work and also to Mr. G. Kvifte and Mr. O. Krogness for their help in connection with the exposures of the interferometer pictures.

We also wish to thank "Statens Forskningsfond" for granting the money necessary for these investigations.

LIST OF PAPERS

1. L. Vegard: The origin of the red colour of the aurora of Jan. 26, 1926. Det Norske Vid.-Akad. Avh. I, No. 2, 1926, Nature 117, 1926.
2. L. Vegard: Results of investigations of the auroral spectrum during the years 1921—26. Geofys. Publ. Vol. IX, No. 11, 1932.
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4. L. Vegard: Der sichtbare Teil des Nordlicht-spektrums Z. S. f. Phys. 78,567, 1932 and 81,556, 1933.
5. L. Vegard and Leiv Harang: The auroral spectrum in the region of long waves. Geofys. Publ. Vol. X, No. 5, 1933.
6. L. Vegard and E. Tønsberg: Die spektrale Intensititätsverteilung im Nachthimmellicht und Nordlicht. Z. S. f. Phys. 88,709, 1934.
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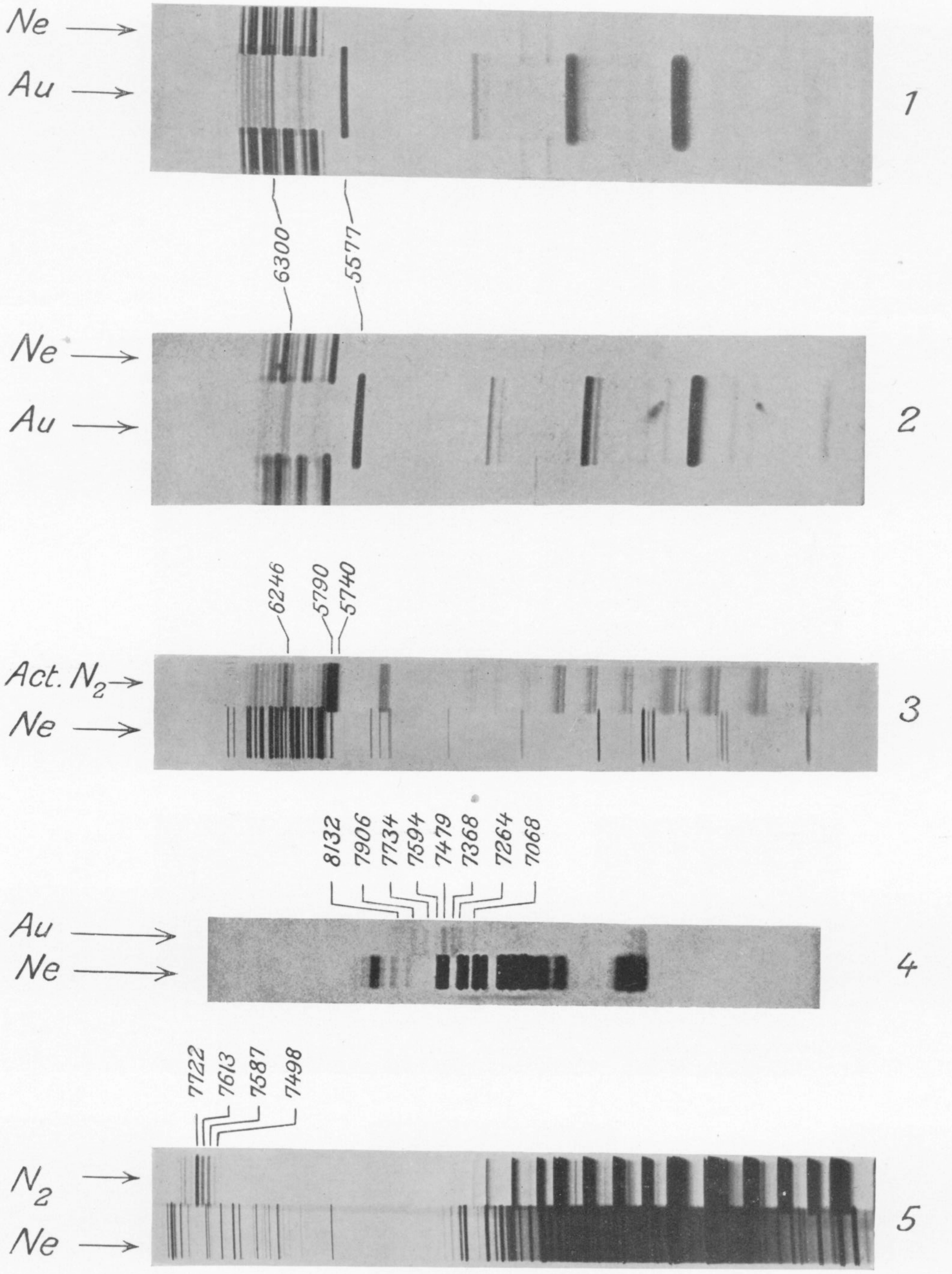
8. L. Vegard: Nature Jan. 2, 1932.
9. L. Vegard and L. Harang: The wave-length of the green auroral line determined by an interferometer method. Geofys. Publ. Vol. XI, No. 1, 1934.
10. Leiv Harang and L. Vegard: Interferometer measurements of the red auroral line 6300. Nature 135, p. 542, 1935.
11. J. J. Hopfield: Phys. Rev. 37,160, 1931.
12. H. D. Babcock: Contrib. from Mount Wilson Obs. No. 259, 1923.
13. L. Vegard: Nature Vol. 138, p. 930, 1936.
14. L. Vegard and E. Tønsberg: Enhancement of red lines and bands in the auroral spectrum from a sunlit atmosphere. Nature Vol. 137, p. 778, 1936.

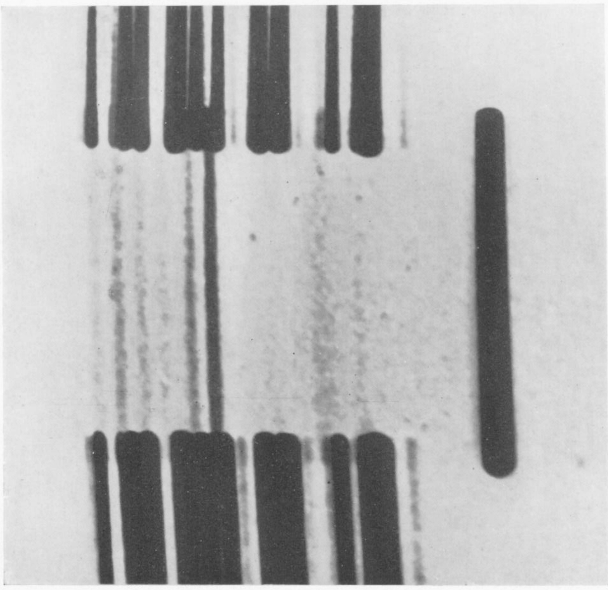


Nos. 1 and 2: Auroral spectra (Au) from the Auroral Observatory, Tromsø, taken with the new big glass spectrograph on Ilford hyper-sensitive pan-chromatic plates. Neon comparison spectrum (Ne). No. 1: Exposure from Sept. 1935 to 2. Jan. 1936. No. 2: Obtained during the Spring of 1936.

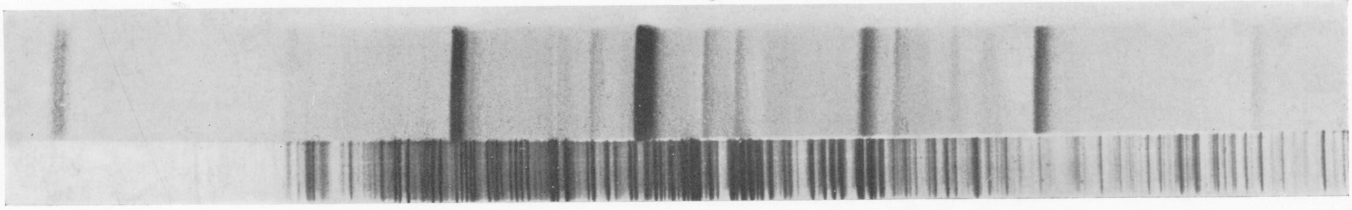
No. 3: A spectrum of the afterglow of gaseous nitrogen taken at Oslo by Mr. Lund. The red part consists of bands of the 1st positive group. The doublet series in the blue part belongs to the β-bands of NO.

No. 4: An auroral spectrum (Au) in the infra red taken at the Auroral Observatory with the grating spectrograph on the plates Agfa 700—900 $\mu\mu$. Exposed Feb. 23. from 18 ^{h} 30 ^{m} to 2 ^{h} and Feb. 24. from 18 ^{h} 30 ^{m} to 24 ^{h} 1933. Neon comparison spectrum Temp. of spectrograph between — 12°—15° C.

No. 5: Spectrum of positive column of N_2-discharge taken with a big glass spectrograph at Oslo on plates Agfa 810 $\mu\mu$. Neon comparison spectrum.

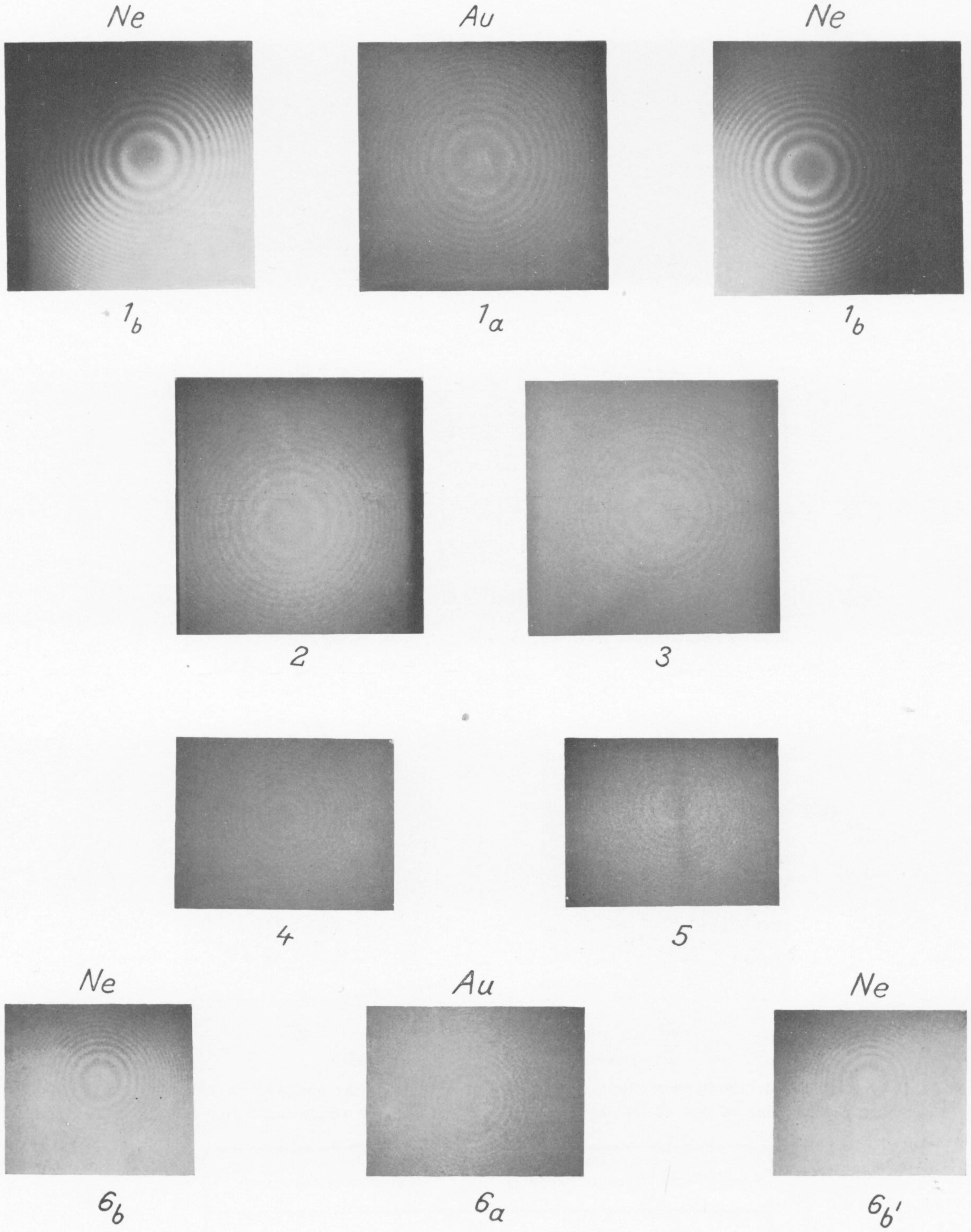


1



2

No. 1: Enlarged copy of the spectrogram No. 1 of Plate II containing the long wave region.
No. 2: Spectrogram taken with the large quartz spectrograph on Ilford double express plates exposed from Nov. 1933 to April 1934.



Interference Pictures from Tromsø.

Nos. 1, 2, 3 are interference pictures taken with the 2,5 mm etalon.

No. 1 on 21. Jan. 1936, la, is the ring-system of the red auroral line, 1_b and 1_{b_1} the ring-systems of the standard neon line.

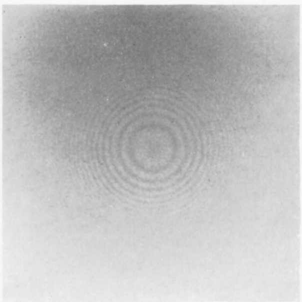
Nos. 2 and 3 are ring-systems of the red auroral line taken on Dec. 20th and 21st 1935 respectively.

Nos. 4, 5, 6: Interference pictures taken with the 5 mm etalon.

Nos. 4 and 5 are ring-systems of the red auroral line taken on Feb. 17th and 19th 1936 respectively.

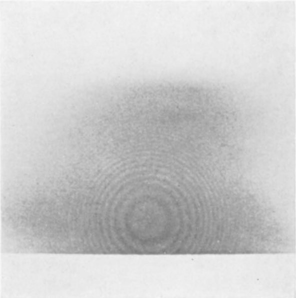
No. 6_a is the ring-system of the auroral line, 6_b and 6_{b_1} those of the standard neon line from a plate taken Feb. 22. 1936.

Au



1

Au



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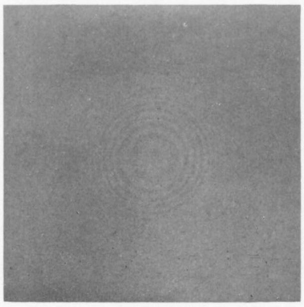

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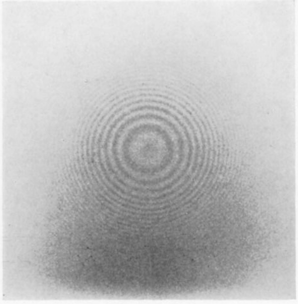
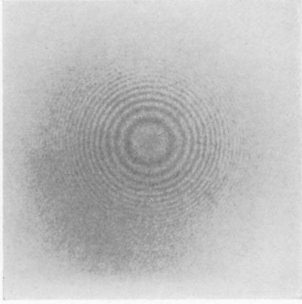


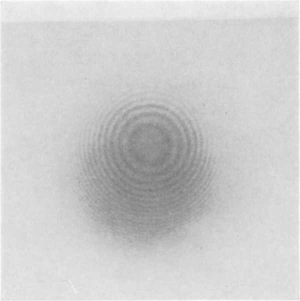
4

Au



5

Ne



6

Interferometer Pictures from Oslo.

Nos. 1—5: Reproductions of interference ring-systems of the red auroral line obtained on 16th—17th Oct. 1936 at Oslo. No. 6 is a reproduction of one of the interferometer pictures of the yellow neon line used as a standard.

No. of picture	Time of exposure	Character of aurora
1	20^{10}—22^{55}	Strong arc in N. partly red rays
2	23^{05}— 0^{50}	Arcs, draperies and rays, sometimes red streamers
3	0^{10}— 0^{50}	Arcs, draperies and rays, sometimes red streamers
4	1^{05} - 2^{10}	Rays partly red. Flaming aurorae
5	2^{25}— 4^{15}	The aurorae are becoming weaker