CONTINUED INVESTIGATIONS ON THE SPECTRA OF AURORA AND TWILIGHT AND THE IONOSPHERIC TEMPERATURE

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(Manuscript received December 10th, 1949.)

§ 1. **Introductory Remarks.**

The present paper deals with results of aurorae and twilight spectrograms taken for various purposes at the Auroral Observatory, Tromsø, during the years 1942—48. The spectrograms which are reproduced on the plates I and II fall into four groups:

1. Spectrograms of long exposure mainly taken for spectral analysis in order to detect and measure weak lines. For this purpose we used the big glass spectrograph, which has been described in paper 2 of the list and which will be called (B)*). The spectrograms obtained are shown on Pl. I No. 1 and 2.
2. Spectrograms taken to obtain the negative nitrogen bands with a dispersion and density suitable for measuring the ionospheric temperature at different altitudes and in a sunlit atmosphere. A glass spectrograph (A) (described in paper 1. § 2, fig. 1 Pl. IV), gave the band 4278 with suitable density and dispersion. The spectrogram obtained is shown on Pl. I No. 3.

   By means of the big quartz spectrograph (Q) (see paper 2, § 5, fig, 4) the band 3914 was obtained with suitable density and a fairly good dispersion. The spectrograms of this band are shown on Pl. I, No. 4, 5 and 6.
3. For the study of variations of spectral intensity distribution, auroral spectrograms were taken with a small glass spectrograph (a) of high light power, described in paper 1 § 2, fig. 3, A series of such spectrograms are shown on Pl. II, No. 12 (a—f).
4. Series of twilight spectrograms were taken with spectrograph (a) in rapid succession, first from zenith and then from a direction near the horizon, for the determination of the screening height (H_s) for the radiation causing the excitation of the yellow sodium line and for the determination of the upper limit (H_u) of the sodium layer, mainly responsible for the high intensity of the sodium D-doublet in twilight. The method was described in the papers 3, 4 and 5. A number of such series of twilight spectrograms are shown on Pl. II No. 1—11.

The essential data relating to the spectrograms reproduced on plates I and II are given at the end of the paper as an «explanation to the plates».

*) Compare § 6, fig. 5, 6, 7 and 8 of paper No. 2.

§ 2. **Results from the Spectrograms taken with spectrograph (B) (Pl. I No. 1 and 2).**

The spertrogram Pl. I No. 1 with an effective time of exposure of 36^h shows in addition to the green and red OI-lines the bands of the negative and 1st and 2nd positive group of nitrogen very distinctly, and, in addition, also a number of weak lines or bands can be seen on the photograpich negative, but probably not all of them can be seen in the reproduction.

The spectrogram No. 2 taken with the full length of the slit only shows the OI-lines and the strongest bands of the negative group and a few bands of the 1st positive group. The absence of the weaker lines is due to the short exposure (3^h). On both spectrograms the intensity of the red OI-doublet is small as compared whit that of the green OI-line. Wave-length measurements were undertaken only for the strongest spectrogram No. 1.

In the region of the long waves from the limit in red to the green line 5577, the lines and bands, which were observable in the comparator microscope were measured from the original negative directly.

In the region of short waves ($\lambda < 5577$) and also in the long-wave region, a number of lines or bands could be seen, which, however, were too weak to be measured directly from the negative. For this reason we tried to detect and measure the lines from photometer diagrams obtained with a Moll registering photometer.

In order to distinguish maxima due to lines from those due to irregularities in the photographic film, we took two sets of diagrams corresponding to different horizontal sections across the spectrograms. Only distinct maxima, having the same position on both diagrams, were measured.

The results are given in table I a for the region of long waves to the green auroral line, and in table I b for the short wave region.

Table I a.

λ from Spectr. No. 1. Pl. I		Previously observed	Interpretation
Measured from Negative	Measured from Photogram		
	6539	6543	
		6526	1.P.G.
6508	6518	6512	
6467	6473	6469	
	6455	6454	1.P.G., OI

Table I a (continued).

λ from Spectr. No. 1 Pl. I		Previously observed	Interpretation
Measured from Negative	Measured from Photogram		
6440		6441	OI
		6398	1.P.G.
6364	6366	6364	OI ($^3P_1 - {}^1D_2$)
6300,3	6300,3	6300,3	OI ($^3P_2 - {}^1D_2$)
	6225	6229	
	6192	6185	1.P.G.
	6172	6176	1 P.G.
6150	6147	6154	
		6139	
		6129	1.P.G.
6115	6114	6109	1.P.G.
	6067	6068	1.P.G.
	6048	6056	OI 6046
6006	6011	6010	1.P.G.
		6001	NI
	5998	5993	1.P.G., OI: 5995
5972	5975	5977	
		5967	1.P.G.
	5935	5948	
5893	5899	5892	NaI, (D_1, D_2)
		5867	1.P.G.
5834	5842	5835	1.P.G.
		5772	
		5751	OI, ε (1—16)
5729	5738	5743	
	5686		
5679	5676	5677	NII (5676)
5621	5624	5620	1.P.G.
5577,35	5577,35	5577,35	OI ($^1D_2 - {}^1S_0$)

Table I b.

Wave-length λ		Interpretation
Measured from Photogram	Previously Observed	
(5485)	5472	1.P.G.
(5327)	5332	
5263	5258	
5228	5230	
5201	5203	
(5168)		
(5087)	5080	
5052	5049	
5009	5006,7	OIII ($^1D_2 - {}^3P_2$)
(4994)	4987	NII
(4954)	4961	OIII ($^1D_2 - {}^3P_1$)
	4942	OII
(4927)	4927	OII

Table I b (continued).

Wave-length λ		Interpretation
Measured from Photogram	Previously Observed	
(4880)	4891	OII
(4870)	4873	OII
(4860)	4856	OII
(4818)	4812	NII
(4790)	4790	NII
4709	4709	N.G. (0—2)
4652	4652	N.G. (1—3)
4634	4633	NIII, NII
4613		
4596	4597	N.G. (2—4)
(4578)	4572,3	
(4570)	4565	
(4552)	4554,8	N.G. (3—5)
4536	4535	ε (3—15)
(4518)	4515	NIII
4493	4488	N.G. (5—7) NI
4462	4468	OII
4448	4452	OII
4435	4434	NII
4417	4415,2	OII
4371	4368,3	OI, OII
4347	4349,2	OII
	4346,5	2.P.G. (0—4), OII
(4330)	4335	OII, NI
4318	4319,5	OII
4295	4295	OII
4278	4278	N.G. (0—1)
4236	4236	N.G. (1—2)
4224	4226,3	NII
	4223	NI
4196	4200	N.G. (2—3)
(4170)	4172	OII
(4164)	4164	OII
4095	4093	OII, 2.P.G. (4—8)
4077	4076	OII
4058	4059	2.P.G. (0—3)
(4042)	4042	NII
3995	3997	2.P.G. (1—4) NII
3985	3983	OII
3938	3943	2.P.G. (2—5)
3914	3914	N.G. (0—0)
3884	3884	N G. (1—1) OII
3872	3874	OII
3805	3805	2.P.G. (0—2) OII
3755	3755	2.P.G. (1—3) OIII
3705	3711	2.P.G. (2—4)
3642		
(3618)		
(3598)		
(3576)	3578	2.P.G. (0—1)
3530	3536	2.P.G. (1—2)

In table I a the first column gives the λ-values directly measured from the negative, and the second, those measured from photograms. The wave-lengths of bands and lines previously measured are given in the third column. We notice that a considerable number of lines, too weak to be measured from the photographic negative, have been measured from the photogram, *and that all of them within the limit of* error correspond to bands or lines previously measured directly from the negative plates. Thus the additional lines detected on the photogram are, no doubt, real.

In the short wave region most weak lines were too weak to be measured directly from the negative and this part of the spectrum has only been measured from the photograms.

In the case where the coincidence of the maxima on the two photograms is not quite convincing, the λ-value found is put into brackets. It appears from the table, however, that with a few exceptions the λ-values measured correspond to values previously detected and measured from negatives. The following lines (5168, 4613, 3642, 3618, 3598) have not been previously detected. The question as to their reality can only be answered by means of further observations.

When, as in the present case, we have spectrograms with sharp lines and a fairly clear background, we think that the results here given will show that a photometric method, like that here adopted, can be used with advantage by the detection, separation and measurement of very weak lines.

§ 3. Auroral Spectrograms taken with the small Spectrograph (*a*). Pl. II No. 12 (a—f).

The series of spectrograms shown on Pl. II No. 12 (a—f) were taken during the nights Febr. 2—5, 1948. They only show the green and red OI-lines and the strongest negative nitrogen bands and a band in red probably belonging to the 1st positive group of nitrogen. They correspond to different observational conditions and we have therefore found it of interest to determine the relative intensity distribution. By means of spectrograms taken by the same spectrograph and the same types of plates from a ligth source of known intensity distribution, the apparent photographic intensity could be reduced to true relative intensities in the way described in previous papers e.g. in paper 1 § 11 and 12. The results are given in table II. The intensities are given in per cent of that of the auroral line, wich is put equal to 100.

Table II.
Relative Intensities of Auroral Lines and Bands from Spectrograms on Pl. II, No. 12.

Spectrum	Date	1. Pos Group	6300	5577	4278	3914	Type
a	2.2.48	19	41	100	9	21	Top of Rays
b	»	15	17	100	7	20	Diffuse Arcs
c	»	23	23	100		19	Arcs
d	4.2.		53	100			Sunlit A & R
e	»	14	25	100	7	16	A, R & Dr.
f	5.2.	19	22	100	5	10	Sunlit A & R

We would particularly call attention to the pairs of spectrograms (*ab*) and (*de*). Spectrum (*a*) corresponds to the tops of rays and (*b*) to the lower part of diffuse arcs. We notice the considerable increase of the relative intensity of the red OI-doublet with increasing altitude. Also the negative bands show the well-known altitude effect, but as the negative bands on this kind of plate appear very weak as compared with the green line, the effect cannot in the present case be measured with any great accuracy.

Comparing spectrogram (*d*) corresponding to sunlit aurora, with (*e*) corresponding to night conditions, we notice the enhancement of the red OI-doublet from aurorae in a sunlit atmosphere.

In the case of the spectrum (*f*) from a sunlit aurora taken the following evening, we have no night spectrum for comparison.

§ 4. Measurements of the Ionospheric Temperature.

Since the first quantitative determination of the temperature of the ionosphere based on the intensity distribution of the rotational bands of nitrogen were published in 1932 (1) a considerable number of measurements have been made. Until 1938 all measurements were based on the negative band 4278 obtained with the big glass spectrograph (*A*), and these spectra were taken during the night by directing the collimator towards the part where the auroral streamers had their maximum intensity — which is usually found near the lower limit. This means that the temperatures thus found correspond to aurora appearing in the night at a height interval of say 110—130 km (papers 4, 6, 7).

In order to account for the peculiar distribution of matter in the jonosphere — the slow rate at which the density diminishes upwards — it is most important to determine the ionospheric temperature at greater altitudes, and from sunlit aurora, which means from a part of the ionosphere exposed to sunlight.

The possible change of temperature with altitude can be investigated by taking spectrograms from near the tops of long ray streamers. As the luminescence in this upper part is quite weak, it is most essential to use a spectrograph of fairly high light power. We found, by using the quartz spectrograph (*Q*) that the strongest negative band 3914 could be obtained with a fairly moderate time of exposure, and that the dispersion was sufficient to give a fairly accurate temperature determination.

In 1938 we therefore began to use this instrument for temperature measurements, and the values found by the spectrograph (*Q*) were in satisfactory agreement with those obtained by means of spectrograph (*A*) (8, 9).

We also succeeded in obtaining the band 3914 by directing the collimator towards the tops of auroral rays and from sunlit aurorae (8, 9, 10). The results of temperature measurements made up to 1944 were given in paper (10) table VIII.

In 1946 we obtained with spectrograph (*Q*) three spectrograms of the band 3914, two corresponding to the lower and one to the upper limit (Pl. I No. 4, 5, 6) and with the spectrograph (*A*) we obtained a good spectrogram from sunlit aurorae (Pl. I No. 3).

The method of determining the temperature from the negative nitrogen bands have been dealt with in previous papers (1, 6, 7), but for the sake of convenience we shall recall to memory the basic formulae.

Let I_K be the intensity corresponding to the rotational quantum number K, then:

$$\log_{10}\left(\frac{I_K}{K}\right) = -\varkappa K(K+1) \qquad (1)$$

where

$$\varkappa = \frac{h^2 \log_{10} \varepsilon}{8\pi^2 JkT}.$$

Introducing the values of h, ε, J and k, we find:

$$T_\varkappa = \frac{1.2855}{\varkappa} \qquad (2)$$

Plotting $\log_{10}\left(\frac{I_K}{K}\right)$ against $K(K+1)$ we should get a straight line, the slope of which gives us $\varkappa$.

The curve $(I_K - K)$ has a maximum corresponding to a rotational quantum number K_m. From this the temperature should be found by the formula:

$$T_K = 2.96\, K_m(2K_m + 1) \qquad (3)$$

If the intensity distribution of the lines within the rotational band follows the Maxwellian law and the lines are well separated, we should have $T_K = T_\varkappa$. With the dispersion here used the individual lines are not separated, and mainly on account of overlapping T_K is always smaller than $T_\varkappa$. By taking spectrograms from light sources of known temperature with spectrographs of about the same dispersion, we have found the following formula for the corrected values T_{Kc} of the temperature:

$$T_{Kc} = 1.06\, T_K + 38\ (K^\circ) \qquad (4)$$

In the previous papers referred to, we have shown how to find an upper limit to the effect of overlapping. From the intensities I_K' corrected for overlapping, we find new values $\varkappa'$ and K_m', from which corresponding temperatures $T_\varkappa'$ and T_K' are found by means of the equations (2) and (3).

From the experiments with light sources of known temperature we find that $T_\varkappa'$ and T_K' are too high, and that in fact $T_\varkappa$ — within the limit of error — gives the true temperature of the source.

In order to compare results from ordinary aurora with those corresponding to the top of rays or to sunlit aurora, it is useful to compare the means values $T_m = \frac{1}{4}(T_K + T_\varkappa + T_K' + T_\varkappa')$, As a rule T_m is nearly equal to $T_\varkappa$ and should therefore also give nearly the true ionospheric temperature.

For each of the 4 spectrograms we have drawn 2 diagrams, shown on fig. (1 a, 1 b), (2 a, 2 b), (3 a, 3 b), (4 a, 4 b). One gives the curves $(I—K)$ and $(I'—K)$ from which the values K_m and K_m' are found. The second gives the straight lines

$$\left[\log_{10}\left(\frac{I_K}{K}\right) \rightarrow K(K+1)\right]$$

and

$$\left[\log_{10}\left(\frac{I_K'}{K}\right) \rightarrow K(K+1)\right]$$

from which $\varkappa$ and $\varkappa'$ are determined. The corresponding temperatures are also given on each diagram. The results are collected in table III.

Table III.

Measurements of Ionospheric Temperature at Tromsø 1946.

Spec.-graph	Pl. I No.	Exposure Interval	Effective Exposure	Band used	T_k	T_k'	$T_\varkappa$	$T_\varkappa'$	T (mean)	Remarks
Q	5	30.1—31.1	2h 0m	3914	182° K	261° K	218° K	262° K	231° K	Lower part
»	4	3.2—7.2	2h 15m	»	112 »	281 »	225 »	279 »	224 »	Top of Rays
»	6	19.2—21.2	2h 0m	»	172 »	290 »	238 »	313 »	253 »	Lower part
A	3	4.2—14.3	4h 10m	4278	195 »	261 »	204 »	257 »	229 »	Sunlit Aur.

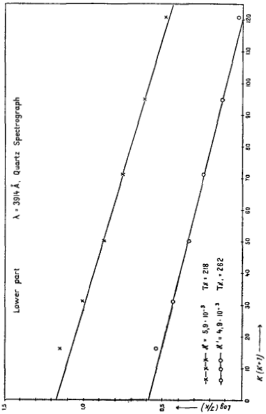


Fig. 1 a.

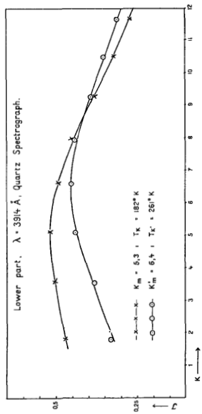


Fig. 1 b.

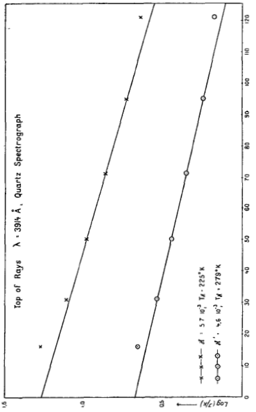


Fig. 2 a.

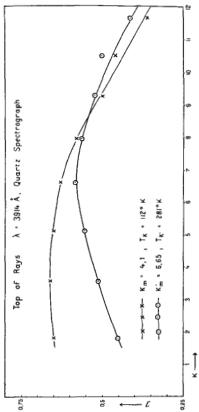


Fig. 2 b.

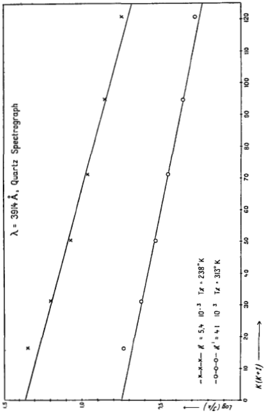


Fig. 3 a.

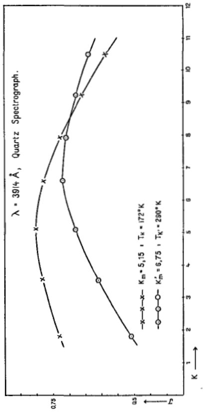


Fig. 3 b.

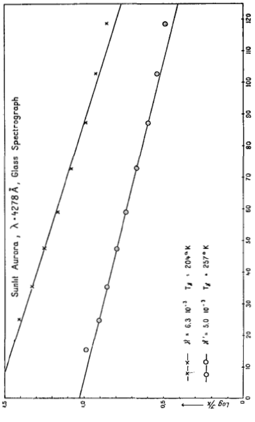


Fig 4 a.

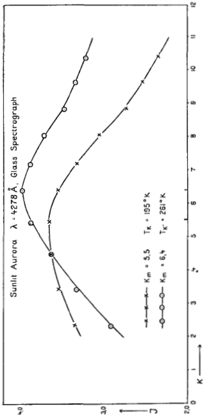


Fig. 4 b.

In table IV are given the ionospheric temperatures as yet measured from the upper limit and from sunlit aurorae.

Table IV.
Temperatures from upper Limit and Sunlit Aurorae.

Date	Spectrograph	Ionospheric Temperature	Conditions of Observations
16.10—28.10, 1938	Q	— 63° C	Upper Limit
26.2—2.4, 1941	»	— 33 »	Sunlit Aurorae
15 10—17.11, 1941	»	— 40 »	» »
3.2—7 2, 1946	»	— 49 »	Upper Limit
10 10—3.11, 1942	A	— 57 »	Sunlit Aurorae
4 2—14 3, 1946	»	— 43 »	» »

In table V we have given the mean values obtained by the two spectrographs (A) and (Q) for ordinary exposures (lower limit), for tops of rays (upper limit) and for sunlit aurorae.

Table V.
Mean Temperatures (T_m) obtained with Spectrographs (A) and (Q).

Conditions of Observations	Spectrograph	Number of measurements	T_m
Lower Limit	A	11	— 44,2° C
» »	Q	8	— 45,0° C
Means lower limit			— 44,6° C
Upper limit	Q	2	— 56,0° C
Sunlit Aurorae	Q	2	— 36,5° C
» »	A	2	— 53,0° C
Mean sunlit aurorae			— 45,0° C

We notice from table V:

1. That both spectrographs give on an average, practically the same ionospheric temperature.
2. The sunlit aurorae have given nearly the same temperature as aurorae under night conditions.
3. The temperatures found from the upper limit are on an average a little lower than those found for the lover limit. The difference may be due to errors, *but the measurements up to the present, have given no indication of an increase of temperature with increasing altitude in the ionosphere.*

§ 5. The Yellow Sodium Line in Twilight.

As stated in previous papers (3, 4, 5) the solar light, which is essential for the excitation of the sodium line in twilight, is absorbed by the lower part of the atmosphere. The upper limit (the screening height H_s) of the absorbing layer of the atmosphere as well as the upper limit (H_u) of the sodium layer, mainly responsible for the sodium light in twilight, are determined from the point of time τ, when the sodium line disappears at two different points in the sky. In our present and previous work, we have taken observations towards zenith and in a direction forming a small angle α with the plane of the horizon and which is situated in the azimuth plane of the sun.

Under these conditions (H_s) and (H_u) can be calculated from the formulae (5):*)

$$H_s = R\left(\frac{\cos\alpha \cos h_z}{\cos(\alpha + h_\alpha - h_z)} - 1\right) \quad (5)$$

$$H_u = R\left(\frac{\cos\alpha}{\cos(\alpha + h_\alpha - h_z)} - 1\right) \quad (6)$$

R is the radius of the earth, h_z and h_α are the heights of the sun at the moments τ_z and τ_α, when the D-line disappears at zenith and in a direction forming an angle α with the horizon respectively. When τ is given in Mean European Time (M.E.T.) the corresponding hour angle of the sun (t) is found by the formula:

$$t = 15\,(\tau - 1 + \triangle) + \lambda \quad (7)$$

The time equation ($\triangle$) is found from the Nautical Almanac, λ is the longitude of the observatory.

The values of h_z and h_α are found from the formula:

$$\sin h = \sin\delta \sin\varphi + \cos\delta \cos\varphi \cos t \quad (8)$$

The sun's declination δ is taken from the Nautical Almanac. For Tromsø Observatory, we have:

Latitude: $\varphi = 69° \, 39',8$
Longitude: $\lambda = -18° \, 56'.9$

*) As shown in a paper by one of us (Kvifte (13)) the equations given in paper (5) can be reduced to the simpler form here given.

Thus apart from fixing the direction of the collimator axis, τ_z and τ_u are the only quantities which have to be observed for the determination of H_s and H_u. They are found by taking two series of spectrograms one from the zenith and one in a direction rear the horizon in the azimuth plane of the sun. For each spectrogram in the series, we determine the intensity by means of a Moll registering photometer an plot the intensity as a function of time. We determine the time τ when the intensity is reduced to zero. Details with regard to the procedure are given in a previous paper (5).

The observational material to be dealt with consists of pairs of spectral series for 11 evenings. The spectrograms are reproduced on Pl. II No. 1—11. The essential data are given in the explanations to the plate at the end of the paper.

On 6 spectrograms (Nos. 1, 2, 3, 6, 9 and 11) the green auroral line appears together with the sodium D-line, but only on two (No, 6, 9) the red OI-doublet is observed. Further, the green auroral line appears more frequently on the spectrograms from near the horizon, than on those from the zenith.

In the cases when auroral lines have been observed, we have determined the intensity of the sodium D-line and the red OI-doublet relative to that of the green line, or the quantities I_{5893}/I_{5577} and I_{6300}/I_{5577}. The results are given in table VI.

Table VI.

Date	Pl. II No	Spectrum	I_{5893}/I_{5577}	I_{6300}/I_{5577}
19.10.42	1	Z	0,55	0
»	»	»	0,027	0
»	»	H a	1,86	0
»	»	» b	0,075	0
20.10.42	2	Z	0,61	0
»	»	»	0,25	0
»	»	»	0,38	0
»	»	H a	0,37	0
»	»	» b	0,20	0
»	»	» c	0,04	0
21.10.42	3	H a	0,82	0
»	»	» b	0,48	0
»	»	» c	0,13	0
»	»	» d	0,23	0

Table VI (continued).

Date	Pl. II No.	Spectrum	I_{5893}/I_{5577}	I_{6300}/I_{5577}
4.2 46	6	H a	1,66	0
»	»	» b	0,31	0
»	»	» c	0,055	0
»	»	» d	0,022	0,074
7.2 46	9	H a	1,32	2,93
»	»	» b	0,24	0,88
»	»	» c	0,19	1,13
»	»	» d	0,00	1,76
14 3.46	11	H a	1,93	0
»	»	» b	0,86	0

The values obtained for I_{5893}/I_{5577} give no indication of any simple correlation between the intensity of the D-line and the green auroral line. This is also evident from the fact that the auroral lines in many cases do not appear at all in twilight although the sodium line appears with the usual intensity. *This leads to the conclusion that the appearance of the auroral lines is due to aurorae,* a conclusion which is also supported by the fact that the auroral lines appear less frequent at the zenith than near the western horizon. *Thus it is certain that the solar radiation which is mainly responsible for the excitation of the D-doublet of sodium in twilight, does not excite the green and red auroral lines.* These lines are usually excited by a corpuscular type of solar radiation, or e.g. in the light of the night sky through certain recombination processes.

Also the intensity of the red OI-doublet relative to that of the auroral line calls for considerable interest. In all our spectrograms the auroral lines are emitted from a sunlit atmosphere, and it has been found, that, as a rule, a certain auroral type shows a greater value of I_{6300}/I_{5577} in a sunlit atmosphere than in the night.

From the last column of table VI and from Pl. II we notice that out of the 6 evenings, where the green line is observed, the red doublet only appears with observable intensity during two evenings, on Feb. 4th and 6th 1946 (series Nos. 6 and 9). During the other 4 evenings the green auroral line is not accompanied by the red doublet, although the green line e.g. on the spectral series Nos. 1 and 2 is very strong.

Thus the intensity of the red doublet relative to that of the green line is essentially governed by atmospheric conditions and excitation pro cesses, not directly due to sunlight, although sunlight in some indirect way produces a noticable, but not very great, enhancement of the red doublet.

Table VII.

Results of Twilight Observations at Tromsø ($\varphi = 69° 39.8'$, $\lambda = -18° 56.9'$).

Date	τ_0 (M.E.T.) Z	τ_0 (M.E.T.) H ($\alpha = 10°$)	t Z	t H	h_z	h_α $\alpha = 10°$	H_s	H_u	$\triangle \tau_z$	d
	h m	h m					km	km	min	km
19.10.42	17 18½	18 07	87°,32	99°,45	— 8°,33	— 12°,58	34	102	23	31
20 10	17 13	18 02	85,95	97,45	— 8,15	— 12,33	35	100	20	27
21.10	17 08	17 58	84,70	97,20	— 8,15	— 12,50	40	105	22	30
				Mean	— 8°,21	— 12°,47	36,3	102,3		30
31.1 46	16 17½	17 08	64,95	77,35	— 8,07	— 12,12	32,5	97	20	24
1.2.	16 22	17 13½	66,07	78,95	— 8,13	— 12,30	35	100	16	(20)
4.2.	16 33	17 22	68,70	80,95	— 8,08	— 12,10	31,5	96	20	25
5.2.	16 38½	17 26	70,07	81,95	— 8,25	— 12,20	27	94	20	25
6.2	16 40½	17 29	70,57	82,70	— 8,12	— 12,17	32	97	21	27
7.2.	16 42	17 32	70,95	83,45	— 7,95	— 12,17	39,5	102	14	(18)
13.3.	18 53	19 46	104,82	118,07	— 7,87	— 12,17	42,5	103	17	23
14 3	19 00	19 48	106,57	118,57	— 8,10	— 12,07	30	94	19	25
				Mean	— 8,07	— 12,16	33,8	97,9		25
				Total Mean	— 8,10	— 12,25	34,9	99,3		27

In table VII we have for each of the 11 evenings given the time-values τ_z and τ_α, the corresponding hour angles of the sun t_z and t_α and the heights of the sun h_z and h_α at the moment when the sodium D-doublet disappears on the twilight spectrograms. For each evening we have calculated the screening height (H_s) and the upper limit (H_u) for the sodium layer, which is mainly responsible for the sodium line in twilight.

We notice that the values of (H_s) and (H_u) found for 1942, are slightly greater than those for 1946. The total mean ($H_s = 34{,}9$ km and $H_u = 99{,}3$ km) is further seen to be somewhat smaller than those previously found from observations at Tromsø and Oslo (4,5).

The mean values found from previous observations will be seen from table VIII.

Table VIII.

Place of Observations	Year	H_s	H_u	Number of Determinations h_z	Number of Determinations h_α
Tromsø	1939	50 km	109 km	16	6
Oslo	»	58 »	119 »	4	7
»	1942—43	43,4 »	105,1 »	21	24

The heights H_s and H_u i table VIII are computed, partly graphically (Oslo and Tromsø 1939) and partly by means of the formulae (5) and (6), from *mean* values of h_z and h_α. The two last columns of table VIII contain the number of determinations of these quantities which has been used in the calculation of mean.

We see that the means of h_z and h_α are based on an unequal number of determinations. The most reliable procedure for determining H_s and H_u is to compute them for such days only, when it has been possible to obtain both a h_z- and a h_α-value (13). We have therefore in the material from Tromsø 1939 and from Oslo 1939 and 1942—43, picked out those days which fulfil this condition and calculated the heights for each day separately by means of the formulae (5) and (6).

Table IX contains the mean values thus found together with those from the present paper. The last column gives the number of days in which both h_z and h_α have been determined. These numbers will to a certain extent represent the weight of the respective means of H_s and H_u.

Table IX.

Place of Observation	Year	H_s	H_u	Number of days of observation
Tromsø	1939	30,6 km	93 km	5
Oslo	»	45 »	106 »	4
»	1942—43	42,5 »	104,5 »	20
Tromsø	1942	36,3 »	102,3 »	3
»	1946	33,8 »	97,9 »	8
Mean for Oslo		42,9 km	104,8 km	24
Mean for Tromsø		33,3 »	97,2 »	16
Total Mean		39,1 km	101,8 km	40

By comparing the results in tables VIII and IX it is seen that the mean heights obtained from the observations in 1939 are lowered considerably by the new procedure of evaluation while those from Oslo 1942—43 have remained practically unaltered.

The total means given in the last row of table IX ought to be the most accurate yet obtained.

It is to be remembered that the screening height H_s of about 40 km, in a satisfactory way corresponds to the height where the ozone concentration in the atmosphere has become extremely small, and that the most probable height of H_s yet found is in good agreement with the view *that the ultraviolet solar radiation strongly absorbed by ozone is essential for the excitation of the sodium line and that the screening effect is due to atmospheric ozone.*

The mean value of H_s for Tromsø is somewhat lower than that obtained at Oslo. The difference seems to be too great to be due to errors. If the effect is real, it should mean that the height of the ozone layer in the atmosphere, decreases with increasing latitude. This view is supported by diagrams given by Gøtz (14), p. 288, fig. 32) showing that the maximum ozone concentration is considerably higher at Arosa than at Tromsø.

The principal errors in the determination of (H_s) and (H_u) is due to errors in the angle (α) and in the determination of the (τ_z) and (τ_α) (13).

We are now going to improve the devices for fixing exactly the collimator axis at any desired angle. In order to increase the accuracy by the determination of the time, when the D-line vanishes, we intend to use spectrographs of greater light power in order to diminish the time of the exposure.

In a recent letter to Nature (11) one of us (Vegard) proposed a method for the determination of the thickness of the sodium layer, which is mainly responsible for the strong yellow line in twilight.

The method is based on a simple interpretation of the way in which the intensity of the D-line varies with times. This variation usually shows the following feature: After the twilight sets in, the intensity of the D-line remains nearly constant for some time, after which it diminishes rapidly and vanishes after a while $(\triangle\tau)$. This type of the variation is simply explained if we suppose the sodium to be restricted to a fairly thin layer of thickness (d).

As long as the shadow line for the effective light in the direction of the collimator is below this layer — the whole layer will be exposed to the effective radiation and the observed intensity of the D-line will remain nearly constant. At the time when the shadow limit cuts the lower part of the sodium layer, the intensity begins to diminish and becomes zero after a time $(\triangle\tau)$ when it cuts the upper border of the sodium layer at the altitude (H_u). For the zenith observations, this interpretation of the intensity variation leads to the following equation for the thickness (d) given in the paper referred to (11).

$$d = (R + H_s) \cos \varphi \sin h_z \cos \delta \sin t \triangle \tau_s \quad (9)$$

The Oslo spectrograms from 1942—43 (20 series) (5) gave values of (d) varying from 8,4 to 27,6 km, with a mean value of 16,2 km (11). The values of ($\triangle \tau_s$) and (d) derived from our present observations from Tromsø are given in the last two columns of table VII.

In this case the variations of the thickness (d) is fairly small and probably not greater than the possible errors, because the time ($\triangle \tau_s$) cannot be measured very accurately from the present observations.

The series from 1942 give a mean value of 30 km, those from 1946 give 25 km, for the thickness (d), and the total mean of all series in:

$$d = 27 \text{ km}.$$

Thus the sodium, mainly responsible for the emission of the yellow D-doublet in twilight, is mainly distributed in a height interval between say 73 and 100 km.

The appearance of the sodium line in the auroral spectrum shows that the sodium concentration does not necessarily vanish at an altitude (H_u), but it merely drops to a smaller order of magnitude.

The appearance of the yellow sodium doublet in the aurora is subject to great, rapid and irregular variations which are much more frequent and rapid than those observed in twilight. As stated in previous papers (3, 4, 5) these variations suggest that the sodium is entering the atmosphere from outer space and that sodium like hydrogen is coming in from the sun and being carried to the earth by means of long coronal streamers (12).

In connection with the considerable amount of registrations, measurements and calculations involved in the treatment at Oslo of this experimental material, our thanks are due to Mr. A. Omholt for valuable assistance, and to «Nansenfondet» for financial support.

List of Papers.

1. *L Vegard,* Geofys. Publ. (G. P.), Vol. IX, No. 11, 1932.
2. *L. Vegard,* G. P., Vol. X, No. 4, 1933.
3. *L. Vegard:* The Atmospheric Layer from which the Yellow Line in Twilight originates. Nature 145, 623, 1940.
4. *L Vegard* and *E. Tønsberg,* G. P., Vol. XIII, No. 1, 1940.
5. *L. Vegard* and *G. Kvifte,* G. P., Vol. XVI, No. 7, 1945.
6. *L. Vegard* and *E. Tønsberg,* G. P., Vol. XI, No. 2, 1935.
7. *L. Vegard* and *E. Tønsberg,* G. P, Vol. XII, No. 3, 1938.
8. *L. Vegard,* G. P., Vol. XII, No. 14, 1940.
9. *L. Vegard* and *E. Tønsberg,* G. P, Vol. XIII, No 5, 1941.
10. *L. Vegard* and *E. Tønsberg,* G. P., Vol. XVI, No 2, 1944.
11. *L. Vegard:* Thickness and Height of the Sodium Layer Responsible for the Strong Yellow Line in Twilight. Nature 162, 300, 1948.
12. *L. Vegard:* Coronal Phenomena and their Relation to Solar and Terrestrial Processes. G P., Vol. XVI, No. 1, 1944.
13. *G. Kvifte.* On the Distribution of Atmospheric Sodium. Recently communicated to the Academy of Science at Oslo to appear in the G. P. 1949.
14. *F. W. P. Götz:* Die vertikale Verteilung des atmosphärischen Ozons. Gerlands Beiträge zur Geophysik, 3, Suppl.b. 1938.

Explanation to Pl. I.

No.	Spectrogr.	Exposure		Plate	Remarks
		Interval	Effektive time		
1	Glass (B)	9.10.47—7.2.48	36^h	Kodak Superpan. press	He + H Compar. spectr.
2	» »	9.3.—30.3.48	3^h	Ilford H. P. 3	» » »
3	» (A)	4.2—14.3.46	$4^h\,10^m$	Ilford double X press	Sunlit Aurora
4	Quartz Q	3.2.—7.2.46	$2^h\,15^m$	» » »	Top of Rays
5	» »	30.1.—31.1.46	$2^h\,00^m$	» » »	Arcs (lower limit)
6	» »	19 2.—21.2.46	$2^h\,00^m$	» » »	Aurora, night cond.

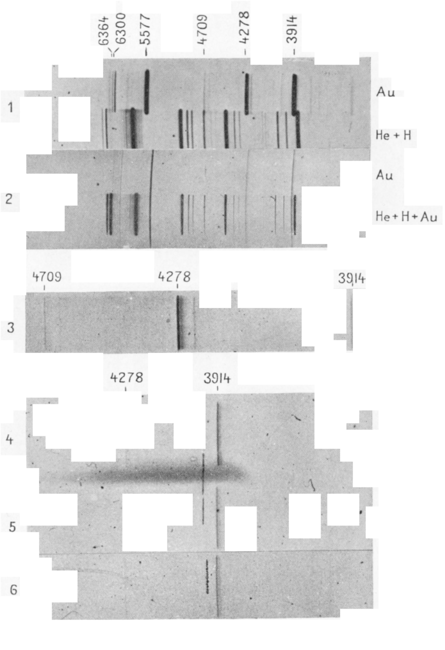
Explanation to Pl. II.

Sprectrograms taken at Tromsø with small glass spectrograph on Agfa I.S.S. plates. Series No 1—11 Twilight, No.—12, Aurora.
Z. means observations towards zenith. *H* means obs. near the horizon ($\alpha = 10°$).

Series no.	Date	Direction	Time Interval of Exposure of Series	Remarks
1	19.10.1942	Z	16 50—17.30	Aurora present
		H	17.33—18.13	» »
2	20.10.42	Z	16.43—17.16	» »
		H	17.16—17.57	» »
3	21.10.42	Z	16.41—17.20	» »
		H	17.22—18.02	» »
4	31.1.46	Z	15.50—16.20	» absent
		H	16.20—17.00	» »
5	1.2 46	Z	16.02—16.30	» »
		H	16.30—17 20	» »
6	4.2.46	Z	16 06—16.36	» present
		H	16.36—17 30	» »
7	5.2.46	Z	16.16—16.52	» absent
		H	16.53—17.44	» »
8	6.2.46	Z	16.16—16.52	» »
		H	16.52—17.40	» »
9	7.2.46	Z	16 18—16.54	» »
		H	16 54—17.42	» present
10	13.3.46	Z	18.33—19.03	» absent
		H	19.12—19 36	» »
11	14.3.46	Z	18.38—19 10	» »
		H	19.11—19.44	» present

No. 12. Auroral Spectrograms.

Spectr.	Date	Direction	Height	Exposure	Type
a	2.2.48	N—N W	ca. 50°	21 00—22.14	Top of Rays
b	»	S	» 30°	22.15—23 20	Diffuse Arcs
c	»		» 90°	23.25—00.30	Arcs
d	4.2 48	W	» 20°	17.50—18.15	Arcs & Rays sunlit
e	»	»	» 30°	18.15—02.00	A & R night condition
f	5.2.48	»	» 30°	17.13—18.00	A & R Sunlit


6364
6300
5577
4709
4278
3914
1
2
3
4
5
6
Au
He + H
Au
He + H + Au
4709
4278
3914
4278
3914

Pl. II.