INVESTIGATIONS OF THE AURORAL SPECTRUM BASED ON OBSERVATIONS FROM THE AURORAL OBSERVATORY, TROMSØ

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CHAPTER I.

Equipment and Plan of the Work.

Introduction.

§ 1. The investigations of the auroral spectrum which where commenced in 1922 and continued during the following years, were for the greater part based on observations undertaken at Tromsø — and only a few spectrograms were obtained at Oslo. The results of these investigations, covering the period from 1922—26, were given in a number of notes and papers[1], and a more complete account of the observations and the results was given in a paper recently published in Geophys. Publications. (List of Papers No. 28).

These investigations greatly extended our knowledge regarding the auroral spectrum, its intensity-distribution and variations, and they furnished important information as to the composition and physical state of the upper atmospheric layers.

Although these investigations had given a number of definite results, they had also shown that a great many problems relating to the auroral spectrum and its variations still remained to be solved.

A considerable number of weak lines were observed, but on account of their weakness, they were only obtained with small dispersion and consequently the accuracy of determination was too small for a reliable identification of the lines.

Apart from the strong green line, the region of long waves from green to infra-red was insufficiently explored. In the region from green to the limit of the visible spectrum in red, a number of bands and lines were observed, but only with small dispersion; and investigations of the infra-red part of the spectrum, for which preparations were made already in 1925, were not brought into effect during the first period of my studies on the auroral spectrum.

Regarding the studies of the variations of the spectrum some important effects were found, such as a variation of the intensity distribution with altitude, and the very pronounced variation of the red part of the spectrum. The means at my disposal did not enable me to follow up these discoveries, although a systematic investigation of the laws governing these effects would call for the greatest interest.

It soon became clear to me that if it were to be possible in a satisfactory way to carry on further investigations of the auroral spectrum along these lines, it would be practically necessary to have at our disposal near the auroral zone an observatory which was designed and equipped so as to meet the special demands of these observations, and where the work could be continued for a considerable number of years.

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[1] Compare list of papers at the end of this communication.

In 1924 I sent Dr. Wickliff Rose (President of the International Education Board founded by Rockefeller) a letter in which I drew up a plan for a new observatory in Northern Norway for the study of Aurora Borealis, Terrestrial Magnetism, Atmospheric Electricity and allied phenomena, and asked whether the Board might be willing to give substantial support to such a plan.

The plan met with interest at the Board and also from my colleagues O. Krogness, C. Størmer, S. Sæland and others. Further negotiations from our side with the leader of the office in Paris, Professor Dr. August Trowbridge, led to the building of the new Auroral Observatory at Tromsø, which was to be conducted through an organisation called the "Norwegian Institute of Cosmical Physics", by an executive committee.

According to the statutes of the Institute, the various subjects of research contained in our programme are to be divided between the members of the executive committee in a way which pays due regard to the special subject in which each member is most interested and has the greatest experience.

The present writer was assigned the special duty of attending to the spectral observations, their further treatment and the publication of the results.

A description of the organisation, and of the new Auroral Observatory and its programme of work has recently been given in a paper[1] published by the members of the executive committee, whose present members are: Leiv Harang, Ole Krogness, Carl Størmer, Sem Sæland and the present writer.

Regarding the general plan and the equipment of the observatory I must refer to this paper; and in this connection I shall merely give some details regarding the plan and equipment which are of special interest in connection with the spectral work.

Before proceeding to describe the equipment, however, I will give a brief summary of some of the most important problems relating to the auroral spectrum which were included in the programme of the new auroral observatory.

§ 2. Important problems relating to the auroral spectrum to be dealt with at the Auroral Observatory.

First of all, our task would be to complete the exploration of the auroral spectrum throughout the whole region from the limit in ultra-violet given by the atmospheric absorption, and as far into the infra-red as our observational methods permit. A good deal of this kind of exploration work has already been carried out during my previous investigations (cp. list of papers), and perhaps the more conspicuous lines and bands in the visible and ultra-violet region were detected and more or less accurately measured.

In 1925 certain preparations were made for the spectrographic exploration of the infra-red region by means of photographic plates made sensitive to infra-red by proper treatment, but the auroral work could not be continued and the exploration of the infra-red region had to be left for the new observatory.

The existence of the infra-red auroral luminescence was shown at the Tromsø Observatory in January 1932 by W. Bauer, who succeeded in obtaining auroral photographs by means of infra-red plates and suitable filters in front of the camera.

On Febr. the 4th, 1932, spectrograms of the infra-red part of the auroral spectrum were obtained by the writer in collaboration with L. Harang and will be described in this paper (27)

These investigations will be continued.

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[1] The Auroral Observatory at Tromsø. Publ. from Det Norske Institutt for Kosmisk Fysikk. Nr. 1, Bergen 1932.

Even in the visible and ultra-violet region, however, the exploration work cannot be considered as completed. On account of the great variability of the auroral spectrum, we may expect a great many lines to appear in certain forms for short intervals of time, and by increasing the light power of our instruments and the sensitiveness of the photographic plates, we may obtain spectra corresponding to various types of aurorae, giving lines not to be found on spectrograms of very long exposures; for such spectrograms may merely show lines which on the average appear with considerable intensity.

For such a first exploration and in order to detect which lines and bands may appear, it is necessary to use instruments of very high light power; but that means small dispersion and a comparatively large error in the wave-length determination.

In order to obtain a better definition of lines and bands, and in order to increase the accuracy of the wave-length measurements, spectrograms should be taken with larger spectrographs for all spectral regions. In this way we hope to be able to measure, at any rate the more common lines, with such accuracy as to render possible a fairly definite interpretation.

How far we may increase the dispersion will, inter alia, depend on the spectral region, the intensity and structure of the lines and bands we are dealing with, and the sensitiveness of the photographic material for the spectral region considered.

Spectrographs with their optical parts made of glass or quartz, which are to be recommended for the region of more or less short waves, are not so suitable in the long-wave part, on account of the rapid diminution of dispersion with increasing wave-length.

In order to obtain spectra in the region of long waves with considerable dispersion, grating spectrographs of high light power will be used. In order to obtain spectrographs which combine high light power with a large dispersion, we intend for the future work to use prisms with a suitable liquid as diffracting medium.

In the case of some of the stronger auroral lines, it may be possible to undertake wave-length measurements of very high precision by means of interferometer methods. First of all, such measurements may be carried out for the strong green auroral line by an arrangement similar to that used by Babcock[1] by the interferometric determination of the green line appearing in the light of the night sky (26).

Similar interferometric methods may also be used for some other auroral lines. As stated in previous papers (14, 17, 18, 28) some lines in the red part, especially one or two in the region 6300 to 6400, may in red-coloured aurora appear with an intensity of the same order of magnitude as the strong green line. In such cases it ought to be possible to undertake interferometric measurements also for these red lines.

An accurate determination of the wave-lengths of these red lines is of particular interest firstly because they have a fundamental bearing on the interpretation of the auroral spectrum and, secondly, because the variability of the relative intensity of these red lines to a large extent is responsible for some of the most conspicuous colour-changes shown by the aurora, and the great variability may give valuable information regarding the physical states of the auroral region.

Already during the investigations undertaken from 1921—26 a first attempt was made to measure the relative energy of the more conspicuous lines of the auroral spectrum. On account of the variability of the distribution of intensity within the auroral spectrum, such energy measurements can only give a kind of typical average distribution for the epoch covered by the observations; but, still, a knowledge of this typical distribution of energy may be of great value for the physical interpretation of the auroral spectrum

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[1] Astrophys. Journ. 57, 1932.

and we therefore intend to continue these intensity measurements at the new Auroral Observatory with improved methods.

At the new Observatory we also intend to pay great attention to the study of the variations of the auroral spectrum. Already through the investigations undertaken during previous years a number of interesting variations were found (6, 7, 18, 28).

Thus it was shown that the intensity of the strong green line relative to that of the principal negative nitrogen bands diminished with increasing altitude. Further, it was found that a number of weak lines in the region between 4700 and 4200 became more intense as we pass upwards, as compared with the negative nitrogen bands.

These altitude effects, discovered in 1923, ought to be more systematically studied at the new Observatory, and these investigations should be extended to all spectral regions for which lines may be observed, and should be combined with height measurements of the auroral displays.

In order to study possible variations of the auroral spectrum within a certain auroral display, we may with advantage use photographic filters, and compare simultaneous photographs taken through filters which permit different parts of the auroral spectrum to pass through.

Preparations for such observations were already made in 1923. I selected a number of Wratten filters suitable for the purpose, and attempts were made to obtain auroral photographs through such filters with cameras of the Størmer type.

It appeared, however, that the camera lenses had not a sufficient light power for obtaining such photographs with the photographic material at our disposal. Recently such investigations were taken up at the Tromsø Observatory by L. Harang and with remarkable success, and later on similar work was done by W. Bauer, partly in collaboration with L. Harang. For the further description of these investigations we would refer to their published papers[1], [2].

On the basis of spectra which Størmer[3] in collaboration with Moxnes obtained from sunlit auroral rays, Størmer suggested that the sunlit aurora would have a spectrum where the intensity of the green line — as compared with that of the negative nitrogen-bands — was very much smaller than for northern light not exposed to sunlight. As the spectrum of the sunlit aurora corresponded to a very large altitude, the relative intensity of the green line will be largely reduced on account of the altitude effect, and for that reason only their spectra cannot give any information as regards a possible influence of sunlight on the intensity distribution within the auroral spectrum. It is, however, to be hoped that by more systematic and accurate determinations of the altitude effects, we may be able to find out how far the sunlight has an effect like that suggested by Størmer.

As the sunlit rays are usually faint and only last for a short time, the "filter" method might perhaps give the best prospects for success. Also spectrographs of very high light power will be used for such investigations and should, under favourable conditions, be expected to give the most reliable results.

In previous investigations it was found that the intensity distribution within the auroral spectrum — independent of the altitude effects — varied with the type of aurorae. These variations are also apparent from the difference of colour shown by the various types.

In the investigation of these intensity variations special attention should be paid to the relative intensity within the red part. Some of the red luminescence appears as

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[1] Leiv Harang, Filteraufnahmen von Polarlicht. Z. S. f. Geophys. 7, 324, 1931.

[2] W. Bauer: Naturwiss. 20, 287, 1932.

[3] Cfr. C. Størmer Z. S. f. Geophys. 5, 177, 1929, 6, 463, 1930 and L. Vegard Z. S. f. Geophys. 6, 42, 1930 and 7, 196, 1931.

somewhat diffuse lines, which by the writer have been referred to the 1st. positive group of nitrogen.

In addition, we have two sharp lines already referred to, one fairly strong near 6300, and a second near 6360 (30). It was shown that in certain observed cases, the red colour of the aurora is due to the relative intensification of lines probably identical with one (or perhaps both) of these red lines. It is also possible that red north light may be caused by a relative intensification of the bands which we referred to the first positive group.

During my stay at Bossekop 1912, I observed a drapery-shaped auroral arc (17, 18) which was deep red from the bottom edge and for some distance upwards, but farther up it had the ordinary green colour. A similar drapery-shaped arc was observed last winter by Harang and Bauer[1] and its height carefully measured. It appeared that its bottom edge reached the unusually low altitude of 70 km. The red north light observed by the writer in 1926, of which the red colour was due to the intensification of a line near 6300, had a deeper red colour which was not confined to the lower limit.

It may be possible that the red colour of the bottom edge of drapery-shaped arcs may be due to a relative intensification of some other lines or bands in red e. g., the bands belonging to the 1st positive group.

For the interpretation of the red lines near 6300 and 6360, it is — as pointed out in a previous paper (30) — also of great interest to measure the relative intensity of these lines and to find out whether it keeps constant or not.

Spectrograms of the red part of the spectrum during the period 1922—26 showed that the intensification of the line near 6300 was a phenomenon of a universal character, taking place simultaneously at Tromsø and at Oslo, and the observations indicated that its *relative intensity varied in a similar way as the sunspot frequency*[2].

Systematic investigations on these points should be undertaken at the Auroral Observatory and if possible the results should be compared with simultaneous ones from other localities near the auroral zone and at lower latitudes.

Visual spectroscopic observations seem to indicate variations of the relative intensity of lines appearing in the green part — between 5577 and 4700, where the group of lines called the second green line (15) call for special interest. These variations should be studied.

Finally the relative intensity of the infra-red part of the spectrum and its possible variations are to be investigated.

The spectrographic observations undertaken at Bossekop during the winter 1912—13 (1, 2) proved definitely that the negative nitrogen bands dominated the blue and violet part of the spectrum, and later observations showed that the 2nd positive group also appears fairly strong, especially in the ultra-violet part. (4, 5, 7).

As is well known, the structure of these bands is caused by the rotational energy of the molecules from which they are emitted, and already in 1923, I pointed out that the development or intensity-distribution of these bands might give us some definite information regarding the temperature of the auroral region. In dealing with these problems we must take into account the possibility that the emitting centres may receive rotational energy directly from the collision with the exciting solar electric rays, so that the rotational energy derived from the development and intensity distribution of the band-

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[1] L. Harang and W. Bauer: »Über einen Nordlichtbogen in weniger als 80 km. Höhe über der Erde. Gerlands Beitrage z. Geophys. 37, 109, 1932.

[2] Since this was written my colleague Størmer has mentioned to me that earlier observations also indicate a tendency for the red aurora to appear at times of sunspot maxiuma. (Cfr. H. Fritz: Das Polarlicht p. 135. Leipzig 1888.

spectra may be greater than that existing without ray bombardment. The temperature derived from the band-spectra should then give an upper limit of the temperature of the auroral region.

In order to estimate how far the development of the rotational bands was influenced by the ray bombardment, and how far it depended on the temperature of the gas which was bombarded, a number of laboratory experiments was made partly in collaboration with Mr. J. Aars. By these experiments a bundle of cathode rays of small ray intensity was sent into a tube containing nitrogen which could be cooled by means of liquid air. The experiments showed that the cooling reduced the extension of the striations (R-branch) of the negative bands to the extent which was to be expected if the emitting centres had about the same temperature as the surrounding gas. The experiments of J. Aars showed further that variation of the pressure and velocity of the rays had no noticeable influence on the development of the R-branch.

A calculation of the temperature by means of the theoretical formula for the intensity distribution within the R-branch, also showed that the temperature of the emitting centres, under the conditions of our experiments within the limit of error, was equal to that of the surrounding gas. This result will show that a single collision between a swift cathode ray and a molecule, resulting in an excitation process, does not essentially increase the rotational energy of the molecules.

Experiments undertaken with canal rays[1], however, show that the collision results in a marked increase of the rotational energy of the excited molecule.

If therefore the aurorae are produced by cathode rays, the temperature derived from the development of the nitrogen bands should give nearly the true temperature of the auroral region from which the light is emitted. If positive rays play an important part, the temperature of the auroral region may be considerably lower than that derived from the band spectra.

A very accurate determination of the temperature from band spectra would be facilitated if we could obtain spectrograms of the bands with a dispersion so large, that the individual rotational components were well separated.

As shown in a previous paper, we may also utilise spectra with small dispersion when they are compared with spectra from known temperatures, taken with about the same dispersion. In papers recently published (28, 29), I have carried out a determination of the temperature of the auroral region in the way indicated, and based it on spectrograms taken with fairly large dispersion during the years 1924—25.

These first determinations, however, cannot claim any great accuracy, but on account of the very great importance of the problem, such investigations will be undertaken at the new Observatory with improved methods and experimental equipment.

It is our plan to take spectra of the negative bands with increased dispersion. We hope to do this by using highly sensitised plates and applying prisms with a suitable liquid as diffractive medium. In this way we may increase the dispersion very considerably without any essential reduction of light power.

At the same time we intend to make laboratory experiments the main object of which will be to study the influence of the electric ray bombardment on the rotational energy of the molecules, and to find the accuracy with which the temperature of the emitting centres may be determined when we use spectrographs of different dispersion.

It is also to be expected that the temperature of the auroral region is subject to large variations. If the composition and velocity of the corpuscular rays vary, the "apparent" temperature measured from the band spectra may vary on account of the

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[1] Not published.

rotational energy, which may be imparted to the emitting molecules by positive rays which may possibly form parts of the corpuscular rays that enter our atmosphere. If various types of aurorae correspond to a change of composition in the electric rays, we may expect the various auroral types to give different "apparent" temperatures.

The temperature changes may no doubt also be real. Thus it is possible that the temperature varies with altitude, with the time of the day and with the season of the year.

It is our plan to develop methods which will make it possible to determine the possible temperature variations. For this purpose we shall have to utilise spectrographs of light power, and try to determine the temperature from bands obtained with small dispersion. We may, at any rate hope, in this way to measure fairly accurately possible changes of temperature, even if considerable errors would be attached to the absolute determination.

§ 3. Arrangements and instruments.

The Observational Platform.

In the spectrographic work undertaken at Tromsø during the years 1922—26, the spectrographs were placed on a platform on the roof of the building of the Geophysical Institute at Tromsø. It appeared, however, that such an arrangement was very inconvenient because the big spectrographs, when once put up, had to remain on their stands, and it was difficult to undertake necessary tests, changes and readjustments.

In planning the new Observatory, we therefore took advantage of this experience and arranged an observational platform on the ground. A description of this arrangement is given in a paper already referred to, published by the executive committee.

In this connection I shall merely call attention to certain details which are of importance in connection with the spectrographic work.

The spectrographs are to be mounted on stands provided with rubber wheels. The platform has a concrete floor which is connected with the broad doorway of the laboratory building by a concrete road. The instrument can therefore easily be wheeled into the laboratory when it is wanted for experimental tests, adjustments or rearrangements of some kind.

On one side of the platform there is placed an observational stand which serves various purposes. It contains a switchboard with all electrical terminals necessary for the supply of electric energy for high tension currents, for telephones and for signals of various kinds and purposes. The stand may also be turned into an observational table. The platform with stand and the door communicating with it, are shown in Figs. 1 a, b, c and 2.

Equipment for the spectral work.

At the present time the Observatory has for the spectral work the following instruments:

1. A large glass spectrograph with Rutherford prism built in 1921 for auroral investigations.
2. A small glass spectrograph of high light power with Rutherford prism built in 1922.
3. A large spectroscope of high light power provided with micrometer screw, for wave-length measurements. Under favourable conditions the wave-length may be determined with an accuracy of 1 Å. The instrument was designed by the writer and made by Carl Leiss, Berlin.
4. A small glass spectrograph with about the same light power and dispersion as No. 2. It has an ordinary 60° prism and a Görlitz camera lens. It was built by

the instrument-maker Jacobsen at the Observatory from a design made by Director L. Harang.

5. A small glass spectrograph with an extremely high light power, provided with a camera lens (F:1) made of a single piece of glass.
6. A glass spectrograph built as No. 5, but considerably larger.
7. A large quartz spectrograph with two Cornu prisms.
8. A large glass spectrograph combining a fairly large dispersion with a high light power.
9. A grating spectrograph of high light power and a comparatively large dispersion for long waves.

   The old spectrographs Nos. 1 and 2 were described in previous publications (4, 5, 7, 28). In this connection I shall give a more detailed description of the new spectrographs Nos. 5, 6, 7, 8, and 9 which were designed by the writer.
10. Fabry-Perots interferometers to be used for precision measurements of the wavelengths and structure of the stronger lines and bands.

§ 4. The two glass spectrographs with camera lens made of one piece of glass.

The two glass spectrographs Nos. 5 and 6 are similarly constructed, and as regards optics they merely differ with regard to absolute dimensions. They are intended for the study of intensity variations, and these investigations do not claim any high degree of sharpness of lines, but it is most essential that they should have the highest possible light power.

Their construction is seen in Fig. 3. The optical parts consist of the camera lens (3) made of one piece of glass and two 30° prism (2) and (2′), one of which (2) has a spherical surface, so that at the same time it serves as collimator lens. In this way the loss of light through reflection and absorption is reduced to a minimum.

The camera lens for each of the two instruments has a light power F:1 and was made by John E. Mellish, St. Charles Illinois U. S. A. It is ground so as to give a fairly sharp image of parallel homogeneous rays. The prisms were made of flint glass of high transparency by Carl Leiss, Berlin.

For the spectrograph No. 5, the diameter and focal distance of the camera lens were 55 mm and the effective aperture of the prisms 52×52 mm. The spherical surface of prism (2) gave a focal distance of 250 mm.

The larger spectrograph No. 6 had a camera lens with diameter and focal distance, equal to 105 mm and the prisms had an effective aperture of 100×100 mm. The focal distance of the spherical surface of prism (2) was 400 mm. All focal distances correspond to the green spectral region. The mechanical parts were made by the instrument-maker M. Jacobsen at the Observatory.

§ 5. The large quartz spectrograph.

The large quartz spectrograph No. 7 combines a high light power with a considerable dispersion. Its construction is seen from Fig. 4. The optical parts consist of two 60° Cornu prisms (4) and (4′). (Side of basis 100 mm, height, 70 mm), a collimator lens (3) (diameter 80 mm and focal distance 600 mm) and a camera lens 5 (diameter 90 mm, focal distance 450 mm.) Further, the instrument was provided with a condenser lens, diameter 40 mm, focal distance 200 mm.

The quartz optics of the instrument and the slit (1) were made by Carl Leiss, Berlin.

The other mechanical parts were made according to a design of the writer, by the instrumentmaker H. Jørgensen at the Physical Institute of the University at Oslo. The plateholder (8) could be moved backwards and forwards on a sledge by means of the screw (10) and

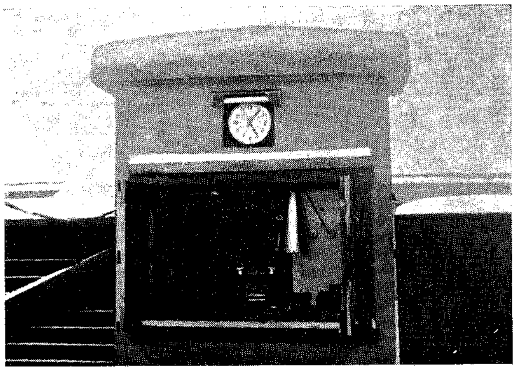

Fig. 1 a. The stand on the observation platform.

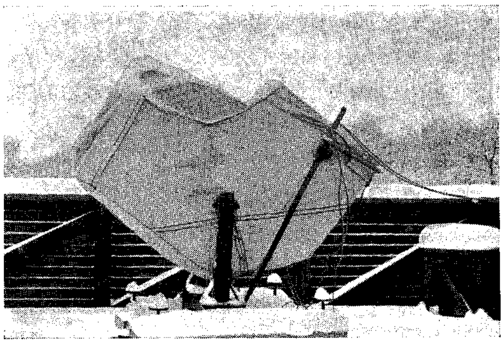

Fig. 1 b. The large glass spectrograph on the observation platform.

Fig. 1 c. Observation Platform with "stand" and instruments.

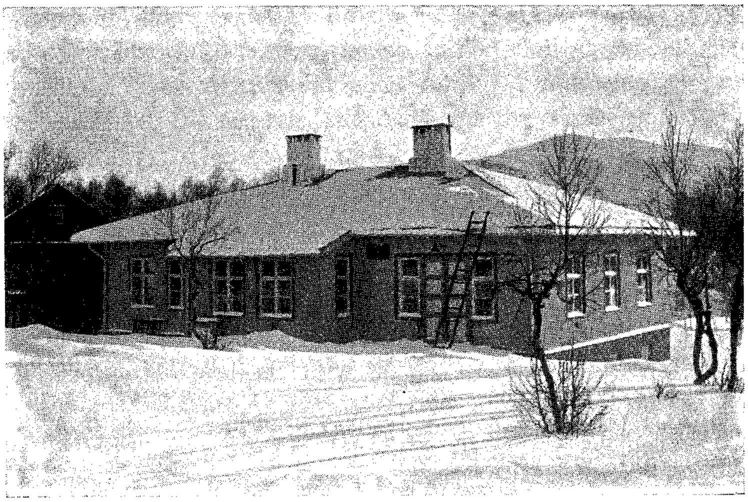

Fig. 2. Observatory building showing the door which communicates with the observation platform.

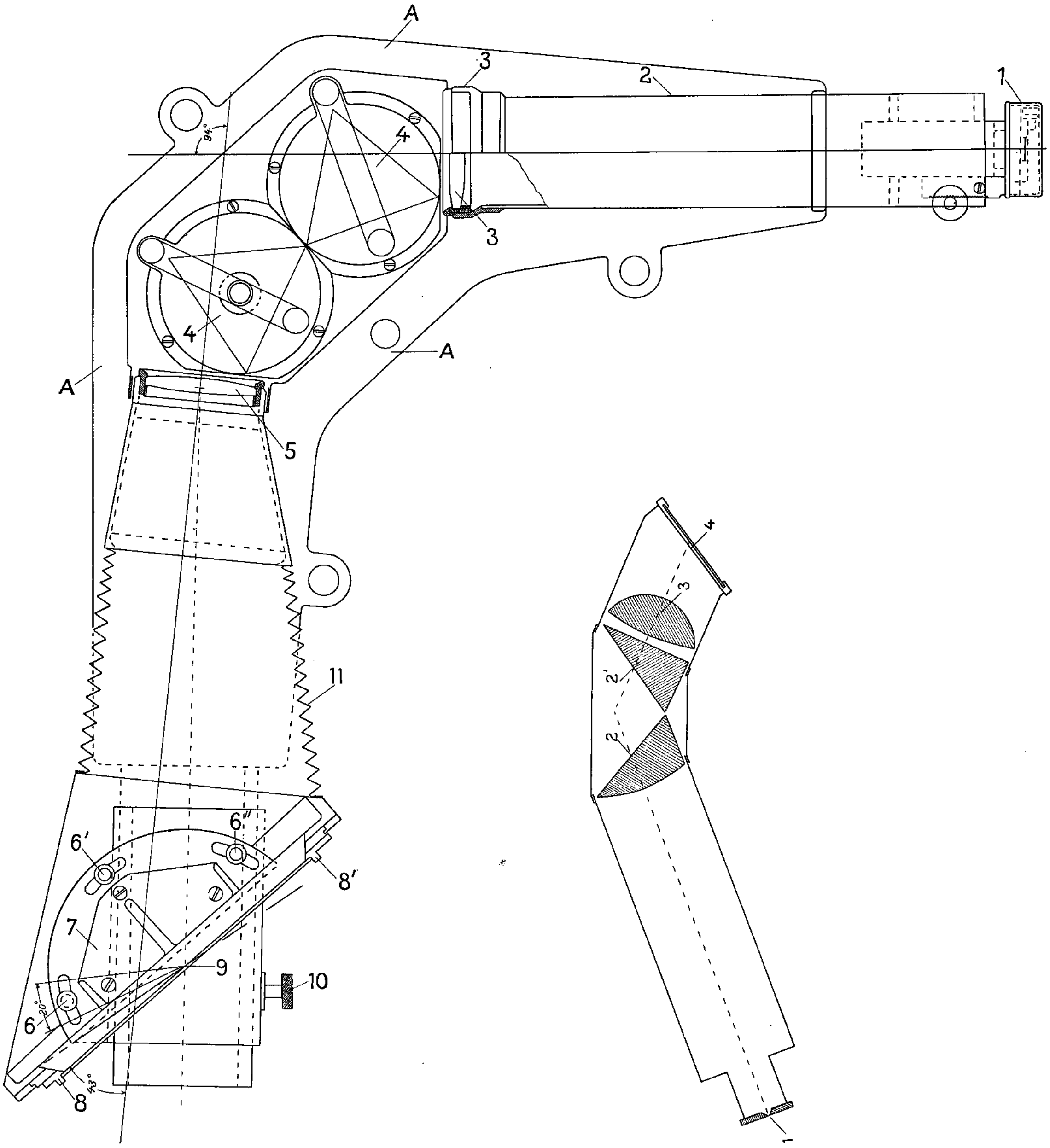

Fig. 4.

Fig. 3.

it could be turned round an axis (9) and fixed by the screws (6). The plate-holder and camera lens were connected with bellows (11).

Optical parts, collimator (2) with slit, as well as the plate-holder arrangement, were mounted to the same bottom plate (A). The optical parts were carefully protected against false light.

The dispersion of the instrument within the region between 5000—3000 Å, which is of the greatest importance in connection with its use for auroral investigations, is given in Table I.

Table I.

λ	3000	3500	4000	4500	5000
$\frac{d\lambda}{ds}$ Å/mm	14	24	35	50	67

§ 6. The new large glass spectrograph.

The old large spectrograph (No. 1) used in my earlier investigations had a considerable dispersion (cf. 28 in the list of papers). Its light power, although not small, was insufficient for obtaining the weaker auroral lines. It was therefore very important to have a large spectrograph of considerably higher *light* power and with as large dispersion as practically possible. In such an instrument, the dimensions of the optical parts will be fairly large, so the absorption may be quite marked. It was therefore most important to select a kind of glass, with an absorption as small as possible, when due regard is taken to other properties which the glass has to fulfil.

After having discussed the matter with the firm Carl Zeiss, Jena, we found suitable kinds of glass with a transparency so high, that the whole apparatus transmits — with fairly large efficiency — far into the ultra-violet to about 3400, and even farther.

My previous investigations had also shown the importance of having a convenient system for adjusting the optical parts, so as to give the best possible light power and sharpness for any part of the spectrum. After having looked into this matter, I found a suitable arrangement which is based on the employment of two prisms.

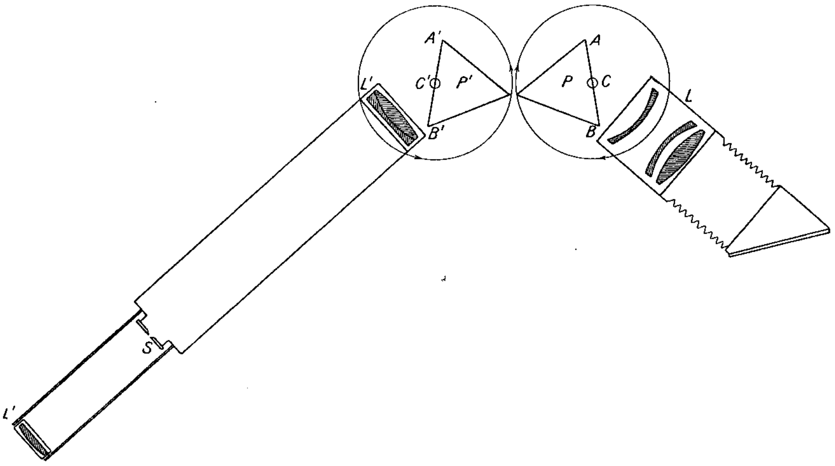

Fig. 5.

The general plan showing the construction and adjusting principle of the spectrograph is illustrated in Fig. 5. The adjustment must fulfil the following conditions.

1) The optical axis of the camera lens must cut the surface of the prism AB at its centre C.
2) The collimator axis must cut the surface of the second prism P' at the centre C' of the surface $A'B'$ of the prism.

These conditions are fulfilled by letting the camera lens with plate-holder, as well as the prism P, turn round the same vertical axis C, and by letting the collimator and the second prism P' turn round the axis C'.

Suppose that the system consisting of collimator, two prisms and camera has the right position for a certain wave-length λ. In order to obtain the right position (minimum deviation) for another wave-length λ_1, the prism P must be turned an angle α, say, and the camera an angle $2\,\alpha$, in the same direction. At the same time the prism P' and the collimator must be turned an angle α and $2\,\alpha$ respectively, but in the opposite direction.

Thus the adjustment has theoretically only one parameter (degree of freedom) and might be worked with one single operation. I found it, however, convenient to let the

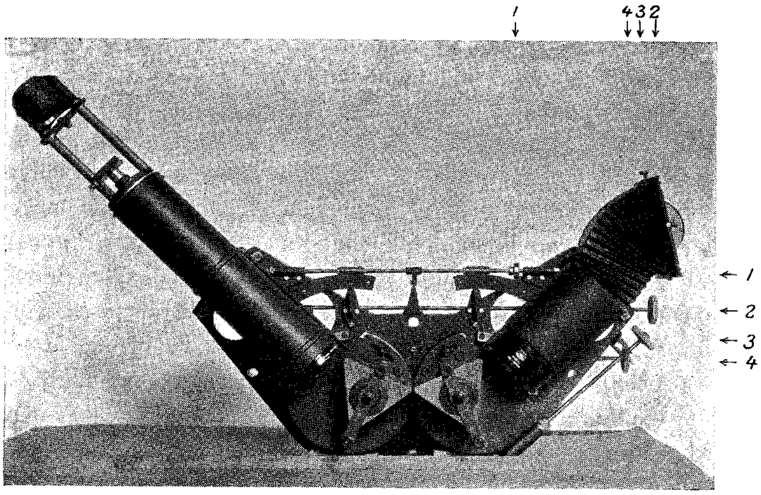

Fig. 6.

system have two independent motions. With one operation we may move each of the two prisms an angle α in an opposite direction. The camera and collimator may be turned an arbitrary angle β in opposite directions, and we have in any case to give β the right value. The mechanical construction by means of which this adjusting arrangement was effected is illustrated in Figs. 6, 7 and 8 showing some photographs of the instrument. Details of construction will be seen from Figs. 9, 10 and 11.

Each of the two prisms is put on a prism-table which for the larger part has a circular form with centre coinciding with the axis of rotation *C*. Part of the circumference is formed like a toothed wheel. The form of the prism-table and the mounting of the prism on it, are shown in Fig. 9.

The prism is put into a metal frame (15, 16, 17, Fig. 9) and is fixed by means of the screw 18. When the prism-tables are put in proper position, the tables act like two tooth-wheels, and if one table is moved a certain angle, the second table is moved the same angle in an opposite direction. One of the tables can be moved by means of a screw No. 3 Fig. 6. When by turning the screw No. 3, the prisms have obtained their proper position, they may be fixed by turning the handle No. 4 (Figs. 7 and 10) with a screw 8 (Fig. 10) which works the fastening arrangement.

The arrangement for moving the collimator and camera is shown in the photographs (Figs. 6 and 7) and particularly in the drawing Fig. 10.

The rod (1) which turns in the layers (6) Fig. 10 carries two screws (5) and (5′), which again move the two circularly formed metallic wings (*w*) and (*w*′). One of these wings is attached to the collimator, the second one to the camera and in this way a turning of the screw (1) will turn collimator and camera equal angles in opposite directions. The camera and collimator can be fastened by turning the rod (2) carrying the screws (7) and (7′), which act on a fixing device. On Fig. 8, we notice two pointers which may move along a divided scale. One of the pointers is rigidly attached to the prism-table, the second, to the camera. We may now easily fix the position of camera and collimator which corresponds to a given position of the prism-tables.

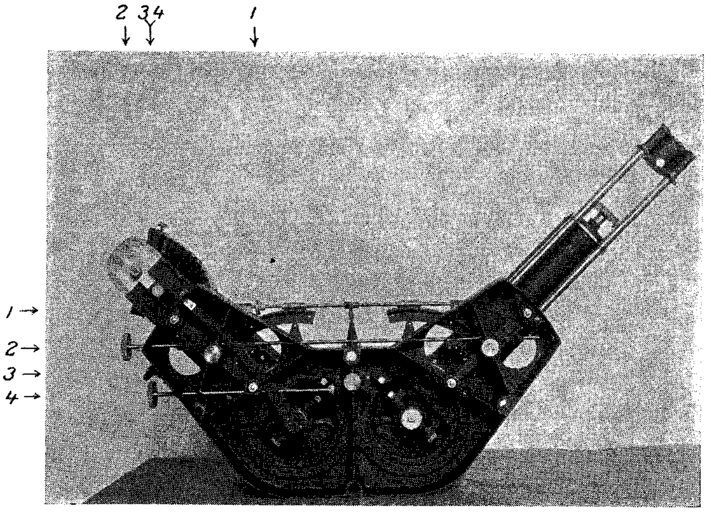

Fig. 7.

The construction and mounting of the plate-holder are shown in Fig. 11. It can be moved on a sledge by means of the screw (9) and the position indicated by pointer and scale (not shown). The plate-holder can also be turned round on axis *D*, fixed by the screw (13), and its position indicated by pointer and scale.

The plate is put into a frame which can be moved up and down in the plate-holder by means of the screw (11) and can be fixed by another screw.

All optical parts are well protected against false light, as shown in Fig. 12. The optical parts were made by the firm Carl Zeiss, Jena.

The camera lens had an effective diameter 100 mm, and focal distance 250 mm. It was composed of 3 lenses as indicated in Fig. 5.

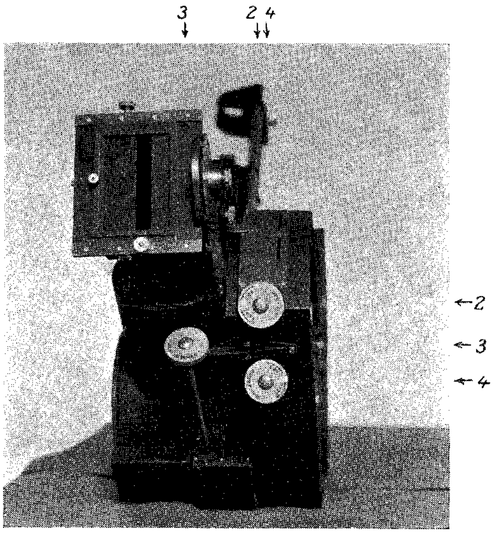

Fig. 8.

The collimator lens had an effective diameter 100 mm and focal distance 520 mm. The condensor lens had a diameter 60 mm and focal distance 250 mm. Each of the two 60° prisms had a basis with side-length 140 mm and height 93 mm.

The mechanical parts were made at the Physical Institute, Oslo, under the guidance of the writer.

Drawings were made by Mr. Bror With and the instrumental work was executed by Mr. H. Jørgensen.

Plate I. 1. e shows the reproduction of a Neon spectrum taken on a pan-chromatic plate with the new large glass spectrograph. The spectrogram is considerably enlarged. The true dispersion on the original plate for various wave-lengths is given in Table II.

Table II.

λ	6000	5000	4000
$\frac{d\lambda}{ds}$ Å/mm	270	160	80

§ 7. The Grating Spectrograph.

In order to obtain a grating spectrograph suitable for auroral investigations, I found it necessary to introduce a lens of high light power in front of the photographic plate. The concave grating used was ruled by The National Physical Laboratory, England. Its radius of curvature was 100 cm. The ruled area is 5 × 3.5 cm and the mean grating interval is 0.00006942 inch at 18.8° C.

It gave a comparatively strong 1st order spectrum. This grating was kindly lent to me by my colleague Professor Sem Sæland. The construction of the instrument will be seen in Fig. 13. The slit (6) at the end of the collimator (5) was placed at a distance of 50 cm in front of the grating (3), which was mounted on the metal-holder (4). The grating could be turned round a vertical axis (*A*), and when it was given the right position it could be fixed by a screw-arrangement.

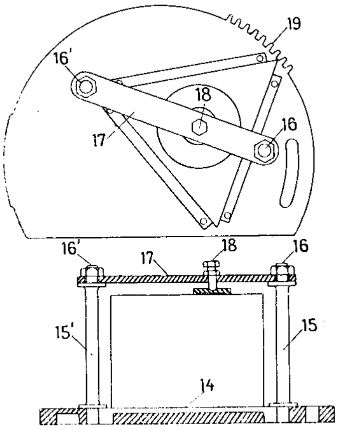

Fig. 9.

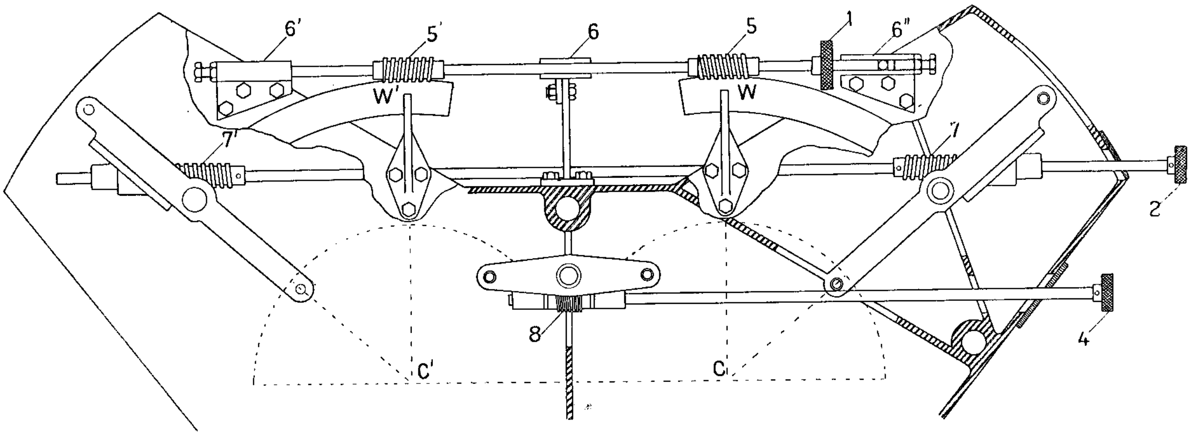

Fig. 10.

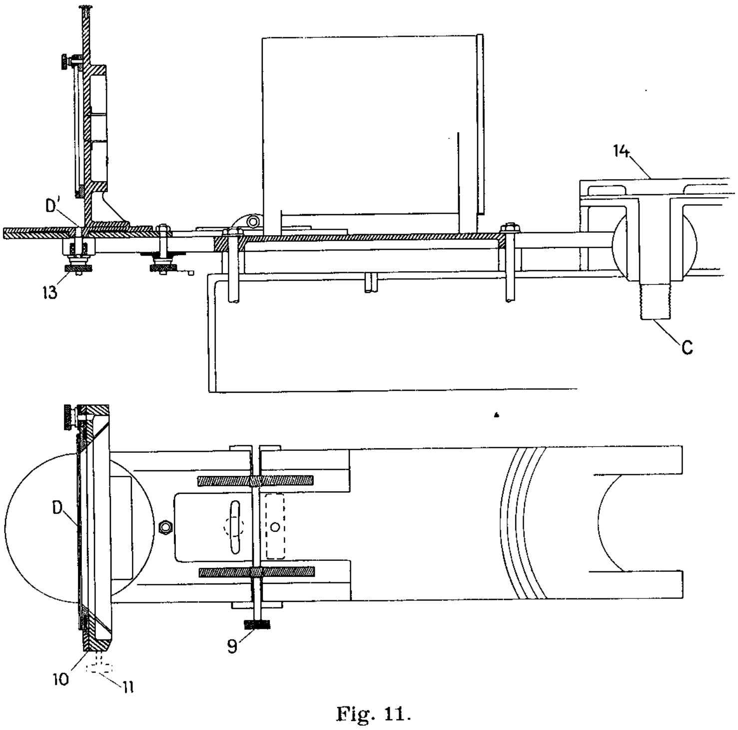

Fig. 11.

The diffracted beam of a homogeneous ray bundle entering the slit, would — for a certain order of diffraction — leave the grating as a parallel bundle of rays. These bundles pass through the lens (2) which forms a sharp spectrum on the photographic plate. The plate-holder with the lens was mounted on a metal plate which could be turned round the axis *A* independent of the rotation of the grating about the same axis. The angle between the normal of the plate and the optical axis of the lens could be varied within certain limits, and, further, the lens could be moved in the direction of its axis.

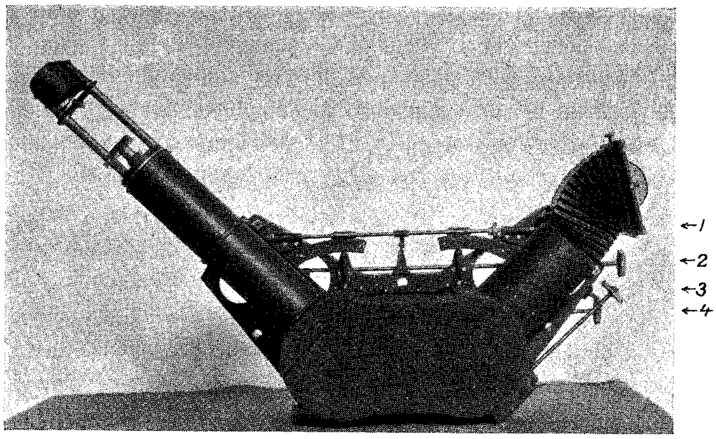

Fig. 12.

The lens (F:1.25) had an effective diameter of 4 cm and focal distance 5 cm, and was delivered by the firm "Astro Gesellschaft, Berlin" which was recommended to me by my colleague Professor Carl Størmer.

The mechanical parts were made — according to my design — by the instrument-maker of the Physical Institute, Oslo, Mr. Kristian Andersen. The instrument is shown in Fig. 14.

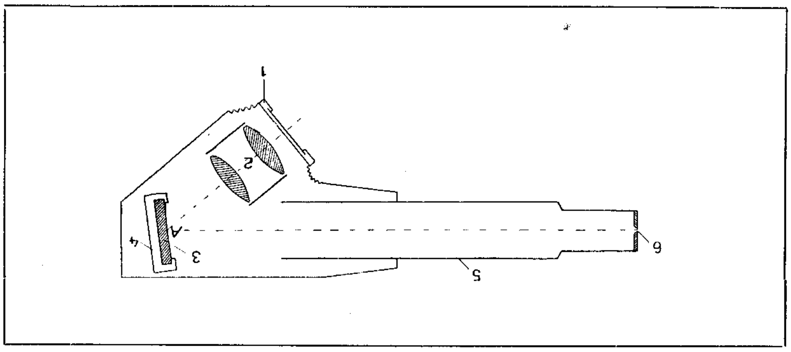

Fig. 13.

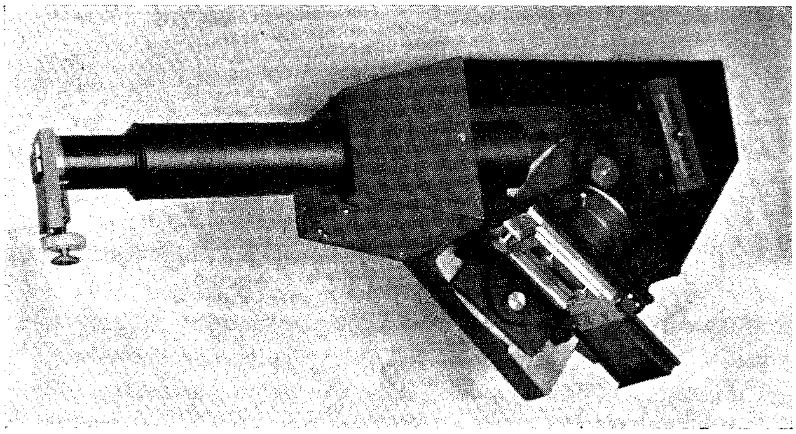

Fig. 14.

With the adjustment now used at the Auroral Observatory for investigating the long wave part of the spectrum, the instrument gives in the first order, a nearly constant dispersion in this region of about 305 Å per mm. With this instrument we may easily take spectra of higher order with correspondingly larger dispersion. We may also fairly easily increase the dispersion by replacing the present lens with one of longer focal distance.

The instrument was finished in Sept. 1932, and taken to Tromsø by the writer at the beginning of October of the same year.

§ 8. The Fabry-Perot Interferometers.

Some years ago I obtained — from Adam Hilger, London — a Fabry-Perot etalon consisting of two parallel glass plates each of them lightly silvered on one side. The plates were mounted in the well-known way in a metallic frame with their silvered surfaces turned towards each other, and separated by means of a cylindrical quartz ring of 1 cm in length.

This etalon was to be used in front of a lens of high light power, and the interference ring system — formed in the focal plane of the lens — had to be analysed.

In the case of very strong lines such as the green auroral line, we may remove all other strong lines and bands by means of suitable filters, and we can photograph the image of interference rings directly on a plate placed in the focal plane of the lens. If it is difficult to obtain a sufficiently selective filter for the line to be analysed, it is intended to let the interference image in the focal plane fall on the slit of a spectrograph of extremely high light power, or the interferometer may be put in front of the prism of a spectrograph. Then we should obtain interference fringes of each line typical for the wave-length and structure of each particular line. (Cfr. Pl. I. 1. f.)

In trying to obtain interference fringes of the green auroral line with this etalon, it appeared that the silver layer absorbed too much of the light to get pictures within a reasonable time of exposure. It was also found more convenient to use etalons which simply consisted of one single plane — parallel quartz plate silvered on both sides.

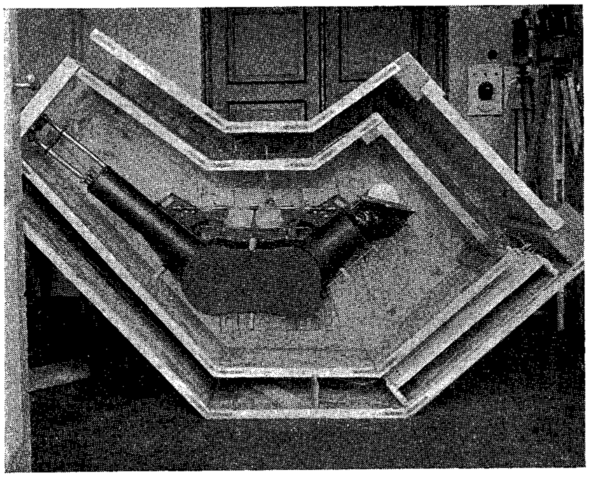

Fig. 15.

Two such quartz plates, one 2.5 mm and one 5 mm thick were made by Adam Hilger. In order to get a suitable thickness of the silver coating, samples of the silvering were sent to me for absorption tests until I found a thickness which combined a fairly small absorption with a good definition of the interference fringes. The optical thicknesses were accurately measured by the National Physical Laboratory. Further details will be given in connection with the publication of the results obtained in cooperation with Leiv Harang.

§ 9. The protection and temperature regulation of the spectrographs.

In order to obtain the somewhat weak lines with the larger spectrographs, we must be prepared for exposures lasting for days or even weeks. The instruments, therefore, must be protected against rough weather and kept at a fairly constant temperature during the exposures.

For this purpose the instruments were put into a wooden box of suitable form, which was mounted on a stand in such a way that it could be rotated round a vertical and a horizontal axis. The arrangements chosen for the new instruments are essentially the same as those used in the investigations commenced in 1921 and are described in previous papers (4, 5, 7, 17, 18, 28).

In order to improve the heat isolation and the efficiency of the temperature regulations, the box had double walls with an air space in between. The new construction of one of the boxes will be seen from Fig. 15, showing the large glass spectrographs in its box, from which the side wall has been removed.

The elements for the electric heating were placed in the space between the two walls in such a way that the air was made to circulate round the inner box. The contact thermometer for the automatic regulation of the temperature was also placed in the space between the two boxes, but at a proper distance from the heating elements. The relays were placed in the laboratory building or in the stand of the observation platform.

Fig. 16 shows the large glass spectrograph and the quartz spectrograph in their boxes on the platform.

During the first winter season of 1929—30 only the following three instruments were in working order: The new glass spectrograph, the small (N. O. fig. 6 a) old glass spectrograph and the small new glass spectrograph with Görlitz lens.

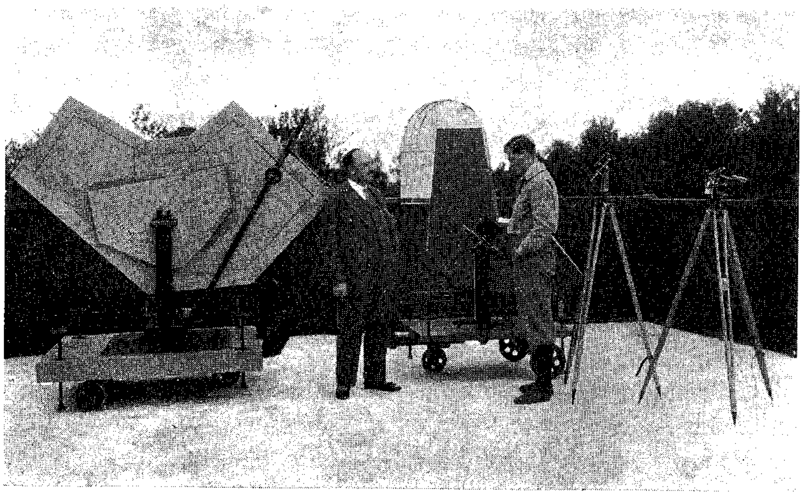

Fig. 16.

The new quartz spectrograph was mounted during my stay at Tromsø in part of July and Aug. 1930. The two small glass spectrographs with camera lens (F: 1) made of one piece of glass were mounted in a somewhat provisional way, so test exposures could be made, during the autumn of 1930.

In this preliminary mounting of the optical parts the adjustment was difficult, and during my stay at Tromsø in Oct. 1932 we decided to rebuild the apparatus so as to allow a more exact and convenient adjustment.

The large old glass spectrograph was taken down from its stand on the roof of the Weather Bureau Building, but was not properly mounted until October 1932.

CHAPTER II.

Observations and results.

§ 10. Account of the spectral work at the new Observatory during the first three winter seasons.

The spectrographic work at the new Observatory commenced in the autumn of 1929. On account of the long distance between Tromsø and Oslo my opportunities of visiting the Observatory and taking part in the observational work were somewhat limited. Consequently most plans, instructions and discussions relating to the spectral work had to be conducted by post or wire. The observational work itself was placed in the hands of the director of the Observatory, Mr. L. Harang.

He had — in accordance with instructions and correspondance — to prepare and test the photographic plates, to put up the spectrographs with necessary temperature regulation for auroral exposures, to direct and control the exposures, take necessary comparison spectra, intensity scales, &c.

Every now and then he sent me reports regarding the progress and the state of work. When the plates with spectrograms were developed, they were sent to me for measurements, further treatment and publication.

As already mentioned in a previous §, particular interest is attached to the region of the auroral spectrum towards long waves. With the instruments which stood at our disposal for the winter season 1929—30, we intended to use plates having a fairly large sensitivity in the region 5000—7000.

A fairly good sensitiveness in the green part (5200—5300) had previously (15, 28) been obtained by treating Sonja E. W. plates with pina-flavol. We then took the pan-chromatic B plate, and treated it with pina-flavol and hoped to a obtain a high sensitiveness both in green and red.

When the plates after long exposures were developed, the general fog was too dense, and they showed no auroral spectra of any value.

During the season some auroral spectrograms were obtained with the small new spectrograph with a Görlitz lens. They were taken more or less for the sake of testing the new instrument, but as they show certain variations of type and a considerable number of weaker lines, some of them (shown on Plate I. 2. a, b, c) were measured and will be dealt with later on.

For the following winter season 1930—31 we intended to take spectrograms with very long exposures both with the new quartz spectrograph and with the new large glass spectrograph. For the first one we used Sonja E. W. For the second we intended to concentrate our attention on the red part and use pan-chromatic plates without treatment with pina-flavol.

In the autumn some more or less preliminary exposures were made with the large glass spectrograph in order to test its mechanical stability, to obtain the highest possible sharpness of the lines and to test its light power in relation to the aurorae.

On Sept. the 20th 1930 an auroral spectrogram was taken with this instrument on a Sonja E. W. plate with half an hour's exposure (Pl. I. 1. a). Taking into account the comparatively small time of exposure, the spectrogram shows a considerable number of lines some of which belong to the faint ones.

On Oct. 10th of the same year another spectrogram was taken on a pan-chromatic plate with an effective exposure of two hours. In this case we merely obtained some of the very sharpest lines and no red lines at all.

It became clear that in order to obtain the lines in red with the ordinary pan-chromatic plates then at our disposal, and from aurorae of the ordinary colour, we should have to use very long exposures.

The large spectrograph was then put up provided with a pan-chromatic plate, which was exposed occasionally (about 65 north-light hours) until the beginning of April 1931.

The spectrogram, however, merely showed the auroral line and the strongest bands in blue and violet. This unexpected result is probably due to the slit having been partly covered by ice or snow-flakes or some other matter, as has occasionally blown into the instrument without being noticed.

The plate from the large quartz spectrograph was developed at the same time, after about the same period of exposure. The plate was very foggy, but showed a very strong auroral spectrum in the region of short waves. (Pl. II. 1. c.)

That winter we tried to obtain spectra in the green part, by means of the small old glass spectrograph. We then used an Agfa rapid plate treated with pina-flavol. It was developed after an exposure of 40 effective north-light hours, but it gave only a fairly weak spectrum and nothing that could be seen having any particular interest.

At the beginning of 1931 we introduced in the same instrument a new plate (Agfa-Cromo Isorapid) which has a fairly marked sensitiveness in the region 5200—5300. The plate was developed after an exposure of 18 north-light hours. It showed the auroral line and the blue part quite strongly, but none of the other green lines or any other line of particular interest was observed, and therefore the spectrogram was not measured and will not be further dealt with.

One of the two glass spectrographs with camera-lens (F:1) made of one piece of glass had now been brought into working order and a few exposures were made partly to test the instrument and partly to compare the relative intensity of the green auroral line in various auroral forms.

Using Agfa-Isocrom plates we obtained the stronger lines with suitable density for intensity measurements by exposing an auroral arc of moderate strength for ten minutes. This gave a very promising result, and this type of spectrograph ought to be very useful for the study of spectral variations. We obtained on the same plate spectra (Pl. I. 2. d, e) of several forms showing marked differences as regards the relative intensity of the strong green line.

For the winter season of 1931—32, it was my intention to continue the spectral investigations according to the following programme:

In the summer of 1931 I received from A. Hilger, London, the interferometer plates, the optical thickness of which was measured by the National Physical Laboratory, England, and it then became possible to commence the interferometer measurements of the stronger auroral lines, especially the green line.

Mr. Harang took up this work with great ability and success during the first part of the winter season. Some preliminary results obtained from two photographs of interferometer fringes, obtained by Harang Sept. the 14th and Oct. the 29th were published in a preliminary note (26).

Since then the experimental methods have been improved and a large collection of interference pictures of the green auroral line has been obtained. A complete account of the results will be given in a separate paper to be published in co-operation with Harang.

During the winter season 1931—32 we intended to use the large quartz spectrograph for obtaining — with long exposures — spectrograms of large density in the region of short waves. With the glass spectrograph it was intended to continue the exploration of the region of long waves and also to use plates sensitive to infra-red, so as to be able to detect and measure possible lines or bands in the infra-red region.

During a visit to Berlin in the summer of 1931, I was fortunate enough through Dr. Ing. C. Brüche at the A. E. G. Research Laboratory — to come into contact with Dr. Lacmann and Dr. Schmieschek of "Deutsche Versuchsanstalt für Luftfahrt", who gave me very valuable information regarding photographic plates for various spectral regions, and methods for increasing their sensitiveness through hypersensitizing processes.

In this connection I may mention that for the infra-red part I was recommended the plate Agfa 810, and a sensitizing procedure for these plates invented by Schmieschek, by means of which the exposure for equal density was reduced to a small fraction, compared with the time required with the same plate in its ordinary state. They kindly gave me an accurate recipe of the chemical solutions to be used and the procedure to be followed.

All necessary particulars regarding the plates Agfa infra-red (810) and the hypersensitizing process were sent to Mr. L. Harang in Sept. 1931, and I asked him to order the infra-red plates as well as the necessary chemicals for their treatment.

It would naturally take some time to make these preparations, and therefore we decided to try to obtain a strong spectrogram on a pan-chromatic plate with the large glass spectrograph, and to give special attention to the wave-length measurements by means of the interference method.

In the meantime I was to use the infra-red plates at the Physical Institute, Oslo, especially for the study of the luminescence from solidified gases.

The necessary plates (Agfa infra-red 810) and the chemicals for the Schmieschek hypersensitizing method were obtained early in the autumn of 1931. The firm Agfa recommended another hypersensitizing method with solutions of ammonia.

In our experiments at Oslo, we found that the ammonia-sensitizer increased the sensitiveness four or five times, or nearly as much as was obtained by the Schmieschek-method. We therefore used the simpler ammonia-method in our first series of investigations on the infra-red spectrum.

Through Dr. C. Brüche it was arranged that Mr. W. Bauer, an engineer, of the Technical High School, Danzig, should come to the Tromsø Observatory with the object of taking cinematographic records of the Aurorae, and to find suitable material and methods for the auroral photography. Partly in collaboration with Harang, he was also to take simultaneous cinematographic photographs from two stations for the determination of the height and position of the auroral displays[1].

As already mentioned, Mr. Harang had with great success taken up the study of the auroral light and its composition by means of photographs taken on various sorts of photographic plates, combined with suitable coloured filters in front of the camera lens[2]. Following this line of research, Mr. W. Bauer made preparations to photograph the aurorae with the infra-red plates already referred to (Agfa 810) by using a filter, which absorbed all visible and ultra-violet light, for which the photographic plate was sensitive.

During an auroral display on Jan. 9. 1932, he succeeded in taking photographs in this way of an auroral arc with a time of exposure of 2 minutes[3]. This result proved that the aurora emitted an infra-red luminescence in the region, say between 7500—9000 Å with a considerable intensity.

Being informed through Professor Størmer of this most interesting result, I was naturally very anxious that the spectrographic investigations of the infra-red part already planned and prepared, might be carried out, and in January 1932 I sent Mr. Harang the following telegram:

> "Try first opportunity to take auroral spectrum in infra-red with the small glass spectrographs which give sharpest lines. We have here for this purpose tested Agfa infra-red plate 810 sensitized with ammonia. Gives high sensitiveness in the region 7300 and 9000 Å. If you want necessary plate material telegraph. Vegard."

Mr. W. Bauer had, however, with success used the Schmieschek-sensitizer, and as Mr. Bauer kindly let Mr. Harang make use of his solutions, this method was also adopted by him.

Already on February 4th Mr. Harang succeeded in taking two spectrograms in infra-red, one with the small old glass spectrograph, and one with the new one with the

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[1] L. Harang and W. Bauer, Gerlands Beiträge z. Geophysik, 37, 109, 1932.

[2] L. Harang, Z. S. f. Geophys. 7, 324, 1931.

[3] W. Bauer, Ultrarote Nordlichtphotographie, Naturwiss. 20, 287, 1932.

Görlitz lens, and the plates were immediately sent to me for measurement. Preliminary communications of the result were given in two brief notes, one to Nature and one to Naturwissenschaften[1].

Both of the two small glass spectrographs have a very small dispersion in infra-red, and it was therefore a matter of great importance to photograph the infra-red auroral spectrum with instruments of higher dispersion. I therefore wrote to Mr. Harang and asked him to try to obtain infra-red spectra with one of the large glass spectrographs.

The pan-chromatic plate, which had been under exposure in the new glass spectrograph since September, was developed on Febr. the 23rd. 1932, and showed the strong spectrum given on Plate II. 1. a. A sensitized infra-red plate (810) was introduced.

Several attempts were made during the rest of that winter season to obtain infra-red spectra with this large spectrograph. In two cases the plates were not sufficiently exposed, in one case the general fog of the plate was too dense, but a fourth plate showed two faint lines (or bands) in the infra-red. As the plate had merely been exposed for a few hours during one evening, the result is very promising, and it ought to be possible to obtain fairly strong infra-red spectra with this instrument.

§ 11. Spectra taken on Sonja E. W. Plates with the small glass spectrograph. (Görlitz lens.)

We shall give the results of four spectra already referred to, which were taken in March 1930. Three of them are reproduced on Plate I. 2. a, b, c. One taken on March 17th was practically identical with the one reproduced on Pl. I. 2. a, which was taken the following evening.

These spectra, which show a considerable number of weak lines in the blue part, are also interesting because they give an instance of a very pronounced change of the auroral spectrum (Cfr. Paper No. 28). Comparing the spectrum *a* and *b* Plate I. 2., we notice that the latter spectrum shows a large number of lines in the region between 4700 and 4278 not visible on spectrogram *a*, although the latter spectrum shows the ordinary lines and bands with much higher density. Many of these weak lines on spectrum *b*, are diffuse and difficult to measure. The spectrum *c*, Plate I. 2. is of a type lying between *a* and *b*. The results of the wave-length measurements are given in Table III.

The intensity and character of the lines are denoted in the following way:

v. st. = very strong
st. = strong
m. = medium strength
w. = weak
f. = faint
d. = diffuse
B. = character of a broad band.

The last column indicates the interpretation.

NB $(n_2 n_1)$ means a band from the 1st negative group of Nitrogen corresponding to a transition between the vibrational quant-numbers n_2 to n_1, *PB* $(n_2 n_1)$ indicates in a similar way, bands belonging to the 2nd positive group of Nitrogen. L.S. means that the line within the limit of error may be identified with a line belonging to the nitrogen line spectrum.

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[1] L. Vegard, Nature, March 26, 1932. Naturwiss. 20, 268, 1932.

Table III.

Spectrograms taken with one of the small glass spectrographs 1930.

Date: 17—3	18—3 Pl. I. 2. a	Pl. I. 2. c	26—3 Pl. I. 2. b	Interpretation
5577.4 st.	5577.4 st.	5577.4 st.	5577.4 st.	Auroral line N_1[1]
4868.7 f. d.	4863.7 f.			L.S.
4788.9 f. d.	4770.9 f. ?			L.S.
4708.6 st.	4708.6 st.	4708.6 st.	4708.6 m.	N.B. (0.2)[1]
4652.9 m.	4652.6 st.	4652.0 m.	4652.0 m.	N.B. (1.3)
4599.2 f.	4602.6 f.		4597.5 f. ?	N.B. (2.4)
4547.0 w. d.	4542.2 w. d.	4544.4 f. d.	(4565.5 f. d.?)	N.B. (3.5)
	4489.2 w.	4489.8 f.	4507.2 w.	P.G. (2.7)
	(4437.4 f.?)			L.S.
4425.5 m.	4421.3 m. d.	4428.4 f. d.	4428.2 m.	L.S.
4376.8 f.	4379.3 w.		(4369.6 w.)	L.S.
4343.0 m.	4346.2 m.	4343.5 m. d.	(4327.3 w.)	P.G. (0.4)
4277.8 v. st.	4277.8 v. st.	4277.8 v. st.	4277.8 v. st.	N.B. (0.1)[1]
4236.1 st.	4235.5 st.	4234.5 st.	4236.8 m.	N.B. (1.2)
4201.9 f.	4199.3 w.	4203.6 f.		N.B. (2.3)—P.G. (2.6)
4177.8 f. ?	4177.0 f.	4182.1 f.		L.S.
	(4145.3 f. ??)			P.G. (3.7)
4058.7 m.	4056.8 m.	4056.0 w		P.G. (0.3)
3997.0 m.	3996.6 m.	3994.3 w.	3994.5 f. ?	P.G. (1.4)
			(3959.8 f. d.?)	L.S.
3913.9 st.	3913.9 st.	3913.9 st.	3913.9 st.	N.B. (0.0)[1]

§ 12. Some preliminary spectrograms taken with the smaller of the two glass spectrographs, having a camera lens made of one piece of glass. (F:1).

On Dec. 22. 1930 between 17^h 30^m and 18^h in the evening, two spectrograms were taken on Agfa Cromo Iso Rapid plates with the smaller of the two spectrographs with F:1 camera lenses. They are reproduced on Pl. I. 2. e.

Spectrogram e_1. The instrument was directed towards aurorae in the north consisting of fairly weak diffuse quiet areas, sometimes slightly pulsating, but without radiant structure. Elevation of collimator about 60° above the horizon. Exposure 15 minutes.

Spectrogram e_2. Intense aurorae with radiant structure, covering almost the whole northern sky; sometimes they show red borders. Exposure 10 minutes.

Under the conditions of these exposures the green auroral line and the negative band 4278 appear with a density of about the same order of magnitude, and therefore this band should be used for the determination of possible relative changes of the intensity of the green auroral line. Registrams were taken with the Moll registering microphotometer of the auroral spectra and of the intensity scale. The microphotometer curves for the two auroral spectra are shown in Fig. 17 (e_1 and e_2). The intensity measurements gave the following results. Denoting the lines (5577) and (4278) by b and d respectively, we find:

$$(I_b/I_d)_1 = k \cdot 1.015, \quad (I_b/I_d)_2 = k \cdot 1.192$$

where k is the same for both spectra. For the ratio D whose deviation from unity gives a measure of the intensity variation, we get:

$$D = \frac{(I_b/I_d)_1}{(I_b/I_d)_2} = 0.85$$

The relative intensity of the auroral lines is relatively smaller in the case of diffuse areas as compared with aurorae showing more definite forms.

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[1] Lines used in the determination.

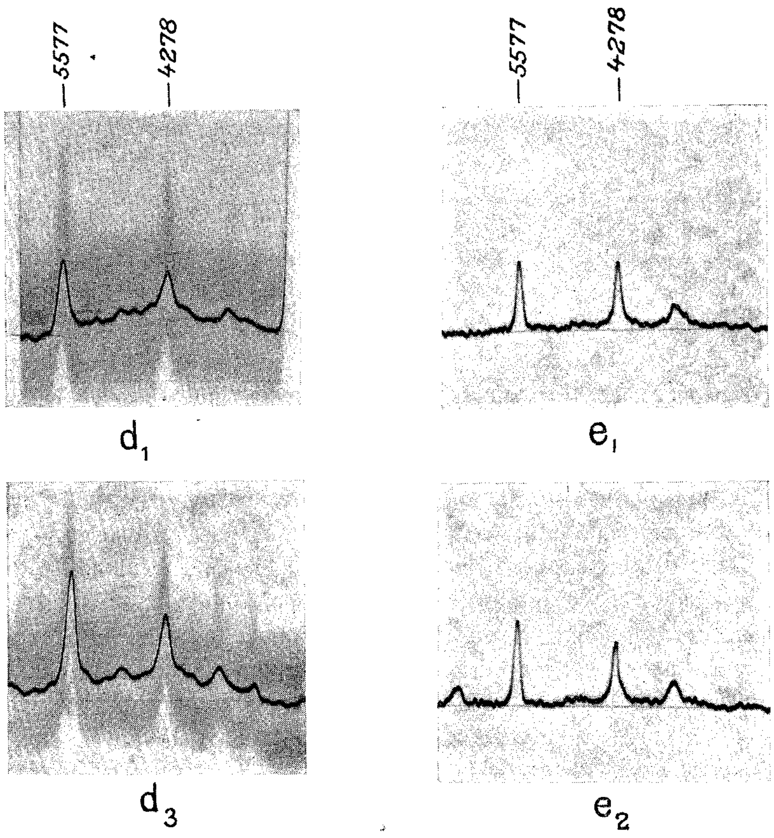

Fig. 17.

On January 25. 1931 three spectra were taken on the same Agfa Isochrom plate in succession, during the same evening. They are reproduced on Pl. I. 2. d.

Spectrogram d$_1$, corresponds to quiet areas in the north. Exposure 10 minutes.

Spectrogram d$_2$. Diffuse auroral luminescence, covering almost the whole sky, but every now and then this situation was interrupted by the appearance of auroral rays and draperies of short duration. Exposure $1^h\ 30^m$. The auroral line is too dense for accurate intensity measurements.

Spectrogram d$_3$. Diffuse auroral luminescence over large parts of the sky, but in this case no rays and draperies appeared. Exposure 1 hour.

This spectrogram has a photographic density very suitable for intensity measurements and of a magnitude about that of spectrogram d_1.

Comparing the spectrograms d_1 and d_3, we notice at a glance that the green auroral line is relatively weaker on the spectrogram d_3. An intensity scale (time scale with constant light source) was photographed on the same plate.

Registrams of the two spectra d_1 and d_3 and the intensity scale were taken with a microphotometer of the Moll type, and in this way relative intensities were measured and calculated in the manner described in a previous communication (28). Reproductions of the registrams of the two auroral spectra d_1 and d_3 are shown in Fig. 17 (d_1 and d_3).

Denoting the green auroral line by b, and the band 4278 by d (as in paper 28), we find for the spectrogram 1, corresponding to the auroral arc:

$$\left(\frac{I_b}{I_d}\right)_1 = 1.51\,k$$

and for the spectrogram 3, corresponding to the diffuse uniform luminescence:

$$\left(\frac{I_b}{I_d}\right)_3 = 1.16\,k$$

k is a constant which depends on wave-length, photographic plate and properties of the spectrograph, but which for two given lines is the same for two spectrograms on the same plate.

For the ratio D, we get:

$$D = \frac{(I_b/I_d)_3}{(I_b/I_d)_1} = 0.77$$

The relative intensity of the green line (5577) as compared with that of the principal negative bands is considerably smaller in the case of the diffuse uniform luminescence than in the case of the auroral arc. The reduction of intensity is found to be 23 %. As to the intensity variation found on the plate from December 22. 1930 and on that from January 25. 1931 we are no doubt dealing with the same effect. In both cases north light in the form of diffuse areas gives a relatively weaker auroral line than aurorae showing the more definite forms of arcs, bands and draperies.

If the uniform diffuse luminescence on an average was situated at the same height as that of the auroral arc, the intensity variation would mean that the luminescence was excited in a different way in the two cases. We must, however, take into account that the luminescence on an average might correspond to different altitudes, and the intensity-variation observed would be accounted for by means of the altitude effect, if the uniform luminescence had an average altitude effect of say 140 km, and the arc the usual altitude of about 100 km.

According to height measurements of the diffuse areas undertaken by L. Harang at Tromsø, these auroral forms were found to be situated at an altitude of 100—110 km. If this is to be regarded as a general rule for this type of aurorae, the great intensity of the negative nitrogen bands — as compared with that of the auroral line — would mean that the light from the diffuse areas is excited in a way which differs from that of the luminescence from arcs and draperies.

The spectrographic results here found are in agreement with results previously obtained by Harang[1] by means of filter photographs. He finds that the diffuse light which may appear as a background for arcs and draperies gives a relatively much stronger effect through a blue filter than through a green one.

§ 13. Results obtained with the quartz spectrograph.

A spectrogram which was taken on Oct. 31. with a fairly short exposure and which is reproduced on Pl. II. 1. b, merely shows the stronger bands which are well known from previous investigations. This spectrogram, therefore, was not measured.

The only spectrogram of great density as yet obtained with the new quatz spectrograph, is the one exposed during the winter season 1930—31. It was taken on Sonja E. W. plates. A reproduction is given on Pl. II. 1. c.

Only part of the photographic plate can at one and the same time give sharp lines. In our case, the instrument is adjusted for sharpness in the region between 3000—5000 Å, The region of long waves was more or less out of focus, and we notice the very broad and diffuse image of the green auroral line.

It appears that not only the principal negative bands, but also some bands belonging to the 2nd positive nitrogen group appear very strong, and for the first time, we notice

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

Table IV.

Spectrogram Pl. II. 1. c taken on Sonja E. W. pl. 1930—31 with the large Quartz Spectrograph.

λ Measured	From earlier obs.	Interpr.	λ Measured	From earlier obs.	Interpretation
Unsharp	5577.4		3709.6 w. d.	3711.8	P.G. (2.4)
	4708.6	N.B. (0.2)	3685.3 f. d.		
	4651.8	N.B. (1.3)	3603.0 f.		
4277.9 st.	4277.4	N.B. (0.1)	3582.9 w.		N.B. (1.0)
4235.2 w. d.	4236.2	N.B. (1.2)	3576.4 st.	3577.9 P.	P.G. (0.1)
4177.6 f. d.?	(4182.5)		3570.0 w. d.	R.	
4075.6 f. d.?	(4078.2)		3563.5 f. d.		N.B. (2.1)
4057.9 w. d.	4058.5	P.G. (0.3)	3535.6 m.	3537. 2 R.	P.G. (1.2)
3997.5 w.	3998.5	P.G. (1.4)	3531.5 f.	R.	
3987.6 d. f. ? ?					
3945.8 f.	3941.3	P.G. (2.5)	3500.7 f. d.	3505.8	P.G. (2.3)
3915.2 v. st.	3914.4 P.	N.B. (0.0)	3483.9 f.?		
3903.3 st. d.	3904.0 R.		3467.2 w.	3470.1	P.G. (3.4)
3884.2 w. d.?	3885.3 P.	N.B. (1.1)	3426.1 w.	3432.0	
			3371.0 st.	3371.6	P.G. (0.0)
3872.1 f.	R.		3339.3 f.		P.G. (1 1)
3805.6 m.	3805.4 P.	P.G. (0.2)	3285.7 f.?	3284.9	P.G. (3.3)
3801.0 w. d.	R.		3200.5 f. d.	3208.0	
3769.0 f.			3159.0 m.	3159.7 P.	P.G. (1.0)
3754.3 m.	3756.0	P.G. (1.3)	3155.2 f. d.	R.	
3728.6 f.?			3135 7 w.	3135.6	P.G (2.1).

not merely the heads which are produced by the P-branch, but also the broad "striations" due to the R-branch.

The results of the wave-length measurements are given in the table IV. In the case of the band of the 1st negative and the 2nd positive group, we measured not merely the head of the P-branch, but also the maximum produced by the R-branch.

§ 14. Lines in the visible and ultra-violet part, obtained with the large glass spectrograph.

In the period here considered, we obtained with the new large glass spectrograph three spectra, giving lines in the visible and ultra-violet region. They are reproduced on Pl. I. 1. a and b and Pl. II. 1. a.

The spectrum, Pl. I b, taken Oct. 10, 1930, has mainly interest as a test of the sensitivity of the pan-chromatic plates. It merely shows the green auroral line and the

Table V.

Spectrogram Pl. II. 1. a taken on Sonja E. W. pl. 20/9—1930 with the new large glass spectrograph.

λ Measured	Lines from previous obs.	Interpretation	λ Measured	Lines from previous obs.	Interpretation
4708.6 w.	4708.8	N.B. (0.2)	4199.2 f.	4199.2	P.B. (2.6) N.B. (2.3)
4653.9 f.	4651.9	N.B. (1.3)	4168.9 f. d.		N.B (3.4)
4598.2 f.?	4593.1	N.B. (2.4)	4087.1 f. d.?	(4078.2) ?	P.B. (4.8) ?
4554.3 f.	4552.1	N.B. (3.5)	4052.0 f.	4058.5	P.B. (0.3)
4371.5 f.	4375.8		3995.0 w.	3998.5	P.B. (1.4)
4344.4 f.?	4346.1	P.B. (0.4)	3954.1 f. d.?	3941.3	P.B. (2.5)
4319.9 f.			3913.9 v. st.	3914.4	N.B. (0.0)
4277.8 st.	4277.8	N.B. (0.1)	3902.7 m.	3904.1	
4265.4 m.	4269.7	P.B. (1.5)	3883.2 w.	3885.3	N.B. (1.1)
4236.5 m.	4236.2	N.B. (1.2)	3806.9 w.	3805.4	P.B. (0.2)
4218.0 f. d.			3754.1 w.	3756.0	P.B. (1.3)
			3577.7 m.	3577.9	P.B. (0.1)

Table VI.

Wave-lengths directly measured from spectrogram (Pl. II. 1. a) from the large glass spectrograph, compared with previous values.

Spectra Pl. II. 1. a	From previous obs.	Spectr. Pl. II. 1. a	From prev. obs.
6374.7 f. d.	6318.3	4202.5 w.	4199.2
6309.1 w.		4175.3 f.	4182.5
5993.9 f. d.	5997	4143.9 f. d.	4142.6
5894.9 f. d.		4120.9 »	
5583.2 v.st.	5577.3	4095.7 »	
5241.9 f. d.	5238.0	4076.7 f.	4078.2
5010.3 »		4058.5 m.	4058.5
4864.1 »	4857.4	3998.9 m.	3998.5
4710.5 st.	4708.8	3943.5 f.	3941.3
4653.9 m.	4651.9	3915.8 v. st.	3914.4
4537.6 f. d.		3903.6 m.	3904.
4488.0 f.	4480.7	3885.1 w.	3885.3
4425.1 f. d.	4423.6	3803.9 m.	4805.4
4374.4 f.	4375.8	3755.3 m.	3756.0
4348.8 w.	4346.1	3711.8 w.	3711.8
4320.6 f.		3580.1 m.	3577.9
4279.1 v. st.	4277.4	3537.5 w.	3537.2
4238.4 m.	4236.2		

three principal bands of the 1st negative nitrogen group. The wave-length of the green line was measured and found to be 5578.0. This result would indicate that sharp lines in this region may be measured with such an accuracy that the error is less than 1 Å.

The spectrum Pl. I. 1. a was taken on Sonja E. W. plates, Sept. 20. 1930 and in spite of the small time of exposure (half an hour) it shows a considerable number of weak lines, which were not previously obtained on spectrograms with so large a dispersion, and a few of them were new lines.

The lines observed are given in Table V. Besides, we have put up the wave-length values of corresponding lines from previous observations. (Cfr. publication No. 28).

We notice that the table contains the following new lines:

4319.9, 4218.0 and 4168.9.

On the spectrogram Plate II. 1. a, which was exposed on a panchromatic plate from Sept. 1931 to Febr. 1932, the stronger lines are very dense and broad. The main interest of this plate is attached to the appearance of a number of lines and bands in the red part.

A Neon-lamp was used for the comparison spectrum. We measured first of all the wave-lengths of all auroral lines, directly by means of the comparison spectrum. The results of these measurements are given in Table VI.

The results of the measurements as given in Table VI were recently given in a preliminary communication, in Z. S. f. Phys. (30) together with some data of the spectrogram from Oct. 10. 1930 (Table V).

In this preliminary communication it was pointed out that too large wave-length values were found for all stronger lines especially towards long waves. As no systematic error was found in the ultra-violet region near 3500 Å, it was concluded that the too large values, found in the visible part, could not be explained as an ordinary, constant displacement of the comparison spectrum. We therefore suggested that the too large values might be due to over-exposure. It is, however, very unlikely that an over-exposure should always act in the same direction, and, moreover, some lines which are not so dense also give a too large wave-length.

It therefore seems as if the comparison spectrum has not been taken under the same instrumental conditions as the auroral spectrum, so that e. g., the temperature may not have been the same. Now, the effect of temperature changes on the spectral lines may be a somewhat complicated one, and will no doubt be a function of the wave-length. We shall therefore consider the errors found for the stronger well-known auroral lines to be real and due to a systematic displacement of the comparison spectrum, depending on the wave-length. Calculating this displacement for various lines and smoothing out the curves, we found the following table for the corrections to be applied to the values given in Table VI.

λ	7000 Å	6000 Å	5000 Å	4000 Å	3500 Å
$\Delta\lambda$	− 8.1 Å	− 5.2 Å	− 3.0 Å	− 1.0 Å	− 0.0 Å

Applying corrections in accordance with this table we find the corrected values given in Table VII.

Table VII.

Corrected wave-length values from Pl. II. 1. a.

6368.5	5238.5	4535 3	4319.0	4142.6	3997.9	3803.2
6303.1	5007.3	4486.0	4277.6	4119.7	3942.6	3754.8
5988.7	4861.5	4423.3	4236.9	4094.5	3914.9	3711.4
5890.0	4708.1	4372.7	4201.1	4075.6	3902.8	3580.0
5579.2	4651.6	3247.2	4174.0	4057.4	3884.3	3537.4

As already pointed out in the preliminary communication (30) the two red lines (6303) and (6368) are very probably identical with the red line 6318 which have been obtained in a number of previous spectrograms. These spectra, however, were taken with instruments of very small dispersion and a broad slit, and therefore the two lines did not appear to be separated. The vicinity of the weak line 6368 will then have the effect of displacing the apparent intensity maximum of the stronger line 6303 towards longer waves.

The discussion as to the interpretation of these and other auroral lines will be left for a separate paragraph.

§ 15. The infra-red auroral spectrum.

The two spectrograms on Agfa infra-red (810) plates already mentioned obtained on Febr. 4th, showed one faint band and a broad one with a well-marked maximum towards long waves and a less-marked one in the opposite direction.

One of the spectrographs having a somewhat broad slit (Pl. I. 1. c) shows infra-red bands of large density; but the structure of the bands is not so well defined as on the much weaker spectrogram of the other spectrograph (Pl. I d) taken with a narrower slit. The latter spectrogram, therefore, was used for wave-length measurements. The results were briefly described in the two notes already referred to (27), where the bands were interpreted as belonging to the 1st positive group of nitrogen. The spectrogram taken with the new large glass spectrograph on Agfa infra-red plates 810, showed two faint diffuse lines (or bands) in the infra-red. They were sufficiently marked to be seen and measured on the original plate, but they were too faint to be shown in reproduction.

All these spectra on infra-red plates showed fairly strong spectra in the region of short waves, but merely gave lines which were well-known from previous observations, so that this part of the spectrum was not measured.

The measurements of the infra-red bands gave the results given in Table VIII.

The values found by the large spectrograph agree well with those first found by the small one if the very small dispersion of the latter is taken into account.

Table VIII.

Small glass spectrograph	New large glass spectrograph
8095 Å	8093.7 Å
7883 »	7880.6 »
(7740)	

CHAPTER III.

Discussion of the Results.

§ 16. The lines and bands observed and their interpretation.

The lines and bands which were observed and measured on the spectrograms previously described are collected in Table IX.

The first column gives the wave-lengths of the lines and bands obtained with the small glass spectrographs, the second and third column contain the results from the quartz spectrograph and the new large glass spectrograph respectively. The fourth column contains the estimated mean values as they are found from the three previous columns, when due regard is paid to the accuracy with which the line is determined with each spectrograph.

In the fifth column we have given the lines and bands previously observed which were given in a recent publication (28) dealing with the results from 1922—1926. It appears from the Table IX that the material from the Auroral Observatory — as yet treated — gives 22 lines and bands not previously observed. Five of these are merely the R-branches of some of the stronger bands belonging to the second positive group of nitrogen, for which we previously observed only the heads due to the P-branch. On the other hand, the results from 1922—26 contain 5 faint lines, which were not found in our present material. The total number of lines and bands recorded up to the end

Table IX.

Lines from present material.

Small glass spectrograph	Large quartz spectrograph	New large glass spectrograph	Estimated Mean	Lines from previous obs.
8095	-	8093.7	8094	-
7883	-	7880.6	7882	-
(7740)	-	-	(7740)	-
-	-	-	-	6564.9 (B)
-	-	6368.5	6368.5 }	6318.3
-	-	6303.1	6303.1 }	
-	-	-	-	6147. (B)

Table IX.

(continued).

Small glass spectrograph	Large quartz spectrograph	New large glass spectrograph	Estimated Mean	Lines from previous obs.
-	-	5988.7	5988.7	5997. B
-	-	-	-	5940 (?)
-	-	5890.0	5890.0	-
-	-	5578.6	5578.6	5577.2
-	-	5238.5	5238.5	5238.0
-	-	-	-	5139.0
-	-	5007.3	5007.3	4998.0
4866.1	-	4861.5	4863.8	4857.4
4780.0	-	-	4780.0	4779.2
4708.6	-	4708.3	4708.5	4708.8
4652.4	-	4652.7	4652.5	4651.9
4600.9	-	4598.2	4599.0	4593.1
4544.5	-	4554.3	4549.4	4552.1
-	-	4535.3	4535.0	-
(4507) (?)	-	-	(4507) ?	-
4489.5	-	4486.0	4487.8	4480.7
(4437) (?)	-	-	(4437) ?	-
4425.8	-	4423.3	4424.6	4423.6
4377.0	-	4372.1	4374.6	4375.8
4344.2	-	4345.8	4345.0	4346.1
-	-	4319.5	4319.5	-
4277.8	4277.9	4277.7	4277.8	4277.4
-	-	4265.4	4265.4	4269.7
4235.7	4235.2	4236.7	4235.9	4236.2
-	-	4218.0	4218.0	-
4201.0	-	4200.1	4200.5	4199.2
4179.0	4177.6	4172.0	4176.2	(4182.5)
(4145.3)	-	4142.6	4142.6	4142.6
-	-	4119.7	4119.7	-
-	-	4092.0	4092.0	-
-	4075.6	4075.6	4075.6	(4078.2)
4057.2	4057.9	4057.4	4057.5	4058.5
3996.3	3997.5	3996.9	3996.9	3998.5
-	-	-	-	(3981.3)
-	3945.8	3942.6	3944.2	3941.3
3913.9	3915.2	3914.4	3914.5	3914.4
-	3903.3	3902.8	3903.0	3904.0
-	3884.2 P	3883.8	3884.0	3885.3
-	3872.1 R	-	3872.0	-
-	3805.6 P	3805.0	3805.3	3805.4
-	3801.0 R	-	3801.0	-
-	3769.0	-	3769.0	(3773.8)
-	3754.3	3754.5	3754.4	3756.0
-	(3728.6)	-	(3728.6)	-
-	3709.6	3711.4	3710.5	3711.8
-	3685.3	-	3685.3	(3693.3)
-	3603.0	-	3603.0	-
-	3582.9	-	3582.9	-
-	3576.4 P	3578.5	3577.4	3577.9
-	3570.0 R	-	3570.0	-
-	3563.5	-	3563.5	-
-	3535.6 P	3537.4	3536.5	3537.2
-	3531.5 R	-	3531.5	-
-	3500.7	-	3500.7	3505.8
-	(3483.9)	-	(3483.9)	-
-	3467.2	-	3467.2	3470.1
-	3426.1	-	3426.1	3432.0
-	3371.0	-	3371.0	3371.6
-	3539.3	-	3339.3	-
-	3285.7	-	3285.7	3284.9
-	3200.5	-	3200.5	3208.0
-	3159.0 P	-	3159.0	3159.7
-	3155.2 R	-	3155.2	-
-	3135.7	-	3135.7	3135.6

of the winter season 1932 amounts to 71, or rather 72 if λ 5988.7 and λ 5997 are regarded as two bands.

The mean value of the wave-lengths for all auroral lines and bands given in Table IX are collected in the first column of Table X. In the second column we have given the relative intensities, the intensity of the P-branch of the (0.1) band of the negative nitrogen group being put equal to 100.

The intensity values are based on the measurements of the true relative intensities for a number of auroral lines described in previous papers (17, 28). The lines measured are the green auroral line and a number of bands belonging to the negative and 2nd positive group of nitrogen covering the region from 4708 to the limit in ultra-violet. In this latter region the intensities of lines not previously measured can be estimated quite correctly by comparing them with neighbouring lines of known intensity. In the region from 4708 towards the limit in infra-red, however, we have only measured the intensity of the green auroral line, and the intensity-estimates of the relatively weak lines in this part of the spectrum are liable to considerable uncertainty. It is, however, our intention to extend the intensity measurements also to the region of long waves.

Our interpretation of each line or band is indicated in the last column of Table X.

Table X.

λ	I	Interpretation	λ	I	Interpretation
8094 B	30	1 PG. (6.5) (5.4)	4119.7	8	N (4119.6), OII (HeI)
7882 B	100	1 PG. (7.6)	4092.0	8	2 PG. (4.8), OII (4093)
(7740) B	60	1 PG. (8.7) (2.0)	4076.0	8	OII (4075.9)
6565 B	40	1 PG. (7.4)	4058.0	14	2 PG. (0.3)
6368.5	30	OI ($^3P_1$—$^1D_2$) 1 PG. (9.6)	3997.7	15	2 PG. (1.4)
6303.1	50	OI ($^3P_2$—$^1D_2$), N_3, 1 PG. (10.7)	(3981.3)	5	b′, OII (3983)
6147 B	10	1 PG (4.0) & (5.1)	3942.8	10	2 PG. (2.5)
5997 B	15	1 PG. (15.12) (8.4)	3914.4 P	200	NG. (0.0)
5989 B	15		3903.5 R	-	
(5940)	3	1 PG. (8.4), N_4	3884.5	10	NG. (1.1)
5890	10	1 PG. (9.5) (10.6)	3872.0	5	N (3870) OII (3876) (HeI)
5577.3	400	OI ($^1D_2$—$^1S_0$), N_1	3805.4 P	20	2 PG. (0.2)
5238	10	1 PG. (16.11), N_2	3801.0 R	-	
5139	10	1 PG. (19.14) O	3769.0	5	N (3771), OII (3763)
5002.6	10	N (5002.7) Nebulium	3755.2	17	2 PG. (1.3)
4861.6	10	OII (4861.0), Hβ, N	(3728.6)	5	N (3729), OII (3727)
4779.6	5	NII (4779.8)	3711.1	10	2 PG. (2.4)
4708.7	40	NG. (0.2)	3685.3	8	b′
4652.2	20	NG. (1.3)	3603.0	5	O-Band (?)
4596.1	15	NG. (2.4)	3582.9	8	NG. (1.0)
4550.8	10	NG. (3.5)	3577.6 P	40	2 PG. (0.1)
4535.0	8	N (4545—4530)	3570.0 R	-	
(4507)	6	N (4507.6)	3563.5	8	NG. (2 1)
4484.3	8	NG. (5.7)	3536.8 P	20	2 PG. (1.2)
(4437)	8	N (4434) (HeI)	3531.5 R	-	
4424.1	15	N (4426) Ar (4424)	3503.2	9	2 PG. (2.3)
4375.2	8	OII (4378), N (4375)	(3483.9)	5	2 PG. (7.8)
4345.6	15	2 PG. (0.4)	3468.7	12	2 PG. (3.4)
4319.5	8	b′, OII (4319.6)	3429.0	8	b′, (2 PG. (5.6))
4277.6 P	100	NG. (0.1)	3371.3	36	2 PG. (0.0)
4267.6 R	52		3339.3	5	2 PG. (1.1)
4236.0	24	NG. (1.2)	3285.3	7	2 PG. (3.3)
4218.0	15	OI (4217.1), N (4219)	3202.7	10	b′, (2 PG. (8.7)) (HeII)
4200.0	10	NG. (2.3), 2 PG. (2.6)	3159.3 P	23	2 PG. (1.0)
4176.2	7	N (4176.1)	3155.2 R	10	
4142.6	7	2 PG. (3.7) (HeI)	3135.7	14	2 PG. (2.1)

§ 17. Auroral bands belonging to the 1st negative and the 2nd positive group of nitrogen.

As shown in 1913 (1) the spectral region in blue and violet is dominated by the strong negative nitrogen bands. In 1923 I found that a considerable number of bands belonging to the 2nd positive group of nitrogen appeared in the region of short waves (4, 5, 6, 7). At the same time it was suggested that certain diffuse bands in red were to be referred to nitrogen bands of the 1st positive group.

When in 1932 we succeeded in obtaining the first auroral spectrum in infra-red, the bands observed were also referred to the 1st positive group of nitrogen, and I have also found that certain bands in the yellow and green part probably belong to this group.

The abbreviated designations contained in the third column of Table X have the following meaning:

1 *PG* $(n_1 n_2)$ means a band belonging to the 1st positive nitrogen group and which corresponds to a transition from an upper vibrational level n_1 to a lower one n_2.

2 *PG* $(n_1 n_2)$, band belonging to the 2nd positive nitrogen group and formed by transitions n_1 to n_2.

NG $(n_1 n_2)$ indicates in a similar way bands of the negative nitrogen group. *P* and *R* indicate *P*- and *R*-branch respectively. *N*, *O*, *Ar* indicate spectral lines belonging to these elements:

I, indicates lines from the normal atoms.

II, III, indicate lines from atoms having lost 1, 2, electrons.

N_1, N_2, N_3, N_4 indicate bands observed in the green and red luminescence from solid nitrogen.

b' is an ultra-violet vibrational series characteristic of the luminescence from solid nitrogen.

A number of the most important bands belonging to the negative nitrogen group are given in Table XI, arranged in the usual way so as to show the quant-numbers n_1 and n_2 of any band. The values correspond to the heads formed by the *P*-branch.

Table XI.

Heads of the negative group of Nitrogen.

n_2 \ n_1	0	1	2	3	4	5	6	7	8	9	10	11
0	**3915**	3583	3309	3079	-	-	-	-	-	-	-	-
1	**4279**	**3885**	3565	3300	3077	-	-	-	-	-	-	-
2	**4711**	**4238**	3859	3550	3294	-	-	-	-	-	-	-
3	5230	**4653**	**4200**	3836	3539	-	-	-	-	-	-	-
4	5866	5150	**4601**	68 4174	3819	3534	-	-	-	-	-	-
5	-	5756	5078	56 4555	4142	-	-	-	-	-	-	-
6	-	-	5655	14 5012	4517	31 4122	-	-	-	-	2988	-
7	-	-	-	65 5562	4959	87 4486	4112	-	-	-	3175	3034
8	-	-	-	-	5487	4914	4468	-	-	-	3382	3224
9	-	-	-	-	-	5422	4883	4461	-	-	3614	-
10	-	-	-	-	-	-	5374	4866	4468	-	-	-
11	-	-	-	-	-	-	-	5342	4366	-	-	-
12	-	-	-	-	-	-	-	-	31 5330	85 4884	-	-
13	-	-	-	-	-	-	-	-	-	5346	-	-
14	-	-	-	-	-	-	-	-	-	-	5386	-
15	-	-	-	-	-	-	-	-	-	-	-	5451

Table XII.

1st positive group of N_2.
Each band has several heads. The table gives the head of largest wave-length.

$n_1 \backslash n_2$	0	1	2	3	4	5	6	7	8	9	10
0	10505	-	-	-	-	-	-	-	-	-	-
1	8910	10215	-	-	-	-	-	-	-	-	-
2	7753	8722	9939	-	-	-	-	-	-	-	-
3	6876	7627	8542	9681	-	-	-	-	-	-	-
4	6188	6790	7505	8370	9436	10779	-	-	-	-	-
5	5634	6129	6706	7388	8206	9203	10446	-	-	-	-
6	-	5594	6071	6625	7275	8048	8983	10136	-	-	-
7	-	-	5555	6015	6546	7165	7897	8787	9843	-	-
8	-	-	-	5516	5960	6469	7060	7753	8575	9568	-
9	-	-	-	-	5479	5906	6395	6958	7613	8386	9308
10	-	-	-	-	-	5442	5854	6323	6859	7480	8206
11	-	-	-	-	-	-	5406	5804	6252	6764	7352
12	-	-	-	-	-	-	-	5371	5753	6184	6672
13	-	-	-	-	-	-	-	-	5337	5705	6118
14	-	-	-	-	-	-	-	-	-	5303	5658
15	-	-	-	-	-	-	-	-	-	-	5270

Table XII (continued).

1st positive group of N_2 (continued).

$n_1 \backslash n_2$	11	12	13	14	15	16	17	18	19	20	21
10	9064	10094	-	-	-	-	-	-	-	-	-
11	8032	8832	9781	-	-	-	-	-	-	-	-
12	7228	7868	8613	9487	-	-	-	-	-	-	-
13	6582	7109	7711	8405	9212	-	-	-	-	-	-
14	6053	6496	6995	7560	8208	8953	-	-	-	-	-
15	5612	5990	6412	6884	7417	8021	8709	-	-	-	-
16	5238	5566	5929	6330	6778	7279	7841	8479	-	-	-
17	-	5206	5522	5869	6252	6675	7145	7671	8261	-	-
18	-	-	5175	5479	5811	6175	6575	7018	7508	8055	-
19	-	-	-	5145	5437	5754	6100	6479	6895	7354	7859
20	-	-	-	-	5115	5396	5699	6028	6387	6778	7205
21	-	-	-	-	-	5086	5355	5645	5958	6297	6664

Table XII and XIII give in a similar way the most prominent bands of the 1st and 2nd positive group respectively.

In Tables XI and XIII those nitrogen bands which may be identified with observed auroral bands, given in Table X, are indicated by heavy print.

In the case of the bands referred to, the negative and the 2nd positive group of nitrogen, the identification is perfectly certain with the exception of the four bands 4200 3484, 3429 and 3203. Both the negative and 2nd positive group have a band which within the limit of error coincides with the auroral band 4200. The fact that this band is stronger than the band 2 *PG* (2.5) indicates that the band 4200, at any rate partly, is to be referred to the negative nitrogen group.

On the spectrogram from the Tromsø Observatory a faint band or line is detected with wave-length 3484 which nearly coincides with the band 2 *PG* (7.8) with wave-length 3482. The coincidence, however, may be accidental.

In the ultra-violet region two bands 3203 and 3429 appear which were detected already through the spectrograms obtained with the quartz spectrograph in 1923. At

Table XIII.

Heads of 2nd positive group of Nitrogen.

n_2 \ n_1	0	1	2	3	4	5	6	7	8	9
0	**3371**	**3159**	2977	2820	2686	2572	2479	-	-	-
1	**3577**	**3339**	**3136**	2962	2814	2690	2589	2510	-	-
2	**3805**	**3536**	3309	3116	2953	2817	2706	2621	2562	2533
3	**4059**	**3755**	**3500**	3285	3104	2954	2832	2739	2675	2644
4	**4344**	**3998**	**3710**	3469	3267	3102	2968	2866	2796	2762
5	4666	4269	**3942**	3671	3446	3263	3115	3002	2926	2888
6	-	4574	**4201**	3894	3642	3437	3274	3150	3066	3025
7	-	4917	4490	**4141**	3857	3628	3446	3309	**3217**	3171
8	-	-	4814	4416	4094	3837	3634	**3482**	3380	3330
9	-	-	-	4723	4356	4067	3840	3670	3557	3502
10	-	-	-	-	4648	4321	4065	3876	3749	3688
11	-	-	-	-	4975	4602	4313	4100	3959	3891
12	-	-	-	-	-	4915	4587	4347	4189	4112
13	-	-	-	-	-	-	4891	4619	4441	4355
14	-	-	-	-	-	-	-	4921	4719	4622
15	-	-	-	-	-	-	-	-	5027	4917

that time most auroral bands belonging to the 2nd positive group were rightly interpreted, but in the case of the two bands mentioned, I found that the deviation from possible bands of the 2nd positive group was greater than the possible error, and further, that the two bands had a structure different from the usual quite sharp maxima (heads) of the bands of the 2nd positive group.

From Table XIII, we notice that the only bands of the 2 *PG* that can come into consideration are 2 *PG* (8.7) wave-length 3217 and 2 *PG* (5.6) wave-length 3437. They differ by 14 and 8 Å from the corresponding auroral bands, and this deviation is much larger than the possible error which in this region is usually only of the order of one Ångström. This interpretation of the two bands has also recently been suggested by Kaplan[1], but as we saw, it cannot be accepted because the agreement with the observed auroral bands is unsatisfactory.

§ 18. A new band series in the auroral spectrum coinciding with the b′ series emitted from solid nitrogen.

The two bands 3202.7 and 3429 together with the three faint bands (or lines) 3685.3, 3981.3 and 4324 form a vibrational series, and we find that this series within the limit of error coincides with a series called *b′*, which was observed from the luminescence emitted when a layer of solid neon mixed with nitrogen, at the temperature of liquid helium, was bombarded with cathode rays[2]. The observed lines of the *b′*-series are given in Table XIV together with the corresponding auroral bands:

Table XIV.

b′	4719	4324	3985	3688	3429	3202	3000	2820	2658	2513
Auroral bands	-	4320	3981	3685	3429	3203	-	-	-	-

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[1] J. Kaplan, Phys. Review. 42, 86, 1932.

[2] L. Vegard, Ann. d. Phys. 6, 487, 1930.

The agreement is here very satisfactory when the weakness and diffuse character of the bands is taken into account.

As seen in Table X, the two faint diffuse lines 3981 and 4320 also nearly coincide with lines of the ionised oxygen atom (*OII*), but these concidences may be accidental.

The b' series appears in the afterglow and is thus emitted from nitrogen in the solid state, and it is found[1] to be closely related to the series b, B and B', which are all to be referred to the same electronic transition as the ε-system[2].

If we are right in referring the five auroral lines of Table XIV to the b' series, it does not necessarily mean that these bands in the case of the aurorae are emitted from nitrogen in the solid state. According to the interpretation of the ε-system given in previous papers[3] this band system results from an electronic transition towards the normal state of the N_2 molecule from an *upper metastable level which is most probably identical with the bottom level of the electronic transition, which produces the 1st positive group of nitrogen.* (N^A).

The transition from this metastable level (usually called A) may take place in α-nitrogen, where the molecular axes and the atoms occupy fixed positions; but the transition from the metastable A-state towards the normal state of the N_2 molecules may also take place if the pressure is extremely low.

In the auroral region the pressure is of the order of magnitude of 1/10000 mm Hg which may be sufficiently low for transitions for metastable states to occur. As both the 2nd and 1st positive group appear fairly strong in the auroral spectrum, a considerable number of N_2 molecules will, under the auroral luminescence process, be left in the A-state, and we should, therefore, under the conditions present expect to find bands in the auroral spectrum corresponding to the forbidden transitions from A to the normal N_2-state.

§ 19. Auroral bands belonging to the 1st positive group of nitrogen.

As the final electronic state (B) of the second positive nitrogen group is the upper state of the 1st positive group, we must expect the 1st positive group to accompany the 2nd positive group with an intensity of about the same order of magnitude. This conclusion is also in accordance with laboratory experiments.

On Plate II. 2. a and b, two nitrogen band-spectra are reproduced which were taken on pan-chromatic plates during my stay at Würzburg 1912, for the purpose of collecting material for the interpretation of the auroral spectrum. Reproductions of similar spectra, taken at Würzburg, were given in a paper describing my results from the auroral expedition 1912—13. (1 and 2).

The spectrum (*a*) from the negative glow is dominated by the negative nitrogen bands, and only traces of the strongest bands of the 2nd positive group are to be seen, and the 1st positive group is entirely absent.

The spectrum (*b*) from the positive column is in the region of short waves dominated by the 2nd positive group, and in the region of long waves the 1st positive group now appears with considerable intensity. With the pan-chromatic plates used (Wratten plates) the density of the bands of the 1st positive group is considerably smaller than that of the stronger bands of the second positive group, and this is in agreement with the auroral spectrograms obtained with the same kind of plates. The auroral bands which we referred to the 1st positive group had a much smaller density than the stronger of the 2nd positive group.

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[1] loc. cit.

[2] loc. cit.

[3] L. Vegard, Ann. d. Phys. 6, 487, 1930, Z. S. f. Phys. 75, 30, 1932, Z. S. f. Phys. 97, 471, 1932.

Table XV.

Bands of 1st pos. gr. from Spectr. Pl. II. 2. b.

λ	n_1	n_2	λ	n_1	n_2	λ	n_1	n_2
6781	4	1	6114	13	10	5807	11	7
6748			6076	6	2	5800		
6704	5	2	6070			5777		
6660			6019	7	3	5759	12	8
6630	6	3	6012			5751		
6582			6003			5736		
6550	7	4	5987			5727		
6502			5963	8	4	5406	11	6
6472	8	5	5958			5388		
6433			5941			5374	12	7
6398	9	6	5911	9	5	-	-	-
6361			5901			-	-	-
6327	10	7	5880			-	-	-
6285			5859	10	6	-	-	-
6235	11	8	5848			-	-	-
6181	12	9	5829			-	-	-

Table XVI.

Infra-red bands of 1st pos. gr. from spectr. Pl. II. 2. c.

λ	Interpretation
w. 8197 m. 8112	**(5.4)** [(10.10) (14.15)]
m. 8011	**(6.5)** [(11.11) (15.16)]
w. 7838	**(7.6)** [(12.12) (16.17)]
st. 7722	**(8.7)** [**(2.00)**]
m. 7613	(3.1)
m. 7587	(9.8)
m. 7498	(4.2)
m. 7465	(10.9)

Plate II. 2. c shows a spectrogram taken last year at Oslo on the infra-red plates (810) from the positive column of an N-discharge tube. Also in this case the strong 2nd positive group is accompanied by fairly strong bands belonging to the 1st positive group.

For the discussion of the particular bands belonging to the 1st positive group of nitrogen which appear in the auroral spectrum, it will be of interest to give the wavelength of those maxima of the 1st positive group which appear on the spectra Pl. II. 2. (b) and (c). The bands measured and the corresponding vibrational quant-numbers are given in Table XV for spectrogram *b*, and in Table XVI for spectrogram *c*.

When we are about to interpret the bands observed by comparing them with Table XII, we must keep in mind that the vibrational zero-line (B—A) has a multiple structure, and consists of 3—5 components. The frequency difference between successive components has the considerable value of 20 cm^{-1}. As each component produces a rotational band, the individual components — or the corresponding heads — will not always be separated even by the fairly large dispersion of the spectrograms (b) and (c), Pl. II. 2. The values given in Table XII correspond to the component (head) which has the largest wave-length. The value we measure gives a kind of average position of the components which appear, and the wave-length values will therefore as a rule be smaller than those given in Table XII. This is clearly shown by comparing the measured values of the Tables XV and XVI with those of Table XII.

The same rule will apply to the interpretation of the auroral bands which have been obtained with still smaller dispersion. The auroral spectrograms taken with the small glass spectrographs have a dispersion so small, when compared with the widths of the slit, that bands belonging to the same sequence may form one broad continuous band.

As already pointed out in a previous communication (27), the infra-red auroral bands here given are to be referred to the 1st positive group of nitrogen.

The vibrational quant-numbers given in the preliminary notes, were referred to the following term formula given by Birge[1]:

$$\nu = 10979 + 1718.4\, n_1 - 14.44\, n_1^2 - 1474.4\, n_2 + 13.93\, n_2^2 \qquad (1)$$

Later on it was shown by Poetker[2] that the vibrational quant-number of the bottom level had to be reduced by one unit, and the frequency formula takes the form:

$$\nu = 9518.59 + 1718.4\, n_1 - 14.44\, n_1^2 - 1446.5\, n_2 + 13.93\, n_2^2 \qquad (2)$$

The quant-numbers given in this paper correspond to the latter formula. The auroral band 8094 is now to be explained as due to an overlapping of two bands 1 *PG* (6.5) and (5.4). The band 7882 corresponds to 1 *PG* (7.6) and 7740 to 1 *PG* (8.7).

As seen in Table XII the band 1 *PG* (8.7) is identical with 1 *PG* (2.0), and we cannot tell which of the two has the greater influence on the auroral band 7740. As the other two bands belong to the sequence $n_1 - n_2 = 1$, it is likely that the third band 7740 is to be referred to the same sequence and thus identified with 1 *PG* (8.7).

Looking at Table XV we notice that in the laboratory experiments a number of maxima appear in the region 6400—6700, all belonging to the sequence

$$n_1 - n_2 = 3.$$

In the auroral spectrum we find by small dispersion a broad band in this same region (6400—6700) with a maximum at 6565 just where the observed sequence $n_1 - n_2 = 3$ has its maximum. The diffuse auroral band 6400—6700 is therefore no doubt to be referred to the sequence $n_1 - n_2 = 3$ of the 1st positive group.

It is a matter of great interest that this same sequence has a component 6361 and two components 6328, 6285 with an average 6306. It is therefore possible that the two lines or bands 6303 and 6368 may be referred to the 1st positive group of nitrogen. As we shall see later on, however, these two lines very nearly coincide with two oxygen lines.

In the region 5950—6200 we also observe diffuse auroral bands for which, in the present material, we found three maxima 6147, (5997, 5989). Comparing with Table XV we find that these bands no doubt belong to the sequence:

$$n_1 - n_2 = 4.$$

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[1] T. Birge, Bull. Nat. Res. Couns. 57, 232, 1926.

[2] A. H. Poetker, Phys. Rev. 30, 812, 1927.

As seen from Table XII the sequence $n_1 - n_2 = 5$ has components in the region 5238, where we observe the diffuse band called the second green auroral line. If this group of lines is due to the 1st positive nitrogen group, it should be the vibrational transitions (15.10), (16.11) and (17.12) which might come into consideration. The band or line 5139 might be a number of the same sequence corresponding to the transition (19.14).

Now, it is a typical feature for the 1st positive group that the relative intensity of the various bands may change, and in this way we might explain that the auroral spectrogram obtained by Slipher[1] in 1928 gave a wave-length 5206, while my spectrogram from 1926 as well as those of later years gave 5238[2].

The value obtained by Slipher might correspond to the band (17.12) while the values found by me might be referred to (16,11) and perhaps (15.10).

It was shown in 1926 by the present writer that the second green auroral line consisted of several components which were found to agree well with the components for the band N_2 observed in the luminescence from solid nitrogen. We cannot at present decide which of these interpretations is the right one.

In the paper of Kaplan previously referred to, he suggests that the N_2-band is to be referred to the 1st positive group, and that would mean that both interpretations of the second green auroral line should be identical. In my opinion, however, the N_2-band from solid nitrogen is not to be referred to the 1st positive group. Sometimes in the luminescence from solid nitrogen we observe bands belonging to the 1st and 2nd positive group and the negative group, but they do *not* appear in the afterglow. The bands N_1, N_2, N_3, N_4 as well as a number of other band series and systems, which are typical of the solid state, (appear in the afterglow) may appear even when no trace of the 1st and 2nd positive group or of the negative group is to be observed.

Regarding the interpretation of the luminescence bands I must refer to the published paper (e. g. 24, 25).

The negative nitrogen group should have a component (0.3) ($\lambda = 5227$) in the region of the second green line. This cannot explain the essential part of the group of lines with maximum at 5238, and as seen from the intensity curve for the negative bands appearing in the auroral spectrum (paper 28, p. 48), we should expect the intensity of 5227 to be extremely small.

§ 20. On the origin of the strong green line 5577, the second green line and the red lines 5940, 6303 and 6368.

Investigations on the luminescence from solidified nitrogen carried out at the Cryogenic Laboratory of Leiden[3] led to the discovery of a variety of new bands. The most conspicuous of these bands appearing in green and red were called N_1, N_2, N_3 and N_4.

In the case of pure nitrogen these bands were broad and diffuse. The N_1-band extended on both sides of the strong green auroral line, N_2 coincides with the second green line (or band), N_4 coincides with the weak auroral line 5940, and it was assumed that the diffuse N_3-band was a manifestation of the same effect as the one which produces the red line, which was found to be mainly responsible for the red colouring of certain auroral displays, and for which we found the wave-length 6318 (14.28). This line which was measured from spectrograms with small dispersion may be the same as the lines 6303 and 6368, which was obtained with the large glass spectrograph.

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[1] V. M. Slipher & L. A. Sommer: Naturwiss. 17, 802, 1929.

[2] L. Vegard. Nature, 119, 849, 1927, Naturwiss. 17, 980, 1929.

[3] L. Vegard. Proc. Roy. Akad. Amsterdam v. 27, 113, 1924. Comm. from the Phys. Lab. Leiden. No. 168 d, No. 175, No. 173 d, No. 200, 205 a and 205 b.

In mixtures of neon and nitrogen the N_1 and N_3 bands gradually became sharper[1]. With diminution of nitrogen concentration, the two weak maxima of N_1 disappeared and the principal maximum became sharper and moved towards the position of the strong green auroral line. When the nitrogen concentration became very small, we found a wave-length of N_1: 5578, which within the limit of error is identical with the wave-length 5577.4 of the auroral line. Under the same conditions we found a wave-length of the N_3 band 6320 which agrees very well with that found for the red auroral line.

It would therefore seem as if the luminescence from solid nitrogen gives a satisfactory interpretation of the most conspicuous auroral lines and bands in the green and red part of the spectrum.

Later investigations as to the nature of the luminescence from solid nitrogen indicate that those bands which are typical of the solid state, and which appear in the afterglow, originate from electronic "jumps" from metastable states, and are only found for α-nitrogen and not for β-nitrogen, which exist above 35.5° K.

The reason for this was found to be that the molecular elements of β-nitrogen rotate, while in α-nitrogen the atoms occupy fixed positions. Thus in α-nitrogen, the metastable state should be kept undisturbed for a period which at least is of the same order of magnitude as the duration of the metastable state.

It is clear, however, that the excited molecules may also be left undisturbed in the metastable state until transition takes place, if the pressure is sufficiently low.

Therefore, the identification of the auroral lines mentioned, with the bands from solid nitrogen, does not mean that the emitting centres in the auroral region should necessarily be in the solid state. The appearance of these lines may be accounted for by the extremely low pressure existing above 80—100 km.

As is well known, Mc.Lennan has detected an oxygen line with a wave-length 5577.35 which, within the limit of the very small error of say 0.005 Å, coincides with the very accurate value of the green line from the night sky luminescence found by Babcock by an interference method. Recent investigations carried out by the author in collaboration with Mr. Harang showed definitely that the green line from the night sky is identical with the green auroral line.

The oxygen line of Mc.Lennan corresponds to the transition from the metastable state $2p\,{}^1S_0$ to the metastable state $2p\,{}^1D_2$[2].

The latter state is also metastable, and we should expect to observe in the auroral spectrum the lines which correspond to the transition from $2p\,{}^1D_2$ towards the normal triplet state ${}^3P$. The positions of the levels $2p\,{}^1S_0$, $2p\,{}^1D_2$ and $2p\,{}^3P_{(0,1,2)}$ were determined by R. Frerichs[3].

Expressed in wave-numbers these levels are:

P_2 : 109831 cm^{-1}
P_1 : 109672 »
P_0 : 109605 »
${}^1D_2$: 93962 »
${}^1S_0$: 76037 »

Both ${}^1D_2$ and ${}^1S_0$ are metastable states; but under the low pressure of the auroral region, Mc.Lennan assumes that the transitions ${}^1S_0 \to {}^1D_2$ and ${}^1D_2 \to {}^3P_{(012)}$ may occur. These transitions give the following values for the wave-length in vacuum:

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[1] L. Vegard. Ann. d. Phys. V, 79, 377, 1926.

[2] J. C. Mc.Lennan, J. H. Mc.Leod and Mc.Quarrie: Proc. Roy. Soc. A, 114, 1927.

[3] Rudolf Frerichs, Phys. Rev. V. 36, 398, 1930.

$^1S_0 \rightarrow {}^1D_2 : \lambda = 5578.8$

$^1D_2 \rightarrow {}^3P_2 : \lambda = 6301.6$

$^1D_2 \rightarrow {}^3P_1 : \lambda = 6365.4$

$^1D_2 \rightarrow {}^3P_0 : \lambda = 6392.6$

The two red lines were obtained in laboratory experiments by Paschen[1] who finds $\lambda = 6300$ and 6364.

The interpretation of the strong green auroral line given by Mc.Lennan would mean that the oxygen atom after the emission of this line would be left in the $^1D_2$ state, and if the average life of the state $^1S_0$ and $^1D_2$ is of the same order of magnitude, we should expect the appearance of the green line to be always accompanied by the red lines 6300, 6364 and 6392.

According to the intensity rules given by the "quantum mechanics", the first line should be the strongest and the last one the weakest.

In the auroral spectrum we observed, on the spectrogram from the new large spectrograph, two red lines 6303 and a weaker one 6368. On account of the distortion of the comparison spectrum previously mentioned, the accuracy is somewhat reduced and the difference between the wave-length of two auroral lines and the corresponding oxygen lines is probably not larger than the possible experimental error.

The intensity of the red auroral lines decreases with increasing wave-length, and these red auroral lines show at any rate qualitatively the intensity distribution of the corresponding oxygen lines.

As pointed out in a previous paper, an accurate determination of the relative intensities of the red auroral lines, and their intensity relative to that of the green auroral line, is a question of great importance, and we have now commenced observations of this kind at the Northlight Observatory.

Although the present observations indicate that the oxygen lines, corresponding to the transition $^1D_2 \rightarrow {}^3P_{(012)}$, appear in the auroral spectrum, we shall have to wait for further observations before making any definite statement.

§ 21. On the appearance of other oxygen lines in the auroral spectrum.

If the lines 5577, 6303 and 6368 are to be referred to oxygen in the way proposed by Mc.Lennan, we should also expect other oxygen lines to appear with considerable strength in the auroral spectrum.

If the $^1S_0$ state were reached through an electronic "jump" from some higher electronic level of the neutral *O*-atom, we should expect to find the *OI* spectrum fairly intensive in the auroral luminescence. A considerable number of the *OI* lines have been classified into series, and a Grotrian diagram of the corresponding energy levels has been given by Frerichs[2].

First of all we should expect to find a number of strong lines, in the same infra-red region for which the plates used for the infra-red auroral spectra were sensitive. The most prominent *OI* lines are formed by the addition of the "active light electron" to the core $2\,s^2\,2\,p^3$, and those situated within the region of the infra-red sensivity of our plates are the following:

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[1] F. Paschen. Z. S. f. Phys. 65, 1, 1930.

[2] loc. cit.

Table XVII.

Prominent infra-red OI lines.

λ	Transition
8446.4	$(^4S)\ 3\,s\ ^3S_1-(^4S)\ 3\,p\ ^3P$
8233.1 8230.1 8221.8	$(^2D)\ 3\,s\ ^3D_{1,2,3}-(^2D)\ 3\,p\ ^3P$
7952.2 7950.8 7947.6	$(^2D)\ 3\,s\ ^3D_{(123)}-(^2D)\ 3\,p\ ^3F_{2,3,4}$
7775.7 7774.0 7772.0	$(^4S)\ 3\,s\ ^5S_2-(^4S)\ 3\,p\ ^5P_{3,2,1}$
7481.3 7479.2 7476.6	$(^2P)\ 3\,s\ ^3P_{0,1,2}-(^2P)\ 3\,p\ ^3D_{1,2,3}$

None of the infra-red lines of Table XVII are observed in the auroral spectrum.

Apart from the strong green line (5577) and the two red lines (6303 and 6368), the interpretation of which is under discussion, we have already interpreted all stronger auroral bands as belonging to the 1st and 2nd positive group and the negative group of nitrogen, and some faint bands were referred to the *b′* series. The lines not interpreted in this way are all faint, and the wave-length measurements as a rule so inaccurate that the error may exceed 1 Å. These faint auroral lines which we are now trying to interpret, are given in Table X, but for the sake of convenience they are collected in Table XVIII.

Table XVIII.

Faint auroral lines.

λ	Possible Interpretation	λ	Possible Interpretation
5003	N (5003) Nebulium	4218	OI[1]
4862	OII, N, H_β	4176	N (4176.1)
4780	NII (4780)	4120	N (4119.6)
4535	N (4545—4530)	4076	OII (4076)
4507	N (4507.6)	3872	N (3870) OII (3876)
4437	N (4434)	3769	N (3771) OII (3763)
4424	N (4426)	3729	N (3729) OII (3727)
4375	N (4375) OII (4378)	3603	1st neg. gr. oxygen (1.6)

We notice from Table XVIII that 13 lines may be referred to the nitrogen line spectrum. Some of these lines fell in the neigbourhood of *OII*, but with the exception of one line (4861) the agreement with *N*-lines is better than for the oxygen lines.

In order to see which oxygen lines might be expected in the visible part of the spectrum, we shall compare with spectrograms of oxygen, obtained in the laboratory under conditions which might correspond to those existing in the atmosphere during an auroral display.

Two such spectrograms which I took at Würzburg 1912 on pan-chromatic plates are reproduced on Pl. II. 2. d and e. The spectogram (d) corresponds to the negative glow at a pressure of 0.01—0.05 mm and spectrogram (e) corresponds to oxygen canal rays.

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[1] Transition: $(^4S)\ 2\,s^2\ 2\,p^3\ 4\,p^3\ P_{0,1,2}-2\,s\ 2\,p^5\ ^3P_{0,1,2}$.

Table XIX.

Spectrum of oxygen canal-rays taken in 1911.

No. on the copy	λ	Origin	No. on the copy	λ	Origin
1	6456	O_I	17	4465	O_{II}
2	6158	O_I	18	4452	O_{II}
3	5436	O_I	19	4417	O
4	5330	O_I	20	4415	O_{II}
5	5020	O_I	21	4380	O_{II}
6	4968	O_I	22	4368	O_I O_{II}
7	4857	O_{II}	23	4351—4336	O
8	4803	O_I	24	4320	O_{II}
9	4773	O_I	25	4317	O_{II}
10	4676	O_{II}	26	4276	O_{II}
11	4662	O_{II}	27	4254	O_{II}
12	4650	O_{II}	28	4190	O_{II}
13	4642	O	29	4185	O_{II}
	4639	O_{II}	30	4120	O_{II}
14	4596	O_{II}	31	4076	O_{II}
15	4591	O_{II}	32	4072	O_{II}
16	4468	O_{II}	33	4070	O_{II}

Some of the more prominent lines are indicated by numbers and the bands by B_1, B_2. The wave-lengths for each of the lines and bands thus marked are given in Table XIX and XX.

We notice that none of the *OI* lines, given in the Tables are to be found in the auroral spectrum, although they appear with considerable intensity in the canal ray spectrum. The only line of Table XIX which might be referred to *OI* is 4218, but this *OI* line corresponds to a transition from the somewhat unusual state ($2\,S\,2\,p^5$) in which one of the normal *s*-electrons has been brought into a ($2\,p$) orbit. As no other lines of this type appear[1] the coincidence with the *OI* line is probably accidental.

Among the *OII* lines given in Table XIX No. 7 nearly coincides with the auroral line 4861, while the much stronger lines No. 10, 11, 12, 13 do not appear at all. The lines No. 14 and 15 would be masked by the band *NG* (2.4). The strong lines 16, 17, 18, 19, 20 do not appear. The lines 21 and 22 fall in the neighbourhood of the auroral line 4375, but the *N*-line coincides better. The group of strong lines denoted by No. 23 is not observed, the two lines No. 24 and 25 nearly coincide with the band 4319, which might also be referred to the b' series. No. 26 would be masked by the strong band *NG* (0.1). No. 27, 28, 29 and 30 are not observed.

No. 31, 32 and 33 form a group of strong lines near the auroral line 4076. This is in fact the only fairly good coincidence with *OII* lines although the *OII* spectrum has a fairly large number of lines in the blue part.

The oxygen bands B_1, B_2 on spectrogram *d*, plate II. 2., belong to the red 0_2^+ bands. They are very diffuse and B_1 and B_2 are very faint. B_3 and B_4 are split up in a number of components. The result of the measurements is given in the first column of Table XX. The second column shows the edges as they are given by Frerichs[2]. Some of the components of the B_4 band fall in the region of the second green line, but have probably nothing to do with the auroral band 5238, because the band B_4 extends to 5271 and further the B_3 band, falling in the region between the strong green auroral line and 5632 is not present in the auroral spectrum. The bands B_1 and B_2 would be partly masked by the bands of the 1st positive group of nitrogen. Thus the red 0_2^+ bands are not found in the auroral spectrum with any noticeable intensity.

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[1] Compare R. Frerichs, loc. cit. p. 408.

[2] Compare W. Weizel. Handb. der Exp. Phys. Ergänzungsb. 366, 1931.

Table XX.

Red O_2^+ bands on Pl. II. 2. d from neg. glow at low pressure.

Band	λ obs.	Edges according to Frerichs
	-	6857 (0.2)
B_1	6359.2	6420 (0.1)
B_2	5970.6	6027 (0.0)
B_3	5631.6	5632 (1.0)
	5622.5	-
	5614.3	-
	5603.9	-
	5595.9	-
	5586.9	-
	5579.4	-
B_4	5271.1	5296 (2.0)
	5265.2	-
	5261.7	-
	5256.3	-
	5350.1	-
	5243.3	-
	5240.1	-
	5234.4	-
	5231.5	-

Table XXI.

Bands belonging to the 1st negative group of oxygen.

n_2 \ n_1	0	1	2	3	4
4	OH[1]	OH	3044	2970	OH
5	3398 Å	OH	OH	OH	-
6	3603	3495	3394	OH	-
7	3831	3707	3594	-	-
8	4083	-	-	-	-
9	4465	-	-	-	-

Table XXII.

Schumann-Runge-Füchtbauer bands of oxygen. The numbers correspond to zero-lines.

n_2 \ n_1	0	1	2
12	3105 Å	-	-
13	3234	-	-
14	3371	-	-
15	3518	-	3358
16	3674	3584	3501
17	3842	3743	-
18	4022	3914	3988
19	4216	4097	4174
20	-	4294	4374

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[1] OH means that the band coincides with an OH band.

Some bands of the 1st negative oxygen group (given in Table XXI) and some belonging to the Schumann-Runge-Füchtbauer system (Table XXII) give vibrational bands falling within the observed spectral region. Some of these bands would be masked by strong nitrogen bands, but in those cases where the bands do not coincide with well-known nitrogen bands, there is no indication of their presence in the auroral spectrum, with the exception of the band 3603 of the negative *O*-group, which coincides with a faint auroral band for which no other interpretation has been found. As no other band of the 1st negative oxygen group is observed in the auroral spectrum, it is very doubtful whether the band 6303 is due to oxygen.

§ 22. On the possibility of referring the auroral lines 5577, 6303, 6368 to oxygen.

The discussion as to the appearance of oxygen bands and lines in the auroral spectrum thus leads to the conclusion that (apart from the lines 5577, 6303 and 6368) hardly any *OI* lines and oxygen bands, but perhaps a few faint *OII* lines, appear in the auroral spectrum.

This fact shows that very little oxygen luminescence is produced during an auroral display through the direct impact with the primary cosmic rays.

The excitation of the negative nitrogen bands requires an energy of about 20 volts depending on the vibrational quant-number n_1. The excitation of the nitrogen lines observed in the auroral spectrum will require an energy of about the same magnitude as that required to dissociate an N_2 molecule (9.1 volts) and to ionise one of the atoms (14.5 volts) or 23.6 volts. The corresponding energy for oxygen is 5.1 for dissociation, and 13.5 for the ionisation of the *O*-atom.

The electric rays which have sufficient energy to excite the nitrogen spectrum through direct impact, should also be sufficient for the production of the oxygen spectrum. The energy of the electric rays from the sun is no doubt very much larger than that required for excitation through direct collision. This is evident from the height measurements, when they are seen in connection with the distribution of matter in the atmosphere[1].

If the electric rays are to reach the usual altitude of 100 km of the bottom edge of the aurorae, they must have energies at least corresponding to thousands of electron-volts. If then, the strong green line and the two red lines (6303 and 6368) originate from oxygen, they cannot be formed as the result of the direct excitation of the electric rays, but must be formed through some indirect excitation process, as in the case of excitation from direct impact with the electric rays, the $^1S_0$ state would be reached through electronic jumps from higher levels, and there would be a strong emission of the *OI* spectrum.

The fact that the intensity of the green line is of the same order of magnitude as the strongest nitrogen-bands and in fact is stronger than any single nitrogen band, indicates that the excitation of the *OI* $^1S_0$ state must be bound up with the excitation of nitrogen, in other words that the *OI* $^1S_0$ state is produced through some collision of the second kind between oxygen and some excited state of nitrogen. The following processes might first of all come into consideration:

The fairly intensive emission of the 1st and 2nd positive group of nitrogen means that a relatively large number of nitrogen molecules are left in the metastable *A* state (N_2^A). The energy of this state is usually assumed to be 8 volts. My interpretation of the ε-system from solid nitrogen, however, leads to a value of 6.2 volts. The energy

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[1] Compare paper No. 18.

required to dissociate an oxygen molecule and to bring one of the atoms into the S_o state is $5.1 + 4.2 = 9{,}3$ volts. The energy of the $N_2{}^A$ state would in no case be sufficient for this process.

The oxygen in the highest parts of the atmosphere exists to a great extent in the form of ozone (O_3) and nitrogen in the ($N_2{}^A$) state might transfer its energy to O_3 according to the equation:

$$N_2{}^A + O_3 = O_2 + OI\ ({}^1S_o) + N_2 \tag{3}$$

The energy would in this case be sufficient, provided that the dissociation of O_3 in an oxygen O-atom require an energy equal or smaller than 2 volts. The dissociation energy of ozone is not exactly determined; but should hardly exceed 2 volts.

If the green auroral line were formed according to this process, we should expect to find some correlation between the relative intensity of the green auroral line and the amount of ozone present in the atmosphere. The relative intensity of 5577 should increase with increasing ozone concentration.

If the predominant part of oxygen atoms in the ${}^1S_o$ state were formed in this way, the number of light quanta of the line 5577 emitted in a certain time should be smaller than the total number of light quanta belonging to the 2nd positive group, emitted during the same interval of time, or:

$$\lambda_g I_g \overset{=}{<} \Sigma \lambda_p I_p \tag{4}$$

where g refers to the green line and p to a component of the positive group. We have fairly accurate measurements of the intensity of the more prominent heads of the 2nd positive group, relative to that of the green line. With the dispersion used, the intensity of the head measures approximately the intensity of the P-branch. Assuming the R-branch to have the same number of transitions as the P-branch, we find that the condition (4) is fulfilled.

Another way of explaining the formation of the OI (${}^1S_o$) state is the following:

The electric ray bombardment may produce "active nitrogen". It is in this connection not necessary to adopt any definite opinion as to the nature of active nitrogen, it is sufficient to utilize the experimental fact, that the energy of active nitrogen, which is available for the excitation of other molecules or atoms, is found to be $E_a = 9.55$ volts[1]. By collision of the second kind particles of active nitrogen may transfer this energy to an oxygen molecule, in accordance with the equation:

$$E_a + O_2 = O + OI\ ({}^1S_o) + \varepsilon \tag{5}$$

Now the dissociation of O_2 into one normal atom and one in the ${}^1S_o$ state requires an energy of 9.3 volts, which means that ε is only 0.2 volts. The available energy of active nitrogen is just a little larger than that required by the excitation process. As the energies involved are nearly equal, we may have a kind of "resonance" effect, which will increase the possibility of the process taking place.

The excitation of the oxygen line 5577 by means of active nitrogen has been shown by some important experiments carried out by J. Kaplan[2].

In the auroral region a fairly large part of the total quantity of oxygen exists in the form of ozone, and therefore the relative intensity of the green auroral line might diminish with the increasing O_3-concentration, provided the excitation of the $OI\,{}^1S_o$ state took place in accordance with the equation (5).

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[1] I. Okubo and H. Hamada, Phil. Mag. 5, 372, 1928.

[2] Joseph Kaplan, Phys. Rev. 33, 154, 1929.

If no such correlation exists between the intensity distribution within the auroral spectrum and the ozone concentration, we are not allowed to conclude that the excitation process given by equations (3) and (5) are false.

It may be that at any time there will be a sufficient quantity of O_3 and O_2 respectively to give a maximum efficiency of the excitation process.

If the green auroral line were formed according to equation (5), the amount of active nitrogen formed in a certain time interval, must be of the same order of magnitude as the amount of nitrogen which during the same time interval is engaged in the formation of the nitrogen band spectra.

We might then expect to find those bands of the 1st positive group which are enhanced in the luminescence from active nitrogen, to appear particularly strong in the auroral spectrum. A comparison of the strong bands of active nitrogen with the bands or lines appearing in the auroral spectrum shows that there is no indication of the spectrum of active nitrogen.

This may, however, merely mean, that the presence of oxygen prevents that process of recombination which leads to the ordinary luminescence of active nitrogen. The available energy is to a large extent transferred to the oxygen molecules, and should partly appear in the emission of the lines 5577, 6300 and 6364.

This is also in accordance with experimental facts. While according to Thiede the presence of traces of oxygen should be necessary for the afterglow of gaseous nitrogen, the luminscence soon vanishes by increasing oxygen concentration.

It appears from the previous considerations that by regarding the excitation of the oxygen line (${}^1S_0 - {}^1D_2$) as due to a secondary effect bound up with the primary excitation of nitrogen, we may account for the extraordinary intensity of the strong green line (5577) and the appearance of the red lines 6300 and 6364 although hardly any other *OI*-lines or oxygen bands appear in the auroral spectrum.

Before the question regarding the interpretation of the auroral line 5577 may be regarded as settled, we should wait for more accurate determination of the red auroral lines situated near the oxygen lines (${}^1D_2 - {}^3P_{012}$).

At the Auroral Observatory we have during the last winter season been trying to obtain more accurate wave-length measurements of these red lines and to measure their relative intensities.

Some important observations in this direction have already been obtained, and the results will be published by the writer together with Mr. L. Harang, in a subsequent paper.

Previous investigations (14, 17, 18, 28) showed that the intensive red colour of certain auroral displays was entirely due to the happearance of a red line which is also situated near the oxygen lines (${}^1D_2 - {}^3P_{012}$).

In the small spectroscope used it appeared as one single line. The spectrograms obtained of this strong red line were taken with such small dispersion that with the fairly broad slit used the lines 6303 and 6368 could not be separated.

It is therefore probable that the red line producing the red colour is the enhanced form of the line 6303 or rather the two red lines 6303 and 6368. It will be of great importance during our future spectral investigations to decide how far the red lines which produce the red coloured aurorae are identical with the two lines 6303, 6368, which seem to be always present in the auroral luminescence, although they are usually very weak.

If it turns out that the enhanced red lines producing the red colouring of the type which appeared Jan. 1926 are the oxygen lines (${}^1D_2 - {}^1P_{013}$), we are faced with the problem of explaining how it is possible that under certain conditions the relative intensity of the lines O (${}^1D_2 - {}^3P_{012}$) may be so enormously increased.

A number of possibilities might suggest themselves, e. g., change in the properties of the primary electric rays, change in the composition and density of the higher strata of the atmosphere and change in the ozone concentration. Before proceeding to discuss these matters further we shall have to wait for more experimental data.

In this connection I might merely call attention to the possibility that the action of excited nitrogen in the N_2^A-state on ozone may result in O-atoms in the $^1D_2$-state and not in the $^1S_0$-state. This means that the relative intensity of the red auroral lines should increase with increase of ozone concentration, in accordance with the fact that the relative intensity of the red lines as well as the ozone concentration both vary in a similar way as the sunspot-frequency.

§ 23. On the possibility of referring lines of the auroral spectrum to hydrogen or helium.

Most earlier theories regarding the distribution of matter in the upper atmospheric layers were based on the assumption that above a certain altitude the motion of matter in bulk is insignificant as compared with the velocity of the diffusion, and that consequently the pressure of each gas forming a component of the atmosphere would vary upwards as if the other components were not present.

Starting from the composition of the atmosphere which is derived from its analysis in the lower layers, the assumptions mentioned led to the consequence that the atmosphere above a certain altitude of about 100 km (the auroral sphere) should be mainly composed of the light gases hydrogen and helium. Already through the results of observations on the auroral spectrum obtained in 1923 (4, 5, 6, 7) it was found that such a sphere dominated by the light gases H_2 and He did not exist. The result was confirmed by later observations on the auroral spectrum undertaken during the period from 1922—1926. (28).

On the other hand it was found that nitrogen was a predominant component up to the very highest altitudes where aurorae may appear. It might be argued that the luminescence of H_2 and He might be quenched by the presence of other gases, mainly nitrogen. In order to test this possibility luminescence spectra from helium-nitrogen and from hydrogen-nitrogen mixtures of varying relative concentration were studied, and the intensity of the helium and hydrogen lines relative to that of the nitrogen bands was examined for varying compositions of the mixtures.

These experiments were carried out in 1922 partly in collaboration with one of the students, Mr. Lars Grimestad. The spectra of the hydrogen-nitrogen mixtures were taken by him. The results of these experiments were referred to in my papers on the auroral spectrum from 1923, but no details have as yet been given. On account of the great importance attached to these experiments with regard to the possibility of an upper hydrogen-helium layer, we will give some more details in the present communication.

In the case of the hydrogen-nitrogen mixtures the light was produced in a discharge tube 25 cm long, and 3.5 cm in diameter with aluminum electrodes. The mixture to be investigated was kept in a big glass bulb, connected with the discharge tube by a capillary tube. During the discharge, the gas mixture was allowed to flow continually through the tube. By regulating the velocity of the gas stream in the capillary, and the velocity of the pumping, the pressure could be varied within wide limits. Usually we worked at three pressures of about, 0.06, 0.6 and 1.5 mm. For each mixture, spectra were taken for each of the three pressures, as well as for each pressure both from the negative glow and the positive column; sometimes at low pressures, we also took spectra of the glow, close in front of the cathode. These spectra show a great many details of interest. In this connection we will merely call attention to the results so far as the relative intensity of the Balmer-series of hydrogen and the negative nitrogen bands are concerned.

In order to illustrate the results in this respect a number of spectrograms of the negative glow, corresponding to a number of different mixtures and the medium pressure (0.5—0.8 mm H_g), are reproduced on Plate III. 1. Nos. 1, 2 . . . 8. The absolute pressure and the composition of the mixture are given in the "explanation to Plate V" to be found at the end of this paper.

The spectrum No. 1 corresponding to 99.4 % hydrogen and 0.6 % N_2 shows principally the hydrogen lines H_β and H_γ and the hydrogen band spectrum, but even this small percentage of N_2 is sufficient to give the band 4278 with quite marked intensity. The spectrograms now follow in the order of increasing N_2 and decreasing H_2-concentration. The hydrogen band spectrum soon becomes weaker, but the relative intensity of the series lines H_β and H_γ only decreases gradually with decreasing H_2 concentration, while the nitrogen bands and especially those belonging to the negative group, become stronger.

On the spectrogram No. 8 corresponding to 2 % hydrogen, the H_β line is just visible. This same type of variation is shown for all pressures and also for the spectra from the positive column, only with the difference that in the spectra from the positive column the bands of the second positive group of nitrogen become more prominent as compared with the negative bands.

If we compare spectra corresponding to the same mixture either from the negative glow or from the positive column, we find that the intensity *of the Balmer-series relative to the nitrogen bands (4708 or 4278) increases with decrease of pressure.* This effect is illustrated by the spectrograms Nos. 3 and 4, which only differ with regard to the absolute magnitude of the gas pressure. No. 3 corresponds to a pressure 0.8 mm and No. 4 to 0.08 mm H_g. While the Balmer-lines are equally dense on both spectrograms the negative nitrogen band 4278 is much weaker on No. 4 corresponding to the lowest pressure. This means that the power of nitrogen to reduce the intensity of the hydrogen-lines for a certain concentration will be less marked as the pressure becomes smaller.

Now we know that in the auroral region the pressure is extremely low, and therefore the intensity of the Balmer-series relative to that of the negative bands should, for a given percentage of H_2, be larger than in our experiments.

Taking into account the great density shown by the negative nitrogen bands on many of our auroral spectrograms, we ought to be able to detect even a hydrogen concentration of 2 %, if it existed in the auroral region.

The experiments on the spectra from helium-nitrogen mixtures were undertaken in a way similar to those described for H_2—N_2 mixtures. The main difference being that in the case of He—N_2 the luminescence was produced by a bundle of cathode rays from a Wehnelt cathode. Some of the spectograms are reproduced on Plate V Nos. 9, 10, 11 and 12. The cathode ray velocities correspond to tensions which are given in the explanation to Plate V, and which vary between 230 and 310 volts. The spectrograms are arranged in the order of decreasing *He* concentration, No. 9 corresponds to 2/3 *He* and 1/3 N_2 and No. 12 to 1/4 *He* and 3/4 N_2. We notice that the *He* lines are relatively strong also on spectrogram 12, corresponding to 25 % *He.* We conclude from these experiments that we ought to be able to detect the presence of only a few per cent of Helium in the auroral region.

It is evident from the previous discussion of the auroral spectrum, that none of of the *somewhat strong* auroral bands and lines can be referred to hydrogen and helium, but there remains to be considered the circumstance whether any of the very faint lines might possibly originate from these elements.

As mentioned in previous papers, some of our spectrograms show a faint line 4862, which, within the limit of error, coincides with H_β. This line, however, may with equally good accuracy be referred to *OII* or *N*. As we have found no indication of H_α and H_γ in the auroral spectrum it is very improbable that this line originates from hydrogen. Even if it were so, its very small intensity as compared with that of the nitrogen bands would lead to the conclusion that the atmosphere in the auroral region could only contain 2—3 $^0/_0$ hydrogen. Comparing the faint auroral lines with the spectrum of helium, we find that the following lines given in Table XXIII, within the limit of error, coincide with helium lines:

Table XXIII.

Auroral line	He-line
4437	4437.5 He I (2 ^1P—5 $^1S_0$)
4143	4143.8 - (2 ^1P—5 ^1D)
4120	4120.9 - (2 $^3P_{012}$—5 $^3S_1$
3872	3871.9 - (2 ^1P—9 ^1D)
3202.7	3203.1 He II 2 (S, P, D) – 5 (S, P, T)

The agreement between the wave-length values is very satisfactory, but the interpretation may still be very doubtful, on account of the most singular selection of lines. Table XXIII does not contain two lines belonging to the same series, and a number of helium lines which usually appear with the greatest strength in the helium spectrum are not observed.

The first four lines of the Table may equally well be referred to the nitrogen and oxygen line spectrum, and as regards the last line 3203 which is referred to the b^1-series, it is to be noticed that it has the character of a fairly diffuse band, so the helium line cannot account for the whole band. It is of interest to notice that all the helium lines of Table XXIII, which nearly coincide with auroral lines, correspond to transitions from levels with fairly high principal quant-number $n = 5$ and in one case $n = 9$. By an ordinary direct excitation from electric rays we should expect other lines of the same series, with lower quant-numbers to appear with considerable strength. We might assume that helium (like oxygen) was excited indirectly through collisions of the second kind, and in such a way that certain states were preferred because of a kind of resonance effect, but even in that case we should expect lines corresponding to lower quant-numbers to appear strong in the auroral spectrum. The coincidences with helium lines are therefore probably accidental.

All the auroral lines and bands of Table XXIII are at any rate extremely faint as compared with the stronger lines and bands of the auroral spectrum, and independent of the question as to whether some of these lines belong to helium or not, we conclude that the higher atmosphere cannot contain more than a few per cent of helium. *Hence, our present analysis has confirmed the conclusion drawn in previous communications (4, 5, 7, 17, 18, 28), that an upper atmospheric layer dominated by the light gases hydrogen and helium does not exist.*

The conclusions to be drawn from the fact that a fairly heavy gas like nitrogen is a predominant component of the atmosphere to its extreme limit, was dealt with in previous papers. (4, 5, 7, 18, 28).

The absence of a hydrogen-helium layer means that the distribution of matter cannot be calculated on the assumption of an ideal equilibrium where the velocity of diffusion dominates in comparison with translatory and turbulent motions. Apart from the question as to the distribution of ozone, the composition of the atmosphere seems to keep fairly constant to its very limit, because the mixing processes dominate over diffusion. Even if hydrogen in large quantities came into the auroral region, it would probably unite with activated oxygen, existing in the form of ozone or excited atoms, to form water vapour, which might condense and form a haze or clouds, as it sinks downwards. In this way we find a possibility of explaining the *luminous night clouds.* Supposing the electric rays coming from the sun, in certain rare cases, to a large extent to consist of hydrogen atoms (protons), they would then finally combine with the activated oxygen, and, at the low temperature of the auroral region, the water vapour thus produced, might condense and form clouds of ice particles, as soon as the vapour fell down to a height of sufficiently large total pressure. According to height measurements of the luminous night clouds undertaken by Jesse[1], Størmer[2] and others this condensation should take place at a height of about 80 km[3].

§ 24. The type of nitrogen spectrum emitted by the aurorae, and the physical conditions of excitation which may account for it.

The nitrogen spectrum emitted by the aurorae shows the following typical features. The negative bands corresponding to the vibrational series (on_2) $(n_2 = 0.1.2)$ appear with dominating intensity in such a way that the intensity rapidly diminishes with increasing value of n_2. The bands corresponding to the series $(1\ n_2)$ $(n_2 = 0, 1, 2, 3)$ are on an average much fainter than those of the (on_2) series, and the intensity varies with n_2 in another way. For the $(1, n_2)$ series the intensity is at a maximum for the band (1, 2). Of the series $(2, n_2)$ we observe the bands corresponding to $n_2 = 1, 3, 4$.

The second positive group is comparatively weak in the visible part, but fairly strong in the ultra-violet. The intensities of the more prominent bands of the negative and positive groups appearing in the auroral spectrum were found from quantitative measurements, and are given in a previous paper (28) and in Table X.

The 1st positive group appears with an intensity of about the same order of magnitude as that of the second positive group. Probably some lines from atomic nitrogen appear, but they are very weak.

As already shown in papers from 1912 (1, 2) a nitrogen spectrum essentially of this type is found from the negative glow of a somewhat wide discharge tube. In the negative glow the light is produced by fairly swift cathode rays. But in this case we know that a considerable number of positive ions N_2^+ are formed in the negative glow. As the negative group originates from N_2^+-ions the idea would naturally suggest itself that the very large intensity of the negative bands was due to the presence in the negative glow of such ions, which were then excited to emission of the negative bands through the bombardment of the cathode rays which have passed through the cathode fall of potential.

It appears, however, that a nitrogen spectrum of the auroral type may be obtained *when a bundle of cathode rays passes through a chamber filled with ordinary nitrogen which has not been ionised or put into any excited or abnormal state.*

This is clearly shown by some experiments which I made in 1922, by which a bundle of cathode rays from a Wehnelt cathode was made to pass through a narrow

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[1] O. Jesse, Astron. Nachr. 140, 161, No, 3347.

[2] C. Størmer. His results will soon be published in Geophys. Publ. Oslo.

[3] An account of earlier attempts to explain the luminous night clouds is to be found in Handb. der Geophys. 9 in an article by B. Gutenberg "Der Aufbau der Atmosphäre".

bore of an aluminium cylinder, which divided the discharge tube from the "observation chamber". A reproduction of a spectrogram obtained in this way is shown on Pl. III. 2. No. 1. The velocity of the cathode rays corresponds to 300 volts.

We notice that the intensity distribution of the negative bands and the second group on this spectrogram are essentially the same as for the auroral spectrum. (Compare spectrogram Pl. II. 1. a).

In 1926—28 a more extensive series of experiments was carried out in a similar way at our institute by Mr. J. Aars. He took spectra corresponding to different pressures, temperatures and velocities of the cathode rays. The effect of temperature on the development of the nitrogen-bands, and the determination of the temperature of the auroral region by means of the nitrogen bands, were dealt with in previous papers (28, 29).

In this connection we fix our attention on the type of spectrum and its intensity distribution. A number of spectrograms corresponding to various pressures, tensions and temperatures are reproduced in the paper by Aars[1]. Fig. 9 of this paper gives a reproduction of a number of spectrograms taken with the same quartz spectrograph as was used for the auroral investigations which I undertook during the years 1922—24. They correspond to a pressure of 0.025 mm Hg., and a cathode ray velocity of 600 volts. The spectra (A) correspond to the temperature of liquid air, the spectra (B) to room temperature. For the sake of convenience a pair of these spectra are reproduced on Pl. III. 2. 2 A and 2 B.

The auroral spectra obtained with the quartz spectrograph used by Aars were published in various papers (4, 5, 9, 17, 18), but a complete collection will be found in paper No. 28 Plate II No. 1—6.

Comparing these auroral spectrograms with those given in Fig. 9 of Aars's paper, we find that they are essentially of the same type and show the same intensity distribution. In both cases the negative bands dominate the visible part. The 2nd positive group is fairly weak in the visible part, but stronger in ultra-violet.

We shall also consider the spectra reproduced in Fig. 9 in Aars's paper. They form two groups corresponding to the pressures 0.012 and 0.05 mm Hg. For each pressure he gives three pairs of spectrograms corresponding to cathode rays of 300, 600, 900 volts. The spectra corresponding to the pressure 0.05 mm are reproduced at the end of this paper on Plate III. 2. Nos. 3, 4, 5 in the order of increasing cathode ray velocity. The spectra (A) and (B) correspond to liquid temperature of the air and room respectively.

We notice the remarkable fact that the intensity of the bands of the 2nd positive group, relative to that of the negative one, is most pronounced at the smallest cathode ray velocity; *and as the velocity increases, the spectral type (relative intensity of the bands) approaches that of the auroral luminescence.*

We thus find that the type of nitrogen spectrum emitted by the north-light is essentially the same as that obtained when nitrogen is bombarded by a bundle of cathode rays with velocities which on an average should not be less than some hundred volts.

This result — as pointed out in previous papers — is in perfect agreement with the results of previous investigations[2] on the formation of the auroral forms and the electric rays producing them.

Through very extensive studies of the form, structure and intensity distribution along the streamers, I came to the conclusion that the aurorae were generally produced by rays

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[1] J. Aars. Ann. d. Phys. 1, 216, 1929.

[2] L. Vegard: Recent results of north-light investigations and the nature of the cosmic, electric rays. Phil. Mag. 47, 1921.

of negative electrons. The initial velocity may vary in various cases, but should on an average correspond to some thousand volts.

Independent of any view we take regarding the physical process through which the negative and positive bands are excited, we see that the theory of Birkeland, according to which the aurorae are produced by cathode rays from the sun, would lead to just the type of nitrogen spectrum we actually observe from the auroral luminescence.

A more intimate knowledge regarding the excitation process may also be of interest, because it may give us some additional knowledge regarding the state of the upper atmosphere.

The fact that the negative bands appear with dominating intensity when swift cathode rays penetrate through nitrogen, would suggest that the negative bands are excited as the result of a single collision. If the excitation were produced in steps, so that first an N_2^+-ion was formed, and then the upper state for the negative bands was reached through a second collision with a moving electron, then we should expect the relative intensity of the negative bands to diminish with decreasing pressure and decreasing density of the cathode rays. But no such effect is found.

On the contrary, the experiments of Aars show that *the intensity of the negative bands as compared with that of the second positive group increases considerably with diminution of the pressure;* and the intensity distribution does not seem to depend on the density of the cathode ray bundles. This would show that the negative group is excited through a single collision between a normal nitrogen molecule and a swift cathode ray.

This view with regard to the excitation of the negative nitrogen bands is supported by the results of the analysis of nitrogen canal rays and their emission.

From the well-known experiments of J. J. Thomson, and from recent investigations by Hogness and Lunn[1] and others, we know that the canal ray bundle of nitrogen contains large quantities of N_2^+-ions. On the other hand, we know that the negative nitrogen bands give no canal ray Doppler-effect, which means that the swift moving N_2^+-ions in the canal ray bundle do not emit the negative bands. This would show that the upper electronic state of the negative nitrogen bands is not easily excited from the normal N_2^+-state. It seems as if a collision of the ion N_2^+ with a molecule or electron, either leads to the complete dissociation of the N_2^+-ion into atoms and atmoic ions, or the N_2^+-ion is left unchanged. The occurrence of this dissociation process is clearly shown by the fact that the ratio N^+/N_2^+ increases with increase of pressure.

In the "unmoved" spectrum, on the other hand, the negative bands appear with great intensity[2]. This means that when a neutral molecule is hit by a canal ray particle, the upper electronic state of the negative bands is easily excited.

As stated in previous papers the rays producing the aurorae probably consist of swift electrons mixed with positive particles. The type of spectrum emitted by the aurorae, however, indicates that most of the luminescence is excited by electronic rays although the positive rays may be responsible for the excitation of some of the weaker lines of the auroral spectrum.

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[1] Hogness and Lunn, Phys, Rev. 26, 786. 1925.

[2] Compare spectrograms given in papers Nos. 1 and 2 in the list of papers.

§ 25. Variation of the intensity distribution within the auroral spectrum and the corresponding colour changes.

Through the investigations on the auroral spectrum described in the present and particularly in a number of previous papers (4, 6, 7, 14, 18, 20, 28), various types of intensity variations were discovered which will correspond to various types of changes of colour shown by the total auroral luminescence.

Some of these variations in the spectral intensity distribution refer mostly to the green and blue region, and will give variations of the sum effect, which are not very conspicuous to the eye. Such effects are the intensity variations of the strong green line, relative to that of the nitrogen bands, the relative variations of the intensity of the "second green line" — which may be seen in the spectroscope — and the relative enhancement of a number of usually weak lines in the blue region. Compare e. g., paper No. 28 and the two spectrograms (b) and (a) of Pl. I. 2. of the present paper. These spectral variations account for changes of colour from green, greenish-white, white and bluish-white.

The most conspicuous colour changes are those corresponding to a relative enhancement of lines and bands in the red part. Before the more systematic studies of the auroral spectrum were commenced in 1922, I had already observed several cases of red coloured aurorae, and certain possible explanations of these colour changes were discussed in various papers published in the period 1917—21.

Although no details were known as to the spectral intensity variations, these considerations — as far as they go — contain points of lasting value, and I find it of interest to give an account of these earliest attempts at an explanation of the colour changes.

From a paper published 1917[1], giving a summary of the auroral investigations up to that date, we will quote what is said about the explanation of colour changes:

"Das Spektrum des Nordlichts ist nicht ganz konstant, sondern zeigt Variationen, die den starken Farbenänderungen entsprechen. Wie erwähnt ist die Farbe des Nordlichst in der Regel grünlich-weiß, kan aber, auch bis in Dunkelrote übergehen. Um diese Farbenänderungen zu erklären, könnte man sich denken, daß die verschieden gefärbten Lichterscheinungen von qualitativ verschiedenen elektrischen Strahlen herrührten, oder aber, daß die roten Nordlichter bei tieferem Hereindringen der Strahlen in die Atmosphäre enständen. Ein von mir am 11. Oktober 1912 in Bosskop beobachteter Bogen hatte so einen dunkelroten unteren Rand, während aufwärts die Farbe in die gewöhnliche, grünlich-gelbe überging. Dies sollte darauf deuten, daß die letztere Annahme die richtige sei. Hierbei begegnet man doch die Schwierigkeit, daß vielleicht auch Strahlen auftreten können, die in ihrer ganzen Ausdehnung rot sind[2]. Eine weitere mögliche Erklärung wäre die, daß die Farbe sich mit der Geschwindigkeit der Strahlen ändere[3]. In diesem Falle sollten aber alle Nordlichter roten unteren Rand zeigen, indem ja alle Strahlen immer allmählich ihre Geschwindigkeit verlieren[4]".

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[1] L. Vegard: Bericht über die neueren Untersuchungen am Nordlicht. Jahrbuch d. Rad. und Elektronik. B. 14, 383, 1917.

[2] Solche Strahlen beobachtete ich am 17. April d. J. um Mitternacht in Christiania.

[3] Daß Farbenänderungen durch Änderung der Strahlengeschwindigkeit hervorgerufen werden können, ist von Gehrecke, Seeliger und Rau nachgewiesen worden.

[4] Sollte man mit Hilfe der Effekte von Gehrecke, Seeliger und Rau die Farbenänderungen erklären. so müßte man annehmen, daß gewöhnlich die Strahlen in der Atmosphäre nicht gang absorbiert werden, sondern daß sie durch die ablenkende Wirkung des erdmagnetischen Feldes wieder in den Weltraum hinausgewoffen werden, ehe sie ihre Geschwindigkeit verloren haben. Die rote Farbe

The problem relating to the red colouring of the aurorae was taken up for discussion on a somewhat broader basis in a paper published in 1921[1], where a paragraph headed "On the change of colour of the aurorae" runs as follows:

"A most curious and most characteristic feature of an auroral display is the variation of the colour, which means a corresponding change in the spectrum of the light emitted. Ordinarily the colour is greenish-yellow, sometimes bluish-white, and very often an aurora shows reddish-blue veins in between the ordinary greenish-yellow. Every now and then considerable parts of the aurorae may be dark red, almost with the colour of blood. Sometimes the red colour only appears near the bottom edge, while the upper part has the ordinary greenish-yellow colour. A most brilliant aurora of this kind of colouring was observed simultaneously by Krogness at Haldde and by the present author at Bossekop on October 11, 1912. A magnificent drapery-shaped arc which was extended in the usual direction across the sky appeared with a dark-red bottom edge, while the upper part had the ordinary colour. At the same time other parallel drapery-shaped arcs appeared which, however, were greenish-yellow".

At other times the aurorae seem to be painted red all over. On April 17, 1917 the author observed at Christiania (Oslo) another interesting case of red-coloured aurorae, which on this occasion appeared on the northern sky in various forms. Sometimes it had the form of a diffuse arc, sometimes it was more like the pulsating form, and all the while long rays, passing nearly to the zenith, were formed. While the forms changed, the position was kept fairly unaltered, indicating that the change of form was not accompanied by any essential change of the properties of the cosmic rays. Usually the aurora had the ordinary colour, but all of a sudden a large part of it would become dark-red all over, the change of colour not being accompanied by any essential change of form. It appeared as if the aurora, with the shape it had taken, had suddenly been painted red. There was in this case no difference in colour between the lower and the upper part of the auroral streamers. The same phenomenon was also observed by Professor Størmer from another place near Christiania.

A similar phenomenon was observed by Krogness at Tromsø on November 29, 1918. An auroral display of ordinary colour suddenly — with its rays, streamers, and arcs — turned dark-red and this condition lasted for a comparatively long time — about half an hour. This is the only instance of this kind that has been observed since the observatory[2] was erected.

With regard to the explanation of these curious colour phenomena, a number of possibilities have been mentioned by the present author in some previous papers[3]. If the change of colour were of such a nature that it could be regarded as a function of the height, it would be most natural to suppose that it was due to a change in the composition of the atmosphere. An aurora like that observed on October 11, 1912, with a red bottom edge, would naturally suggest an explanation of the sort that the red colour appears where the electric rays were penetrating down below a certain height of the atmosphere. If so, the bottom edge of the red aurora should be nearer the ground than that of an ordinary greenish-yellow aurora. There are, however, as yet no exact height-measurements of this type of aurora. If, however — as indicated by the auroral displays

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sollte dann vollständiger Absorption und Anregung mit sehr langsamen Strahlen entsprechen. Eine solche Erklärung der Farbenänderungen stößt jedoch auf erhebliche Schwierigkeiten, auf die wir hier nicht eingehen wollen.

[1] L. Vegard. Results of north-light investigations and the nature of the cosmic-electric rays, Phil. Mag. 42. 47, 1921.

[2] Haldde-Observatory.

[3] L. Vegard. Jahrbuch d. Rad. u. Electronik XIV p. 463 (1917).

on April 17, 1917 and November 29, 1918 — the red colour appears all along the auroral streamer, an explanation of this sort can no longer be upheld; but the change of colour must be due to some change regarding the way in which the light is excited. In other words, it must be due to some change of properties of the cosmic electric rays.

But the question now is: Is it necessary to assume that change of colour means a change of carrier? The fact that an ordinary aurora changes into a red colour without change of place can hardly be brought into harmony with the assumption that a change of carrier is necessary to produce changes of colour. Although our observational material in this respect is very limited, and although we are unable to solve the problem, it may be of value to suggest an explanation which does not require the assumption of change of carrier, but only change of velocity.

Now we may at once remark that if all electric rays which were engaged in the production of an aurora, were completely absorbed near the bottom edge, light should be emitted in the atmosphere from the bombardment of rays, which had velocities that varied from zero near the bottom edge to the initial velocity they possess when they enter the atmosphere. Under these conditions the colour might change from the bottom edge and upwards, but if there were no change in the composition of the atmosphere all the aurorae should have shown the same colouring.

From the study of the luminosity distribution and its variations, we were led to the view that the electric rays did not pass straight down parallel to the lines of force to be absorbed at the bottom edge but they turned round the magnetic lines of force and could be driven out into space from the effect of the magnetic field or from the combined action of magnetic and electric fields; and if so, it is possible to explain variations of colour even when we would suppose that all rays that enter the atmosphere are strictly identical both as regards carrier, charge and velocity. It is thus a well-known fact[1] that the spectrum of a gas, and especially that of nitrogen, varies enormously with the velocity of the cathode rays which produce it; and, as a matter of fact, the luminosity produced in nitrogen by cathode rays of small velocity in a vacuum tube has a colour very similar to the red colour which the aurorae may assume. The red colour, then, should appear when the electric rays were moving in such a way that most of them were completely absorbed, and the greenish-yellow should appear when the greater part of the rays was turned back to space with a fairly large velocity. This view also explains that a drapery often has red streamers mixed in between the ordinary greenish-yellow ones. This would only mean that in the red streamers a relatively greater number of the rays is completely absorbed, or, on an average, has suffered a greater loss of kinetic energy."

Already in the paper quoted it has been pointed out that we are dealing with at least two types of red-coloured aurorae.

A. Aurorae which are deep red all over. The colour is independent of altitude.

B. Aurorae where the red colour is mainly confined to the region near the lower limit, and the colour is essentially a function of altitude.

The physical explanation of the red colouring will no doubt contain essential points of difference for the two types. The *A* type appeared repeatedly in 1926, and its spectrum was examined in the spectroscope and several spectrograms were obtained. It appeared that the red colouring of this type was due to enhancement of what appeared (with the small dispersion used) to be single sharp lines with a wave-length (6309—20).

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[1] See E. Gehrche & R. Seeliger, Über das Leuchten der Gase unter Einfluß von Kathodenstrahlen Verh. d. Phys. Ges. XIV pp. 335, 1023 (1912) Fulcher, Astroph. Journal XXXIV, p. 388 (1911). L. Vegard, Ann. d. Physik, xli. p 625 (1913): lii. p. 72 (1917).

It seems very likely that the enhanced line is the same as that which ordinarily appears and which was recently shown to be a doublet (6303, 6368). It will be an important object for further observations to find out whether the enhanced "line" causing the red-coloured aurorae of type (A) is identical with the doublet (6303, 6368). If so, and if this doublet corresponds to the oxygen lines ($^1D_2$—$^3P_{21}$) the red colouring would mean that certain physical changes take place which increase the relative probability for the forbidden transitions ($^1D_2$—$^3P_{21}$) to occur. We have already mentioned that the enhancement is connected with increase in the ozone concentration.

Whatever the origin of the enhanced line may be, the red colouring of this type is of universal nature, appearing simultaneously at Tromsø and Oslo (compare paper No. 28), and the spectral investigations from the period 1922—1926 showed that the enhancement of the red line has a pronounced maximum near that of the sunspots. *In other words: the probability for an enhancement of the red line and the production of red coloured aurorae of type A, should follow the variation of the sunspot frequency.*

It is of interest to notice that since the more continual auroral observations began in 1910, all the cases in which red aurorae of the type *A* have been observed, closely coincide with a sunspot maximum. Thus aurorae of this type were observed at Oslo by the writer in 1917 and 1926, and I believe that Størmer observed the same phenomena. Krogness observed colouring of this type in 1918 at Tromsø.

With regard to the *type B* with red bottom edge, it seems to be very rare. Since 1910 — as far as I know — only two cases of this type have been recorded. One during my stay at Bossekop in 1912 (simultaneously observed by Krogness at Haldde) and a second one observed at the new Observatory in 1932 and photographed by Harang and Bauer simultaneously from two stations, both observations of type *B* near sunspot minimum.

This difference with regard to the time of occurrence also indicates that the two types of red aurorae A and B are essentially different. Already in the papers quoted, I dealt with the explanation of the red aurorae of the type *B*.

It was mentioned that the luminescence produced when a bundle of cathode rays penetrated into a atmosphere mainly consisting of nitrogen, would change colour and turn into red, as the velocity of the rays near the bottom edge was gradually reduced on account of absorption. That a colour variation of this type actually occurs under such conditions was shown by the experiments of Gehrcke and Seeliger already referred to.

From the spectrograms taken by Aars we concluded that the intensity of the 2nd positive group, relative to the negative one, increased with decreasing cathode ray velocity. On account of the close physical connection between the 1st and 2nd positive groups we conclude that also the intensity of the 1st positive group with its red bands, increases as the velocity of the electron rays diminishes below a certain limit. This is the spectroscopic explanation of the effect observed by Gehrke and Seeliger.

From the spectrograms taken by J. Aars it appears that the intensity of the 2nd positive group (and also the 1st positive one) relative *to that of the negative group increases rapidly with increase of pressure. The probability of obtaining an aurora with a red bottom edge due to a relatively large intensity of the 1st positive group of nitrogen, should thus increase with decreasing altitude of the bottom edge.*

When the cosmic electric rays descend below a certain limit their chance of being completely absorbed (before returning to space) will be increased, so that a comparatively large percentage of the luminescence will be produced by cathode rays of small velocity. Further, the relative *intensity of the red bands of the 1st positive group will be increased through increase of pressure.*

As already pointed out in the paper from 1921, we should expect that the aurorae of type B, with a red bottom edge, would reach exceptionally low altitudes. Now Harang and Bauer succeeded in obtaining height measurements for the auroral arc of type B, which they observed on March 8, 1932[1]. They found that the arc with the red bottom edge came down to an altitude of about 70 km, while ordinarily the altitude of the bottom edge of an arc is from 100 km and upwards.

It thus seems very likely that in the case of the red-coloured arcs of type B, *the red colour is mainly due to a relative increase of the red bands belonging to the 1st positive group of nitrogen, the enhancement of which is due to reduction of the cathode ray velocity from absorption, and to the increase of nitrogen pressure with decreasing altitude.*

In the spectral investigations which I am undertaking in collaboration with L. Harang and E. Tønsberg, special attention will be paid to both types of red aurorae. Even if the aurorae of type B only last for a short time, we may hope to obtain spectrograms from the bottom edge by means of the small spectrographs with high light power, and perhaps to make important observations by means of spectroscopes.

In the case of type A, we may obtain spectrograms also with the large spectrographs, because the enhancement of the red line producing the red colour of this, was found to remain for fairly long periods of time, and we should hope to obtain spectra of the enhanced red line during the winter seasons near the next sunspot maximum.

The height measurements of Harang and Bauer of the arc with red bottom edge show that this type of arc corresponds to rays of exceptionally large penetrating power and initial velocity. As this type seems to occur at sunspot minimum, it would follow that the rays of largest penetrating power were emitted from the sun during the time near a sunspot minimum. This result, if confirmed by a more extensive series of observations, would naturally remind us of the variation of the solar corona during the sunspot cycle.

It is found that the corona is more dense near sunspot maximum, but the faint streamers are much longer at sunspot minimum. According to the coronal theory proposed by the writer (cp. paper No. 21) the coronal rays are developed as the result of the emission of electric rays from the sun, and the average length of the streamers should increase with increasing velocity of the cathode rays emitted from the sun. Thus we see, that *both the aurorae and the solar corona lead to the view that the maximum velocity of the cathode rays emitted from the sun is larger at sunspot minimum than at sunspot maximum;* but the absolute density is smaller. If we take records of the lowest altitudes reached by the aurorae every winter season, we ought to find an eleven years' period with the minimum altitude coinciding with the sunspot minimum.

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In obtaining the results dealt with in the present paper I have had the advantage of receiving valuable support from collaborators and other persons who in various ways have essentially assisted in the observational work and the building of the new instruments.

First of all my thanks are due to the director of the Tromsø Observatory, L. Harang B. Sc., who has taken care of the exposures of the spectrograms and the photographic work connected with it.

In S. Stensholst B. Sc., I have had a most valuable collaborator who has made a great many of the measurements and a great deal of the calculation work necessary for the wave-length determinations.

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[1] L. Harang and W. Bauer. Gerlands Beiträge zur Geophys. 37, 109, 1932

Great merit is due to J. Aars B. Sc., for the investigations he undertook for the study of the variations of the nitrogen spectrum with temperature, pressure and velocities of the cathode rays, and which have an important bearing on the interpretation of the auroral spectrum.

Most valuable investigations were also carried out by Lars Grimestad B. Sc., on the relative intensities of spectra obtained in mixtures of hydrogen and nitrogen.

Bror With M. Sc., (engineering) has very ably assisted in making the drawings for the new large glass spectrograph, and the instrument-makers of the Physical Institute, Oslo. Mr. Kr. Andersen and Mr. H. Jørgensen have both done excellent work in connection with the building of the new large spectrographs.

To all these persons I wish to express my sincere thanks.

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Papers concerning the auroral spectrum previously published by the author.

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. 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. Phys. 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 Nordlichtstrahlen 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 sunlight. Nature Dec. 1929.
21. Die Korona der Erde und Sonne und ihre Beziehung zu kosmischen Erscheinungen. Gerlands Beiträge zur Geophys. 32, 288, 1931.
22. Light emitted from solid nitrogen, when bombarded with cathode rays and its bearing on the auroral spectrum. Proc. Koninkl. 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. Wave-length of the green auroral line determined by interferometer. Nature Jan. 1932.
27. Spectrographic observations of infra-red lines of the auroral spectrum. Nature. March, 1932.
28. Results of investigations of the auroral spectrum during the years 1921—26. Geophys. Publ. IX No. 11 — 1932.
29. The temperature of the auroral region determined by the rotational series of the negative nitrogen bands. Terr. Magn. Sept. 1932.
30. Der sichtbare Teil des Nordlichtspektrums. Z. S. f. Phys. 78, 9 und 10, 1932.

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PLATES

Explanation of Plate I, fig. 1.

a. Auroral spectrum (Ne. comparison spectrum) taken on Sonja E. W. plates with the new large glass spectrograph, Sept. 20. 1930. Effective exposure about half an hour.

b. Auroral spectrum (Ne. comparison spectrum) taken on pan-chromatic B, with the new large glass spectrograph, Oct. 10. 1930. — Exposure two hours.

c. Auroral spectrum on Agfa infra-red plates (810 μ) taken with the old small glass spectrograph. Febr. 4. 1932.

d. Auroral spectrum on Agfa infra-red plates (810 μ) taken with the new small glass spectrograph with Görlitz lens. Febr. 4. 1932.

e. Ne-spectrum showing the sharpness to be obtained with the new large glass spectrograph.

f. Spectral lines with interference fringes obtained by Harang with one of the small glass spectrographs with the slit in the focal plane of the interferometer lens.

Explanation of Plate I, fig. 2.

a. Auroral spectrum taken on Sonja E. W. plates March 18. 1930 with the new small glass spectrograph with Görlitz lens. Exposures $1^1/_2$ hours.

b. Auroral spectrum on Sonja E. W. plate taken with the new small glass spectrograph. March 26. 1930. Exp. 30 minutes with diffuse north-light.

c. Similar spectrum on Sonja E. W. with the new small glass spectrograph March 1930.

d. Three auroral spectra taken with one of the glass spectrographs with camera lens made of one piece of glass, on isochrom. plates January 25. 1931. d_1 corresponds to diffuse arcs, d_2 and d_3 to extensive quiet areas.

e. Spectra taken with the small glass spectrograph with F:1 lens on Agfa isochrom. plates Dec. 22. 1930. e_1 corresponds to quiet extensive areas without radiant structure. Exposure 15 minutes. Elevation of collimator 60° above the horizon.
e_2: north-light of definite form, partly with red borders. Taken on the same plate as e_1 with spectrograph in unaltered position. Exposure 10 minutes.

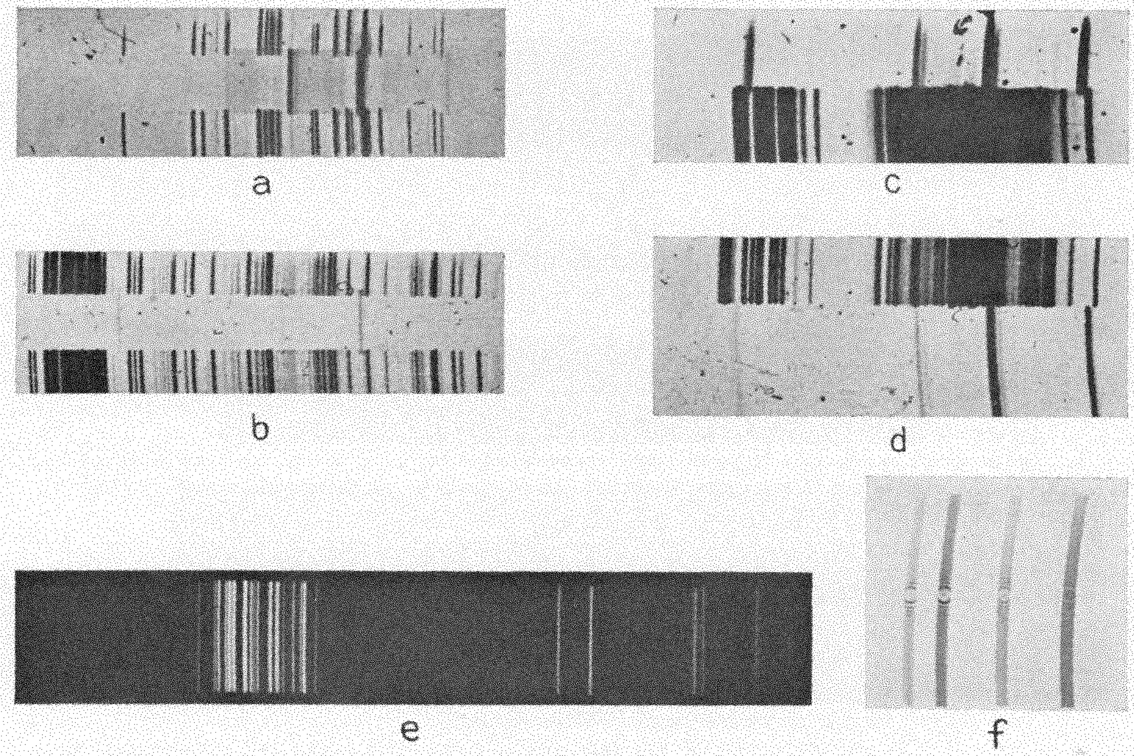

Fig. 1.

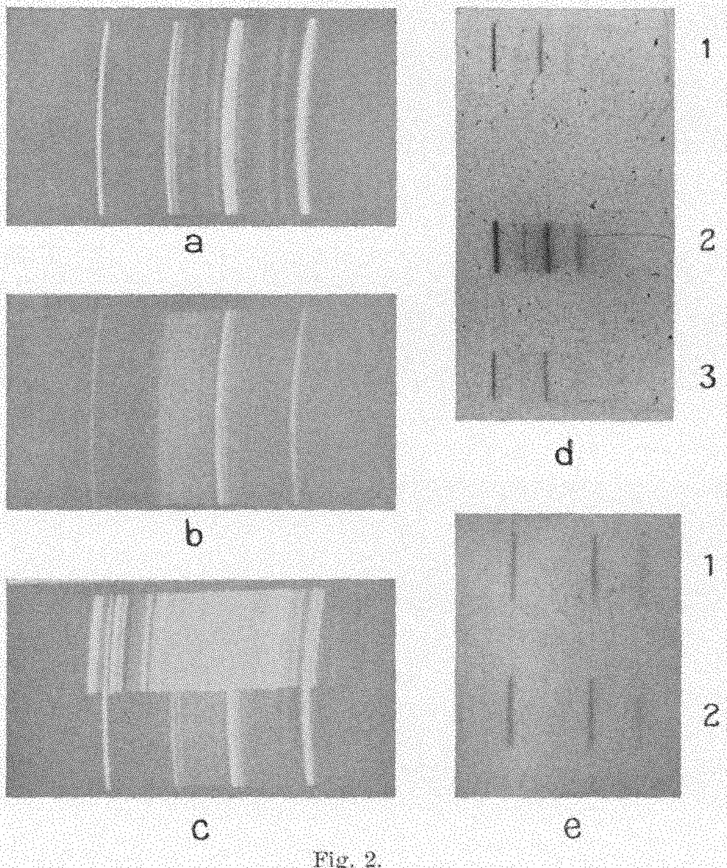

Fig. 2.

Explanation of Plate II, fig. 1.

a. Auroral spectrum taken with the new large glass spectrograph on pan-chromatic plates during the winter season Sept. 1931—Febr. 1932. Ne-He comp. spectr.
b. Spectrogram taken with the new large quartz spectrograph. Oct. 1931 on Sonja E. W. plates.
c. Spectrogram obtained with the new large quartz spectrograph during the winter of 1930—31. Fe comparison spectrum.

Explanation of Plate II, fig. 2.

Spectrogram a. Negative glow from a canal ray tube, pressure about 0.1 mm Hg. Taken on pan-chromatic plate. Würzburg 1912.
— b. Positive column of the same tube and pressure, taken on the same plate as a.
— c. Positive column of discharge tube. Taken at Oslo Febr. 1932 on Agfa infra-red 810. Neon comparison spectrum.
— d. Negative glow from oxygen canal ray tube, taken at Würzburg 1912 on pan-chromatic plates.
— e. Spectrum of oxygen canal rays taken on the same plate as (d).

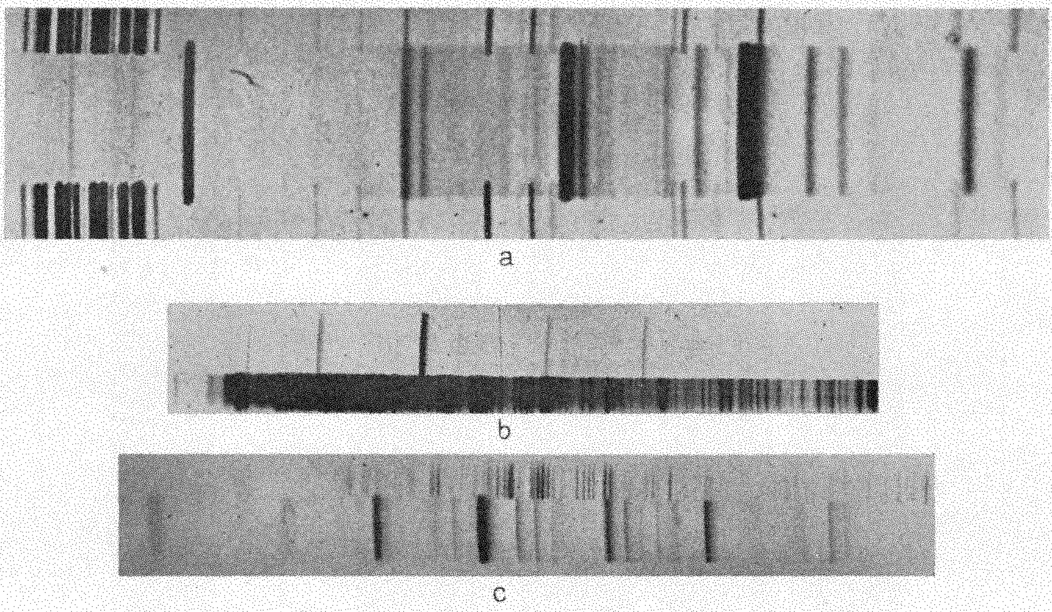
a
b
c

Fig. 1.

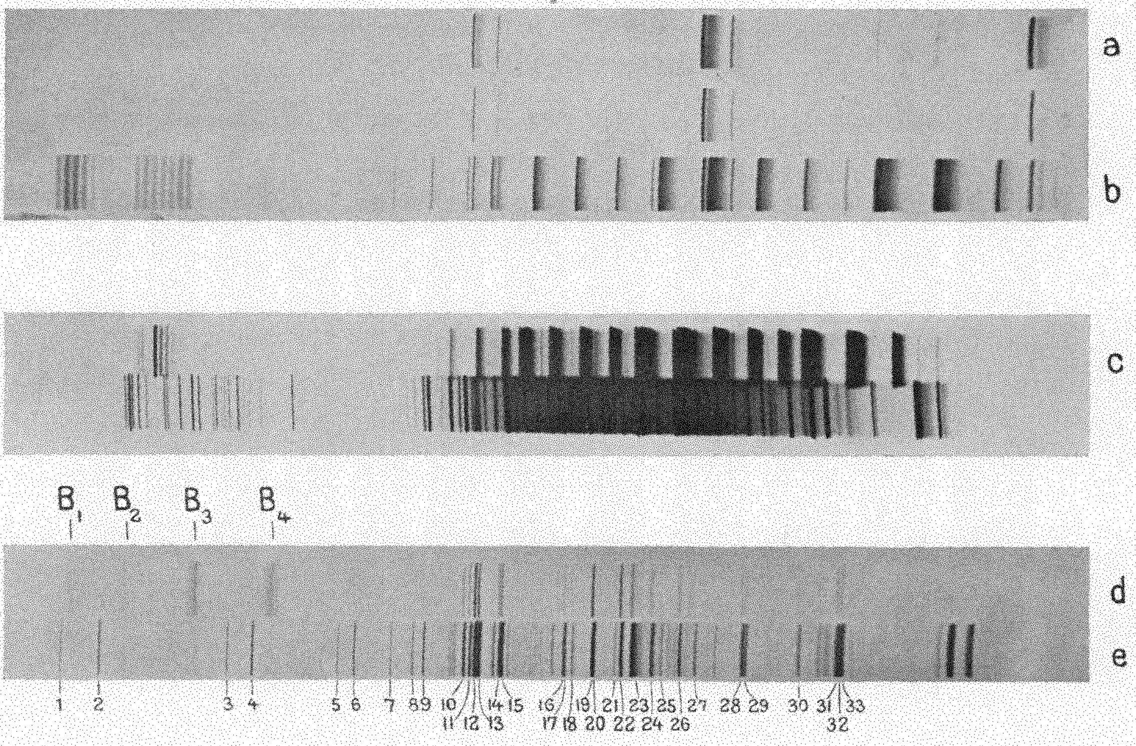
a
b
c
B1
B2
B3
B4
d
e
1
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Fig. 2.

Explanation of Plate III, fig. 1.

Spectra 1—8 correspond to negative glow in Hydrogen-Nitrogen mixtures.
Spectra 9—12 from luminescence produced in Helium-Nitrogen mixtures by Wehnelt cathode rays of 230—310 volts.

Hydrogen-Nitrogen

1.	total	pressure	1.0	mm	Hg	0.6 %	N_2,	99.4 %	H_2
2.	»	»	0.9	»	»	2.2 »	»	97.8 »	»
3.	»	»	0.8	»	»	27.1 »	»	72.9 »	»
4.	»	»	0.08	»	»	27.1 »	»	72.9 »	»
5.	»	»	0.70	»	»	50.0 »	»	50.0 »	»
6.	»	»	0.7	»	»	80.0 »	»	20.0 »	»
7.	»	»	0.5	»	»	90.0 »	»	10.0 »	»
8.	»	»	0.4	»	»	98.0 »	»	2.0 »	»

Helium-Nitrogen

9.	discharge	potential	310	volts,	$^1/_3$ N_2	+ $^2/_3$	He
10.	»	»	230	»	$^1/_2$ »	+ $^1/_2$	»
11.	»	»	250	»	$^2/_3$ »	+ $^1/_3$	»
12.	»	»	240	»	$^3/_4$ »	+ $^1/_4$	»

Explanation of Plate III, fig. 2.

No. 1.	Spectrum of nitrogen on "Flavin" plate 1922 from the luminescence produced by 240 volt cathode rays, penetrating into a chamber behind the discharge tube. Kept at liquid air temperature. He. comparison spectrum.
Nos. 2—5	Reproductions of spectrograms from nitrogen on "rapid" plates, obtained by J. Aars 1927 in a way similar to that described for No. 1.
No. 2.	Spectrum taken with large quartz spectrograph. Pressure 0.025 mm. Cathode ray velocity 600 volts.
Nos. 3, 4, 5.	Spectra taken with large glass spectrograph at the pressure of 0.05 mm Hg and cathode ray velocities corresponding to 300, 600 and 900 volts respectively.

(A) corresponds to the temperature of liquid air. (B) to room temperature.

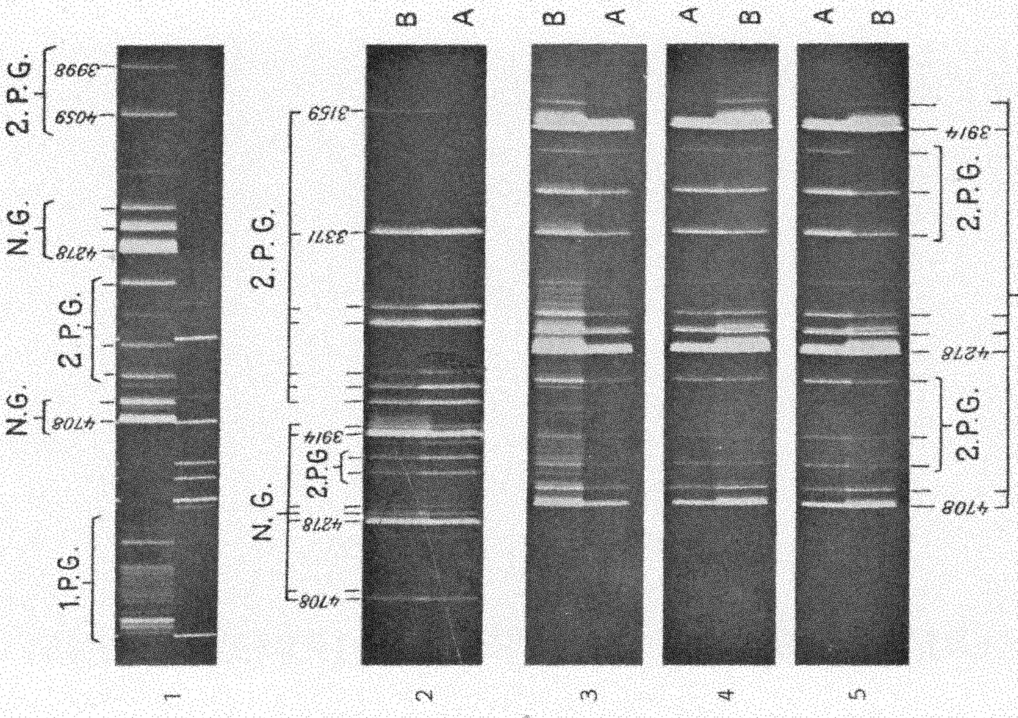
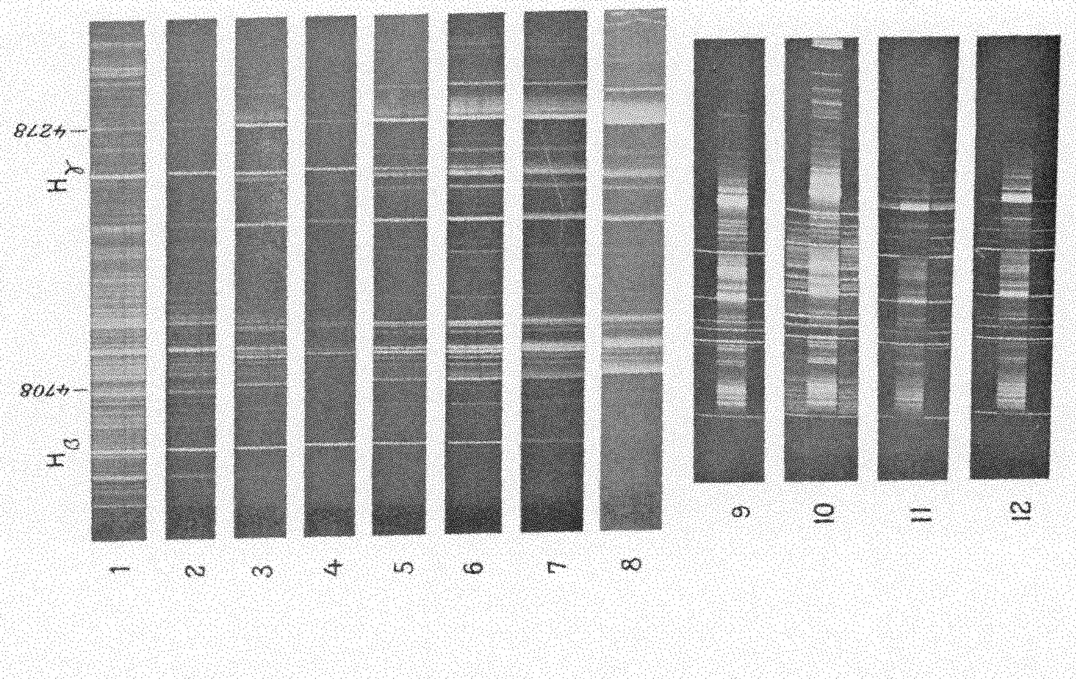

2.P.G.
3998
4059
N.G.
4278
2.P.G.
N.G.
4708
1.P.G.
1
2.P.G.
3159
3371
N.G.
3914
2.P.G.
4278
4708
B
A
2
3
4
5
3914
2.P.G.
N.G.
4278
2.P.G.
4708

Fig. 2.


Hγ
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Hδ
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Fig. 1.

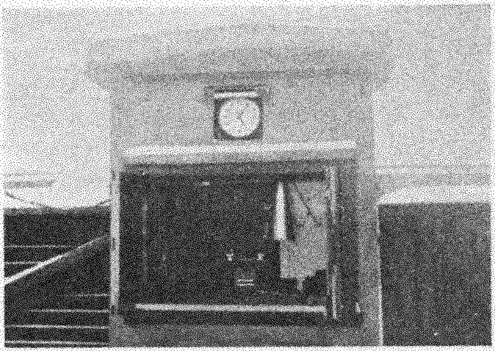

Fig. 1 a. The stand on the observation platform.

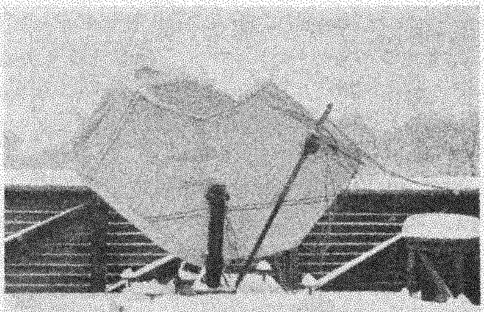

Fig. 1 b. The large glass spectrograph on the observation platform.

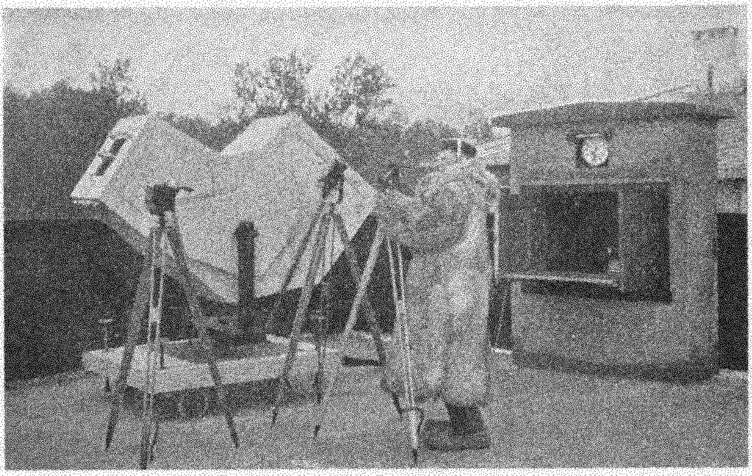

Fig. 1 c. Observation Platform with "stand" and instruments.

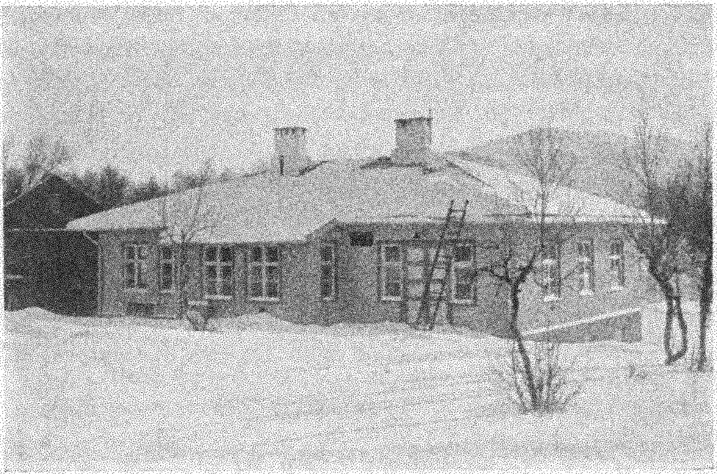

Fig. 2. Observatory building showing the door which communicates with the observation platform.

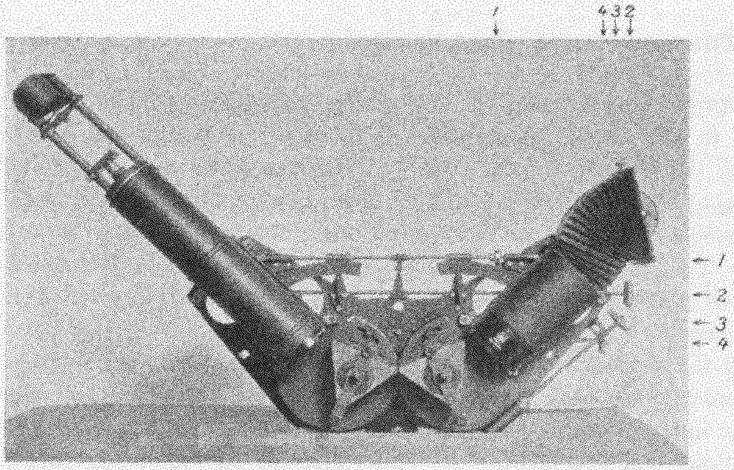

Fig. 6.

system have two independent motions. With one operation we may move each of the two prisms an angle α in an opposite direction. The camera and collimator may be turned an arbitrary angle β in opposite directions, and we have in any case to give β the right value. The mechanical construction by means of which this adjusting arrangement was effected is illustrated in Figs. 6, 7 and 8 showing some photographs of the instrument. Details of construction will be seen from Figs. 9, 10 and 11.

Each of the two prisms is put on a prism-table which for the larger part has a circular form with centre coinciding with the axis of rotation C. Part of the circumference is formed like a toothed wheel. The form of the prism-table and the mounting of the prism on it, are shown in Fig. 9.

The prism is put into a metal frame (15, 16, 17, Fig. 9) and is fixed by means of the screw 18. When the prism-tables are put in proper position, the tables act like two tooth-wheels, and if one table is moved a certain angle, the second table is moved the same angle in an opposite direction. One of the tables can be moved by means of a screw No. 3 Fig. 6. When by turning the screw No. 3, the prisms have obtained their proper position, they may be fixed by turning the handle No. 4 (Figs. 7 and 10) with a screw 8 (Fig. 10) which works the fastening arrangement.

The arrangement for moving the collimator and camera is shown in the photographs (Figs. 6 and 7) and particularly in the drawing Fig. 10.

The rod (1) which turns in the layers (6) Fig. 10 carries two screws (5) and (5′), which again move the two circularly formed metallic wings (w) and (w'). One of these wings is attached to the collimator, the second one to the camera and in this way a turning of the screw (1) will turn collimator and camera equal angles in opposite directions. The camera and collimator can be fastened by turning the rod (2) carrying the screws (7) and (7′), which act on a fixing device. On Fig. 8, we notice two pointers which may move along a divided scale. One of the pointers is rigidly attached to the prism-table, the second, to the camera. We may now easily fix the position of camera and collimator which corresponds to a given position of the prism-tables.

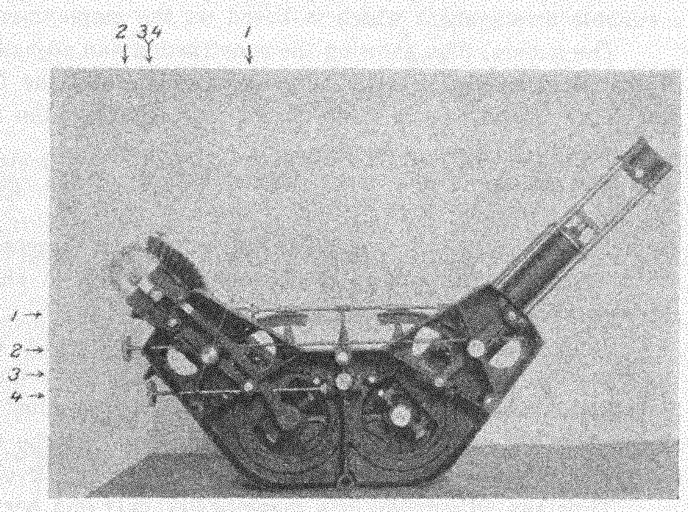

Fig. 7.

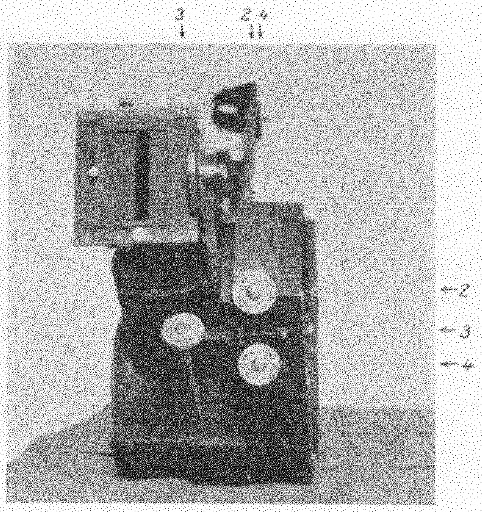

Fig. 8.

The construction and mounting of the plate-holder are shown in Fig. 11. It can be moved on a sledge by means of the screw (9) and the position indicated by pointer and scale (not shown). The plate-holder can also be turned round on axis *D*, fixed by the screw (13), and its position indicated by pointer and scale.

The plate is put into a frame which can be moved up and down in the plate-holder by means of the screw (11) and can be fixed by another screw.

All optical parts are well protected against false light, as shown in Fig. 12. The optical parts were made by the firm Carl Zeiss, Jena.

The camera lens had an effective diameter 100 mm, and focal distance 250 mm. It was composed of 3 lenses as indicated in Fig. 5.

The collimator lens had an effective diameter 100 mm and focal distance 520 mm. The condensor lens had a diameter 60 mm and focal distance 250 mm. Each of the two 60° prisms had a basis with side-length 140 mm and height 93 mm.

The mechanical parts were made at the Physical Institute, Oslo, under the guidance of the writer.

Drawings were made by Mr. Bror With and the instrumental work was executed by Mr. H. Jørgensen.

Plate I. 1. e shows the reproduction of a Neon spectrum taken on a pan-chromatic plate with the new large glass spectrograph. The spectrogram is considerably enlarged. The true dispersion on the original plate for various wave-lengths is given in Table II.

Table II.

λ	6000	5000	4000
$\frac{d\lambda}{ds}$ Å/mm	270	160	80

§ 7. The Grating Spectrograph.

In order to obtain a grating spectrograph suitable for auroral investigations, I found it necessary to introduce a lens of high light power in front of the photographic plate. The concave grating used was ruled by The National Physical Laboratory, England. Its radius of curvature was 100 cm. The ruled area is 5 × 3.5 cm and the mean grating interval is 0.00006942 inch at 18.8° C.

It gave a comparatively strong 1st order spectrum. This grating was kindly lent to me by my colleague Professor Sem Sæland. The construction of the instrument will be seen in Fig. 13. The slit (6) at the end of the collimator (5) was placed at a distance of 50 cm in front of the grating (3), which was mounted on the metal-holder (4). The grating could be turned round a vertical axis (*A*), and when it was given the right position it could be fixed by a screw-arrangement.

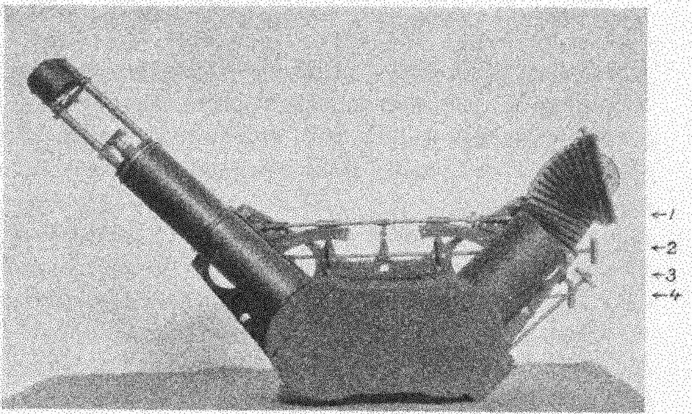

Fig. 12.

The diffracted beam of a homogeneous ray bundle entering the slit, would — for a certain order of diffraction — leave the grating as a parallel bundle of rays. These bundles pass through the lens (2) which forms a sharp spectrum on the photographic plate. The plate-holder with the lens was mounted on a metal plate which could be turned round the axis *A* independent of the rotation of the grating about the same axis. The angle between the normal of the plate and the optical axis of the lens could be varied within certain limits, and, further, the lens could be moved in the direction of its axis.

The lens (F:1.25) had an effective diameter of 4 cm and focal distance 5 cm, and was delivered by the firm "Astro Gesellschaft, Berlin" which was recommended to me by my colleague Professor Carl Størmer.

The mechanical parts were made — according to my design — by the instrument-maker of the Physical Institute, Oslo, Mr. Kristian Andersen. The instrument is shown in Fig. 14.

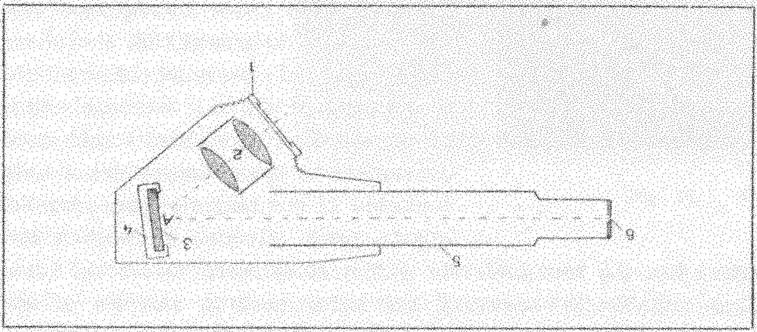

Fig. 13.

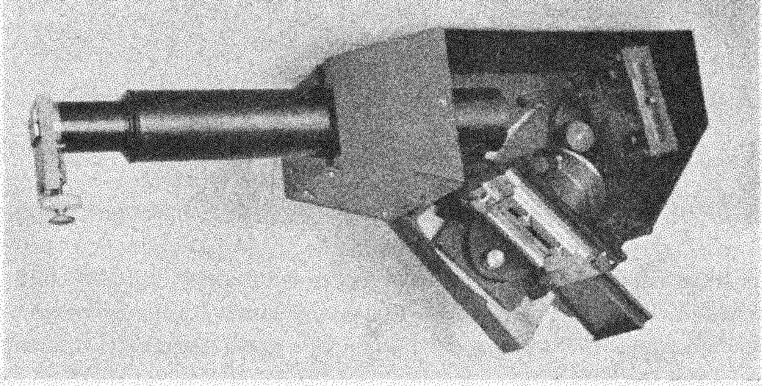

Fig. 14.

With the adjustment now used at the Auroral Observatory for investigating the long wave part of the spectrum, the instrument gives in the first order, a nearly constant dispersion in this region of about 305 Å per mm. With this instrument we may easily take spectra of higher order with correspondingly larger dispersion. We may also fairly easily increase the dispersion by replacing the present lens with one of longer focal distance.

The instrument was finished in Sept. 1932, and taken to Tromsø by the writer at the beginning of October of the same year.

§ 8. The Fabry-Perot Interferometers.

Some years ago I obtained — from Adam Hilger, London — a Fabry-Perot etalon consisting of two parallel glass plates each of them lightly silvered on one side. The plates were mounted in the well-known way in a metallic frame with their silvered surfaces turned towards each other, and separated by means of a cylindrical quartz ring of 1 cm in length.

This etalon was to be used in front of a lens of high light power, and the interference ring system — formed in the focal plane of the lens — had to be analysed.

In the case of very strong lines such as the green auroral line, we may remove all other strong lines and bands by means of suitable filters, and we can photograph the image of interference rings directly on a plate placed in the focal plane of the lens. If it is difficult to obtain a sufficiently selective filter for the line to be analysed, it is intended to let the interference image in the focal plane fall on the slit of a spectrograph of extremely high light power, or the interferometer may be put in front of the prism of a spectrograph. Then we should obtain interference fringes of each line typical for the wave-length and structure of each particular line. (Cfr. Pl. I. 1. f.)

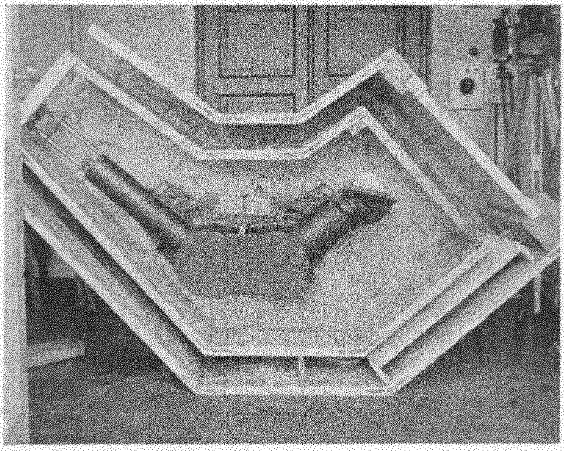

Fig. 15.

In trying to obtain interference fringes of the green auroral line with this etalon, it appeared that the silver layer absorbed too much of the light to get pictures within a reasonable time of exposure. It was also found more convenient to use etalons which simply consisted of one single plane — parallel quartz plate silvered on both sides.

Two such quartz plates, one 2.5 mm and one 5 mm thick were made by Adam Hilger. In order to get a suitable thickness of the silver coating, samples of the silvering were sent to me for absorption tests until I found a thickness which combined a fairly small absorption with a good definition of the interference fringes. The optical thicknesses were accurately measured by the National Physical Laboratory. Further details will be given in connection with the publication of the results obtained in cooperation with Leiv Harang.

§ 9. The protection and temperature regulation of the spectrographs.

In order to obtain the somewhat weak lines with the larger spectrographs, we must be prepared for exposures lasting for days or even weeks. The instruments, therefore, must be protected against rough weather and kept at a fairly constant temperature during the exposures.

For this purpose the instruments were put into a wooden box of suitable form, which was mounted on a stand in such a way that it could be rotated round a vertical and a horizontal axis. The arrangements chosen for the new instruments are essentially the same as those used in the investigations commenced in 1921 and are described in previous papers (4, 5, 7, 17, 18, 28).

In order to improve the heat isolation and the efficiency of the temperature regulations, the box had double walls with an air space in between. The new construction of one of the boxes will be seen from Fig. 15, showing the large glass spectrographs in its box, from which the side wall has been removed.

The elements for the electric heating were placed in the space between the two walls in such a way that the air was made to circulate round the inner box. The contact thermometer for the automatic regulation of the temperature was also placed in the space between the two boxes, but at a proper distance from the heating elements. The relays were placed in the laboratory building or in the stand of the observation platform.

Fig. 16 shows the large glass spectrograph and the quartz spectrograph in their boxes on the platform.

During the first winter season of 1929—30 only the following three instruments were in working order: The new glass spectrograph, the small (N. O. fig. 6 a) old glass spectrograph and the small new glass spectrograph with Görlitz lens.

The new quartz spectrograph was mounted during my stay at Tromsø in part of July and Aug. 1930. The two small glass spectrographs with camera lens (F: 1) made of one piece of glass were mounted in a somewhat provisional way, so test exposures could be made, during the autumn of 1930.

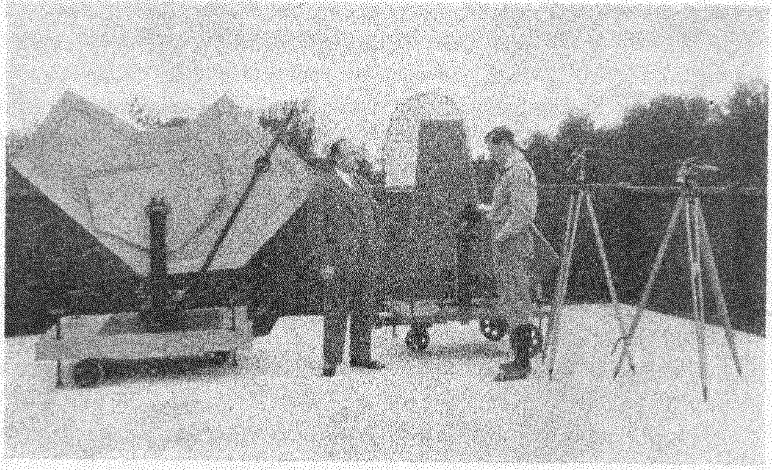

Fig. 16.

In this preliminary mounting of the optical parts the adjustment was difficult, and during my stay at Tromsø in Oct. 1932 we decided to rebuild the apparatus so as to allow a more exact and convenient adjustment.

The large old glass spectrograph was taken down from its stand on the roof of the Weather Bureau Building, but was not properly mounted until October 1932.

CHAPTER II.

Observations and results.

§ 10. Account of the spectral work at the new Observatory during the first three winter seasons.

The spectrographic work at the new Observatory commenced in the autumn of 1929. On account of the long distance between Tromsø and Oslo my opportunities of visiting the Observatory and taking part in the observational work were somewhat limited. Consequently most plans, instructions and discussions relating to the spectral work had to be conducted by post or wire. The observational work itself was placed in the hands of the director of the Observatory, Mr. L. Harang.

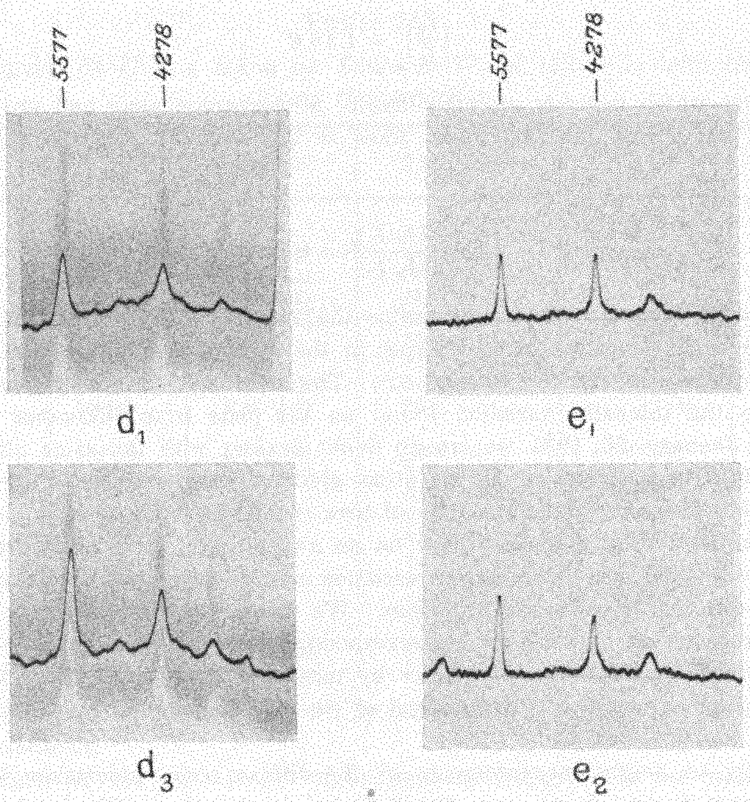

Fig. 17.

On January 25. 1931 three spectra were taken on the same Agfa Isochrom plate in succession, during the same evening. They are reproduced on Pl. I. 2. d.

Spectrogram d$_1$, corresponds to quiet areas in the north. Exposure 10 minutes.

Spectrogram d$_2$. Diffuse auroral luminescence, covering almost the whole sky, but every now and then this situation was interrupted by the appearance of auroral rays and draperies of short duration. Exposure $1^h\ 30^m$. The auroral line is too dense for accurate intensity measurements.

Spectrogram d$_3$. Diffuse auroral luminescence over large parts of the sky, but in this case no rays and draperies appeared. Exposure 1 hour.

This spectrogram has a photographic density very suitable for intensity measurements and of a magnitude about that of spectrogram d_1.

Comparing the spectrograms d_1 and d_3, we notice at a glance that the green auroral line is relatively weaker on the spectrogram d_3. An intensity scale (time scale with constant light source) was photographed on the same plate.

Registrams of the two spectra d_1 and d_3 and the intensity scale were taken with a microphotometer of the Moll type, and in this way relative intensities were measured and calculated in the manner described in a previous communication (28). Reproductions of the registrams of the two auroral spectra d_1 and d_3 are shown in Fig. 17 (d_1 and d_3).

Denoting the green auroral line by b, and the band 4278 by d (as in paper 28), we find for the spectrogram 1, corresponding to the auroral arc:

$$\left(\frac{I_b}{I_d}\right)_1 = 1.51\,k$$

and for the spectrogram 3, corresponding to the diffuse uniform luminescence: