RESULTS OF INVESTIGATIONS OF THE AURORAL SPECTRUM DURING THE YEARS 1921—1926

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CHAPTER I.

Preparations and Equipment.

§ 1. Introduction.

Although an auroral display observed in the darkness of night may appear quite brilliant, still the luminescence — apart from the famous green line — is extremely faint when we try to analyse its spectral composition visually. If we look at an aurora of ordinary strenght and colour through a spectroscope, we usually see only the green line. The two lines 4278 and 3914, which are always present with an intensity of the same order of magnitude as the green line, appear faint in a spectroscope on account of the small sensitiveness of the eye for that spectral region. Sometimes when the aurorae are very strong, we may spectroscopically observe a few faint lines in green and blue, but as they are usually faint and of short duration, a spectroscopic determination of their wavelength meets with great difficulties, and measurements of the same line may show so great fluctuations that it may be difficult to decide which measurements are to be referred to the same lines.

In the case of aurorae, showing abnormal colours, a few lines in the visible spectrum — besides the green one — may appear fairly strong, thus in the case of red aurora I have observed one line in the red part of about the strength of the strong green line.

From the time when Ångstrøm, in 1869, first observed the strong green line and until 1912 a considerable number of observations of the auroral spectrum were made by a great many observers. Most of these were visual observations, but attempts were also made by A. Paulsen[1] and J. Westmann[2] to adopt a photographic method. The accuracy to be obtained with the small spectrographs and minute dispersion they used were most unsatisfactory.

A summary of the results of observations of the auroral spectrum obtained during this first period was given by H. Kayser in volume 5 of his "Handbuch der Spektroscopie".

It appears from his summary that the accuracy of the wavelength determinations at that time was insufficient for any definite opinion to be formed as to the origin of the observed lines. He gives his opinion in the statement "Also über den chemischen Ursprung der Nordlichtlinien wissen wir noch gar nichts".

At that time the most probable value for the wavelength of the strong green line was taken to be 5570, which we now know to differ more than 7 Å from the true value, and the errors of the other lines might be several times as large.

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[1] A. Paulsen: C. R. 130, 655, 1900.

[2] J. Westmann: Mission sc. pour la measure d'un arc de meredien au Spitzberg, Stockholm 1904.

Studies regarding the physical nature of the aurorae, their intensity distribution, and the properties of the electric rays producing them, made it clear to me that an extension of our knowledge of the auroral spectrums would be of far reaching importance for further advances regarding our understanding of the physical phenomena connected with an auroral display.

Together with a number of collaborators I have — practically continuously — during the last 20 years been engaged in studies concerning the auroral spectrum.

In the winter 1912—13 I undertook an expedition to Bosekop in Finnmarken, mainly with the object of studying the auroral spectrum. For this purpose I took with me a spectroscope with accurate micrometer scale and a large spectrograph which combined a large light power, with a dispersion about 5 times as large as the one previously used for auroral investigations.

Details regarding equipment and results have been given in previous publications. (1.2). Some of the strongest lines in the blue and violet part were obtained on the spectrogram and it was shown that they belonged to the negative band-spectrum of Nitrogen.

The spectroscopic observations gave for the wavelength of the green line $\lambda = 5576.9$ Å, a value which is considerably larger than that ordinarily assumed at that time. Two faint lines in green and blue were also measured with the spectroscope, but on account of the weakness of the lines the values cannot claim any great accuracy.

Measurements of the green line with a spectroscope of considerably higher dispersion and a good micrometer arrangement, were continued at Oslo and my most reliable series of measurements gave the wavelength $\lambda = 5577.6$ Å (I U).

In 1919 V. M. Slipher measured the wavelength of the green line appearing sometimes in the light of the night sky. He obtained $\lambda = 5578.05$ Å. This result compared with that which I obtained for the green auroral line strongly supports the view that the green line of the night sky is identical with the green auroral line. Although from these measurements we probably knew the walvelength of the green line with a probable error of less than 1 Å, the origin of the line was still as mysterious as ever.

A more complete knowledge of the whole auroral spectrum and its variations which in itself is of the highest importance might at the same time furnish valuable information as regards the origin of the green line.

Grants from the »Government Funds for Scientific Research« given in 1921 and the following years and also from the »Nansen Fund« enabled me to take up investigations on the auroral spectrum in a more systematic way.

On the basis of experience gained through previous work, new instruments for spectral work were constructed to suit the special conditions of the auroral observations. By the kind permission of Professor O. Krogness I was able to carry out the observations at the Geophysical Institute at Tromsø.

On account of my duties at the University of Oslo I had to arrange the work in such a way that for the greater part of the time the instruments and observations were attended to by an assistant, who worked in accordance with a definite programme and directions given by post and wire from Oslo.

During the first years, from 1922—24, I was very ably assisted by Mr. Einar Tønsberg, at that time a student of physics at the University.

In the summer 1922 I went to Tromsø together with Mr. Tønsberg to instal the instruments and make all necessary arrangements. Observations commenced in the autumn of the same year, and were continued essentially with the same experimental arrangements until the end of 1926.

During the winter season 1924—25 I was assisted by Mr. Bj. Stav and for the rest of the time by Mr. O. W. Lund an engineer, who at that time was assistant at the Geophysical Institute.

Already during the autumn 1922 very successful spectrograms were obtained, and from February to the end of March 1923 I stayed at Tromsø to take part in the work and to perform certain observations which were of special importance and which will be delt with later on.

The work of the first season gave important results which produced a fundamental change regarding our conceptions as to the composition and state of the upper atmosphere. During the later seasons the work was extended in various directions. A great amount of work was done to obtain the weaker lines of the spectrum including those which appear in the red and green part.

The more important results obtained during this first period of investigations, from 1922—26, and the consequences to which they led, were given in preliminary communications published partly in the proceedings of the Norwegian Academy, partly in the Comptes Rendus of the French Academy, and in various scientific journals. A list of previous publications will be found at the end of this communication.

The results obtained are thus only given in fairly short and preliminary notes scattered in a large number of proceedings and journals. In the present communication I intend to give a more complete and final description of the results, and more details regarding instrumental equipment and methods of work than could be given in the short and preliminary notes and papers.

§ 2. The instrumental equipment.

The spectrographs.

In the study of the auroral spectrum we are first of all dealing with two principal problems:

1. An accurate determination of the wavelengths of the various lines and bands appearing in the auroral spectrum.
2. Study of the variations taking place and which manifest themselves in the change of colour of the aurora.

For the solution of the first problem we should want spectrographs of high dispersion. But here we meet with the great difficulty arising from the small intensity of the aurorae.

In order to obtain spectrograms with a reasonable time of exposure we must keep the lightpower of the instrument above a certain limit. But this will at the same time put a practical limit to the dispersion of those spectrographs which can be used for auroral investigations.

We are thus faced with the problem of constructing a spectrograph which combines a large dispersion with a high light power.

For the study of the variations it is more essential to have the highest possible light power, and the instruments suitable for this kind of work will have a fairly small dispersion.

In accordance with these considerations the following instruments were constructed and built.

1. A big glass spectrograph with a fairly large light power and considerable dispersion, intended to give fairly accurate wavelength determinations in the visible part of the spectrum.
2. One large quartz spectrograph of high light power, in which the ultra-violet part had a sufficient dispersion to give wavelength values with an error of less than 1 Å.
3. Two small glass spectrographs of very high light-power and small dispersion. These instruments were used partly for the study of the variations, partly for obtaining a survey of the whole visible spectrum, and to get a rough estimate of the wavelength of the very weak lines which could not be obtained by the large spectrographs.

Before proceeding to construct the instruments I carefully considered the factors which determines the light power and dispersion. A simple theoretical consideration shows that the geometrical light power of a spectrograph only depends on the light power of the camera lens and not on that of the collimator lens, provided the opening of the latter and the magnitude of the prisms are sufficient to allow the light bundle to fill the camera lens.

Now it might seem that the task of building a spectrograph combining a desired dispersion with a very large light power would be a very simple one. We should have to select a camera lens of great light power and a given focal distance, and then let the prisms and collimator lens have the same effective opening as the camera lens. But large dispersion means either long focal distance of camera lens or great dispersion angle of the prism-system or both combined. In any case a high geometric light power combined with large dispersion would mean large dimensions of the camera lens and prisms. If for a given focal distance of the camera lens we increase the geometrical light power, we should reach a limit, where the increase of geometrical light power is counterbalanced by the increased absorption of the glass.

In the case of quartz spectrographs the absorption effect is of less significance, but here we face the difficulty that large pieces of quartz were not obtainable or at any rate extremely expensive.

The result was that in order to obtain a suitable dispersion of the big spectrographs I had to use a camera lens of moderate light power. I found it to be advantageous for all spectrographs to use a collimator lens of fairly small light power and long focal distance. This gives the collimator a convenient length. The lens can be made quite thin, and the loss of light due to reflection can be reduced to a minimum.

The image of the slit falling on the plate will be reduced in the proportion of the focal distance of collimator and camera lens. The slit can be kept fairly wide and need not be of the very highest quality.

The large glass spectrograph is illustrated in fig. 1. (See Pl. IV.) The camera lens had an effective diameter of 7.5 cm and a focal distance 40 cm. The collimator lens had an effective diameter of 7.5 cm and a focal distance of 56 cm. The spectrograph had one large Rutherford prism with a height of 7 cm and of such dimensions as to make the effective opening 7×7 cm.

A condensor lens (diam. 3 cm, focal distance 20 cm) fixed into a brass tube was placed at a distance of 20 cm in front of the slit. In this way a picture of an aurora could be thrown on the slit. The condensor lens could easily be put up and removed during the work.

If we direct the collimator on an evenly luminous area with angular dimensions in all directions greater than the cone angle of the collimator, then the introduction of the condensor lens, will produce no increase in the intensity, but on the contrary it will produce a reduction of intensity due to reflection and absorption by the lens. The condensor lens therefore is only to be used for aurorae which consist of intense narrow bands, streamers or patches, or if for special purposes it is wanted to throw a picture of the aurora on the slit.

The big quartz spectrograph is illustrated in fig. 2. (See Pl. IV). The collimator lens has an effective diameter of 6 cm and focal distance of 48 cm. The camera lens has the same effective opening but a focal distance of 30 cm (corresponding to a wavelength of 3000 Å).

A quartz condensor lens 3 cm diam. 20 cm focal distance could be placed in front of the slit. In this original form the spectrograph had one Cornu prism 6 cm high and effective opening 6×6 cm.

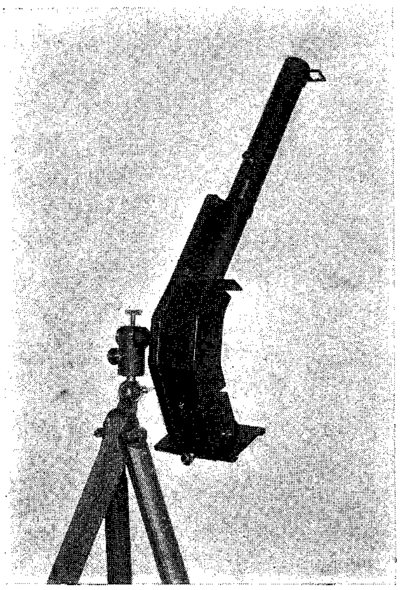

Fig. 3.

These two instruments were built by Dr. Carl Leiss, Berlin, in accordance with my instructions and drawings. In 1923 the dispersion of the quartz spectrograph was increased by introducing a second Cornu prism.

Two small spectrographs shown in figs 3 and 4, were built by the instruments makers at the Physical Institute, Oslo.

The camera lens was an Erneman Kinostigmat F : 2 with a focal distance of 6 cm. The collimator lens had an effective opening of 3 cm and a focal distance of 20 cm. Each instrument had one Rutherford prism with effective opening 2.7—2.8 cm, and in front of the slit a condensor lens with opening 4 cm and focal distance 20 cm. The latter was fixed into a brass tube, which could be easily fixed to and removed from the collimator tube. Figs 3 and 4 show the instruments with the condensor lenses adjusted. The prisms, collimators and condensor lenses were made by Carl Leiss.

In order to increase the light power still further a cylindrical lens was fixed in front of the plate holder. By means of a simple device it could be put into the path of the light bundle and in that position it produced a contraction of the length of spectral lines and thus produced an intensified image. If not wanted it could be turned out of the path of the bundle of rays. The large glass spectrograph and the two small ones were provided with such cylindrical lenses.

§ 3. Regulation of temperature.

From the experiences gained by the spectrographic observations I made in 1912—13 at Bosekop, it was evident that each exposure with one of the large spectrographs might last several weeks.

On the other hand we know that the position of a certain spectral line on the plate will vary with change of temperature. The sensitiveness to changes of temperature generally increases with increase of dispersion.

It is therefore essential that the spectrographs are kept at a nearly constant temperature throughout the exposures.

If the exposure only lasts for part of an evening and the dispersion is small, we need not introduce any special precautions. As long as the small spectrographs are merely used with short exposures they may be erected in the open air.

The large spectrographs, however, had to be put into a well isolated box in which the temperature was kept constant by means of an authomatic regulating device.

The box was given a form suitable for the instrument and could be turned on a vertical and a horizontal axis. The box is shown in figs 5 and 6, corresponding to a vertical and a horizontal position of the collimator.

During exposures the casette was kept open, and the apparatus was put into action by directing the collimator towards the north-light and by opening a cover in front of the slit.

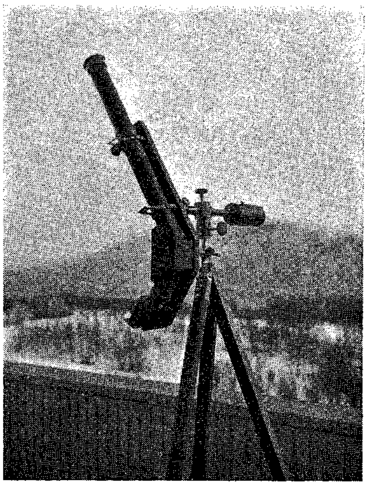

Fig. 4.

The box was heated electrically and the heating regulated by means of a contact thermometer put into a circuit which worked on a relay, which again breaks the heating current when the temperature rises above a certain value. (Say 15° C.)

During the work it appeared advantageous to take spectrograms with exposures of several days also with the small spectrograps. One of the small spectrographs which was to be used for long exposures was therefore put into a box with temperature regulation.

§ 4. Arrangement of instruments at Tromsø.

The instruments were finished during the first part of 1922, and in the summer of that year I went to Tromsø together with Mr. Einar Tønsberg who was going to conduct the observations during the following winter.

The instruments were mounted on the observation platform on the top of the main building of the Weather Bureau at Tromsø. The house with the platform on the top is shown in fig. 7. The necessary cables and electrical circuits for heating-current, relays and telephones etc. were brought up from a room below, from which all necessary regulations could be made.

The comparison spectra were made by means of vacuum-tubes or condensed sparks, and the necessary accessories for this purpose were placed on stands suitably arranged on the platform. The sparks and vacuum-tubes were run by means of an induction coil placed in a room below the platform. A well isolated circuit for high tension led from this room to the platform.

Fig. 8 shows the two large spectrographs in their boxes mounted on the platform on the top of the building. We notice the stand and table for the tubes and sparkgaps to be used for comparison spectra.

When not in operation the instruments were covered with canvas bags of a suitable form (fig. 9).

CHAPTER II.

Results of observations as regards the lines appearing in the auroral spectrum.

§ 5. Remarks regarding method of measurements and the accuracy to be obtained.

The wavelengths of the lines appearing in the auroral spectrum were found by measuring their position relative to known lines of the comparison spectrum. The plates were measured with a comparator provided with an accurate screw. The head of the screw, which had a diameter of 10.8 cm was provided with an accurate scale. Each interval on the scale corresponds to about $^1/_{100}$ mm and $^1/_{10}$ of the interval could be estimated.

For a certain part of the spectrum the wavelength was determined by the formula:

$$\lambda = \lambda_0 + \frac{a}{s+b} \cdot \quad \ldots \ldots \ldots \ldots \quad (1)$$

s is equal to $S - S_2$ when S is the reading of the auroral line in question S_2 the reading of a known line of the comparison spectrum. λ_0, a and b are three parameters,

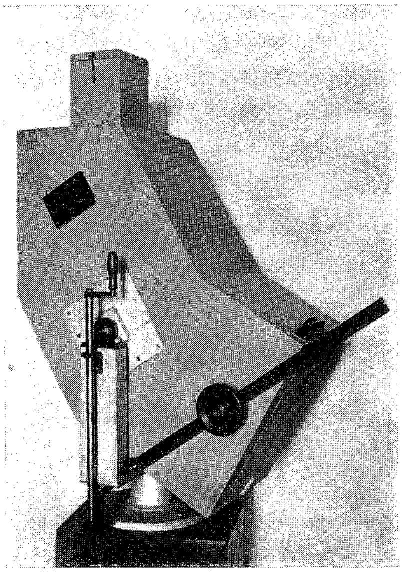

Fig. 5.

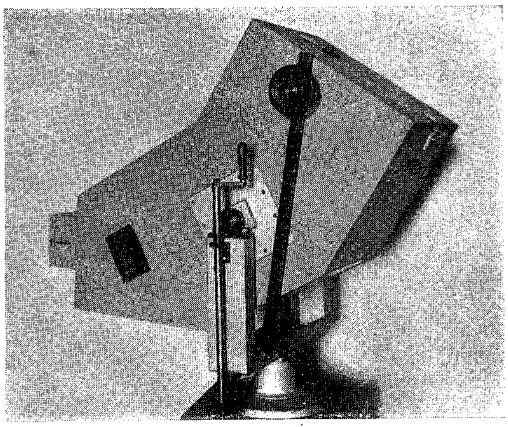

Fig. 6.

Fig. 7 a.

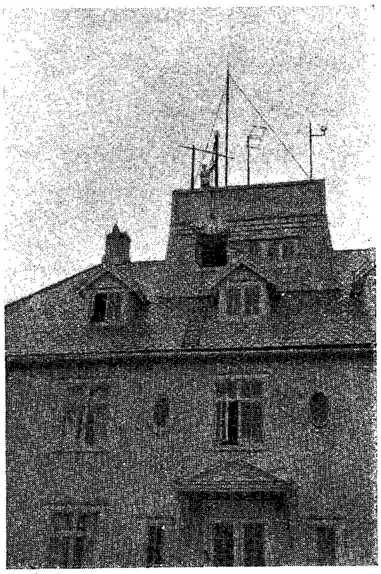

Fig. 7 b.

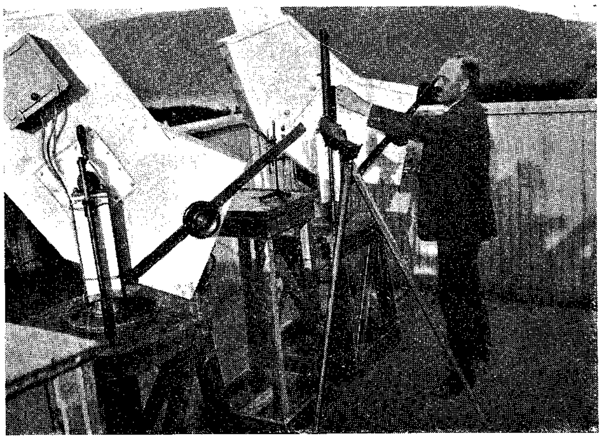

Fig. 8.

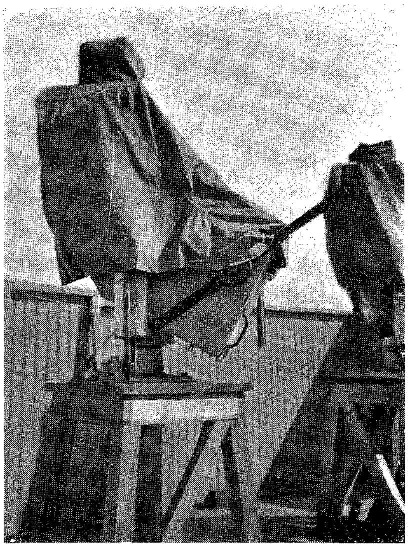

Fig. 9.

Fig. 7 a. The Weather Bureau at Tromsø. Fig. 7 b. One of the spectrographs on its way upwards to the observation platform. Fig. 8. The spectrographs on the observation platform. Fig. 9. Spectrographs with Canvas bags.

which are to be determined by means of three sharp lines λ_1, λ_2, λ_3 of the comparison spectrum suitably selected within the spectral region considered.

Let the corresponding readings of the three lines be S_1, S_2, S_3 and let us put:

$$\begin{aligned} s_1 &= S_1 - S_2 \\ s_3 &= S_3 - S_2 \\ k &= -\frac{s_3}{s_1}\,\frac{\lambda_1 - \lambda_2}{\lambda_2 - \lambda} \end{aligned}$$

then the three parameters of equation (1) are given by the formulae:

$$\left.\begin{aligned} a &= -(\lambda_1 - \lambda_2)\;(s_1 + b)\frac{b}{s_1} \\ b &= \frac{ks_1 - s_3}{1 - k} \\ \lambda_0 &= \lambda_2 - \frac{a}{b} \end{aligned}\right\} \qquad (2)$$

The dispersion of the spectogram at any point is given by the formula:

$$\frac{ds}{d\lambda} = \frac{(s + b)^2}{a} \quad \ldots\ldots\ldots\ldots\ldots \qquad (3)$$

Usually we give the inverse of the dispersion $\frac{d\lambda}{ds}$ which we may call the scale value, and which is given in Ångstrøm per mm.

As a rule a formula derived from three lines is only used within the interval $\lambda_3 - \lambda_1$. Outside this interval we select a new set of lines and so on. For the sake of control we can often with advantage for a certain interval use two formulae of type (1) corresponding to two different combinations of the three standard lines, necessary for the determination of the parameters.

The accuracy to be obtained depends on the dispersion of the instrument in the region considered, and the distinctness of the lines, and on circumstances which may vary from one plate to another, and which may be expressed as the quality of the exposure. Very weak or very strong lines on the spectrograms will as a rule be less accurately determined than lines of moderate density. Apart from such factors depending on the degree of exposure and the quality of the plate, the degree of accuracy will mainly depend on the dispersion.

The scale value $\frac{d\lambda}{ds}$ of the big glass spectrograph, the quartz spectrograph (with 1 and 2 prisms) and one of the small glass spectrographs is given in Table I for various parts of the spectrum.

Table I.

Scale value $\frac{d\lambda}{ds}$ im Å/mm

λ	Small glass. spectrogr.	Quartz spectr. 1 Prism	Quartz spectr. 2 Prisms	Large Glass Spectr.
3000	-	33	22	-
4000	121	74	57	20
5000	337	137	111	52
6000	665	-	-	105
7000	1100	-	-	174

We do not intend to overload this publication by giving details of calculations for each spectrogram, but in order to illustrate our procedure, Table II gives some details for one of the plates from the quartz spectrograph (Pl. II No. 6).

Table II.

	I					II		
$S_1 =$	95 345	$\lambda_1 =$	5085.8	Å	$S_1 =$	95.345	$\lambda_1 =$	5085.8
$S_2 =$	91.447	$\lambda_2 =$	4678.2	-	$S_2 =$	88.343	$\lambda_2 =$	4415.7
$S_3 =$	88.343	$\lambda_3 =$	4415.7	-	$S_3 =$	74.088	$\lambda_3 =$	3611.8
$k =$	1.236472	$b =$	— 33.5083	-	$k =$	1.697005	$b =$	— 37.4996
$a =$	— 103749.9	$\lambda_0 =$	1582.0	-	$a =$	— 109448.6	$\lambda_0 =$	1497.1
	III					IV		
$S_1 =$	74.088	$\lambda_1 =$	3611.8	Å	$S_1 =$	95.345	$\lambda_1 =$	5085.8
$S_2 =$	68.523	$\lambda_2 =$	3403.6	-	$S_2 =$	88.343	$\lambda_2 =$	4415.7
$S_3 =$	59.326	$\lambda_3 =$	3133.2	-	$S_3 =$	68.523	$\lambda_3 =$	3403.6
$k =$	1.27249	$b =$	— 59.7393		$k =$	1.87412	$b =$	— 37.6865
$a =$	— 121078.8	$\lambda_3 =$	1376.8		$a =$	— 110668.1	$\lambda_3 =$	1479.2

S	I	II	III	IV	Mean
98.960	5577.3	-	-	-	5577.3
91.761	4707.6	4708.4	-	4708.6	4708.2
91.141	4650.3	4651.1	-	4651.2	4650.9
87.800	4374.2	4374.1	-	4374.0	4374.1
87.480	-	4350.1	-	4350.0	4350.1
86.509	-	4279.6	-	4279.4	4279.5
85.935	-	4239.6	-	4239.3	4239.5
85.360	-	4200.7	-	4200.3	4200.5
84.475	-	4142.8	-	4142.4	4142.6
83.444	-	4078.5	-	4077.9	4078.2
83.137	-	4059 9	-	4059.3	4059.6
82.114	-	4000.0	-	3999.2	3999.6
80.578	-	3915.1	-	3914.0	3914.6
78.460	-	-	-	3805.6	3805.6
77.800	-	-	-	3773.8	3773.8
77.424	-	-	-	3756.0	3756.0
76.475	-	-	-	3712.4	3712.4
75.990	-	-	-	3693.3	3693.3
73.304	-	-	3579.9	-	3579.9
72.264	-	-	3539.0	-	3539.9
71.450	-	-	3508.0	-	3508.0
70.483	-	-	3472.4	-	3472.4
67.604	-	-	3372.9	-	3372.9
60.356	-	-	3159.8	-	3159.8

The top part of the table corresponds to the comparisonspectrum and gives the wavelength (λ) and positions (S) on the plates for each combination of three lines used for determining the parameters of the formula (1). Four different sets of values and corresponding dispersion formulae were used for various parts of the spectrogram (designated by I, II, III, IV).

The bottom part of table II corresponds to the auroral spectrum. The first column gives the position on the plate (S) of each line appearing in the auroral spectrum of that plate. The columns headed I, II, III, IV, give the wavelengths of the lines calculated by means of the combinations of standard lines and formulae I, II, III, IV respectively.

In case one line has been determined by two formulae we take the mean value. A comparison of various values obtained by different formulae for the same line gives us a means of estimating the accuracy of our determinations. Comparing corresponding values of column II and IV we notice that they only differ by a fraction of an Å. This, however, only gives a measure of the accuracy as far as it depends on the reading of well-defined comparison lines and on the accuracy of the dispersion formula.

But the differences shown by corresponding lines of the two columns would give the right impression for the accuracy with which lines of the auroral spectrum by means of this spectrograph may be measured under ideal conditions.

The accuracy for the determination of auroral lines may be reduced in various ways:

1. The line may be very weak or very strong or near to some other line. If any of these cases happen the accuracy with which we can fix the position of the line will be reduced. A very strong line will be broadened and as a rule in an assymetric way.
2. The apparatus may not be quite in focus for all parts of the spectrum.
3. In order to obtain an auroral spectrum with one of the large spectrographs we usually have to expose the same plate for several weeks. During that time the plate must be kept open, while the spectrograph must be turned round into the direction of the strongest aurora. Although great care was taken to keep the plate and plateholder in a fixed position, there may still be a chance of a small displacement.

   In this way there is a possibility for a small displacement of the comparison spectrum relative to that of the aurora. As a rule such a small displacement is not fatal, for if we only know the wavelength of one or a few of the auroral lines with sufficient accuracy the displacement can be found and used for the determination of the other lines.

   In order to make sure whether a displacement has taken place or not, we have adopted the procedure to expose the comparison spectrum partly before and partly after the exposure of the auroral spectrum.
4. As we have to use instruments with very high light power, it may be difficult to obtain lines of the highest degree of sharpness when the entire openings of the lenses are utilized. Further the sharpest images of spectral lines for various wavelengths will lie on a curve and therefore the lines of the spectrum falling on the photographic plate will not be equally sharp every where.

   If the source of light is limited so that the collimator is only partly filled with light, small variations in the position of the lines may be caused by moving the source in the direction perpendicular to the slit.

   Errors of this kind can be avoided if we always take care that the collimator is evenly filled with light. This will on an average be the case during the exposure of an aurora, but we must also be very careful that the comparison spectrum is taken with evenly filled collimator. In the case of the glass spectrographs this may be obtained by putting a glass plate of high scattering power between the slit and the source of light so it acts like an evenly luminous surface.

   In the case of the quartz spectrograph it was found convenient to put a white card in front of the slit and expose it to the source of light consisting of a condensed cadmium spark.
5. Finally we have errors due to changes of temperature. As already mentioned, these were reduced by keeping the spectrographs in well isolated boxes heated electrically and provided with an automatic regulation, by means of which the temperature inside the box was kept nearly constant.

When we are about to deal with the lines observed in the auroral spectrum, it must be kept in mind that the accuracy for the same spectrograph and equally good definition of the lines, as a rule will increase with increased dispersion towards shorter waves, and that for a given line the accuracy will vary for the different spectrographs. The smallest spectrograph, according to table I, should give a considerably smaller accuracy than the two large spectrographs. On the other hand, we may with the small spectrographs obtain spectrograms with exposures of one evening, and if the lines are sharp and well defined, the accuracy obtained with the small spectrographs as compared with that of the larger ones, may be greater than it is to be expected from a comparison of the dispersion given in Table I.

It is evident therefore that the results should be given separately for each instrument and the results obtained with one instrument should not be mixed with those of another.

§ 6. Spectra and lines obtained with the small glass spectrographs.

Spectrograms giving the stronger auroral lines were obtained with the small glass spectrographs by exposing the plate for 25—30 minutes to north light of ordinary intensity. As far as light power is concerned, this means a very large improvement on the glass spectrographs used at Bosekop 1912—1913 which in fact also had a considerable light power.

Although this result was very encouraging it is far from the ideal, which would be to take the spectrum of each individual auroral form, in the course of one or a few minutes, according to the intensity of the display.

The small spectrographs, however, had a light power practically so high as it was to be obtained by the technical means which at that time were available. The light power, however, was large enough for a number of important results regarding intensity variations of the auroral spectrum to be obtained, and by extending the exposures to several auroral nights, we obtained spectrograms where the strong lines were greatly over exposed and which showed a number of faint lines. These strongly exposed spectra are of very great importance for the question as to what substance may possibly be present in the auroral region of the atmosphere.

To begin with — during the winter season 1922—23 — a considerable number of spectrograms were taken with the small spectrographs, the object of which mainly were to test our instruments for various photographic plates and with the cylindrical lens in in front of the plate or with this lens removed.

From December 1922 we began to use the small spectrographs with long exposures and varying types of photographic plates. In this way we intended to obtain a survey of the whole visible spectrum including also very faint lines.

A considerable number of spectrograms obtained with the small spectrograph giving merely a few well known lines, and which did not present any particularly interesting features as regards intensity distribution, were not measured and they will not be dealt with in this paper.

Plate I gives enlarged reproductions of some of the more important spectrograms obtained with the small glass spectrograph. The results of the wavelength measurements are collected in Table III.

The spectra Nr. 11, 12, 13 were obtained by the writer at Oslo during the year 1926. No. 16 is a reproduction of a spectrogram taken by Lord Rayleigh[1] and it is

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[1] Lord Rayleigh. Proc. Roy. Soc. London (A) 101, 114 and 312, 1922.

Table III.

Spectra from the Small Glass Spectrograph.

Pl. I No.	1	2	3	4	7	8	9	10	12	13	14	15	
Date	27/9—22	31/10—22	19/11—22	12/1—23	22/10—25	22/2—25	21/12—25	19/2—26	5/3—26	15/10—26	5/10—26	10/12—26	Mean
Phot. Pl.	Imp. Ecl.	Panchr. B	Panchr. B	Imp. Ecl.	Panchr. B	Panchr. B	Panchr. B	Panchr. B	Panchr. B	Panchr. B	Panchr. B	Sonja E*	Value
	-	-	6713 6384	-	6572.3	6572.2	(6550)	6639 6447	-	-	6550.3	-	6564.9
	-	-	-	-	6322.7	6321.6	6323.3	6316.7	6316.3	6309.1	6318.6	-	6318.3
	-	-	-	-	-	-	-	-	-	-	6147.6	-	6147.6
	-	-	5978	- -	5999.3 ?	- -	- -	6087 5930	-	-	5994.7	-	5997.0
	-	-	-	-	-	-	-	-	-		-		
	-	5574.0	5577.4*	-	5577.4*	5583.4	5577.4*	5577.4*	5577.4*	5577.4*	5581.6	5578.3	5580.1
	-	-	-	-	-	-	-	(5229)	-	-	(5223.3)	5238 0	5238.0
	-	-	-	-	-	-	-	-	-	-	-	5139.0	5139.0
	-	-	-	-	-	-	-	-	-	-		4998.0	4998.0
	-	-	-	4857.4	-	-	-	-	-	-	-	-	4857.4
	-	-	-	4779.2	-	-	-	-	-	-	-	-	4779.2
	(4713.3)	4708.2*	4708*	4708.3	4705.7	4708.0	4708*	4709.2	4707.8	4708*	4709.1	4705.8	4707.7
	4655.4	4651.4	-	4650.8	4651.5	4649.4	(4649)	4653.9	4653.0	-	4649.6	4648.0	4651.4
	-	-	-	4591.9?	-	-	4576	-	-	-	4594.2	-	4593.1
	-	-	-										
	-	-	-	4552.1	-	-	-	-	-	-	(4540.9)	-	4552.1
	-	-	-	4478.5?	-	-	-	-	-	-	-	4482.9	4480.7
	-	-	-	4426.5	-	-	(4418)	4427.8	-	-	4422.1	4425.9	4425.6
	-	-	-	4378.9	-	-	(4365)	-	-	-	4375.8	-	4377.4
	-	-	-	4345.8	-	-	(4334)	-	-	-	4346.9	4345.5	4346.1
	4276.4	4278.0*	4278*	4279.0	4275.9	4279.3	4278*	4277.7*	4277.9*	4278*	4276.1	4277.2	4277.3
	-	-	-	-	-	-	-	-	4264.2	-	4263.0	-	4263.6
	4239.1	4241.5	-	4238.4	4237.9	4239.8	4236	-	4235.5	-	4235.5	4232.9	4237.4
	-	-	-	4200.0	-	-	-	-	-	-	4199.9	4197.8	4199.2
	-	-	-	4182.5	-	-	-	-	-	-	-	-	4182.5
	-	-	-	-	-	-	-	-	-	-	4078.7	-	4078.7
	4057.8	(4051.9)	-	4059.7	-	-	-	-	-	-	4058.3	4058.5	4058.6
	3997.4	-	-	4000.4	-	-	3999	-	-	-	3997.7	3996.3	3998.2
	-	-	-	3941.5	-	-	-	-	-	-	-	3938.0	3939.8
	3913.3	3914.4*	3914*	3913.7	(3909.4)	(3917.9)	3914*	3913.9*	3914.0*	3914*	3915.3	3916.6	3914.7
	-	-	-	-	-	-	-	3903 4	3904.2	-	3902.3	3903.2	3903.3
	-	-	-	-	-	-	-	-	-	-	3882 4	3883 4	3882.9
	3810.6	-	-	3807.0	-	-	-	-	-	-	3804.0	3807.8	3807.4
	-	-	-	3758.5	-	-	-	-	-	-	(3748 0)	-	3758.5

* Treated with pinaflavol.

given here for the sake of comparison. The rest were taken at Tromsø. The more important data relating to each spectrogram are given in the "Explanation of the plates" to be found at the end of this paper.

Spectra Nos 1—6 were all taken with the cylindrical lens placed in front of the plate. The spectrograms obtained in this way showed somewhat diffuse lines. Further, the introduction of a cylindrical lens, while increasing the light power, had the disadvantage that it did not allow a comparison spectrum to be taken in the ordinary way. The comparison spectra shown on the reproductions were obtained by moming the plateholder up or down; but in this way there may be a small relative displacement between the two spectra. If we assume one of the auroral lines to be known, this displacement may be found and thus it is possible to utilise also the spectrograms taken with cylindrical lens for determining the wavelengths of the auroral lines.

In some cases we did not use the comparison spectrum at all, but adopted the following procedure. All weaker auroral lines were determined by means of three of the stronger auroral lines, which were known with sufficient accuracy, and which were used for the determination of the dispersion formula equation. (1).

The auroral lines used as standards for determining the wavelength values are marked with a cross (*) in Table III.

During the later years from 1924—1926 all spectrograms to be treated here were taken without cylindrical lens. In these cases reliable comparison spectra were taken in the ordinary way by moving a slide — suitably cut — in front of the slit. The spectra taken in this way also give sharper lines and therefore more accurate wavelength values.

Plate I No. 1 shows a spectrum obtained with an exposure of merely half an hour. The three principal sequences of negative bands denoted by *c*, *d*, *e* appear very strong. The principal line of the three sequences are

$$c - \lambda = 4708$$
$$d - \lambda = 4278$$
$$e - \lambda = 3914$$

In addition a number of weak lines appear. Some of these lines are marked on the spectrogram No. 4 b and denoted by *f*, *g*, *h*, *i*. *k*.

Spectrum No. 2 was taken on a panchromatic plate in order to see if any lines appeared in the red part. Although the green line and the negative nitrogen bands appear quite strong, we cannot see any trace of red lines. A subsequent spectrogram No. 3 obtained $^{29}/_{11}$ 1922 was more successful and shows a weak diffuse band in red between $\lambda = 6384$ and 6713, and a still fainter with a maximum at 5978.

The spectrograms 4 a and 4 b with an effective time of exposure of nearly 7 northlight hours was remarkable, because it gave in the blue and violet part a considerable number of lines not previously observed. Fig. 10 *a* shows a photographic density curve obtained with a Moll microphotometer.

The spectra Nos 5 and 6 are of interest because the green auroral line and the principal heads of the negative nitrogen bands appear quite strong, while no other lines are present. The two spectra were taken on Flavin plates not sensitive to red, but in the blue part we should have expected lines like *f*, *g*, *h* No. 4 to appear, belonging to the second positive group of nitrogen and also a number of other lines in the interval 4708—4278.

No. 7 which was exposed for 15 effective northlight hours on a panchromatic plate gives two faint and diffuse red lines 6572.3 and 6322.7, and perhaps traces of a band at 5999.3. In addition the spectrograms merely show the auroral line and the principal

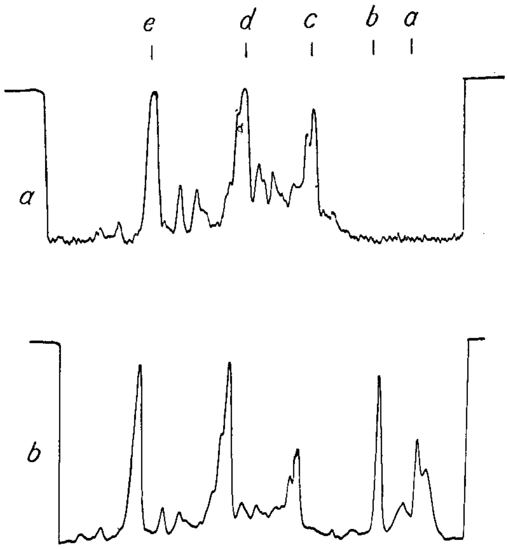

Fig. 10.

heads of the negative bands. This is most remarkable when seen in relation to the large photographic density of these lines and the very long time of exposure.

The aurorae appearing during a number of evenings may thus emit a luminescence, which in the visible part consists almost entirely of the principal heads of the negative group of nitrogen and the green auroral line.

The second positive group, which as we shall see is particularly strong in the ultraviolet part, no doubt appears, but with an intensity which is unusually small.

The spectrogram No. 8[1], corresponding to an exposure of $19^1/_2$ effective northlight hours on a panchromatic plate, shows the two same red lines as were observed on the previous spectrogram, and which are also in this case very faint and diffuse. In addition, this spectrogram shows a considerable number of lines in the interval 4708—4278, they lie very close together and by the small dispersion they form a nearly continuous band filling up the interval between the two negative bands mentioned, and they were found too diffuse for measurements.

The spectogram No. 9 is a most remarkable one. The plate (panchromatic B) was kept uncovered in the spectrograph from $^{21}/_{12}$ 1925—$^{4}/_{2}$ 1926 and exposed for 35 northlight hours. During this interval — on Jan. 26 — a most extraordinary auroral display occured, which was also very prominent at Oslo, and which maintained a very deep red colour for hours. The writer observed the display at Oslo, and observed the spectrum visually through a spectroscope, and a spectrogram was taken with one of the small glass spectrographs, which at that time we had to our disposal at Oslo. In the spectroscope *only one line was seen in the red part*, but this line was so strong that it appeared to be of about the same strength as the strong green line. The same is seen from the spectrogram No. 11 which I obtained at Oslo. Unfortunately the instrument by some inexplicable accident had come out of focus so that the lines were very dull, but we notice that the red line (*a*) is almost as dense as the auroral line (*b*). This is also seen from the photometric curve fig. 11.

This red colouring of the aurora of Jan. 26 was a very universal phenomenon, for also at Tromsø intense red aurorae appeared and we see that the spectrogram from Tromsø No. 9 shows a line (*a*) in red of nearly the same density as the green auroral line (*b*). This is the more remarkable as the plate for a great part of the time was exposed to aurorae of the ordinary colour, giving only a very faint red line. In addition to this strong red line, we notice the weak diffuse band near 6550, which is usually found for aurorae of ordinary colour.

The deep red colour of the aurora of Jan. 26 *was due to the fact that one single line appeared with an unusual strength.* Preliminary accounts of these results were given in Nature (13) and in proceedings of the Norwegian Academy (14).

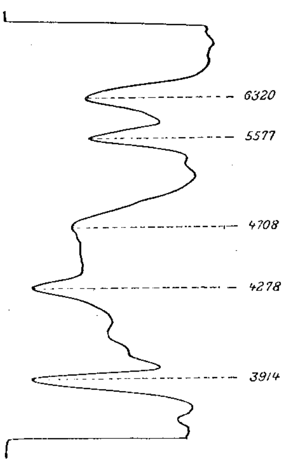

Fig. 11.

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[1] The appearance of two comparison spectra is probably due to a slip of the sledge carrying the plate-holder.

From the Tromsø spectrogram which gave fairly sharp lines, the wave-length of the strong red line was found to be 6323.3 Å. On account of the small dispersion of the spectrograph in this region an error of several Å units may attach to this value.

The accuracy of the wave-length of the red line was greatly increased by means of two spectrograms I took at Oslo. One (No. 12) was obtained $^5/_3$ 1926 and the second one (No. 13) was taken $^{15}/_{10}$ — of the same year. Although the red line is relatively weak, it is very sharp and well defined on both spectrograms from which we derive the wave-length 6316.3 and 6309.1.

On the spectrogram taken at Tromsø from Febr. 19. to April 7. (No. 10) the red part of the spectrum has resumed its ordinary strength and consists of the usual two lines or bands at 6317 and 6550. The first is no doubt the same line as the one which is emitted with great strength from the red aurorae — the second one is a diffuse band; in the present case the limits are found to be 6339 and 6444. In addition a faint red band is found in the region between 5930—6087.

In one case also a trace of a sharp line could be seen in this region. It was, however, too faint for reproduction and was seen under favourable conditions, when light was reflected from the exposed surface. These surface conditions, however, were gradually changed so that the line could only be noticed the first weeks after development. By marking the position of the line we found its wavelength to be 5947, a value which cannot claim any great accuracy.

The spectrograms described do not show with certainty more than one single green line (5577).

From data given in the older literature[1] and also from my own spectroscopic observations at Bosekop 1912, we know, that also other lines appear in the green part, but they are usually too faint to be observed in the spectroscope.

Above all, there is one line of particular interest, which should have a wavelength somewhere in the region 5220—5250. On the spectrogram No. 10 a trace of a faint line in green was noticed, for which we found the wave-length 5229. On account of the faintness of the line the value is not very realiable.

The difficulty with which we have to deal in obtaining the second green line on our spectrograms arises from various circumstances. First of all the line (or lines) is always very faint, and from visual observations it seems as if it only appears with any noticeable intensity in certain auroral displays which are quite rare, and finally most plates — both orthochromatic and panchromatic have a pronounced minimum of sensitiveness in the spectral region.

The panchromatic plates used, however, had also throughout the green part a sensitiveness so marked that it might be hoped that the second green line would appear if the time of exposure was sufficiently long.

During the autumn 1926 a panchromatic plate was exposed for 40 effective hours. As the result we obtained the spectrogram No. 14, of which a photometric curve is given in fig. 10 b. Even on this plate only a trace of the second green line could be seen on the original plate. In other respects, however, the spectrogram was very successful. The red part, and especially the line near 6320, was quite pronounced and a number of faint lines in the blue part came out quite distinctly, and could now be measured relative to an accurate comparison spectrum with the result given in Table III.

In the meantime experiments were carried out at the physical institute at Oslo with the object of making the plates more sensitive in the green part, by using a suitable sensitizing bath. We found that certain plates gave very good results when treated with a solution containing pinaflavol, recommended by the Kodak Company.

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[1] Cfr. H. Kayser, Handb. d. Spektr. V. 56.

The panchromatic plates did not stand this treatment successfully, but certain orthochromatic plates gave a very high sensitiveness in green after the treatment and could be kept for some weeks without being damaged. Instructions were given to Mr. Lund at Tromsø. A plate (Sonja E), sensitized with pinaflavol was put into the spectrograph for northlight exposure on Dec. 12. 1926 and developed Dec. 30. after an exposure of 15 effective northlight hours.

In this case we were very successful. The spectrogram reproduced on Plate I, No. 15 gives the second green line (b′) with considerable density, and in addition we obtained two other green lines, 5139 and 4998, which had not been previously observed. The spectrogram also contained — in the blue and violet part — a number of weak lines, which were well defined and could be fairly accurately measured.

A closer inspection of the plate showed that the second green line (b′) is not a single line, but it has the appearance of a narrow band. This will be evident if we compare the breadth of b′ with that of a single line with approximately the same density. The limits of the band were found to be 5220 and 5269. The maximum density of the band corresponds to the wave-length 5238.0.

The accuracy of these values can be estimated by means of the wavelength which we find for some of the well-known auroral lines. This comparison should lead to the conclusion that the errors attached to the position of the maximum density of (b′) should not exceed 4—5 Å units.

If we make the simplest possible assumption and suppose the band to be formed by two lines of about equal strength lying close together, the wavelength of these lines might be roughly estimated, and we would find $\lambda = 5250$ and 5225 — approximately. We must not forget, however, that these two values are quite hypothetical. The only thing we can say with certainty is that the band (b′) is not a single line, but has a structure. Taking into account the breadth of a line, the components should be placed in the interval 5225 and 5250.

The last column of Table III gives the mean values for the 32 lines observed with the small glass spectrographs during the period from 1922 to 1926.

In the calculation of the mean value, lines used as standard lines are marked with a (*), and uncertain lines put into brackets, are left out of consideration.

As already mentioned in previous papers, the negative nitrogen bands appear much sharper in the auroral spectrum than when they originate from ordinary discharge tubes. This means that the rotational bands are less prominent in the auroral light and mostly restricted to small rotational quant numbers which shows that the auroral light is emitted at a relatively low temperature. The temperature of the auroral region as determined from the rotational bands will be dealt with in a separate chapter.

§ 7. Spectra and lines obtained with the large Glass Spectrograph.

The spectograms obtained with the large glass spectrograph are shown on Pl. II, No. 7—14. Particulars are given in the explanation to the plates at the end of the paper. The results of wave-length measurements are collected in Table IV.

Hoping that we might obtain some lines in red, we commenced our exposures with a panchromatic plate, (Pl. II, No. 13); but even after an exposure of 20 hours only the green auroral line appeared.

The auroral line itself is very sharp, but in some inexplicable way some lines of the He-comparison spectrum had become unsharp, a circumstance which reduces the accuracy with which the wavelength can be determined. In fact, we obtained for the strong green auroral line the wavelength $\lambda = 5578.4$.

Table IV.

Spectra from the Large Glass Spectrograph.

Plate II No.	7	8	9	10	11	12	
Date	9/12—22	8/1—23	9/10—23	7/1—24	16/1—24	15/9—24	Mean
Phot. Plate	Imp. Ecl.	Imp. Ecl.	Imp. Ecl.	Imp. Ecl. Ortho	Imp. Ecl. Ortho	Imp. Ecl.	
	-	-	-	5577.4*	5577.4*	-	5577.4*
	4708.6	4708.6	4708.9	4708.7	4709.0	4709.2	4708.8
	4696.8	-	4698.9?	-	4697.2?	4700.8	4698.4
	4651.2	4650.4	4652.4	-	4651.7	4653.9	4651.9
	4276.8	(4275.9)?	4277.2	4277.5	4277.0	4278.3	4277.4
	(4265.7)	4268.6	4269.4	4269.7	4269.4	4271.4*	4269.7
	4235.3	-	4237.1	4236.5	4235.4	4236.9	4236.2
	3912.6	3913.3	3913.0	3914.4	3914.8	3914.4	3913.8

Babcocks's value for the green line from the light of the night sky is 5577.35. Now his interference method gives only the fractionary parts, and his value is based on previous measurements by the writer and the measurements by Slater already referred to. These measurements are probably correct within one Å unit, but on account of the interest attached to this line it is of importance to repeat the ordinary spectrographic measurements in order to ascertain that these measurements give errors smaller than 1 Å. If the green line from the night sky is identical with the strong green auroral line, and if the Babcock value is correct, the value for the green line from the spectrogram No. 13 should be 1 Å too large.

In order to increase the accuracy, an ortho-chromatic plate was exposed for 3 hours during March 25.—26. The spectrogram (Pl. II, No. 14) showed a very sharp and distinct auroral line and also a very sharp comparison spectrum.

From this spectrogram the green auroral line was carefully determined, independently by myself and one of my assistents Mr. Jonathan Aars, and we obtained the values $\lambda = 5577.1$ and $\lambda = 5577.2$ respectively. As the error of measurements of the spectral lines is less than $^1/_{100}$ mm the error should be less than 1 Å. In fact the difference between our mean value and that of Babcock is merely 0.2 Å.

The exposure on the panchromatic plate had been very little successful, but by using plates extremely sensitive in the blue and violet part, we hoped to obtain good spectra in the region of short waves. Most of our exposures were therefore made either with Imperial Eclipse plates Nos. 7, 8, 9, 12 or with imp. eclipse ortho (Nos. 10, 11). In spite of the very long exposures, from 18—44 effective northlight hours, we merely obtained the stronger lines of the negative band spectrum of nitrogen, and on the ortho-plates also the green auroral line.

On account of the long time of exposure the plate had to stand uncovered for several weeks. By developing the plate No. 7 and 8 obtained during the first winter it was found to be covered with a very thin black layer (fog). This blackening was not due to light, but was undoubtedly of chemical origin. It was shown to be most intense where the air, circulating inside the instrument, most conveniently struck the plate. Some active substance (e. g. ozone or nitrogenoxydes formed by the relay breaks) must have been mixed into the air. In the summer 1923, however, precautions were taken, which made the fogging disappear.

The three first spectra (Nos. 7, 8, 9) were taken in the ordinary way, without introducing the cylindrical lens in front of the plate. In order to get deeper into the spectrum and perhaps obtain some of the weaker lines, which we discovered by means of the small spectrograph — we introduced the cylindrical lens — and the three spectrograms Nos. 10, 11, 12 were taken in this way.

Although the negative bands came out with a considerably increased density, none of the faint lines were to be seen.

In the case of the spectra taken with a cylindrical lens, the wave-lengths were determined by assuming one of the auroral lines to be known, and by means of this line the position of the auroral lines relative to the comparison spectrum was fixed.

For the spectra Nos. 10 and 11, the green auroral line was used as a standard with wave-length 5577.4.

§ 8. Spectra and lines obtained with the Quartz Spectrograph.

The quartz spectrograph appeared to have a considerably greater light power than the large glass spectrograph, although its geometrical light power is smaller. This is no doubt due to the considerable absorption taking place in the glass, especially in the large Rutherford prism of the large glass spectrograph.

The time of exposure used for the quartz spectrograph was of about the same magnitude as that used for the large glass spectrograph. During the winter 1922—23 we obtained four very good spectra shown on Plate II, Nos. 1—4. They gave a considerable number of lines both in the visible and ultraviolet part. The wave-lengths of the observed lines are given in Table V.

After a second prism had been put in, two spectra were taken during the winter 1923—24. They are shown on Pl. II, Nos. 5 and 6. It should be noticed that these spectrograms are reproduced with a smaller enlargement than those of Nos. 1—4, obtained with only one prism. In the case of spectrogram No. 5 there was found to be a small displacement of the comparison lines, in the interval 4000—4700. The explanation of this peculiar displacement is probably that the collimator was not evenly filled with light when the comparison spectrum was taken.

The wave-lengths of the observed lines are given in Table V.

Altogether 34 lines were observed with the quartz spectrograph the last column of Table V gives the mean value for the observed lines.

If we assume that the visible spectrum ends at the strong line 3914 the table contains 17 lines in the ultraviolet part. Most of these are fairly strong. They can be accurately determined and as we shall see identified as lines belonging to the 2nd positive group of nitrogen. In addition a few faint lines were found.

Two lines 3774 and 3693 were only observed on spectrogram No. 6, Pl. II. They were so faint that their existence may be doubtful. The line 3432, however, was measured on two spectrograms and is no doubt real. The lines 3285 and 3208 are very diffuse, and have the character of bands. The values given correspond to the wave-length of maximum density.

These bands were measured from spectrogram No. 1, Pl. II. They are too faint to be seen on the reproduction, but they come out very distinctly on the photometric curve taken from this photogram and shown on fig. 18 A. The curve also shows the considerable breadth of these lines (or bands). The same bands were also visible on spectrogram No. 4, Pl. II, and can also just be seen on the photometric curve fig 18 A.

Table V.

Spectra from the Large Quartz Spectrograph.

Pl. II No.	1	2	3	4	5	6	
Date	$^{27}/_{9}$—22	$^{3}/_{11}$—22	$^{21}/_{12}$—22	$^{8}/_{1}$—23	Autumn 23	Jan. 24	Mean value
Phot. Pl.	Imp. Ecl.	Imp. Ecl.	Imp. Ecl.	Imp. Ecl.	Imp. Ecl.	Imp. Ecl. ortho	
	-	-	-	-	-	5577.3	5577.3
	4708.6	(4706.7)	-	4708.3	(4700.3)	4708.2	4708.4
	4653.1	4652.3	-	4651.1	(4644.4)	4650.9?	4651.9
	4421.5	-	-	-	(4421.2)	-	4421.5
	-	-	-	-	-	4374.1	4374.1
	-	-	-	-	-	4350.1	4350.1
	4277.3	4278.2	4277.6	4279.0	(4275.4)	4279.5	4278.3
	-	-	-	-	(4262.9)	-	(4262.9)
	4239.1	4236.6	-	4239.6	(4233.7)	4239.5	4238.7
	-	-	-	-	(4197.5)	4200.5	4200.5
	-	-	-	-	-	4142.6	4142.6
	-	-	-	-	4074.1	4078.2	4078.2
	(4054.3)	4058.1	-	4058.6	4057.7	4059.6	4058.5
	3997.5	3998.5	-	3999.7	3997.2	3999.6	3998.5
	-	-	-	-	3981.3	-	3981.3
	-	-	-	-	3941.3	-	3941.3
	(3911.6)	3915.3	3914.5	3913.7	3914.9	3914.6	3914.6
	-	-	-	-	3904.0	-	3904.0
	-	-	-	-	3885.2	-	3885.2
	3805.2	3805.2	-	3805.8	3805.0	3805.6	3805.4
	-	-	-	-	-	(3773.8)?	3773.8
	3756.3	3755.1	-	3756.7	3755.7	3756.0	3756.0
	3710.7	3711.6	-	3712.5	-	3712.4	3711.8
	-	-	-	-	-	(3693.3)?	(3693.3)
	3575.6	3577.2	3577.8	3577.9	3578.7	3579.9	3577.9
	3535.7	3537.2	3535.5	3537.4	3538.3	3539.0	3537.2
	3502.9	-	-	3506.5	-	3508.0	3505.8
	3467.8	-	-	3468.3	3471.8	3472.4	3470.1
	3432.7	-	-	3431.2	-	-	3432.0
	3371.5	3371.5	3371.2	3370.8	3371.9	3372.9	3371.6
	3284.9	-	-	-	-	-	3284.9
	3208.3	-	-	-	-	-	3208.3
	3160.4	3159.7	-	3159.9	3158.8	3159.8	3159.7
	3134.5	3135.6	-	3136.8	-	-	3135.6

Nos. 1, 2, 3, 4, Quartz spectrograph with one prism.
Nos. 5 and 6 » » » two prisms.

§ 9. The total number of lines and some remarks regarding their origin.

All lines observed during the period from 1922—26 are collected in Table VI. The lines and bands in the red part are only obtained with the small glass spectrograph — and those in the ultraviolet beyond 3755 are only obtained with the quartz spectrograph.

In the interval between 5577 and 3758 it happens that a line has been observed with two or three spectrographs. In such cases we have usually reason to believe that one of the spectrographs on account of higher dispersion give the most accurate value, which then is entered in the table.

For the lines obtained with the large glass spectrograph, we take the values given by this spectrograph as the most accurate. Only, in the case of the line 3914, where also the other spectrographs have a fairly large dispersion we took the mean value.

Table VI.

Spectrograph	Auroral Lines	Neg. Nitrogen bands			2nd. pos. Nitr. gr.			Possible origin of faint lines
		λ	n_1	n_2	λ	n_1	n_2	
g	6564.9 $\left\{\begin{matrix}6700\\6400\end{matrix}\right\}$ B	-	-	-	-	-	-	1st. pos. gr. N_2
»	a 6318.3	-	-	-	-	-	-	1st. pos. gr. N_2
»	6147 B	-	-	-	-	-	-	
»	5997 B	-	-	-	-	-	-	
»	5940 f. l.	-	-	-	-	-	-	
G	b 5577.2 v. st.	-	-	-	-	-	-	
g	b′ 5238.0 W. B.	-	-	-	-	-	-	
»	5139.0 w.	-	-	-	-	-	-	
»	4998.0 w.	-	-	-	-	-	-	4995. N. L.*
»	(4857.4) w. ?	-	-	-	-	-	-	4860. N.L., O II. Hβ
»	(4779.2) f. ?	-	-	-	-	-	-	4779. N. L.
G	c 4708.8 m.	4708.6	0	2	-	-	-	
»	4698.4 d. w.							
»	4651.9 m.	4651.2	1	3	-	-	-	
g	4593.1 w.	4599.4	2	4	-	-	-	
»	4552.1 w.	4553.8	3	5	-	-	-	
»	4480.7 w.	4484.9	5	7	-	-	-	
Q+g	4423.6 w.	-	-	-	-	-	-	4426. N. L. Ar.
Q+g	4375.8 w.	-	-	-	-	-	-	4375. N. L. Ar.
g	4346.1 w.	-	-	-	4344.1	0	4	
G	d 4277.4 v. st.	4278.0	0	1	-	-	-	
»	4269.7 m.							
»	4236.2 m.	4236.3	1	2	-	-	-	
g	4199.2 w.	4198.7	2	3	4201.0	2	6	
»	4182.5 f.	-	-	-	-	-	-	4180. N. L. Ar.
Q	4142.6 f.	-	-	-	4141.1	3	7	
g	(4078.2) f. ?	-	-	-	-	-	-	4075. O. Ar.
Q	4058.5 m.	-	-	-	4058.7	0	3	
»	3998.5 m.	-	-	-	3998.5	1	4	
»	(3981.3) f. ?	-	-	-	-	-	-	3983. O. Ar.
»	3941.3 w.	-	-	-	3943.1	2	5	
g+G+Q	e 3914.4 v. st.	3914.4	0	0	-	-	-	
Q	3904 d.	-	-	-	-	-	-	
»	3885.3 m.	3883.9	1	1	-	-	-	
»	3805.4 m.	-	-	-	3805.1	0	2	
»	(3773.8) f. ?	-	-	-	-	-	-	3771. N. L. Ar.
»	3756.0 m.	-	-	-	3755 5	1	3	
»	3711.8 w.	-	-	-	3710.7	2	4	
»	(3693.3) f. ?	-	-	-	-	-	-	3692. O. I. Ar.
»	3577.9 st.	-	-	-	3577.0	0	1	
»	3537.2 m.	-	-	-	3536.8	1	2	
»	3505.8 f.	-	-	-	3500.5	2	3	
»	3470.1 w.	-	-	-	3469.0	3	4	
»	3432.0 w.	-	-	-	-	-	-	
»	3371.6 st.	-	-	-	3371.5	0	0	
»	3284.9 w. B.	-	-	-	3285.0	3	3	
»	3208.0	-	-	-	-	-	-	
»	3159.7	-	-	-	3159.2	1	0	
»	3135.6	-	-	-	3135.8	2	1	

* N. L means Nitrogen line spectrum.

The spectrograph by means of which each line is measured, is indicated in the first column of Table VI.

G is the large glass spectrograph
g » » small » »
Q » » quartz »

To the right of each line given in the second column, we have indicated the strength and character of the line.

B means a more or less broad band
d » diffuse line
f » faint
w » weak
m » medium strength
st. » strong
v. st. » very strong.

Very faint lines, the existence or position of which may be doubtful, are put into brackets and marked with a (?).

As already pointed out in previous papers (1, 2, 4, 5, 6, 7) all stronger lines with wave-lengths shorter than 4710 are to be referred to the first negative and second positive group of nitrogen. In the third column those lines of the neg. group are given, which appear in the auroral spectrum. The fourth columns give the occilatory quant numbers n_1 and n_2 corresponding to the upper and lower level of the transition, responsible for the line in question.

The two next columns give in a similar way the lines belonging to the 2nd positive group.

We notice from Table VI that in the interval from the negative band 4709 to the limit in ultraviolet, all stronger lines belong to the negative group and 2nd positive group of nitrogen.

Close to each of the three principal negative bands 4709, 4278, 3914, the three lines 4698, 4270, 3904 are given. They are no doubt due to the contracted form of the rotational bands (R-branch) which accompany each of the three negative bands, and their displacement from the oscillatory bands gives a measure for the extention and development of the rotational bands and should give an indication of the temperature at which the bands are emitted in the auroral region. (Compare Chapter IV).

With regard to other lines not belonging to the neg. and 2nd positive group, some of them 4182, 4078, 3981, 3773, 3693, were only observed on one spectrogram and were extremely faint. As lines approximately coinciding with these lines were recently found on spectrograms obtained at the Tromsø Observatory, their existence in the auroral spectrum may be considered as certain; but on account of their faintness, errors of several Å units may attach to the present values.

The other lines in this interval 4424, 4375, 3432 and 3208 appeared quite clearly on at least two spectrograms. With the exception of the last one, which is very diffuse, the lines should be determined fairly accurately with an error not much exceeding 1 Å.

Until more accurate wave-length values can be found, it is not possible to give a perfectly reliable interpretation of these weak lines.

If we take an element with a considerable number of known spectral lines, it is very probable that some lines are found which within the limit of error coincide with the auroral lines.

In order to arrive at an interpretation which has at any rate a considerable probability of being the true one, we must confine ourselves to such elements which may possibly be present in the auroral region in sufficiently large quantities to give lines with an intensity of the same order of magnitude as those emitted from Nitrogen. These elements are Nitrogen, Oxygen and perhaps Argon Hydrogen and Helium. None of the Helium series occur.

As regards the Balmer series of Hydrogen, it may be mentioned that we found, on one of the spectrograms from the small glass spectrographs (Pl. I, No. 4) a weak line with a wave-length 4857.4, which is not far from H_β, but we find both N and O lines which even better fit in with the observed line. In the red part we observed a broad diffuse band in the region of H_α but no trace of a definite line which might indicate the presence of H_α. Neither do we find H_γ, H_δ etc. It is also to be noticed that the line 4857 was only observed on one spectrogram and was not found on others, which were much longer exposed and gave very dense lines e. g. Pl. I, Nos. 9, 14 and 15.

As already pointed out in previous papers, the spectrograms of long exposure obtained with the small glass sprectrographs show that hydrogen lines are not present in the auroral spectrum, although even very weak lines ought to have been indicated.

From this result we were able to draw the important conclusion, that Hydrogen cannot be a dominating component of the atmosphere above, say 100 Km, as was the generally accepted idea previous to our spectrographic results. The idea, that the light gases Hydrogen and Helium should be dominating in the upper atmosphere, was built on theoretical calculations based on the assumption that above a certain altitude an ideal equilibrium took place, and that above this level the pressure of each gas varied upwards as if the other components of the atmosphere were not present.

As pointed out already in 1923 — the immediate consequence of our analysis of the auroral spectrum was that the basis of this calculation was shown to be fundamentally wrong. We shall return to the question later on.

In the case of the argon spectrum, the number of lines is so large that there is a considerable chance that this gas possesses a line in the neighbourhood of any given line, and as a matter of fact — as indicated in the last column of Table VI, we find Ar.-lines so near most of the faint lines here considered, that the difference of wave-length is within the limit of error. We have no reason to assume that the percentage of Argon increases upwards, and then it is not likely that Argon should emit lines comparable in strength with those of Nitrogen and Oxygen. Further it is very unlikely that just a few Ar.-lines out of a large number make their appearance.

When we are about to interprete the lines of the auroral spectrum, we should first of all consider the spectra of Nitrogen and Oxygen.

The question as to whether oxygen-lines are present in the auroral spectrum is of special importance in connection with the interpretation of the strong green auroral line.

As is well known. Mac. Lennan identifies it with an oxygen line corresponding to the transition $^1D_2—^1S_0$ of the neutral oxygen atom. If this interpretation is correct we should expect to find other lines of the neutral oxygen atom.

If we look at Fowler's table[1] for the series spectra of oxygen, none of these lines are observed in the auroral spectrum.

Considering the list of all observed oxygen-lines, the number is very considerable, and just as in the case of Ar. there is a considerable chance for approximate coincidences with any observed line. It appears from the table VI, that we find three oxygen-lines 4074, 3983 and 3692, which within the limit of a few Å units coincide with faint auroral lines. — Later observations from the Auroral Observatory at Tromsø indicate that the two latter lines at any rate are not to be referred to oxygen, but are members of an oscillatory series of Nitrogen. As to the line 4078.2 it is extremely weak, and its wave-length so uncertain that it is at present impossible to form any opinion as to whether it is identical with the oxygen line mentioned.

If we consider the line spectrum of nitrogen we find that the lines 4426, 4375, 4180, 4081, 3771 within the limit of error coincide with weak auroral lines.

Also in the case of nitrogen, the number of tabulated lines is fairly large, and therefore the probability for accidental coincidences is by no means negligible.

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[1] A. Fowler, Reports on series of line-spectra. London 1922.

As the result we may say that the weak auroral lines in the interval considered are not determined with sufficient accuracy for a reliable opinion to be formed as to their origin. The fact that the auroral spectrum in this region is dominated by the nitrogen bands, and that there is a fairly large number of coincidences with nitrogen lines, makes it at any rate very probable that some of the faint lines originate from nitrogen.

We will then consider those lines and bands which have wave-lengths larger than 4709 and which are given in Table VI.

The most conspicuous feature of this part is the appearance of the strong green line (5577) and the red line for which the average wave-length from our present material was found to be 6318. The latter is usually very weak, but may in the red aurorae assume an intensity of nearly the same order of magnitude as the auroral line.

Further, a most interesting feature is the appearance of the group of lines (or band) b′ (5238) which was called the second green line, and a line in red 5940, which was only once observed extremely faintly on a photographic plate. Although its wave-length is very uncertain, there is no doubt regarding its existence, for it was also observed spectrographically by Carlheim Gyllenskiold[1].

As regards the interpretation of the strong green auroral line, there are two interpretations that ought to be very seriously considered, the interpretation proposed by Mc. Lennan, according to which it is due to a transition $2\,p^1\,S_0 - 2\,p^1D_2$ of the neutral oxygen atom, and an interpretation proposed by the present writer according to which the green line is referred to nitrogen and is due to an electronic transition which is engaged in the formation of a conspicuous band, obtained when nitrogen in the solid state is bombarded with electric rays. — As pointed out in a previous paper these bands may also be emitted from gaseous Nitrogen of extremely small density.

In addition to this band (called N_1) solid Nitrogen also emits three other bands N_2, N_3, N_4 which according to the writer might account for the lines b′, a and the weak line 5940.

From the interpretation given by Mc. Lennan, we should expect a number of other oxygen lines to appear in the auroral spectrum.

One is a red line corresponding to the transition $^1D_2 - ^3P_2$ and whose wave-length, according to Paschen and Frerichs[2] is $\lambda = 6300$.

The difference of wave-length between this line and the red auroral line (6318) is so large that it can hardly be due to errors of determinations.

Other oxygen lines should according to Mc. Lennan appear in the infra-red part of the auroral spectrum.

By the spectrographic work undertaken at the Auroral Observatory at Tromsø under the conduction of L. Harang, we have recently succeeded in obtaining the red line with a spectrograph of large dispersion. Further we obtained, for the first time spectrograms[3] of the infra-red auroral luminescence, the existence of which was shown a few weeks earlier by Dr. Bauer[4]. In connection with cinematographic exposures of the aurorae, he succeeded in obtaining a photograph of an aurora, on plates sensitive to infra red and with a suitable filter in front of the camera lens.

On account of the new data thus obtained, we shall leave the question as to the interpretations of the lines a, b, b′ for a further discussion in connection with the publication of the new Tromsø material.

Also the two other lines in green 5139, and 4998 call for great interest but their interpretation is still an open question. It is a matter of interest to notice that the

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[1] H. Kayser, Handb. d. Spectr. V. 56, 1910.

[2] R. Frerichs, Phys. Review 36, 398, 1930.

[3] L. Vegard, Nature March 1932, Naturwissenschaften 20, 268, 1932.

[4] W. Bauer, Naturwissenschaften 20, 287, 1932.

line 4998 is so near to the coronal line 5003 that perhaps the difference may be within the limit of possible error.

As the bottom level for the second positive group is the level of start for the 1st positive group, the presence of the second positive group should involve that also the 1st positive group should appear in the auroral spectrum with an intensity comparable to that of the second positive group.

I consider it as fairly certain that the red bands between (6400 and 6700) are to be referred to the 1st positive group of Nitrogen. This is probably also the case with the lines 6148 and 5997 which have the character of narrow bands.

As to the weak lines 4857 and 4779 both are somewhat uncertain. The possible origin of the first one has already been discussed, the second one nearly coincides with a nitrogen line 4779.

CHAPTER III.

The Intensity Distribution within the Auroral Spectrum and its variation.

§ 10. Some general remarks regarding the determination of relative intensities of the lines of a spectrum.

Supose that by means of some spectrograph we have taken the photograph of a spectrum, and that we want to find the relative intensities of the lines by means of the photographic densities of the lines.

For the practical solution of this problem in the case of the auroral spectrum, we adopted a procedure which may be shortly described as follows:

1. The photographic density of the lines was measured by means of a registering microphotometer of the Moll type, made by Kipp and Zonen, Holland. It is not necessary to give a strict definition of the photographic density. It is sufficient to know that each density corresponds to a definite deflection (u) on the instrument.

2. We must have a photographic intensity scale which enables us to find the relation between the density as measured by the deflection (u) and the quantity of light received by the plate per unit area.

An intensity scale can be obtained in a mumber of ways. We found it most convenient to take spectra of a constant light-source with varying times of exposures. As a rule we took three spectra with times of exposure in the proportion 1 : 2 : 4. In order that photographic intensity measurements should give reliable results, it is most essenstial that spectra for the intensity scale are taken on the same plate as the spectrum to be measured. This is especially important in the case of the auroral spectra for which we often have to use long exposures lasting for weeks. The plate may be more or less foggy all over, and in order to eliminate this fog in our measurements, the intensity spectra must be taken on the same plate as the auroral spectra.

Let deflection of the photometer when the plate is perfectly transparent be u_0, and when it is perfectly opaque u_∞ and let us suppose the instrument is so regulated that $(u_\infty - u_0)$ remains constant. Let u_g be the deflection corresponding to the general fog of a plate. A deflection u_g then corresponds to a intensity 0. And for a given wavelength and a deflection u the intensity is a single valued function of $(u - u_g)$.

In order that this function shall be correctly determined, the intensity scale must have the same value of u_g and the quality and treatment of the plate should be the same as for the spectrum to be measured. These conditions are fulfilled in the simplest way by taking the scale on the plate to be investigated.

3. Let us suppose that monochromatic light falls on the plate. Let the intensity per unit area be i, then the photographic density, obtained by exposing the plate for a certain time to this intensity, is a function of the wave-length.

According to the law of Schwartzschild, the density on a given plate is a function of $i\ t^p$, wheret is the time of exposure and p a coefficient characteristic of the sort of plate we use, or, when we arrange our experiments in such a way that the density is measured by the deflection u we may put:

$$i\ t^p = \varphi_\lambda\ (u)\ .\ .\ .\ .\ .\ .\ .\ . \tag{4}$$

Both p and $\varphi\ (u)$ may depend on the wave-length λ of the light.

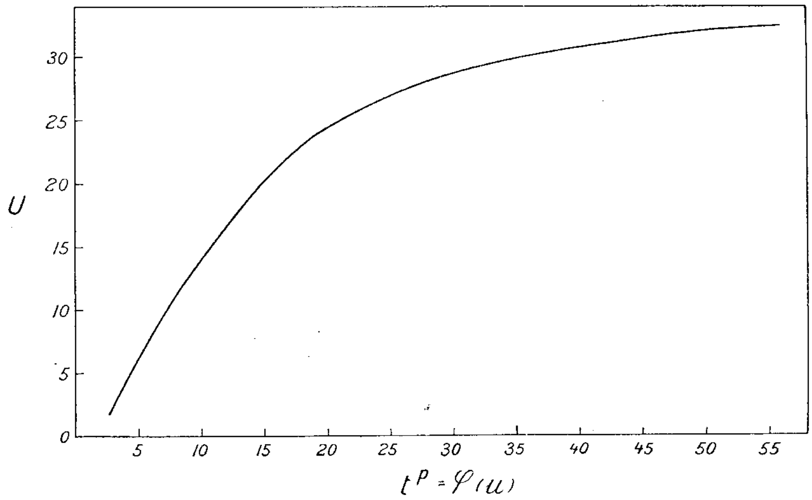

Fig. 12.

For our present purpose — the determination of the typical intensity distribution of the auroral spectrum —, we may with sufficient accuracy assume, that for a certain plate, (p) is independent of the wave-length and that $\varphi_\lambda\,(u) = \dfrac{\varphi\,(u)}{k_\lambda}$ where $\varphi\ (u)$ is independent of λ and k_λ is a coefficient which characterises the sensitivity of the plate for the wave-length in question. The equation (4) may then be written:

$$k_\lambda\ i\ t^p = \varphi\ (u)\ .\ .\ .\ .\ .\ .\ .\ . \tag{5}$$

The function $\varphi\ (u)$ is determined by exposing the plates with a number of known values $k_\lambda\ i\ t^p$ and measuring the corresponding densities by means of the deflection u. In our case we vary the quantity by keeping $k_\lambda\ i$ constant and varying the time of exposure t.

After having determined the exponent p for the sort of plate we use, we calculate the quantities t^p and construct a curve with (u) as ordinate and t^p as abscisse and obtain a graphical representation of the function $\varphi\ (u)$ in an arbitrary scale. (Such a curve is shown in fig. 12).

In order to obtain a curve which is free from the arbitrary units of the u and $k_\lambda\ i\ t^p$ it is common to draw the curve on a logarithmic scale, but this is not at all necessary and this procedure was not adopted in the present work.

§ 11. The determination of the relative changes of intensities of spectral lines obtained under different conditions.

We shall fix our attention on two spectral lines (*a*) and (*b*) appearing in the auroral spectrum. We suppose that on the photographic plate we have taken two auroral spectra I and II, corresponding to different conditions e. g. aurorae of different form, colour or altitude. We wish to measure the change of *relative* intensity of the two lines.

This problem was treated in a previous paper[1] in connection with the determination of the intensity variations in the Balmer-series by the excitation of light by canal rays.

Let the intensity of the homogeneous light of a line with wave-length λ, when entering the slit be I, then the intensity i (amount of energy per unit area) falling on the plate per second is:

$$i = I\ f\ (\lambda)\ \ldots\ldots\ldots \tag{6}$$

where $f\ (\lambda)$ is a function characteristic of the spectrograph used. Applying equation (5) for the two lines considered (*a*) and (*b*) and for the two spectra I and II to be compared, we obtain: For spectrum I:

$$\left.\begin{aligned} k_a\, i_a\, t^p &= \varphi\,(u'_a) \\ k_b\, i_b\, t^p &= \varphi\,(u'_b) \end{aligned}\right\}\ \text{and:}$$

$$\left(\frac{i_a}{i_b}\right)_I = \left(\frac{I_a}{I_b}\right)_I \frac{f\,(\lambda_a)}{f\,(\lambda_b)} = \frac{k_b}{k_a} \cdot \frac{\varphi\,(u'_a)}{\varphi\,(u'_b)}\ \ldots\ldots\ldots \tag{7 b}$$

Similarly for spectrum II:

$$\left(\frac{I_a}{I_b}\right)_{II} \frac{f(\lambda_a)}{f(\lambda_b)} = \frac{k_b\, \varphi\,(u''_a)}{k_a\, \varphi\,(u''_b)}\ \ldots\ldots\ldots \tag{7 b}$$

For the relative change of intensity of the two lines D, we obtain:

$$D = \frac{\left(\frac{I_a}{I_b}\right)_I}{\left(\frac{I_a}{I_b}\right)_{II}} = \frac{\varphi\,(u'_a)\ \varphi\,(u''_b)}{\varphi\,(u'_b)\ \varphi\,(u''_a)}\ \ldots\ldots\ldots \tag{8}$$

The expression to the right is obtained from the photographic density curve *previously defined and* which is obtained from our intensity scale photographed on the same plate as the two spectra *I* and *II* to be compared.

§ 12. The determination of relative intensities of spectral lines belonging to the same spectrum.

In order to determine relative intensities of lines within a line spectrum, it would according to equation (7) be necessary to find relative values for the product $k_\lambda\, f\ (\lambda)$.

For this purpose we have to photograph a spectrum from a light-source with known intensity distribution on the various wave-lengths. We assume that for this purpose we

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[1] L. Vegard: Ann. d. Phys. 39, 111, 1912.

have a source giving a continuous spectrum. Let the total intensity of the light passing through the slit be I_T, then:

$$I_T = \gamma \int_0^\infty E_\lambda \, d\lambda \; . \; . \; . \; . \; . \; . \; . \; . \qquad (9)$$

Where γ is a constant independent of λ.

We assume that we know E_λ as function of λ for the source used. The intensity of the light falling on the plate at a point corresponding to a wave-length λ will be:

$$i = O \cdot f \cdot (\lambda) \cdot E_\lambda \frac{d\lambda}{ds} \; . \; . \; . \; . \; . \; . \; . \; . \qquad (10)$$

where O is the aperture of the slit and $\frac{ds}{d\lambda}$ is the dispersion of the spectrograph for the wave-length considered. Equation (5) now takes the form:

$$k_\lambda \, O \cdot f(\lambda) \, E_\lambda \frac{d\lambda}{ds} t^p = \varphi(u) \qquad \text{and}$$

putting $k_\lambda f(\lambda) = Q$

$$Q = k_\lambda f(\lambda) = C \frac{\varphi(u)}{E_\lambda \cdot \frac{d\lambda}{ds}} \; . \; . \; . \; . \; . \; . \; . \; . \qquad (11)$$

where C is a constant for a given spectrum.

In order to find relative values of Q we have for each wave-length to measure the deflection (u), determine φ (u) by means of the photographic density curve fig. 12, and divide the value thus found by $E_\lambda \frac{d\lambda}{ds}$. Inserting the values thus found for $k_\lambda f(\lambda)$ into equation (7), the relative intensity of any two lines in the spectrum is given by the expression:

$$\frac{I_a}{I_b} = \frac{Q_b}{Q_a} \frac{\varphi(u_a)}{\varphi(u_b)} \; . \; . \; . \; . \; . \; . \; . \; . \qquad (12)$$

where u_a and u_b are the deflections on the microphotometer curve for the two lines. The φ function is to be determined from the density scale taken on the same plate as the spectrum to be measured.

In practice we give the intensity of the lines in relation to one definite line; the intensity of which is put equal to an arbitrary number e. g. 100.

§ 13. Variations in the spectral composition of the auroral luminescence.

In our description in a previous paragraph, of the spectra which were taken with the small glass spectrographs and are reproduced on Plate I, we mentioned that the composition of the spectra varied considerably from one exposure to another.

In order to make a qualitative estimate of these changes, we must of course take into account the different sensitiveness of the plates in various parts of the spectrum.

Among the variations which can be seen from the spectrograms of Plate I, we may mention the following:

1. The intensity of the red line 6318 varies enormously as compared with that of the other principal auroral lines. This is seen by comparing a number of spectrograms

taken with the same type of panchromatic plate, and for which the principal lines (green lines and negative bands) show nearly the same degree of intensity. We may e. g. compare the spectrograms No. 7, 8, 9, 10, 11 and 14. While on spectrogram 9 and 11, the intensity of the red line is of the same order of magnitude as that of the green line, the same red line on the other spectrograms is extremely weak, and although the principal lines are extremely dense, the red line is just visible.

From the results of measurements on the relative intensity of the auroral lines to be described later on, I should estimate that the intensity of the red line relative to that of the auroral line may vary in the proportion 1 : 10.

2. The intensity of the positive bands as compared with that of the negative bands is not always the same. In order to see this, we may e. g. compare the spectrum 9 and 14. Both are taken on the same sort of plate (Panchrom B.) and although on spectrum 9, the negative bands are equally dense as on No. 14, we notice that the conspicuous lines of the positive group 4059 and 3998 (*g* and *h* No. 4 b.) appear fairly marked on the latter spectrogram, while they are hardly visible on No. 9. The same is seen by comparing spectrum 8 and 14 or No. 1 with No. 8 and 9.

3. As previously mentioned a considerable number of lines, partly of unknown origin, appear in the interval between the negative bands *c* and *d* (4708, 4278). The relative intensity and apparent number of these lines undergo great changes.

Thus if we again compare the spectrograms No. 9 and No. 14, we see that these lines appear more numerously and relatively much denser on the first mentioned spectrogram, in spite of the fact that the positive bands *g* and *h* appear much stronger on the latter. Under some conditions the lines in the interval *c*—*d* are very weak. This feature is very pronounced for the spectra No. 1, 2, 3, 5, 6, 7. In the case of the spectrum No. 4, which is strongly exposed, the lines in the interval *c*—*d* are fairly dense, but much more distinct than in the case of spectrum No. 9. This probably means that the lines appearing with noticeable density are less numerous in the case of the spectrum 4.

Finally we have to consider the exceptional type of spectrum obtained by Lord Rayleigh.

Apart from the green auroral line (5577) and a faint line 4166, the spectrum only shows the negative nitrogen bands, but with considerable density. But the negative bands in his spectrum are very much broader and more diffuse than they were found for any of those spectra which we ever obtained at Tromsø and Oslo.

We notice that also the lines of the comparison spectrum are very broad and have the appearance of double lines. In this way I think that the curious structure of the sequence at 4708 may be explained. But even if due account be paid to dullness of the image, the negative bands are broader than usual. This broadness may be accounted for in the following way:

The intensity of successive members of each of the three sequences corresponding to $n_2 - n_1 = 2.1$ and 0 may fall off less rapidly than usually found for the auroral spectra. As we shall see later on, the intensity of the line (1.3) is usually very much weaker than (0.2) from the Rayleigh spectrogram they appear to be of almost equal strength.

The extraordinary appearance of the Rayleigh bands may be accounted for by assuming an extraordinary intensity distribution among the oscillatory bands, resulting from a change of probability of the various vibrational transitions. This change of intensity distribution of the oscillatory bands combined with the dull image given by the instrument, will account for the appearance of the Rayleigh spectrum. It is, however, not necessary to assume that his spectrogram corresponds to more intense and broad striations due to rotational lines.

Thus the Rayleigh spectrum is explained without assuming that an unusually high temperature should have existed in the auroral region during this particular auroral display.

§ 14. Variation of the auroral spectrum with altitude.

Before the year 1922, when the investigations here described were commenced, it was a current idea that the atmosphere, say above 100 Km, mainly consisted of light gases like hydrogen and helium, and the green auroral line was supposed to originate from an unknown gas: geocoronium. Although the knowledge acquired at that time regarding the properties of matter had shown that the periodic system of elements gave no room for such an element, still considerable interest is attached to the question as to whether the auroral line might originate from a gas with a molecular weight essentially smaller than that of nitrogen.

In that case we should expect to find that the intensity of the green auroral line relative to that of the principal nitrogen bands would increase upwards.

Apart from these particular questions as to the origin of the green auroral line, investigations of the possible variation of the auroral spectrum with altitude, call for great interest, as it might give us some valuable information about the constitution of the upper strata of the atmosphere.

Thus the green auroral line can be followed in the spectroscope to very great altitudes along the auroral streamers, and if the intensity of the nitrogen bands relative to that of the green line increased upwards, then we would know that nitrogen is a dominating component of the atmosphere to the very extreme limit of the atmosphere.

If an auroral form (arc, drapery or ray) was sufficiently intense the experiment might be carried out in the following way:

By means of the lens in front of the slit, a picture is formed of the auroral form in such a way that the slit is parallel to the direction of a streamer on the picture. Each small interval of the slit would then only receive light from a certain height-interval of the auroral streamer and a single spectrum would show the variation of the composition and the intensity distribution of the auroral spectrum upwards. Such a procedure is not possible with the present spectrographic technique. Its application also meets with the difficulty that the intensity of the auroral streamers undergoes great changes as we pass from the lower to the upper limits.

It is, however, possible to find a procedure which enables us to take two spectrograms which we know correspond to a considerable difference of altitude. Such spectrograms might be obtained in various ways.

As it is well known, most aurorae have their lower limit at an altitude of nearly 100 km, but every now and then an auroral display may appear considerably higher. We might then try to obtain spectra of aurorae appearing at various altitudes.

In order to carry out the investigation along these lines, it would be necessary to combine the spectrographic exposures with height measurements of the aurorae. This procedure meets with the difficulty that aurorae with their lower limit considerably higher than 100 km are fairly rare and usually faint. It would therefore be difficult to obtain a spectrogram of such aurorae with sufficient density, and taken in such a way as to be comparable with the spectrum taken from the low aurorae. It would be more or less a matter of chance and good luck to obtain two comparable spectra of this kind.

In order to make sure whether and how the auroral spectrum varied with altitude, I therefore adopted a simpler method which would have greater chance of leading to a positive result within a reasonable time.

From the experience which has been gained through the auroral height measurements performed in accordance with Størmer's method, we know that the ordinary types of arc drapery shaped arcs and draperies reach down to altitudes of about 100 km. If we take one spectrum from the light near the bottom edge, and another from parts near the top of the streamers, the two spectra will correspond to a difference of altitude which can be roughly estimated on the basis of our height measurements.

In February 1923 I went to Tromsø mainly for the purpose of trying to study the variation of the auroral spectrum with altitude. A weak aurora appearing on March 4. was not favorable for these investigations. On March 11. fairly intense aurorae were playing for several hours between 20^h and 24^h. This aurora was of the most common type. It consisted of arcs and drapery-shaped arcs with radiant structure. They had the ordinary greenish colour. This auroral display was just of the type wanted for my experiments. I used the two small glass spectrographs. To increase the light power the cylindrical lenses were put in front of the photographic plates. Previous tests had shown that the plate Imperial Eclipse Ortho gave a density of the green line similar to that of the negative nitrogen bands.

The condenser lens previously described was put in front of the horizontally directed slit. The collimator of each instrument carried a sight-arrangement, which made it possible to direct the axis of the collimator towards any desired point of the sky. Both spectrographs were in operation. During the observations the instruments were kept almost like a gun (compare fig. 3 and 4). At first the collimator axis was directed towards the lower limit of the drapery shaped arcs. This first exposure took about half an hour. Then the slide of the plateholder was moved and a new exposure was taken on the same plate, but in this case the collimator axis was always directed towards the upper part of the streamers near the upper limit.

As the aurora is less intense near the upper limit, we continued the exposure for three hours.

Finally an intensity scale was taken *on the same plate*, by taking three spectra of a Ne—He tube corresponding to exposures 5,10 and 20 seconds. On one of the two plates the spectrum corresponding to the upper limit was too weak as compared with that of the lower part of the aurorae.

The exposure with the second spectrograph was very successful. (Reproduced on Pl. III No. 1). The spectra have just the right density for accurate intensity measurements. From the experience gained through previous work on the length of ray streamers of various auroral forms I estimated that the two spectra corresponded to a difference of altitude varying from 50—80 km. Also the next evening we had very good opportunities for work. The northlight set in at 21^h in the evening with drapery-shaped arcs of the ordinary type and kept on almost continuously until $1^h\ 45^m$ in the morning.

Plates and instruments were the same as those used the previous night, but we adopted a somewhat different procedure. The slide carrying the plate-holder was very accurately made, and it was possible to expose alternately the upper and lower limits When the slide of the plateholder was in one position (marked 3), the collimator was directed towards the lower part of the streamers, and when it was in a position indicated by 3.5 on the scale, the instrument was directed towards the tops of long streamers.

Every now and then, when the auroral band showed no particularly high streamers, we put the plateholder on the mark 3 and exposed on the lower part. As soon as the streamers became longer, the slide was put on the mark 3.5 and exposure was made near the top of the streamers.

In this way we obtained also that night one very good plate giving the two spectra to be compared with a very suitable density. A reproduction of the plate, showing the two auroral spectra (h_1) and (h_2) corresponding to the lower and upper limit respectively, as well as the intensity scale, is given on plate III No. 2. In No. 3 of the same plate the spectra are reproduced on a still larger scale. Both nights arcs, draperies and drapery-shaped arcs were formed in rapid succession from the northern sky to the south of zenith.

For the success of our method of investigation it is essential that the auroral form must have a certain height above the horizon nor must it be too near the zenith.

Our exposures were therefore made in such a way that the average height above the horizon was about the same for both the lower and upper limit. In this way we obtain that our measured intensity variations need no correction for atmospheric extinction. This correction will at any rate be of the same order of magnitude as the experimental error.

After these two successful nights bad weather set in, and kept on for nearly the rest of my stay at Tromsø. Only on March the 25th was an aurora observed. We obtained a plate with spectra corresponding to the upper and lower limits, but in this case the spectrum for the lower part was too dense, and that of the upper part too weak, so they could not be utilised for the study of variations in the relative intensity of the lines.

During the four weeks I had at my disposal at Tromsø, I had thus been able to carry out the investigations which formed the main object of my journey. I had obtained two plates giving comparable spectra corresponding to two levels of the atmosphere, with a difference in altitude of about 60 km.

§ 15. Conclusions to be drawn from the auroral spectrograms corresponding to different altitudes.

If we compare two auroral spectra corresponding to different altitudes, we notice at a glance two characteristic differences:

1. The intensity of the green auroral line relative to that of the negative nitrogen bands *decreases* with increasing altitude.
2. Some lines, especially three, appearing in the interval 4708 and 4278 are relatively much more intense in the spectrograms corresponding to the greater heights.

Although no comparison spectrum was taken, the wave-lengths of the weaker lines might be found by means of the green auroral line and the principal negative nitrogen bands.

The spectra were taken with a broad slit and with a cylindrical lens in front of the plate. We cannot therefore expect to obtain any great accuracy. We should also remember that a broad slit will produce a displacement towards shorter waves of the maximum density of the negative nitrogen bands. When these lines are used as standards, this displacement will have the effect that we obtain too large wave-length values for the faint lines.

The result of the direct measurements of the two spectra corresponding to the upper limit is given in Table VII.

The lines used as standards are marked with a cross (*).

Table VII.

$^{11}/3$ 1923 Pl. III No. 1 b	$^{12}/3$ 1923 Pl. III No. 2 b	Corresp. auroral lines from Tb. VI	Probable Origin
5577*	5577*	-	-
-	4883	4857	?
4708*	4708*	-	-
-	4660	4652	N. B. (1.3)
4564	4566	4552	N. B. (2.5)
4442	4444	4480—4424	N. B. P. B. (5.7)
4352	4353	4346	P. B. (0.4)
4278*	4278*	-	-
4196	4188	4199—4183	N. B. (2.3)
-	4078	4078	?
3986	3992	3998—3981	-
3914*	3914*	-	-

The first and second column contain the values corresponding to the spectra from March 11 and 12 respectively.

As the spectra previously measured are taken with long exposures, the spectrograph in those cases has no doubt received much light corresponding to upper limits. The lines appearing on our spectra for the upper limit are thus to be found among the lines previously tabulated. These lines are given in the third column. On account of the broad slit used and the inaccuracy of the determinations there may be some doubt as to the right corresponding line.

The most conspicuous of the enhanced lines are the three for which we find the wave-lengths 4565, 4443, 4353. The first one is most probably identical with 4552 which is the negative band $n_1 = 2$, $n_2 = 5$. The second 4443 is somewhat broad and it probably consists of two lines. The nearest ones previously found are 4480 which is a negative N-Band and 4424, the origin of which is not certain. It may perhaps be the positive band 4416. The third line is no doubt identical with the positive band (0.4) of nitrogen.

Thus it appears that at any rate some of the enhanced lines belong to the negative and positive group of nitrogen.

Hence we conclude that the auroral luminescence as the altitude increases is transformed in such a way, that some of the lines of the negative group, corresponding to the higher vibrational quant numbers, and some lines of the 2nd positive group become stronger as compared with the lines of the principal series of the negative bands.

It is possible that also lines which do not belong to the negative group and the second positive group may become relatively stronger with increasing height. Such lines are perhaps 4078 and 4883, the origin of which is quite uncertain.

§ 16. Quantitative measurement of the change of relative intensity distribution for auroral spectra corresponding to different altitudes.

The general method and procedure to be followed in the determination of the relative change of the intensities of lines appearing in the two spectra were delt with in a previous paragraph. The relative change of intensity is measured by means of the quantity D given by equation (8). If no variation takes place $D = 1$, therefore $1—D$ may be said to give a measure of the relative change.

100 (1—D) might be said to give the relative intensity variation in per cent.

As seen from equation 8, D only depends on the values $\varphi(u)$ for the various lines, and the value of $\varphi(u)$ is taken from the intensity curve of the type given in fig. 12. It is, however, to be remembered that when we compare two spectra, we have to use the intensity curve $\varphi(u)$ which we obtain from the intensity scale photographed on the same plate as the spectra we compare.

The photographic density is indicated by the deflection (u) of the galvanometer of a Moll registering microphotometer. We take registrams of the three spectra, which are taken with times of exposures which are in proportion 1 : 2 : 4. From these registrams we easily construct the curve $\varphi(u)$ where u is ordinate and t^p is the absciss. The value of (p) was determined by Mr. J. Aars for those plates which were used for intensity measurements. He found:

For Imperial eclipse $p = 0.904$
» » » ortho $p = 0.938$.

For the study of intensity variations with altitude, we used imp. ecl. ortho plates. Similar registrams are taken for the two spectra to be compared.

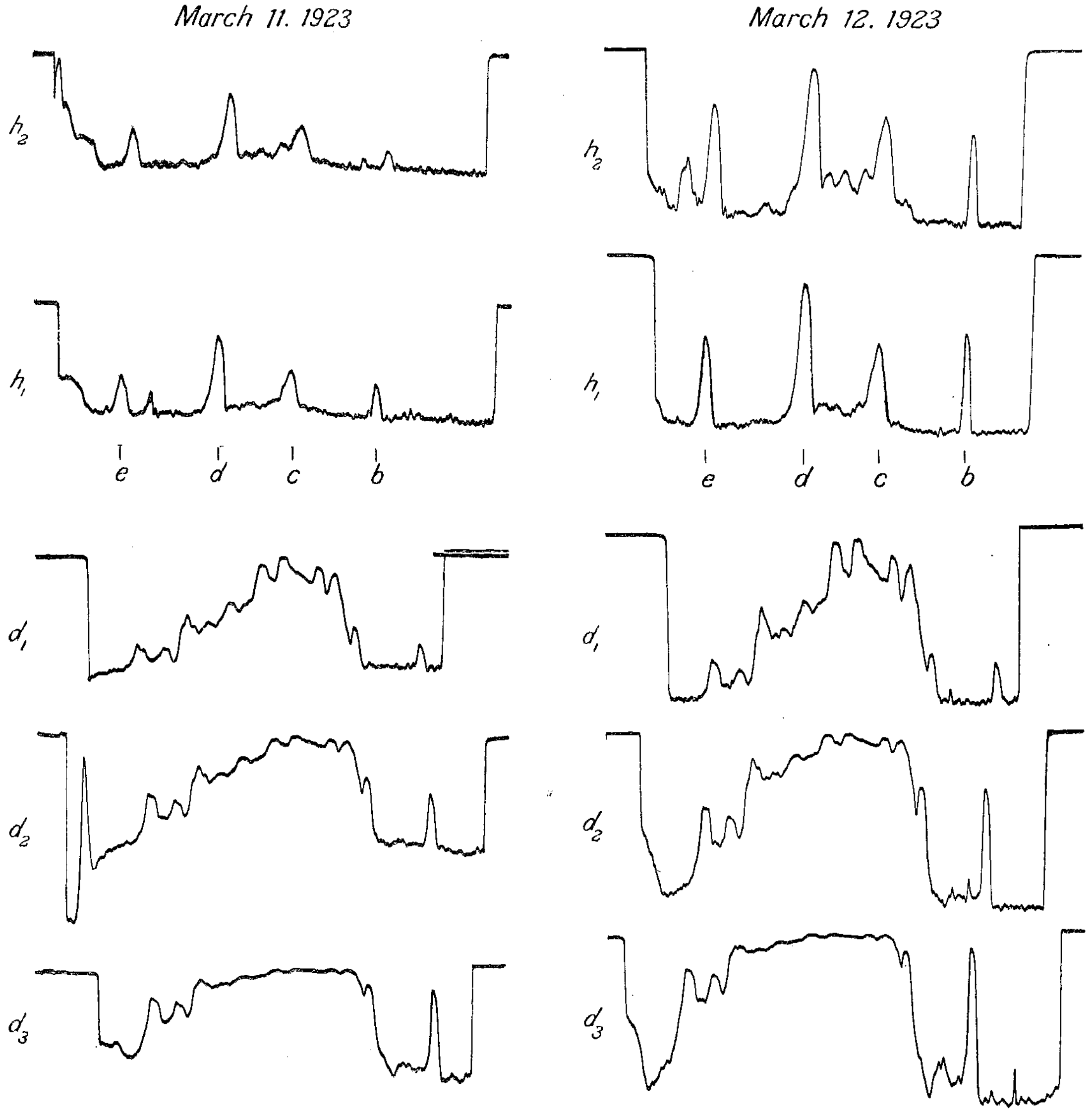

Fig. 13.

The complete set of registrams for the two plates obtained March 11th and 12th is given in fig. 13. The curves h_1 and h_2 correspond to auroral spectra of the lower and upper limit respectively. The curves d_1, d_2 and d_3 correspond to the spectra of the density scale. From the latter diagrams we determine the curve.

The diagrams h_1 and h_2 give us the u values u_a, u_b for the various auroral lines and from the $\varphi(u)$ curve we select the corresponding values $\varphi(u_a)$, $\varphi(u_b)$ which enter into the equation (8).

In the determination of the $\varphi(u)$ values, we must take care that all the registered curves correspond to the same sensitiveness of the microphotometer.

In order to reduce the deflections (u) to the same sensitiveness, we register on each diagram a short line which we obtain by introducing an opaque screen in front of the thermopile. This line corresponds to infinite density and gives us u_∞. Similarly we determine u_0 corresponding to zero density, or more definitely to the unexposed part of the plate. If we take diagrams of the same plate with varying sensitiveness of the microphotometer, the deflection for any density was found to be strictly proportional to $(u_{\infty} - u_0)$ and thus $\frac{u}{u_{\infty} - u_0}$ gives a relative value for the deflection, reduced to a standard sensitiveness of the microphotometer.

As will be seen from the spectrograms and the density-curves, the auroral line and the principal lines of the negative group appear on the plate with a density of the same order of magnitude, and in this respect we should have the most favourable conditions for an accurate determination of the change in the relative intensity of the auroral line.

The change in intensity of the weak lines — e. g. 4565, 4443 and 4353, as compared with the principal lines of the negative bands, are more difficult to measure accurately, on account of the great difference of density of the lines to be compared.

On the plate from March the 11th some of the weak lines are only visible on the plate, corresponding to the upper limit. It is therefore impossible to determine the relative change in the intensity of the weak lines from these spectrograms. But the two spectra on this plate are most important, because they clearly prove the existence of the effect, consisting of a relative increase of intensity as we pass upwards.

From the original plates, as well as from the photometric curves. we notice that on the spectrogram which corresponds to the greater altitude, and gives the weak lines mentioned above, the principal negative lines are less dense than they appear on the spectrogram from the bottom edge, although on this spectrogram the weak lines are hardly visible.

On the plate from March the 12th some of the weak lines appear also on the spectrogram for the lower limit, but they are too weak for accurate intensity measurements. The deflections $(u - u_0)$ are small and therefore relatively inaccurate, and further the photographic threshold effect becomes more conspicuous, and is likely to introduce relatively large errors.

The lines which appear on the plate from March the 12th with measurable density in both spectrograms are 4565, 4463 and 4353, which will be denoted by α, β, γ, respectively. The relative values of $\varphi(u)$ for the lines to be compared are given in Table VIII.

Table VIII.

Relative values of $\varphi(u)$.

	March 11. Pl. III, No. 1		March 12. Pl. III, No. 2 and 3	
γ	Lower limit	Upper limit	Lower limit	Upper limit
b 5577	78	55	105	70
c 4708	113	115	89	84
α 4566	-	-	36	41
β 4444	-	-	33	39
γ 4353	-	-	35	38
d 4278	217	213	202	186
e 3914	100	100	100	100

The value of $\varphi(u)$ for the line 3914 is put equal to 100. The relative intensity variation of the green auroral line as well as that of the weak lines α, β, γ can be seen directly from the table.

It appears from the table that the relative intensity of the three principal lines of the negative band spectrum within the limit of error is independent of altitude. The variation shown by the spectra from March 12th for the line 4278 is no doubt due to inaccuracy of measurements resulting from the large photographic density of this line.

In order to obtain to relative variation of the green auroral line and of the weak lines relative to that of the principal negative bands, we calculate the value of D equation (8), for each of the three principal lines, indicated by c, d and e and take the mean value.

Table IX gives the result for the green auroral line (b).

If we indicate the intensity of one of the principal negative bands by (n) and that of the auroral line by (b), the double proportions D of Table IX are formed in the following way:

$$D = \frac{\left(\frac{b}{n}\right) \text{ upper limit}}{\left(\frac{b}{n}\right) \text{ lower limit.}}$$

Table IX.

$$D\,(b.n) = \frac{\left(\frac{b}{n}\right) \text{ upper}}{\left(\frac{b}{n}\right) \text{ lower.}}$$

	March 11. Plate III, No. 1	March 12. Plate III, No. 2
D (bc)	0.69	0.71
D (bd)	0.72	0.72
D (be)	0.71	0.67
Mean	0.707	0.700

A preliminary result of the quantitative determination of the relative intensity variation of the green auroral line was first given in my article "Nordlicht" in "Handbuch der Experimental Physik" (V. 25, p. 447), which I wrote in 1926. Some further details were given in a subsequent paper (19).

The auroral line was compared with the line 4708, and these preliminary measurements gave for March 11th $D(bc) = 0.69$ and for March 12th $D(bc) = 0.76$. The final more careful measurements gave almost identical average D-values for both evenings. This shows that when we deal with the ordinary type of draperies and drapery-shaped arcs we operate in the same height interval every evening and with the same properties of luminescense with respect to the intensity of the green line relative to that of the principal nitrogen bands.

The average lower limit of arcs, drapery-shaped arcs and draperies was found by Vegard and Krogness[1] to be 109, 107 and 110 km respectively. For the average upper limit of draperies and drapery-shaped arcs, we found 176 and 174 km. These numbers correspond to the Haldde Observatory, Bosekop, and Gargia, but the results are also applicable to Tromsø, which has very much the same position relative to the auroral zone.

I should estimate that the spectrum for the lower limit corresponds to a height, which on an average is situated 5 km above the extreme lower limit, and therefore the spectra of the lower limit should correspond to an average altitude of 113 km. In a similar way, we may estimate that the spectra for the upper limit correspond to an altitude about 15 km below the extreme upper limit, or to an altitude of 165 km.

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[1] L. Vegard and O. Krogness: Position in space of the Aurora Polaris. Geophy. Publ. I, No. 1, 1920.

Thus the spectra of the lower limit, and those of the upper correspond to an average difference of altitude of 50—60 km.

Table X gives for the three weak lines indicated by α, β, γ, the D-values, which are now formed in the following way:

$$D = \frac{\left(\frac{\nu}{n}\right) \text{Lower limit}}{\left(\frac{\nu}{n}\right) \text{Upper limit}}$$

where ν indicates the intensity of one of the weak lines α, β and γ and (n) as before the intensity of one of the principal negative bands.

Table X.

$$\mathrm{D}(\gamma n) = \frac{\left(\frac{\nu}{n}\right) \text{lower}}{\left(\frac{\nu}{n}\right) \text{upper.}}$$

Line α	Line β	Line γ
$D(\alpha c) = 0.83$ $D(\alpha d) = 0.81$ $D(\alpha e) = 0.88$	$D(\beta c) = 0.80$ $D(\beta d) = 0.78$ $D(\beta e) = 0.85$	$D(\gamma c) = 0.87$ $D(\gamma d) = 0.85$ $D(\gamma e) = 0.92$
Mean 0.84	0.81	0.88

All three lines show about the same variation of intensity relative to that of the negative bands, but it is to be remembered that the present D-values cannot claim any great accuracy for the reason already mentioned.

Relative to the green auroral line not only the negative nitrogen bands, but all lines of measureable intensity in the blue and violet part become stronger as we pass from, say 100 km, towards larger altitudes within the auroral region.

This opens out the possibility of investigating the relative intensity variation with altitude of the green line by means of suitable absorption-filters. Experiments in this direction were planned and commenced by the writer in 1924. The intention was to photograph the auroral display simultaneously with two filters and compare the intensity distribution of the two pictures.

First of all we had to try to obtain auroral pictures through the filters. Such exposures were made by my assistent Mr. E. Tønsberg, but with the photographic material, which we had at our disposal at that time, it was not possible to obtain good auroral pictures in this way, and after a first attempt no further effort was made.

After the new observatory at Tromsø was errected Mr. L. Harang[1] took up the work along the same lines and then with remarkable success.

By using times of exposures varying between 40—80 seconds he obtained simultaneous photographs with two nearly identical cameras — one provided with a green filter, the other with a blue filter in front of the lens.

In accordance with the results of my previous spectrographic observations, he found that on the picture taken with a green filter, the intensity diminishes much more rapidly

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[1] L. Harang: Filteraufnahmen von Polarlicht Z. S. f. Geophysik 7, 324, 1931.

with increasing altitude than on the picture taken with a blue filter. The magnitude of the effect is in very good agreement with my spectrographic results.

It must, however, be remembered that Harang compares the green luminescence mostly consisting of the strong green line with the total emission in the blue and violet part. In this part the principal negative nitrogen bands are very dominating, but in addition also a number of other lines appear which show a still greater increase of intensity upwards as compared with that of the green line. It is therefore to be expected that Harang will find an effect somewhat greater than that found by the writer, by comparing the green line and the principal negative bands. As a matter of fact Harang finds for the same height interval a somewhat greater effect than found by me.

In this connection it must also be borne in mind that my estimate of the difference in height corresponding to the two spectra is of course somewhat uncertain. Everything taken into account, we may say that the results obtained by Harang, by means of the filter-method and my spectrographic results agree remarkably well.

In 1929 Størmer and Moxnes obtained a spectrogram from very long auroral rays which were exposed to sunlight.[1] This spectrum he compared with that of another plate from an aurora of the ordinary height and drew the conclusion that the green line is relatively much weaker for the sunlit aurorae.

In a previous paper[2] the writer pointed out that the spectrograms obtained by Størmer and Moxnes for various reasons were not comparable. On the other hand it was stated that spectra like those taken by Størmer and Moxnes — when comparable — are bound to show a very large effect in the direction mentioned. The two spectra correspond to a great difference in height and therefore the variation of relative intensity of the green line should be very large merely on account of the height effect which was discovered by the writer in 1923.

How far an aurora exposed to sunlight has a different spectral intensity distribution than another *at the same altitude* not exposed to sunlight is still an open, but most important, question.

§ 17. The typical intensity distribution within the auroral spectrum.

As we saw in the previous paragraphs, the intensity distribution within the auroral spectrum shows considerable variations. It may vary from one display to another, as found for the intensity of the red line 6318, it may differ somewhat for various auroral forms, and for the same type it varies with altitude. Finally we must also take into consideration that the apparent intensity distribution will vary with the zenith distance, on account of the fact that the loss of energy due to scattering increases with diminution of the wave-length. Therefore the long waves will be more prominent near the horizon than near the zenith.

Usually we direct the instruments towards points of the sky lying fairly high above the horizon, and the instruments are very rarely directed towards zenith. The intensity distribution obtained on our spectrograms thus corresponds to an average height above the horizon of say 30—45°.

On account of this variability, we cannot speak of any definite intensity distribution within the auroral spectrum. If, however, we take spectra with exposures lasting for weeks, we obtain a fairly constant type of spectra, which give a kind of average or

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[1] C. Størmer, Z. S. f. Geophysik 5, 177, 1929.

[2] L. Vegard, Z. S. f. Geophysik 9, 42, 1930.

typical intensity distribution. But even spectra obtained in this way, may show considerable differences as regards the relative intensity of individual lines. Thus we find that the red auroral line 6318 may keep strong during a period of several months and remain extremely weak for other long periods. Also the average relative intensity of the green auroral line seems to show long periodic variations.

On account of the considerable variability of the intensity distribution within the auroral spectrum, we can only give a somewhat rough determination of the typical intensity distribution — as we may obtain it from spectra with long exposures. Although it is most important — as already seen — to measure the changes of the intensity distribution with great accuracy, the determination of the typical distribution does not call for any great precision.

The general theory and method for the determination of the relative intensities of lines appearing at different parts of the auroral spectrum, were given i a previous paragraph.

In order to carry out such measurements, it is necessary to have a light-source for which we know how the energy is distributed on the various wave-lengths. For this purpose I found it most convenient to use the spectrum of the sun or rather the spectrum of diffuse daylight. The energy distribution of this source may differ in the ultra-violet part, but is fairly constant for the visible spectrum, and will undoubtedly be sufficiently well-defined for the present purpose.

The energy distribution within the spectrum of the sun (or the value of E_λ as a function of λ equation 9), is shown in the curve fig. 14, constructed from values given in a work of C. G. Abbot.

For the final determination of the intensity distribution, we used spectra from the quartz spectrograph and the large glass spectrograph.

With each spectrograph spectra of diffuse daylight were taken on each sort of photographic plate used for the auroral spectra to be treated. A series of such spectra were taken on the same plate with varying time of exposure. In this way we could, for each plate, construct a density curve $t^p = \varphi (u)$ like fig. 12. Reproductions of such spectra are shown in Pl. III No. 6 and 7.

By means of the Moll microphotometer, registrams were taken of a sufficient number of such spectra. For the sake of illustration some registrams of sun-spectra corresponding to various plates and spectrographs are shown in fig. 15.

Curve A corresponds to a spectrum taken on Imperial Eclipse plate with the quartz spectrograph with one prism. Fig. 15 B shows curves of sun-spectra taken with the quartz spectrograph with two prisms. The curves No. 1 and 2 correspond to Imperial Eclipse ortho No. 3 and 4 to Imperial Eclipse plates.

The curves Fig. 15 C correspond to spectra taken with the large glass spectrograph (No. 1 Imp. Eclipse. No. 2 Imp. Eclipse ortho).

From these curves we derive in the way described in § 11, the quantity $Q = k_\lambda f(\lambda)$ by means of equation (11). The quantity $\frac{d\lambda}{ds}$ for any wave-length was found by means of the dispersion curves constructed for each spectrograph.

Some $Q(\lambda)$ curves are given in figs. 16 and 17. Fig. 16 No. 1 corresponds to the quartz spectrograph with one prism and Imperial Eclipse plates. Fig. 16 No. 2 corresponds to the same instrument with two prisms and Imperial Eclipse ortho plates.

The curves fig. 17 apply to the large glass spectrograph. No. 1 corresponds to Imperial Eclipse, No. 2 to Imp. Ecl. ortho. plates.

After the exposure of the aurorae was finished, and before the plate was taken out of the spectrograph, three spectra from a constant light-source were taken, with times of exposure e. g. in the proportion 1 : 2 : 4.

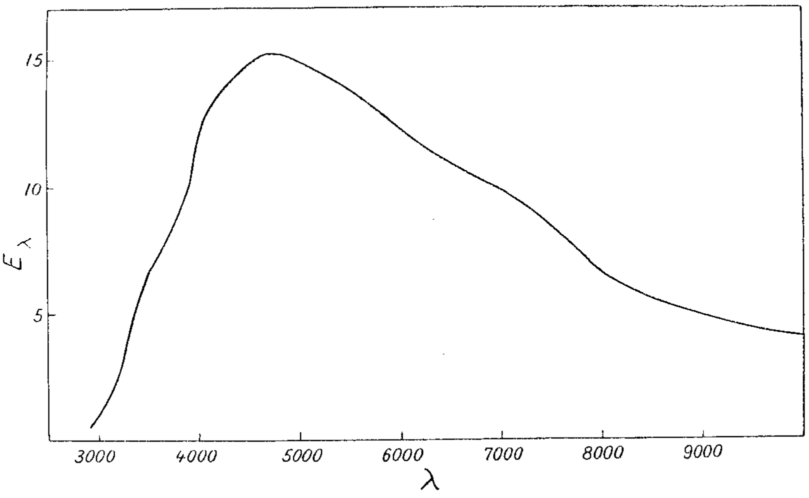
15
10
5
E_λ
3000
4000
5000
6000
7000
8000
9000
λ

Fig. 14.

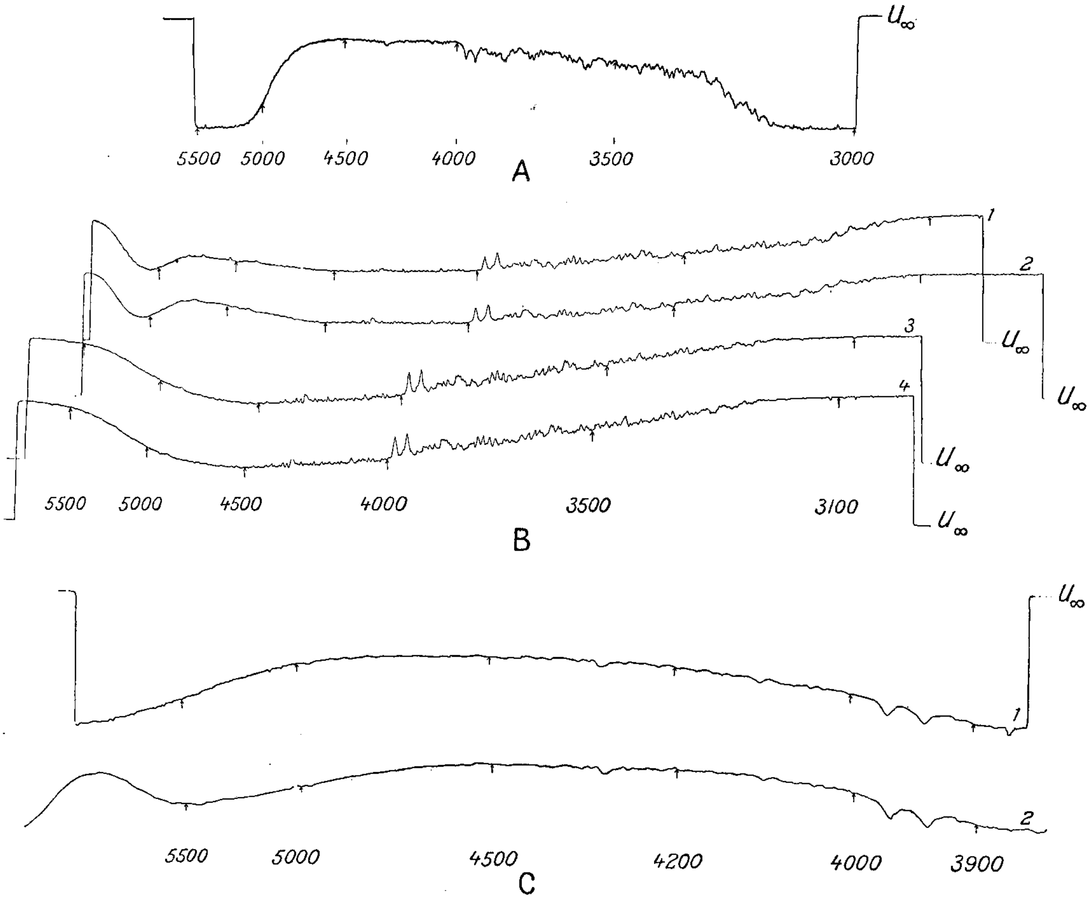
U_∞
5500
5000
4500
4000
3500
3000
A
1
2
3
4
U_∞
U_∞
U_∞
U_∞
5500
5000
4500
4000
3500
3100
B
U_∞
1
2
5500
5000
4500
4200
4000
3900
C

Fig. 15.

These spectra gave the density scale to be used for the intensity measurements within the auroral spectrum on this particular plate. Reproduction of plates showing auroral spectrum and density scale are given on Pl. III. Nos. 4 and 5.

The microphotometric curves for those auroral spectra which were used for the determination of the intensity distribution are given in figs. 18 and 19. The four curves fig. 18 A correspond to spectra taken with the quartz spectrograph with one prism and are reproduced on Pl. II. Nos. 1—4.

Fig. 18 B. shows curves of the density scale corresponding to the spectrum Pl. II, No. 4.

The two upper curves Nos. 1 and 2 of fig. 19 correspond to the two spectra Pl. II, Nos. 5 and 6, which were taken with the quartz spectrograph, after the introduction of a second prism. Curve No. 1 corresponds to an Imp. Ecl. plate. No. 2, showing the green auroral line, corresponds to a spectrum on Imp. Ecl. ortho plate.

The curves Nos. 3, 4, 5 and 6 correspond to spectra Pl. II, Nos. 9, 12, 10 and 11 respectively. Curves Nos. 3 and 4 correspond to Imp. Ecl. plates. Nos. 5 and 6 to Imp. Ecl. ortho. We notice the high transparency of the plate between the lines. This shows that the general fog, which we obtained on our first plates had now disappeared.

From the spectra taken with the large glass spectrograph only somewhat strong lines can be measured, but they show in this case a suitable density. When for any plate the density curve is found, the values of $\varphi\ (u)$ can be found for any line of the auroral spectrum.

The corresponding Q values are found from the $(Q\ \lambda)$ curve and the relative intensity of the lines is found by means of equation 12.

On the spectrograms from the two large spectrographs we have treated all lines which appear with measurable density: 23 lines in all. A considerable number of lines obtained with the small glass spectrographs within the spectral region of our measurements, must be supposed to have an "average" intensity smaller than the weakest lines measured on spectrograms from the large spectrographs in the same spectral region.

It must be remembered that some of these lines for short intervals and in certain auroral displays, may appear with an intensity considerably larger than the average which we obtain by very long exposures. It is also to be remembered that the measurements here described correspond to Imperial Eclipse or Imperial Eclipse ortho plates and they therefore give no information whatever about the intensity of lines appearing outside the region of reasonable photographic sensitiveness of the plate. Thus the result says nothing about the relative intensity of the second green line (b') or the lines appearing in the red part.

The relative intensities of the lines measured on the various spectrograms are given in Table XI, where the intensity of the negative bands 4278 is put equal to 100.

Some preliminary results regarding the intensity distribution — which were given in the "Handbuch der Experimental-physik XXV — differ from the final results given in this communication. This difference is due to the omission of the dispersion factor $\frac{d\lambda}{ds}$ in the equations (10) and (11).

The relative intensity of the green auroral line was not measured from the spectra obtained with the quartz spectrograph, because the instrument was not in focus for that part of the spectrum.

The relative intensity which we found for the auroral line from the two plates measured, differs very considerably. This would indicate that the average relative intensity of the green auroral line, obtained by exposures lasting several months, may undergo considerable variations. The question as to the reality of such variations in a most

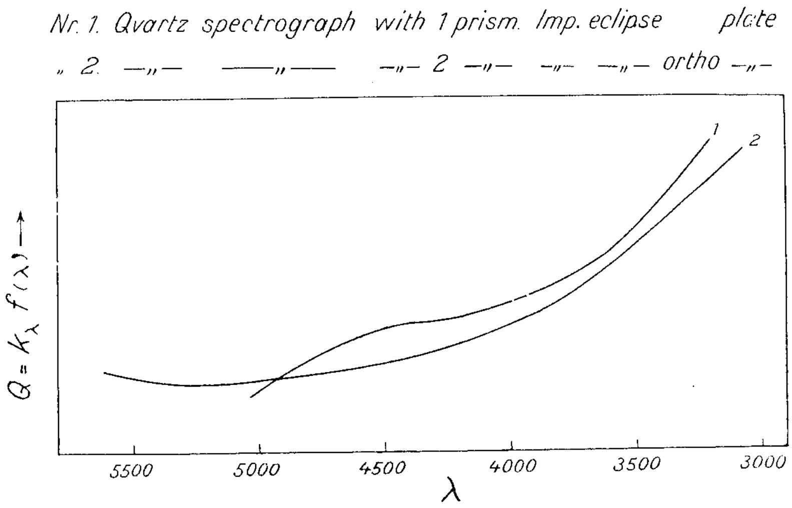

Fig. 16.

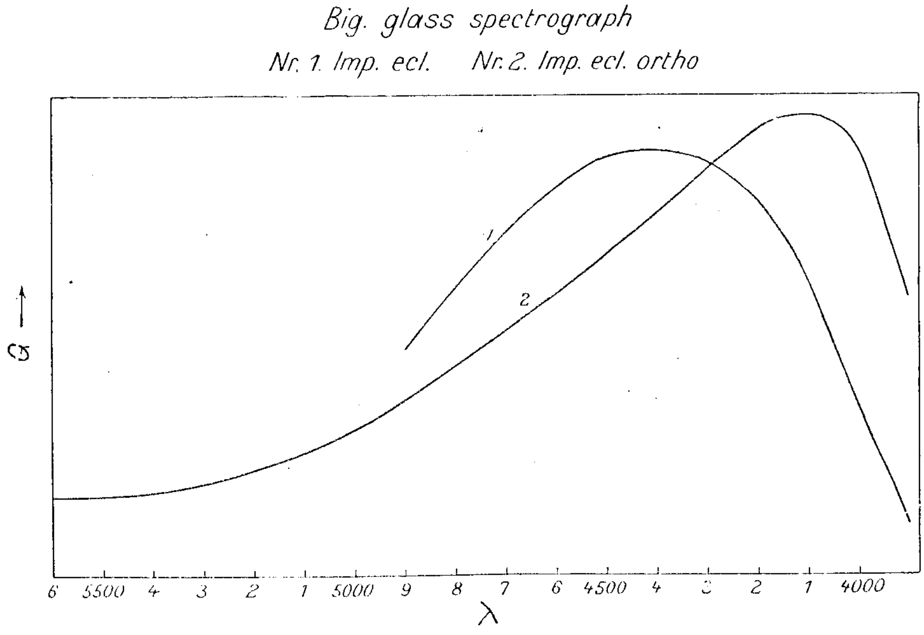

Fig. 17.

important one and ought to be tested by future measurements. We have already mentioned that the intensity of the red line 6318 undergoes changes of this type.

In the case of the spectrograms Pl. II, Nos. 1, 2 and 4 the strongest negative bands are too dense for accurate measurements, therefore the intensity of the weaker lines, as compared with that of the strong negative bands, is not very reliable for these spectra.

The average intensity distribution derived from all measurements is given in the last column of Table XI, and is graphically represented in Fig. 20 a.

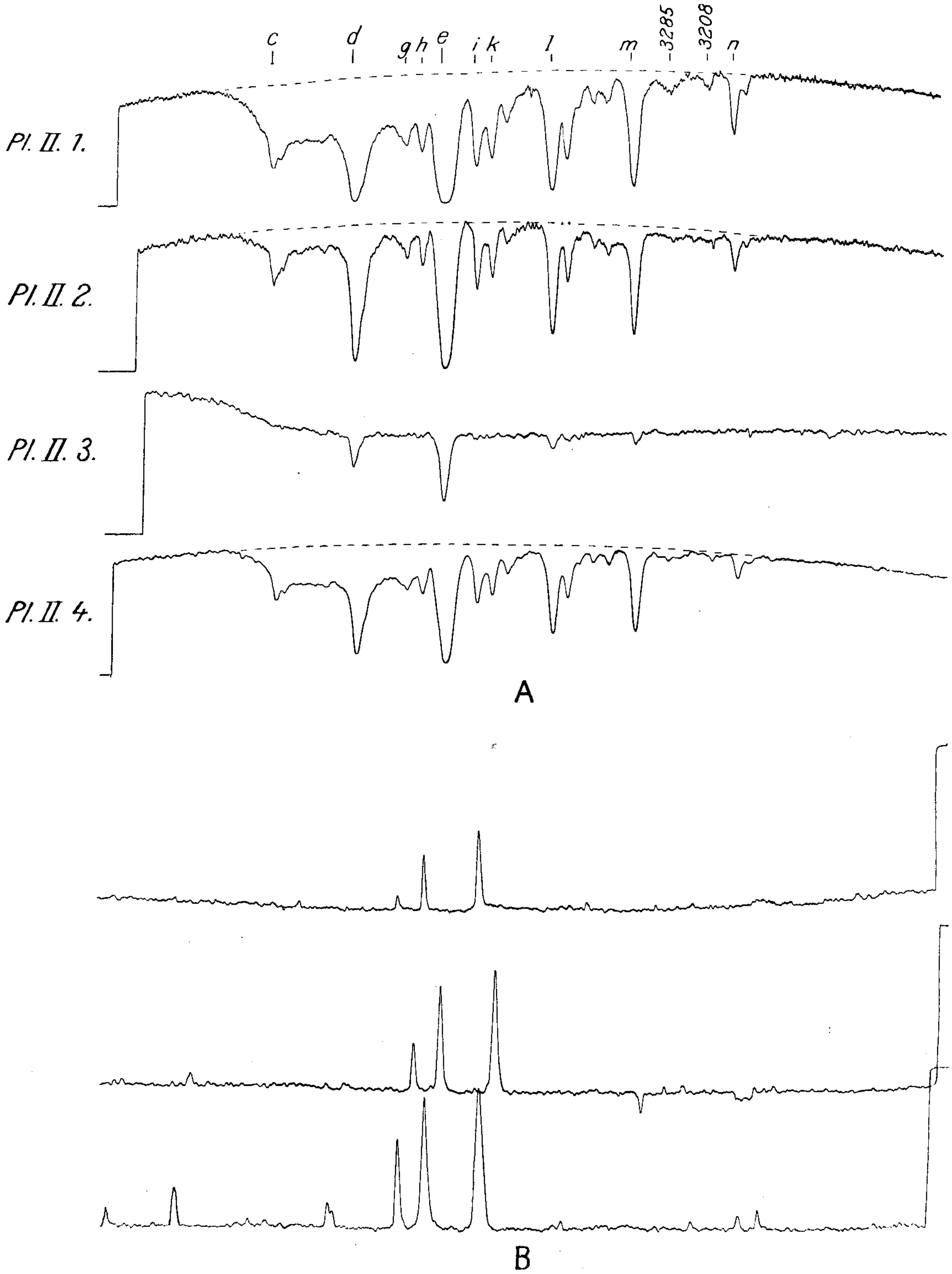

Fig. 18.

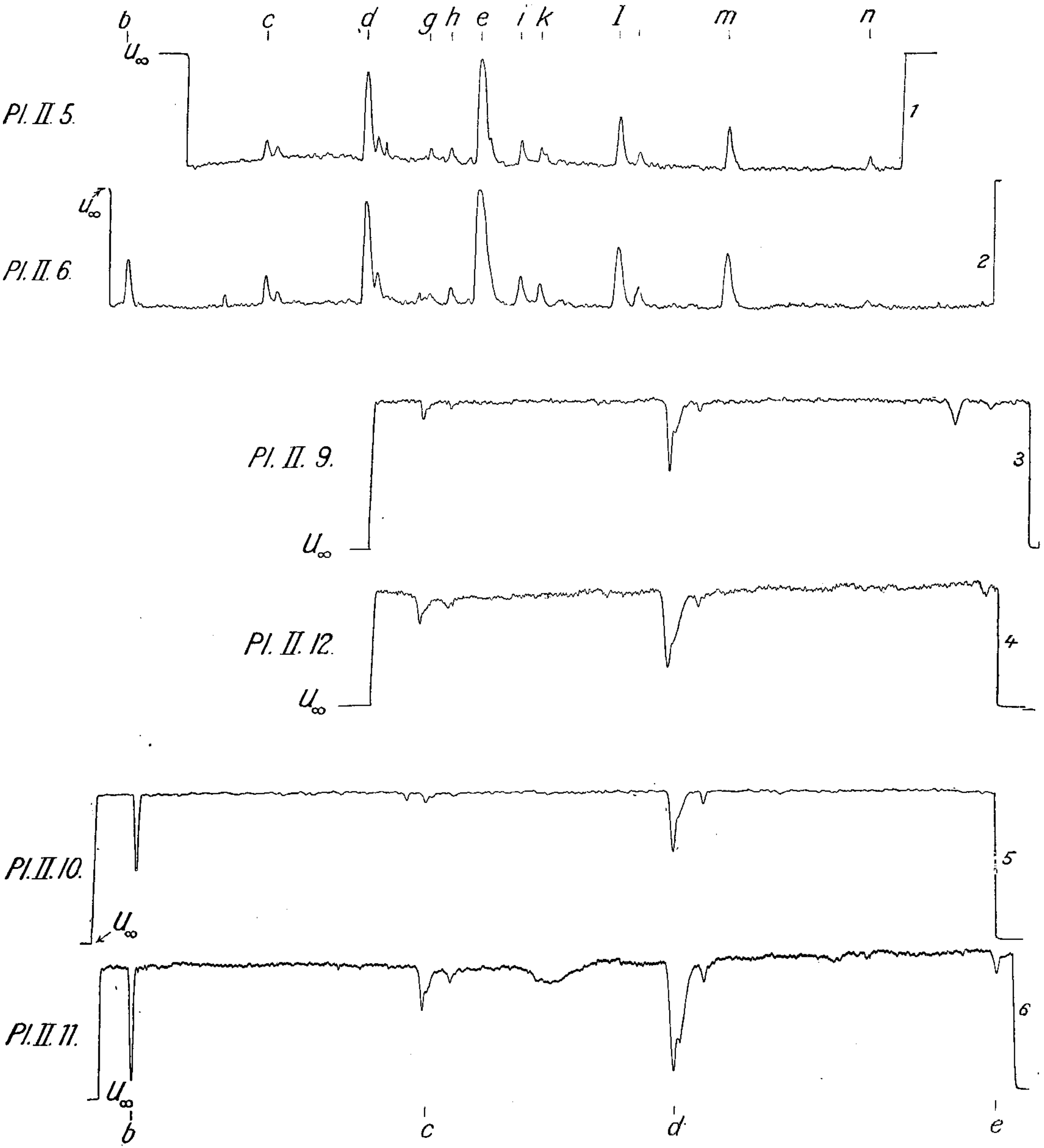
b
c
d
g
h
e
i
k
l
m
n
U_∞
Pl. II 5.
1
U_∞
Pl. II 6.
2
Pl. II 9.
U_∞
3
Pl. II 12.
U_∞
4
Pl. II 10.
U_∞
5
Pl. II 11.
U_∞
6
b
c
d
e

Fig. 19.

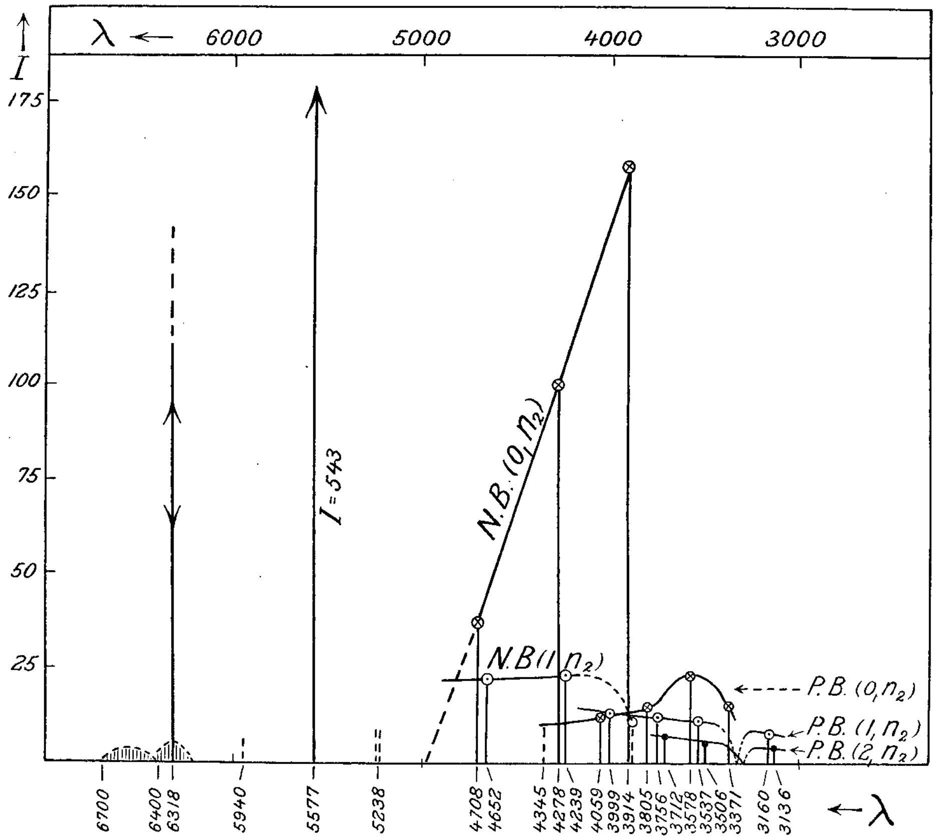

Fig. 20 a.

Table XI.

Intensity distribution within the auroral spectrum.

No.	Quartz spectrograph Pl. II 1	Pl. II 2	Pl. II 3	Pl. II 4	Pl. II 5	Pl. II 6	Large glass spectrograph Pl. II 9	Pl. II 10	Pl. II 11	Pl. II 12	Mean
5577	-	-	-	-	-	-	-	648	438	-	543
4708	41	19	-	40	25	28	39	49	45	50	37
4698	-	-	-	-	-	-	27	39	34	-	33
4652	29	15	-	30	17	15	25	-	20	28	22
4422	17	8	-	21	-	-	-	-	-	-	15
4278	100	100	100	100	100	100	100	100	100	100	100
4270	-	-	-	-	-	-	51	51	54	63?	52
4239	-	-	-	-	18	17	25	31	16?	22	23
4059	16	8	-	19	10	7	-	-	-	-	12
3999	16	9	-	19	10	9	-	-	-	-	13
3914	147	162	159	157	167	{140 120	-	-	-	-	158
3904	-	-	-	-	12?	-	-	-	-	-	12?
3805	18	11	-	19	11	9	-	-	-	-	14
3756	15	9	-	16	8	5?	-	-	-	-	12
3712	7	4	-	9	-	-	-	-	-	-	7
3578	32	19	28	27	18	13	-	-	-	-	23
3537	12	7	19	13	7	5	-	-	-	-	11
3506	5	-	-	5	-	-	-	-	-	-	5
3470	4	3	-	5	-	-	-	-	-	-	4
3432	4	4	-	5	-	-	-	-	-	-	4
3372	21	14	17	19	13	9	-	-	-	-	16
3160	10	7	-	8	4	2?	-	-	-	-	7
3136	4	4	-	5	-	-	-	-	-	-	4

§ 18. The influence of atmospheric extinction on the intensity distribution.

The intensity distribution given in Table XI and fig. 20 a, corresponds to the luminescence as it is observed near the surface of the earth, and is different from that existing in the auroral region. This difference is due to the fact that the atmospheric extinction — mostly caused by the scattering of light — is a function of the wave-length. According to Rayleigh the scattering coefficient is inversely proportional to λ^4.

Let a bundle of parallel rays enter the atmosphere with an intensity I_0 and in a direction forming an angle (z) with the vertical line, then the intensity (I) at the surface of the earth may be written:

$$I = I_0 \, p^{\sec z}$$

or

$$I_0 = \frac{I}{p^{\sec z}} \, . \tag{13}$$

The coefficient of transmission p depends on the wave-length, according to the formula of Rayleigh $l n p = -\frac{k}{\lambda^4}$. The values of p for various wave-lengths have been found by Muller, Abney, Langly and Abbot. Knowing the p values corresponding to any wave-length, we calculate the intensity distribution existing during emission in the auroral region by means of equation (13).

The average zenith distance (z) is approximately equal to 45° and taking e. g. the p values given by Abbot (Pertner-Exner p. 754)[1] the value $p^{\sec 45} = p^{1.42}$ can be found for any wave-length. The mean intensity distribution of the auroral spectrum corrected for atmospheric scattering is given in Table XII and graphically represented in fig. 20 b. The second column contains the mean intensity distribution given in the last column of Table XI. The intensity distribution corrected for atmospheric scattering is given in the 4th column of Table XII.

Table XII.

Intensity distribution I_0 corrected for atmospheric extinction.

λ	I	$p^{\sec z}$	I_0	
5577	543	0.65	409	-
4708	37	0.57	32	N (0.2)
4698	33	0.57	28	-
4652	22	0.56	19	N (1.3)
4422	15	0.52	14	-
4278	100	0.49	100	N (0.1)
4270	52	0.49	52	-
4239	23	0.48	24	N (1.2)
4059	12	0.43	14	P (0.3)
3999	13	0.42	15	P (1.4)
3914	158	0.40	194	N (0.0)
3904	12	0.39	15	-
3805	14	0.35	20	P (0.2)
3756	12	0.35	17	P (1.3)
3712	7	0.34	10	P (2.4)
3578	23	0.28	40	P (0.1)
3537	11	0.27	20	P (1.2)
3506	5	0.26	9	P (2.3)
3470	4	0.25	8	P (3.4)
3432	4	0.24	8	-
3372	16	0.22	36	P (0.0)
3160	7	0.15	23	P (1.0)
3136	4	0.14	14	P (2.1)

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[1] Compare Pertner and Exner: Meteorologische Optik p. 738, Wien — Leipzig — 1922.

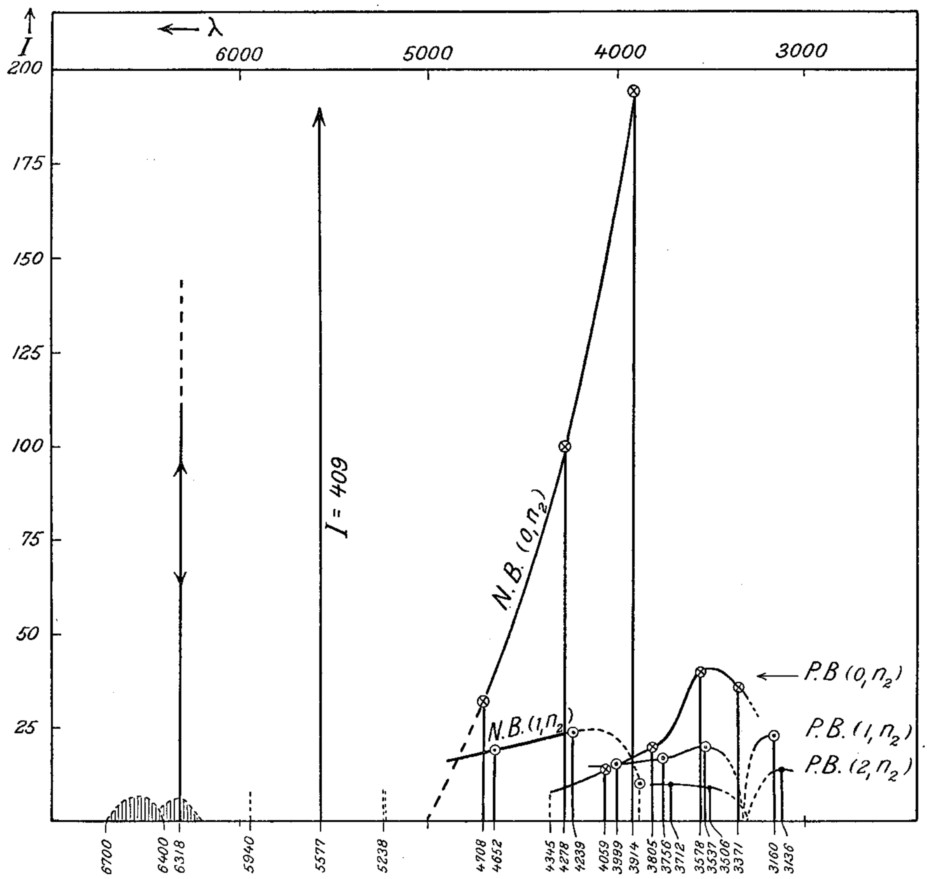

Fig. 20 b.

It appears from Table XII and fig. 20 b that the green line 5577 is by far the strongest. In the red-coloured aurora, the red line for which we found a wave-length 6318 probably comes next to the green line as regards intensity, but ordinarily or in "the average spectrum" the first two lines of the principal vibrational series (*o*, *n*) of the negative nitrogen bands come next to the green line as regards energy.

We notice also that the intensity of the lines of the principal series (*o*, *n*) diminishes very rapidly with increasing vibrational quant number n of the final electronic state of the negative band system. This rapid fall suggests that the line (0.3) with wave-length 5227 should appear in the auroral spectrum with an imperceptible intensity. Now, the line (0.3) has a position not far from that of the second green line — or rather group of lines — denoted by b'. The mean position of the group b' 5238 is so much greater that it cannot be identified with the negative band 5227. As the latter line, however, lies in the interval of the group b', it is not impossible that the line 5227 may be one of the components of the b' group.

The intensity of the lines in the negative group belonging to the same sequence: $n_2 - n_1 =$ constant $= S$, decreases very rapidly with increase of the quant number n_1, and the rapidity of the intensity fall diminishes with increasing sequence number S.

The lines of the second positive group of nitrogen are very weak as compared with the stronger negative bands. The intensities of lines belonging to the same series with constant n_1 vary only slightly.

The principal series P (*o*, n_2) is the strongest and shows a maximum for $n_2 = 1$. In the case of the series P (1, n_2) and P (2, n_2) the lines P (1.1) and P (2.2) are too weak to be observed. These series therefore may be said to have two intensity maxima one for short and one for longer waves.

The series P (1, n_2) has maxima for the lines P (1.0) (3160) and P (1.2) (3527) and the series and P (2, n_2) shows two maxima at P (2.1) (3136) and P (2.4) (3712).

The intensity distribution of the second positive group with one maximum for the principal series (0, n_2) and two for the series (1, n_2) and (2, n_2) agrees at any rate qualitatively with the Franck-Condon theory of the intensity distribution for vibrational band-series. A distribution of the type here found, is characteristic for a band-system for which the frequency of vibration for the lower and upper electronic levels differs from each other in a marked way.

The intensity distribution of the principal series of the negative group is typical for a transition between states having nearly the same vibrational frequencies.

It is of interest to notice that the intensity distribution within the spectrum differs very essentially from that recently given by L. A. Sommer[1] for a spectrum for the night sky. According to his intensity estimates, the principal negative bands (0, n_2) should not be stronger than those of the following series (1, n_2) and the bands of the second positive group are given as being of the same intensity as the negative bands.

While the negative and positive bands are given intensity (1) the auroral line is put equal (10), which differs very considerably from the relative intensities found for the auroral spectrum.

It is also very remarkable that L. A. Sommer using an instrument of moderate light-power has obtained a spectrum of the night sky with so many relatively weak lines by an exposure during only one night. With the instrument he used, even a bright auroral display would hardly have given so many weak lines with the same time of exposure. On account of the interest attached to this curious type of night-sky luminescence, it would have been of great value if Dr. Sommer had given a photographic copy of the spectrum obtained. Before going into further considerations regarding the type of night-light spectrum given by Dr. Sommer, I think we should wait for further observations of the night-sky luminescence.

CHAPTER IV.

The temperature of the auroral region determined by the rotational series of the negative nitrogen bands.

§ 19. Preparations and preliminary work.

The spectrographic observations during my stay at Bosekop 1912—13 had shown that the blue and violet part of the auroral spectrum is dominated by bands belonging to the negative group of nitrogen.

These bands consist of a marked head, which by the small dispersion to be used for auroral work, had the appearance of a line. In the direction towards short waves this line is accompanied by a broad band or striation with a distinct maximum.

The theory of band spectra, developed on the basis of modern atomic conceptions, had shown that the striations were developed as the result of molecular rotation. This theory involves that the development and intensity distribution of the rotational components is a function of temperature, in such a way that with increasing temperature the intensity maximum is pushed towards larger quant numbers and the striation becomes broader.

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[1] L. A. Sommer, Z. S. f. Phys. 57, 582, 1929.

When the spectrographic work on the auroral spectrum was taken up again in 1922 one of the problems to be delt with was to determine the temperature of the auroral region by means of the rotational nitrogen bands.

In a laboratory where we can produce intense sources of light and use spectrographs with sufficiently large dispersion to separate the individual rotational components, the determination of the temperature of the light source from the band spectra might be carried out without any great difficulty, but in the case of the aurora, the luminescence is so faint that we had to use spectrographs with a dispersion which was too small for the separation of the individual rotational components. Even if we cannot obtain such ideal auroral spectrograms, we might still be able to measure the temperature by considering the variations of the rotational striations as a whole. Already after I obtained my first spectrograms in 1923, I commenced investigations in this direction after the following plan:

The nitrogen in a vertical glass tube — which might be put into a Dewar receiver containing liquid air or other cooling liquids, — was exposed to a bundle of cathode rays. The cathode rays came from a Wehnelt cathode placed in an upper discharge tube and in such a way that a fairly narrow bundle of rays from the active area was made to pass through a narrow boring in a metal cylinder which separated the discharge tube from the lower one which was to be cooled.

The luminescence produced by the cathode rays was to be analysed by spectrographs with nearly the same dispersion as that used for the study of the auroral spectrum. In this way we were able to examine the luminescence from a light source whose temperature could be changed in a known way. By comparing the development of the rotational band striations from the aurorae with that of the spectra obtained from the artificial source of known temperature, we should be able to draw definite conclusions regarding the temperature of the upper atmosphere.

In 1923 spectra from nitrogen exposed to cathode rays were taken at room temperature and at that of liquid air, and then compared with the spectrograms obtained from the aurorae.

Some preliminary results from these investigations were described in papers published in 1923 (6.7). In these papers a merely qualitative comparison was made, which showed that the temperature was considerably lower than ordinary room temperature. These investigations were not carried further at that time on account of other work, especially the study of the luminescence from solidified gases which has occupied much of my time from 1923 to the present day.

Meanwhile the spectrographic work was continued at Tromsø during the years 1923—26. With the big spectrographs, we obtained a number of spectrograms which gave some of the stronger negative nitrogen bands with a photographic density which was suitable for measuring the intensity distribution within the striation due to the rotational bands.

Just at that time the structure of the nitrogen bands was analysed and the series formulae determined. The second positive group was analysed by P. Lindau[1] and the negative bands by Maria Fassbender[2]. It appears from these analyses, that the fairly sharp heads obtained by small dispersion are due the P-branch, while the striations are due to the R-branch.

Maria Fassbender measures the intensity distribution of the components within each branch, but she does not connect the intensity distribution with the temperature of the light source.

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[1] P. Lindau: Über den Bau der zweiten positiven Gruppe der Stickstoffbanden Z. S. f. Phys. 26, 343, 1924 and 30, 187, 1927.

[2] Maria Fassbender: Untersuchungen über das negative Stickstoffspektrum Z. S. f. Phys. 30. 73. 1927.

Even the auroral spectrograms of highest dispersion did not give each individual component of the R-branch, and — as already mentioned — we had therefore to determine the temperature of the auroral region by studying the transformation of the R-branch in the form of a continuous band showing a distinct maximum. In order that this method of measuring the temperature of the upper atmosphere should be reliable, it is essential that the development of the R-striation by the conditions under which light is produced, is a function of temperature and is independent of the pressure and velocity of the exciting rays.

Being much occupied with other problems, I suggested to one of my collaborators, Mr. J. Aars that the should take up experimental investigations along these lines. By means of an experimental arrangement similar to that previously described, he was to investigate the development of the R-striations at the temperature of liquid air as well as at room temperature and use spectrographs with nearly the same dispersion as that used for the auroral spectrograms. Thus he would obtain a photographic material which might be used for a quantitative determination of the temperature of the upper atmosphere. For each temperature he was to take up spectrograms with constant ray-velocity and varying pressure as well as for constant pressure and varying cathode-ray velocity.

These investigations were commenced in 1925 and the results were communicated for publication in 1928[1]. In accordance with my previous results he found that the R-striations of the bands were very much shorter at the temperature of liquid air than at room temperature, and in addition he found that at a certain temperature of the gas the development and position of any striation are independent of the pressure of the gas and the velocity of the cathode-rays.

This result indicates that the temperature of the gas along the ray bundle is not essentially increased through the bombardment of the rays, and consequently the temperature of the light source should be — say 18° C. at room temperature and about — 190° C. at that of liquid air. The temperature derived form the rotational bands of the auroral spectrum should give the temperature of the auroral region as it is without the electric rays which produces the aurorae.

It was then my intention to work out the results of all my observational material relating to the auroral spectrum including also the determination of the temperature by means of the auroral nitrogen bands and the results obtained by Mr. J. Aars.

Owing to various other duties and problems which took my time, the working up of this material has advanced rather slowly, and therefore the results of the quantitative temperature measurements first appear now in connection with this complete account of observations from the period 1921—26.

§ 20. General remarks regarding the method used in the determination of temperature.

The temperature determinations will be based upon the band 4278 of the negative nitrogen group. This band system originates from the positive nitrogen ion N_2^+ and corresponds to a transition to the normal Σ-state from an upper level usually taken to be a Σ-state.

According to the quantum theory of band spectra, the intensity distribution within the R-branch is given by the equation:[2]

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[1] Jonatan Aars: Ann. d. Phys. 1. 216, 1929.

[2] Compare W. Weizel, Bandenspektren. Handb. d. Experimental Phys. Ergänzungswerk p. 191, 166. Leipzig 1931.

$$I = c\,j\,e^{-\varkappa\left(j+\frac{1}{2}\right)^2} \tag{14 a}$$

$$\varkappa = \frac{h^2}{8\pi^2 J k T} \tag{15}$$

j is the rotational quant number corresponding to the *upper* electronic level, h is Plancks constant$=6.55\ 10^{-27}$, J is the moment of the inertia of the N_2^+ in the upper state and $J=13.4\ 10^{-40}$, k is Botzman's constant $= 1.37\ 10^{-16}$. T is the absolute temperature.

The equation (14 a) may also be written in the form:

$$l n \frac{I}{j} = c^1 - \varkappa\left(j+\frac{1}{2}\right)^2 \tag{14 b}$$

The quant numbers (m) used by Fassbender differ from j by an additional constant. In fact we have:

$$m = j + \frac{1}{2}$$

and equation (14 a) may be written:

$$I = c\left(m - \frac{1}{2}\right) e^{-\varkappa m^2} \tag{14 c}$$

Investigations on the relation between temperature and the development of rotational bands were made by Birge[1] and in recent years by Ornstein[2] and v. Wijk[3], who find that the intensity distribution of the components of the R-branch obey a law of the type given by equation (14).

In the case of our auroral spectrograms where the R-branch takes the shape of a continuous band, we might adopt the following procedure:

In the formula (14) we regard the quant number j (or m) as a quantity which varies contiuously. We measure the intensity distribution within the R-branch as a function (j). Plotting $ln\frac{I}{j}$ against $\left(j+\frac{1}{2}\right)^2$ we should get a straight line from the slope of which $\varkappa$ and T can be found.

We may also determine T from the position of the intensity maximum of the R-striation. Derivating equation (14 c) with respect to (m) the condition of maximum gives:

$$T = \frac{h^2}{8\pi^2 k J}(2m_1^2 - m_1) = 2.96\,(2m_1^2 - m_1) \tag{16}$$

where m_1 is the value of (m) which gives maximum of intensity.

In order to find the quant number (m) corresponding to a given point of the R-branch, we measure the position ($\Delta\lambda_R$) of the point relative to the head of the R-branch, the wavelength of which (λ_p) is known.

The wavelength λ_R of the point in the R-branch is:

$$\lambda_R = \lambda_p - \Delta\lambda_R \tag{17}$$

From the Fassbender analysis we obtain the value (m) corresponding to a given wavelength λ_R. Having determined the intensity distribution within the R-branch as a func-

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[1] R. T. Birge: Astrophys. Journ. 55, 273, 1922.

[2] L. S. Ornstein & W. R. v. Wijk: Untersuchungen über das negative Stickstoffbandenspektrum Z. S. f. Phys. 49, 315, 1928.

[3] W. R. v. Wijk, Z. S. f. Phys. 59, 313, 1930.

tion of λ we obtain in this way corresponding values of I and j (or m) and the curve $\left(ln\frac{I}{j}\right) - \left(j+\frac{1}{2}\right)^2$ can be constructed.

Taking out the value m_1 corresponding to maximum intensity, we may determine the temperature by means of equation (16).

These "absolute" determinations of the temperature from the position of the intensity maximum, may now be corrected by comparison with the spectra from the sources of known temperature.

§ 21. Results of our temperature determinations. Spectra and intensity curves.

The auroral spectrograms obtained with the large glass spectrograph show some of the strongest heads of the negative nitrogen bands, but only the band 4278 gives the *R*-branch with a photographic density sufficiently strong for intensity measurements.

Out of a material of 6 plates, we selected three, which gave the best conditions for measurements. These spectra are indicated by *A*, *B*, *C* and are reproduced in Pl. II No. 9, 10 and 11 respectively.

B and *C* being taken with a cylindrical lens in front of the plate give lines, which are less sharp than those of the spectrum *A* taken in the ordinary way. At the wavelength of 4278 the auroral spectrograph had a dispersion of 27 Å per mm. Registrams of the 4278 band are given in fig. 21. (A, B, C).

From the plates obtained by J. Aars we selected two which were taken by the large glass spectrograph with a dispersion at 4278 of 34 Å per mm. The registrams of the 4278 band are given in fig. 21.

The diagram *D* corresponds to room temperature and *E* to the temperature of liquid air[1].

The registred curves were measured with a comparator. The diagrams were placed on a table which could be moved perpendicularly to the motion of the microscope. From the known dispersion, curves were constructed giving the deflection of the microphotometer (u) as a function of the wavelength. The left part of fig. 22 gives the so transformed curves for the auroral spectra. Fig. 23 gives the corresponding curves for the spectra *D* and *E*. The position of the intensity maximum can be directly measured from these curves.

In order to apply the method of determining the temperature by means of the intensity distribution law, the relative intensity distribution within the *R*-branch was found for the three auroral spectra. This was done in the usual way by means of the intensity scale photographed on each of the three plates. The intensity curves are indicated by A^1, B^1, C^1 and shown to the right of fig. 22. The maximum intensity of the *P*-head is in all cases put equal to 100.

The temperature determined from the position of the maximum intensity.

From the structure analysis of Fassbender, we estimate the wavelength of the *P*-head to be 4278; from the microphotometric curves (or the transformed curves fig. 22 and 23) we then find the wavelength corresponding to the intensity maximum, and from the Fassbender tables we find corresponding values of the quant number (m). The temperature is calculated from the equation (16).

In the case of the auroral bands we took the mean value of the three spectra. The results are given in table:

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[1] In the paper of J. Aars referred to reproductions of a number of his spectrograms will be found.

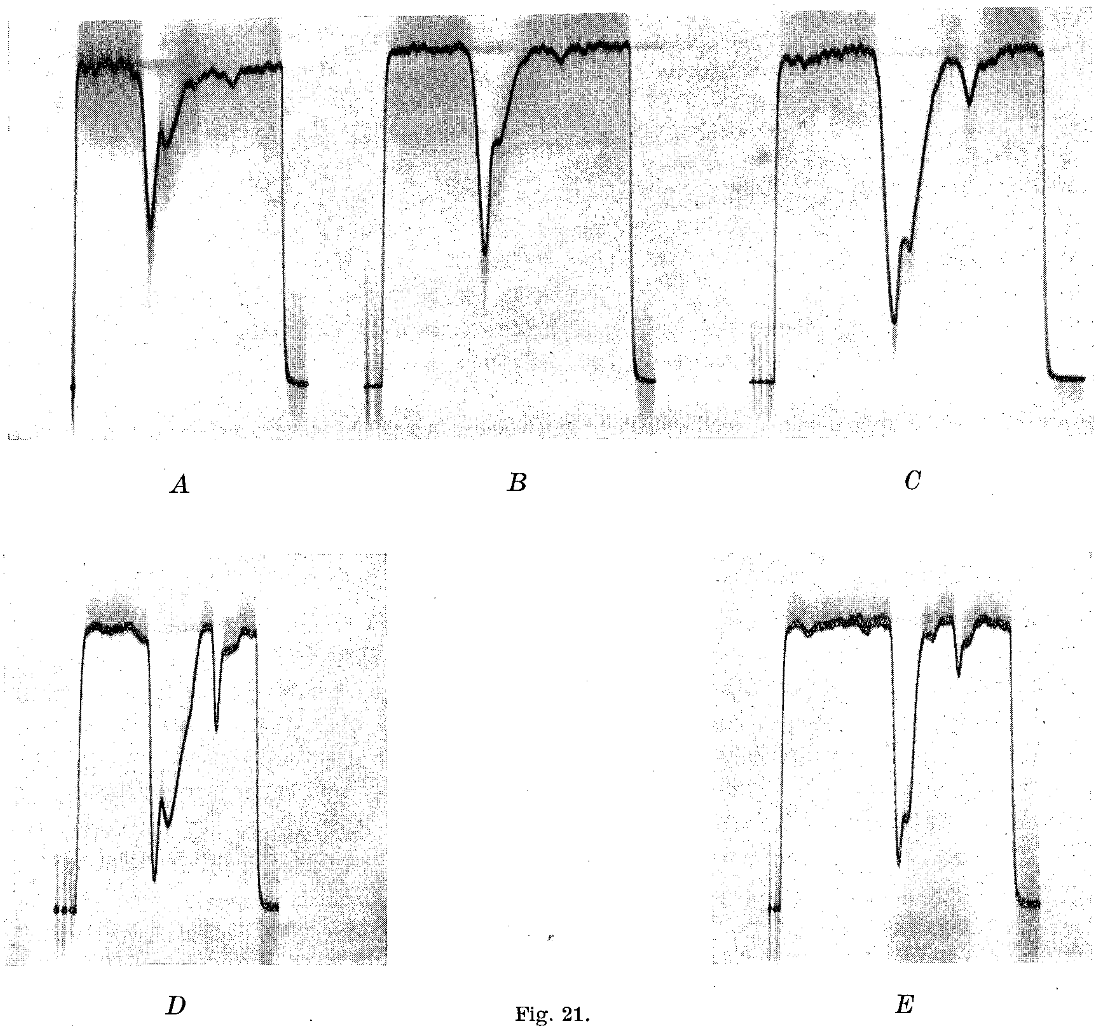

Fig. 21.

Table XIII.

	$\lambda_{\max}$	m_1	T
Room temp.	4268.3	6.6	238° K
Auroral region	4269.0	6.0	195° K
Liquid air temp.	4272.0	2.85	40° K

It appears that in the case of the artificial light sources the temperature derived from the band spectra comes out too low. This result in connection with those of Aars[1] shows that the electric rays under the conditions of our experiments do not *produce any marked increase of temperature*, and the effective temperature of the artificial light sources may be put equal to that of the main bulk of the gas surrounding the cathode ray bundle.

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[1] J. Aars loc. cit.

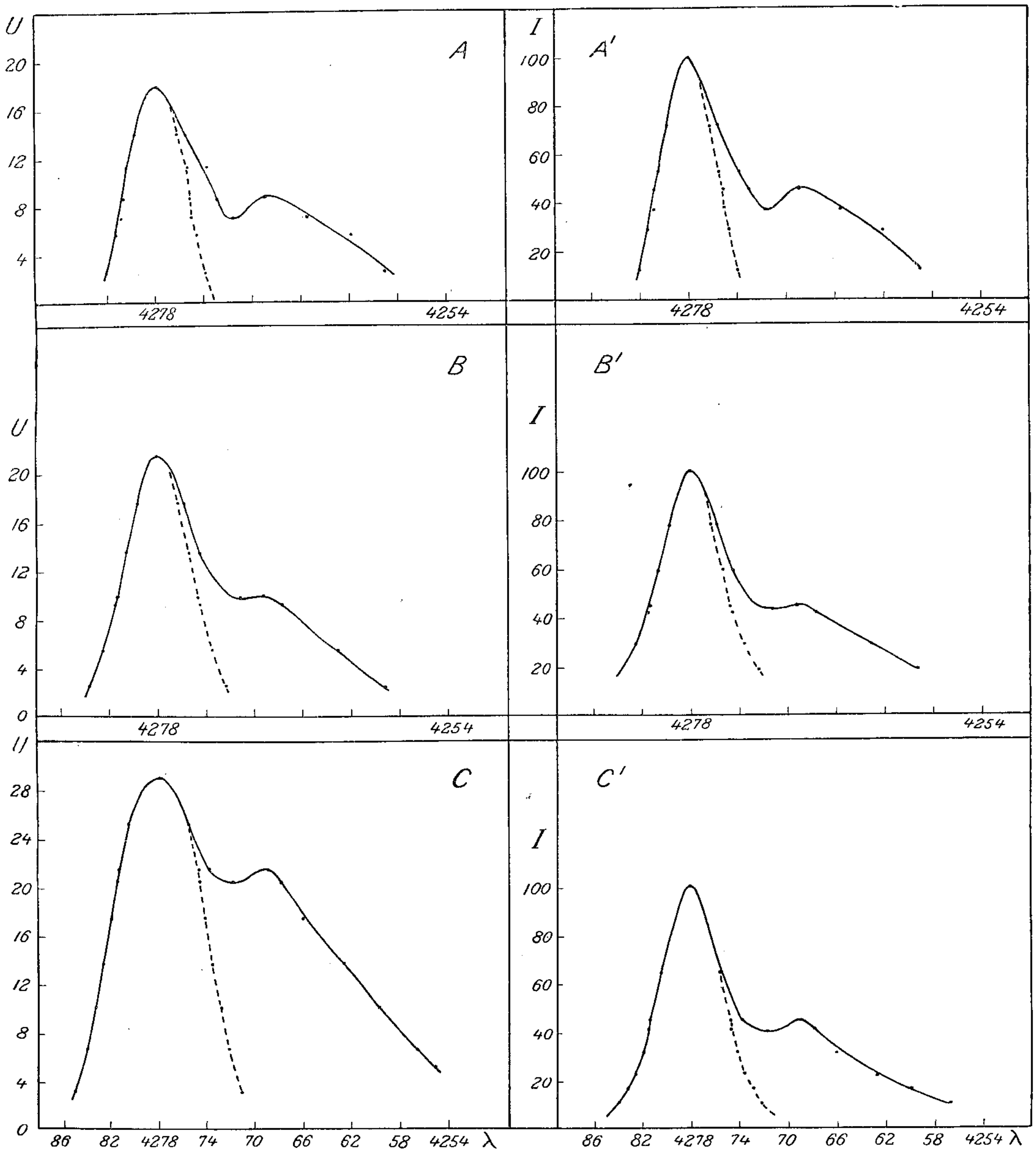

Fig. 22.

This result also shows that if the cosmic rays, producing the aurora consist of moving electrons, they should not essentially increase the temperature from what it is without ray bombardment.

By the "absolute" determination of the temperature by means of the position of the maximum intensity, there is a systematic error which in some way results from the small dispersion used. As the dispersion in the case of the auroral spectra is about the same as that of the artificial light sources, all spectra should be comparable, and we may correct the auroral temperature by means of the spectra from the light sources of known temperature, which may be put equal to 291°K and 83°K.

By simple interpolation we find the correction for the auroral temperature to be $+51°$ which added to the value of the table XIII gives a temperature of the auroral region equal to 246°K or $-27°$C.

We might also undertake this interpolation in the following way:

Putting T equal to 291° in equation (16) we find the quant number (m_1) of the intensity maximum at room temperature to be $m_1 = 7.27$, which corresponds to the wavelength $\lambda = 4267.55$. This means that the wavelength of the intensity maximum was found too large with the amount $\Delta\lambda = 0.75$ Å. This correction $\Delta\lambda$ applied to the auroral spectra and that of liquid air temperature leads to the values given in Table (XIV).

Table XIV.

	λ_m	m	T	t
Room Temp.	4267.55	7.27	$291^\circ K$	+ 18 C
Auroral region ..	4268.25	6.65	$242^\circ K$	— 31 C
Liquid air	4271.25	3.69	$70^\circ K$	—203 C

The temperature of the auroral region found from the intensity distribution within the R-branch.

The curves A^1. B^1 and C^1 fig. (22) give the relative intensity within the R-branch as a function of λ and from the Fassbender tables we find the relation between I and and the quant number m (or j). The results are given in the table (XV). The first and second column give the quant numbers j and the corresponding wavelength values within the region of the R-branch for which the intensity can be fairly accurately measured. For each of the three spectra A, B, C are given corresponding values of I and $\frac{I}{j}$.

Table XV.

Intensity distribution within the R-branch (4278) of the auroral spectrum.

		A		B		C	
j	λ	I	$ln\frac{I}{j}$	I	$ln\frac{I}{j}$	I	$ln\frac{I}{j}$
5	4269.49	44.5	2.19	44.5	2.19	44	2.18
6	68.42	45.5	2.03	43.5	1.98	44	1.99
7	67.29	43	1.82	41	1.77	39	1.72
8	66.10	40	1.61	38	1.56	34	1.45
9	64.85	36	1.39	34	1.33	29.5	1.19
10	63.54	32.5	1.18	30.5	1.12	25	0.92
11	62.16	27.5	0.92	27	0.90	21	0.65
12	60.72	22	0.60	22.5	0.63	17.5	0.38
13	59.21	14	0.08	19	0.38	16	0.21

The relation between $ln\frac{I}{j}$ and $\left(j+\frac{1}{2}\right)^2$ is illustrated in fig. (24). It appears that in the case of spectrum A the points lie almost exactly on a straight line, in the case of B and C there are some deviations, which are probably due to the fast that the two spectra were taken with a cylindrical lens in front of the plate. It might of course also be caused by real changes of temperature in the auroral region. In the case of spectra B and C, we draw the straight lines so as to give the average slope. The temperatures determined from the slope of the lines of fig. (24) are given in Table XVI.

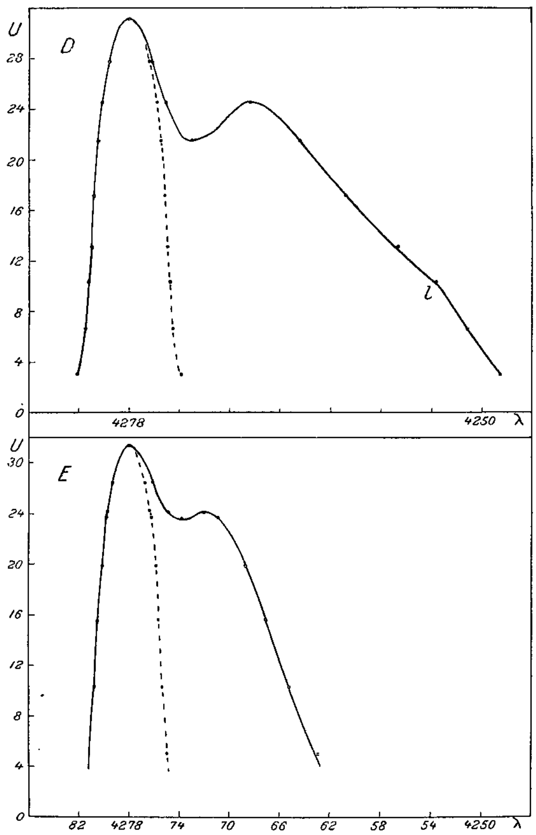

Fig. 23.

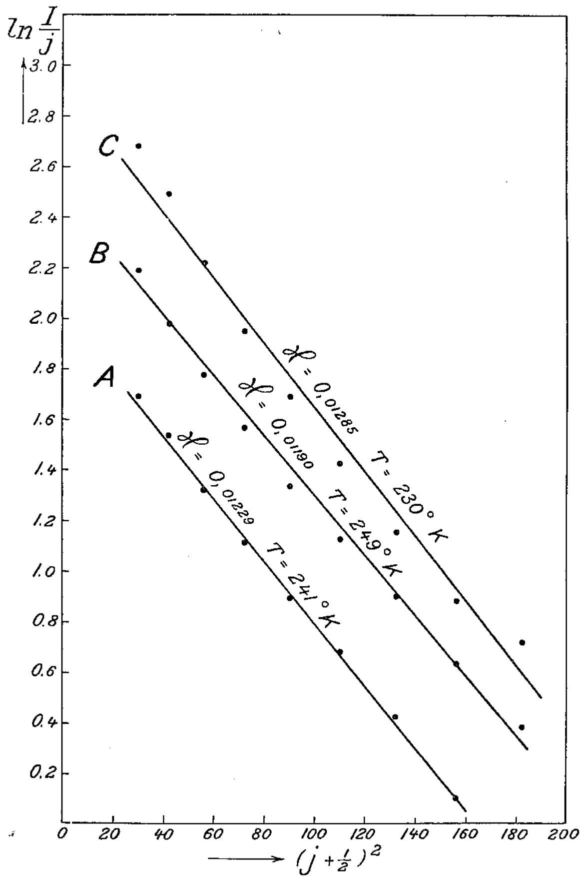

Fig. 24.

Table XVI.

Spectrum	$\varkappa$	T	t
A	0.01229	241°K	—32°C
B	0.01190	249°K	—24°C
C	0.01285	230°K	—43°C
Mean		240°K	—33°C

Discussion of the results.

The "absolute" determination of the temperature of the auroral region by means of the intensity distribution is independent of any comparison with sources of known temperature, but we notice the remarkable fact that this absolute determination gives almost exactly the same temperature as the relative determination obtained by comparing the position of the intensity maximum with that of light sources of known temperature.

The "relative" determination by means of the spectra obtained at room temperature and at that of liquid air gave a temperature of the auroral region equal to 244°K or —29°C. The absolute determination gives the average value 240°K or —33°C.

The average temperature of the auroral region obtained by the two methods is 242°K or —31°C.

Although there may be an error of some degrees in our determination, this fairly accurate knowledge of the temperature in the auroral region will be of highest importance for the physics of the upper atmosphere.

Thus the high temperature assumed by Lindemann and Dobson[1] to account for the appearance and distribution of meteors does not exist, and as pointed out in previous papers[2] we have to account for the meteor distribution by the elevation of matter due to electric fields. This will be dealt with in a later paragraph.

The temperature found is derived from auroral band spectra obtained by exposures lasting for several weeks or months. It is therefore to be considered as an average temperature of a fairly long period. Further the luminescence comes from various altitudes. From the statistical treatment of the height of the aurorae and of the intensity distribution along the streamers[3], we may estimate that the luminescence by long exposures corresponds to a height interval of between 100 and 125 km; and according to our measurements the average temperature of this interval should be about —30° C.

It is, however, very likely that the temperature may undergo great changes, and the aurorae appearing early in the evening — as well as the sunlit aurorae, would give a higher temperature than those appearing in the middle of the night. It is also to be expected that the temperature at a certain height may increase with the polar distance and may at a certain locality vary with the season.

In order to study such variations, we are restricted to the use of spectrographs with high light-power and small dispersion. It is, however, possible that we might develop fairly accurate methods based on spectra taken with small dispersion.

A number of spectra of this type, which were obtained and compared with spectra corresponding to the temperature of liquid hydrogen (22), would seem to indicate that the temperature under certain conditions may be extremely low. In order to study such possible variations we shall have to take spectra — both of the aurorae and the nitrogen lightsources of known temperature — with a very narrow slit, and make accurate measurements of the position of the *R*-maximum.

In order to obtain more accurate values for the average temperature of the interval 100—125 km, it would be of great value to use instruments of still higher dispersion than that of the large spectrograph now used. When we take into account the rapid development of the photographic technique and of the sensitizing processes, it might be possible to obtain spectra of the 4278 band with a dispersion say, twice as large as that used by the present measurements.

The possibilities created by the erection of the new auroral observatory will — I hope — enable us to obtain such spectrograms by a slight modification of one of the large glass spectrographs.

The average temperature found for the auroral region, although quite low, is not so low as it was previously estimated by direct comparison of the auroral spectra with those of the artificial sources. This too low estimate has various reasons. First of all the small dispersion of the spectrographs, secondly the bands of the second positive group — although in certain cases, they appeared with considerable density — did not show any striations due to the *R*-branch; while similarly exposed bands from a discharge tube gave very broad striations. From the measurements of Ornstein and v. Wijk, we know that in the case of discharge tubes the temperature may be very high and as

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[1] F. A. Lindemann and G. M. Dobson: Proc. Roy. Soc. A. 102, 411, 1922.

[2] L. Vegard: Phil. Mag. 46, 193, 1923, Z. S. f. Phys. 16, 367, 1923 and Z. S. f. Geophys. 6, 42, 1930.

[3] L. Vegard and O. Krogness: Position in space of the Aurora Polaris. Geophys. Publ. I. Nr. 1. 1920.

compared with bands from such sources, the positive auroral bands would give the impression of extremely low temperatures in the auroral region.

The temperature found for the upper atmosphere does not mean that the interpretation of the green and red auroral lines — proposed by the writer, and according to which they should be due to nitrogen — must be abandoned. As shown in a paper[1] recently published, the luminescence of solid nitrogen, which according to my view should correspond to the auroral lines, are emitted from metastable states of the nitrogen molecule. Such transitions which are disturbed by collisions in ordinary gas, may appear in the solid state, because the molecules are kept in fixed positions in the crystal lattice; *but the forbidden transitions may also occur at very reduced pressure.* According to the interpretation given for the N_1 and N_3 bands of solid nitrogen, which should correspond to the strong green and red auroral lines, these lines should be caused by an electronic transition towards the normal state of the nitrogen ion N_2^+, which is also the final state for the transition which results in the formation of the negative nitrogen bands.

CHAPTER V.

Important conclusions to be drawn from the results of our investigations on the auroral spectrum.

§ 22. General remarks.

The knowledge gained regarding the auroral spectrum and its variations has very important consequences with regard to the physical properties of the auroral luminescence, the composition and state of the upper strata of the atmosphere, and the explanation of other cosmic phenomena such as the zodiacal light, the solar corona and comets' tails.

These consequences have been dealt with in a number of previous communications published in 1923 and the following years (4, 5, 6, 7, 8, 9, 10, 11, 14, 15) and summaries were given in two articles on "Northlight" published in Handb. d. Radiol. VI and Handb. d. Experimentalphysik XXV and in some papers published in various scientific journals (19, 20, 21).

As already mentioned, the main object of the present work is to give a complete description of the observed facts, it will therefore be superfluous in the connection to enter into details regarding the many consequences which have been thorouhly discussed in previous papers.

For the sake of completness, however, I will give a summary of the conclusions which were drawn from our spectral studies of the auroral luminescence.

§ 23. The Hydrogen-Helium layer does not exist.

The auroral spectra give no indication of the existence of an upper limiting atmospheric layer mainly consisting of the light gases hydrogen and helium. The basis for the calculations which led to the view that there existed an upper hydrogen-helium layer must in some way be fundamentally erroneous.

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[1] L. Vegard: Z. S. f. Phys. 75, 30, 1932.

One of the essential assumptions underlying the calculations is that above a certain height no mixing by currents takes place, so that an ideal equilibrium determine by diffusion sets in, according to which the density of each gas varies upwards as if the others were not present. This is no doubt the essential assumption which has to be given up in order that the results of our investigations of the auroral spectrum may be accounted for.

§ 24. Nitrogen is a dominating component in the auroral region and exists largely in the form of positive ions (N_2^+).

Apart from the strong green auroral line, the origin of which is yet uncertain, the auroral spectrum is dominated by the negative band spectrum of nitrogen. The 2nd positive group in the violet and ultraviolet part and probably the 1st positive group in the part towards long waves also appear with marked intensity.

The very dominating intensity of the negative group, which originates from the positively charged nitrogen molecule (N_2^+), indicates that in the auroral region nitrogen to a large extent exists in the form of positive ions (N_2^+), even when no bombardment with electric rays takes place. The state of nitrogen in the upper atmosphere during an auroral display is very much the same as that of the negative glow in a discharge tube, where there is always a considerable amount of positive ions (N_2^+) which are bombarded with cathode rays. The result is also in this case a spectrum dominated by the negative group.

§ 25. The auroral line is not emitted from a gas lighter than nitrogen.

The intensity diminution with increasing altitude of the green line as compared to that of the nitrogen bands (the spectral altitude effect) shows that the green auroral line does not originate from a gas lighter than nitrogen.

§ 26. The physical state of the upper atmosphere.

Spectroscopically the green auroral line can be followed to the very top of the auroral ray streamers of several hundred km in height. This fact, when seen in relation to the "spectral altitude effect", shows that nitrogen is a predominant component of the atmosphere to its extreme limit towards empty space.

Now, the auroral rays near the auroral zone may reach altitudes of about 300 km; and at lower latitudes, they may — according to Størmer — be followed to heights of 800 km.

If nitrogen were distributed in the atmosphere in accordance with the formula $dp = -\varrho g dh$, which holds for an ordinary neutral gas, the distribution of matter at the various altitudes ($\varrho = \varphi(h)$) may vary with the distribution of temperature, and in such a way that an increase of temperature upwards would make the density (ϱ) diminish less rapidly upwards. A simple calculation, however, will show (4, 5, 6, 7) that any temperature distribution, which might come into consideration, would give a diminution of density upwards, which is too rapid to account for the very long auroral rays, which may keep a fairly constant light intensity per unit length for several hundred kilometers. The assumption of a very high temperature would produce an increase of the density at a certain height, *but would not essentially alter the law of variation, according to which the density drops rapidly as we pass upwards.*

If we apply the gas formula of nitrogen and assume a temperature of $220° K$, we find (4.5) that its pressure above, say 150—160 km has become quite imperceptible, and is by far too small to account for the fairly strong luminescence hundreds of kilometers above this latitude.

In the previous chapter the temperature in auroral region — measured by the rotational energy — was found to be about $242° K$ or —30 centigrades. Thus the temperature of $220° K$ on which our calculations of the distribution of matter were based, is just of about the right magnitude.

The nitrogen which auroral investigations have shown to exist several hundred kilometers above the ground, cannot therefore be carried to these altitudes merely by the thermal motion, but is lifted towards larger altitudes by electric forces.

The upper atmospheric layer is ionised through the action of the sunlight of short wavelength (and to a small extent also by cosmic radiation). Electrons are driven out with a velocity given by the Einstein formula of photoelectric action. The atmosphere is left behind with a certain volume charge. This upper positively charged layer will have the effect of producing a reversion in the direction of the electric force of the field surrounding the earth.

The electric force above a certain limit will — at any rate for some hundred kilometers — be directed upwards, the positively charged gas will be driven upwards by the action of the electric field. For the lower part where the density is not too low — the variation of pressure — at any rate within a certain interval of time — will be given by the formula:

$$dp = (-g\varrho + \sigma F)\ dh \tag{18}$$

where σ and F are electric volume density and electric force respectively. F varies in an unknown way, but if the field is stationary, they are mutually connected by the equation of Poisson, which for the atmospheric layers may be written:

$$\frac{dF}{dh} = 4\pi\sigma \tag{19}$$

The negative electrons which are driven away as the result of the action of the sun's radiation, will be retarded by the action of the electric field. Let the potential where the electron is liberated be V_s and the potential at a certain height (h) be V_h, the maximum altitude which can be reached by the electron would be given by the equation:

$$h\nu = w_o + e\ (V_s - V_h) \tag{20}$$

where w_o is the energy necessary for making the electron free from the molecule. From the equation (20) we find $(V_s \div V_h)$ and this difference will increase with increasing frequency. As the result of the retardation of photocathodic rays, electrons will accumulate within a certain height interval above the ordinary positively charged layer, and we will have a kind of electronic cloud with a negative volume charge.

If we consider the earth's electric field, as we pass upwards, it will vary in the following way.

At first the electric force F is negative (directed downwards) but $\frac{dF}{dh}$ is positive and the absolute value of F diminishes. At a certain height $F = o$. Then both F and ϱ keep positive for a certain interval of altitude. But as we pass further upwards the volume density diminishes, $\frac{dF}{dh}$ diminishes and a certain height $\frac{dF}{dh} = o$, and F has its maximum. In the height interval between $F = o$ and $\frac{dF}{dh} = o$ (F max.) the atmospheric matter is driven upwards by the electric field. This does not mean that the motion of matter upwards, cases at the level $\frac{dF}{dh} = o$; for on reaching this level the matter may have acquired a considerable velocity in the upwards direction. As the density of matter in the auroral region is extremely small, the statistical equation (18) will cease to hold and the single ions or charged clusters may move individually by the action of the electric field. In that case (neglecting the effect of gravitation) the particles will have acquired their maximum velocity upwards when they pass the layer $\frac{dF}{dh} = o$ (or $\varrho = o$). In their further motion they will be retared and fall down again. The positively charged particles may also pick up electrons, become neutralized and fall down again by the action of gravitation. Some may be negatively charged and be driven down by the combined effect of gravitation and the electric field.

Passing still further up, $\frac{dF}{dh}$ and σ become negative and reach a minimum somewhere in the middle of the electronic cloud layer.

The theory of the propagation of electric waves round the earth led to the assumption that there existed a layer of fairly high conductivity somewhere in the upper atmosphere. (The Kennelly-Heaviside layer).

The auroral studies not merely showed the existence of a conductive layer, but gave for the first time a definite idea as to the structure of the upper atmosphere, and the physical forces and processes which are at play.

From the picture just sketched regarding the limiting layer of the atmosphere, we can also form a rough idea as to the way in which electric conductivity varies with altitude.

The rays of very short wavelength (apart from the cosmic rays) which are the most effective ionizers, will soon be absorbed by atmospheric matter. Now, in the region where the matter is driven upwards by electric forces, it will have a very minute density, and the greatest absorption of ultraviolet light and high frequency radiation will set in just below this region, or just near the altitude at which the direction of the electric force is reversed. Accordingly, we should have a very pronounced maximum of electric conductivity somewhere near this altitude (70—100 km). This conductivity will be mostly due to ions of molecular order of magnitude.

When we pass upwards, the ion-concentration rapidly diminishes, partly on account of diminution of the density ϱ, and partly because the charged particles in this region are in rapid motion. Within a certain height-interval, where the positive ions are turned down again, there will be an accumulation of ions resulting in a second maximum of *ionic* conductivity.

Still higher up we find the layer where electrons turn back — the electronic cloud. Although the number of ions per unit volume may be much smaller than that of the lowest maximum, the electronic conductivity may be quite considerable, on account of the large mobility of the electrons.

The structure of the upper atmosphere resulting from our auroral investigations is illustrated in fig. 25. E represents the surface of the earth. The variation with altitude of the electric force F and the density is represented by the curve 1 and 2 respectively. The electric conductivity is represented by the curve 3. A is the level where the electric force is first reversed. B. is the level of zero electric density.

Above this level the volume density is negative. The levels C and D indicate the second and third maximum of electric conductivity.

The matter in the layer between A and B will be lifted up, as it were, by the effect of the electric forces.

At the level A there must be a very rapid change in the density of matter, for below it, the electric field will produce on matter a mechanical force which is directed downwards. The effect is equivalent to an increase of the gravitational force on each particle or an increase of molecular weight. Above the level A the electric field produces a mechanical force directed udwards, and it will on an average reduce the action of gravity. Below the level the density will be so great that the statistical equation (18) may be applied, but as we pass upwards from the level A the density may soon be so small and the mean free path so long, that the charged particles may move more or less individually under the influence of the electric field and take the form of electric rays.

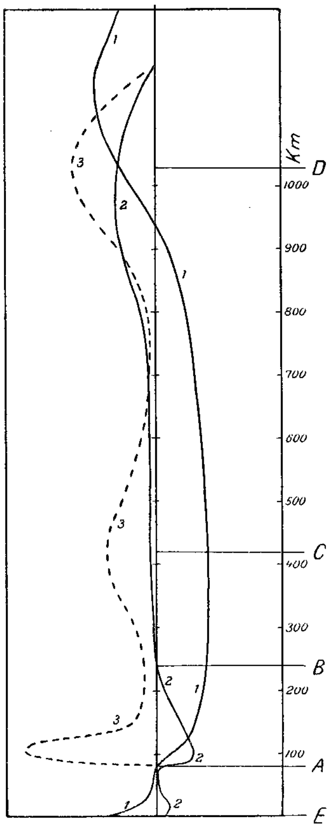

Fig. 25.

The velocities of the particles within a volume element are not equally distributed in all directions, but the velocities along the vertical line are very dominating. These velocities may on an average be very large, but as they are not arbitrarily directed — we cannot say that the gas has a temperature corresponding to the average translatory energy. For an ordinary gas the temperature is given by the equation (21).

$$T = \frac{2\,W_t}{3\,k} \tag{21}$$

k is the Boltzmn constant and W_t the average translatory energy. It is, however, not permissible to apply this equation to the upper layer of the atmosphere above the level A, because the matter has a sort of radiant constitution.

The true temperature is the part which is subject to the law of equipartion of energy, and which is determined by the average *rotational* energy of the *molecules*, and from the rotational nitrogen bands we found for the true temperature about 240° K. Thus the existence of large translatory motions of matter in the upper atmosphere does not involve a very high temperature.

§ 27. Variations of the physical state of the upper atmosphere.

The state of the upper atmosphere, previously described and indicated in fig. 21 is maintained through the action of the sun's radiation. The intensity of the ionisation and of the electric field will vary with the intensity of the radiation and the amount of matter to be found above the level A, and the height to which an appreciable amount of matter is carried, will vary with the intensity of the solar radiation which at the moment falls upon the atmospheric layer considered.

Let us suppose that for the auroral region we construct surfaces of equal density, then a surface corresponding to a definite density will be much higher on the day side than on the night side, with a fairly sudden drop in the evening and morning. Further the surface will on an average be higher at lower latitudes than in the polar region. As already pointed out in 1923, a consequence of this state of things will be, that we should expect to get much higher auroral rays early in the evening — near sunset —

than in the middle of the night. If we could observe aurorae just near sunrise in the morning, we might perhaps also then expect to find exceptionally long rays.

The long morning rays, however, will be more difficult to obtain than the long evening rays. In the evening the atmosphere has been bombarded all the day by sunrays, and it will take some time before the atmospheric state, characteristic for the day settles down to the night state. We may therefore get long rays till after sunset. In the morning, however, the night state will be maintained till the sunrays have been acting for a certain time sufficient for the development of the day state. Therefore we can hardly obtain the long rays before the sunshine has become so brightt hat the weak aurorae will be masked by the daylight.

Further we should expect that the auroral rays should be longer and more frequent at lower latitudes. Both these consequences are in accordance with the observations.

Already before this state of the upper atmosphere was discovered through the investigations of the auroral spectrum, Størmer had noticed the remarkable fact that the maximum height of the auroral rays was found to be greater at lower latitudes than near the auroral zone. And a few years ago Størmer[1] found that the very long rays are most frequent so early in the evening that the upper part of the rays are still exposed to sunshine.

As I pointed out in a paper recently published[2] the existence of these long evening rays was foretold by the writer as a necessary consequence of the physical state of the upper atmospheric layer.

Not only the distribution of matter, but also the electric field, the distribution of volume charge and the electric conductivity of the various layers will vary greatly with the intensity of the sun's radiation. The development of the relative magnitude of the three maxima (C_1, C_2, C_3) of the atmospheric conductivity will undergo great changes. Thus we should expect the average height of the conductive layers to decrease towards higher latitudes.

On account of the very complicated process involved, it will not be easy to state definitely the character of the variations of the conductivity taking place. But it is to be hoped that the exploration of the conducting layers by means of radio waves will give us some definite information with regard to the variation of the position and electric conductivity of the conductive layers.

§ 28. The Zodiacal light.

As described in a number of previous papers, the constitution found for the upper strata of the atmosphere leads to a simple explanation of the zodiacal light.

The positively charged particles which in the electric field may acquire fairly large velocities, move under the influence of the magnetic field of the earth. The rays will then have a tendency to follow the magnetic lines of force. As a result of this action of the magnetic field and of the more intense ultra-violet radiation towards lower latitudes, matter will accumulate at large latitudes towards the equatorial regions. The surfaces of equal density will take the form of a lens with its axis nearly coinciding with the magnetic axis of the earth.

Photoelectrons and positive ions may have sufficient energy to excite the characteristic spectrum of the gases present in the upper atmosphere.

We may therefore expect to find that the upper strata always emit some luminescence of a similar type as that emitted by the Northlight. In this way we explain the luminescence

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[1] C. Størmer, Z. S. f. Geophys. 5, 177, 1929.

[2] L. Vegard, Z. S. f. Geophys. 6, 42, 1930.

of the night sky, and the fact that the green auroral line as well as the negative nitrogen bands are found in the night sky luminescence.

The general luminescence of the upper atmospheric region should increase with the thickness of the layer above the surface A, fig. 25. Therefore the intensity of the night sky luminescence should increase towards the equator and be particularly strong just after sunset and before sunrise. At these hours of the day the highest parts of the lens-shaped distribution of matter will be directly exposed to sunlight, and the luminescence will be greatly intensified by the scattered sunlight.

After sunset we observe the cone-shaped luminescence which is called zodiacal light and before sunrise in the morning we observe a similar light phenomenon called "Gegenschein".

The zodiacal light is thus a kind of twilight phenomenon caused by the peculiar distribution of matter in the upper strata of the atmosphere, and the luminescence is a mixture of scattered sunlight and light typical for the atmospheric matter, and is of the same type as that of the night sky luminescence and similar to that of tho Aurora Borealis.

§ 29. The sun's corona and the comets' tails.

The state of the atmosphere above the level A, fig. 25, where the matter is lifted through the action of electric forces, bears a striking resemblance to the solar corona, and we may say that the part of the earth's atmosphere, where the matter is distributed according to the gas laws, is surrounded by a "terrestrial corona" with a kind of radiant structure where the gas laws do not hold good.

In previous papers[1] it was shown that the agencies which produce the terrestrial corona and bring matter of the upper atmosphere towards large altitudes are even more effective in the upper strata of the sun's atmosphere (chromosphere), because there, the ultra-violet radiation, which on the earth is the primary cause of the electric elevation of the "coronal" matter is very much more intense.

If, by the photoelectric action or in connection with solar activity, electrons are driven out from the sun with large velocities, the matter will be left behind with a positive volume charge and will be driven upwards through the action of the electric field. The electrons, so to speak go ahead, and pull the positive ions behind them. In this way we explain the radiant structure, and the distribution of matter within the solar corona. With regard to details, I must refer to the published papers[2].

Thus the coronal rays consist of a mixture of electrons, and ordinary matter which largely exists in the form of positive ions. In this way we were led to regard the possibility that also the electric rays producing the aurorae have a similar constitution as the coronal streamers.

The ray bundles penetrating into our atmosphere should be composed of a mixture of negative electrons and positively charged particles, probably with an abundance of negative electricity. The positive and negative ray-particles will be kept together by electrostatic forces and form a ray-bundle, which as a whole is deflected in the magnetic field of the earth in a direction corresponding to negative rays.

The average specific charge (s) of the bundle will be:

$$s = \frac{\Sigma e}{\Sigma m}$$

where the sum (Σ) is to be taken over all particles, positive and negative for unit length of the ray bundle. As the charge (e) may be both positive and negative the average

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[1] L. Vegard. Results of observations from the solar eclipse 1927 and the constitution of the solar corona and sunspots. Det Norske Vid. Akad. Skr. I, Nr. 2, 1928 and Nr. 21, in the list of papers.

[2] Loc. cit.

specific charge (*s*) may be very small, and in this way we may explain the great angular distance between the auroral zone and the magnetic axis-point without taking our refuge in the magnetic effect of some exterrestrial current-system, and without getting into conflict with the results of our auroral height measurements.

In papers published in the years 1911—13[1] the writer dealt with the physical explanation of comets' tails.

Calculations of the repulsing forces of the pressure of radiation on the basis of the measurements of Lebedew[2] showed that the radiation pressure theory in its original form had to be abandoned.

As an alternative explanation it was suggested that the matter of the comets was put in motion away from the sun, through impulses imparted to the molecules by collissions of radiation composed of particles carrying large energy and impulse, e. g. positive rays (or radiation quanta of high frequency).

In papers dealing with the formation of the coronal structures as the limiting form of the atmosphere of stars and planets[3], it was shown that these same physical processes which are engaged in the development of coronal rays might also give a simple explanation of the transformation of the comet, and the formation of its tail as it approaches the sun.

On account of the penetrating cosmic radiation which is constantly acting, any celestial body will have a positive potential relative to the surrounding space, which takes up the photoelectrons of high energy which are liberated through the action of the penetrating cosmic radiation.

When the comet approaches the sun, it may come within the region of the sun's electric field, and at the same time the intensity of the ultraviolet light from the sun will increase. Just as in the case of the upper atmosphere of the earth, the sun's ultraviolet radiation will produce a local electric field round the comet and develop a coronal structure round its nucleus.

The matter will be driven away from the centre of the comet, but on account of the small gravitational attraction of the comet, and the rapid diminution of the local electric field surrounding its nucleus, the positive particle may partly move so far that the electric field of the sun becomes stronger than the local field of the comet. The positive ions are driven away from the sun, and will form a bundle of radiant matter which appears as a tail attached to the comet, and turned away from the sun.

§ 30. Periodic variation of the relative intensities of the strong green and red lines.

Our investigations of the variation of the intensity distribution within the auroral spectrum have shown that the relative intensity of the more conspicuous lines in the green and red part of the auroral spectrum varies considerably. It is not only different for different auroral forms and at different altitudes, but for a given form and altitude, the relative intensity of the green line (5577) and the red line (6318) undergoes great changes with *time*. This variation is not very marked for the green line, which always appear with dominating strength, but it is most conspicuous for the red line. Our quantitative determinations of the relative intensity distribution within the auroral spectrum, showed that the average relative intensity of the green line during an exposure lasting

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[1] L. Vegard, Archiv. f. Mat. & Nat.vid. 31, Nr. 13, 1911.
» Ann. d. Phys. 41, 641, 1913.

[2] Lebedew: Ann. d. Phys. 32, p. 411, 1910.

[3] L. Vegard: Loc. cit.

from $^{7}/_{1}$—$^{15}/_{1}$ 1924 came out considerably different from that obtained during an exposure from $^{16}/_{1}$—$^{12}/_{4}$ 1924.

This result, however, needs to be confirmed by continued measurements. The relative intensity changes of the red line, however, is so pronounced that it can be clearly seen and estimated without photometric measurements. From the discription of the considerable number of spectrograms taken with the small glass spectrograph on panchromatic plates, it appears that the condition which is essential for the production of a relatively strong red line, is of very universal character. Thus it was found that during the year 1926 the red line came out relatively strong both at Oslo and Tromsø.

The spectra obtained at Tromsø at various times show that the average intensity of the red line varies from year to year. The experimental material is at present too limited to enable us to give definite statements with regard to the possible laws underlying these variations.

It is, however, a remarkable fact that the red line was exceptionally strong during 1926 which is near a sunspot maximum, and our material indicates that the relative intensity of the red line varies in a similar way as the sunspot activity.

It will be of great importance for future work to study in a systematic way the variation of the average intensity of the red line, and to continue such investigations for a considerable number of years. Using spectrographs of very small dispersion, and of the highest possible light power, we should be able to obtain the red line with a fairly short exposure. We might also easily construct a convenient apparatus, where pictures of aurorae were taken simultaneously by cameras with suitable filters of different colour.

Until we know the nature and origin of the red line, it will not be possible to form any definite opinion regarding the cause of the conspicuous variation of the intensity of the red line.

In a previous paragraph we mentioned that the electric rays producing the aurorae might possibly be regarded as a mixture of positive and negative rays. If so there might be a change in the *composition* of the rays, which might account for the variations of the spectrum, because positive rays composed of different particles may give essentially different conditions for the excitation of luminescence in the atmospheric matter.

If the electric ray bundles producing the aurorae were similarly constituted as the "rays" of the solar corona, we have also to consider the possibility that coronal matter precipitates towards the earth, and in this way also the composition of the upper strata of the atmosphere may undergo changes.

It has recently been suggested that the coronal matter to a large extent consists of oxygen.[1] If so, it is to be expected that the relative concentration of oxygen as compared with nitrogen may be greater in the auroral region than at lower altitudes. If it should turn out that Mac. Lennan's interpretation of the strong green line is the right one, we should probably have to assume a relatively large oxygen concentration, in order to account for the very dominating intensity of this line.

Such a continual precipitation of oxygen raises a number of other important questions. At the surface of the earth, oxygen is taken away from the atmosphere (absorbed) by oxydation. At any epoch of the history of the earth, the oxygen in the atmosphere will be in an approximately stationary state, where the amount of oxygen absorbed through oxydation is equal to the amount received in the form of "coronal" ray precipitations. In the course of geological periods the concentration of oxygen may vary considerably, and in this way influence the conditions of organic life.

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[1] T. L. De Bruin, Das Spektrum der Sonnencorona, Naturwiss. 20, 269, 1932.

In these investigations I have received invaluable assistance from a number of young collaborators. From 1922 to 1924 the observations at Tromsø were attended to by Mr. Einar Tønsberg, who obtained a number of most important spectrograms. Great merit is also due to Mr. O. W. Lund and Mr. Bj. Stav who assisted in the observations at Tromsø during the latter period until the end of 1926.

In connection with the treatment of the observational material, I have in various ways received most valuable assistance from Mr. J. Aars and Mr. S. Stensholt. I feel it a duty and a great pleasure to thank my collaborators for their most valuable and important contributions to the results of these investigations.

My sincere thanks are also due to "Det Videnskapelige Forskningsfond av 1919" and to "Kristian Birkelands fond" for granting the considerable amount of money which was necessary to cover the costs of the instrumental equipment, and the expenses in connection with the observational work and the treatment of the experimental material.

Papers concerning the auroral spectrum previously published by the authors.

1. Photographische Aufnahmen des Nordlichtspektrums mit einem Spectrographen von großer Dispersion. Phys. Z. S. 14, 677, 1913
2. Bericht über eine Expedition nach Finmarken 1912—1913. Vid. Selsk. Skr. I. 1916, Nr. 13, Oslo.
3. Geophys. Publ. 2, Nr. 5.
4. Vid. Akad. Skr. I. 1923, No. 8, 9, 10, Oslo.
5. Phil. Mag. 46, 193, 1923.
6. Phil. Mag. 46, 577, 1923.
7. Zeit. S. f. Phyis. 16, 367, 1923.
8. Sur le spectre de l'aurore boréale et les couches superieures de l'atmosphere. C. R. 176, 947, 1488, 1923.
9. Nature 113, 716, 1924.
10. Naturwissenschaften 13, 541, 1925.
11. Naturwissenschaften 15, 438, 1927.
12. Phys. Z. S. 25, 685, 1924.
13. Nature 118, 801, 1926.
14. The origin of the red colour of the aurora of Jan. 26, 1926. Det Norske Vid. Akad. avh. I, 1926 No. 2. Nature 117, 356, 1926.
15. Spectrographic observations of the second green line of the Auroral Spectrum. Nature 119, 849, 1927. Det Norske Vid. Akad. avh. I, 1927, No. 2.
16. Naturwissenschaften 17, 980, 1929.
17. Handb. d. Radiologie, VI 570, 1924, Leipzig.
18. Handb. d. Experimental physik B. 25, 385, 1927.
19. Die Sonnenbelichteten Nordlichstrahlen und die Konstitution der höheren Atmosphärenschickten. Z. S. f. Geophys. 6, 42, 1930 7, 196, 1931.
20. Variation of intensity distribution of the auroral spectrum and the possible influence of sunligt. Nature. Dec. 1929.
21. Die Korona der Erde und Sonne und ihre Beziehung zu kosmischen Erscheinungen. Gerlands Beitrage zur Geopyhs. 32, 288, 1931.
22. Light emitted from solid nitrogen, when bombarded with cathode rays and its bearing on the auroral spectrum. Proc. Konink1. Akad. 27, Nr. 1 and 2, 1924.
23. Spectra from solidified gases and their interpretation. Det Norske Vid. Akad. Skr. I, 1930, Nr. 2.
24. Ann. d. Phys. 79, 377, 1926 and 6, 487, 1930.
25. Z. S. f. Phys. 75, 30, 1932.
26. Wavelength of the green auroral line determined by the interferomenter. Nature. Jan. 1932.
27. Spectrographic observations of infra-red lines of the auroral spectrum. Nature. March, 1932

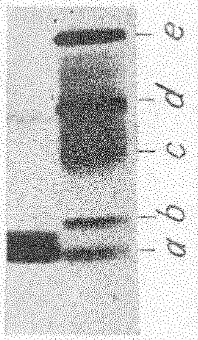
Explanations to Plate I.

Spectrograms Nr. 1—15 were obtained by the two small glass spectrogrsphs built in 1921—22. Nr. 16 is an auroral spectrogram obtained by Lord Rayleigh 1921, and reproduced here for the sake of comparison.

Nos. 11, 12, 13, were obtained at Oslo, the rest are taken at Tromsø.

For No. 1, 2, 3, 4, 5, 6 a cylindrical lens was used in front of the plate.

No.	Date	Effective time of exp.	Phot. Plate	Comp. Spectrum
1	27/9 1922	$0^h\ 32^m$	Imperial Eclipse	Cd
2	31/10 1922	$0^h\ 48^m$	Pancrom B	N_2
3	29/11 1922	$1^h\ 9^m$	Erythrosinbadet pancrom.	Cd
4 a, b	12/1—13/1 1923	$6^h\ 48^m$	Imperial Eclipse	He
5	25/2—9/3 1924	$12^h\ 35^m$	Hauff Flavin	Cd
6	25/3—7/4 1924	$3^h\ 14^m$	—	»
7	22/10 1924 1/2 1925	$15^h\ 0^m$	Pancrom. B.	»
8	12/2—13/4 1925	$19^h\ 35^m$	—	»
9	21/12 1925 4/2 1926	$35^h\ 0^m$	—	»
10	19/2—7/4 1926	$55^h\ 0^m$	—	»
11	26/1 1926	3^h	—	Ne
12	5/3 1926	a few hours	—	»
13	15/10 1926	—	—	»
14	5/10—8/12 1926	40^h	—	He
15	10/12—30/12 1926	15^h	Sensibilised with pinafluvol	He



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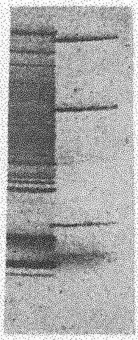
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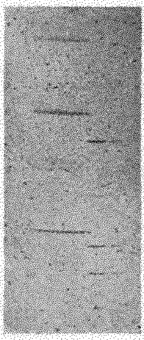
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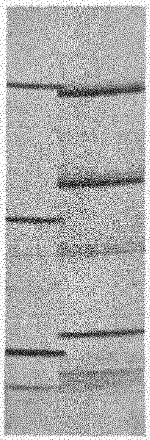
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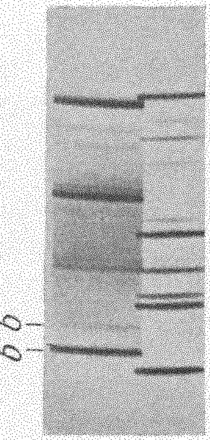

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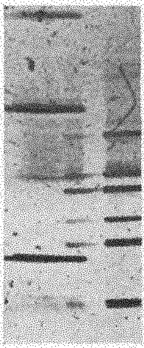
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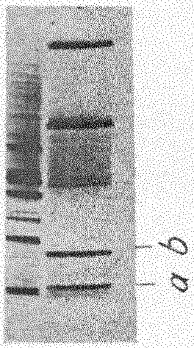

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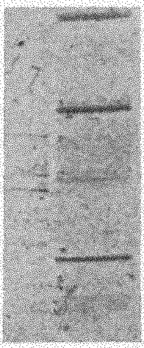
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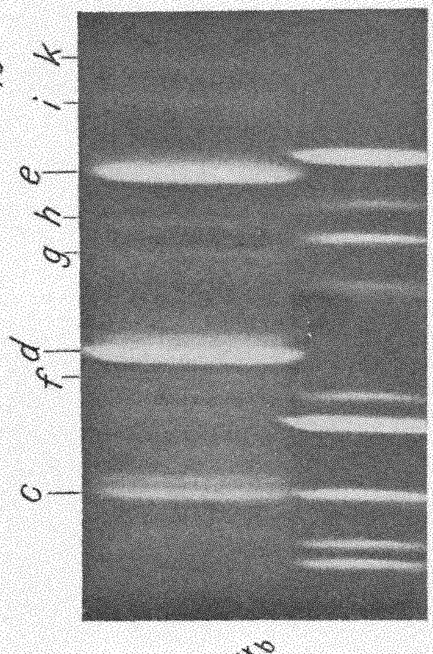

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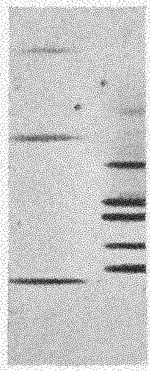
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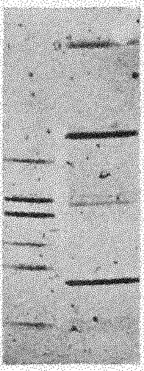
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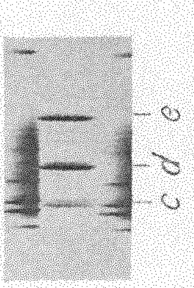

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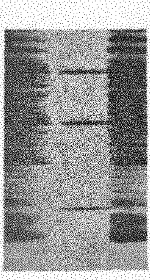
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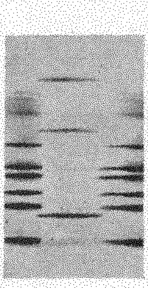
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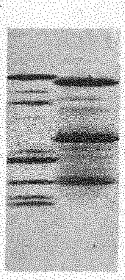
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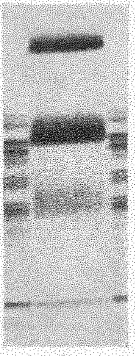
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Explanations to the Plate II.

Nos. 1—6 were obtained by the large quartz spectrograph. A condensed Cd-spark was used for comparison spectrum. In the case of Nos. 1—4 the spectrograph had only one prism, in the case of Nos. 5 and 6 a second prism had been introduced.

Nos. 7—14 were obtained by the large glass spectrograph with He-comparison spectrum. In the case of Nos. 10, 11, and 12 a cylindrical lens was used in front of the photographic plate.

The temperature of the instruments during the exposures was 15° C.

Nr.	Date	Eff. time of exp.	Ph. Plate
1	27/9—2/11 1922	15^{h} 17^{m}	Imp. Ecl.
2	3/11—21/12 1922	18^{h} 39^{m}	—
3	21/12 1922—5/1 1923	3^{h} 58^{m}	—
4	8/1—24/3 1923	39^{h} 25^{m}	—
5	autumn 1923	43^{h} 42^{m}	—
6	jan.—april 1924	64^{h}	—
7	9/12—28/12 1922	17^{h} 59^{m}	—
8	8/1—24/3 1923	39^{h} 32^{m}	—
9	9/10—31/12 1923	43^{h} 54^{m}	—
10	7/1—15/1 1924	18^{h} 36^{m}	— ortho
11	16/1—12/4 1924	44^{h} 14^{m}	— »
12	15/9 1924—15/4 1925	39^{h} 35^{m}	Imp. Ecl.
13	27/9—1/12 1922	20^{h} 3^{m}	Pancrom.
14	25/3—26/3 1923	3^{h} 0^{m}	Ortho crom.

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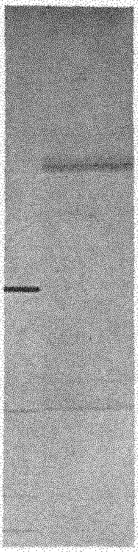

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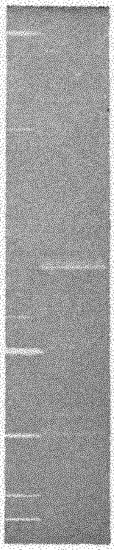

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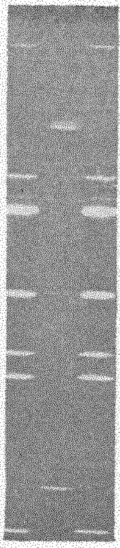

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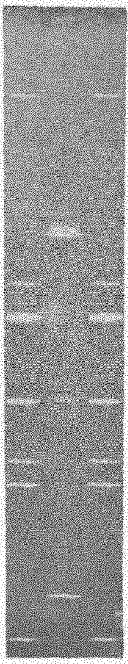

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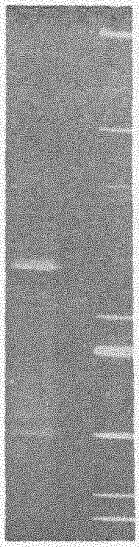

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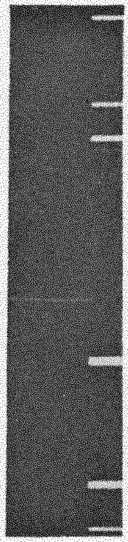

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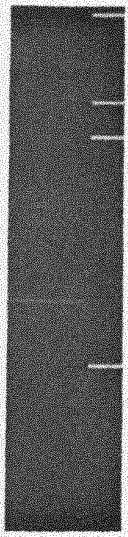

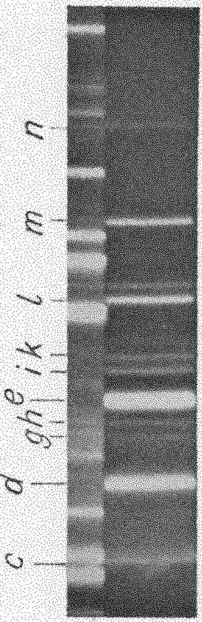

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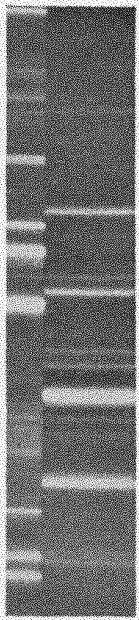

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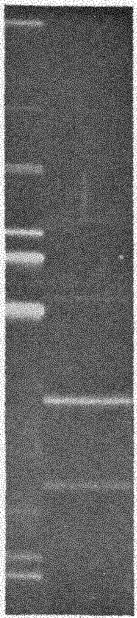

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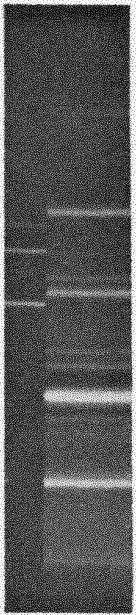

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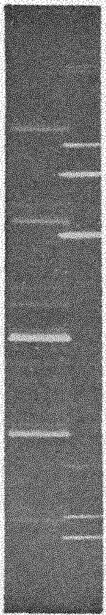

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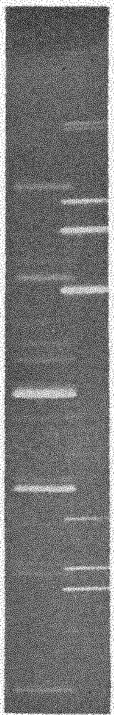

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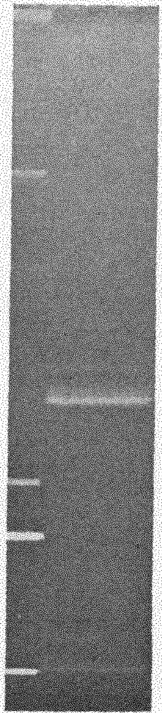

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Explanations to Plate III.

Spectra illustrating the methods and results of the study of the intensity distribution, within the auroral spectrum.

Nos. 1, 2 and 3, show auroral spectra corresponding to different altitudes. No. 1 was exposed on March 11. 1923.

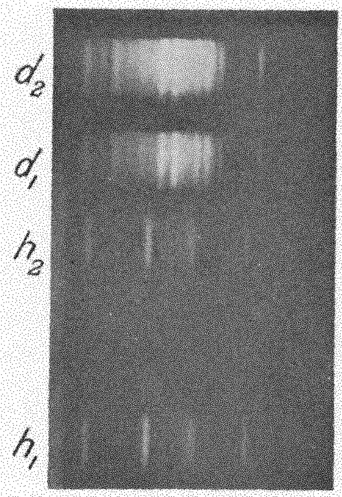
Nos. 2 and 3 are reproductions on a different scale of a plate exposed March 12. 1923. The auroral spectra h_1 and h_2 correspond to the lower and upper limit respectively. The spectra d_1, d_2, d_3 from a Ne-lamp with times of exposure in the proportion 1:2:4 give the density scale.

No. 4. Auroral spectrum (A) obtained with the quartz spectrograph (Pl. II No. 5) and with spectra for the density scale on the same plate.

No. 5. Auroral spectrum (A) is taken $^{11}/3$ 1923 on Imperial Eclipse Ortho plate. Exposure 4^h15^m and spectra for the density scale with exposures in the proportion 1:2:4.

No. 6. Spectrum from sunlight on Emperial Eclipse Plate taken with the Quartz spectrograph with two prisms. Time of exposure 1:2:4:8.

No. 7. Spectra from sunlight on Imperial Eclipse ortho plate, taken with the large glass spectrograph. Time of exposure in proportion 1:2:4:8.



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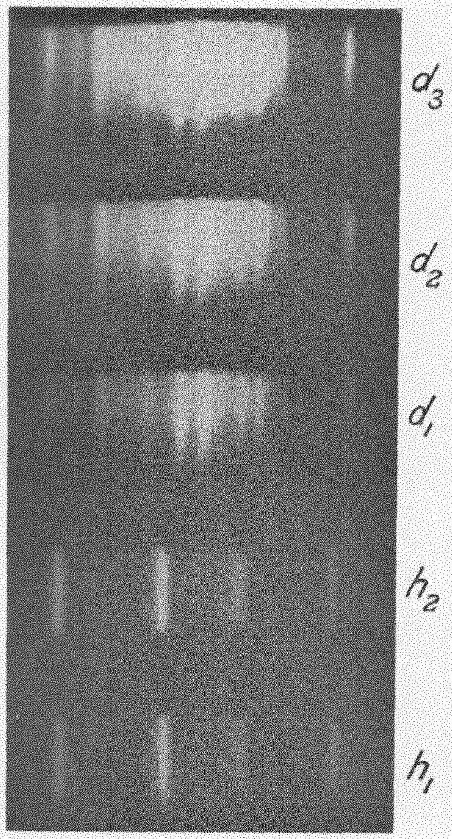

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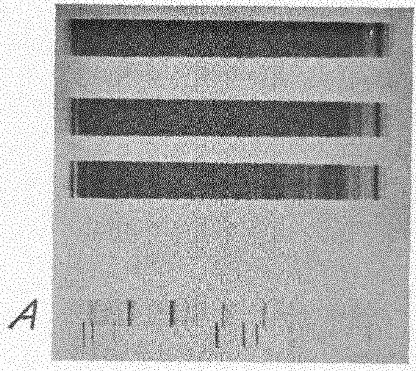

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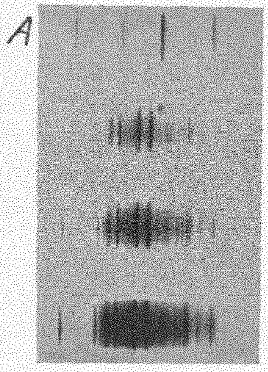

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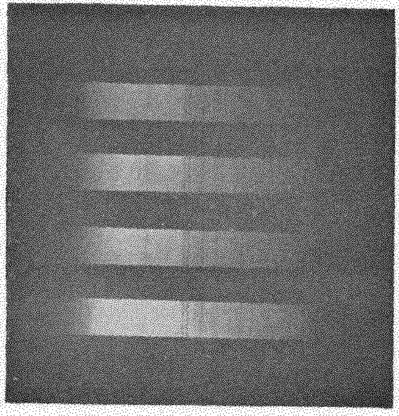

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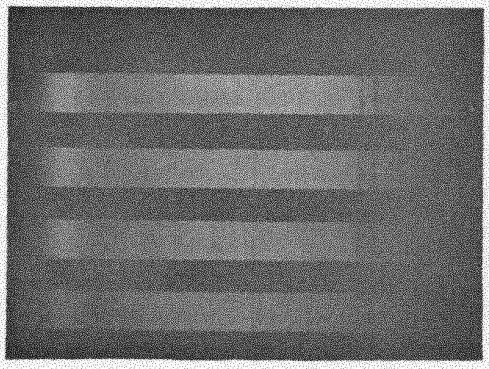

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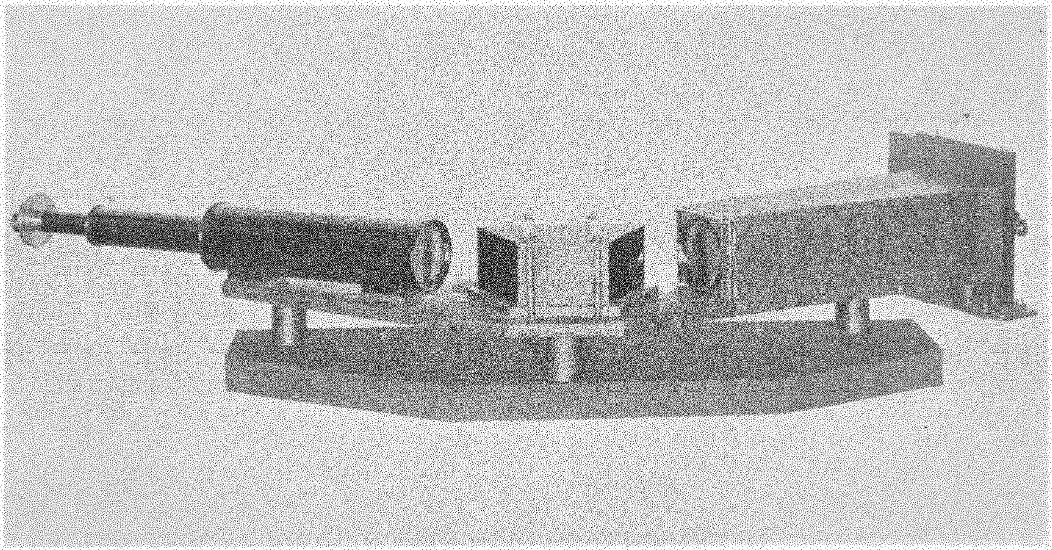

Fig. 1.

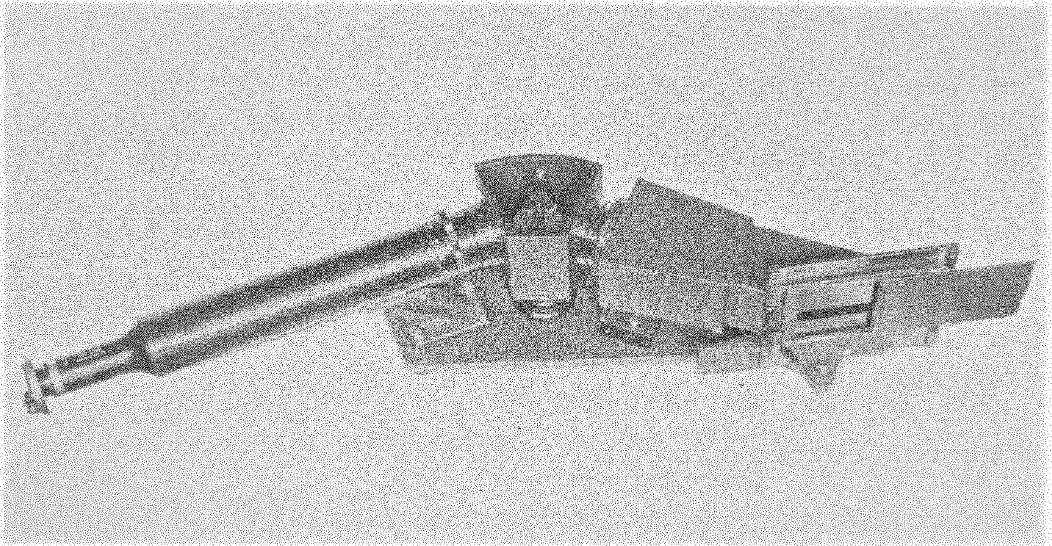

Fig. 2.

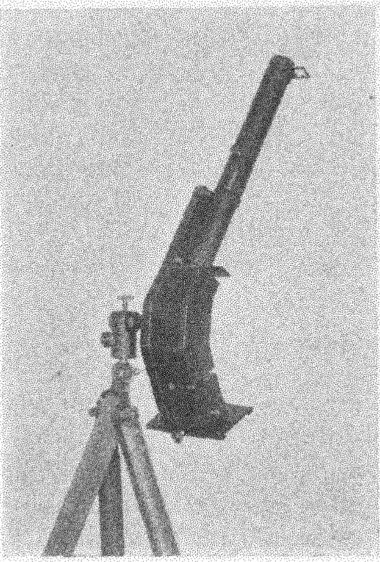

Fig. 3.

These two instruments were built by Dr. Carl Leiss, Berlin, in accordance with my instructions and drawings. In 1923 the dispersion of the quartz spectrograph was increased by introducing a second Cornu prism.

Two small spectrographs shown in figs 3 and 4, were built by the instruments makers at the Physical Institute, Oslo.

The camera lens was an Erneman Kinostigmat F : 2 with a focal distance of 6 cm. The collimator lens had an effective opening of 3 cm and a focal distance of 20 cm. Each instrument had one Rutherford prism with effective opening 2.7—2.8 cm, and in front of the slit a condensor lens with opening 4 cm and focal distance 20 cm. The latter was fixed into a brass tube, which could be easily fixed to and removed from the collimator tube. Figs 3 and 4 show the instruments with the condensor lenses adjusted. The prisms, collimators and condensor lenses were made by Carl Leiss.

In order to increase the light power still further a cylindrical lens was fixed in front of the plate holder. By means of a simple device it could be put into the path of the light bundle and in that position it produced a contraction of the length of spectral lines and thus produced an intensified image. If not wanted it could be turned out of the path of the bundle of rays. The large glass spectrograph and the two small ones were provided with such cylindrical lenses.

§ 3. Regulation of temperature.

From the experiences gained by the spectrographic observations I made in 1912—13 at Bosekop, it was evident that each exposure with one of the large spectrographs might last several weeks.

On the other hand we know that the position of a certain spectral line on the plate will vary with change of temperature. The sensitiveness to changes of temperature generally increases with increase of dispersion.

It is therefore essential that the spectrographs are kept at a nearly constant temperature throughout the exposures.

If the exposure only lasts for part of an evening and the dispersion is small, we need not introduce any special precautions. As long as the small spectrographs are merely used with short exposures they may be erected in the open air.

The large spectrographs, however, had to be put into a well isolated box in which the temperature was kept constant by means of an authomatic regulating device.

The box was given a form suitable for the instrument and could be turned on a vertical and a horizontal axis. The box is shown in figs 5 and 6, corresponding to a vertical and a horizontal position of the collimator.

During exposures the casette was kept open, and the apparatus was put into action by directing the collimator towards the north-light and by opening a cover in front of the slit.

Fig. 4.

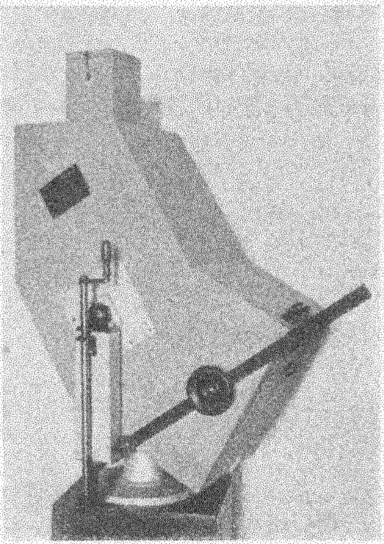

Fig. 5.

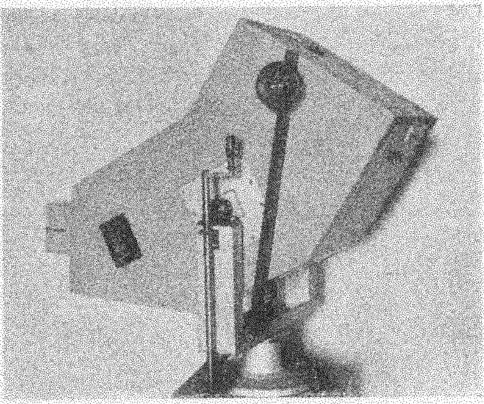

Fig. 6.

Fig. 7 a.

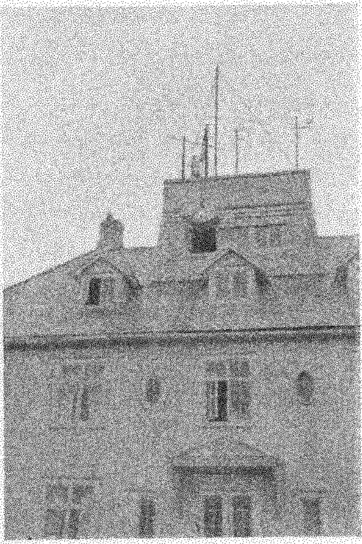

Fig. 7 b.

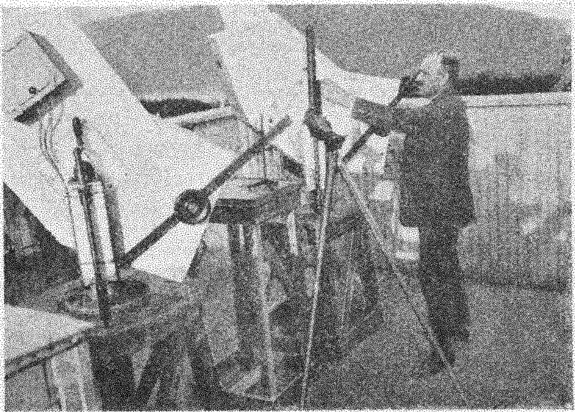

Fig. 8.

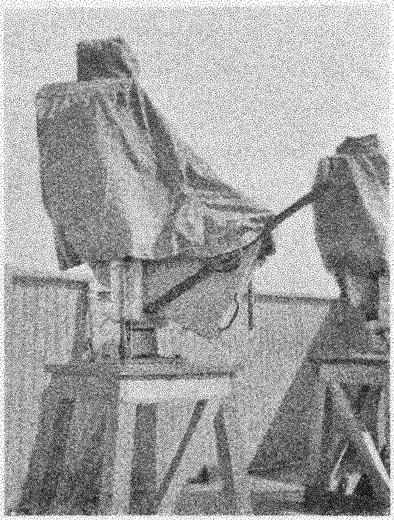

Fig. 9.

Fig. 7 a. The Weather Bureau at Tromsø. Fig. 7 b. One of the spectrographs on its way upwards to the observation platform. Fig. 8. The spectrographs on the observation platform. Fig. 9. Spectrographs with Canvas bags.