THE WAVELENGTH OF THE GREEN AURORAL LINE DETERMINED BY AN INTERFEROMETER METHOD

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(Manuscript received 13th April 1934)

§ 1. Introduction.

The fact that the green auroral line so greatly predominates in the visible part of the spectrum makes it possible to obtain interferometer fringes of this line without the use of the monochromator. If the light is strong enough for visual observations, we should be able to see the fringes and make measurements on them by simply directing the interferometer towards an auroral display; for the intensity of all other lines in the visible region is as a rule negligible as compared with that of the green line. In case we wish to photograph the fringes, we should have to remove the spectral region of short waves in order that light of high photographic effect should not mask the interferometer fringes formed by the light from the strong green line. The removal of the light of short wavelength may be simply effected by means of a yellow filter suitably selected.

Thus such an interferometer for the analysis and wavelength measurements of the strong green line simply consists of an interferometer etalon of some kind placed in front of the lens of a camera, when we wish to photograph the fringes, or in front of the objective of a telescope suitably constructed, in case we wish to make visual observations. As an interferometer etalon we may conveniently use either a Lummer-Gehrke plate or a Fabry-Perot etalon.

In connection with more extensive investigations of the auroral spectrum commenced in 1921[1], one of us (*V*) at the same time planned to make use of interferometer methods — first of all for the study of the strong green line in the way indicated — and possibly also for the investigation of other parts of the spectrum.

[1] Preliminary accounts of the results of these investigations lasting from 1922—26 were given in a number of papers, and a complete description will be found in a paper by L. Vegard published in Geophys. Publ. IX No. 11, 1923.

For visual observations, an interferometer consisting of a Lummer-Gehrcke plate in front of a small telescope was ordered in 1921 from Carl Leiss, Berlin. At the same time the necessary plates for a Fabry-Perot etalon to put in front of a camera lens of high light power for photographic records of the interferometer fringes, was ordered from Adam Hilger, London. The Lummer-Gehrcke instrument was tested at the Physical Institute, Oslo, and was found to give very sharp fringes of spectral lines from artificial light sources. When it was tried by one of us (*V*) for aurorae, first at Oslo and later on in March 1923 at Tromsø, it appeared that even strong aurorae gave a luminescence which was too faint to give observable fringes in the interferometer.

The Fabry-Perot interferometer consisted of two plane-parallel glass plates lightly silvered on one side. They were mounted in the usual way with the silvered surfaces facing each other and separated by a quartz cylinder 1 cm long, and exactly made by Hilger so as to make the silvered surfaces exactly parallel. The etalon was placed in front of a camera lens of light power (1 : 2).

Before this instrument was completed and tested, Babcock[2] in 1923 published his well-known paper, where he describes his measurements of the wavelength of the green line from the night sky luminescence, and where he had used an interferometer method essentially the same as that previously described and intended to be used for auroral studies.

Babcock assumed the green line from the night sky luminescence to be identical with the green auroral line, and he based his interferometer measurements on previous determinations of the green auroral line

[2] H. D. Babcock. Contrib. from Mount Wilson Obs. No. 259, 1923.

by Vegard[1], who found a value of 5577.6, and by Slipher[2] who found 5578. These values were probably correct to within 1 Å unit and sufficiently accurate for the determination of the whole part of the order number, and the fraction was found from the interference fringes. In this way Babcock obtained the wavelength 5577.350.

After Babcock's results had appeared, our work was devoted to the exploration of other parts of the auroral spectrum, and to experimental researches of importance for the interpretation of the auroral spectrum. Babcock's measurements, however, referred to the night sky luminescence, and it was still a matter of importance to make direct interferometer measurements of the green line of *ordinary polar aurorae*, in order to make sure that in both types of luminescence we are dealing with the same green line. In the case of aurorae, we might hope to be able to use interferometer methods for investigating also other parts of the spectrum.

As is well known, the aurorae polaris are produced by electric rays of some kind coming in from space. If the rays are composed of atoms or molecules, they might themselves emit light when they enter the atmosphere, and make collisions with atmospheric matter. Such lines would show a large Doppler effect. But even if all auroral luminescence is emitted from the gases present in the auroral region, the emitting centres might be given a certain motion through the impact of the electric rays which excite the luminescence. It is therefore a matter of importance to make accurate wavelength measurements, in order to find out whether the emitting centres on an average have a greater velocity along the auroral streamers than in a direction perpendicular to them. This can be done by comparing spectra from aurorae near the horizon with spectra corresponding to aurorae appearing near the magnetic zenith.

Investigations along these lines were included in the research programme for the new Auroral Observatory at Tromsø. Instead of using a Fabry-Perot etalon consisting of two plane parallel glass plates as previously described, we now intended to use etalons consisting of a single plane parallel quartz plate, lightly silvered on both sides. The glass plates of our first etalon were covered with a silver layer of the usual density; but these layers were too thick for the faint auroral luminescence.

Two quartz plates were obtained from A. Hilger, one 2.5 mm and the other 5.0 mm thick approximately. After having tested several gold and silver coatings, we finally found a silver layer which combined fairly high transparency with good definition of the fringes. The optical thickness of each of the two quartz plates was measured at the National Physical Laboratory. All necessary data relating to the optical properties of the quartz etalons will appear from the report from this laboratory given in the next paragraph.

§ 2. "Report on the measurements of two quartz etalons.

For:

Messrs. Adam Hilger Ltd.

Description:

Each etalon consists of a natural quartz plate with optically plane and parallel faces, coated with thin semi-transparent silver films. The nominal thicknesses of the two etalons are 2.5 mm and 5 mm respectively, and their diameters are approximately 5 cm.

Examination for planeness and paralellism.

The errors of flatness of the individual surfaces do not exceed 0.1 band and in mercury green light up to 3 mm from the edges.

The etalons were examined for optical parallelism by illuminating them in turn with a beam of mercury green light of limited aperture. The diameters of circular interference fringes were observed in light transmitted through various regions of the etalons, the etalons being supported in a vertical plane without strain. On the accompanying diagram (Fig. 1)[3] each dot represents the centre of a circle about 14 mm diameter on the actual etalon, and the associated figure indicates the variation, of order of interference in mercury green light, referred to the central region as zero. It will be seen that the 2.5 mm etalon is constant in order of interference to 0.1, while the 5 mm etalon is constant to 0.12.

Measurement of optical thickness.

The optical thicknesses of the two etalons were measured in terms of four standard radiations whose accepted wavelengths in dry air, at 15° C and 760 mms pressure containing a normal amount of carbonic acid gas, are:

[1] L. Vegard. Vid.-Akad. Skr. Oslo, I No. 13, 1916. Geophys. Publ. II No. 5. 1921.

[2] V. M. Slipher. Astrophys. Journ. 49 p. 266, 1919.

[3] The figure is not reproduced.

Cadmium Red $\lambda_1 = 0.6438\ 4696\ \mu$
(International Standard)
Crypton Yellow $\lambda_2 = 0.5870\ 9154\ \mu$
(Pérard, Rev. d'Optique 7, 1, 1928)
Crypton Green $\lambda_3 = 0.5570\ 2892\ \mu$
(Pérard, Rev. d'Optique 7, 1, 1928)
Cadmium Green $\lambda_4 = 0.5085\ 8224\ \mu$
(Pérard, Rev d'Optique, 7, 1, 1928).

In order to calculate the wavelengths of these radiations in natural quartz at a particular temperature, it is first necessary to reduce the values in air to vacuum, then assuming a knowledge of the refractive indices of natural quartz for the ordinary ray at that temperature, the wavelengths in quartz may be calculated by means of the relation:

$$\lambda_q = \frac{\lambda \text{ vac}}{\mu_q},$$

where λ_q = wavelength in quartz at t° C
μ_q = refractive index of quartz at t° C
$\lambda_{vac.}$ = wavelength *in vacuo.*

The values of the wavelengths *in vacuo* were calculated by means of the following formula for the refractive index of dry air, containing a normal amount of carbonic acid gas:

$$(\mu_a - 1)\, 10^6 = \left[288.069 + \frac{1.4787}{\lambda^2} + \frac{0.03161}{\lambda^4}\right] \frac{h}{760} \frac{1}{1 + 0.003716\, t}$$

where μ_a = refractive index of air,
λ = wavelength in air, microns,
h = barometric height in mms,
t = temperature in degrees Centigrade.

The formula quoted is due to Pérard (Trav. et Mem. du B. I. P. M. XVIII, 42, 1929). From this the wavelengths *in vacuo* may be calculated, remembering that the standard values are for air at 15° C, and 760 mms pressure, and that $\lambda_{vac} = \lambda_a \mu_a$.

Thus, *in vacuo*

$\lambda_1 = 0.6440\ 2493\ \mu$
$\lambda_2 = 0.5872\ 5427\ \mu$
$\lambda_3 = 0.5571\ 8360\ \mu$
$\lambda_4 = 0.5087\ 2399\ \mu$.

Pérard has obtained accurate values for the refractive index of natural quartz etalons cut with their optical faces accurately normal (within 2 or 3 minutes of arc) to the optical axis (Jour. de Physique, Serie VI, VIII, 344 (1927). At 15° C, the mean values for the four radiations are:

λ_1 .... $\mu_q = 1.542{,}706{,}48$
λ_2 .... $\mu_q = 1.544{,}754{,}65$
λ_3 .... $\mu_q = 1.546{,}068{,}35$
λ_4 .... $\mu_q = 1.548{,}655{,}21$

Pérard (loc. cit.) also gives the variation of the refractive index with temperature:

$$\mu_t = \mu_0 + ht$$

where μ_t = refractive index of quartz at $t°$ C
μ_0 = —»— —»— 0 C

$$h = a + \frac{b}{\lambda}$$

in which λ = wavelength in microns, value in air

$a = -\ 6.95 \cdot 10^{-6}$
$b = +\ 0.58 \cdot 10^{-6}$ micron.

From these equations, the laws of variation of refractive index with temperature for the four radiations may be calculated:

λ_1 ...... $\mu_t = 1.542{,}797{,}08 - 0.000{,}006{,}04 \cdot t$
λ_2 ...... $\mu_t = 1.544{,}844{,}20 - 0.000{,}005{,}97 \cdot t$
λ_3 ...... $\mu_t = 1.546{,}157{,}00 - 0.000{,}005{,}91 \cdot t$
λ_4 ...... $\mu_t = 1.548{,}742{,}36 - 0.000{,}005{,}81 \cdot t$

The optical thicknesses of the two plates were measured by illuminating them with a convergent beam of radiations from a cadmium lamp and a crypton lamp, either source being directed on to the etalons as desired. The whole aperture of each etalon, up to 3 mm from the edge, was utilised. A real image of the circular interference fringes, produced in light transmitted by the etalons, was focussed on the wide slit of a monochromator which had a camera substituted for the usual second slit. In this way a photographic record was obtained of the four radiations on which were superposed images for the corresponding circular interference patterns. The diameters of 5 rings in each radiation were subsequently measured on a travelling microscope comparator, and from these measurements the excess fraction was calculated. With a knowledge of the approximate thickness of the two etalons, which has been obtained by mechanical measurements before the etalons were silvered, and the wavelengths calculated according to the method already described, the order of interference may be derived by the method of exact fractions usually applied to Fabry-Perot etalons.

In Tables 1 and 2 are given the results of the measurements of the optical thicknesses of the two etalons.

Table 1.

Optical Thickness of 2.5 mm etalons.

Temperature of Standardisation .... 19.68 °C				
Approximate Thickness, measured by Mechanical Means 2.513 mm				
	λ_1	λ_2	λ_3	λ_4
Observed orders of Interference	12.034.506	13,215.437	13,940.504	15,293,994
Calculated Wavelengths at 19,68 °C (Micron)	0.4174 7198	0.3801 6710	0.3603 9388	0.3284 9980
Optical Thickness mm	2.512,034	2.512,037	2.512,036	2.512,037
Mean value of Optical Thickness at 19.68 °C = 2.512,036 mm.				

Table 2.

Optical Thickness of 5 mm etalon.

Temperature of Standardisation .... 19.87 °C				
Approximate Thickness, measured by Mechanical Means 5.0175 mm				
	λ_1	λ_2	λ_3	λ_4
Observed orders of Interference	24,035.073	26,393.544	27,841.645	30,544.822
Calculated Wavelengths at 19.87 °C (Micron)	0.4174 7229	0.3801 6738	0.3603 9414	0.3285 0003
Optical Thickness mm	5.016,988	5.916,982	5,016,983	5.016,987
Mean values of Optical Thickness at 19.87 °C = 5.016,985 mm.				

Reference to the paper by Pérard (loc. cit.) shows that the refractive index for the ordinary ray in natural quartz varies with different specimens by about three parts in one million. For this reason the probable errors associated with the values of optical thicknesses are ± 0.000,004 mm in the case of the 2.5 mm etalon, and ± 0.000,008 for the 5 mm etalon. Taking into account the additional errors of observation, the total errors associated with the values in terms of millimetres are:

± 0.000,005 mm for the 2.5 mm etalon,
± 0.000,010 mm for the 5 mm etalon.

With regard to the values of the orders of interference, since these are observed quantities and do not involve any assumption concerning the refractive index, the errors are smaller, and are probably less than ± 0.01 in each case.

The etalons may be regarded as suitable for observation of faint sources, and were actually standardised under definitely faint source conditions. Fig. 2 a[1] is an enlargement of a photograph of fringes in cadmium radiations, due to the 2.5 mm etalon. It will be observed that the interference phenomena are rather sharper than those shown in fig. 2 b[1], which were obtained from the 5 mm etalon. This difference is considered to be due to the silver deposits on the smaller etalon being of rather better quality than those on the larger etalon, and not to errors of flatness and parallelism.

The law connecting temperature and length in a direction along the optical axis of quartz is given by Pérard:

$$l_t = l_0 (l + 7.124\,t \cdot 10^{-6} + 8.202\,t^2 \cdot 10^{-9}).$$

Utilising this in addition to the data already quoted, it may be calculated that on raising the temperature of a 5 mm etalon from 15 °C to 20 °C, the order of interference for the crypton green line (λ_3) increases by only 0.5.

6th July 1931. (Signed.)"

Director.

[1] Fig. not reproduced.

§ 3. General remarks regarding the procedure followed by the wavelength measurements.

Let us consider rays of wavelength λ which fall on the quartz etalon Q (Fig. 1) under an angle of incidence (α). After having passed the etalon under the angle of refraction (β), the bundle leaves it under an angle (α). In the focus plane of the camera lens (L) the bundle strikes the photographic plate P along a circle with a radius (r) determined by the equation:

$$r = p \operatorname{tg} \alpha \qquad (1)$$

where p is the focus distance of the lens.

The difference of path between a direct ray and one which has been twice reflected from the silvered surface is:

$$\delta = 2\, e\, \mu_\lambda \cos\beta, \qquad (2)$$

where e is the thickness of the plate, μ_λ the refractive index of quartz for the wavelength and temperature considered. For the number (P) or the number of waves contained in the difference of path, we have:

$$P = \frac{\delta}{\lambda_v} = \frac{2\, e\, \mu_\lambda}{\lambda_v} \cos\beta. \qquad (3\,a)$$

The maximum order number P_0 corresponding to perpendicular incidence will be composed of a whole number (n) and an excess fraction (ε) and

$$\underline{P = (n+\varepsilon)\cos\beta.} \qquad (3\,b)$$

Maximum of light intensity is obtained when P takes the value of the whole numbers: $n, n-1, n-2 \ldots.$ And the corresponding values of β will be given by the equations:

$$\frac{n}{n+\varepsilon} = \cos\beta_1, \ \frac{n-1}{n+\varepsilon} = \cos\beta_2 \quad \text{etc.} \ldots. \qquad (4)$$

The values $\beta_1, \beta_2 \ldots.$ can be found from the diameters of the interference rings counted from the inner and outwards.

Knowing the focus distance p, the values of (α) are found from equation (1) and the corresponding (β) values from the relation:

$$\sin\beta = \frac{\sin\alpha}{\mu_\lambda} \qquad (5)$$

We now assume that we know the thickness (e) to within a fraction of a wavelength, and the wavelength with an accuracy of about 1. Ångström. From the equation (3 a) we can determine P_0 so accurately that the whole part of it (n) is known.

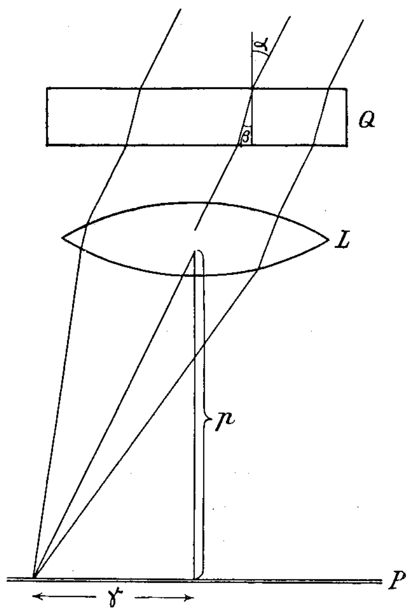


Fig. 1.

The determination of the diameters of the fringes and the corresponding β-values then gives us a number of equations (4) from each of which the excess fraction (ε) can be determined. Knowing the fractional part, a more accurate value of the wavelength is found by the formula

$$\lambda_v = \frac{2\, e\, \mu_\lambda}{(n+\varepsilon)}. \qquad (6)$$

This procedure for calculating (ε) would be somewhat laborious, and as long as the angles (β) and (α) are small, we can follow a much simpler procedure.

We put:

$$\cos\beta = 1 - \frac{1}{2}\beta^2 \qquad (7)$$

and the equation (4) takes the form

$$n - i + 1 = (n+\varepsilon)\left(1 - \frac{1}{2}\beta_i^2\right),$$

$$i = 1, 2, 3, \ldots.$$

or

$$i - 1 + \varepsilon = \frac{n+\varepsilon}{2}\beta_i^2. \qquad (8)$$

Applying this equation to two fringes with order number i and k, we obtain two equations from which (n) may be eliminated and the excess fraction (ε) is determined by the equation:

$$\varepsilon = \frac{(i-1)\beta_k^2 - (k-1)\beta_i^2}{\beta_i^2 - \beta_k^2} \qquad (9\,a)$$

This equation may be applied if β is so small that β^n when $n \gtreqless 4$ may be neglected. If quantities corresponding to $n \gtreqless 3$ may be neglected we obtain from equations (1) and (5)

$$\beta = \frac{r}{\mu_\lambda p} = \frac{d}{2 p \mu_\lambda}, \tag{10}$$

where (d) is the diameter of the interference ring. Using equation (10) the formula (9 a) for (ε) takes the very convenient form

$$\varepsilon = \frac{(i-1) d_k^2 - (k-1) d_i^2}{d_i^2 - d_k^2} \tag{9 b}$$

In order to determine λ_v from equation (6) we must know the value of the thickness (e) and the refractive index (μ_λ) under the conditions present. The thickness of the plate at the temperature t is:

$$e = e_0 (1 + \alpha t + \beta t^2), . \tag{11}$$

where e_0 is the thickness at 0 °C and:

$$\alpha = 7.124 \cdot 10^{-6}$$
$$\beta = 8.202 \cdot 10^{-9}.$$

From the data given in the report from the National Phys. Laboratory we find the thickness at 0 °C for the two etalons to be:

For etalon I $e_0 = 2.5116757$ mm
» » II $e_0 = 5.0162586$ »

The variation of the refractive index of quartz (μ_λ) with temperature is given by the equation:

$$\mu_t = \mu_0 + \left(a + \frac{b}{\lambda}\right) t, \tag{12 a}$$

where

$$a = -6.95 \cdot 10^{-6}$$
$$b = +0.58 \cdot 10^{-6}$$

when λ is measured in micron.

In our case we find it more convenient to use the formula:

$$\mu_t = \mu_0 (1 + \gamma_\lambda t). \tag{12 b}$$

The refractive index μ_0 for any wavelength can be deduced from the values given in the report by means of an interpolation formula of the form

$$\mu_\lambda = A + \frac{c}{\lambda - k}. \tag{13}$$

The variation of the quantities (e) and (μ) with temperature is very considerable and the accuracy to be obtained by our wavelength measurements essentially depends on the accuracy with which we are able to measure the effective temperature of the etalon. The arrangement for measuring the temperature will be described in a subsequent paragraph.

Under the conditions we have to work it is difficult to measure the absolute effective etalon temperature with a desirable accuracy in the ordinary way, by placing thermometers in the box containing the instrument. We therefore adopted a procedure by which we compare the interference fringes of the green auroral line with those from a line of known wavelength. This method may be said principally to consist in the determination of the effective temperature of the etalon by the interferometric picture obtained from a known spectral line.

For this comparison we used the yellow Neon line

$$\gamma = 5852 \cdot 488 \text{ Å I. U. } (15\ ^\circ\text{C } 760 \text{ mm}).$$

When the temperature has obtained a fairly constant value, the interferometer picture is taken of the Neon line, then the picture of the auroral line is taken and finally another picture of the Ne line is taken, all three pictures on the same plate. If the ε-value is the same in the two neon pictures this means that the temperature has kept constant. If there is some change, we may assume that the mean value of ε- for the two Ne-pictures corresponds to the average temperature of the etalon during the exposure of the auroral line. The temperature of the box is also measured at regular intervals, and we can plot the temperature curve as a control. If, as sometimes happens only one of the Ne-pictures is sucessful, we may use the plate if the auroral picture is good, for we can then reduce the ε-value of the neon picture to the temperature of the auroral picture by means of the observed temperature variations.

Introducing into equation (6) the temperature equations (11) and (12 b), we obtain:

$$\lambda_v = \frac{2 e_0 \mu_{0\lambda}}{(n + \varepsilon)} (1 + \alpha t + \beta t^2)(1 + \gamma_\lambda t). \tag{14 a}$$

Let this equation apply to the auroral line and let us denote the wavelength of the neon line with λ'. Then

$$\lambda'_v = \frac{2 e_0 \mu'_{0\lambda}}{(n' + \varepsilon')} (1 + \alpha t_1 + \beta t_1^2)(1 + \gamma'_\lambda t_1). \tag{14 b}$$

Assuming $t_1 = t$ and dividing the two equations, we obtain:

$$\lambda_v = \lambda'_v \frac{n' + \varepsilon'}{n + \varepsilon} \frac{\mu_{0\lambda}}{\mu'_{0\lambda}} (1 + (\gamma_\lambda - \gamma'_\lambda) t). \tag{15 a}$$

As the difference $\gamma_\lambda - \gamma'_\lambda$ is extremely small, the directly measured temperatures are sufficiently accurate to find the temperature correction of equation (15 a).

The fact that the expression for λ given in equation (15 a) is practically independent of temperature, does not mean that the temperature has little influence on the accuracy of the results, for the equation (15 a) is based on the assumption that the neon picture corresponds to the temperature existing when the auroral picture was taken. But in order that this may be fulfilled, a very accurate temperature control must be established.

If we suppose that the ε' value of the neon ring system corresponds to a temperature which differs from that of the auroral ring system, and we put

$$t_1 = t + \Delta t,$$

then the expression of the wavelength takes the form

$$\lambda_V = \lambda'_V \frac{n' + \varepsilon'}{n + \varepsilon} \frac{\mu_{0\lambda}}{\mu'_{0\lambda}}$$
$$[1 - (\alpha + \gamma + 2\beta t)\Delta t + (\gamma_\lambda - \gamma'_\lambda) t]. \quad (15\text{ b})$$

In this equation the influence of temperature enters with its full force. Instead of using equation (15 b) we can reduce the ε' value to the temperature of the auroral picture and use equation (15 a).

The wavelength in International Units (I. U.) can be found from the wavelength in vacuum by the formula:

$$\lambda_{\text{I. U.}} = \frac{\lambda_V}{\mu_a} \quad (16)$$

where μ_a is the refraction index of air at 15 °C and 760 mm pressure. For the calculations we wish to know the values of $\mu_{0\lambda}$, γ_λ and μ_a for the green auroral line (*a*) and the Neon line (*Ne*). The values are given in Table I.

Table I.

		Auroral line	Neon line
Wavelength in vacuum........		5578.899 Å (approx.)	5854.1103 Å
Refractive index of quartz at 0 °C ($\mu_{0\lambda}$)		1.5461239	1.5449194
Temp. cof. of μ_0 (γ_λ)		$-3.81.\ 10^{-6}$	$-3{,}86.10^{-6}$
$\mu_0 - 1$		$277.673\ 10^{-6}$	$277.203\ 10^{-6}$
Whole part of order number (n) at 0 °C	5 mm	27803	26476
	2.5 mm	13921	13256
$\frac{d\varepsilon}{at}$ at 0 °C	5 mm	0.0928	0.0874
	2.5 mm	0.0466	0.0438

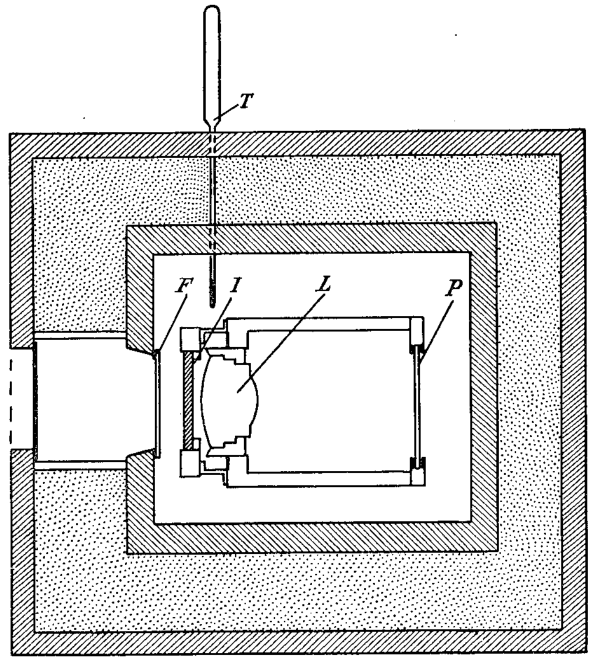


Fig. 2.

In the table we have given the wavelength reduced to vacuum. In the case of the auroral line the number is based on the wavelength in air 5577,35 which independent of Babcock's measurements must be approximately true. As we shall see later on, the approximate correctness of this value was confirmed by some spectrograms of the auroral line taken with a spectrograph of large dispersion.

In the table we also give for the two etalons the order number (n) corresponding to 0 °C for the two lines and the variation of the order number P or ε with temperature at 0 °C.

§ 4. Instrumental arrangements.

The general principle of the method of our measurements was dealt with in the introduction.

The instrumental arrangement for obtaining the fringes was similar to that which Babcock[1] had used in his interferometric investigation of the green line from the night sky.

The light belonging to the green auroral line was isolated by a suitable filter, passed through the Fabry-Perot etalon which was mounted in front of an objective of great light power and focussed on the plate.

The filter, — a Wratten filter No. 16, — and the photographic plate, (— Agfa isochrom), were the same

[1] Mt. Wilson Contr. No. 259, 1923.

which had been used for filter photography of the individual auroral forms in the light of the green auroral line[1]. Pl. III No. 1, 2 and 3 illustrate the transparency of the filter and the spectral sensivity of the plate used. No. 1 is an auroral spectrum upon which a Ne-spectrum is superposed. On account of the great sensivity in green of the plate, only the green line of the auroral spectrum is visible. No. 2 shows the spectrum of a glow-lamp after the light has passed through the filter, and No. 3 shows the spectrum of the glow-lamp without filter.

The objective used was an Ernemann »Ernostar« anastigmat of aperture ratio f/1,8 and with focal length 105 mm.

The instruments were mounted in a wooden box which was placed in another wooden box, and the room between them was filled up with heat-insulating material. Fig. 2 shows the arrangement.

F is the filter, *J* the Fabry-Perot etalon, *L* the "Ernostar" objective and *P* the photographic plate. The inner box was closed with the filter, the outer with a piece of plane glass.

As a variation of temperature causes variation in the thickness and of the refractive index of the etalon, constancy of temperature during the exposure is required. The etalon in this arrangement, — without any thermostat control, — appeared to work satisfactorily, and all the plates from the 2.5 mm etalon — except one — were taken with the instruments in this arrangement. In order to control and eliminate variation of temperature during the exposure, the following procedure of exposure was adopted. Before exposure a picture of the fringes of the yellow Ne-line was photographed on the plate. The plate was then moved without opening the box by means of a string. After exposure of the auroral line, a new picture of the Ne-line was photographed on the plate. The temperature during the exposure was read off on the thermometer *T*. Any slow variation of temperature will be detected when measuring the two Ne-line systems of fringes. On account of the considerable fluctuations of temperature in the open air, we cannot be sure that the temperature inside the box is constant all over, and it is also difficult to apply the true string corrections. Consequently the effective temperature of the etalon may differ from the one observed on the thermometers. We have therefore based our measurements on the pictures of the neon line which are taken on the same plate, and which give us the effective temperature of the etalon.

On some of the plates taken with the 2.5 mm etalon, the plateholder had been moved so far that only a part of the second Ne-picture came out on the plate, and the excess fraction ε- could not be measured for this Ne-picture with sufficient accuracy. In this case the ε-value of the first Ne-picture was reduced to the temperature existing during the auroral exposures by means of the observed temperature variations. The results from these plates are given in a separate table, but it seems that they are equally accurate as in the case when we have a Ne-picture both before and after the exposure of the auroral line.

The 5 mm etalon required longer exposures, and in that case we placed the wooden double box in another cubic box with a height of 1 m, in which the temperature was controlled by a thermostat arrangement consisting of a contact thermometer, relays and some elements for electric heating. The temperature was controlled by a thermometer which was placed over the etalon, and read off before and after the exposure.

§ 5. The wavelength of the green line redetermined from spectrograms taken with a large glass prism-spectrograph.

The spectroscopic measurements at Bosekop 1912 and at Oslo a few years later had given $\lambda = 5507.6$ Å I. U. as the most accurate value of the wavelength of the green line[2].

In March 1923 one of us[3] obtained a very successful spectrogram of the auroral line. The wavelength was measured independently by Vegard and Amanuensis Aars, who found the values 5577.2 and 5577.1 respectively. The dispersion of the instrument in that region being about 70 Å per mm the error should not exceed a few tenths of an Å unit.

In order to remove any trace of uncertainty regarding the wavelength measurements of the green line which forms the basis of the interferometer measurements, we decided to take a few more spectrograms of the green line with the same large glass spectrograph as used in 1923.

We obtained 1 successful spectrogram on Jan. 2. 1933, and two during the evening of Jan. 7. of the same year. Reproductions of these spectrograms are given in Pl. III, No. 4, 5, 6. On spectrogram No. 4

[1] Leiv Harang: Zs. f. Geophys. 7, 325, 1931.

[2] Cfr. L. Vegard, Geophys .Publ. II No. 5, 1933.

[3] L. Vegard, Geophys. Publ. IX, No. 11 p. 21.

the screen in front of the slit has been moved so that the comparison (Ne-He) spectrum and the auroral spectrum fall one above the other. In order to avoid the possibility that the moving of the screen might produce some change in the instrument, the two spectrograms Nos. 5 and 6 where taken in such a way that the screen all the time remained untouched. As a consequence the auroral line falls in between the lines of the comparison spectrum.

The wavelength was determined by the well known interpolation formula:

$$\lambda = \lambda_0 + \frac{a}{S+b} \tag{17}$$

S is the measured position on the plate of the auroral line relative to that of a known line, λ_0, a, b are constants to be determined by means of three known lines, selected so that two are on one side and one on the other side of the auroral line.

In order to eliminate possible errors by the interpolation, we determined the wavelength of the auroral line by using the two different groups (a) and (b) of known lines given below:

	Group (a)	Group (b)
λ_1	5852.49 Ne	5764.42 Ne
λ_2	5460.73 Hg	5400.56 Ne
λ_3	5015.68 He	5015.68 He

The results of our measurements are given in Table II. All plates give values which differ only by a few tenths of an Å unit. The average value 5577.35, which is in close agreement with previous spectrographic and spectroscopic determinations happens to be identical with Babcock's value. It is now sufficiently accurate as a basis of our interferometer measurements, and has been used for the determination of the whole part (n) of the order number.

Table II.

Date	Pl. No.	Wavelength		
		Group (a)	Group (b)	Mean
2/1 — 1933	Pl. III No. 4	5576.94	5577.59	5577.25
7/1 — 1933	Pl. III No. 5	5577.22	5577.61	5577.42
7/1 — 1933	Pl. III No. 6	5577.23	5577.23	5577.37
			Mean	5577.35

§ 6. Results from interferometer measurements obtained in 1931 and 1932 by means of the 2.5 mm etalon.

The first successful photographs of the interference fringes from the auroral line together with corresponding pictures of the yellow Neon line were obtained on Sept. 14th and Oct. 29th 1931. These two plates were measured and a preliminary note was published[1]. The wavelength was found to be $\lambda = 5577.343$. It appeared that a large number of maxima were obtained for the auroral line. On the best pictures of the auroral line we can count at least 40 maxima. A reproduction of one of the first interferometer pictures taken Sept. 14. 1931, is shown on Plate I, No. 1.

During the years 1931—1932, 14 additional pictures of the interference fringes of the auroral line were obtained with the 2.5 mm etalon. On some of these plates only one picture of the yellow neon line was good enough for measurements. In this case the fractional part ε for neon was reduced to the temperature of the auroral picture by means of the observed temperature variation. In one case (Febr. 2, 1931) a thermostat was used, so the temperature can be regarded as constant.

Some of the interference pictures are reproduced on Pl. II.

The three pictures taken on the same plate are arranged in the order in which they are taken (Ne_1, Au, Ne_2).

The wavelength measurements of all our plates were undertaken independently at Tromsø and Oslo. As the interference maxima are not sharp, there will be some small errors in the individual measurements of the ring diameters entering into the equation (9 b). The diameters were measured in two directions perpendicular to one another.

In order to eliminate errors in (ε) due to errors in the (d)-values, the fractional part ε was calculated for a large number of combinations of two lines. As the validity of the formula (9 b) is restricted to small values of (α), only the inner rings can be used.

By most of the Tromsø measurements the maxima (i) and (k), entering in the equation (9) were selected according to the rule:

$$i = k + 1. \qquad k = 2, 3 \ldots . 7.$$

[1] Nature. Jan. 2, 1932.

At Oslo we used the combination rule:

$$i = k + 3. \qquad k = 2, 3 \ldots . 6$$

The dimensions of the ring system will be seen from Table III, giving the diameters of the inner rings corresponding to the interferometer picture of the auroral line taken with the two etalons:

Table III.

Ring No.	2.5 mm etalon 15/I—1932	5 mm etalon 1/II—1933
	Diameter of rings	Diameter of rings
2	4.94 mm	3.31 mm
3	6.32 »	4.20 »
4	7.44 »	5.00 »
5	8.42 »	5.72 »
6	9.28 »	6.37 »
7	10.10 »	6.94 »
8	10.84 »	7.47 »
9	11.54 »	7.99 »

Table IV contains the results of our wavelength measurements corresponding to the plates on which we could only measure one neon ring system. Table V gives the results from those plates on which both Ne-ring systems could be measured. For each plate are given the ε-values for both the neon and the auroral line, as they were measured at Tromsø and Oslo. The last column contains the wavelength of the green line, found by taking the mean of the values obtained at Tromsø and Oslo, which are given in the two previous columns.

By this first series of measurements, the Tromsø values came out somewhat smaller than those at Oslo, but the average difference only amounts to some thousandth of an Å unit. This disparity may be due to difference with regard to the combination of rings and to the personal "equation".

From the wavelength values given in the last column we have for each of the tables IV and V calculated the mean error (σ) from the equation:

$$\sigma = \sqrt{\overline{(\lambda_i - \lambda_m)^2}}^{\,1} \qquad (18)$$

where λ_i is the observed wavelength and λ_m the mean given in the last line of each Table. The most probable error $\varrho = 0.67\,\sigma$ is given for each series of measurements.

[1] $\overline{(\lambda_i - \lambda_m)^2} = \frac{1}{n-1} \sum_1^n (\lambda_i - \lambda_m)^2$.

§ 7. Does the auroral line show any Doppler effect?

As already mentioned in the introduction, it might be possible that the atoms emitting the green auroral line may have a pronounced motion along the auroral streamers. As a consequence the auroral line should show a Doppler effect, which we can measure by comparing the wavelength obtained when the instrument is directed towards magnetic zenith, with those obtained from pictures taken in directions perpendicular to the streamers (magnetic lines of force).

During the spring 1933, a number of pictures of the auroral line in both these directions, were obtained with the 2.5 mm etalon. Pictures of the neon line were used for comparison in the usual way.

The pictures from two of the plates are reproduced on Pl. III, No. 7 and 8 corresponding respectively to a direction parallel and perpendicular to the ray streamers. The results are given in Table VI.

Comparing the average wavelength in the two directions we see that they are identical within the limit of error. The Doppler-effect cannot exceed 0.006 Å. As both directions give the same wavelength, we have calculated the mean of all the 7 measurements independent of the direction of the instrument. The total mean and the mean error calculated from equation (18) is given at the bottom of the table.

Taking the average of all values from our exposures with the 2.5 mm etalon given in the Tables IV, V and VI, we obtain for the wavelength of the green auroral line:

$$\lambda = 5577 \cdot 3584 \, (\pm \, 0.0063).$$

This average value is within the limit of error equal to that found by Babcock for the night sky luminescence, and as already pointed out in the preliminary note, it *can be regarded as proved that the green line of the night sky luminescence is identical with the strong green auroral line.*

§ 8. Measurements with the 5 mm etalon.

Comparing our values with those of Babcock, we notice that our values are a little higher. It was therefore of importance to undertake some further measurements with the 5 mm etalon for which the interference order number is doubled.

During Nov. 1933 seven plates were taken. Each plate contained two Ne and one auroral picture. The pictures from two of the plates are reproduced on Pl. III, No. 9 and 10.

Table IV.

2.5 mm etalon.

Date	Obs. Temp.			ε-Ne		ε-Aurora		λ = 5577 + table			
	Ne_1	Au.	Ne_2	Tromsø	Oslo	Tromsø	Oslo	Tromsø	Oslo	Mean	
18/11—1931 (a)	— 3.7	— 3.97	— 4.16	0.689	0.629	0.492	0.475	0.346	0.328	0.337	
18/11—1931 (b)	— 4.03	— 4.28	— 4.60	0.670	0.643	0.427	0.474	0.358	0.336	0.347	
23/11—1931 . .	— 0.08	— 0.98	— 1.88	0.821	0.862	0.605	0.636	0.345	0.352	0.349	
31/12—1931 . .	— 11.87	— 11.65	-	0.362	0.389	0.133	0.116	0.360	0.377	0.368	
7/2 —1932 . .	— 13.37	— 14.42	— 15.48	0.286	0.517	0.022	+ 0.960 [1]	0.348	0.386	0.367	
23/2 —1932 . .		Thermostat		0.785	0.808	0.598	0.564	0.349	0.374	0.361	
							Mean. .	0.351	0.359	0.355	(± 0 008)

[1] The whole number n reduced by 1.

Table V.

2.5 mm etalon. — Plates from 1931—32 with Ne-picture before and after auroral line.

Date	Temperature		ε-Neon		ε-Aurora		λ = 5577 + table			
	Ne_1	Ne_2	Tromsø	Oslo	Tromsø	Oslo	Tromsø	Oslo	Mean	
17/11—1931 (a)	— 1.62	— 2.00	0.733 0.768 } 0.751	0.820 0.798 } 0.809	0.577	0.581	0.343	0.366	0.355	
17/11—1931 (b)	— 1.97	— 2.13	0.735 0.714 } 0.725	0.713 0.758 } 0.736	0.550	0.577	0.343	0.338	0.341	
20/11—1931 . .	+ 0.06	+ 0.17	0.867 0.842 } 0.855	0.846 0.871 } 0.859	0.678	0.665	0.347	0.355	0.351	
16/12—1931 . .	— 4.39	— 4.87	0.655 0.691 } 0.673	0.684 0.726 } 0.705	0.482	0.467	0.348	0.368	0.358	
28/12— 1931. .	— 7.3	— 8.45	0.554 0.550 } 0.552	0.552 0.528 } 0.540	0.296	0.289	0.371	0.369	0.370	
1/1 —1932 . .	— 7.5	— 8.45	0.605 0.497 } 0.551	0.560 0.524 } 0.542	0.359	0.301	0.345	0.365	0.355	
5/1 —1932 . .	— 9.35	— 9.87	0.464 0.472 } 0.468	0.478 0.505 } 0.492	0.257	0.236	0.351	0.370	0.360	
15/1 —1932 . .	— 1.12	— 2.8	0.830 0.764 } 0.797	0.848 0.783 } 0.815	0.601	0.556	0.353	0.379	0.366	
						Mean. .	0.350	0.364	0.357	± 0.0060

Table VI.

2.5 mm etalon.

Direction nearly perpendicular to streamers (horizon)			
Date	λ = 5577 + table value		
	Tromsø	Oslo	Mean
20/1—1933........	0.368	0.369	0.3685
21/1—1933........	0.366	0.364	0.365
21/3—1933........	0.365	0.364	0.3645
Mean...	0.366	0.366	0.366

Direction nearly parallel to streamers (zenith.)			
Date	λ = 5577 + table value		
	Tromsø	Oslo	Mean
19/2—1933 (a)......	0.367	0.349	0.358
19/2—1933 (b)......	0.363	0.380	0.371
20/2—1933.........	0.347	0.363	0.355
24/2—1933.........	0.344.	0.366	0.355
Mean...	0.355	0.364	0.360

Total mean 5577.363 (± 0.0045).

Table VII.

5 mm etalon.

Date	ε-Neon		ε-Aurora		λ = 5566 + table value			
	Tromsø	Oslo	Tromsø	Oslo	Tromsø	Oslo	Mean	
1/11—1933	0.367 0.429 } 0.398	0.401 0.425 } 0.413	0.235	0.275	0.348	0.343	0.345	
3/11—1933	0.495 0.426 } 0.460	0.469 0.447 } 0.458	0.226	0.345	0.363	0.339	0.351	
6/11—1933 (a)....	0.481 0.421 } 0.451	0.446 0.493 } 0.470	0.307	0.349	0.345	0.341	0.343	
6/11—1933 (b)....	0.435 0.473. } 0.454	0.498 0.515 } 0.507	0.310	0.376	0.345	0.343	0.344	
7/11—1933	0.397 0.553 } 0.475	0.469 0.480 } 0.475	0.302	0.358	0.351	0.340	0.345	
8/11—1933	0.486 0.495 } 0.490	0.503 0.568 } 0.536	0.396	0.427	0.336	0.339	0.338	
22/11—1933	-	0.422 0.436 } 0.429	-	0.312	-	0.340	0.340	
				Mean...	0.348	0.341	0.3445	± 0.0027

The apparatus, consisting of camera and etalon, was kept inside a thermostat, where the temperature was regulated by electric heaters. The results obtained from these plates are given in Table VII.

It appears from Table VII that the wavelength values obtained with the 5 mm etalon are somewhat smaller and show a smaller probable error (ϱ) than those obtained with the 2.5 mm etalon. The considerable difference in average values would suggest that at any rate for one of the etalons, the results are effected by a small systematic error, probably due to some influence of temperature, not taken into account in our method of calculation.

As previously mentioned, we correct for temperature variation by assuming that the ε-values, which we find as the average of the two neon pictures, correspond to the temperature of the auroral fringe system.

Now we must take into account that the auroral picture requires a long exposure, and that the light intensity is most variable. Supposing that the temperature changes at a constant rate, and that the neon pictures are taken symmetrically with regard to the interval of exposure of the auroral line, even under these conditions the neon value of ε-derived from the two neon pictures need not correspond to the "effective" mean temperature of the auroral picture, because most of the auroral light may have hit the plate either at the beginning or end of the interval of exposure. Errors will also enter into our results, if the rate of change of temperature during the time between the exposure of the two neon spectra is not constant.

The accuracy obtained for the wavelength depends on the accuracy with which the ε-fractions are measured from the plate, and the accuracy with which we have determined the temperature; or rather the error we make by assuming the average ε-value of the two neon pictures to correspond to the "effective" average temperature of the auroral picture. The resulting error in the wavelength can easily be found from equation (15 b).

Differentiating we obtain with sufficient approximation:

$$\frac{d\lambda}{\lambda} = \pm \frac{d\varepsilon_1}{n_1} \mp \frac{d\varepsilon}{n} \mp (\alpha+\gamma+2\beta t)\, d(\Delta t) \qquad (19)$$

where $\Delta t = t_1 - t$, and t_1 is the average temperature of the system when the neon pictures were taken, and t the effective temperature during the exposure of the auroral line. The errors $d\varepsilon_1$ and $d\varepsilon_2$ ought to be evenly distributed on the positive and negative side, and give zero as an average.

As regards temperature, we have in our calculations put $\Delta t = 0$, which means that in equation (19) we have to put:

$$d(\Delta t) = \Delta t.$$

Now it is quite possible that there is a greater probability for Δt to be positive than negative, for after the first neon picture is taken, the temperature may change more rapidly than later in the night, when the temperature usually remains more constant. As a consequence t_1 must be greater than t or $\Delta t > 0$. This means that by putting $\Delta t = 0$ we obtain a too large value for the wavelength, and a systematic error of this origin would just explain the larger value obtained by means of the 2.5 mm etalon. The only safe way of diminishing the systematic error is to keep the temperature as constant as possible.

Comparing the results obtained with the two etalons, we find those obtained with the 5 mm etalon the more reliable, and for two reasons:

(1) Assuming that the ε-values are determined with about the same accuracy for both etalons, the errors in wavelength due to errors in ε should be twice as great for the thinner etalon. (2) In the case of the exposures made with the 5 mm etalon the instrument was kept inside a thermostat, and although we cannot guarantee the very highest degree of constancy, there should be no reason for a systematic error due to change of temperature.

As a matter of fact, we find that the values of the wavelength derived from the various plates taken with the 5 mm etalon are more constant than those derived from the pictures taken with the 2.5 mm etalon. For these reasons we consider the values obtained with the 5 mm etalon as the more reliable, and we do not think that we get nearer the true value by mixing the results obtained with the two etalons and then taking the mean value.

When the conditions and procedure of our observations are taken into account, the most probable wavelength of the green auroral line derived from our observational material will be:

$$\lambda = 5577 \cdot 3445 \text{ I. Å. U. } (\pm 0.0027).$$

§ 9. The sharpness of the interference fringes, its relation to the width of the spectral lines, and the temperature of the auroral region.

The sharpness of the interference fringes is mainly influenced by the following causes:

1. The reflecting power of the silvered surfaces, which determines the intensity curve corresponding to a perfectly homogenous radiation.

2. The natural width of the spectral lines, which means that the wavelengths are distributed according to some law, between the value $\lambda_0 - \delta_\lambda$ and $\lambda_0 + \delta_\lambda$, when $2\delta\lambda$ is the width of the line.

3. For the auroral line we have to use long exposures, and an increase of width may result from variations in temperature.

The question now arises regarding the possibility of determining the natural width $2\delta\lambda$ from the observed fringes. In order to determine the natural width, the breadth of the fringes due to the causes (1) and (3) must be small or at any rate not large, as compared with the breadth of the fringes resulting from the natural width.

The intensity distribution corresponding to a perfect homogenous radiation of wavelength λ is given by the equation[1]

$$I/I_0 = \frac{1}{1 + \frac{4\tau}{(1-\tau)^2}\sin^2\varphi} \tag{20}$$

and

$$\varphi = 2\pi\left(\frac{\delta}{\lambda} - n\right)$$

where I_0 is the maximum intensity corresponding to an optical difference of path equal to $(n \cdot \lambda)$, where n is a whole number, τ is the fraction of light reflected from the silvered surface in one reflection. We see that the distribution of intensity between two maxima essentially depends on the reflecting power τ.

In order to avoid too much reduction of intensity through the etalon, it was necessary to use a very thin silver coating on the quartz surfaces. This means that the reflecting power is considerably smaller than that of an ordinary polished silver surface.

From an estimate of the total reduction of intensity suffered by ordinary light when it passes through the etalon, we can find the reflecting power. Let

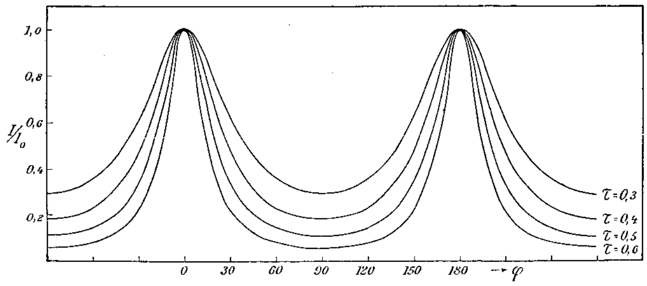


Fig. 3.

i_0 and i_1 be the intensity before and after the passage through the plate, then we can easily deduce the following equation:

$$\frac{i}{i_0} = \varkappa = \frac{[1-(\tau+a)]^2}{1-\tau^2} \tag{21 a}$$

which gives:

$$\tau = \frac{1}{1+\varkappa}\left\{1 - a \pm \sqrt{\varkappa(\varkappa + 2a - a^2)}\right\} \tag{21 b}$$

(a) is the fraction of light absorbed by the passage of one of the silver films. Now we may estimate that by passing the etalon, the light intensity in the yellow region is reduced about 1/3 or $\varkappa = \frac{1}{3}$. Putting $a = 0$ we get $\tau = 0.5$ while $a = \frac{1}{8}$ gives $\tau = 0.34$[2].

In Fig. 3 we have drawn the theoretical intensity curves calculated from equation (20) for some values of τ.

Registrams of the interference fringes of the green auroral line and of the neon line are given in Fig. 4.

Comparing the curves of Fig. 3 with the interference fringes and the curves Fig. 4, we notice that a value of (τ) of the estimated magnitude (between 0.3—0.4) would give an intensity distribution within the fringe-system identical with that observed. It is to be noticed that if the registered curves Fig. 4 were transferred to intensity curves, the maxima would be somewhat sharper. It follows from this comparison that the observed width of *the fringes can be explained as mainly due to the small reflection power of the silver film.*

Assuming on the other hand that the pictures were taken with etalons with so high reflecting power that the width of the fringes was mainly due to the natural width $2\delta\lambda$, then from the interference pictures

[1] Compare E. Gehrcke. Die Anwendung der Interferenzen in der Spektroskopie und Metrologie. Braunschweig. 1906, p. 39.

[2] It is to be remembered that a and τ vary with λ so the sharpness of the fringes varies with wavelength. In fact, by our etalons it is increased when we pass from violet towards red.

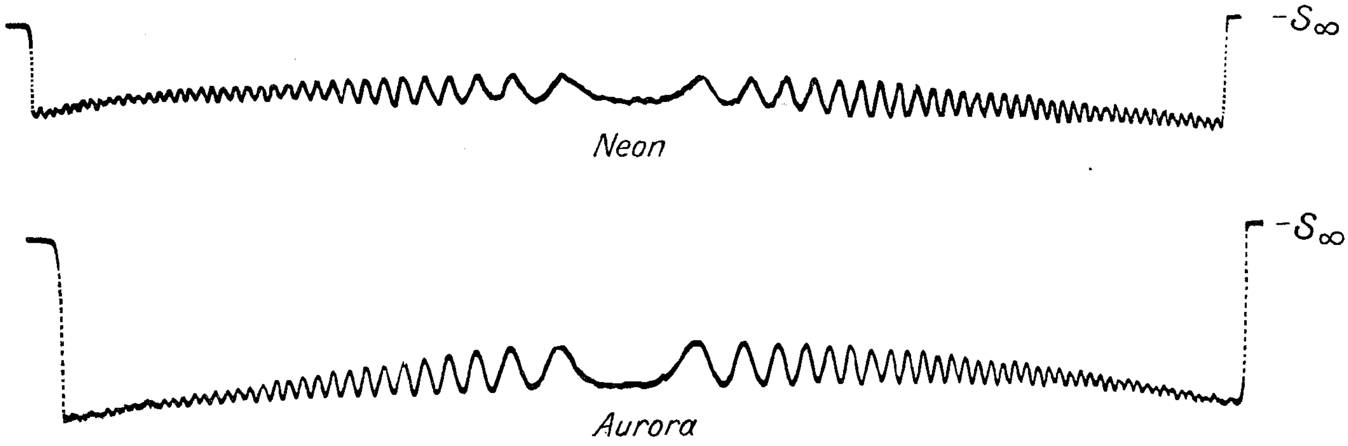


Fig. 4.

we can easily calculate that the width of the observed fringes would correspond to a width of the line of the order of magnitude $2\delta\lambda = 0.07$ Å. This width is by far too large to be real. If due to Doppler-effect from thermic motion, it would give a temperature for neon as well as for aurorae of several thousand degrees.

Also from these considerations we come to the conclusion that the width of the fringes is mainly determined by the intensity distribution given by a perfect homogeneous ray, when the small reflecting power of the etalon is considered. This is also in accordance with the fact that the auroral and neon line give about the same sharpness of the fringes (compare Fig. 4). This result means that the effect of the natural width of the spectral line is masked by the width due to the small reflecting power — and the broadening due to temperature variations of the etalon.

Unless we are able to obtain interferometer pictures with etalons of much higher reflecting power, we cannot determine the exact natural width of the green auroral line, but using etalons of high reflecting power, the time of exposure would be largely increased and the broadening of the fringes, due to temperature variations, would probably be more pronounced.

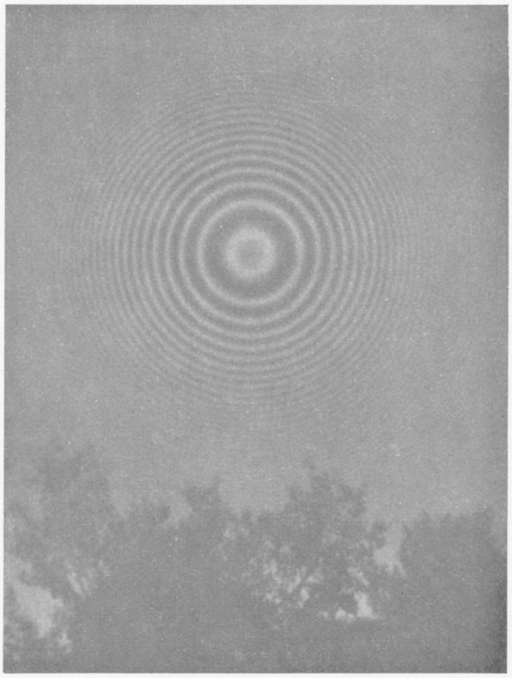
As long as we cannot determine the natural width, we have no means of determining the temperature of the auroral region from the green auroral line. All estimates made in this way can only give an upper limit of the temperature, but the true temperature may have any value below this limit.

The method which may be expected to give a fairly accurate temperature, is that previously described by one of us[1], and which consists in the determination of the intensity distribution within the R-branch of rotational bands belonging to the negative (or perhaps also the positive group) of nitrogen.

Our thanks are due to Mr. S. Stensholt B. Sc. for valuable assistance in the calculations carried out at Oslo.

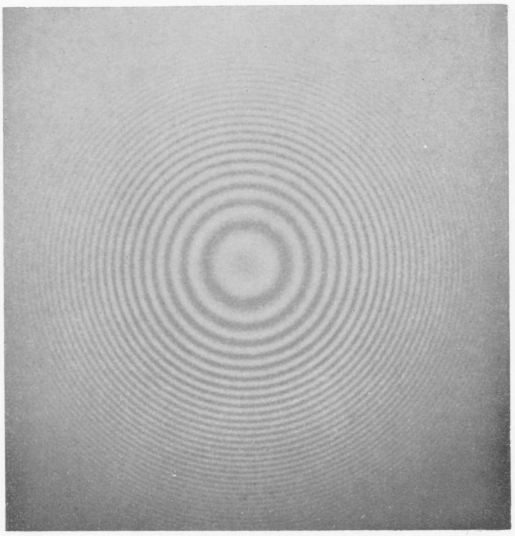
[1] L. Vegard, Geophys. Publ. IX, No. 11, p. 51. Terr. Magn. V. 37, p. 389, 1931.

1



Aurora
5577, 35

2



Neon
5852, 488

No. 1. Interference picture of auroral line obtained Sept. 14, 1931 with 2.5 mm etalon.

No. 2. Corresponding picture of the yellow neon line 5852,488.

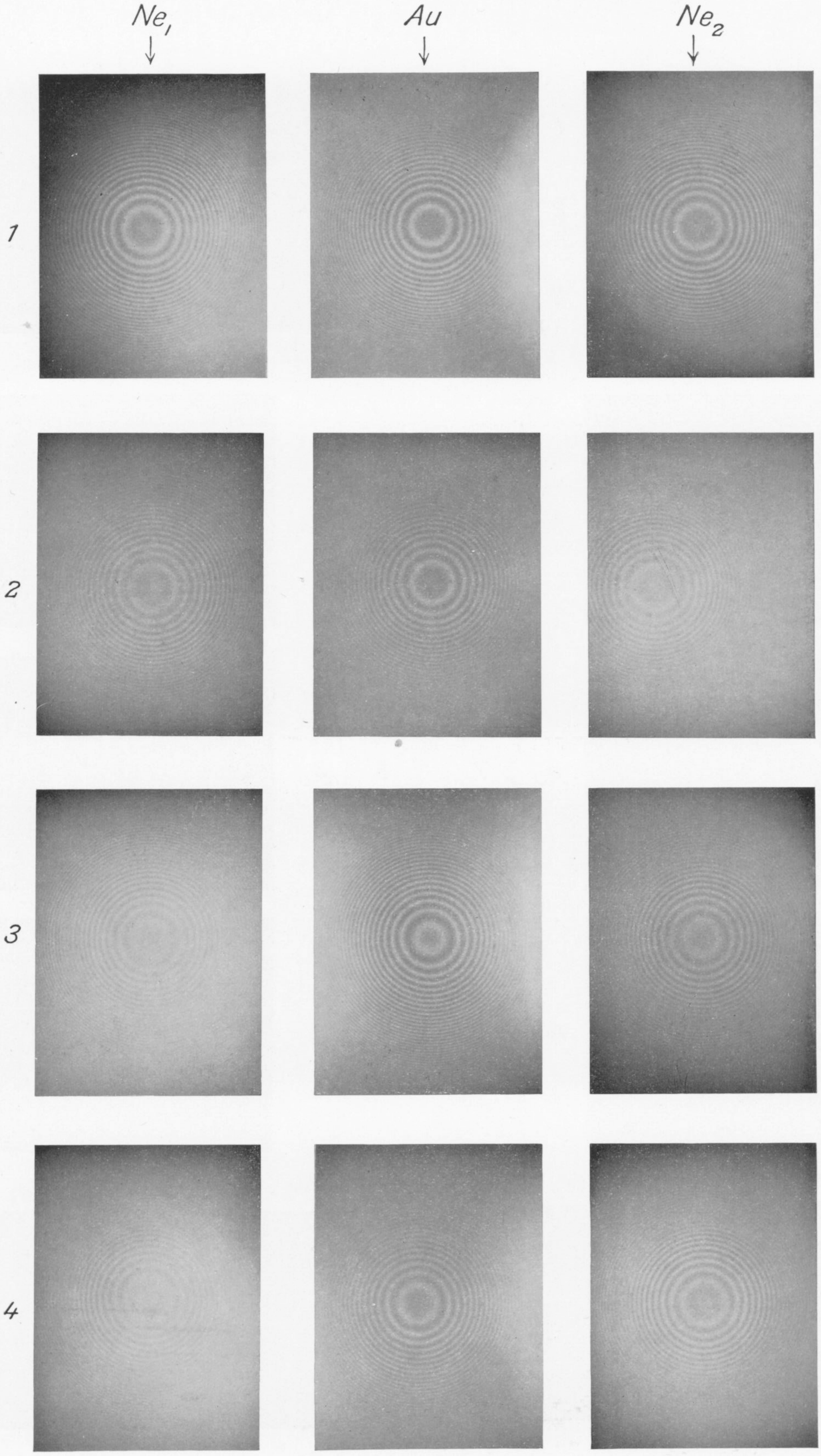
Explanation of Plate II.

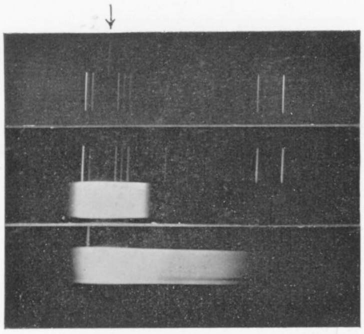
Pictures obtained with the 2.5 mm etalon. The three pictures arranged in the same horizontal row belong to the same plate with one neon picture Ne_1 and Ne_2 taken before and after the exposure of the auroral line (Au).

Group	No. 1	taken	Nov.	17,	1931.
,,	,, 2	,,	,,	20,	1931.
,,	,, 3	,,	Jan.	1,	1932.
,,	,, 4	,,	,,	15,	1932.

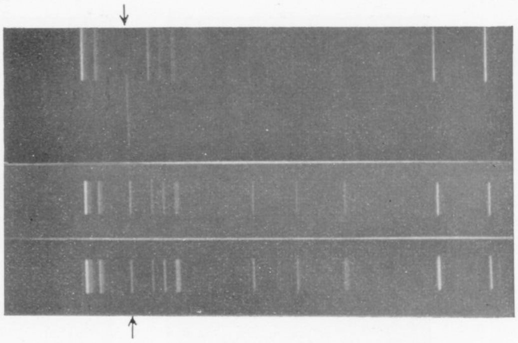
Explanation of Plate III.

No. 1—6. Spectra taken with large glass spectrograph.
No. 1. Spectrum of auroral line. Ne-He comparison spectrum.
No. 2. Spectrum of a glow-lamp with Wratten filter No. 16 in front of the slit.
No. 3. Spectrum of the same lamp without filter.
No. 4, 5 and 6. Spectrum of green auroral line with Ne-He comparison spectrum. No. 4 from Jan. 2, 1933 and No. 5 and 6 from Jan. 7, 1933.
No. 7. Group of interference pictures of the auroral line (Au) with corresponding Neon pictures. (Ne_1 and Ne_2) taken with camera directed towards zenith on Febr. 24, 1933. (2.5 mm etalon).
No. 8. Group of pictures of auroral line (Au) and corresponding neon pictures (Ne_1 and Ne_2) taken Jan. 20, 1933 with camera in a nearly horizontal direction. (2.5 mm etalon.)
No. 9 and 10. Group of pictures taken with 5 mm etalon of the auroral line (Au) and the neon line (Ne_1 and Ne_2). No. 9 taken Nov. 6, No. 10 on Nov. 7, 1933.

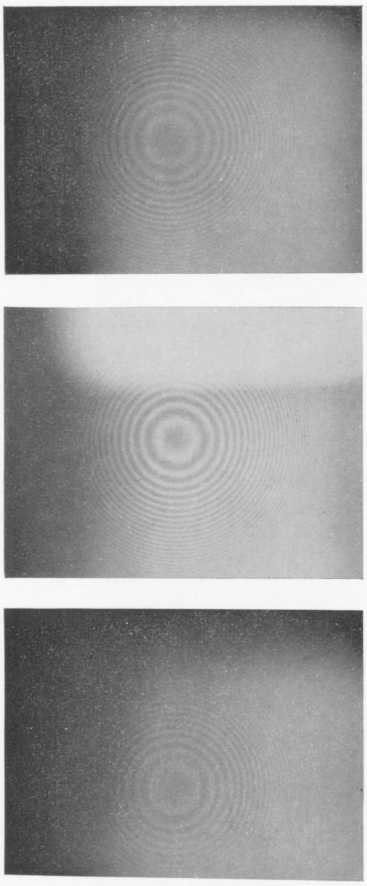

Ne_1
Au
Ne_2
1
2
3
4



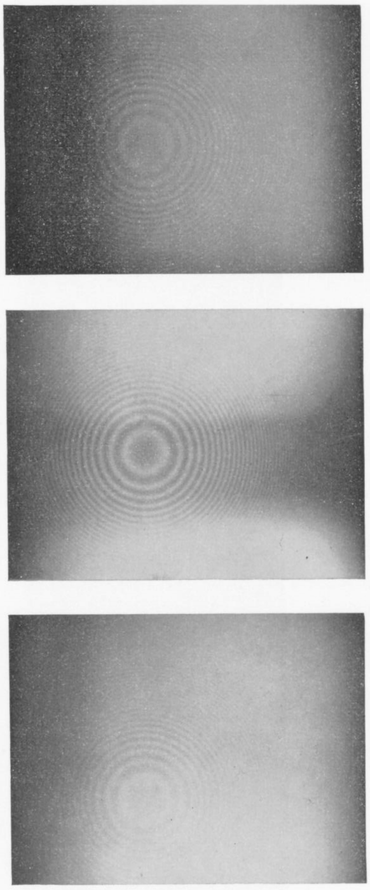
1
2
3



4
5
6

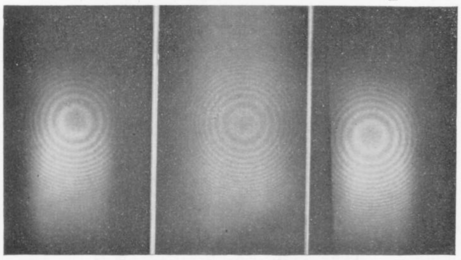


Ne_1
Au
Ne_2
7



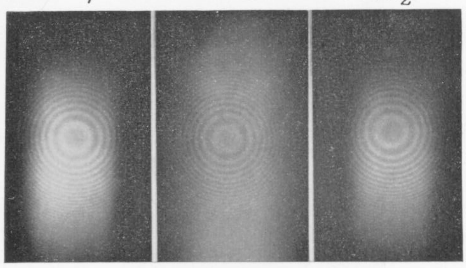
8
Ne_1
Au
Ne_2

Ne_1 Au Ne_2



9

Ne_1 Au Ne_2



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