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# RECENT PROGRESS RELATING TO THE STUDY OF AURORAE AND KINDRED PHENOMENA

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**Summary.** From auroral studies it was found that the structure of the ionosphere, the zodiacal light, the solar corona and the bundles of electric rays which produce aurorae and most magnetic disturbances is due to the photoelectric effect of solar X-rays of various frequencies and different distributions.

The electric bundles producing the aurorae are formed by photoelectrons from the sunspot area and neutralized by positive ions, mainly protons. In the years 1939-41 it was found, by means of Doppler effect, that the bundles carried protons with velocities amounting to at least $2.10^8$ cm/sec.

The neutralized bundles led to an auroral theory essentially similar to the Birkeland-Störmer theory, but variation of the proton flux in the bundle led to many consequences which could be verified with spectral studies of the aurorae. Thus variations with latitude and altitude were found in accordance with theory. From the fact that protons and electrons give essentially different spectra a number of variability effects could be explained. Thus the red aurorae of type A and B were found to be due to protons and electrons respectively. Recently detected enhancements of atomic lines were found to be due to increase in the relative proton flux.

The velocity of protons is as a rule much smaller than that of the electrons. Consequently the bundle carries a surplus of negative electricity into the atmosphere where it produces electric and magnetic disturbances of various kinds, and gives the earth a negative charge.

Temperature measurements from $N_2^+$ bands corresponding to altitudes of several hundred km gave no indication of any increase of temperature with altitude.

**1. Introduction.** Spectral analysis of the auroral luminescence dating back to 1923 [1] led to the conclusion that a number of phenomena appearing in the upper atmospheres of the sun and the earth are due to the photo-electric effect of solar X-rays of various frequencies and varying distribution on the sun's surface. When these X-rays enter into the upper atmosphere of the earth, they produce ionosation maxima e.g. the ionospheric layers E and $F_2$. They set up electric fields which influence the distribution of matter in the ionosphere, and give the upper atmosphere a coronal structure, which, under the influence of the earth's magnetic field, also accounts for the zodiacal light [2, 3, 4, 5].

When the same type of X-rays as those producing the E- and $F_2$-layers, act on the upper solar atmosphere, they produce the solar corona [2, 6] which is composed of bundles of photo-electrons electro-statically neutralized by positive ions of high specific charge, preferably protons. The bundle elements are kept together — partly by solar magnetic fields, partly through an automatic focussing effect due to the mutual attraction between the bundle elements. (Cfr. [4], p. 612, and [17, 18, 19, 20].

Through sun-spot activity, highly ionised matter with great energy is brought up to the sun's surface. X-rays of small wavelength and secondary electrons of correspondingly high energy will be emitted. These electron bundles neutralized by positive ions (protons) will thus have much greater energy than those forming the coronal streamers and they will work their way to distances greater than that between sun and earth. They are emitted from limited sources, and, in the way indicated, they maintain fairly limited cross sections and form the ray bundles which produce the aurorae and certain types of magnetic disturbances.

As already shown in previous investigations [13, 14, 17, 18, 19, 20] the constitution of the solar ray-bundles and the consequences to which it leads can be tested and verified by studying the auroral spectra and their variations.

As is well known, the intensity of the H-lines emitted from the solar bundles during an auroral display, is subject to great variations, indicating variations in the proton flux ($\nu_p$) relative to that of the electrons ($\nu_e$). In a neutralized bundle the number of electrons (n) pro unit volume is equal to that of the protons hence:

$$(1) \qquad \nu_p = n\,V_p,\quad \nu_e = n\,V_e \text{ and}$$

$$\nu_p / \nu_e = V_p / V_e$$

where $V_p$ and $V_e$ are the velocities of protons and electrons respectively.

Thus the condition of neutralization involves that the relative proton flux $\nu_p/\nu_e$ is equal to the relative velocity $V_p/V_e$, but it sets principally no limit to the variation of the magnitude of the relative proton flux, which must be evaluated by means of the auroral spectra and the way in which they vary.

It is the object of the present report to give a summary of recent work which has been done with the object of showing firstly that the neutralized bundle gives the proper basis for the theory of aurorae and magnetic disturbances and of other phenomena related to the physics of the ionosphere. Secondly, that the neutralized bundles lead to variations of the intensities of H-lines, which have been confirmed by experiments, and, finally, that electron- and proton-excitation gives spectra which differ in a typical way, and that, therefore, the variation of proton flux will greatly influence the spectral composition of the auroral luminescence and its variability.

Research along these lines is continuing and results have already been published 17, 18, 19, 20].

**2. The neutralized electron bundles and the auroral theory.** The current density (i) of the neutralized electron-proton bundle is given by the equation (paper 4 p. 612):

$$i = en\ (V_e - V_p) \tag{2}$$

and the deviating force (K) acting on unit volume in a magnetic field (F)

$$K = en\ (V_e - V_p)\ F \sin\varphi = i\ F \sin\varphi \tag{3}$$

where $\varphi$ is the angle between (F) and the direction of the bundle.

Thus the neutralized bundle is magnetically active (eq. 2) and is deviated in the magnetic field of the earth in a similar way as a single electrified particle or a current element (eq. 3).

This means that the bundle will move in the earth's magnetic field in very much the same way as a single electrified particle as dealt with in the theory of Birkeland and Störmer. Thus the merits of Störmer's calculations, to explain the typical distribution of the aurorae on the earth with regard to space and time, can be directly transferred to the neutralized bundle.

From studies of the height and structure of aurorae it follows that, at any rate for aurorae reaching down below say 110 km, $V_e \gg V_p$ [24, 13].

Thus as a rule the magnetic field, the automatic focussing effect and the deviating force (K) in a magnetic field are dominated by the electron flux.

This means that the relative proton flux $\nu_p/\nu_e$ may vary from a very small value to a quantity, which for most aurorae, is smaller than unity. In rare cases, where even the lower parts of the aurorae are situated at great altitudes of say some hundred km, the electron velocity $V_e$ is very small, and, if so, the proton velocity may possibly be as great as $V_e$, so the proton flux may even dominate the excitation of the auroral luminescence.

Cases of this sort have been dealt with in previous papers (cfr. [19], p. 7—8, [20] p. 40, and [25] p. 99—102).

In the free space, where, ordinarily, the ion-concentration is negligible, the condition of electro-static neutralization must be fulfilled and the protons must keep within the bundle and they will cause a diminution of the deviability of the orbits in a magnetic field at a rate which increases with the proton velocity.

If an electron and a proton move in the same magnetic field perpendicular to the lines of force, the ratio between the radius $\varrho_p$ of the proton orbit to that of the electron $\varrho_e$ will be:

$$\varrho_p/\varrho_e = \frac{M_pV_p}{M_eV_e} = 1800\, V_p/V_e \tag{4}$$

If $V_p$ is greater than $V_e/1800$ the deviability of the protons is smaller than that of the electrons. Usually $V_e$ is about 6.10⁹ cm/sec., in which case the deviability of the proton will be smaller than that of the electrons in the bundle, when $V_p \gtreqless 3.10^6$ cm/sec.

The maximum proton velocities measured from the Doppler effect of the H-lines are of the order (1—3). $10^8$ cm/sec, and, therefore, under ordinary circumstances, the deviability of solar ray bundles is governed by the proton flux.

In this connection we should remember that according to the theory of Störmer the distances from an aurora to the magnetic axis point increase when the deviability of the orbits diminishes, or with an increase of proton velocity.

### 3. The variability of the intensity of auroral hydrogen lines seen in relation to the properties of the solar ray bundles.

*a. General remarks.* Even on the very same spot the relative intensity of the H-lines is subject to great variations with time. These are very irregular, but may be mainly ascribed to variations of the sources of the sun. Statistical treatment, however, will no doubt bring out certain regularities e. g. regularities regarding relations with time of the day, magnetic coordinates (eq. magn. latitude), time of the year and solar activity. As we shall see, it is also of particular interest to study the way in which the intensity of auroral H-lines varies with altitude.

b. *Variations of H-intensity with magnetic latitude.*

As the magnetic latitude of the aurorae increases with proton velocity, the relative proton flux will also increase when we consider aurorae at nearly the same altitude and produced by solar bundles which have about the same electron velocity. Under these conditions we have approximately.

$$\nu_p/\nu_e = V_p/V_e = k\,\frac{H}{B_e} \tag{5}$$

where H is the intensity of a hydrogen line and $B_e$ is the intensity of a nitrogen band, which is mainly excited by fairly swift electrons e. g. a $N_2^+$ 1N band.

Attempts to detect and measure a possible latitude effect of the proton flux was first made by comparing spectrograms from Oslo with spectrograms from Tromsø. The first results, described in [14], were derived by comparing 12 spectrograms from Oslo with 11 from Tromsø obtained during the years 1939—1943. *At Oslo the relative H-line intensity was found to be about 5 times greater than at Tromsø.*

During the winter 1952—53 new series of spectrograms were taken at Oslo and Tromsø. The spectrograms to be compared were taken with two practically identical spectrographs with equal adjustment and on the same sort of photographic plates. The results were given in a paper by Vegard and Kvifte: Theory and Observations of the Enhancement of Auroral Hydrogen Lines with Increasing Distance from the Magnetic Axis Point [26].

The result from the present observational material is, that the average relative intensity of the hydrogen lines at Oslo is more than 6 times greater than at Tromsø.

At Tromsø we may often have the opportunity to compare spectrograms, taken with the same spectrograph on the very same plate, from aurorae in the northern sky with similar auroral types appearing in the southern sky. The distance between the aurorae compared may be up to the order of 1000 km.

The determination of the latitude effect from spectrograms taken from the same spot has already been dealt with in previous publications [19, 20, 27].

Since the winter 1953/54 a considerable number of spectrograms for determination of the latitude effect has been taken and will be dealt with in a publication soon ready for publication. At present we would only mention that the results already published have been confirmed by the later observations.

Practically without exception, we have found that even in the cases when the $H_\alpha$-line towards the south appear quite distinct, the $H_\alpha$-line on the spectrogram towards the north is either absent or very faint.

### c. *The separation of protons and electrons in the bundle by absorption in the ionosphere. Altitude effect.*

The auroral luminescence we observe is a result of the processes going on when the bundle passes downwards through the ionosphere.

When the bundle enters the upper atmosphere there will be plenty of ions, and the protons and electrons are not tied up with the condition of electro-statical neutralization, but, apart from the influence of the earth's magnetic field and the automatic focussing effect, they are free to move and to be absorbed independently of each other. In this way the proton and electron-rays of the solar bundle have been separated and the effects of each component may accordingly be studied.

Each component may be characterized (or perhaps identified) by the type of spectrum it produces in the atmospheric gases through which it passes. But we now meet with the difficulty that the composition of the atmosphere is very variable.

We know, however, that the atmosphere mainly consists of nitrogen and oxygen, and laboratory experiments have shown that excitation of molecular nitrogen and oxygen with *electron rays* gives spectrograms with strong bands and few and fairly weak lines, while excitation with *positive rays* gives spectrograms which are rich in lines, whereas the bands are absent or extremely weak (cf. [20] Pl. II).

Fortunately, in the case of the proton rays they can be directly observed by means of the hydrogen lines they emit.

In order to emit H-lines the protons of the bundle must pick up electrons, and this is a process, which starts when the bundle enters an atmospheric layer of sufficiently great density. This means that the H-emission pro unit length of the proton bundle, when it enters the atmosphere, increases from zero to a maximum, after which it stops at a height $h_p$.

The luminescence produced by the electron rays of the bundle will stop at a height $h_e$. As already mentioned, the flux and relative velocity $V_p/V_e$ is probably much smaller than unity, and consequently $h_p > h_e$.

In the atmospheric layer between $h_p$ and $h_e$ there should be no emission of H-lines from the proton bundle, and the auroral luminescence, in this interval, should be excited by electrons only.

When the electrons pass downward from $h_p$ to $h_e$, the velocity gradually dininishes. Apart from the forbidden OI-lines the spectrum is dominated by the bands of $N_2^+1N$, and, further, in the long wave part, particularly from green to near infra-red by the 1st. positive group of nitrogen ($N_21P$), and, finally, in ultra-violet by ($N_22P$). The excitation functions show that the intensity of the ($N_21P$) bands increases rapidly as the electron energy diminishes and forms a sharp pronounced maximum at about 12 volts, just before it gets down to the ignition potential of about 8 volts and is stopped. (Regarding excitation functions cfr. [22. 23].

Thus near the absorption height ($h_e$) a sequence of red bands from the 1st. positive group appears with great intensity and for altitude $h_e <$ 100—90 km it may be so dominating as to give the bottom part of the aurorae a deep red colour. *This is the red aurorae of type B, which we see is due to electron excitation.*

The procedures to be followed for the verification of the altitude effects of hydrogen lines were described in paper 20 p. 44 as follows:

> «If auroral arcs, bands, draperies or groups of rays are situated at some distance from zenith, it is possible to compare spectrograms taken near the bottom edge with others taken from near the top of the streamers, and if these are fairly long as in ray-groups and draperies, we may get pairs of spectrograms corresponding to height differences of 50 km, or much more in the case of very long rays. In the second procedure we direct the spectrograph towards magnetic zenith and form a picture on the slit of the radiation point and its nearest surroundings. If an auroral corona is formed by fairly long streamers the tops of these will seem to meet near the radiation point, and in this way we find that a great part of the light entering the slit is emitted near the top of the rays and streamers.»

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The auroral displays, however, are very complex and vary with regard to forms and motions, and it is only under favourable circumstances that we can obtain comparable spectrograms in the way mentioned.

We have already in previous papers published reproductions of spectrograms which show the absence of H-lines (usually we use $H_\alpha$ as the most sensitive indicator) from the lower border, while $H_\alpha$ appears quite distinctly on spectrograms corresponding to the upper part of the auroral streamers (cfr. [26, 27, 19, 20]).

During the four winters since 1953/54 a great number of auroral spectrograms have been taken under well-defined conditions which were suitable for the study of the altitude effect of the H-lines, or of the proton flux. The results, which we hope to publish in the near future, agree with those already published and which can be summarized as follows:

For all ordinary auroral types like arcs, bands, draperies and for certain ray bundles for which we have obtained well-defined spectrograms from near the lower border and from near the upper limit, *we find that for those taken near the lower border the H-lines are absent, while those from the greater altitudes show H-lines (mostly $H_\alpha$) quite distinctly.*

This means that the protons stop at an altitude ($h_p$) which is considerably greater than that of the electrons ($h_e$). In the height interval ($h_p—h_e$) the auroral luminescence is excited by electrons.

As the relative flux is proportional to the relative velocity, the height ($h_p$) should increase when the proton flux gets smaller, provided $h_e$ is the same. When a certain proton flux passes down through the atmosphere the intensity of the H-lines depends on the rate at which the protons are neutralized by picking up electrons, *and at very great altitudes the protons may give vanishingly small H-line-emission.* We shall later deal with cases which must be interpreted in this way.

Spectrograms from near the bottom edge of arcs and draperies, which are excited by electron rays, often show no traces of the red OI-doublet, but in the red part we only see the red sequence of $N_21P$-bands.

*Thus the enhancement of the red OI-doublet cannot be caused by excitation by electrons.* The only possibility seems to be that the transition to the $^1D_2$ state is carried out by protons. This would also agree with the fact that the intensity of the OI-doublet, besides that of the protonflux, is enhanced towards lower latitudes as well as towards greater altitudes.

This view was confirmed in a striking way by a spectrogram taken at Tromsø Nov. 14. 1952 of a red aurora of type A. This spectrogram was reproduced and discussed in [25, 19 and 20]. Although at Tromsø red aurorae of the A-type are rare and the H-lines usually weak, this spectrogram of red aurorae shows a $H_\beta$-line of about the same intensity as the $N_2^+$ 1N (o-2) band. Compared with the strong forbidden OI-lines, the $N_2^+$ 1N bands were unusually weak.

Thus the spectrogram of the red A-type showed just the very features we know to be characteristic of excitation by positive rays. The intensity distribution is indicated by table 2 in [19].

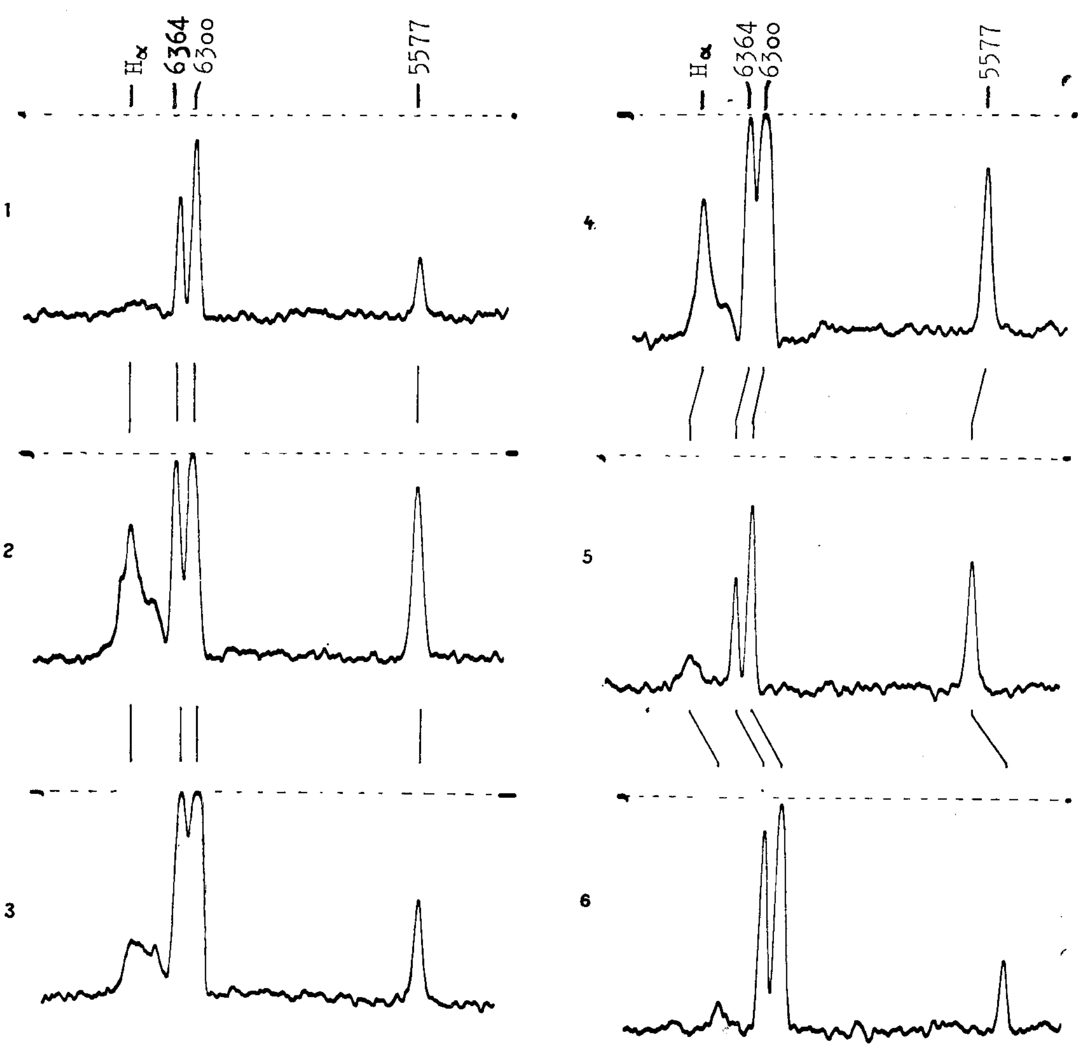

Fig. 1.

As it is well known the enhancement of the red doublet and the probability of observing red aurorae of the A-type increases with solar activity. *If, therefore, the enhancement of the red OI-doublet is due to proton ecxitation, the proton flux should also be greater in years of maximum, than in years of minimum, of sun spots.*

During last winter red aurorae of the A-type have appeared quite frequently, and spectrograms of red aurorae of the A-type have been taken both at Tromsø and at Oslo.

At Tromsø we have used the big spectrograph «F» earlier described (cfr. [20], p. 44). It combines the high lightpower F : 0.65 with a fairly good dispersion. During the last few winters a considerable number of F-spectrograms have been taken from red aurorae of the A type. When the red aurorae are not disturbed by other types, we get spectrograms like that taken from the red aurora of 14.11.52, previously

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Table 1. *Intensities of the red OI–doublet and* $H_\alpha$ *relative to that of the OI-line (5577) from 6 «F» spectrograms of red aur. type A at Tromsø 1956.*

| No of phot. curve fig. 1 | Exposure Date | Durat. Min. | $I\left(\frac{6300}{5577}\right)$ | $I\left(\frac{6364}{5577}\right)$ | $I\left(\frac{H\alpha}{5577}\right)$ | Auroral Type |
|---|---|---|---|---|---|---|
| 1 | 2.10 $21^{14}$ | 26 | 3.8 | 0.8 | 0.07 | Tops of rays, red type A |
| 2 | 26.10 $20.^{35}$ | 25 | 6.5 | 1.5 | 0.16 | Red aur. type A. |
| 3 | » $21.^{40}$ | 15 | 60 | 20.8 | 0.2 | Strong aur. type A. |
| 4 | 9.11 $23.^{52}$ | 11 | 13 | 4,4 | 0.17 | Strong aur. type A |
| 5 | 10.11 $01.^{09}$ | 5 | 1.3 | 0.4 | 0.11 | Bottom of red R, type A |
| 6 | 10.11 $01.^{15}$ | 12 | 9 | 3 | 0.16 | Tops of red R, type A. |

described. These spectrograms are dominated by the forbidden OI lines (5577, 6300 and 6364) and usually the $H_\alpha$-line appears strong. In order that the strongest lines would not be too heavily exposed, the features appearing on the region of shorter waves were too weak to appear on the F-spectrograms from red aurorae of the A type. Photometer curves illustrating the long-wave part of six such spectrograms are shown in Fig. 1.

The intensity of each component of the red doublet and the $H_\alpha$-line relative to that of the green line (5577) is given in Table 1.

We notice the fairly great intensity of the $H_\alpha$-line, but, as it is broadened by Doppler effect, the heights of the maximum on the photometer curve and the values in table 1, do not give a true impression of its intensity.

If our view regarding the excitation of the red doublet is correct, there should be close correlation between the enhancement of the red doublet and the proton flux. We have, however, not yet found any general method for measuring the proton flux corresponding to a certain spectrogram.

The spectrogram gives only an idea of the $H_\alpha$-line emission from the spot on the sky, on which we have directed our instrument, and the relation between proton flux and the H-line intensity may vary greatly e. g. with the distance to the lower, or to the upper, part of the aurorae.

We usually find that small H-line intensities are found when the instrument has been directed either near the bottom or top the of the auroral ray streamers, even when the proton flux is great. Cfr. Table 1.

d. *Spectrograms recently obtained at Oslo from partly red auroral rays.* From 11.3.56 to 22.1.57 we had at Oslo 6 nights with aurorae. The aurorae mostly consisted of long rays which had greatly enhanced OI-doublet (6300, 6364) and which sometimes appeared red. Spectrograms taken with short exposure 12.3, 3.4, 56 and 21.1.57 were essentially of the type characteristic of the red aurorae of the A type.

In order to see if these aurorae with greatly enhanced OI-doublets — mainly caused by proton excitation — showed any unusual features in the short-wave part, a number of *strongly exposed* spectrograms was taken.

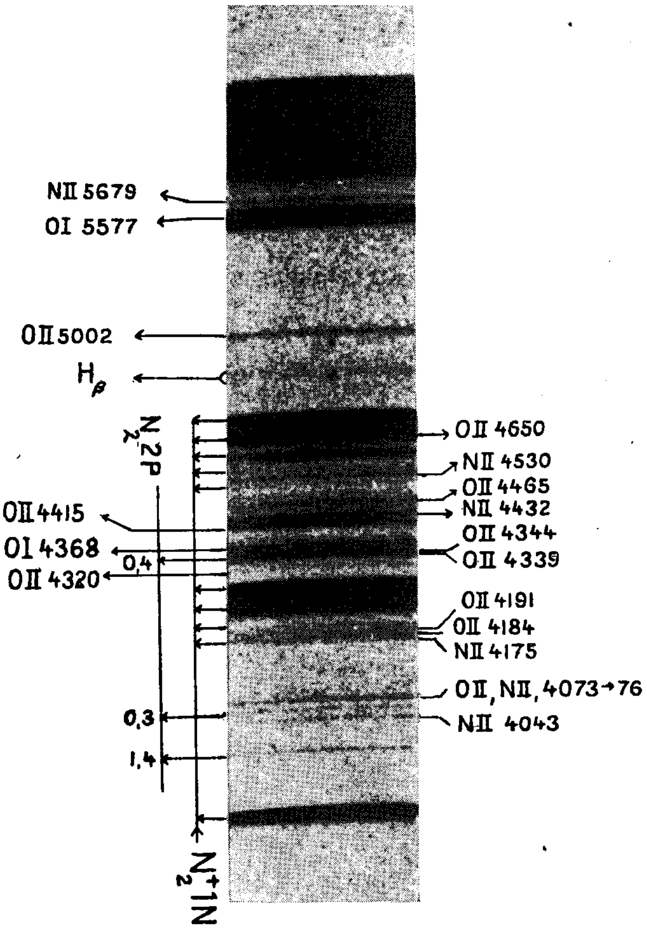

Fig. 2.

It was immediately evident that certain lines were considerably enhanced on these spectrograms.

During the time from 21.4 $23^{00}$ to 22.4 $03^{10}$ three spectrograms were taken from altitudes of the order of 400–500 km from very long rays, the heights of which were measured by Störmer. No difference between the three spectrograms was to be seen as regards degree of exposure and distribution of bands and lines with the exception of the H$_\beta$-line intensities. While the 1st and 3rd spectrograms showed the H$_\beta$-line very distinctly, it was not to be seen on the 2nd spectrogram. The only reasonable explanation of the absence of H$_\beta$ is that the 2nd spectrogram corresponds to such a great altitude that the relative number of protons which had picked up an electron was too small to give a noticeable H-line emission. The proton-excitation is about the same, but the rate of H-line emission is different.

The enhancement of certain lines on the spectrograms with intensive OI-doublet

Table 2. *Enhanced Features* (x) *from a spectrogram* (*Fig. 2*) *taken at Oslo Jan. 21-22 1957 of red Aurorae of Type A.*

Features marked O usually present
Features marked X usually absent.

| λ | Interpretation | Intensity | Upper energy level e.v. | λ | Interpretation | Intensity | Upper energy level e.v. |
|---|---|---|---|---|---|---|---|
| 3914O | $N_2^+$1N (0, 0) | Strong | | 4368O | OI | 39 | 12.4 |
| 3997O | $N_2$ 2P (1,4) | 64 | | 4415O | OII | 45 | 26.2 |
| 4043X | N II | 44 | 26.2 | 4432X | NII | 35 | 26.2 |
| 4059O | $N_2$ 2P (0, 3) | 35 | | 4465X | OII | 27 | 33.2 |
| 4073X | OII | | 28.7 | 4512O | $N_2^+$ 1N (4, 6) | 13 | |
| 4074X | NII V.K. (2, 13) | 51 | 26.2 | 4530X | NII | 29 | 26.2 |
| 4076X | O II | | 28.7 | 4551O | $N_2^+$ 1N (3, 5) | 16 | |
| 4175O | $N_2^+$ 1N (3, 4) | 27 | | 4593O | » (2, 4) | 39 | |
| 4184X | OII | 23 | 31.3 | 4648O | » (1, 3) | 94 {56 | |
| 4191X | O II | 26 | 31.3 | 4650X | OII, V.K. (4, 16 | 38 | 25.6 |
| 4200O | $N_2^+$ 1N (2, 3) | 25 | | 4709O | $N_2^+$ 1N (0, 2) | 87 | |
| 4239O | » (1, 2) | 100 | | 4843X | V.K. (2, 15) | | |
| 4278O | » (0, 1) | 410 | | 4830–80 | $H_\beta$ | | |
| 4320O | OII | 14 | 31.7 | 5002O | NII | 92 | 20,9-23,1 |
| 4339O | O II | 41 | 31.7 | 5577O | OI | v. strong | 4.19 |
| 4344O | $N_2$ 2P (0.4) | | 31.7 | 5679O | NII | 123 | 20.7 |
| 4351O | OII | | 28.5 | | | | |

came out particularly distinctly on certain spectrograms from the brilliant auroral displays which were seen over the whole of Europe during the night 21–22 Jan. this winter.

A reproduction of one such spectrogram taken at midnight Jan. 21–22, is shown in Fig. 2. Wavelength (λ), interpretation, intensity and upper energy levels for most of the distinct and measurable features appearing on the spectrogram fig. 2 are given in Table 2.

The features which are usually absent and which should be greatly enhanced from proton excitation are marked with a cross. (×). The enhanced lines are listed at the right side of fig. 2.

The table contains 6 OII-lines and 4 NII-lines which are greatly enhanced. It happens that the upper energy level of the 4 enhanced NII-lines is the same (26,2 el.volts).

In a previous paper Vegard and Kvifte published a spectrogram showing enhancement of auroral lines with altitude [21]. The enhancement of the lines in Table 2, however, is not to be regarded as an altitude effect. These variable lines as well as

Table 3.

| Wavelength $\lambda$ | n'–n" | Relative intensity of sequence n″—n′= 2of | | |
|---|---|---|---|---|
| | | Vegard Usual type | 21–22 Jan 57 $23^{42}$-$00^{45}$ | Störmer Oslo 1938 |
| 4709 .................... | 0–2 | 100 | 100 | 100 |
| 4650 .................... | 1–3 | 59 | 108 | 97 |
| 4595 .................... | 2–4 | 44 | 45 | 85 |
| 4551 .................... | 3–5 | 26 | 18 | 70 |

those with which they have been compared are measured on the very same spectrogram and correspond to the same altitude.

The enhancement is due to a change in intensity distribution resulting from a change in the excitation process, which, under present circumstances, must mean excitation by the protons of the solar bundle. We might also say that the enhanced lines are part of the type of auroral spectrum which corresponds to a great proton flux and to the red aurorae of type A.

The enhancement is merely to be regarded as a consequence of the fact that excitations with protons should give more and stronger lines than excitation with electrons.

From the spectrogram Fig. 2 it appears as if the second band $N_2^+$ 1N (1–3) of the sequence $\triangle$ n = 2 should be stronger than the first one $N_2^+$ 1N (0–2). This is not, however, an effect like that observed by Störmer and dealt with in [19] (p. 7) [25] (99), in which case the intensities within the sequence diminished more slowly with increase of vibrational quant number than is ordinarily the case.

Table 3 gives the intensity distributions of the bands within the sequence $\triangle$ n = 2 of the negative nitrogen bands. We see that the intensity distribution found from spectrum Fig. 2 differ essentially from that found by Störmer, while it only differs from the normal distribution by the apparently too great intensity of the second band. This, however, is due to overlapping of the OII-line 4650 and perhaps of the V. K. (4–16) as indicated in Table 2.

**4. The influence of protons on the excitation of forbidden NI-lines.** In previous papers we have called attention to the fact that the forbidden NI-doublet ($^4S_{3/2}$—$^2D_{5/2,3/2}$) (5202, 5197) (mean wavelength 5199) is subject to great variations, and in [20] we have shown that there seems to be a close correlation between these variations and those of the proton flux, indicating that the protons in the solar bundle have a great influence on the excitation of the NI-doublet in the auroral luminescence. Regarding the arguments, we refer to tables XV and XVI of [20]. These tables show that the green NI-doublet have the same type of variation with latitude, altitude and proton flux as the red OI-doublet.

Similar variability of the other forbidden lines of NI, NII and OII in the auroral luminescence have not yet been observed.

The intensity variations shown by the red OI-doublet and the green NI-doublet strongly support the view that protons have a preference for transferring a neutral O-or N-atom from the ground state to the lowest metastable states D. Vegard-Kaplan bands of unusual intensity, which were observed by Petrie in the auroral luminescence, indicate that the protons have great efficiency in transferring the normal $N_2$ molecule from the ground state $X^1\Sigma$ to the metastable state $A^3\Sigma$.

## 5. Primary and secondary effect of solar X-rays on ionospheric processes.

The solar X-rays naturally fall into two groups:

a. The soft and fairly constant X-radiation which is spread over the sun's surface, and which by photo effect in the sun's atmosphere produces the coronal streamers, primarily ionizes the upper atmosphere of the earth and produces the E-layer. From the height of the E-layer we find by simple calculation, that the photon energy is of the order of 1000-1500 e-volts. The day-side of the earth's atmosphere above the E-layer is made to emit electrons of velocities corresponding to 1000—1500 e-V. These electrons will produce electro-statically neutralized bundles similar to the streamers of the solar corona.

In the upper atmosphere the photo-electrons will produce the $F_2$-layer far above the E-layer. The electron bundles will account for the slow rate of diminution of density upwards, and the zodiacal light.

We must, however, take into account that the source of secondary electron-radiation is attached to the upper atmosphere itself, and the electron bundles will spread to all sides and help to maintain the $F_2$-layers on the night side of the earth.

b. The second group of X-rays is sporadic and emitted from highly ionized matter in the sun-spot region. In this case not only the primary X-rays, but also the neutralized electron bundles formed from secondary photo-electrons, will penetrate into the earth's atmosphere (ionosphere) and produce various effects of which the aurorae are the most conspicuous.

From the altitude of the bottom edge of an aurora we can find approximately the corresponding electron energy of the solar bundles. The method is described in [13] and [24]. As a rule the altitude is about 100 km, and the corresponding electron and photon energy is of the order of 10 000 e. V.

The lowest auroral heights observed are about 65—70 km corresponding to an electron energy of the order of 200 000 e. V.

The X-rays belonging to this group will produce directly similar maxima as the E-layer, but they will be situated at lower altitudes e. g. in the so-called D-region. The height will diminish with an increase of photon energy.

On account of the action of the magnetic field the bundles will mostly hit the earth on the night side. They will ionize the upper atmosphere and produce maxima (false, sporadic E-layers) which are found at various altitudes. Most of them will be situated near the altitude of the ordinary E-layer.

When the bundle enters the ionosphere the electrons and protons are free to move and will be absorbed independently of each other. The separation of electrons and protons in the bundle will disturb the electrical state, particularly in the upper part of the ionosphere. The electron flux, which is greater than that of the protons, will produce an accumulation of negative electricity. The fields set up will repulse the electrons in the $F_2$-layer which may be driven upwards or made to vanish.

Ionospheric electric currents, accompanied by magnetic disturbances and possibly by mass transport (ionospheric winds), will set in. The accumulation of electrons may possibly, at any rate partly, account for the negative charge of the earth.

*These consequences of the properties and effects of the neutralized electron-proton bundle must be the basis of the study of the ionospheric processes.*

**6. The ionospheric temperature at great altitudes measured by means of $N_2^+$ IN-bands.** The slow rate of increase of density upwards in the ionosphere, which we have found to be an effect of secondary electron emission produced by solar X-rays, might formally be explained by assuming a rapid increase of temperature upwards. To account for the density at altitudes of 300—500 km, temperatures of the order of thousands of degrees might be wanted. In order to test the possibility of such a great increase of temperature upwards, we have devoted much work to the measurement of the band temperatures for the greatest possible altitudes, and the results have been compared with those from the usual height interval 100—120 km.

We have first of all used the big spectrograph «V» with a light power F : 1,2 and a dispersion about twice that of the «F»-spectrograph [30].

By directing the «V» spectrograph towards the radiation point of long rays, we obtained spectrograms mainly from the tops of long rays. The dispersion was sufficient to give separation of the rotational components and a fairly high accuracy.

A great number of temperature measurements were made by means of («F») spectrograms from Tromsø. At Oslo we used the (C)-spectrograph with a light-power F : 0,96. On account of overlapping, the values found from these spectrograms were somewhat too high, but the error could be eliminated by comparing with spectrograms taken from the height interval 100—120 km. Some results from recent years have already been published [20, 30, 31] and a great many measurements from the last two winters will soon be ready for publication.

*Up to the present the results have given no indication of an increase of temperature with altitude. This also applies to temperature measurements which were carried out from tops of rays observed at Oslo corresponding to altitudes, which, according to Störmer, amounted to 400—600 km.*

**7. Continued work on wavelength measurements and identifications of weak auroral features.** The first spectrogram taken with the big «V»-spectrograph in February 1950 at once greatly increased our knowledge regarding the lines and bands appearing in the auroral luminescence [12, 30].

Since then a great deal of work has been devoted to the detection, measuring and interpretation of auroral features appearing on the spectrograms from the «V»-spectrograph taken at Tromsø. The results obtained during the three winters 1950/51 — 1952/53 are dealt with in great detail in [30, 31 and 20].

During the last winter seasons we have taken special care to obtain strongly exposed «V» spectrograms with a narrow slit, accurate adjustment and careful regulation at constant temperature. The advantage of this procedure was dealt with in [20] p. - 7. In this way we obtained a number of succesful «V» spectrograms, showing very sharp lines, which give good conditions for accurate wavelength measurements and reliable interpretation. Some of these spectrograms have also given good facilities for the study of the doppler effect of the H-lines and the relative intensity of the proton flux.

Details will be given in subsequent publications.

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University of Oslo April 30. 1957.
*L. Vegard.*

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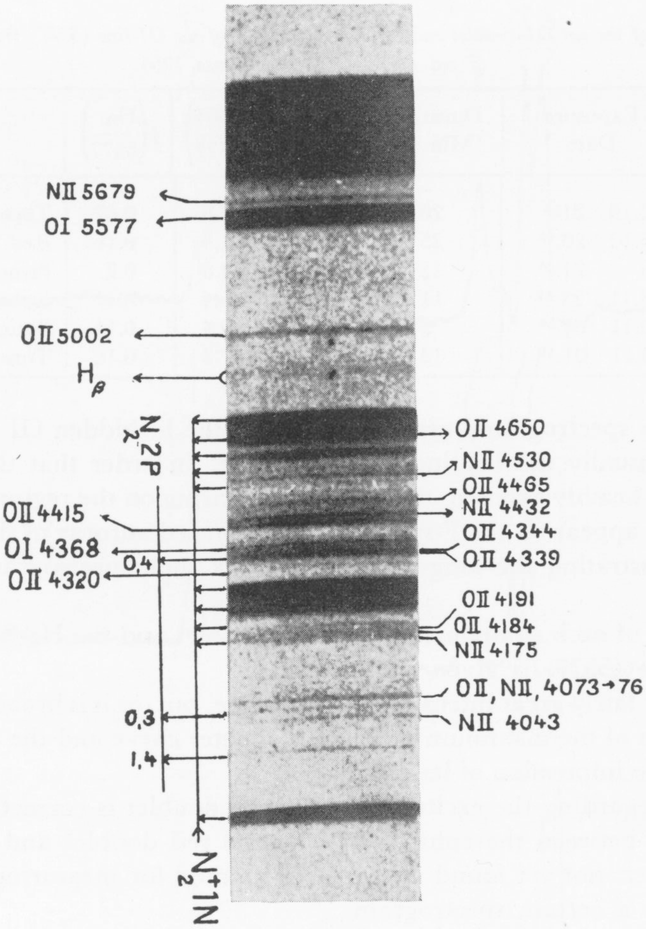

Fig. 2.

It was immediately evident that certain lines were considerably enhanced on these spectrograms.

During the time from 21.4 $23^{00}$ to 22.4 $03^{10}$ three spectrograms were taken from altitudes of the order of 400–500 km from very long rays, the heights of which were measured by Störmer. No difference between the three spectrograms was to be seen as regards degree of exposure and distribution of bands and lines with the exception of the $H_\beta$-line intensities. While the 1st and 3rd spectrograms showed the $H_\beta$-line very distinctly, it was not to be seen on the 2nd spectrogram. The only reasonable explanation of the absence of $H_\beta$ is that the 2nd spectrogram corresponds to such a great altitude that the relative number of protons which had picked up an electron was too small to give a noticeable H-line emission. The proton-excitation is about the same, but the rate of H-line emission is different.

The enhancement of certain lines on the spectrograms with intensive OI-doublet

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Table

| λ |
|---|
| 3914O |
| 3997O |
| 4043X |
| 4059O |
| 4073X |
| 4074X |
| 4076X |
| 4175O |
| 4184X |
| 4191X |
| 4200O |
| 4239O |
| 4278O |
| 4320O |
| 4339O |
| 4344O |
| 4351O |

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