THE DETERMINATION OF THE WAVE LENGTH OF THE GREEN LINE OF THE AURORAL SPECTRUM.

BY

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The wave length of the bright green line of the auroral spectrum, although this line is by far the most prominent one, has not been known with sufficient accuracy to enable any certain conclusions to be drawn with regard to its origin. The results obtained by various observers differ very considerably, this as a rule being due to the fact that the dispersion of the apparatus has been insufficient. The wave lengths given in »Kaysers Handbuch der Spektroskopie« vary between 5543 Å and 5630 Å, and this uncertainty has given room for a great variety of suggestions with regard to the origin of the green line.

Some years ago I undertook an expedition to Bossekop in Finmarken, the main object of which was to study the auroral spectrum, With a spectrograph which combined a considerable dispersion with a great power of light I succeeded in proving that the principal lines in the blue part of the spectrum were identical with the negative bands of Nitrogen, and in view of this fact it might be natural to suppose that also the green line originated from Nitrogen, and that its predominance might be explained from the conditions under which it was produced in the higher strata of the atmosphere.[1]

Among the Nitrogen lines and bands there are also some in the neighbourhood of the green auroral line, and taking into account the great variability of the Nitrogen spectrum, the assumption that the green line is due to Nitrogen should be seriously considered.

This same view has recently been taken up by *Stark*[2] and he even goes so far as to identify the green auroral line with the doublet 5560—5565 Å of the Nitrogen arc spectrum. As a matter of fact, he is able to give the results of several measurements of the green auroral line in support of this identification.

During my stay at Bossekop, I also measured the wavelength of the green line, but these measurements were not sufficiently accurate, as errors of several Ångström units were possible. The figures obtained varied between 5571.3 and 5576.9.

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[1]) *L. Vegard,* Phys. Z. S. 14, p. 677, 1913. Ann. d. Phys. 50, p. 853, 1916. Bericht über eine Exp. nach Finmarken, Christiania Vid.selsk. skr. Mat. nat. kl. 1916, Nr. 13.

[2]) *J. Stark,* Ann. d. Phys. 54, p. 598, 1918.

It was my intention to continue the measurements at Kristiania by means of a spectroscope with a greater dispersion and with grants from the »Birkeland fund« I was able to take up the work again.

At first I installed, in a small roof chamber of the Physical Institute, a grating spectroscope, built for autocollimation. A lense with a pointer in the eye piece was mounted in a frame which could be moved by an accurate micrometer screw. This instrument had a dispersion which would have enabled us to determine the wave length of the green auroral line with an error of less than $^{1}/_{10}$ Å.

I tried this instrument during a fairly strong auroral display, but the light power of the instrument was too small and the auroral line could not be seen. I then decided to go back to instruments with a smaller dispersion but with a greater light power.

This autumn I took up work with a prism spectroscope from Franz Schmidt & Haensch, Berlin. The instrument, which was provided with an accurately made micrometer screw, had a dispersion that would enable me to measure spectral lines in the region considered with such accuracy that the errors shoulp be less than 1 Å. The screw moved along a horizontal scale, one division for each revolution, and one interval of the screw is equal to $^{1}/_{100}$ part of the intervals on the horizontal scale.

The arc spectrum of Baryum was used for comparison. This spectrum was found very suitable because it has very strong and distinct lines very near to the auroral line.

The instrument could be mounted on a granit pillar near my house at Bygdø Allé 94. On the top of the pillar was a wooden frame carrying a circular disk, that could rotate about a vertical axis. The spectroscope being mounted on a tripodstand was placed on the rotating disk. In front of the slit was mounted a prism which could be rotated about the axises and the collimator. By means of the rotating disk and prism light from any part of the sky could be directed into the instrument.

When a series of readings of the auroral line was made, the Baryum arc could be placed in a suitable position relative to the instrument, and the Baryum lines be measured with the instrument in an unaltered position.

Measurements on the 28th of September, 1921.

An auroral display of medium strenght appeared on the northern sky during the evening of the 28th of September. It commenced at about 8 o'clock in the evening and lasted till late at night. The aurora had mostly the form of a diffuse arc on the northern sky. During a short interval draperies appeared and a faint arc was seen for some time near the zenith.

The auroral line could be distinctly seen in my instrument, and two series of observations were taken. Before these series were taken the instrument was brought into working condition by means of the Baryum arc. The spectrum and the pointer were brought into focus, and a suitable width of the slit was found. The instrumental conditions thus found were kept during the whole series of measurements.

It should be remarked that before any of the final measurements were taken the instrument had been placed on the pillar for more than an hour, so any errors due to temperature changes are excluded.

The readings for the auroral line were the following:

First series		Second Series	
30.388	30.360	30.361	30.355
.384	.355	.390	.380
.380	.355	.375	.405
.370	.385	.358	.380
.375	.372	.400	.390
.385	.380	.385	.359
.375	.375	.360	
.360	.370	.400	
.369	.390	.365	
.362		.380	
Mean 30.3732		30.3777	

One division of the micrometer screw equals 0.01 and the mean values only differ by a fraction of a micrometer screw interval.

Between the two series the three Ba-lines $\lambda_1 = 5777.84$, $\lambda_2 = 5535.69$ and $\lambda_3 = 5424.82$ were measured. As these three lines were strong, and the total field of view was bright, the pointer could be more accurately placed than in the case of the faint auroral line. I therefore found it sufficient to take 5 readings of each line.

After the second series I took 8 readings of the line 5535.69 which is nearest to the auroral line. The readings of the more distant lines λ_1 and λ_3 can be taken from the first series of observations.

The Ba-lines gave the following mean values of micrometer readings:

λ	5777.84	5535.69	5424.82
Reading	31.509	30.1118 after 1st series 30.1195 » 2nd »	29.416

To obtain an estimate of the dispersion near the auroral line, I also measured the line $\lambda = 5519.37$, which gave a reading 30.011. Comparing this with the line 5535.69 we find that 10.1 divisions on the micrometer screw correspond to a difference of wave length of 16.3 Å, or one division corresponds to 1.6 Å. Taking the mean of several readings, the error in the mean value will only be a fraction of a scale division and thus we should be able to measure with an accuracy of at least 1 Å.

In the table below is collected the complete set of observations corresponding to each series.

Line	Micrometer Scale		
	First Series	Second Series	Mean of the two Series
Auroral line	30.3732	30.3777	30.3755
$\lambda_1 = 5777.84$	31.509	31.509	31.509
$\lambda_2 = 5535.69$	30.1118	30.1195	30.1157
$\lambda_3 = 5424.82$	29.416	29.416	29.416

To determine the wave length of the auroral line from the observations, we interpolate by means of the formula:

$$\lambda = \lambda_0 + \frac{a}{S + b'} \quad (1\text{ a})$$

where S is the observed value on the micrometer scale corresponding to the wave length λ. The quantities λ_0, a and b are constants which are to be determined from the measured Ba-lines.

It is convenient to measure the micrometer readings relatively to that of the line λ_2 and put

$$s = S - S_2$$

Putting

$$b = S_2 + b'$$

we get

$$\lambda = \lambda_0 + \frac{a}{s + b} \quad (1\text{ b})$$

The quantities a, b and λ are determined by the formula:

$$b = \frac{ks_1 - s_3}{1 - k} \quad (2)$$

$$a = -(\lambda_1 - \lambda_2)(s_1 + b)\frac{b}{s_1} \quad (3)$$

$$\lambda_0 = \lambda_2 - \frac{a}{b} \quad (4)$$

where

$$k = -\frac{s_3}{s_1}\frac{\lambda_1 - \lambda_2}{\lambda_2 - \lambda_3}$$

a, b and λ_0 are now calculated for each series by means of (2, 3, 4) and the wave length of the auroral line is found from (1 b).

The numerical calculation gives the following results for the green auroral line:

1st series: $\lambda = 5578.87$ Å
2nd » $\lambda = 5578.27$ Å
Mean value $\lambda = 5578.57$ Å

Instead of interpolating for each series separately, we can first take the mean value of the readings from the last column of the 2nd table, and then interpolate. In this way we get:

$$\lambda = 5578.59 = 5578.6$$

or in both ways we get a mean value of:

$$\lambda = 5578.6$$

Measurements of the 8th of October, 1921.

During the evening of the 8th of October a fairly strong aurora appeared in the north, lasting from about 8 o'clock in the evening till past midnight. Spectroscopic observations with the same spectroscope were undertaken from 9 o'clock till 11.30. The aurora obtained its greatest brilliancy between 10 and 12 o'clock. During this interval quite brilliant draperies and rays were formed in the north, and the whole time a diffuse arc appeared low down to the north.

After some preliminary observations had been taken, the instrument was adjusted by means of the Ba-arc light.

In the same way as during the observations previously described, the spectrum was carefully focussed so the spectral lines did not move at all when the arc light was placed in different positions before the slit. A suitable width of the slit was selected, the slit being a little more narrow than during the observations of the 28th of September. After the adjustment, a series of 41 readings of the auroral line were taken.

Then the three selected lines of the Baryum spectrum were measured. For each Baryum line 10—12 readings were taken.

Then I took a second series of 30 readings of the auroral light. The mean values of these readings are given in the following table:

Spectral line	Reading (mean values)
Auroral line 1st series	30.3724
λ_1	31.5000
λ_2	30.1177
λ_3	29.4110
Auroral line 2nd series.	30.3738

From these observations we deduce in the same way as before the following values for the wave length of the auroral line.

The first series gives: $\lambda = 5577.9$
The second —»— $\lambda = 5577.7$
Mean value $\lambda = 5577.8$

As the mean value of the results for the two evenings we get

$$\lambda = 5578.2$$

After the measurements were taken the northern lights remained very strong for some time, and I took the opportunity of examining the auroral line with a very narrow slit, in order to see whether it maintained the appearance of a single sharp line, and as a matter of fact I found that the line remained sharp and undivided.

If the line should happen to be a doublet the components cannot differ in wave length by more than about 1 Å unit.

As the direction of the bundle of rays examined was nearly perpendicular to the direction of the cosmic rays, the line is free from Doppler effect, and the wave length found corresponds to that of a motionless source of light.

We see that the wave length is somewhat greater than that usually assumed (about 5570) and very much greater than that required by Stark's identification with the doublet 5560—5565 of the Nitrogen spectrum. The result here found from direct measurement of the auroral light is, however, in good agreement with that of *Slipher*[1]

[1]) *V. M. Slipher,* Astrophys. Journ. 49, p. 266, 1919.

He measured by a spectrographic method the wave length of the green line which is usually seen in the ligth of the sky, and found as the mean of three determinations:

$$\lambda = 5578.05$$

The green line which at night appears in the light of the sky is thus no doubt identical with the green auroral line, and the wave length of this line can no doubt be regarded as known with such a degree of accuracy that the error is less than 1 Å.

When we try to interpret the green auroral line, we have, as mentioned in previous papers[1], first of all to regard two possibilities. The light is emitted from the electric rays themselves, aud secondly the light is emitted from some gas in the atmosphere, through the bombardment of the electric rays.

The first assumption would involve that the aurorœ were produced by rays the carriers of which were atoms or molecules and probably carrying a positive charge. Now if the green line were emitted by the rays it should show a Doppler effect.

During my expedition to Bossekop I examined the line from this point of view. Even when the slit of my spectroscope was made very narrow, the line remained quite sharp, independent of the direction of the collimator relative to that of the auroral rays. There was no change of position of the line sufficiently large to be detected in the instrument.

If the auroral line was emitted from the cosmic rays the velocity of the latter could not be greater than about 3.10^7 cm./sec., but such rays could hardly possess a sufficient penetrating power to reach within a distance of 100 km. above the ground.

This result is so far in accordance with that optained from the study of the auroral structure, and the luminosity distribution. From these studies I was able to conclude that:

$$\frac{mv}{e} < 10^4$$

and if the rays at the same time possess a sufficient penetrating power, only electron rays were possible, provided that the Nitrogen was distributed in the higher strata of the atmosphere, approximately in accordance with the calculations of *Wegener*.

The study of the structure of the aurorœ led to the result that if rays with carrier of atomic dimensions were at all possible, only atoms or molecules of the gases Hydrogen and Helium could possibly come into consideration.

All the facts that we at present possess, however, go to support the view that the auroral line is not emitted from the carrier of the cosmic rays. If so, the line should be due to some gas present in the atmosphere. Whatever may be its origin, its wave length is equal to 5578.2 with an error probably less than 0.5 Å.

In proceeding to the interpretation of the line, we shall first of all have to examine whether any of the elements for some reason or other are excluded. In fact only the gases with a molecular weight equal to or smaller than that of Nitrogen can come into consideration; for on account of the predominance of the auroral line the gas giving the auroral line must make up a considerable fraction of the gas present in the region above 100 km. Now we know that the Nitrogen is present to a considerable amount so as to make itself fairly conspicuous in the auroral spectrum.

Moreover, if in the atmosphere above a certain height the pressure of one gas varies with the height as if the others were not present, a gas with a molecular weight greater

[1]) *L. Vegard,* Phil. Mag. Feb. 1912, Phys. Z. S. 14, 1913. Vid. selsk., Christiania, 1916 skr. No. 13.

than that of Nitrogen would above 100 km. possess a pressure which is very small compared with that of Nitrogen at the same level. Thus the pressure of Oxygen at a heigth of 100 km. should be $p_O = 0.008$ dyn/cm^2 while that of Nitrogen should be $p_N = 0.25$ dyn/cm^2, and the ratio $\frac{p_O}{p_N}$ decreases upwards.

If the auroral line is emitted by some known elmentary gas, only *Nitrogen, Neon Helium* and *Hydrogen* are possible.

Besides, we have to consider the following compound gases with a molecular weight smaller than 28: HFl, H_2O, CO, CN, NH_3, CH_4, C_2H_2. Of these gases CO, CN, C_2H_2, which have a molecular weight equal to or only a little smaller than that of Nitrogen, cannot form any appreciable part of the higher strata of the atmosphere, because these gases are only present in minute traces near the ground.

HFl is not likely to exist in the higher strata of the atmosphere because it will be absorbed by moisture near the ground. Amongst the compound gases, only the gases H_2O, NH_3 and CH_4 should be left for a more serious examination.

If the auroral line is emitted from some known substance, it should be produced when electric rays (probably cathod rays) passed through one of the following gases:

$$N_2,\ Ne,\ He,\ H_2,\ H_2O,\ NH_3 \text{ and } CH_4.$$

The spectra of all these gases have been studied, and especially the spectra of the elementary gases have been examined under a great variety of conditions.

Now it is quite possible that the auroral line is emitted under conditions not as yet produced in the laboratory. It is my intention to carry out experiments with the above mentioned gases under conditions which as far as possible are equal to those under which the auroral line is produced.

At present we shall only regard the results previously obtained, and see whether any of the lines observed[1] might possibly be identical with the auroral line.

In the case of *Nitrogen,* no line with a wave length close to 5578.2 Å is observed. In the positive band spectrum there are two heads with the wave lengths 5592.57 and 5570.60. They both are too far from the auroral line. It might, however, be suggested that the auroral line was a double line, and that the observed wave length was some mean value of the two, but as already mentioned the auroral line was not dissolved even with a very narrow slit.

I have also examined the Nitrogen spectrum when this gas was bombarded by cathod rays at the temperature of the room, and at the temperature of liquid air, but no trace of the auroral line was in any case to be observed. If then the auroræ are produced by electron rays the green line can hardly originate from Nitrogen.

In the *Neon* spectrum, the lines nearest to the auroral line are $\lambda = 5589.40$ and $\lambda = 5562.90$, but none of these lines can come into consideration.

No *Helium* line is observed near to the auroral line.

In the second or »manylined« spectrum of *Hydrogen* a line $\lambda = 5578.3$ was observed by *Hasselberg.* The wave length is within the limit of possible errors identical with that of the auroral line, but still this identification is probably only accidental, for the second spectrum is so rich in lines that there is always a great chance for an approximate coincidence with any given wave length.

Further, the particular Hydrogen line is very weak, and if it really belongs to the second spectrum it cannot be assumed to appear with the same prominence as the auroral

[1]) The observations of spectra here referred to are those given in H. Kayser, Handbuch der Spektroskopie.

line; for the relative intensity of the lines in the second spectrum is found to be very constant. The spectrum as a whole may be more or less prominent relative to the Balmer Series according to conditions, but the relative intensities of the lines of the second spectrum seem to keep fairly constant.

The spectra of the compound gases NH_3, CH_4, H_2 are not sufficiently known under conditions similar to those existing in the auroral region.

In the Swan Carbon spectrum there is a line

$$\lambda = 5583.0 - 5585.5$$

but this line has a too great wave length to be identified with the auroral line.

In the so-called NH_3-spectrum, *Manganini* observed a fairly strong band $\lambda = 5568 - 5597$. The band, however, is too broad to be identified with the sharp auroral line.

For the spectrum of water vapour only some bands in the blue part are observed, but our knowledge of this spectrum is very incomplete.

Summing up our considerations with regard to the origin of the auroral line, we may say that its origin is as mysterious as ever. The approximate coincidence found for H_2 is of no value as long as we cannot explain the predominance of the line.

In this connection it is of interest to mention that in the blue spectrum of Argon there is a fairly strong line with a wave length 5577.98, which inside the limits of experimental errors is identical with that of the auroral line, but we cannot assume the auroral line to originate from Argon because this gas has a molecular weight much greater than that of Nitrogen, and practically no Argon can exist in the auroral region above 100 km.

It appears as if we were driven to the assumption that the green line originated from some light gas »Geokoronium«, different from all known chemical elements.

Such an assumption seems at present to meet with great difficulty from a physical point of view. It cannot be any of the elements which enter into the periodic table, for this table only gives room for elements with the atomic numbers: 1—2—3—4 . . . . . 92, and if Geokoronium had atomic numbers identical with one of these, its spectrum would also have to be identical with that of one of the known elements.

It would then be necessary to assume that the atoms of Geokoronium had a structure essentially different from that of the known chemical elements. It could not consist of one nucleus with a positive charge ne surrounded with n electrons, provided always such systems were linked together according to the rules given by the quantum theory in its application to ordinary elements.

If we keep to the conception that the electric mass cannot exist in smaller quantities than that of the electron, we have to regard two possibilities for the constitution of Geokoronium.

1) The Geokoronium atom has one nucleus with a charge ne, where n is a whole number, but the positive elementary quantum constituting it is in a less condensed form than in the case of Hydrogen and the ordinary elements, and in this less condensed form the orbits of stability of the electrons are formed according to other quant conditions than in the case of the ordinary elements. We might also express it thus: The Hydrogen nucleus is not the primitive positive quantum, but is composed of lighter positive quanta and electrons. The Hydrogen nucleus is only a primary positive quantum for the ordinary chemical elements, and the quant conditions ruling the class of ordinary elements is a property of the atoms which is attached to the formation of the Hydrogen nucleus.

2) The atom of Geokoronium consists of several nuclei, with mutual distances which are large when compared with the diameters of the nuclei of ordinary elements, and small when compared with the atomic diameters. Atoms with such a structure would also fall outside the group of chemical elements contained in the periodic system.

As we see, the question as to the existence of an unknown gas, Geokoronium, is one of far-reaching cosmic and physical consequences, and must be considered as a last resort when all other possible ways of explaining the auroral line have failed.