STUDIES OF THE TWILIGHT SODIUM LINES FROM OBSERVATIONS AT OSLO AND TROMSØ, AND RESULTS OF AURORAL SPECTROGRAMS FROM OSLO

BY

L. VEGARD, G. KVIFTE, A. OMHOLT, AND S. LARSEN

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§ 1. Introductory Remarks.

The observations dealt with in this paper were carried out at Oslo and Tromsø from 1943 to 1952.

As regards aurorae this paper merely deals with some spectrograms, which were taken at Oslo from 1945—49 with a small glass spectrograph (*C*) (cfr. paper 16) of great light power, and which are reproduced on pl. VI and dealt with in chapter 2.

Most of the auroral material obtained during this period has already been treated and published in previous papers (1, 2, 3, 4, 5, 11).

The twilight observations consist essentially of series of spectrograms taken in accordance with Vegard's method on the determination of height and extension of the sodium layer mainly responsible for the great intensity of the yellow *D*-doublet in twilight (ref. 6 and 10). Thus the present paper is to be regarded as a continuation of previous papers, dealing with similar series of twilight observations started by Vegard at Oslo and Tromsø 1939. The results from Oslo up to the spring 1943 and from Tromsø up to 1946 were given in papers Nos. 6 to 11.

The present paper deals with observations at Oslo from 1943 to the spring 1949 and observations at Tromsø taken during the year 1952. The twilight spectrograms are reproduced on the plates I—V, and necessary data given in the explanation to the plates.

The Oslo Spectrograms (Pl. I—IV) were taken with spectrograph (C) (cfr. 8). Spectrograms (Pl. V) were taken at Tromsø with a new large Cojan spectrograph «Forcalquier» (*F*) from Societé Générale d'Optique, Paris, having the high light power (*F* : 0.65) (cfr. papers 18 and 12).

Chapter 1.

§ 2. Vegard's Twilight Method.

Vegard's method for the determination of the height and extension of the sodium layer mainly responsible for the enhancement of the yellow sodium line in twilight, has been dealt with in a number of previous papers (ref. Nos. 6, 7, 8, 9, 10, 11).

Recently Bricard and Kastler (12) raised objections to the Vegard method, but — as we are going to show — they are due to misinterpretations and are in fact directed upon a method which is not to be identified with that adopted by Vegard and collaborators.

R. Bernard observing at the Auroral Observatory, Tromsø, found that the yellow sodium line appeared with great intensity in twilight[1]. Following the effect as the twilight gradually faded, he found that the intensity of the sodium *D*-line kept nearly constant until it fairly abruptly dropped to a value of a lower order of magnitude.

The time τ at which this takes place is most essential for the study of the sodium distribution in the atmosphere and the excitation of the sodium *D*-line in twilight. *It does not fix a point of time when the D-intensity has become zero, but, as shown*

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[1] Twilight spectrograms showing the same effect were obtained by Vegard and Tønsberg at Tromsø Feb. 1936. (14)

in previous papers, it is to be fixed by means of the final fall of the time intensity curve (cfr. papers 7, 8).

For the sake of convenience, however, we call it the «time of disappearance» of the twilight *D*-emission.

Such a relation between intensity and time means that the predominent part of the sodium D-line emission in twilight is restricted to a layer below a certain altitude H_u and that the sodium radiation is excited by sunlight of some sort.

The height H_u is related to the «time of disappearance» τ by the condition that the effective shadow passes the height H_u in the direction of observation at the time of disappearance.

This holds independent of the direction in which we examine the fading of the twilight and the D-emission in order to determine the time τ. The absolute *D*-intensity will increase with increasing zenith distance of the collimator of our instrument, but still the time τ determined in the way described, will give the time when the shadow border passes the height H_u.

In 1938 Vegard proposed to study the distribution of the atmospheric sodium layer mainly responsible for the twilight *D*-line emission by observing during the same evening two sets of intensity-time curves as the twilight phenomenon passed across the sky from east to west. This gives two values of the time τ corresponding to different directions. For the sake of convenience and simplicity of treatment, one series of observations was taken towards zenith and one near the horizon in the azimuth plane of the sun. This selection of directions is not essential to the method and it is therefore not right as done by Bricard and Kastler to call it the «zenith-horizon» method. The general case of two arbitrary directions has been treated by Kvifte (15) who has also discussed the influence on the results of possible errors of observations corresponding to the different ways in which the two directions are chosen.

Observations were commenced at Oslo and Tromsø at the beginning of 1939.

On the assumption that the effective shadow was cast by the solid earth, Bernhard (13) found H_u equal to about 60 km, which would mean that the twilight sodium *D*-emission should be mainly restricted to a layer below 60 km.

Assuming that the surface of the earth gives the effective shadow, it was found that the zenith observations resulting in the «time of disappearanse» τ_z gave a considerably smaller value of H_u than the time τ_h, derived from the observations from near the horizon.

Now there is no reason to believe that H_u *always* varies in such a way in the short time between the two series of observations. The only reasonable interpretation of this fact is that H_u remains essentially the same, and that the effective exciting solar radiation is absorbed by the lower layer of the atmosphere up to a height H_s.

This means that the shadow of the effective solar radiation is cast by a sphere of radius $(R + H_s)$ where R is the radius of the earth. H_s is called the screening height.

This interpretation, however, does not involve that the absorption of the effective rays suddenly stops at a definite height H_s', but on account of the probably rapid fall of concentration of the absorbing substance with increasing height, the thickness of the layer between practically total absorption and total transparency, is probably small as compared with the screening height H_s.

The value we obtain for H_u for given values of τ_z and τ_h is a function of the screen height H_s, and the value of H_u increases with increase of H_s, but more rapidly at zenith than near the horizon, and the true values of H_u and H_s are found by the condition that the true screening height gives the same value of H_u for both directions of observation.

The results from the Oslo observations giving the values of H_u and H_s in this way, were first published in a letter to Nature (6). A more complete account of the observations at Oslo and Tromsø, taken during the spring 1939, was given in a paper by Vegard and Tønsberg (7). These first values of H_u and H_s were found by means of a partly graphical method. In a later publication by Vegard and Kvifte (8), we developed suitable formulae for direct calculations of H_u and H_s.

In a letter to Nature, Vegard (10) announced a procedure for estimating the thickness of the sodium layer mainly responsible for the strong sodium emission in twilight. This method is based on the following simple interpretation of the time-intensity curve of the *D*-emission.

During the time the D-line intensity keeps nearly constant, the whole sodium layer is illuminated by the active solar rays. At the moment, when the intensity begins to drop, the shadow of the screening sphere $(R + H_s)$ just touches the lower part of the sodium layer at a height H_l, and passes away from the layer at the time τ and a height H_u. The thickness $\Delta H_u = H_u - H_l$ was calculated from the zenith observations, which were chosen because zenith observations give the simpler formula for calculation.

The values of ΔH_u given in Nature were derived from Oslo spectrograms from 1942—43 (20 zenith series) and varied between 8.4 and 27.6 km, with a mean of 16.2. Values of ΔH_u from Tromsø observations were given in a paper by Vegard, Tønsberg and Kvifte (16). A series from 1942 gave a mean value of 30 km and those from 1943 gave 25 km.

As already mentioned, the screening must take place in a certain height interval $\Delta H_s = (H_s)_o - (H_s)_t$ where $(H_s)_o$ is the height where noticeable absorption of the effective solar radiation sets in and $(H_s)_t$, the height where approximately total absorption sets in. The existence of an interval of partial absorption will have the effect of reducing the thickness of the sodium layer when it is calculated in the way described. (Cf. Kvifte 20). The thickness found in the way proposed by Vegard should thus give an upper limit of the thickness.

As the absorbing matter decreases very rapidly with increasing height, calculations carried out on the assumption of a sharp screening surface ought to give a fairly good approximation, and we have merely to consider the screening height H_s as a kind of effective mean value within a fairly small interval ΔH_s.

§ 3. The Formulae for Calculating H_u, H_s and and $\Delta H_u = H_u - H_l$ in accordance with the Vegard Method.

The first system of formulae for calculating H_u and H_s were given in the paper by Vegard and Kvifte already referred to (8). In his general treatment of the Vegard method, Kvifte (15) developed formulae for calculating H_u and H_s for two arbitrary directions of observation, and specializing these for one direction towards zenith and one in the sun's azimuth plane and at an elevation angle (α), the formulae take the following form which was adopted in paper (16) already referred to.

$$H_u = R\left(\frac{\cos\alpha}{\cos(\alpha - \beta_1 + \beta_2)}\right) - 1 \qquad (1)$$
$$H_s = R\left(\frac{\cos\alpha\cos\beta_1}{\cos(\alpha - \beta_1 + \beta_2)}\right) - 1$$

β_1 and β_2 are the depression angles of the sun for the zenith and «horizon» observations respectively, and they are found from the points of time of «disapperance» of the twilight sodium effect τ_z and τ_h by the following formula:

$$-\sin\beta = \sin\delta\sin\varphi + \cos\delta\cos\varphi\cos\vartheta \qquad (2)$$

φ is geographical latitude, δ the sun's declination. ϑ is the hour angle of the sun at the moment τ (G.M.T.) and is found by the equation:

$$\vartheta = 15\,(\tau + \Delta - 12) + \lambda \qquad (3)$$

λ is the longitude (E.Gr.) of the spot of observation and Δ the time equation taken from «The Nautical Almanac».

According to Vegard, an upper limit of the thickness ΔH_u of the sodium layer is found from the eqation:

$$\Delta H_u = (R + H_s)\cos\varphi\cos\delta\,\mathrm{tg}\,\beta_1,\ \sec\beta_1\sin\vartheta\,\Delta\vartheta \qquad (4)$$

where $\Delta\vartheta$ is the time difference $(\tau_b - \tau_z)$ (in angular measure) where τ_b is the point of time when the time-intensity curve starts falling somewhat rapidly, and τ_z is the so-called «time of disappearance» of the twilight sodium D-line effect.

The equations 1—4 will be used by the deduction of results from the twilight spectrograms dealt with in this paper.

§ 4. Discussion of the Method.

The problem of determining the distribution of sodium in the atmosphere is a very complex one. By the emission of the sodium D-line, we have to deal with three different types of excitation processes. The emission which we observe during twilight is produced by some effective parts of the sunlight and originates mainly from the lower part of the sodium layer. A second emission appears in the night sky-luminescence and is excited by atmospheric systems, which have drawn their activating energy from the solar radiation on the day side of the earth. This emission originates from minute quantities of sodium present at altitudes up to several hundred kilometers.

Finally, the sodium D-line appears in the auroral luminescence (ref. 7, 17, 18, 19, 8) and is excited by corpuscular solar radiation mainly entering the atmosphere during the night. *In this case the sodium light is emitted from a layer starting from the lower border of the auroral streamers usually at altitudes from 80—110 km, and upwards until the sodium gradually vanishes.*

The object of the Vegard method is to give information regarding the sodium distribution from the D-line emission which is produced by sunlight and which originates from the entire atmospheric sodium layer from a lower level H_l to the extreme upper limit, where the sodium gradually disappears at altitudes of some hundred km.

Any method of determining the sodium distribution from the excitation by sunlight, must be based on the observation of the way in which the D-emission varies, when during twilight the sodium layer is gradually screened more and more from the effective solar radiation; in other words on the observation of the time-intensity curve of the D-emission in twilight.

Now, as previously mentioned, the form of the time-intensity curve shows that the *dominating* part of the atmospheric sodium is to be found below a certain altitude H_u, which is clearly indicated by the fact that the intensity falls to a value which is of a lower order of magnitude as compared with the maximum intensity.

When the shadow of the screening sphere just covers the sodium *below* H_u, the sodium layer *above* H_u — covering a height interval of several hundred km — is still under the influence of the effective solar radiation. But still the total effect of the D-emission from the extensive layer is practically negligible as compared with the maximum intensity of the D-line during twilight. Now the Vegard method postulates that we can determine the height H_u, which is experimentally defined by the time-intensity curve by neglecting this small intensity which is left when the shadow-line has passed the height H_u.

This only means that we neglect effects of a smaller order of magnitude than those considered.

By applying this method it is essential to have good weather conditions with a clear cloudless sky without haziness. *It is further important that the twilight time-intensity curve near the zero point is not disturbed by sodium D-line-emissions due to the other types of excitation.* The D-line emission from the ordinary night glow is very weak as compared with the maximum intensity during twilight, and as it usually keeps fairly constant, it will not have any serious influence on the determination of the «time of disappearance» τ.

The aurorae, however, which often are relatively strong and variable may have a great disturbing influence on the time-intensity curve, and prevent a reliable determination of the «time of disappearance». *The aurora may even come down below the height H_u, where the sodium concentration rapidly increases downwards, and the D-intensity of aurorae may be of the same order of magnitude as that of twilight.*

When taking the observational series to be used for determining the sodium distribution by the Vegard method, we must avoid the presence of aurorae, which will be marked by the appearance of the green and red OI lines 5577, 6300 and 6364 on the spectrograms.

At Oslo where the auroral frequency is small there will be good opportunities for getting observational series free from auroral sodium emission.

At Tromsø, however, the auroral freqency is so great, that is it only on rare occasions that the two successive series of spectrograms can be taken without being disturbed by auroral luminescence. As a rule the auroral frequency in the evening increases with time, *and the disturbing influence will as a rule be greater for the horizon.*

Under favourable conditions the declining part of the time-intensity curve — for both the zenith and horizon series — is sufficiently straight to fix the moment τ by an approximately linear extrapolation to intersection with the time axis.

In order to see how far the results might be influenced by neglecting the small D-intensity above the altitude H_u, we might express the intensities relative to the maximum for the z- and the h-series, and instead of extrapolating to the time axis ($I = o$), we might determine the moments τ_z^1 and τ_h^1 by the points of intersection between the declining part of the time-intensity curve and a line situated at a distance (ΔI) from the axis, where the (ΔI) is the intensity left after the rapid fall of the intensity curve. This procedure might e.g., be useful, if the twilight spectrograms indicate the presence of faint auroral luminescence.

As already stated, the moments τ will — *independent of the elevation angle of the instrument* — indicate the moment when the shadow line just passes the height H_u. The absolute intensity of the D-line is a function of the zenith distance Z of the direction of the collimator, and as Z is constant for the same series of observations, *all intensities of the series are increased in the same proportion and the greater intensity will not influence the position of the zeropoint* τ.

Thus the Vegard method is based on the fact that the moments τ_z and τ_h fix an approximate upper limit H_u, which is supposed to keep constant during the time (of about 1 hour) which it takes to observe the intensity variation in the zenith direction near the horizon.

The critique by Bricard and Kastler (12) is, on the other hand, based on *essentially* different assumptions. They regard the small D-line intensity (I_A) left by the zenith observations at the time τ_z when the shadow line cuts the vertical line at a certain height H_A. Then they calculate the intensity (I_B) above the height H_B, where the new line of observation cuts the shadow line for a zenith distance Z at the time τ_h. By assuming that the times τ are fixed by the disappearance of the D-line *on the photographic plate* of the twilight spectral series, they put up the condition:

$$I_A - I_B = E \tag{5}$$

where E is the intensity threshold value of the photographic plate. From condition (5) and certain idealized assumptions on the sodium distribution and atmospheric conditions, they mean to show that the Vegard method gives systematically too high values for H_z and H_u.

This conclusion is, however, not justified. *Condition (5) has no connection with the Vegard method because it is based on wrong assumptions regarding the disappearance times* τ. As previously mentioned, τ_z and τ_h are actually fixed by extrapolation from intensity-time curves *and are totally independent of any absolute intensives, the threshold plate value included.*

We might point out that the formulae (1) —(4), which result from the Vegard method, do not contain any intensity quantities, but merely measurable angles and the points of time τ_z and τ_h which are directly derived from observed facts, and no definite law with regard to the distribution of sodium with altitude is used.

Kvifte (20) has recently discussed condition (5) in greater detail. He has computed the intensity integrals by taking into account scattered light and atmospheric extinction which were neglected by Bricard and Kastler. By further taking into account the available experimental data, he finds that condition (5) does not lead to any definite conclusions regarding the correctness of the values of H_s and H_u found by the Vegard method.

The Vegard method is still to be regarded as the only one which enable us by twiligt observations to determine some essential features regarding the way in which the predominant part of sodium is distributed in the atmosphere below the height H_u and to fix approximately the effective screening height which again gives information of the effective solar radiation. The sodium distribution above H_u must be studied by other methods e.g., by utilizing the knowledge gained from the aurorae and the air glow luminescence.

It is of course not essential for the application of the Vegard method that the time-intensity curve is determined by means of spectrograms. An instrument which could indicate the instantaneous value of the intensity would naturally have advantages.

The spectrographic method gives only mean values over the time of exposure, but in a previous paper (8) we have described procedures for calculating the time fairly accurately from series of spectrograms.

§ 5. The Height Measurements at Oslo.

a. *Zenith-horizon Series.*

During the years from 1943 to 1949 observations were carried out successfully on 38 nights at Oslo. The spectral series needed for the determination of τ_z and τ_h were taken with a prism spectrograph (C). It has an Astro Camera lens $F : 0.95$ with focal length $f = 7.5$ cm, and is installed in a wooden case with a thermostate. The horizontal slit of the spectrograph was kept fairly wide and the same for all series. A picture of the sky could be cast on the slit by means of a lens, thus ensuring a good definition of the

Table 1.
Values of H_s, H_u and ΔH_u Derived from Twilight Observations at Oslo

Date	Zenith		Horizon			H_s km	H_u km	Δt min	ΔH_u km
	τ_1 (MET)	β_1°	τ_2 (MET)	β_2°	α°				
22.9. 43			20 01	12.88	10.5				
7.10.43	18.36	8.47	19.11	12.84	10.5	37.8	108.4		
Mean 1943		8.47		12.86	10.5	(38.2)	(109.0)		
						37.8	108.4		
24 1.44	17 16	8.05	17.51	12.17	10.5	37.4	101.1		
5.3.46	18.53	8.28	19.29	12.67	10.5	41.6	109.0	18	35
14 3. »	19.12	7.93	19.47	12.25	10.5	45.0	106.9	16	31
17.3. »	19.20	7 91	19.56	12 30	10 5	47.4	109.0	17	33
21.3. »	19.35	8.47						16	31
22.3. »			20.11	12.47	10.5				
23.3. »	19.38 5	8.30	20.13	12 38	10.5	32.3	100.0	16	30
Mean 1946		8.18		12.41	10.5	(38 5)	(104.2)		
						41.6	106.2		32
8.11.48	17 08	7.97	17.42	12.10	10.7	40.5	103 1	11	21
11.11. »	17.03.5	8.10	17.38	12.28	10.7	40.0	104.5	11	20
22.11. »	16.43.5	8.00	17.23	12.50	10.0	44 6	107.6	13	23
Mean 1948		8.02		12.29	10.5	(42.2)	(105.4)		
						41.7	105.1		21
24.1.49	17.17	8.00	17.52.5	12.10	10.7	39.3	102.2	18	32
31.1. »	17.32.5	7.87	18.10.5	12.47	10.7	56.2	117.1	19	35
22.2. »	18.26.5	8.30						19	37
25.2. »	18.34	8.23	19 08.5	12.58	10.7	42.9	109.6	18	36
28.2. »	18.41.5	8.29	19.16	12.60	10.7	40.7	108.3	17	34
1 3. »	18.44 5	8.36	19.20	12.79	10.7	43.1	112.0	14	28
2.3. »	18.47	8.38	19.22	12.74	10.7	40 7	109.9	12	24
4.3. »	18.50.5	8.30	19.27.5	12.70	10 7	46.2	114.1	11	22
10.3. »	19.06	8.37	19.41.5	12.72	10.7	40.7	109.6	13	26
17.3. »	19 24	8.34	20.01	12.79	10 7	44.1	112.6	18	34
18.3. »	19.27.5	8.47	20.05	12.94	10.7	42.6	113 2	16	31
22.3. »	19.37	8.38	20 15	12.90	10.7	45.5	114.7	16	30
25 3. »	19.43.5	8.21	20.20	12.43	10.7	39.4	105.7	15	28
28.3. »	19.54	8.50	20.34	13.05	10.7	44.5	115 6	15	27
29.3. »	19.56.5	8.53	20.36.5	12.96	10.7	40.4	112.0	18	33
30.3. »	19.58	8.37	20.38	12.83	10.7	43.9	112.9	17	31
31.3. »	20.00	8.16	20.41.5	12.71	10.7	50.0	115.6	14	25
1.4. »	20.04	8 45	20.44.5	12.87	10.7	41.4	111.7	18	32
5 4. »	20.10.5	8.00	20.51.5	12.33	10.7	46.0	109.0	12	21
28.4. »	21.19.5	7.95	22.19	12.33	10.7	48.2	110.4	16	21
30.4. »	21.26.5	7.97	22.28	12.30	10.7	46.4	109.0	16	21
4.5. »	21.38.5	7.83	22.48	12.17	10.7	48.9	109 3	16	19
6.5. »	21.46.5	7.93	23.04	12.30	10.7	48.2	110.2	17	20
7.5. »	02.37	8.05	01.21.5	12.25	10.7	41.4	105.1	18	20
7.5 »	21.50.5	7.92	23.08	12.17	10.7	44.9	106.6	18.5	21
8.5. »	02.34	8.08	01.12	12.30	10.7	41.5	105.7	16	18
Mean 1949		8.20		12.57	10.7	(44.0)	(110.1)		
						44.3	110.5		27
Total Mean						43.3	109.2		28

direction of observation. The elevation angle (α) of the collimator-field lens axis could be read to within 1/10°.

The types of plates used were Agfa ISS and Ilford H.P.3. sensitized with NH_3 or pre illuminated. A set of neon spectra, in time-ratios of 2, was photographed on each plate. The neon lamp was in all cases kept at a fixed distance from the slit so that the set of spectra could serve the double purpose of giving the intensity-density curve of the plate, and of forming a basis for comparison of the *D*-line intensities on the different plates.

Reproductions of the twilight spectra are shown on plates I to IV at the end of the paper. Each evening (night) has been given a separate number, and the series from one evening have been devided in a zenith group (*Z*) and a «horizontal» group (*H*). On Plate IV are shown some «all night» series taken in May 1949. These series will be discussed separately.

The results obtained from the main material are contained in table 1. The times for the end of the enhanced twilight sodium light are given by τ in columns 2 and 4, the corresponding solar depressions by β in column 3 and 5. α is the elevation angle of the collimator axis in the horizontal series.

The height H_s of the atmospheric screen, and the (approximate) upper limit of the sodium layer, H_u, given in the columns 7 and 8, have only been computed when both evening series have been sufficiently complete and undisturbed for the determination of τ_z and τ_h.

The time difference Δt (column 9), used in eq. (4) to find the thickness ΔH of the sodium layer (column 10) has been estimated from the time-intensity curve for the zenith direction of observation.

The table is divided by horizontal lines in four groups, each containing the result obtained in a comparatively narrow time interval (1 to 4) months). For each group are given the mean values of β_1 and β_2, the heights H_s and H_u computed from these means (given in brackets), and the means of the H_s and H_u computed for separate days.

It will be noticed that the values of H_s and H_u in brackets in some cases differ from those standing below them. This is meant to illustrate how the introduction of incomplete sets of observations in the material, may give different and presumably more incorrect values for the computed heights (cfr. paper 15). The differences, however, are never great.

The mean values of H_s and H_u given here, agree well with previous results obtained by the same method.

Table 2.

Semi-annual Means of H_s and H_u from Oslo during the years 1939 to 1949.

Year	H_s km	H_u km	n	σ_s	σ_u
1939[1] S	45	106	4	8	7
1942[2] A	43.2	105.7	6	3.3	2.7
1943[2] S	42.2	103.9	14	6.4	4.8
1943[2] A	37.8	108.4	1		
1944 S	37.4	101.1	1		
1946 S	41.6	106.2	4	6.6	4.3
1948 A	41.7	105.1	3	2.5	2.3
1949 S	44.3	110.5	25	4.0	3.7
Mean A	42.2	105.8	10		
Mean S	43.4	107.6	48		
Total Mean ..	43.2	107.3	58	5.	5

[1] From Vegard & Tønsberg (7) (cfr. (11)).

[2] From Vegard & Kvifte (8).

In table 2 are collected all the results obtained at Oslo during the 10 years from 1939 to 1949. The values of H_s and H_u given in the 2nd and 3rd column, are semi-annual means (S = spring, A = autumn in column 1) computed from the number of observations, n, given in the 4th column.

The two last columns contain the «root-mean-square» (equation 6) of the series of data on which the means in column 2 and 3 are founded

$$\sigma^2 = \frac{1}{n-1} \sum_{i=1}^{i=n} (\bar{H} - H_i)^2 \qquad (6)$$

$\bar{H}$ is the arithmetical mean of the individual (n) heights H_i.

The total means of H_s and H_u, 43,2 km and 107,3 km respectively, are given in the last row of the table, The Student's test (20. 27) applied to the data in this row, shows that there is a probability of 0.999 for finding the true values of H_s and H_u within 3 km of the total means given.

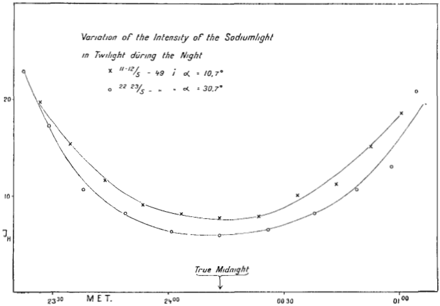

Fig. 1.

All the semi-annual values of H_s and H_u in the table are within these limits. There is therefore in this material no indication of either an annual or a seasonal variation of H_s and H_u.

The material does, on the other hand, justify the following conclusions:
At the latitude of Oslo ($\varphi \approx 60°$ N) between 40 and 45 km of the lower atmosphere is effective in screening out the solar light which excites the sodium light during twilight. The main part of the sodium atoms, radiating in twilight, is contained in a layer with an upper border situated somewhere between 105 and 110 km above the surface af the earth. The thickness of the layer may vary, but is approximately 30 km (cf. table 1, last row and column).

b. *All-night Series.*

The conclusions we have drawn are strongly supported by some series of observations taken in May 1949. On the night of May 11 to 12 a series of 11 spectra was taken in the way that the collimator axis of the spectrograph followed the azimuth plane of the sun through an angle ot 20° on both sides of local midnight. The elevation angle of the collimator axis was $\alpha = 10.7°$. A reproduction of the series is shown in plate IV No. 36. A similar series was taken on May 22 to 23, this time with an elevation $\alpha = 30.7°$. (Pl. IV, no. 37 H_E and H_M). The maximum solar depression i.e., at local midnight, on these two nights was 12°.05 and 9°.57 respectively. In none of these cases did the sodium lines disappear. This can be seen on the reproductions (pl. IV) and better still on figure 1, where the intensity (I_H) of the sodium lines for the two nights has been plotted in arbitrary scale against the time (M.E.T.). At local midnight the sodium lines have still an appreciable intensity. It can therefore with certainty be concluded that the twilight sodium light does not disappear in the directions $\alpha = 10.7°$ and $\alpha = 30.7°$, if the solar depression is not greater than 12°.05 and 9°.57 respectively. These angles are in other words ***minimum*** values of β_2 to be inserted in the formulae (1).

On the night May 22nd to 23rd were also taken zenith observations before and after the horizontal series (pl. No. 37, Z_E and Z_M). The sodium lines are rather weak on these spectrograms, being barely visible on the 3 first of the evening spectrograms and the 3 last of the morning ones. By a liberal estimate the time of disappearance in the evening and reappearance time in the morning have been fixed as the middle of the exposure intervals of the 4th of the Z_E spectra and the 2nd of the Z_M spectra. The solar depressions corresponding to these two points of time, 8.02° and 8.03° respectively, then should be *maximum* values of β_1 for this night.

The procedure was repeated a week later (May 30 to 31, pl. IV, no. 38) by a one hour series around local midnight. The maximum β_1 -values was found to be 8.00°. The data given are collected in table 3.

Table 3.

Minimum Values of H_s and H_u Derived from Twilight Observations in May 1949.

Date	α	τ	Remarks on Sodium light	-β	Remarks on β	Min. val.	
						H_s	H_u
11-12	10.7	L.M.	Visible	12.05	Min value	35	98
30-31	90	23 44- 00 44	Disappeared	8.00	Max. »		
22	90	22 55	Disappeared	8.02	Min. »	40	103
22-23	30.7	L.M.	Visible	9 57			
23	90	01 31	Disappeared	8.03			

L M. = Local Midnight.

When it is now borne in mind that an increase of β_1 and a decrease of β_2 in the formula (1) both will give a lower value of H_s and H_u, it will be understood that when a maximum value of β_1 is combined with a minimum value of β_2, the heights obtained are minimum values. Applications of the data found above on the night May 22 nd to 23 rd, yields $H_s = 40$ km and $H_u = 103$ km. Combination of β_1 from May 30th — 31st with β_2 from May 11th to 12th, yields $H_s = 35$ km and $H_u = 98$ km. The latter results are not so reliable as the former ones, because data from different nights have been combined. The results, however, agree well, and they show that the screening height, H_s, of the lower atmosphere at Oslo *cannot be less than* 35 to 40 km, and the «upper limit», H_u, of the sodium layer *not lower than* say 100 km above the surface of the earth.

§ 6. The Tromsø Observations.

The observations from The Auroral Observatory, Tromsø, were carried out during the spring and autumn of 1952, with a new spectrograph «Forcalquir» of great light power F : 0.65 from Societé Générale d' Optique (For description of the spectrograph, see e.g. (21) and (22) With this spectrograph it was possible to cut down the exposure intervals to 2—4 minutes during the twilight hours and obtain the sodium D-line mainly due to air glow and aurora with measurable density in 10—20 minutes. Observations were carried out on 16 nights. In 5 cases, however, either the zenith or the horizontal series were too heavily influenced by aurorae and have therefore been rejected.

The results of the remaining 11 series are given in table 4 and reproductions of some of them are shown on plate V. It is seen from plate V that the auroral line usually appears with considerable intensity which indicates that the fall of the time-intensity curve of the sodium line may be disturbed by auroral excitation.

As mentioned in § 4 of this paper, the «disappearance time», τ ,may be fixed by extrapolation of the twilight D-line intensity curve to intersection either (1) with the line at the height (Δ I) representing the rest intensity above H_u, or as usual with the time axis (2). Both procedures have been followed here, and the results are given in table 4. For each evening two rows of results are given corresponding to the procedures (1) and (2). The values, found for H_s according to the two alternatives, differ slightly. The differences have a random distribution and are usually not greater than should be expected from an estimate of the precision of the method. The total means of H_s of alternative (1) and (2) differ only by 0.7 km. Thus the two procedures of fixing the disappearance time τ, give practically the same value for the screening height H_s. One must therefore conclude *that the extrapolation procedure* (*alternative 2*) *used in earlier investigations gives fully reliable results, and* that the critique raised against the method on this ground (Bricard and Kastler (12)) is not justified.

The upper limit, H_u, appear to be 3—5 km greater for alternative (2) than for (1). This is what should be expected. The disappearance of the twilight sodium line as defined in the latter case must take place earlier in the evening than in the former case (see table 4). Since now, as just shown, H_s in both cases is the same, this implies that H_u, according to alternative (1) refers to a lower «upper limit» than does H_u in alternative 2. This small difference is, however, of little physical importance when we remember that H_u is not an exact upper limit for the sodium

Table 4.
Values of H_s, H_u Derived from Twilight Observations at Tromsø in 1952.

Date		Zenith		Horizon[1]		H_s km	H_u km
		τ (MET)	β_1 °	τ (MET)	β_2 °		
24.3.52.	1.	19.53.0	8.65	20.26.0	11.05	30.6	104.1
»	2.	19.55.5	8.65	20.29.5	11.30	29.5	106.5
26.3. »	1.	20.02.5	8.65	20.39.0	11.20	37.6	111.2
»	2.	20.05.5	8.90	20.43.5	11.50	35.6	113.5
1.4. »	1.	20.35.0	8.85	21.17.5	11.35	31.5	108.8
»	2.	20.37.5	9.00	21.22.0	11.60	33.8	113.5
Mean Spring 1952	1.					33.3	108.0
	2.					33.0	111.2
2.10.52	1.	18.37.5	9.05	19.07.5	11.55	28.3	108.8
»	2.	18.40.0	9.25	19.10.5	11.80	27.0	111.2
3.10. »	1.	18.32.5	9.00	19.05.0	11.70	38.5	118.2
»	2.	18.34.0	9.15	19.07.25	11.90	38.2	120.6
6.10. »	1.	18.17.5	8.90	18.49.0	11.55	38.0	115.9
»	2.	18.20.0	9.10	18.54.5	12.00	46.0	127.7
7.10. »	1.	18.14.0	8.95	18.45.5	11.65	39.3	118.2
»	2.	18.16.0	9.15	18.49.5	11.95	40.5	123.0
8.10. »	1.	18.08.0	8.80	18.37.0	11.30	32.7	108.8
»	2.	18.09.5	8.95	18.39.5	11.50	32.4	111.2
15.10. »	1.	17.39.5	8.95	18.10.0	11.60	37.1	115.9
»	2.	17.41.0	9.10	18.13	11.85	39.0	120.6
16.10. »	1.	17.38.75	9.25	18.09.5	11.95	34.0	118.2
»	2.	17.42.0	9.55	18.15.0	12.45	37.8	127.7
31.10. »	1.	16.38.0	9.10	17.10.0	11.80	36.7	118.2
»	2.	16.40.5	9.30	17.12.0	12.00	33.1	118.2
Mean Autumn 1952	1.					35.6	115.3
	2.					36.7	120.0
Mean All	1					35.0	113.3
	2.					35.7	117.6

[1] Elevation of spectrograph $\alpha = 20°$.

contents, but rather a height level below which the main part of the radiating sodium atoms is located.

The mean results of table 4 are in good agreement with the height measurements previously taken at Tromsø. In table (5) are collected all heights obtained at the Tromsø Observatory and given as semi-annual means of H_s and H_u (as in table 2). The total «autumn» mean of H_s, 35.8 km. (5th row from below), is here somewhat higher than the «spring» mean, 32.7 km (4th row from below). The deviations of both from the total mean 34.0 km (last row), however, are not greater than might be explained as random fluctuations, considering the comparatively great root-mean-square of the «spring» mean probably caused by uncertainty in the observation series of 1939.

Nothing can be concluded from the data in table 5 as to the existence of a seasonal variation of the upper limit H_u. The use of a new spectrograph in 1952 may have altered the conditions of observation. The 3rd and 2nd last rows of table 5 contain the means of H_s and H_u of the previous measurements (1939 and 1946) and the present ones (1952). The former series were obtained with a small spectrograph (a) described in the papers (23) and (24) of a light power $F : 2.0$, whereas the latter ones were taken with the very large spectrograph «Focalquir», $F : 0.65$. The greater light power of the new spectrograph made it possible to follov the twilight sodium lines further into the night. At the same time the greater dispersion and greater sharpness of the lines secured more accurate intensity measurements. It is remarkable that the old observations lead to nearly the same value of H_s as the new ones.

Table 5.

Semi-annual Means of H_s and H_u from Tromsø.

Year	H_s	H_u	n	σ_s	σ_s
1939[1] S	30.6	93	5	12	10
1942[2] A	36.3	102.3	3	3.2	2.5
1946[2] S	33.8	97.9	8	5.2	3.5
1952 S	33.3	108.0	3	3.7	3.6
1952 A	35.6	115.3	8	3.7	3.6
Mean A	35.8	(111.8)	16	3.5	
Mean S	32.7	(99.0)	11	7.4	
Mean 39-46 ..	33.3	97.2	16	7.6	6.7
Méan 52	35.0	113.3	11	3.6	4.8
Total Mean ..	34.0	(103.8)	27	6.2	(10)

[1] From Vegard & Tønsberg (7).

[2] From Vegard, Tønsberg & Kvifte (11).

The results in table 5 may be summarized as follows: *At Tromsø about 34 km of the lower atmosphere is opaque to the solar light, which during twilight excites the sodium atoms located at this place below an altitude between 100 and 110 km.*

In a previous paper (11, table IX) we found that the mean values of H_s and H_u came out smaller at Tromsø than at Oslo, indicating an increase of the screening height and the height of the «upper limit» of the sodium layer (H_u) towards lower latitudes. The same latitude effect is indicated by the results given in this paper, as will be seen by comparing table 2 and 5, which give for Oslo and Tromsø the following mean values of H_s and H_u.

	H_s km	H_u km
Oslo	43.2	107.3
Tromsø	34.0	103.8

On account of the influence of auroral emission of the D-lines the value of H_u at Tromsø may be somewhat too high.

§ 7. The Annual Variation of the Intensity of the Sodium Lines in Twilight.

As mentioned in § 5, each plate of the Oslo series of observations was supplied with a standard spectrum (Neon) in order to make a comparison possible of the twilight sodium line intensity from evening to evening. The observations were each evening started so early that spectra were obtained of the twilight luminescence while the sodium lines still had the constant intensity. This maximum intensity of the twilight D-lines was then measured in a relative scale for both the zenith (I_z) and the horizon (I_h) observations. The results are collected in table 6. Columns 2 and 3 give zenith and horizon intensities respectively.

During the work carried out in this country on aurorae, air glow and twilight we are familiar with the fact that the absolute and relative intensities of the sodium D-line is subject to great fluctuations in all these phenomena (cfr. e.g. papers 8 and 11). With regard to variations of the D-emission from the air glow, we may refer to investigations by Dufay and Tcheng Mao Lin (25) and Abadie, E. and A. Vassy (26).

In order to eliminate to some degree the random fluctuations, we have tried to reduce the intensity, I_h, from the series near the horizon to the level of the intensity, I_z, in the zenith direction in the following way: Each day, when both zenith and horizon series of spectra were obtained, the quotient $K = I_h/I_z$ was computed. Dividing each observed intensity I_h with the mean value K_m, the ratios $(I_h)_n = I_h/K_m$ represent intensities near the horizon normalised to the scale of the zenith intensities. The mean values $I_d = \frac{1}{2}[(I_z + (I_h)_n]$ are taken as a measure of the relative intensity of the D-line in twilight. The results are collected in table 6. The resulting relative twilight-D-line intensities I_d are given in the last column.

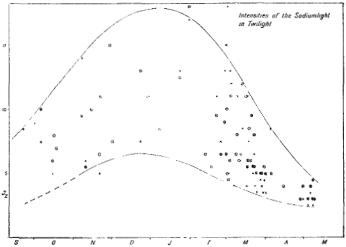

Fig. 2.

Table 6.

Relative Maximum Intensities of the Sodium Light in Twilight, I_z towards Zenith, I_h towards Horizon (Elevation 10°), $K = I_h / I_z$.

Date	I_z	I_h	K	$(I_h)_n = \frac{I_h}{K_m}$	I_d	Date	I_z	I_h	K	$(I_h)_n = \frac{I_h}{K_m}$	I_d
16.10 42	6	12	2,0	5	5,5	23.3.46	8	15	1,9	6,5	7,5
17.10. »	8	21	2,6	9	8,5	8.11.48	9,5	33	3,5	14	12
19.10. » ..	7	14	2.0	6	6,5	11.11. »	5,5	14	2,5	6	6
27.10. »		17		7,5	7,5	22.11. »	6,5	11	1,7	5	6
16.11. »	10	15	1,5	6,5	8,5	24.1. 49	12,5	29	2,3	13	13
23.11. »	11				11	31.1. »	18	38	2,1	17	18
29.11. »		19		8,5	8,5	22.2. »	9,5	26	2,7	11	10
30.11. »	15	31	2,1	13	14	25.2. »	6,5	17	2,6	7,5	7
2.12. »	7,5	15	2.0	6,5	7	28.2. »	9	30	3,3	13	11
30.12 »	11	26	2,4	11	11	1.3. »	6,5	35	5,4	15	11
8.1. 43	8.5	15	1.8	6,5	7,5	2.3. »	10	42	4,2	18	14
13.2. »	6,5	15	2,3	6,5	6,5	4.3. »	6	30	5,0	13	9,5
18.2. »	5,5	11	2,0	5	5,5	10.3. »	8	26	3,3	11	9,5
2.3. »	5	12	2,4	5	5	17.3. »	5,5	13	2,4	5,5	5,5
3.3. »	4,5	12	2,7	5	5	18.3. »	6	25	4,2	11	8,5
9.3. »	6,5	13	2,0	5,5	6	22.3. »	5,5	11	2,0	5	5,5
11.3. »	6	14	2,3	6	6	25.3. »	5	8	1,6	3,5	4,5
12.3. »	6,5	14	2,2	6	6,5	28.3. »	5	10	2,p	4,5	5
19.3. »	8,5	17	2,0	7,5	8	29.3. »	5	9	1,8	4	4,5
20.3. »	6	9	1,5	4	5	30.3. »	5	8,5	1,7	3,5	4,5
23.3. »	5,5	9	1,6	4	5	31.3. »	5,5	10	1,8	4,5	5
24.3. »	5	9	1,8	4	4,5	1.4. »	5	8,5	1,7	3,5	4,5
1.4. »	5	9	1,8	4	4,5	5.4. »	5	19	3,8	8,5	7
15.4. »	4	10	2,5	4,5	4,5	28.4. »	3	6,5	2,2	3	3
22.9. »		19		8,5	8,5	30.4. »	4	6,5	1,6	3	3,5
7.10. »	10	17	1,7	7,5	9	4.5. »	3	5	1,7	2,5	3
24.1. 44	13	17	1,3	7,5	10	6 5. »	4	7,5	1,9	3,5	4
5.3. 46	11	28	2,5	12	12	7.5. » M	3	5,5	1,8	2,5	3
14 3. »	12	20	1,7	8,5	10	7.5. » E ..	4,5	7	1,6	3	4
17.3. »	11	9	0,8	4	7,5	8.5. » M	3	7	2,3	3	3
21 3. »	9,5				9,5	11.5. »		(3)			
22.3. »		13		5,5	5,5	22.5 »	(1)	(3)	(3,0)		

$K_m = 2,3$

The intensities I_d vary considerably from day to day illustrating the great variability of the twilight *D*-line intensity pointed out by us in previous papers (8, 11). Some regularity in the intensity variations is, however, also indicated. In figure 2, I_d has been plotted against the day of observation during the year. Although the points in the diagram thus obtained are widely spread, the majority of them are lying between the two curved lines which are drawn in the figure and which have well marked maxima near the winter solstice. For further study of this apparent seasonal variation, the monthly means of I_d have been computed and are given in table 7 for the three winters for which we have observations. The total weighted monthly means (I), without regard to years, are given in column 5, and a rounded mean (I_r) in the last column. I_r is computed from I by means of the formula:

$$I_r = 1/4\,(I_{n-1} + 2I_n + I_{n+1}) \qquad (7)$$

where I_{n-1}, I_n and I_{n+1} are successive values of I from the months considered. This smoothing procedure serves the purpose of eleminating to some extent the random fluctuations in the material.

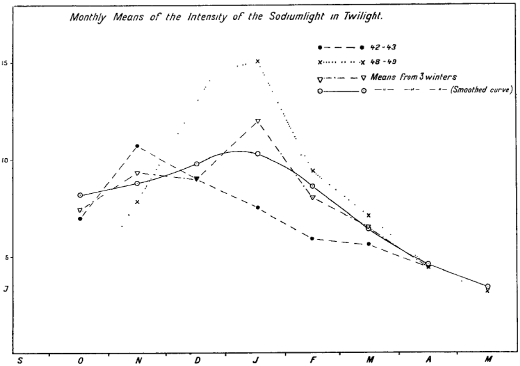

Fig. 3.

Figure 3 shows plots of the monthly means against time during the winter half-year. The two curves, representing the observation series from 1942—43 (dots) and 1948—49 (crosses), differ appreciably in relative intensity, thus indicating a year-to-year variation of the twilight *D*-line intensity. The material is, however, at present not sufficiently complete to enable definite conclusions. Both curves have, at any rate, a marked maximum near midwinter. The time of maximum does not coincide in the two cases, but this may probably be attributed to the limited number of observations. It would be safe to assume that the mean curve (delta marks) — or the smoothed curve (circles) — will give a fairly good impression of the seasonal variation of the intensity of the sodium *D*-lines in the twilight luminescence.

Table 7.

Monthly Means of the Intensity of the Sodium Light in Twilight.

Month	Year			Mean	Rounded Mean
	42—43	43—44	48—49		
September ..		(8,5)		(8,5)	(8)
October	7,0	8,8		7,4	(8,2)
November ..	10,7		7,8	9,3	8,8
December ..	9,0			9,0	9,8
January ..	7,5	10,2	15,1	12,0	10,3
February ..	5,9		9,4	8,0	8,6
March	5,6		7,1	6,5	6.4
April........	4,4		4,4	4,4	4,6
May			3,2	3,2	(3,4)

Dufay (28) has investigated the annual variation of the night glow sodium line intensity. From observations carried out during about 3 years, he found that the mean intensity was nearly represented by a single yearly harmonic wave with max. around the middle of December. The ratio between maximum and minimum intensity was about 5 to 1.

The smoothed curve (fig. 3) of the seasonal variation of the twilight sodium line at Oslo, is not complete because of observations lacking during summer time. Two third of the year are, however, covered by the curve, and during this time the curve shows the same general «trend» with respect to maximum intensity and ratio between winter and summer intensity as Dufay's night glow curve.

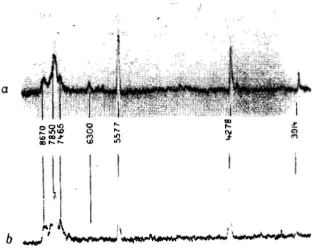

Fig. 4.

As already pointed out, the *D*-emission in twilight and in the night glow originates from very different altitudes and excitation processes, but still the similarity between the seasonal variations indicate some physical correlation between the two phenomena.

Regarding the cosmic-physical consequences of the results, we refer to the appendix by Vegard.

Chapter 2
Auroral Spectrograms from Oslo.

§ 8. Introductory Remarks.

In this chapter we are dealing with some auroral spectrograms taken at Oslo with spectrograph (*C*) from 1945- 49. Reproductions are given on pl. VI, and details regarding type of photographic plate, date, time of exposure, direction of collimator and auroral type, are given in explanations to plate VI at the end of this paper. Two of the spectrograms (Nos. *22* and *23*) were taken on infra red sensitive Eastman *I.L.* plates. The other 21 spectrograms were taken on three different types of pancromatic plates for the main purpose of observing possible variability effects.

§ 9. Observations in the Infra-Red.

Spectrograms showing the presence of auroral bands or lines in the infra red, were described by Vegard in 1932 and 33. The first were taken with glass spectrographs (29, 24) one spectrogram with a grating spectrograph (30). In all 10 band features had been registred in the range from 7000 to 8100 Å.

By means of the two spectrograms taken 3.2 and 17.3 1949 on Eastmann I. L. pl. the range was extended to about 8800 Å.

On the negatives, only 7 bands could be distinguished and measured. In order to detect more details and increase the accuracy, we have made measurements by means of microphotometer registrams as shown on fig 4. To eliminate maxima due to the grain structure and faults on the plate, we took two registrams along two parallel lines across the spectrograms, and only distinctly coinciding maxima on both curves were accepted as real. The results are given in table 8. From the registrams we have measured 17 bands or lines, while only 10 infra red features had previously been measured.

By means of intensity scales photographed on each of the two plates with a light source of known intensity distribution, the true relative intensities of the strongest bands and lines in red and infrared were measured in relation to the green line 5577, the intensity of which was put equal to 100. The results are shown in table

Table 8.

Wave-lenghts Measured from Infra-red Sensitive Plates. Spectrograph «*C*», Oslo.

Date .. ..3.2 49 Plate VI No. 22			17.3.49 23	Means	Previously measured
Measured from	Plate	Photo-registrams			
		8800	8790	8795	
	8655	8665	8650	8655	
	8421	8465	8440	8440	
		8360	8345	8350	
		8210	8210	8210	
		8120	8140	8130	8132
	8052	8040	8045	8045	8035
		7935	7925	7930	7906
	7850	7855	7845	7850	7867
	7715	7750	7750	7740	7734
		7680	7695	7685	
	7533	7565	7550	7550	7594
	7469	7465	7445	7460	7479
		7375	7395	7385	7368
		7325	7320	7325	
		7230	7250	7240	7264
		7095	7100	7100	7068

Table 9.
Intensities of Infra-red Bands obtained with Spectrograph «C» at Oslo.

Type of Plate	Eastman I. L.	
Date	3.2.49	17.3.49
Pl. VI, Sp. No.	22	23
Expos. Interval	22.45—06.30	20.40—02 25
Direction	N	N
Height	40—70°	40—70°
Aur Form.	A & D	All sorts
8800	29	31
8655	19	26
8440	16	15
8350	4,4	4,6
8045	10	10
7850	39	43
7740	37	48
7580	7,1	3,9
7465	11	6,7
6300	29	16
5577	100	100

9. Taking into account the great intensity of the green auroral line a number of bands and lines in the infra red are quite strong.

After these spectrograms were taken, auroral spectrograms in the infra red have been obtained at Tromsø with a new spectrograph designed by Vegard and built by Societé Génèrale d'Optique in Paris under the supervision of Cojan. The results will be found in a paper recently published by Vegard and Tønsberg (31). From these spectrograms about 50 vibrational bands have been observed and measured in the interval between 7000—8800 Å, and with regard to interpretation we refer to this paper.

Recently Meinel (32) using a grating spectrograph of considerable light power and dispersion obtained spectrograms giving some very well-defined bands and lines in the infra-red, for which wave lengths could be measured fairly accurately. Spectrograms giving some infra-red bands and lines have also been obtained by Petric (33).

§ 10. Intensity Variations in the Visible Longwave Part of the Auroral Spectrum.

The spectrograms taken on pancromatic plates and reproduced on pl. VI, are most of them too weak for intensity measurements except in the interval between the green line and the limit in red.

It appears from plate VI that the sodium *D*-lines do not appear distinctly on any of the spectrograms even when other auroral bands and lines are quite strongly exposed. In the case when a line seems to be present in the position of the *D*-lines, it is at any rate partly due to a band of the 1st positive group of nitrogen. The measured relative intensities are given in table 10. The feature apparently coinciding with Na I, has been measured for the three spectrograms Nos. 8, 11 and 16.

It appears from the table that when the red *OI*-line 6300 is weak the bands of the 1st positive group are relatively strong, and, as we see, the red *OI* line has a very small intensity for all the three spectrograms for which the feature near the *D*-line has been measured.

As the bands of the 1st positive group on the same spectrograms are relatively strong, the feature near the *D*-line is essentially produced by a band of the 1st positive group.

It is well known from previous investigations that the red *OI*-doublet is considerably enhanced with increasing altitude and that the intensity of the bands of the 1st positive group increases downwards. These effects are clearly seen from the spectrograms on Pl. VI and from table 10.

We may e.g. compare spectrogram 5 from the top of rays, with 4 and 6 corresponding to the lower limit. Sp. 9 and 10 from corona and top of rays with 8 and 11, spectrogram 12 with 11 and 13. No. 14 with 13 and 15 and 18 with its two neighbours. Thus the spectrograms with small intensity of the red *OI* line and great intensity of 1 *PG* bands correspond to luminescence from a small altitude.

When we remember that the sodium lines sometimes appear on auroral spectrograms fairly isolated and with an intensity of nearly the same order of magnitude as the green and red *OI* lines, the fact that the *D*-lines are absent on all spectrograms on pl. VI, illustrates in a striking way the great variability of the sodium emission in the auroral luminescence.

Table 10.
Intensities Obtained with Spectrograph (*C*) at Oslo. Pl. VI. $I_{5577} = 100$.

Date	Spectr. No.	Exposure Interval	Height & Direction	Aur. Form	5893 NaI 1PG	5993 1PG	6110 1PG	6300 OI	6454 1PG	6540 1PG
9.11.45	1	18.00—20.00	14° N	Dif. A				28	9.7	8.8
25.3. 46	2	20.10—20.22	10° WNW	»				38		
»	3	20.22—20.34	10° »					41		
»	4	20.35—21.05	10° E	Bottom R				20		
»	5	21.05—22.05	55° SW	Topp R				52		
»	6	22.15—23.10	12° N	L.lim. A, D				25	5.3	7.4
»	7	23.10—00.45	50° NE	Fl. Aur. R.				37	3.5	4.7
»	8	00.45—02.40	8° N	Low. l. Dif. A.	2.7	5.2	34	19	5.9	7.1
»	9	02.40—04.45	90°	Corona				39	4.1	4.8
28.3. »	10	23.10—00.45	75° N	Topp R				61	2.7	2.9
»	11	00.50—02.00	10° N	L. lim R.	3.2	3.9	2.9	13	5.4	7.4
17 4.47	12	21.50—22.50	51° N	Topp R.				108		
»	13	22 50—01.05	15° NE	Bottom R.				19	5.2	5.9
»	14	01.05—03.00	35° N	R & A				70	3.0	3.0
18.9. »	15	20.45—01.20	11° N	L. l. dif. A				21	6.6	6.8
25.9. »	16	20.45—04.10	19° N	A & D	3.5	4.0	2.6	13	5.4	7.8
2.10. »	17	20.45—01.25	25° N	L. l. dif. A				10	3.2	5.0
»	18	01.25—03.30	30° N	U. l.				45	4.3	5.5
13.10. »	Not copied	23.15—04.45	9° N	Dif. A				12	5.4	8.5
21.10.48	19	21.10—23.10	25° N	A				14		(5.2)

Intensities

1 PG = 1st positive group of nitrogen.
L. l. = Lower limit.
U. l. = Upper limit.
A = Arc, D = Draperies, R = Rays

APPENDIX

Cosmic-physical Consequences of the Results regarding the Sodium D-line in Twilight

BY

L. VEGARD

The new determinations by the Vegard method of the «upper limit» H_u, the thickness $\Delta H = H_u - H_1$ of the sodium layer producing the main part of the D-emission in twilight and of the screening height (H_s), have given results in good agreement with those published in previous papers. The basis for the cosmic physical consequences which may be drawn is therefore unchanged.

In his announcement in Nature (6) of the method and the first result derived from it, Vegard states some of the most important consequences in the following way:

«It is of interest to notice that the screening height is just above the region of relatively large ozone concentration. The effective height is found to be about the same in the evening and in the morning, showing that there is no noticeable time lag in the emission process.

These results[1] indicate an extra terrestrial origin of the sodium from which the yellow line is emitted. It is possible that in addition to the hydrogen showers previously dealt with[2], showers of sodium coming from the sun may enter the atmosphere. Possibly the hydrogen showers, in connection with sodium and atmospheric oxygen may account for the luminous night clouds.

Our results regarding the position of the effective sodium layer also enables us to make certain estimates regarding the effective solar radiation. If it is ultraviolet light it should be found somewhere in the interval 1900—3100 Å. The screening limit (H_s) is due to ozone absorbtion, the maximum of which lies at about 2500 Å.»

The Doppler displacement of H-lines found on spectrograms obtained at Tromsø in 1940—41 (3, 4, 5, 41), showed that the bundles of solar electric rays were composed of electrons mixed with protons, confirming the view that these bundles are composed af electrons electro-statically neutralized by positive ions of high specific charge (cfr. 41). This constitution involves that the relative intensity of auroral hydrogen lines is nearly proportional to the relative velocity, explaining the great variabitily of the H-line intensity. The great abundance of sodium in the solar atmosphere and the great variability of the D-line in twilight and aurora, suggest that also highly ionised sodium atoms form part of the solar ray bundles.

In a more complete account where also Tromsø observations were included (7), it was shown that the effective solar radiation which excited the D-line in twilight, could not be of the X-ray type.

On the other hand, any solar radiation within the visible part of the solar spectrum would lead to a much lower screening height than that observed, even when the absorption of ozone in this spectral region is duly considered (cfr. 20, 34, 35).

A screening height of the magnitude here found (34—44 km) involves that the excitation process leading to the emission of the sodium D-line in twilight is initiated by ultra-violet sunlight in the wave-length region near $\lambda = 2500$ Å.

Objections to this excitation process have been raised on the ground that a photo dissociation would leave the excited sodium atoms with part of the surplus energy associated with the process, and, if so, the twilight D-line would be

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[1] The great height of the upper limit H_u.

[2] Vegard, Nature **144**, 1089, 1939.

broadened by Doppler effect. Further the twilight D-line excited in this way would be nearly unpolarized.

From experiments on the absorbability of the twilight D-line in sodium vapour, Bricard and Kastler (35, 36) find that the twilight line is very sharp and its width should correspond to a temperature of approximately 240° K, or about the same as found by Vegard and collaborators for the auroral region. Further Bricard, Kastler and Robley (37, 38) consider they have shown that the twilight D-line is slightly polarized.

As far as these experimental results go, they are in good agreement with the assumption, that the twilight D-line is due to a resonance effect produced by the sodium line in sunlight.

Now this optical resonance hypothesis by Kastler et al. claims that in the atmosphere sodium is found in the form of free atoms, but such a state of things is not likely to exist so low down in the atmosphere as would be required by the resonance hypothesis with its low screening height.

As already mentioned, highly ionized sodium atoms may form part of the solar electric ray bundles which enter into the atmosphere and produce aurorae. Coming in contact with oxygen atoms in a neutral or ionized state, they will combine and form sodium-oxid, and perhaps, by the presence of hydrogen, sodium hydroxyd. *In such chemical combinations the sodium D-line could not be excited by resonance, but a photo dissociation by an ultra-violet radiation will be wanted, at any rate as the first step towards the excitation and emission process.*

We suppose that at a height (h) each cm^3 containing N_h sodium-oxygen molecules (say Na_2O), and the effective solar radiation from these molecules, produce q_h free sodium atoms per sec. After a certain time the number of free sodium atoms per cc. is n_h, then we have:

$$\frac{dn_h}{dt} = q_h - \alpha_h (n_O)_h n_h^2 \qquad (1)$$

α_h is a kind of recombination coefficient at the height (h) and $(n_O)_h$ is the number of oxygen atoms per cm^3. To simplify matters the quantity $(n_O)_h$ makes no distinction between molecular and atomic oxygen. When a stationary state is reached $\frac{dn_h}{dt} = 0$, and the number of free sodium atoms ν_h will be given by the equation:

$$\nu_h = \sqrt{\frac{q_h}{\alpha_h (n_O)_h}} \qquad (2a)$$

$q_h = K.N_h$ where K is an efficiency factor of the photon reaction depending on the intensity of the effective solar radiation and constitution and properties of the molecule. This inserted into equation (2a) gives:

$$\nu_h = \sqrt{\frac{K N_h}{\alpha_h (n_O)_h}} \qquad (2b)$$

The existence of a recombination coefficient means that it takes some time for the free sodium atoms to attach themselves to oxygen so as to regenerate the sodiumoxyd. *At low pressure $\alpha_h(n_O)_h$ may be small as compared with q so in a stationary state the number of free sodium atoms may be comparatively great.*

As soon as the free atoms are formed they are exposed to the influence of the sunlight sodium D-line, and the resonance excitation will have an opportunity to set in, because the screening height of the visible light (in casu the sodium D-line) is much smaller than that of the ultra-violet light which causes the photon dissociation. Moreover, the free atoms may also be excited by ultra-violet light.

Now by the photo dissociation the free sodium atoms may either be left in an excited or an unexcited state.

In the first case part of the D-line intensity in twilight would result directly from the dissociation process, and the number of D-photons $(\nu_D)_h$, which in twilight is emitted per sec. from a cm^3 at a height (h) may be expressed by a formula of the type:

$$(\nu_D)_h = \varepsilon q_h + \nu_h (r + \varkappa) \qquad (3)$$

ε is the probability that the sodium atom by photon dissociation is left in an excited state. r is the probability that the sunlight D-line will excite a sodium atom by resonance, and $\varkappa$ is the probability of a sodium atom to be excited by ultra-violet light. In this case the sodium atom is probably first ionised, and the D-emission is the last step in the recombination process. By this excitation the surplus energy will mainly be transferred to the expelled electron. *Consequently this excitation as well as that due to resonance, will give a sharp D-line, the width of which is determined by the temperature of the surrounding atmospheric matter.*

In the layer where the greater part of the D-line during twilight is emitted, the number of sodium atoms ν_h in the stationary state, may be so great *that the term* $\nu_h (r + \varkappa)$ *is dominating as compared with* $\varepsilon\, q_h$.

If the photon dissociation leaves the sodium atoms in an unexcited state $\varepsilon = 0$ and the term $\nu_h (r + \varkappa)$ represents the whole twilight D-emission.

Thus the sharpness of the twilight D-lines and the possible existance of a polarization, as found by Kastler and collaborators, are in good harmony with our results found by the Vegard method regarding the screening height (H_s) *and the upper limit* (H_u) *and thickness* ΔH_u *of the layer from which the main part of the sodium D-line in twilight is emitted.*

The interpretation of the experimental results here given leads us to the problem of specifying the quantities entering into the equations (1—3) in such a way, that it is possible to calculate a theoretical time-intensity curve for the twilight D-emission, which within the limit of error coincides with that observed.

As we know too little about the variation of N_h with altitude and the efficiency or probability factors K, $\varkappa$ and r, the solution would be one based on a method of trial and error.

From the equations 1—2, however, the following conclusions can be drawn:

1. When we pass from above (H_u) and towards lower altitudes, the rapid increase in D-emission when we pass H_h is due to a rapid increase in the concentration of the compounds which contain sodium or in the number N_h. This follows from the fact that the quantity $(a_h (n_O)_h$. increases downwards.
2. Even when below (H_u) the sodium concentration continues to increase or remain constant, the intensity of the twilight D-emission would fall on account of the rapid increase downwards of the quantity $a_h\, (n_O)_h$.

Thus the «lower limit» (H_l), found for the D-line emitting layer, may be accounted for by the rapid increase of $a_h\, (n_O)_h$ towards lower latitudes, and tells us very little about the sodium content below the limit (H_l). Thus besides the rapid increase downwards of the sodium content near (H_u) at altitudes of 90—108 km, very little can be said at present about the sodium concentration below this limit so long as we cannot find more accurately how the quantity $a_h\, (n_O)_h$ varies with altitude.

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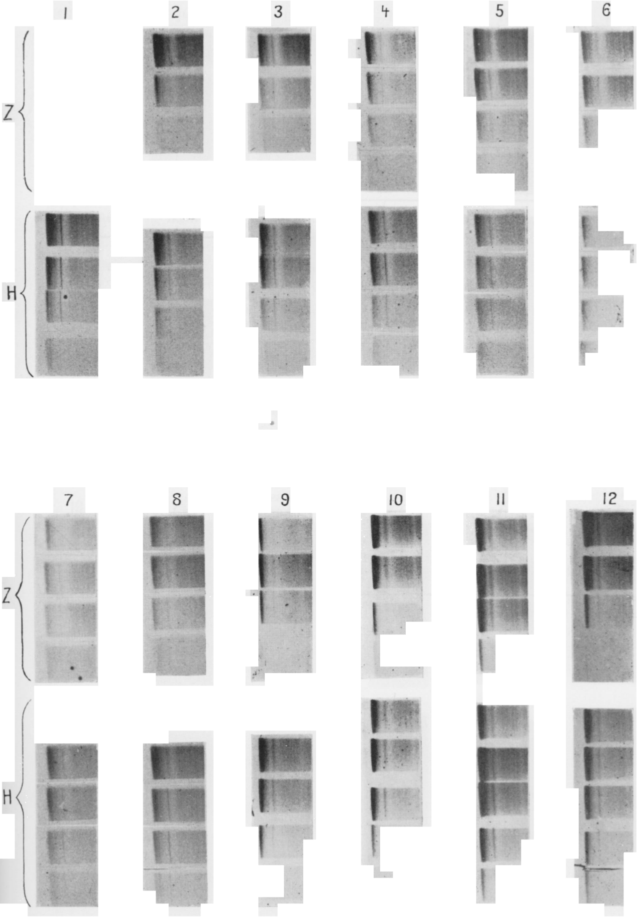
PLATES

Explanation to Plate I.

Twilight at Oslo. Spectrograph (*C*)

Group		Sort of Plates	Date	Interval of Exposure	Height	Azimuth
1	H	Agfa ISS Sensitized with NH_3	22.9.43	19.38—20.09	10,5°	ca. 115° w
2	Z		7.10.43	18.23—18.50	90°	
	H	»	»	18.51—19 23	10,5°	» 100° »
3	Z	»	24.1.44	17.00—17.27	90°	
	H	»	»	17.30—18.01	10,5°	» 70° »
4	Z	»	5.3.46	18.35—19.04	90°	
	H	»	»	19.05—19.35	10,5°	» 100° »
5	Z	»	14.3 46	18.56—19 25	90°	
	H	»	»	19.28—19.59	10,5°	» 110° »
6	Z	»	17.3.46	19.04—19.32	90°	
	H	»	»	19.33—20.07	10,5°	» 110° »
7	Z	»	21.3.46	19.13—19.41	90°	
	H	»	22.3. »	19.45—20.13	10,5°	» 110° »
8	Z	»	23.3. »	19.18—19.46	90°	
	H	»	»	19.47—20.16	10,5°	115° »
9	Z	Ilford H.P. 3. Pre-illuminated	8 11 48	16.48—17.16	90°	
	H		»	17.18—17.40	10,7°	80° »
10	Z	»	11.11. »	16.41—17.11	90°	
	H	»	»	17 13—17.45	10,7°	77° »
11	Z	»	22.11. »	16.19—16.46	90°	
	H	»	»	16.53—17.24	10,0°	72° »
12	Z	»	24.1.49	16.55—17.27	90°	
	H	»	»	17.28—17.55	10,7°	70° »

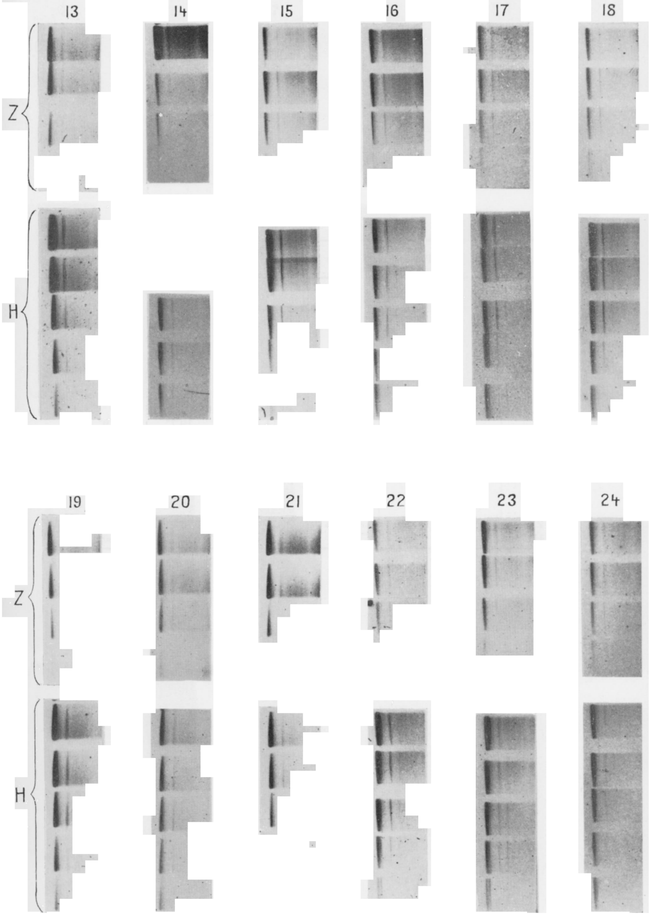
Plate I.



Explanation to Plate II.
Twilight at Oslo Spectrograph (*C*)

Group	Sort of Plates	Date	Interval of Exposure	Height	Azimuth
13 Z	Ilford H.P. 3. Pre-illuminated	31 1 49	17.09,5-17 40	90°	
H		»	17.44—18.21,5	10,7°	75° w
14 Z	»	22 2.49	18 01—18 31	90°	
H ..	»	22.2. »	18.34—18.49	10,7°	89° »
15 Z	»	25.2.49	18.13—18.41	90°	
H	»	»	18.44—19.21	10,7°	91° »
16 Z	»	28.2.49	18.21—18 50	90°	
H	»	»	18.55—19.30	10,7°	94° »
17 Z	»	1.3.49	18.24,5—18.52,5	90°	
H	»	»	18.58—19.33	10,7°	95° »
18 Z	»	2.3.49	18 26,5—18 54,5	90°	
H	»	»	19.01—19 35	10,7°	95° »
19 Z	»	4.3.49	18.32—19.00	90°	
H	»	»	19.06—19.40	10,7°	95° »
20 Z	»	10.3.49	18.47—19.15	90°	
H	»	»	19.21—19.55	10,7°	100° »
21 Z	»	17.3.49	19.04—19 32	90°	
H	»	»	19.38—20.12	10,7°	110° »
22 Z	»	18.3.49	19.08—19.36	90°	
H	»	»	19.41—20 15	10,7°	110° »
23 Z	»	22 3.49	19.18—19.46	90°	
H	»	»	19.51—20.25	10,7°	113° »
24 Z	»	25.3.49	19.25—19 53	90°	
H	»	»	19 58—20.32	10,7°	115° »

Plate II.



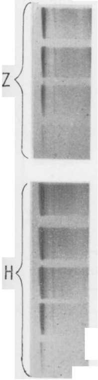
Explanation to Plate III.

Twilight at Oslo Spectrograph (*C*)

Group	Sort of Plates	Date	Interval of Exposure	Height	Azimuth
25 Z	Ilford H.P. 3. Pre-	28.3.49	19 30—19.58	90°	
H	illuminated	»	20 04—20.38	10,7°	117° w
26 Z	»	29.3 »	19 33—20.01	90°	
H	»	»	20.07—20.43	10,7°	118° »
27 Z	»	30.3. »	19.36—20.04	90°	
H	»	»	20 09—20.43	10,7°	118° »
28 Z	»	31.3. »	19 39—20.07	90°	
H	»	»	20.12—20 46	10,7°	119° »
29 Z	»	1.4. »	19.43—20.09	90°	
H	»	»	20.14—20.48	10,7°	119° »
30 Z	»	5.4. »	19.51—20.19	90°	
H	»	»	20 24—20.58	10,7°	122° »
31 Z	»	28.4. »	20.50—21.20	90°	
H	»	»	21.44—22.32	10,7°	150° »
32 Z	»	30.4. »	20 56—21 26	90°	
H	»	»	21.52—22.40	10,7°	154° »
33 Z	»	4.5. »	21.16—21.55	90°	
H	»	»	22.14—23.00	10,7°	160° »

Plate III.

25



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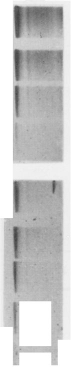

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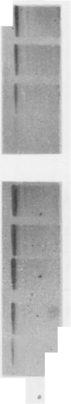

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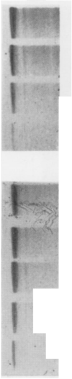

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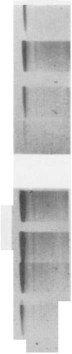

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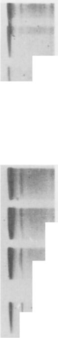

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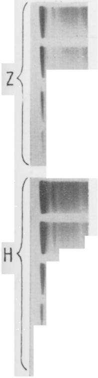

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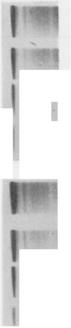

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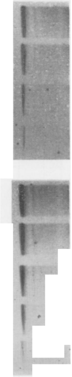
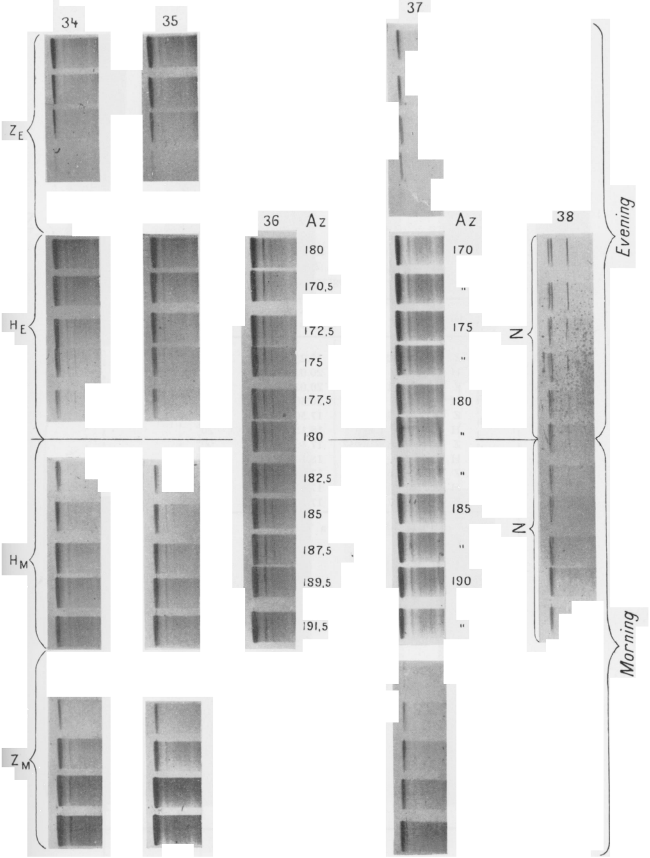


Explanation to Plate IV.

Twilight at Oslo. Spectrograph (*C*).

Group	Sort of Plates	Date	Interval of Exposure	Height	Azimuth
34 Z_E . .	Ilford H.P. 3. Pre-illuminated	6.5 49	21.22—22.01	90°	
H_E . .	»	»	22.24—23.10	10,7°	162° w
H_M . .	»	7.5. »	01.18—02.03	10,7°	162° E
Z_M . .	»	»	02.26—03.05	90°	
35 Z_E . .	»	»	21.25—22.04	90°	
H_E . .	»	»	22.31—23.17	10,7°	164° w
H_M . .	»	8.5. »	01.09—01.55	10,7°	164° *E*
Z_E . .	»	»	02 22—03.01	90°	
36 H . .	»	11 12.5. »	23.22,5—01.04,5	10,7°	170,5 w —170,5 *E*
37 Z_E . .	»	22.5. »	22 22—23.16	90°	
H . .	»	22.23.5. »	23 20—01 07	30,7°	170° w—170° *E*
Z_M . .	»	23.5. »	01.10—02.05	90°	
38 Z. . . .	»	30.31.5. »	23.20—01.07	90°	

Plate IV.


34
35
37
Z_E
H_E
H_M
Z_M
36
Az
180
170,5
172,5
175
177,5
180
182,5
185
187,5
189,5
191,5
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170
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175
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185
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190
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38
N
N
Evening
Morning

Explanation to Plate V.

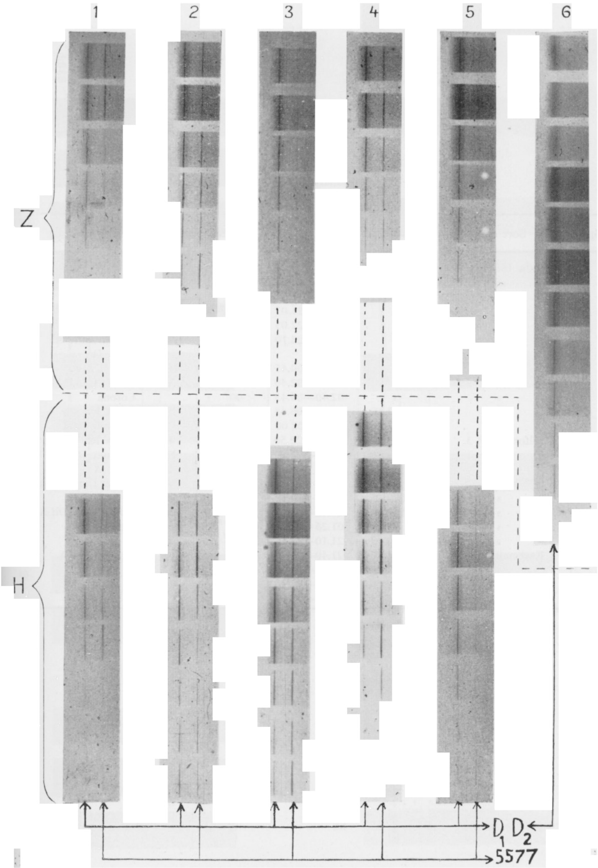
Twilight, Tromsø.

Spectrograph («*F*»).

Group		Date	Interval of Exposure	Elevation angle
1	Z	24 3.1952	19.25—19.58	90°
	H	»	20.03—20 38	20°
2	Z	1.4.1952	20 02—20.45	90°
	H	»	20.50—21.33	20°
3	Z	7.10 1952	17 50—18.12	90°
	H	»	18.15—18.49	20°
4	Z	8.10 1952	17.46—18 08	90°
	H	»	18.10—18.48	20°
5	Z	16.10 1952	17.05—17.39	90°
	H	»	17.41—18 11	20°
6	Z	27.10 1952	17.10—16.53	90°

Type of Plate: Kodak 103 a T.

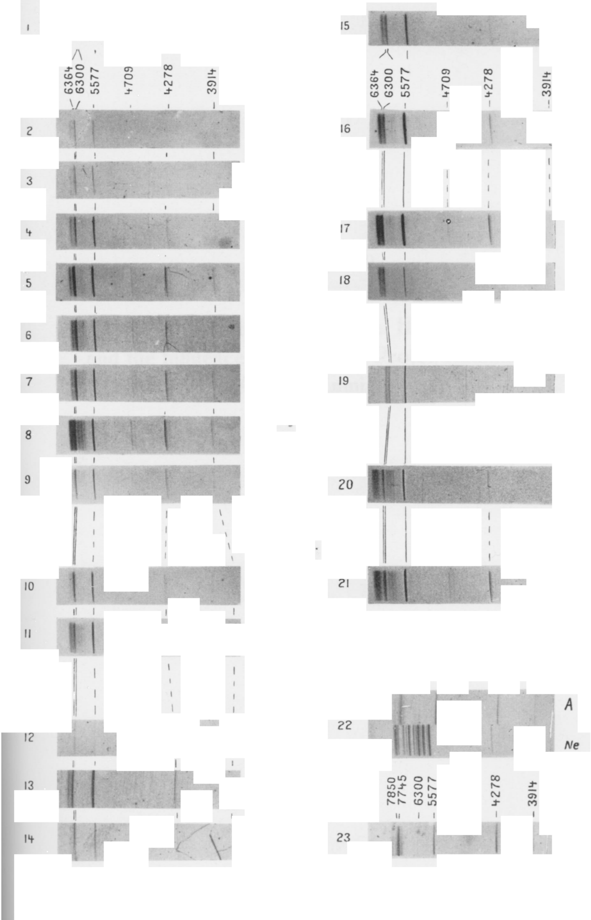
Plate V.



Explanation to Plate.VI
Aurorae at Oslo. Spectrograph (*C*).

Sp No.	Sort of Plate	Date	Interval of Exposure	Height	Direction	Remarks on Auroral Type
1	Agfa ISS Sensitized with NH_3	9.11.45	18.00—20 00	14°	N	Dif. A
2		25.3.46	20.10—20.22	10°	WNW	Twilight
3	»	»	20.22—20 34	»	»	»
4	»	»	20.35—21.05	»	E	Bottom of R
5	»	»	21.05—22 05	55°	SW	Topps of R.
6	»	»	22.15—23.10	12°	N	Lower limit A and Dr.
7	»	»	23.10—00.45	50°	NE	R, Fl. Aur.
8	»	»	00.45—02.40	8°	N	Lower Lim. Dif.A
9	»	»	02.40—04.45	90°		Corona
10	»	28.3.46	23 10—00.45	75°	N	Topp R.
11	»	»	00.50—02.00	10°		Bottom R.
12	Ilford H P. 3	17.4.47	21.50—22.50	51°	»	Topp R
13	»	»	22 50—01 05	15°	NE	Bottom R.
14	»	»	01.05 —03.00	35°	N	R & A
15	»	18.9 47	20.45—01 20	11°	»	Lower Lim. Dif.A
16	»	25.9.47	20.45—04.10	19°	»	A & Dr
17	»	2 10 47	20.45—01.25	25°	»	Lower Lim. Dif.A
18	»	»	01.25—03.30	30°	»	Upper »
19	»	21 10 48	21.10—23.10	25°	»	A
20	Eastman 103 F	19.11 47	21.40—01.15	15°	»	Upper Lim. A.
21	»	13.3.48	21.30—04.00	16°	»	Dif A & R.
22	Eastman I—L	3.2.49	22.45—06.30	40—70°	»	A & R
23	»	17.3 49	20.40—02.25	»	»	All sorts

Plate VI.


1
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4278
3914
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21
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22
Ne
7850
7745
6300
5577
4278
3914
23