THEORY AND OBSERVATIONS OF THE ENHANCEMENT OF AURORAL HYDROGEN LINES WITH INCREASING DISTANCE FROM THE MAGNETIC AXIS POINT

BY

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(Manuscript received March 18th, 1954).

§ 1. Historical Remarks.

The Birkeland-Størmer theory of aurora and magnetic disturbances was based on the hypothesis that limited bundles of electric rays are sent out from the sunspot regions. When such a bundle sweeps near the earth its path will be controlled by the magnetic field of the earth. Under certain conditions part of the bundle may enter into the higher strata of the atmosphere and produce aurorae, and other parts produce magnetic disturbances.

It was shown experimentally by Birkeland and mathematically by Størmer, that the electric particles of a homogeneous bundle could only enter the atmosphere in a circle (or rather part of a spiral) round the magnetic axispoint as a centre. In this way the Birkeland hypothesis explained the existence of the auroral zone.

In fact it would account for the essential features of the aurorae, regarding their abrupt appearance and disappearance, the great variability and rapid motions, their peculiar forms and structures, their distribution with regard to space and time and their relation to solar activity.

Birkeland considers the solar bundles as composed of cathode rays (electrons) and Størmer's theory is based on the calculation of the orbits of a single electrified particle under the influence of the magnetic field of the earth.

Størmer's theory was applicable to any type of an electrically charged particle, and he found that *the angular distance from the magnetic axis to the point where the ray entered the atmosphere (or the «radius» of the auroral zone) increased with the magnetic stiffness of the electric particle.*

In this connection it is of interest to notice that ordinary cathode rays or β-rays gave a much too small radius of the auroral zone. To give a radius equal to that of the auroral zone, rays with a magnetic stiffness at least as large as that of α-rays would be required.

The Birkeland hypothesis was criticized by Schuster (1) who pointed out that limited bundles of rays composed of particles of the same charge could not be stable on account of the mutual electrostatic repulsion. These difficulties were dealt with in a paper by Vegard (2), who found that the difficulty might be overcome by assuming the bundle to be electrostatically neutralized.

From a study of the intensity distribution along the auroral streamers correlated with height measurements, Vegard (3) found that the solar ray bundles had to be dominated by rapidly moving electrons, electrostatically neutralized by positive ions — preferably protons.

In order to reach down to a height of about 100 km, which is usually found for the lower limit of an aurora at high latitudes, the electrons need only a velocity corresponding to about 10,000 electron volts. According to Størmer an electron of such a small energy, hits the earth at a distance of merely about 2° from the magnetic axis. In order to explain that a bundle mainly dominated by electrons can give the right radius of the auroral zone of about 20°, some effects other than those entering in the equations of Størmer must play an important part in the motion of the solar ray bundles.

From the studies of the aurorae and the auroral spectrum Vegard (3, 4, 5) showed that the auroral region extended to altitudes of say 1000 km. Such a slow rate of diminution of the density with increasing altitude, he explained as the result of photo-electric effect of a soft *X*-radiation from the sun.

The theory of the coronal structure of the auroral region was applied to the solar corona and to the formation of the solar ray bundles, which produce aurorae and magnetic disturbances (4, 5, 6, 7, 8, 9, 10).

In paper 5, p. 34, 35 the formation of the ray bundles from the sunspot regions is explained by assuming *that highly ionised matter from deep layers are brought up to the* surface layer through a pumping effect connected to the *vortex motion.* Through the recombination process *X*-rays of considerably greater photon energy than those producing the coronal structures, are emitted. Positive ions preferably those combining great abundance with the greatest specific charge — first of all protons — will follow in the track of the electrons and neutralize the bundle. «This constitution of the auroral ray bundles would have a great influence on the auroral theory and especially on the track followed by the ray bundles under the influence of the magnetic field of the earth. The attachment of positive particles to the cathode rays would very much reduce the effective specific charge of the whole bundle, and thus we might explain *that fairly slow cathode rays with the proper penetrating power, might still have their magnetic deviability so much reduced as to give a diameter of the auroral zone equal to that observed.*»[1]

The constitution of the solar ray bundles and its consequences were further treated by Vegard in the two monographs Nos. 8 and 10, where it was shown that the current density (i) of a ray bundle formed by electrons of velocity V_e and neutralized by protons of velocity V_p is expressed by the simple equation:

$$i = n\varepsilon\,(V_e - V_p) \qquad (1)$$

where (n) is the number of electrons or protons pro cm^3, and ε the charge of each particle.

It was pointed out (10 p. 612), that the solar bundles had the same constitution as the well known long narrow electron ray bundles produced in a vacuum tube, where the electrons are neutralized by positive ions and also prevented from spreading through the mutual electromagnetic atraction between the filaments of the bundle.

§ 2. Detection of Hydrogen Lines and their Doppler Displacement in the Auroral Luminescence.

The constitution of the solar ray bundles proposed by Vegard was confirmed, when in 1939 he found that at Oslo the lines H_α and H_β of Hydrogen appeared with great intensity in the auroral luminiscence while they usually were too weak to be observed, showing that, occasionally, Hydrogen showers from the sun entered into the higher atmosphere (11).

Spectrograms obtained at Tromsø 1940—41, with a spectrograph of much greater dispersion showed the H_β -line, which was broadened and also some times displaced towards shorter waves through Doppler effect (cfr. papers 12, 13, 14, 15, 16).

With a spectrograph designed by Vegard combining a fairly high light power with a considerable dispersion, a succesful spectrogram was obtained at Oslo during the night Feb. 23—24, 1950. Besides giving numerous sharp lines and bands, it showed the H_β-line broadened and displaced through Doppler effect. Preliminary results were published by Vegard in C. R. of the French Academy, in Nature and in Ann. d. geophys, (17). A more complete account of the results was given by Vegard and Kvifte in Geof. Publ. (18).

The detection of the Doppler displacement of the auroral hydrogen lines, and its consequences has been dealt with in a paper by Vegard (21). From aurorae appearing in August 1950, spectrograms were taken by Gartlein (19) and by Meinel (20) showing the H_α -line with Doppler displacement in good agreement with that found by Vegard from spectrograms taken at Tromsø 1940—41 and at Oslo in Feb. 1950.

In the summer 1950 the new spectrograph was put up at the Auroral Observatory, Trømsø,

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[1] The quotation is from paper 5, p. 35.

and during the following winters a number of Hydrogen lines with Doppler effect have been obtained and studied. The results from the winter 1950/1951 were given in reports by Vegard (22) and a more complete account was given in a paper by Vegard and Tønsberg (23).

The Doppler effect of the auroral hydrogen lines and the great variability of their intensity are simple consequences of the constitution of the solar ray bundles just described. The observational facts show that the electric bundles, besides electrons, which have velocities of the order of 10^{10} cm/sec., contain protons with maximum velocities up to at least 2.5 10^8 cm/sec.

According to Vegard, the bundle may also contain other positive ions, which most probably are highly ionised. Thus he assumes that the sodium present in the upper atmosphere comes from the sun as part of the positive ions in the solar ray bundles. The fact that the sodium lines, even in the auroral luminescence, appear sharp without Doppler displacement, may only mean that the sodium lines emitted in the highly ionised state, have wave-length values too small to be observed.

§ 3. The Constitution of the Solar Ray Bundles and the Theory of Aurora and Magnetic Disturbances.

As already indicated the Birkeland-Størmer theory of aurorae and magnetic disturbances can — with certain modifications — be applied to limited solar ray bundles composed of rapidly moving electrons and neutralized by positive ions. (Compare papers 5, 8, 10). These questions have recently been more completely treated by Vegard (21, 22, 24).

It was shown in these papers, that a neutral electron — proton bundle leads to the following relations:

$$\nu_e = n\, V_e$$

$$\nu_p = n\, V_p \qquad (2)$$

$$\nu_p/\nu_e = V_p/V_e \qquad (3)$$

where ν_e and ν_p are the number of electrons and protons, which in unit time passes through unit cross section perpendicular to the direction of the auroral streamers, which near the earth means perpendicular to the magnetic lines of force.

Now the relative intensity of the auroral hydrogen lines increases with the ratio ν_p/ν_e, which is equal to the ratio of the velocities V_p/V_e, Thus the great variability of the intensities of the auroral hydrogen *is simply due to changes of the proton velocity relative to that of the electrons.*

The current density of the bundle is given by equation (1). As V_e is always much greater than V_p, the current density (i) is dominated by the moving electrons, and the bundle — although electrostatically neutralized — is magnetically active. It creates a magnetic field and in accordance with Birkeland, the most prominent magnetic disturbances can be explained as primarily caused by the magnetic fields of the solar ray bundles.

The force (K) acting on unit volume of the bundle in a magnetic field of intensity F, can be approximately expressed by an equation of the form:

$$K = \varepsilon n\,(V_e - V_p)\, F \cdot \sin\varphi = i\, F \sin\varphi \qquad (4)$$

where φ is the angle between F and the direction of the ray bundle.

The exact treatment of the problem of finding the path of a neutralized bundle in the magnetic field of the earth, seems to be very complicated, but as the bundle must remain electro statically neutral, the protons and the electrons must on an average keep together and according to Vegard (8, 10, 21, 22, 24, 26) «the theory of Birkeland and Størmer may be applied to the neutralized bundle and the merits of their theory in explaining the typical features of aurorae and magnetic storms can be transferred to the neutralized bundles.» And it is evident that *the magnetic stiffness of the bundle will increase with increasing velocity of the protons.*

If the electrons and protons were moving independently in a homogeneous magnetic field perpendicular to the lines of force, the following relation holds:

$$\varrho_p/\varrho_e = \frac{m_p}{m_e} \cdot \frac{V_p}{V_e} = 1800\, \frac{V_p}{V_e} \qquad (5)$$

ϱ_p and ϱ_e is the radius of curvature of the proton and electron orbits respectively.

For most aurorae (V_e) is of the order 2.10^{10} cm/sec. Then it follows from equation (5) that $\varrho_p > \varrho_e$ for proton velocities greater than about 10^7 cm/sec. If eg. $V_p = 3 \cdot 10^8$ cm/sec., ϱ_p would be 27 times ϱ_e.

The theory of Størmer, however, cannot be used for a quantitative determination of the increase of the radius of the auroral zone with increase of V_p (or ϱ_p); but it is legitimate to assume that the angular distance from the magnetic axis to the point where the bundle strikes the atmosphere, increases with increase of proton velocity.

On the other hand ,the increase of V_p/V_e means increase of the relative intensity of the auroral hydrogen lines, which therefore should increase towards lower latitudes.

This effect has been dealt with by one of us in some previous papers (21, 24, 26) where the relative intensities of the H_β -line obtained on spectrograms at Oslo were compared with those obtained at Tromsø mostly during the period from 1939—1943.

The intensity of H_β was measured relative to that of the neg. nitrogen band 4709. The mean value of $I(H_\beta/4709)$ calculated from 13 strongly exposed Oslo spectrograms, was found to be 6—7 times greater than the corresponding mean from 12 Tromsø spectrograms.

§ 4. Continued Observations of the Relative Intensities of H$_\beta$ at Oslo and Tromsø.

Even at the same locality the relative intensity of the auroral hydrogen line is subject to great variation. This means that great relative proton influx is only one of several other circumstances which drive the aurora towards lower latitudes. This may e.g. also be effected by the current systems producing strong magnetic disturbances (paper 10 p. 616).

As pointed out by Vegard (21) the relative intensity of the auroral H-lines may also vary with altitude, because the protons are more easily observed than the electrons. Futhermore, it may change during the development of an auroral display.

The problem of finding a possible variation of the relative intensity of the hydrogen lines with latitude is therefore essentially a statistical one.

By these investigations two different procedures might come into consideration:

1. Comparable auroral spectrograms might be taken at two stations situated near the same meridian, but with a suitable differance of latitudes.
2. Spectrograms are taken at the same station with a spectrograph of great light power and observed in different directions.

Knowing the height of the aurora we can calculate the auroral latitude corresponding to each spectrogram.

Finally the possible intensity of the H-lines on spectrograms from the northern sky should be compared with those from the southern one.

Work along these lines has for some time been going on at the Tromsø Observatory, and some results were recently published by one of us (25).

In the present paper we are only concerned with observations carried out in accordance with the procedure (1).

For this purpose we have at our disposal two practically identical spectrographs. One, (a) is used at Oslo, the other, (α), at Tromsø. The optical parts are as nearly as possible identical in quality and geometry and care is taken that always the same width of the slit is used at both stations. These small spectrographs are described in paper (7), and there illustrated in figs. 3 and 4 p. 9.

On account of the small dispersion the relative intensity of the auroral hydrogen spectrum must be measured by means of H_β , and we have found it convenient to express the intensity of H_β in relation to that of the negative nitrogen band 4709 Å.

It is therefore essential that the spectrograms are fairly heavily exposed, so the band 4709 appears very distinctly. This is most important because as a rule H_β — especially at Tromsø — is very weak compared with the band 4709.

To obtain suitable spectrograms fairly long exposures will be wanted with these two spectrographs. *In this way each spectrogram will in a way give an average relative intensity of* H_β *for all the aurorae, which have appeared during the exposure.* Thus the variability of the H_β-intensity at each station should be partly eliminated, so the average intensity difference at the two stations should be due to difference of latitude.

The H_β-line has also been obtained on spectrograms taken with somewhat larger glass spectrographs. One of them indicated by (C) was used at Oslo and a somewhat larger one (B) was used at Tromsø. Although we can measure the relative intensity of H_{β}, the results obtained with different types of spectrographs are not quite comparable. The measured relative intensity will e.g. depend on the dispersion and the slit opening.

As the variation of H_{β} with latitude is very considerable, we have also included the results obtained with the spectrographs (C) and (B), because the errors due to differences of dispersion and slit-width are small as compared with the changes due to differences of latitude.

The spectrograms have been divided into two groups:

a. Those obtained during the years 1939—50. These are reproduced in earlier publications and are not reproduced in this paper.
b. Spectrograms obtained during the winter 1952—53. Enlarged copies of these are reproduced on the plate.

The columns A and B on the plate contain Oslo spectrograms from spectrograph (C) and (a) respectively. The last column contains the Tromsø spectrograms taken with spectrograph (α).

The data regarding exposure, direction, type of aurorae will be found in the «Explanation to the Plate» at the end of this paper.

The spectrograms in the two last columns, which were taken with identical spectrographs and on the same sort of photographic plates, are comparable. *In spite of the heavy exposures of the Tromsø spectrograms, only 3 out of 11 show the H_{β}-line.*

The 7 corresponding Oslo spectrograms (column B) all show the H_{β}-line. On spectrogram No. 5 it is too faint to be measured.

On all Oslo spectrograms in column A taken with spectrograph (C) the H_{β}-line appears with measurable intensity.

For each spectrogram showing the H_{β}-line we have by means of a Moll photometer measured the intensity of H_{β} and the band 4709 and computed the intensity ratio I (H_{β}/4709). If the H_{β}-line is too weak to be observed or measured, we have estimated an upper limit for the ratio I (H_{β}/4709).

The results are given in the tables 1, 2, 3, 4, corresponding to the 4 spectrographs used, (a), (C), (α), and (B).

The tables 1a, 2a, 3a, and 4a give results of the old material.

The tables 1b, 2b and 3b give the results of observations from the winter 1952/53.

Tables 1—4.

The intensity of H_{β} relative to that of the band 4709, I (H_{β}/4709) at Oslo with spectrographs (a) and (C), at Tromsø with spectrographs (α) and (B).

Oslo: Spectrograph (a).

Table 1a.

Group 1: Spectrograms from 1939/40		
Date	Time of exposure	I (H_{β}/4709)
18.10.1939	19.16 — 20.13	1.94
6.12. »	22.05 — 24.05	0.84
3. 1.1940	18.35 — 20.35	0.91
3. 1. »	20.35 — 22.00	1.12
Mean Group 1 at Oslo		1.20

Table 1b

Pl. No. Column B	Group 2: Spectrograms from 1952/53		
	Date	Time of exposure	I (H_{β}/4709)
1	12.9. 1952	3 h. 50 m.	0.58
2	28-29.9. »	5 » 40 »	0.51
3	29-30.9. »	3 » 20 »	0.31
4	8-9.3. 1953	0 » 45 » u	1.05
5	»	0 » 38 » 1	H_{β} weak
6	»	1 » 14 » 1	0.40
7	»	1 » 58 »	0.20
Mean of Group 2 (spectr. a) Oslo			0.51

Oslo: Spectrograph (C)

Table 2a.

Group 1. Spectrograms from 1941—43.		
Date	Time of exposure	I (H_{β}-/4709)
18.9. 1941	21.30 — 23.35	0.46
18-19.9. »	23.35 — 01.30	(<0.65)
19.9. »	01.30 — 03.15	0.44
» »	03.15 — 04.15	(<0.25)
» »	20.47 — 21.48	(<0.25)
11.10. 1942	22.00 — 05.00	0.94
11.3. 1943	19.52 — 21.07	1.30
11-12.3. »	21.07 — 01.00	1.19
Mean Gr. 1 Spectr. C		< 0.68
Mean Gr. 1 Spectr. C measured only		0.87

Table 2b.

Pl. No. Column A	Group 2. Spectrograms from 1952/53		
	Date	Time of exposure	$I\ (H\beta/4709)$
1	29.9. 1952	3 h. 15 m.(u)	0.13
2	2.3. 1953	22.50—24.00	0.98
3	3.3. »	00.22—01.35	0.90
4	8-9.3. »	1 h. 28 m. (1)	0,14
5	8-9.3. »	0 » 25 » (u)	0.19
6	8-9.3. »	1 » 47 » (1)	0.87
7	8-9.3. »	1 » 58 »	0.76
8	9-10.3. »	1 » 45 » (1)	1.08
Mean Group 2 Sp.ms. at Oslo from 1952/53			0.63

Tromsø: Spectograph (α).

Table 3a.

Group 1. Spectrograms from 1940 and 1950		
Date	Time of exposure	$I\ (H\beta/4709)$
6.2. 1940	18.30 — 19.15	<0.15
7-8.2. »	19.00 — 02.30	<0.15
4.12. »	not given	<0.15
5.12. »	»	<0.15
14.1. 1950	2 h. 0 m.	0.20
15.1. »	1 h. 0 m.	0.27
Mean Group 1. Sp. (α) Tromsø		<0.18

Table 3b.

Pl. No. Column C	Group 2. Spectrograms from 1952/53		
	Date	Exposure	$I\ (H\beta/4709)$
1	3.10. 1952	4 h. 0 m.	<0.10
2	4.10. »	0 » 15 »	<0.10
3	15.10. »	1 » 14 »	<0.08
4	25.10. »	5 » 30 »	0.23
5	26.10. »	6 » 45 »	0.08
6	31.10. »	1 » 30 »	<0.11
7	7.11. »	2 » 0 »	<0.13
8	14.11. 1952— 8.1. 1953	2 » 30 »	0.13
9	13-14.1. »	3 » 25 »	<0.12
10	15-28.1. »	5 » 30 »	<0.09
11	29.1. »	2 » 0 »	<0.03
Mean Group 2. Spectrogr. (α) Tromsø			<0.11
Mean from 3 measurable $H\beta$ — lines			0.15

Tromsø. Spectrogram B.

Table 4.

From 1940 and 1941. Spectrograms published		
Date	Time of exposure	$I\ (H\beta/4709)$
6.2.-10.3. 1940	12 — 15 h.	0.17
21.10-26.10. »	30 »	0.15
28.11. 1940-16.1.41	16 »	0.15
21.1.-20.2. 1941	12 »	0.08
20.2.-4.4. »	ca. 21 »	0.06
14.10.-20.10. »	» 17 »	0.12
Mean from Spectrograph (B)		0.12

The mean values found from these tables for the groups of spectrograms are put up in tables 5a and 5b. The first of these contains results from the spectrograms taken with spectrographs (a) at Oslo and (α) at Tromsø.

Table 5b contains results derived from spectrograph (C) at Oslo tables 2a and 2b and (B) at Tromsø table 4.

(n) is the number of spectrograms of each group.

The last column gives the ratio between the mean value of $I\left(\frac{H\beta}{4709}\right)$ at Oslo and at Tromsø and is indicated by $I\left(\frac{H\beta \text{ Oslo}}{H\beta \text{ Tromsø}}\right)$.

Table 5a.

Oslo Spectr. (a)			Tromsø spectr. (α)			$I\left(\frac{H\beta \text{ Oslo}}{H\beta \text{ Tromsø}}\right)$
From Table	n	Mean $I\left(\frac{H\beta}{4709}\right)$	From Table	n	Mean $I\left(\frac{H\beta}{4709}\right)$	
1 a	4	1.20	3 a	6	<0.18	>6.7
1 b	6	0.51	3 b	11	<0.11	>4.7
Mean		0.79	Mean		<0.13	>6.1

Table 5b.

Oslo Spectr. (C)			Tromsø Spectr. (B)			$I\left(\frac{H\beta \text{ Oslo}}{H\beta \text{ Tromsø}}\right)$
From Table	n	Mean $I\left(\frac{H\beta}{4709}\right)$	From Table	n	Mean $I\left(\frac{H\beta}{4709}\right)$	
2 a	5	0.87	4	6	0.12	8.7
2 b	8	0.63				
Mean		0.72	Mean		0.12	6.0

The results from the present material show that the relative intensity of the hydrogen lines at Oslo is on an average more than 6 times greater than that at Tromsø.

An effect of this type is, as we saw, a consequence of the constitution found for the solar ray bundles which produce the aurora and magnetic disturbances. The increase of magnetic stiffness with increasing proton velocity, however, may not be the only cause of the enhancement of H-lines towards lower latitudes.

As mentioned above the aurorae are probably driven towards lower latitudes by the effect of the current systems which produce certain magnetic storms, and it is possible that the proton velocity on an average may increase with increasing violence of the solar outbursts.

How far effects of this kind may play a part in the latitude effect of the intensity of the H-lines, is a problem to be solved by further investigations.

In conclusion we wish to thank Mr. A. Omholt and Mr. A. Kyrkjeeide for able assistance in connection with the results dealt with in this paper, and Norges Almenvitenskapelige Forskningsråd for financial support of the auroral investigations.

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Feb. 1954.

LIST OF PAPERS

1. A. Schuster: Proc. Roy. Soc. 85, p. 44, 1911.
2. L. Vegard: Ann. de phys. IV 50, p. 853, 1916.
3 » Phil. Mag. 42, p. 47, 1921.
4. » Phil. Mag. 46, p. 193, 557, 1923.
5. » Det Norske Vid. Akad. Skr. I, No 2, 1928.
6. » Gerlands Beiträge z. Geophys. 32, p. 288, 1931.
7. » Geof. Publ. Oslo (G.P.) Vol. IX, No 11, 1932.
8. » Ergebnisse d. exakt. Nat. Wiss. Vol. 17, p. 229, 1938.
9. » G.P. Vol. XII, No 5, 1938.
10. » Phys. of the Earth. (Ed. by Fleming.) Vol. VIII, p. 573, 1939 (written 1933)
11. » Hydrogen Showers in the Auroral Region. Nature V, 144, p. 1089, 1939. — Terr. Magn. 1939. — G. P. Vol. XII, No 14, 1940.
12.L. Vegard and E. Tønsberg: G.P. Vol. XIII, No 5, 1941.
13. » G.P. Vol. XVI, No 2, 1944.
14. L. Vegard: Phys. Soc. Gassiot Comittee Report p. 82, 1948.
15. » Proc. of Meeting at Brussels of the Mixed Comm. on Ionosphere, July 1948, p. 111.
16. » Transactions of the Oslo Meeting of IUGG 1948, p. 189, 484.
17. » C.R. Vol. 230, p. 1884, May 1950. — Nature 165, p. 1012, June 1950. — Ann. d. Geophys. Vol 6, p. 157, 1950.
18. L. Vegard and G. Kvifte: G.P. Vol. XVIII, No 3, 1952.
19. C. W. Gartlein: Phys. Rev. Vol. 81, No 3, p. 463, 1951. — Nature 167, p. 277, 1951.
20. A. B. Meinel: Astr. Journ. Vol. 113, No 1, 1951.
21. L. Vegard: G.P. Vol. XVIII, No 5, 1952.
22. » Communication to the Congress of IUGG at Brussels 1951. Ann. de Geophys. T. 8, No 1, 1952.
23. L. Vegard and E. Tønsberg:G.P. Vol. XVIII, No 8, 1952.
24. L. Vegard: Proceed. of the 3rd Meeting of the Mixed Commission on the Ionosphere in Canberra (Australia), Aug. 1952, p. 135, Bruxelles 1952.
25. » Nature Vol. 170, p. 536, 1952.
26. » Nature Vol. 170, p. 1120, 1952.

EXPLANATION TO THE PLATE

Column A. From spectrograph C. Oslo. Plate Kodak 103a-C

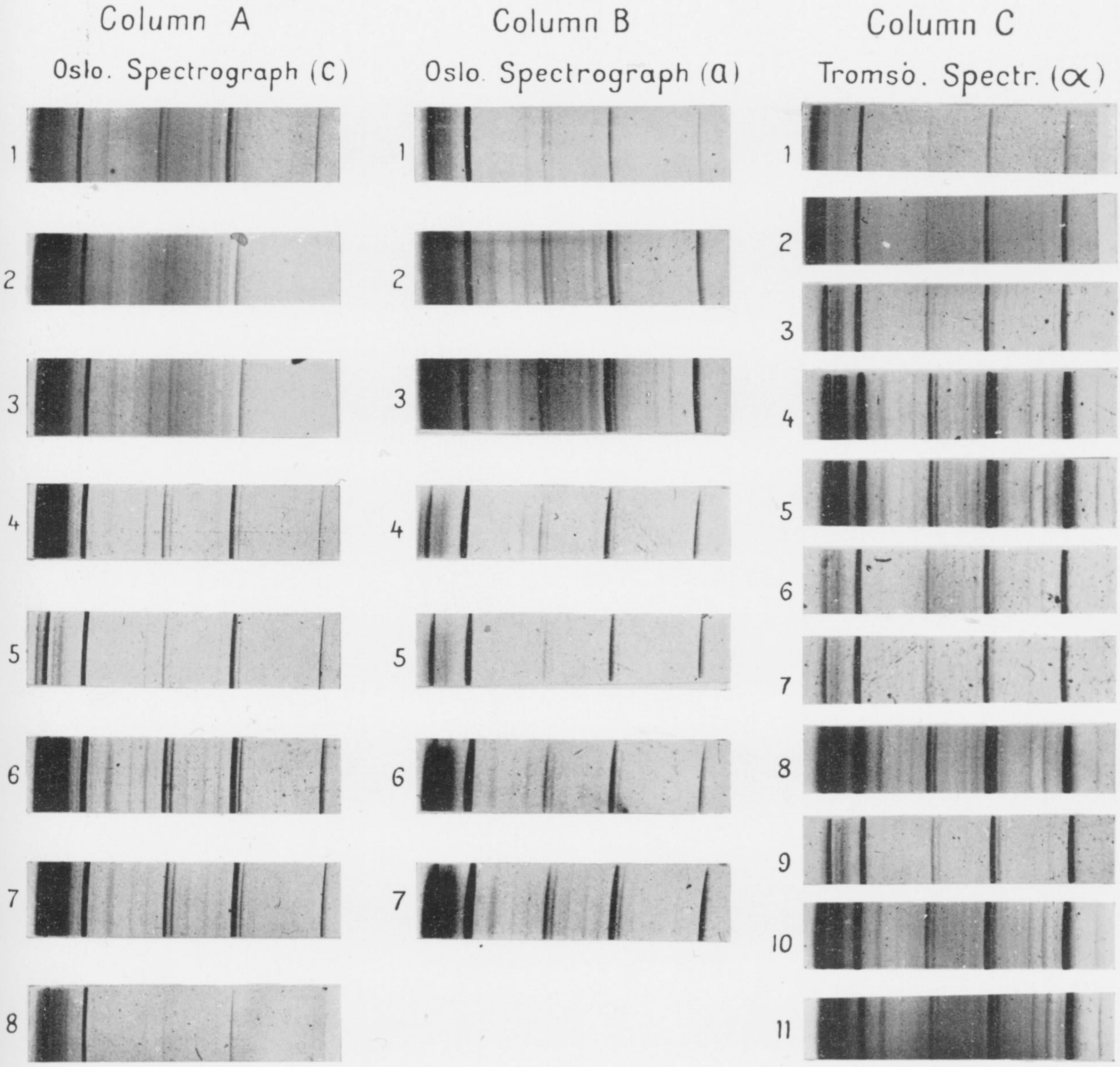
Spectr. No	Date of exposure	Exposure time	Remarks
1	29.9.1952	3h 15m	Upper limit of A. h: 19—24°
2	2.3. 22.50—24.00	1h 10m	A towards *N*, h:10°
3	2—3.3 0.22— 1.35	1h 15m	A towards *N*. *h*: 10°
4	8—9.3 21.27—22.55	1h 28m	Lower limit of *A*, towards *N*. h: 7-17°.
5	» 22.55—23.20	0h 25m	Upper limit of A, towards N. h: 30°.
6	8.3. 23.20—9.3.1.07	0h 47m	Bottom R. towards NNW.
7	9.3. 1.07— 3.05	1h 58m	A and some R low. border h: 13-32°.
8	9.3.53 20.15—22.00	1h 45m	Lower border of *A*.

Column B. From spectrograph (*a*) Oslo. Kodak 103a-C

Spectr. No	Date of exposure	Exposure time	Remarks
1	12.9.1952	3h 50m	Lower limit of A and D. h: ca. 15°.
2	28-29.9 20.55 –2.35	5h 40m	A and pulsating Aur. h: 10-30°
3	29-30.9 21.10—00.30	3h 20m	Middle of A. h: ca. 15°
4	8-9.3.53 22.30—23.15	0h 45m	Upper border of A. h. 22-30°
5	» 23.15—23.53	0h 38m	Bottom of R. h. ca. 30°
6	» 23.53—01.07	1h 14m	Lower border of A. h: ca. 10°
7	» 01.07—03.05	1h 58m	Middle of A. h: 15°—25°

Column C. From spectrograph (*a*) at Tromsø
No 1 and 2 taken on Kodak 103a-F, No 4-11 on Kodak 103a—C.

Spectr. No	Date of exposure	Exposure time	Remarks
1	3.10.52	4h00	Aur. towards N.
2	4.10. 19.15—19.30	0h 15m	Strong aur. towards N.
3	15.10.52	not give	Aur. towards N.W.
4	25.10 19.30—1.00	5h 30m	Aur. towards W. and N., partly strong
5	26.10 20.15—3.00	5h 45m	Aur. towards S and SW.
6	31.10 19.30—22.00	2h 30m	Aur towards E. and N., partly strong
7	7.11 21.00—23.00	2h 00	Aur. towards W., medium strength
8	14.11.52—8.1.53	2h 30m	Aur. towards N.
9	13—14.1.53	3h 00	Various forms and directions
10	15.1—28.1.53	5h 30m	Various forms mostly towards N.
11	29.1.53	2h 00	A. and D. near Z.


Column A
Oslo. Spectrograph (C)
1
2
3
4
5
6
7
8
Column B
Oslo. Spectrograph (a)
1
2
3
4
5
6
7
Column C
Tromsö. Spectr. (α)
1
2
3
4
5
6
7
8
9
10
11