AN AURORAL SPECTROGRAM AND THE RESULTS DERIVED FROM IT

BY

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§ 1. Introductory Remark.

During the night Feb. 23–24, a brilliant aurora was observed at Oslo. From the beginning at 19.20 up to midnight intensive and rapidly changing rays and draperies were playing on the northern sky towards the zenith. After midnight until dawn it generally maintained the form of a double quiet ark of moderate intensity.

At the Physical Institute of the Oslo University we had just obtained a new auroral spectrograph from the French firm Société générale d'optique, built by Dr. J. Cojan in accordance with specifications given by one of us (Vegard). It was very well made, giving extremely sharp lines throughout its whole spectral range.

This spectrograph was constructed in such a way as to provide good facilities for obtaining the great number of weak auroral lines so well separated that the wavelength could be measured with an accuracy sufficient for reliable identification.

Compared with the best spectrograph previously used in our country for this purpose[1], the dispersion of the new spectrograph was about twice as large and the light power more than 5 times greater.

The new spectrograph had two prisms. The effective diameters of the camera and collimator lenses were 178 mm. The camera lense had a light power corresponding to (F : 1,2). The dispersion as a function of wavelength is seen from the curve, fig. 1, where the scale to the right in Å/mm corresponds to the dispersion derived directly from the spectrogram on the photographic plate. The instrument was put on the bottomplate of a box, which could be rotated round a vertical axis. A tube containing a condensor lense and a plane mirror forming 45° with the collimator axis could be rotated round this axis. In this way the instrument could be directed towards any desired point of the sky. The box was provided with arrangements for automatic temperature regulation.

The instrument is now mounted on the observational platform of the Auroral Observatory at Tromsoe.

During the auroral display at Oslo Feb. 23–24, '50, the instrument was placed in one of the rooms of the Institute and pointed towards the northern sky through an open window. *The spectrograph was kept in the same position through the whole night.* The slit opening was 0.21 mm, which corresponds to 0.03 mm on the photographic plate. The exposure was made on a Kodak 103 a T plate and it lasted from 19.35 in the evening till 05.30 in the morning. For

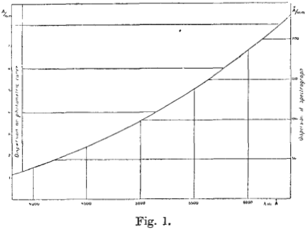

Fig. 1.

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[1] A description of the instrument is given in paper (1) § 8.

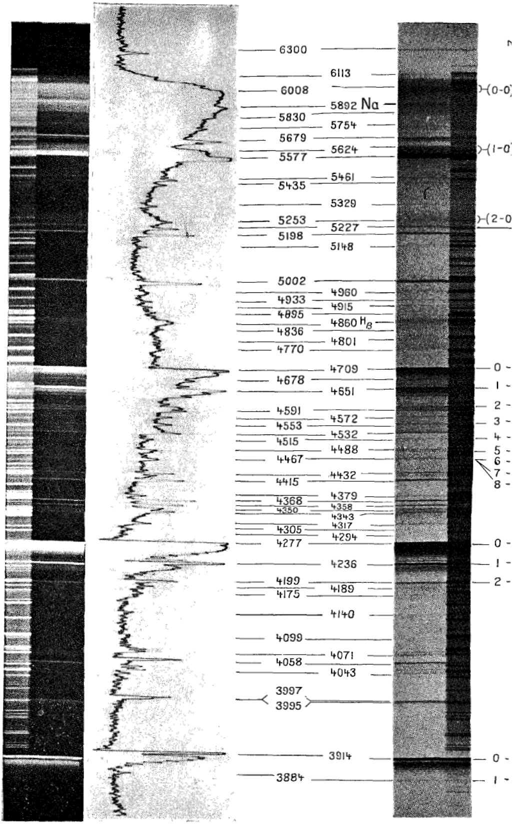
6300
6113
6008
5892 Na
5830
5754
5679
5624
5577
5461
5435
5329
5253
5227
5198
5148
5002
4960
4933
4915
4895
4860 Hβ
4836
4801
4770
4709
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Fig. 2.

the comparison spectrum we used an argon discharge lamp. An intensity scale was taken on the same plate by means of a stabilized Ne-lamp.

A reproduction of the auroral spectrogram is given on the plate fig. 2, showing one positive and one negative picture, and between the two is a registram, taken with a Moll registering photometer. For the sake of orientation the wavelength of some prominent lines and bands are given on the plate.

§ 2. Wavelength Measurements and Identification.

Within the region of the spectrogram (6300–3880) about 114 lines and bands could be directly measured from the original plate, more than 50 of which were not previously observed. Short announcements of these first results were given in some preliminary communications (2. 3. 4).

It was evident, however, that the spectrogram contained a great number of lines, which were too weak to be measured directly from the plate. The wavelengths of these lines were determined by means of photometer curves of great magnification.

In order to avoid, as far as possible, that maxima due to casual irregularities were taken as indications of spectral lines, we took two registrams along two parallel lines across the spectrogram at a suitable distance from each other. *Only distinct and exactly coinciding maxima were taken to indicate the existence of lines.*

By this procedure we were also able to detect multiplets, and study more closely the structure of bands. Such a photometer curve is shown on fig. 3. The dispersion of the photometer curve will be seen on fig. 1 from the scale on the left side.

As a number of sharp lines were exactly measured from the plate, the wavelength of any weak line in between the known ones could be measured with nearly equal accuracy from the photometer curve.

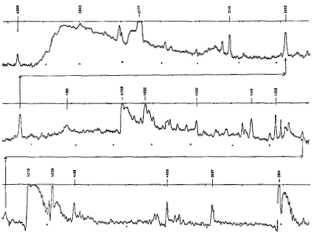


Fig. 3.

The results of the wavelength measurements from the new spectrogram are given in table 1b. The first and second column contain wavelength and measured intensities from previous determinations. The 3rd and 4th columns give the wavelength values from the new spectrogram. λ_p are the values measured directly from the plate, λ_r those found from the photometer curve. In the 5th column measured relative intensities are given for some of the lines, which on the spectrogram appear with a density suitable for intensity measurements. These intensities are approximately comparable to those previously measured and given in the 2nd column. The possible interpretation of lines and bands are given in the last column. If a line or an interpretation is somewhat questionable, it is put into a bracket.

As mentioned the spectrogram here dealt with is limited to the spectral range from 6300 to 3880. For the sake of completeness we have added the auroral lines and bands on both sides of this interval known from earlier investigations.

Table 1 a contains lines and bands and some measured intensities from the long wavelength interval from 6364 to about 8860 in the infra red. For this region we have included some results recently obtained by A. B. Meinel (5) and by W. Petrie (6). Thus the table (1 a) contains some bands, also measured at Oslo, which Meinel refers to a system $A^2\Pi - X^2\Sigma$ originating from N_2^+. For these bands we have used the notation $N_2^+ . 2N$.

The table 1 c covers the results previously obtained for the ultraviolet region beyond 3880 Å. The number of lines and bands in red and infra red will no doubt be considerably increased by means of spectrograms in this region taken with the new spectrograph now at the Tromsoe Observatory.

Table 1 a.

Auroral Lines from Previous Measurements in the Region 8858 Å—6398 Å.

λ	I	Interpretation
8858	(10)	N_2 1.P(1—0)
8774	4	
8714	10	NI (3s $^4P_{5/2, 3/2, 1/2}$ — 3p $^4D_{5/2, 3/2, 1/2}$), N_2 1P (2 — 1)
8684	32	NI (3s $^4P_{1/2, 3/2, 5/2}$ — 3p $^4D_{3/2, 5/2, 7/2}$), N_2 1P (2 — 1)
8665	10	NI (3s $^2P_{3/2}$ — 3p $^2P_{1/2}$) ?
8623	6	$N_2$1P (3 — 2), NI (3s $_2P_{3/2}$ — 3p $^2P_{3/2}$) ?
8525		O_2^+ 1N (0 — 5), N_2 1.P. (3 — 2)
8469	3	
8447	17	OI (3s ^3S — 3p ^3P)
8436	3	NII (3p ^1S — 3d ^1P)
8344	(3)	N_2 1.P (4 — 3), N_2^+ 2.N.(3 — 2)
8291	(2)	N_2^+ 2.N.(3 — 2)
8216	4	NI (3s $^4P_{3/2, 5/2}$ — 3p $^4P_{1/2, 3/2, 5/2}$)
8182	4	N_2 1.P (5 — 4), NI (3s $^4P_{1/2, 3/2}$ — 3p $4P_{3/2, 5/2}$)
(8130)		
8093	4	N_2^+ 2.N (2 — 1)
8064	4	N_2 1.P (6 — 5), N_2^+ 2.N (2 — 1)
7993	4	OI (3p ^3P — 3s′, ^3D), N_2 1.P (6 — 5) ?
7914	8	
7879	16	N_2 1.P (7 — 6), O_2^+ 1.N (0 — 4), OI (3s″ $^1P_1$ — 3p″ ^1D) ? N_2^+ 2.N (1 — 0)
7854	11	N_2 1.P (7 — 6)
7820	5	N_2^+ 2.N (1 — 0)
7774	30	OI (3s ^4S — 3p ^5P), NII (3p ^1D — 3d ^1D)
7746	15	N_2 1.P (2 — 0)
7730		N_2 1.P (2 — 0)
7717	15	
7688	15	
7625	4	N_2 1.P (3 — 1), NI (3p ^4S — 5s $^4P_{3/2}$)
7580	12	NI (3p ^4S — 5s ^4P)
7482	4	N_2 1.P (4 — 2), OI 3s″ ^3p — 3p″ ^3D)
7450	4	
(7385)		N_2 1.P (5 — 3)
7368		N_2 1.P (5 — 3)
7339		O_2^+ 1N (0 — 3), OII (2p^3(^2D — ^2P)) ?
7264		N_2 1.P (6 — 4)
7248		OI (3p ^3P — 5s ^3S), N_2^+ 2N (4 — 2)
7094		N_2^+ 2.N.(3 — 1)
7068		N_2^+ 2.N.(3 — 1)
6860		N_2 1.P (3 — 0), N_2^+ 2N (2 — 0)
6849		N_2 1.P (3 — 0), O_2^+ (0 — 2)
6784	3	N_2 1.P (4 — 1), O_2^+ (0 — 2)
6754		N_2 1.P (4 — 1), NI (3p ^4P — 4d ^4D)
6693	5	N_2 1.P (5 — 2)
6679		N_2 1.P (5 — 2), OII (3d $2P_{1/2}$ — 4p $^2P_{3/2}$)
6669		NI (3p ^2P — 5d ^2P), OII (3d $^2P_{3/2}$ — 4p $^2P_{1/2}$)
6622	3	N_2 1.P (6 — 3), OII (3d $^2P_{3/2}$ — 4p $^2P_{3/2}$) NII (3d ^1D — 4p ^1P)
6605		N_2 1.P (6 — 3), NII (3p ^1D — 3d ^1F)
6592		N_2 1.P (6 — 3), NII (2p^2($^3P_2$ — $^1D_2$))
6563		H_α
6543	6.5	N_2 1.P (7 — 4), NI (3p$^4D_{5/2}$ — 5s $^2P_{3/2}$) NII (2p$_3$ ($^3P_1$ — $^1D_2$)) ?
6526		N_2 1.P (7 — 4), NI (3p $^4D_{3/2}$ — 5s $^2P_{3/2}$)
6512		N_2 1.P (7 — 4), NI (3p $^4D_{1/2}$ — 5s $^2P_{3/2}$)
6467		N_2 1.P (8 — 5), NI 3p $^4D_{7/2, 5/2}$ — 4d $^4D_{7/2, 5/2}$)
6454	5	OI (3p^5P — 5s ^5S), N_2 1.P (8 — 5), VK (1—17) NI (3p $^4D_{3/2}$ — 4d $^4D_{3/2, 5/2}$)
6441		N_2 1.P (8 — 5), NI (3p $^4D_{7/2}$ — 4p $^4D_{5/2}$)
6398		N_2 1.P (9 — 5), O_2^+ 1N (0 — 1)

Table 1 b.

Auroral Lines in the Region (6364 Å—3882 Å) covered by the Spectrogram from February 23, 1950, Oslo.

Previous Measurements		From Spectrogram taken Feb. 23, 1950			Interpretation
λ	I	λ_p	λ_r	I	
6364	3–200	6363			OI $(2p^4(^3P_1 — ^1D_2))$
6300.3	10–600	6299.8	6300		OI $(2p^4(^3P_2 — ^1D_2))$
			6267		NI (3p $^2D_{5/2}$ — 3d $^2P_{3/2}$), O_2 SR(2 — 28)
6253			6252		N_2 1P(11 — 8), [VK(4 — 19)]
			6240		N_2 1P(11—8), NI(3p $^2D_{3/2}$ — 5d $^2P_{1/2,\,3/2}$. NII(3d^{1}F—4p ^{1}D)?
(6229)			6222		[NI(3p ^{4}S — 5d ^{2}P)], O_2SR(5 — 30)
			6208		
			6197		
6I85					$N_2$1P(12—9)
6176					$N_2$1P(12—9), NII(3d^{1}P — 4p ^{1}S), (3d $^3F_{2,\,3,\,4}$ — 4p $^3D_{1,\,2,\,3}$) O_2SR(1—27)
6154			6156		OI(3p ^{5}P — 4d ^{5}D), NII(3d $^3F_2$ — 4p $^3D_2$)
6139					NII(3d $^3F_3$ — 4p $^3D_3$)
6129			6127		$N_2$1P(5—1), [VK(7—21)], [O_2SR(4—29)]
		6113	6119		O_2SR(7—**3**1)
6109	4		6110		$N_2$1P(5—1), NII(3d $^3F_2$ — 4p $^3D_3$)
			6093		$N_2$1P(5—1)
			6078		N_2VK(3—18), NI(3p $^2P_{3/2}$ — 6d $^4P_{3/2}$), O_2SR(0—26)
6068			6071		$N_2$1P(6—2), NI(3p $^2P_{3/2}$ — 6d $^4P_{5/2}$)
		6064	6062		$N_2$1P(6—2), NI(3p $^2P_{1/2}$ — 6d $^4P_{3/2}$), (NII(3p ^{3}P — 3d ^{1}D)) ?
6056					$N_2$1P(6—2)
		6046	6046		OI(3p ^{3}P — 6s ^{3}S), [O_2SR(9—32)]
			6034		
			6025		O_2^+1N(0—0), O_2SR(3—28), (11—33)
6012					$N_2$1P(7—3)
6010		6008	6008		NI(3p ^{2}S — 4d $^2P_{3/2}$), $N_2$1P(7—3), O_2SR(6—30)
6001			6000		NI(3p ^{2}S — 4d $^2P_{1/2}$)
5993	10		5992		$N_2$1P(7—3)
5977		5974.4	5976		O_2^+1N(1—1)
5967			5969		NI(5972, 5966)
		5957.9	5958		$N_2$1P(8—4), OI(3p ^{3}P — 5d ^{3}D), NI(5959), NII(3p $^3P_2$) — 3d $^3D_1$)
5948			5950		$N_2$1P(8—4), VK(6—20), NI((3p^4)$^4P_{3/2}$ — 3p′ $^2P_{1/2}$), NII(3p$^3P_2$ — 3d $^3D_2$)
			5940		$N_2$1P(8—4), NI[(3p^4)$^4P_{3/2}$ — 3p′ $^2P_{3/2}$), NII(3p $^3P_{2,\,1}$ — 3d $^3D_{3,\,1}$)
		5932.6	5930		NI(5931), NII(3p $^3P_1$ — 3d $^3D_2$), O_2SR(2—27) (10—32)
			5925		O_2^+1N(2—2), NI(5927)?, NII(3p $^3P_0$ — 3d $^3D_1$)
			5904		$N_2$1P(9—5), NI(5907, 5905)
5892	5	5892.3	5895		NaI, $D_1N_2$1P(9—5)
			5888		NaI, D_2
			5878		O_2^+1N(3—3), $N_2$1P(9—5)
5867	13	5865.6	5871		
			5859		NI(3p $^4P_{3/2}$ — 6s $^4P_{1/2}$), N_2^+1N(0—4)
5851		5852.2	5850		$N_2$1P(10—6), NI(3p $^4P_{5/2}$ — 6s $^4P_{3/2}$)
			5842		NI(3p $^4P_{3/2}$ — 6s $^4P_{3/2}$), O_2^+1N(4—4), $N_2$1P(10—6), O_2SR(1—26)
5835		5830.3	5828		NI(3p $^4P_{5/2}$ — 6s $^4P_{5/2}$), $N_2$1P(10—6), [O_2SR(7—30)]
5803		5801	5800		$N_2$1P(11—7), NI(3p $^4P_{5/2}$ — 5d $^4F_{5/2}$)
			5790		HgI, NI(3p $^4P_{3/2,\,5/2}$ — 5d $^4F_{3/2,\,7/2}$) (3p ^{4}S — 7s $^4P_{1/2}$)
			5786		$N_2$1P(11—7)

Previous Measurements		From Spectrogram taken Feb. 23, 1950			Interpretation
λ	I	λ_p	λ_r	I	
			5780		N_2VK(5—19), NI(3p $^4P_{5/2}$ — 5d $^4D_{5/2}$)
5772		5771	5770		HgI, NI(3p $^4P_{3/2}$ — 5d $^4D_{5/2}$), (3p ^4S — 7s $^4P_{3/2}$), O_2SR(9—31)
			5766		NI(3p $^4P_{5/2}$ — 5d $^4P_{3/2}$), NII(3s ^1P — 3p ^3D), O_2SR(11—32)
5751		5754	5753		$N_2$1P(12—8), VK(1—16), N_2^+1N(1—5), NI(3p $^4P_{5/2}$ — 5d $^4P_{5/2}$), NII(2p ^{2}($^1D_2$ — $^1S_0$))
5743			5745		$N_2$1P(12—8), NI(3p ^4S — 7s $^4P_{7/2}$), NII(3s ^1P — 3p $^3D_2$), O_2SR(0—25)
5736		5730.5	5735		$N_2$1P(12—8), NI(3p ^4S — 6d $^4D_{5/2}$), NII(3s $^3P_2$ — 3p $^3D_1$)
			5712		$N_2$1P(13—9), NII(3s $^3P_2$ — 3p $^3D_2$), [O_2SR(3—27)]
		5709.2	5709		NI(3p ^4S — 6d $^4P_{3/2}$)
5685			5688		NII(3s $^3P_1$ — 3p $^3D_1$), $N_2$1P(13—9)
5677		5679.9	5677	5.5	NII(3s $^3P_{0,2}$ — 3p $^3D_{1,3}$)
		5666.9	5667	1.3	NII(3s $^3P_1$ — 3p $^3D_2$)
			5658		$N_2$1P(14—10), N_2^+1N(2—6), O_2SR(8—30)
		5629.2	5630	1.9	O_2^+1N(1—0), $N_2$1P(5—0)
5635		5622.7	5623		O_2^+1N(1—0), $N_2$1P(5—0), NI(3p $^4D_{3/2, 5/2}$ — 6s $^4P_{1/2, 3/2}$)
5622			5621		N_2VK(4—18), O_2SR(2—26)
			5616		O_2^+1N(1—0), $N_2$1P(15—11), NI(3p $^4D_{1/2, 7/2}$ — 6s $^4P_{1/2, 5/2}$), O_2SR(5—28)
		5613.9	5612		$N_2$1P(5—0), NI(3p $^4D_{3/2}$ — 6s $^4P_{3/2}$)
		5603	5604		O_2^+1N(1—0), NI(3p $^4D_{1/2}$ — 6s $^4P_{3/2}$), N_2VK(0—15) ?
			5600		NI(3p $^4D_{5/2}$ — 6s $^4P_{5/2}$)
			5595		O_2^+1N(2—1), $N_2$1P(6—1), (15—11)
5577.35	100	5577.9	5577	$\approx$ 100	OI[2p ^{4}($^1D_2$ — $^1S_0$)]
		5553	5554		OI(3p ^3P — 7s ^3S), $N_2$1P(7 — 2), NII(3s $^5P_3$ — 3p $^5D_3$)
			5543		NII(3s $^5P_2$ — 3p $^5D_2$), $N_2$1P(7—2)
		5534	5537		O_2^+1N(4—3), NII(3s $^5P_{1, 3}$ — 3p $^5D_{1, 4}$)
			5531		N_2VK(7—20), $N_2$1P(7—2), NI(3p ^4D — 5d ^4P), NII(3s $^5P_2$ — 3p $^5D_3$), [O_2SR(1—25)]
		5520	5517		O_2^+1N(5—4), $N_2$1P(8—3), [O_2SR(4—27)]
			5513		OI(3p ^3P — 6d ^3D), O_2SR(9—30) (11—31)
			5497		$N_2$1P(8—3), NI(5497), NII(3p $^3P_2$ — 3d $^3P_2$)
			5492		OI(3p′ ^1F — 5d′ ^1G)
			5488		N_2^+1N(4—8)
			5478		$N_2$1P(9—4), NII(3p $^3P_{1, 2}$ — 3d $^3P_{2, 1}$)
5472		5474.7	5475		$N_2$1P(9—4)
			5467	0.22	N_2VK(3—17)
		5460.9	5462	0.74	HgI $N_2$1P(9—4), NII(3p $^3P_1$ — 3d $^3P_1$)
5456			5457		NII(3p $^3P_1$ — 3d $^3P_0$)
			5452		NII(3p $^3P_0$ — 3d $^3P_1$)
			5442		$N_2$1P(10—5)
5436		5435.6	5436	0.47	OI(3p ^5P — 6s ^5S), O_2SR(0—24)
			5434		$N_2$1P(10—5)
			5426		O_2SR(3—26)
			5421		$N_2$1P(10—5)
5415			5417		NI(5419)
			5412		OI(3p′ ^3F — 5d′ ^1G) ?
5403			5405		$N_2$1P(11—6)
5394			5392		NI(3p $^4P_{5/2, 1/2}$ — 7s $^4P_{3/2, 1/2}$)
			5390		$N_2$1P(11—6), O_2SR(10—30)
5371		5371	5375		$N_2$1P(12—7), VK(6—19), NI(3p $^4P_{3/2}$ — 7s $^4P_{3/2}$), [(2p^4) $^4P_{1/2}$ — 4p $^4D_{1/2}$]
			5369		$N_2$1P(12—7), NI(3p $^4P_{5/2}$ — 7s $^4P_{5/2}$), [(2p^4) $^4P_{1/2, 3/2}$ — 4p $^4D_{3/2}$]

Previous Measurements		From Spectrogram taken Feb. 23, 1950			Interpretation
λ	I	λ_p	λ_r	I	
			5360		NI(3p $^4P_{3/2}$ — 7s $^4P_{5/2}$)
		5354	5358	0.22	NI[(2p^4) $^4P_{3/2}$ — 4p $^4D_{5/2}$]
5351			5350		$N_2$1P(12—7), NII(3p $^5P_3$ — 3d $^5P_3$)
			5346		[(2p^4) $^4P_{5/2}$ — 4p $^4D_{5/2}$)], O_2SR(5—27)
			5342		NI(3p $^4P_{5/2}$ — 6d $^4P_{3/2}$), NII(3p $^5P_{2,3}$ — 3d $^5P_{3,2}$)
			5334	0.37	NI(3p $^4P_{5/2}$ — 6d $^4P_{5/2}$), $N_2$1P(13—8)
5332		5328.9	5332		OI(3p ^5P — 5d ^5D), $N_2$1P(13—8), O_2SR(2—25)
			5328		OI(3p ^5P — 5d ^5D), N_2VK(2—16), NI[(2p^4) $^4P^5/_2$—4p$^4D_{7/2}$)] NI(3p $^5P_2$ — 3d $^5P_2$)
			5319		$N_2$1P(13—8), NII(3p $^5P_{1,2}$ — 3d $^5P_{2,3}$)
5311			5315		NII(3p $^5P_1$ — 3d $^5P_1$), NI[(2p^4) $^4P_{1/2}$ — 4p $^4P_{1/2}$)]
			5297		OI(3p ^3P — 8s ^3S), $N_2$1P(14—9)
5289	6	5292	5292		O_2^+1N(2—0), $N_2$1P(14—9), NI[(2p^4) $^4P_{5/2,3/2}$ — 4p $^4P_3/_2$], O_2SR(7—28)
			5282		$N_2$1P(14—9), NI[(2p^4) $^4P_{5/2}$ — 4p $^4P_{5/2}$)
			5272		O_2^+1N(3—1), $N_2$1P(15—10), OI(3p ^3P — 7d ^3D), NO_β(3—18)
			[5264]		[O_2SR(9—29)]
5258			5257	0.37	O_2^+1N(4—2) $N_2$1P(15—10)
		5253.8	5256		NO_β(3—18)
			5250		O_2^+1N(5—3), O_2SR(4—26)
5245			5242		O_2^+1N(6—4), $N_2$1P(16—11), O_2SR(1—24)
			5234		O_2^+1N(7—5), N_2VK(5—18)
5230.6		5226.7	5227	1.22	N_2^+1N(0—3), $N_2$1P(16—11)
5202.9		5198.3	5199	2.5	NI[2p^3(^4S—^2D)], (3p^2S — 5d ^2P), NII(3p $^5D_4$ — 3d$^5F_5$)
			5193		N_2VK(1—15), NII(3p$^5D_4$ — 3d $^5F_4$)
			5180		NII(3p $^5D_{2,4}$ — 3d $^5F_{2,5}$), $N_2$1P(18—13), NI(3p $^4D_{7/2}$ — 6d $^4D_{5/2}$)
			5177		NII(3p $^5D_3$ — 3d $^5F_4$), $N_2$1P(18—13)
			5173		NII(3p $^5D_2$ — 3d $^5F_3$)
5168			5166		NI(3p $^4D_{5/2}$ — 6d $^4D_{5/2}$), $N_2$1P(18—13)
			5154		NI(3d $^4D_{7/2}$ — 6d $\left\{\begin{matrix}^4D_{5/2}\\ ^4P_{5/2}\end{matrix}\right.$), $N_2$1P(19—14), O_2SR(3—25)
		5148	5149	0.38	N_2^+1N(1—4), $N_2$1P(19—14), NI(3p $^4D_{5/2}$ — 6d $^4D_{7/2}$), [O_2SR(0—23) (10—29)]
			5147		OI(3p ^3P — 9s ^3S), NI(3p $^4D_{5/2}$ — 6d $^4P_{3/2}$)
			5140		NI(3p $^4D_{5/2}$ — 6d $^4P_{5/2}$)
5131			5132		OI(3p ^3P — 8d ^3D), NI(3p $^4D_{1/2}$ — 6d $^4P_{1/2}$)
			5125		
			5114		
			5109		
			5105		NII(3p ^1S — 4s ^1P)
			5093		N_2VK(4—17), O_2SR(5—26)
5080			5078		N_2^+1N(2—5), O_2SR(11—29), N_2GK(0—12)
			5067		NI(5068), O_2SR(2—24), N_2GK(0—12)
			5053		$N_2$1P(11—5)
5049		5046	5048	0.15	OI(3p ^3P — 10s ^3S), $N_2$1P(11—5), O_2SR(7—27)
			5043	0.19	NII(3s $^3P_2$ — 3p $^3S_1$)
			5032		N_2VK(7—19), $N_2$1P(11—5), O_2SR(9—28)
5029			5029		$N_2$1P(12—6), NII(3p $^3D_3$ — 3d $^3F_3$)
			5021		$N_2$1P(12—6), NII(3s $^5P_3$ — 3p $^5P_2$)
			5019		OI(3p ^5P — 7s ^5S), NII(3p $^3D_2$ — 3d $^3F_2$)
			5014		N_2^+1N(3—6), $N_2$1P(12—6), NII(3s $^5P_3$ — 3p $^5P_3$)

Previous Measurements		From Spectrogram taken Feb. 23, 1950			Interpretation
λ	I	λ_p	γ_r	I	
			5011		NII(3s $^3P_1$ — 3p ^3S) (3s $^5P_2$ — 3p $^5P_1$)
5006.7			5007?		OIII(5006.9) ($^3P_2$ — $^1D_2$) ?
5005		5003.7	5005	0.20	O$_2^+$1N(3—0)
				2.8	NII(3p $^3D_3$ — 3d $^3F_4$), (3s $^5P_2$ — 3p $^5P_2$), 3p ^3S — 3d $^3P_2$)
		5001.4	5003		NII(3s $^3P_0$ — 3p ^3S), (3p $^3D_{1,2}$ — 3d $^3F_{2,3}$)
			4999		O$_2^+$1N(4—1), NII(3s $^5P_1$ — 3p $^5P_1$), O$_2$SR(4—25)
			[4994]		NII(3s $^5P_2$ — 3p $^5P_3$), 3p ^3S — 3d $^3P_1$)
4987			4990		O$_2^+$1N(5—2), NII(3s $^5P_1$ — 3p $^5P_2$) (3p ^3S — 3d $^3P_0$) ?
			4980		OI(3p ^3P — 11s ^3S)
4975			4974		N$_2$2P(4—11), O$_2$SR(1—23)
		4967.5	4970	0.16	OI(3p ^5P — 6d ^5D) (4968.8, 4967.9, 4967.4)
			4965	0.27	
4961			4962	0.24	N$_2^+$1N(4—7), N$_2$VK(3—16)
4942			4942		OII(3p ^2P — 3d ^2D)
4935		4932.7	4934.5	0.35	NI(3s $^2P_{3/2}$ — 4p ^2S)
4927			4928		O$_2$SR(10—28)
			4923		OII(3p ^4S — 3d $^4P_{5/2}$), [O$_2$SR(8—27)]
4916			4917	0.14	N$_2$2P(1—7)
		4914.5	4915	0.18	NI(3s $^2P_{1/2}$ 4p ^2S)
			4913		NO$_\beta$(3—17)
4902			4907		OII(3p ^4S — 3d $^4P_{3/2}$), O$_2$SR(3—24)
			4896	0.27	[N$_2$VK(6—18)]
		4894.5	4895		NII[(2p^3) $^1D_2$ — 3p $^1P_1$)]
4891			4891		OII(3p ^4S — 3d $^4P_{1/2}$), NO$_\beta$(3—17)
			4887		NI(4886), O$_2$SR(0—22)
		4882	4883	0.16	NI(4882)
			4880	0.14	N$_2^+$1N(6—9)
4873			4873		OII(3p′ $^2P_{3/2}$ — 3d′ $^2D_{5/2}$)
			4867	0.15	NI(4869) ?
			(4865)		OII(3p ^4S — 3d $^4D_{1/2}$)
4861.5		4860.7	4862	0.15	OII(3p′ $^2P_{1/2}$ — 3d′ $^2D_{3/2}$)
4856				0.48	H$_\beta$(4861.3)
			4857	0.15	OII(3p ^4S — 3d $^4D_{3/2}$)
4835		4836	4838	0.39	N$_2$VK(2—15), NI(4838)
			(4835)		
			4814		N$_2$2P(2—8), O$_2$SR(2—23) (9—27)
4812			4812		NII(3p $^3D_3$ — 3d $^3D_2$), NO$_\beta$(2—16)
		4802	4803	0.18	OI(3p ^5P — 8s ^5S), NII(3p $^3D_3$ — 3d $^3D_3$)
4790			4799	0.14	
			4792		NII(3p $^3D_2$ — 3d $^3D_1$), NO$_\beta$(2—16)
			4787		NII(3p $^3D_2$ — 3d $^3D_2$)
4780			4781		NII(3p $^3D_{2,1}$ — 3d $^3D_{3,1}$)
		4770.4	4772	0.22	N$_2$VK(5—17), OI(3p ^5P — 7d ^5D), NII(3p $^3D_1$ — 3d $^3D_2$)
			4758		O$_2$SR(4—24)
4746		(4752)	(4749)	0.12	
		4724	4724	0.09	N$_2$2P(3—9), O$_2$SR(6—25)
4709	7.8	4709.1	4709		N$_2^+$1N(0—2), O$_2$SR(8—26)
			4686	0.23	NI(4686)
			4679		NII(3d ^1P — 4f ^1D)
		4677.8	4677	0.35	OII(3d $^2D_{5/2}$ — 4f $^2G_{7/2}$)
			4676		OII(3s $^4P_{5/2}$ — 3p $^4D_{5/2}$)
			4673	0.15	OI(3p ^5P — 9s ^5S), OII(3s $^4P_{3/2}$ — 3p $^4D_{1/2}$), O$_2$SR(3—23)
			4670	0.14	NI(4670), N$_2$2P(0—5)

Previous Measurements		From Spectrogram taken Feb. 23, 1950			Interpretation
λ	I	λ_p	λ_r	I	
		4661.7	4662	0.35	OII(3s$\,^4P_{3/2}$—3p$\,^4D_{3/2}$), NI(4660)
			4661		
4652	4.6	4651	4652	(5)	N$_2^+$1N(1—3), [N$_2$VK(4—16)], [OI(3p$\,^5P$—8d$\,^5D$)], [OII(3s$\,^4P_{5/2,\,1/2}$—3p$\,^4D_{7/2,\,1/2}$)]
		4642.8	4643		NII(3s$\,^3P_2$—3p$\,^3P_1$), O$_2$SR(0—21)
			4642		OII(3s$\,^4P_{3/2}$—3p$\,^4D_{5/2}$)
			4639		OII(3s$\,^4P_{1/2}$—3p$\,^4D_{3/2}$)
			4632	0.37	O$_2$SR(11—27)
4633		4631	4631		NII(3s$\,^3P_2$—3p$\,^3P_2$)
		4621.9	4621	0.11	NII(3s$\,^3P_1$—3p$\,^3P_0$), OII(3d$\,^2D_{5/2}$—4f$\,^4F_{5/2}$)
4613			4614		N$_2$VK(7—18), NII(3s$\,^3P_1$—3p$\,^3P_1$), OII(3d$\,^2D_{5/2}$—4f$^2\,{}^4F_{5/2,\,7/2}$)
			4610		OII(3d$\,^2D_{5/2,\,3/2}$—4f$^{2,\,4}F_{7/2,\,5/2}$), NII(3d$\,^1F$—4f$\,^1F$)
		4608.5	4608	0.15	NII(3s$\,^3P_0$—3p$\,^3P_1$), N$_2$VK(0—13), O$_2$SR(5—24) (7—25) (9—26)
4597	3.4	4600.7	4601	0.41	N$_2^+$1N(2—4), NII(3s$\,^3P_1$—3p$\,^3P_2$), OII(3d$\,^2D_{3/2}$—4f$\,^2F_{5/2}$)
		4597	4596	0.25	OII(3s$'\,^2D_{3/2}$—3p$'\,^2F_{5/2}$)
		4591	4591	0.54	OII(3s$'\,^2D_{5/2}$—3p$'\,^2F_{7/2}$), NO$_\beta$(3—16)
			4589		OI(3p$\,^5P$—10s$\,^5S$), O$_2$SR(2—22)
4572.3		4573.5	4574	0.29	N$_2$2P(1—6), NO$_\beta$(3—16), [OI(3p$\,^5P$—9d$\,^5D$)]
			4572		
4565			4563		NII(3p$\,^1P$—3d$\,^3F_2$)
			4561		
4554.8	2	4553.3	4553	0.30	N$_2^+$1N(3—5)
			4552		NII(3d$\,^1F$—4f$\,^3G_4$)
4535	1.6	4531.5	4533.5	0.61	N$_2$VK(3—15)
			4532.5		
			4530.5		NII(3d$\,^1F$—4f$\,^1G$)
4515	1.0	4515.1	4516	0.16	N$_2^+$1N(4—6)
			4514		O$_2$SR(6—24)
4509			4511		
			4507		NII(3p$\,^3D_3$—3d$\,^3P_2$)
		4498	4498		NI(4498), [N$_2$VK(6—17)], [NO$_\beta$(2—15)]
4487.5	1.6	4488.2	4491	0.19	N$_2$2P(2—7), OII(3d$\,^2P_{3/2}$—4f$\,^2D_{5/2}$), NI(4492)
			4489	0.12	N$_2^+$1N(5—7), OII(3d$\,^2P_{1/2}$—4f$\,^2D_{3/2}$), (3d$'\,^2P_{3/2,\,1/2}$—4f$'\,^2D_{5/2,\,3/2}$), NII(3p$\,^3D_2$—3p$\,^3P_2$)
			4485	0.08	NI(4485)
			4483		OII(3d$\,^2D_{5/2}$—4f$\,^4D_{5/2}$), [NO$_\beta$(2—15)]
		4474	4477		OII(3d$\,^2P_{3/2,\,1/2}$—4f$\,^4D_{5/2,\,3/2}$), NII(3p$\,^3D_2$—3d$\,^3P_1$)
			4472		
4468		4466.6	4468	0.18	OII(3s$\,^6S$—3p$\,^6P_{3/2,\,5/2}$)
			4466	0.15	OII(3d$\,^2P_{3/2}$—4f$\,^4D_{3/2}$)
			4465	0.14	NII(3p$\,^3D_1$—3d$\,^3P_1$), OII(3s$\,^6S$—3p$\,^6P_{7/2}$)
4452			4452		OII(3s$\,^2P_{3/2}$—3p$\,^2D_{3/2}$)
			4449		NII(3p$\,^1P$—3d$\,^1D$), OII(3p$'\,^2F_{7/2}$—3d$'\,^2F_{7/2}$)
		4443.0	4442	0.15	NII(3d$\,^3P_1$—4f$\,^3D_2$), OII(3p$'\,^2F_{5/2}$—3d$'\,^2F_{5/2}$)
			4440		O$_2$SR(11—26)
4334	1.6	4432.8	4433	0.53	NII(3d$\,^3P_{0,\,2}$—4f$\,^3D_{1,\,2,\,3}$)
4427.4	3	4427.6	4429	0.13	NII(3d$\,^3P_1$—4f$\,^3D_1$)
			4427	0.09	NII(3d$\,^3P_1$—4f$\,^1D_2$)
		4423.2	4424		N$_2$VK(2—14)
			4422		O$_2$SR(0—20) (5—23)
4415.2	2.5	4415.4	4417	0.76	N$_2$2P(3—8), OII(3s$\,^2P_{1/2}$—3p$\,^2D_{3/2}$)
			4415	0.82	OII(3s$\,^2P_{3/2}$—3p$\,^2D_{5/2}$)

Previous Measurements		From Spectrogram taken Feb. 23, 1950			Interpretation
λ	I	λ_p	λ_r	I	
4403		4405	4404	0.10	O$_2$SR(7—24)
4384			4380	0.19	N$_2$VK(5—16)
4377	1.6	4379.1	4379	0.15	OII(3d'^{2}D$_{5/2}$ — 4f'^{2}F$_{7/2}$)
			4377		OII(3d'^{2}D$_{3/2}$ — 4f'^{2}F$_{5/2}$) ?
			4375		NII(3p^{1}P$_1$ — 3d^{3}D$_2$), [O$_2$SR(2—21)]
4368.3	2.4	4368.3	4368	1.24	OI(3s^{3}S — 4p^{3}P), OII(3s^{4}P$_{5/2}$ — 3p^{4}P$_{3/2}$)
4362	1.2				
		4358.3	4358	(0.82)	HgI, NI(4358), OII(3d^{4}D$_{7/2,\,5/2}$ — 4f^{4}D$_{7/2}$)
			4352	0.32	N$_2$2P(4—9), OII(3s'^{2}D$_{5/2}$ — 3p'^{2}D$_{5/2}$)
4349.2		4350.2	4350	0.18	OII(3s^{4}P$_{5/2}$ — 3p^{4}P$_{5/2}$)
			4348	0.12	HgI, OII(3s'^{2}D$_{3/2}$ — 3p'^{2}D$_{3/2}$)
4346.5	3.0	4343.2	4345		OII(3s^{4}P$_{3/2}$ — 3p^{4}P$_{1/2}$), (3d^{4}D$_{5/2}$ — 4f^{4}G$_{7/2}$)
			4343	0.49	N$_2$2P(0—4), OII(3d'^{2}D$_{5/2,3/2}$) — 4f'^{2}D$_{5/2,3/2}$), NI(4343)
			4342		OII(3d^{2}F$_{7/2}$ — 4f^{2}G$_{9/2}$)
4340			4341	0.23	H$_\gamma$, OII(3d^{2}F$_{5/2}$ — 4f^{2}G$_{7/2}$)
			4339		HgI
			4337		OII(3s^{4}P$_{3/2}$ — 3p^{4}P$_{3/2}$), NI(4337), O$_2$SR(4—22)
			4334.5		OII(3d^{4}D$_{5/2,\,3/2}$ — 4f^{4}D$_{5/2}$)
			4330		OII(3p'^{2}P$_{3/2}$ — 3d'^{2}S)
			(4325)		OII(3s^{4}P$_{1/2}$ — 3p^{4}P$_{1/2}$)
			4322		NI(4322)
4319.5	1.6	4319	4319	0.28	N$_2$VK(1—13), OII(3s^{4}P$_{3/2}$ — 3p^{4}P$_{5/2}$), (3p'^{2}P$_{1/2}$ — 3d'^{2}S)
		4317.8	4317		OII(3s^{4}P$_{1/2}$ — 3p^{4}P$_{3/2}$), NI(4318)
			4316		OII(3d^{4}D$_{3/2,\,1/2}$ — 4f^{4}D$_{1/2}$), (3d^{2}F$_{7/2}$ — 4f^{4}F$_{7/2}$)
			(4313.5)		NI(4313), OII(3d^{2}F$_{7/2}$ — 4f^{4}F$_{9/2}$)
			4309		OII(3d^{4}D$_{1/2}$ — 4f^{4}D$_{1/2}$), NO$_\beta$(0—13)
4305		4305	4304		OII(3d^{4}P$_{5/2}$ — 4f^{4}D$_{7/2}$), NI(4306), NO$_\beta$(3—15)
4295		4294	4293		OII(3d^{2}F$_{5/2}$ — 4f^{4}F$_{5/2}$), 3d^{4}P$_{3/2}$ — 4f^{4}D$_{5/2,\,3/2}$), NO$_\beta$(0—13)
			(4288)		OII(3d^{4}P$_{1/2}$ — 4f^{4}D$_{1/2}$), NO$_\beta$(3—15)
			(4285)		NI(4285), OII(3d^{2}F$_{5/2}$ — 4f^{4}F$_{7/2}$)
4278	24.4	4277.8	4278		N$_2^+$1N(0—1), [N$_2$VK(4—15)]
		4241.7	4241	0.85	NII(3d^{3}D$_{3,\,2}$ — 4f$^{3,\,1}$F$_{4,3}$)
4236	5.9	4236.1	4236		N$_2^+$1N(1—2), NII(3d^{3}D$_{1,\,2}$ — ^{3}F$_{2,\,3}$)
			4231		NI(3s^{4}P$_{5/2}$ — 4p^{4}P$_{3/2}$), OI(4p^{3}P — 3d'^{3}P$_2$) ?
			4229		NI(4229.6)
4226.3	(4.0)		4226.5	0.12	NII(3p^{1}D — 4s^{1}P), O$_2$SR(5—22)
			4224		NI(3s^{4}P$_{3/2}$ — 4p^{4}P$_{1/2}$)
4223			4223	0.15	NI(3s^{4}P$_{5/2}$ — 4p^{4}P$_{5/2}$), OI(4p^{3}P — 3d'^{3}P$_1$)
			4221		NI(4221)
4218	(3.0)		4219	(0.10)	N$_2$VK(0—12)
			4217.5		OI(4p^{3}P — 3d'^{3}P$_0$)
			4215.5	0.10	NI(3s^{4}P$_{1/2}$ — 4p^{4}P$_{3/2}$), NO$_\beta$(2—14)
			4214	(0.10)	NI(3s^{4}P$_{3/2}$ — 4p^{4}P$_{5/2}$), O$_2$SR(0—19)
			4211.5	0.17	
			4208	0.09	NI(4209)
			4205	0.10	NI(4206)
4200	2.0	4199.4	4199	0.80	N$_2^+$1N(2—3), N$_2$2P(2—6), NO$_\beta$(2—14)
			4196	0.15	OII(3p'^{2}D$_{3/2}$ — 3d'^{2}P$_{1/2,\,3/2}$)
			4193	0.15	OII(3p'^{2}D$_{5/2}$ — 3d'^{2}P$_{3/2}$), NI(4193)
		4189.7	4189	0.23	OII(3p'^{2}F$_{7/2}$ — 3d'^{2}G$_{9/2}$)
			4188		NI(4187)
4185.9		4185.5	4185	0.10	OII(3p'^{2}F$_{5/2}$ — 3d'^{2}G$_{7/2}$)
			4184		
			4180.5		NII(3d^{3}D$_3$ — 4f^{3}D$_3$)

Previous Measurements		From Spectrogram taken Feb. 23, 1950			Interpretation
γ	I	λ_p	λ_r	I	
4176	1 4		4176.5		NII(3d^{1}D — 4f^{1}F)
		4175	4174.5	0.18	NII(3d ^{3}D$_2$ — 4f ^{3}D$_{2,3}$), N$_2$GK(0—9), O$_2$SR(2—20)
4172		4170	4170	0.12	N$_2$VK(3—14), NII(3d ^{1}D — 4f ^{3}F$_3$)
			4168.5		OII(3p ^{4}P$_{5/2}$ — 3d ^{4}P$_{5/2}$)
			4167.5	0.15	N$_2^+$1N(3—4)
			(4166)		NI(4166.6) ?
4164			4164		NI(4164.8) ?
			4160		NII(3d ^{3}D$_2$ — 4f ^{3,1}D$_{1,2}$)
		4157	4156.5		OII(3p ^{4}P$_{5/2}$ — 3d ^{4}P$_{3/2}$), NII(3d ^{3}D$_1$ — 4f ^{3,1}D$_{1,2}$)
			4153.5		OII(3p ^{4}P$_{3/2}$ — 3d ^{4}D$_{5/2}$)
			4152		NI(3s ^{4}P$_{5/2}$ — 4p ^{4}S)
			4145		NI(3s ^{4}P$_{3/2}$ — 4p ^{4}S), NII(3s ^{5}P$_3$ — 3p ^{5}S), O$_2$SR(4—21)
4141	1.4		4141		N$_2$2P(3—7), OII(3p ^{4}P$_{3/2}$ — 3d ^{4}P$_{3/2}$)
		4140	4140	0.17	N$_2^+$1N(4—5)
			4138.5		
			4137.8		NI(3s ^{4}P$_{1/2}$ — 4p ^{4}S)
			4136.5		
			4134		OII(3p ^{4}P$_{1/2}$ — 3d ^{4}P$_{3/2}$), NII(3s ^{5}P$_2$ — 3p ^{5}S)
			4131		OII(3p ^{4}P$_{3/2}$ — 3d ^{4}P$_{1/2}$) [NO$_\beta$(1—13)]
			4125		NII(3s ^{5}P$_1$ — 3p ^{5}S)
			4123		OII(3p ^{4}P$_{1/2}$ — 3d ^{4}P$_{1/2}$)
4120.4	1.6		4120.5		OII(3p ^{4}P$_{5/2}$ — 3d ^{4}D$_{3/2,\,5/2}$)
			4119		OII(3p ^{4}P$_{5/2}$ — 3d ^{4}D$_{7/2}$)
			4114.5		NI(3s ^{2}P$_{3/2}$ — 3p′ ^{2}D$_{3/2}$), OII(3p′ ^{2}F$_{7/2}$ — 3d′ ^{2}D$_{5/2}$) O$_2^+$2N(0—8), NO$_\beta$(1—13)
4112			4112		OII(3p ^{4}P$_{5/2}$ — 3d ^{2}F$_{5/2}$)
			4111		OII(3p ^{4}P$_{3/2}$ — 3d ^{4}D$_{1/2}$)
			4109.5		OII(3p′ ^{2}F$_{5/2}$ — 3d′ ^{2}D$_{3/2}$), NI(3s ^{2}P$_{3/2}$ — 3p′ ^{2}D$_{5/2}$), NII(3d ^{1}D$_2$ — 4f ^{3}D$_2$)
			4106.5		OII(3p ^{4}P$_{3/2}$ — 3d ^{4}D$_{3/2,5/2}$), (3p ^{4}D$_{7/2}$ — 3d ^{4}F$_{5/2}$)
		4099.8	4100	0.08	NI(3s^{2}P$_{1/2}$ — 3p′ ^{2}D$_{3/2}$)
			4097.5		OII(3p ^{4}P$_{1/2}$ — 3d ^{4}D$_{3/2}$), (3d ^{4}F$_{7/2}$ — 4f ^{4}G$_{9/2}$)
			4095.5		OII(3p ^{4}P$_{3/2}$ — 3d ^{2}F$_{5/2}$), (3d ^{4}F$_{5/2}$ — 4f ^{4}G$_{7/2}$), O$_2$SR(1—19)
4092.8	1.6		4094	0.14	N$_2$2P(4—8), OII(3p ^{4}D$_{7/2,\,5/2}$ — 3d ^{4}F$_{7/2,\,3/2}$)
			4089		OII(3d ^{4}F$_{9/2}$ — 4f ^{4}G$_{11/2}$)
			4086		OII(3d ^{4}F$_{3/2}$ — 4f ^{4}G$_{5/2}$), NII(3d ^{3}F$_3$ — 4f ^{1}F$_3$)
			4085.5		OII(3p ^{4}P$_{5/2}$ — 3d ^{2}F$_{7/2}$), (3p ^{4}D$_{5/2}$ — 3d ^{4}F$_{5/2}$)
			4083		OII(3d ^{4}F$_{5/2}$ — 4f ^{2}G$_{7/2}$), NII(3d ^{3}F$_3$ — 4f ^{3}F$_3$)
		4081.9	4082	0.17	NII(3d ^{3}F$_3$ — 4f ^{3}F$_4$), O$_2^+$2N(0—8)
		4079.4	4077		HgI, OII(3p ^{4}D$_{3/2}$ — 3d ^{4}F$_{3/2}$), NII(3d ^{3}F$_2$ — 4f ^{3}F$_2$)
4076		4075.2	4076	0.50	OII(3p ^{4}D$_{7/2}$ — 3d ^{4}F$_{9/2}$)
			4073	0.43	NII(3d^{3}F$_2$—4f ^{3}F$_3$)
			4072	0.44	OII(3p ^{4}D$_{5/2}$ — 3d ^{4}F$_{7/2}$), N$_2$VK(2—13)
		4071.2	4071	(0.36)	OII(3d ^{4}F$_{7/2}$ — 4f ^{2}G$_{9/2}$) (3p ^{4}D$_{3/2,\,1/2}$ — 3d ^{4}F$_{5/2,\,3/2}$)
		4067	4066		[O$_2$SR(3—20)]
			4061		OII(3d ^{4}F$_{9/2}$ — 4f ^{4}F$_{9/2}$), (3d′ ^{2}F$_{5/2,\,7/2}$ — 4f′ ^{2}G$_{7/2,\,9/2}$)
4059.1	3.4	4058.1	(4058.5)	1.5	N$_2$2P(0—3)
			(4057)		NII(3d ^{3}F$_4$ — 4f ^{3}G$_4$)
4049		4046.6	4047	0.40	OII(3d ^{4}F$_{7/2}$ — 4f ^{4}F$_{7/2}$)
			4045.5	0.35	OII(3d ^{4}F$_{7/2}$ — 4f ^{2}, ^{4}F$_{7/2,\,9/2}$), N$_2$VK(5—15), NII(3d^{3}F$_3$ — 4f ^{3}G$_3$), O$_2$SR(5—21)
4042		4043.4	4043	0.33	NII(3d ^{3}F$_3$ — 4f ^{3}G$_4$)
		4041.3	4041	0.58	OII(3d ^{4}F$_{5/2}$ — 4f ^{4}F$_{5/2}$), NII(3d ^{3}F$_4$ — 4f ^{3}G$_5$), NO$_\beta$(0—12)
		4037	4036.3	(0.25)	NI(4037.4)

Previous Measurements		From Spectrogram taken Feb. 23, 1950			Interpretation
λ	I	λ_p	λ_r	I	
			4035.8	0.28	OII(3d^{4}F$_{5/2}$—4f^{2}F$_{5/2}$), NII(3d^{3}F$_2$—4f^{3}G$_3$)
			4033		OII(3d^{4}F$_{3/2}$—4f^{4}F$_{3/2}$), NI(4033.6)
			(4030)		NO$_\beta$(0—12)
4027.5		4026	4026	0.30	OII(3d^{4}F$_{3/2}$—4f^{2}F$_{5/2}$), NII(3d^{3}F$_3$—4f^{1}G$_4$)
			4024	(0.20)	OII(3d$'\,^2$F—4f$'\,^2$D)
4013			4011		NI(4011.0)
			4009		
			4001		NI(4000, 4001.7
3997.5	3.7	3997.3	3997.5	2.1	N$_2$2P(1—4)
			3995	(0.70)	NII(3s^{1}P—3p^{1}D), NI(3994.9)
			3992.5		
			3991.5		
			3989		O$_2$SR(2—19)
			(3986.5)		
			(3985.5)		OII(3p^{4}P$_{1/2}$—3d^{2}P$_{3/2}$)
3982.6	1.0		3982.5		OII(3s^{2}P$_{3/2}$—3p^{2}P$_{1/2}$)
			3981		
			3979		N$_2$VK(1—12)
3974			3973.5		OII(3s^{2}P$_{3/2}$—3p^{2}P$_{3/2}$)
			3968.5		NI(3970.0) ?
3962.5			3961		NO$_\beta$(2—13)
3957			3955		OI(3p^{3}P$_{2,1}$—3s$''\,^3$P$_2$), NII(3s^{3}P$_1$—3p^{1}D$_2$), NI(3957.2)
			3954		OI(3p^{3}P$_{2,1,0}$—3s$''\,^3$P$_{1,0}$), OII(3s^{2}P$_{1/2}$—3p^{2}P$_{1/2}$)
			(3949)		N$_2$VK(4—14), NO$_\beta$(2—13)
			(3947)		OI(3s^{5}S—4p^{5}P)
			(3945)		OII(3s^{2}P$_{1/2}$—3p^{2}P$_{3/2}$)
3943	2.2		3942.5	1.1	N$_2$2P(2—5)
			3941.5	1.0	N$_2$VK(7—16)
			3930.5		
			3918.5		OII(3s$'\,^2$D$_{3/2}$—3p$'\,^2$P$_{1/2}$), NII(3p^{1}P—3d^{1}P)
3915	47.4	3914	3914		N$_2^+$1N(0—0), O$_2$SR(1—18)
			3887.8		N$_2$VK(0—11), O$_2$SR(3—19)
			3886		
3884.3	2.2	3884.1	3884	3.2	N$_2^+$1N(1—1)
			3883		OII(3p^{4}D$_{3/2}$—3d^{4}P$_{3/2}$) (3p^{4}D$_{7/2}$—3d^{4}D$_{5/2,\,7/2}$)
			3881.5		
			3880.5		NO$_\beta$(1—12)

Table 1c.

Auroral Lines from Previous Measurements in the Region 3874 Å—3114. Å.

λ	I	Interpretation
3873.8	1.0	OII(3p^{4}D$_{1/2,\,3/2}$—3d^{4}P$_{3/2,\,1/2}$) (3p^{4}D$_{7/2}$—3d^{2}F$_{5/2}$)
3857.5		N$_2^+$1N(2—2), N$_2$2P(4—7), VK(3—13), OII(3p^{4}D$_{5/2}$—3d^{2}F$_{5/2}$)
3821.8		N$_2^+$1N(4—4), OII(3p^{2}P$_{1/2}$—4s^{2}P$_{1/2}$)
3805.3	4.9	N$_2$2P(0—2), OII(3p^{2}P$_{3/2}$)—4s^{2}P$_{3/2}$)
3771.6	1.0	N$_2$VK(2—12)
3755.2	4.2	N$_2$2P(1—3), VK(5—14), OII(3s^{4}P$_{5/2}$—3p^{4}S)

λ	I	Interpretation
3728.4	1.0	OII$[2p^2(^4S_{3/2} - {}^2D_{3/2,\,5/2})]$, $(3s\,^4P_{3/2} - 3p\,^4S)$
3711.3	2.4	$N_2$2P(2—4), OII$(3s\,^4P_{1/2} - 3p\,^4S)$
3686	1.6	N_2VK(1—11), (OI$(3s\,^3S - 5p\,^3P)$
3671		$N_2$2P(3—5), VK(4—13) (7—15)
3603	1.0	N_2VK(0—10)
3583	1.6	N_2^+1N(1—0), N_2VK(3—12)
3578	9.8	$N_2$2P(0—1), VK(6—14)
3563.5	1.6	N_2^+1N(2—1)
3536.3	4.9	$N_2$2P(1—2), N_2^+1N(4—3)
3503.5	2.2	$N_2$2P(2—3), VK(2—11)
3484	1.0	$N_2$2P(7—8) ?
3467.5	3.0	$N_2$2P(3—4), NI$[3p^3(^4S - {}^2P)]$
3429	2.0	N_2VK(1—10), OI$(3s\,^3S - 6p\,^3P)$, NII$(3s\,^1P - 3p\,^1S)$
3371.3	9.0	$N_2$2P(0—0), OII$(3d\,^4F_{9/2} - 5p\,^4D_{7/2})$?
3339.3	1.2	$N_2$2P(1—1), VK(3—11)
3285.3	1.8	$N_2$2P(3—3), OII$(3P\,^4P_{5/2} - 4s\,^4P_{5/2})$?
3202.7	2.2	N_2VK(1—9)
3192.4		N_2VK(4—11)
3168.7		$N_2$2P(9—7) ?
3159.3	5.8	$N_2$2P(1—0)
3135.7	3.6	$N_2$2P(2—1), VK(0—8), OII$(3p\,^4D - 4s\,^4P)$?
3114		$N_2$2P(3—2), OII$(3p\,^4D - 4s\,^4P)$

The following abbreviating notations are used:

Atomic Lines.

OI: Lines from neutral oxygen atoms.
OII: ,, ,, singly ionized oxygen atoms.
NI: ,, ,, neutral nitrogen atoms.
NII: ,, ,, singly ionized nitrogen atoms.
NaI D: Yellow line from neutral sodium atoms.
H_α, H_β and H_γ: Lines from the Balmer series of hydrogen.

The mercury lines denoted (Hg I) are due to scattered light from mercury lamps in the town and have nothing to do with auroral luminescence.

Molecular Bands.

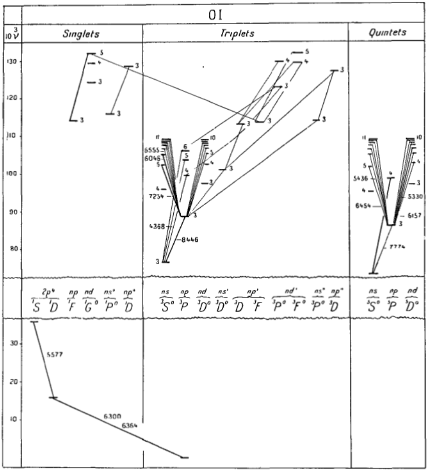
N_2 1.P.: First positive group from neutral N_2.
N_2 2.P.: Second ,, ,, ,, ,, ,,
N_2 V.K.: Vegard–Kaplan bands ,, ,, ,,
N_2 G.K.: Goldstein–Kaplan ,, ,, ,, ,,
N_2^+ 1.N.: First neg. group from ionized N_2 mol.
O_2^+ 1.N.: ,, ,, ,, ,, ,, O_2 ,,
O_2 S.R.: Schuman–Runge bands from neutral O_2.
NO_β: β-bands from NO.

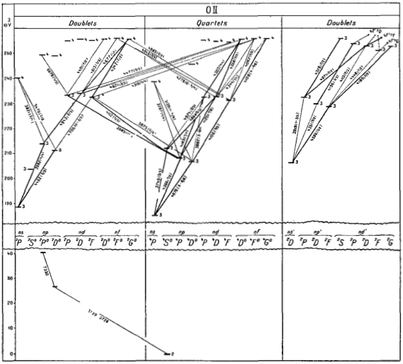
The two numbers in bracket added to the band symbols give the vibrational quant numbers of the upper and lower electronic state respectively.

In addition to the bands N_2 1.P., N_2 2.P., N_2 V.K. and N_2^+ 1.N. previously known to be present in the auroral light, *the new spectrogram shows quite strong bands of the first negative group of oxygen emitted from O_2^+.* Thus this spectrogram has shown, for the first time, that bands from molecular oxygen appear in the auroral luminescence. In a considerable number of cases we find lines which coincide with Goldstein–Kaplan bands from N_2, Schuman–Runge bands from O_2 and with β-bands from NO.

In most cases, however, these bands also coincide with lines or bands which are known to be present in the auroral luminescence. Consequently the existence of bands from these three systems cannot be considered as proved, but they are presented in order to call attention to their possible appearance in the auroral luminescence. In the cases where more than one possible interpretation is found for a band or line, the one for which the interpretation is certain or the most probable is given first.

From the tables 1 we notice—in agreement with our previous results—that a great number of auroral lines originate from atoms of oxygen and nitrogen in the neutral and ionized state.


O I
$10^3 \nu$
Singlets
Triplets
Quintets
130
120
110
100
90
80
30
20
10
6555
6046
7254
4368
8446
5436
6454
5330
6157
7774
5577
6300
6364
2p⁴ ¹S ¹D
np ¹F
nd ¹G°
ns'' ¹P°
np'' ¹D
ns ³S°
np ³P
nd ³D°
ns' ³D°
np' ³D ³F
nd' ³P° ³F°
ns'' ³P°
np'' ³D
ns ⁵S°
np ⁵P
nd ⁵D°


O II
$10^3 \nu$
Doublets
Quartets
Doublets
260
240
230
220
210
200
190
40
30
20
10
0
7330
3729 3726
ns ²P
np ²S° ²P° ²D°
nd ²P ²D ²F
nf ²D° ²F° ²G°
ns ⁴P
np ⁴S° ⁴P ⁴D°
nd ⁴P ⁴D ⁴F
nf ⁴D° ⁴F° ⁴G°
ns' ²D
np' ²P ²D ²F
nd' ²S ²P ²D ²F ²G

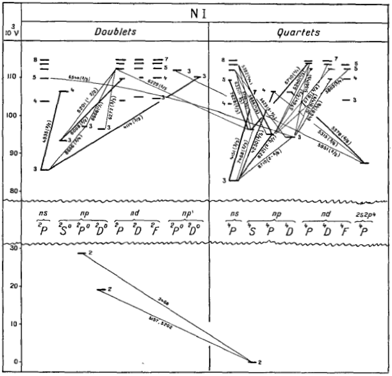

N I
$10^3 V$
Doublets
Quartets
110
100
90
80
30
20
10
0
6544 (3/5)
6229 (1/5)
5201 (1 2/3)
6008 (1/2)
6666 (1/2)
6272 (1/3)
8656 (1/4)
4935 (1/2)
4114 (3/5)
3466
5197, 5202
5378 (4/5)
5315 (3/5)
5851 (4/5)
8710 (2-4/5)
ns
np
nd
np'
2s2p⁴
^2P $^2S^0$ $^2P^0$ $^2D^0$ ^2P ^2D ^2F $^2P^0$ $^2D^0$
^4P ^4S ^4P ^4D ^4P ^4D ^4F ^4P

Fig. 5a.

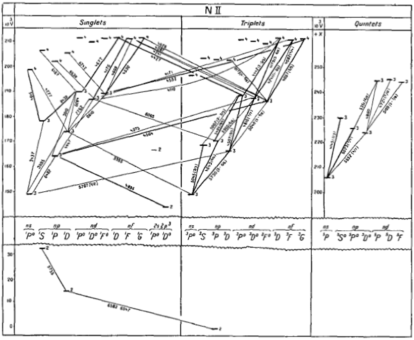

N II
$10^3 V$
Singlets
Triplets
Quintets
+ X
210
200
190
180
170
160
150
250
240
230
220
210
200
30
20
10
0
4227
4552
4171
4110
6065
4375
4564
3385
4895
5767 (3/2)
3437
5045 (3/2)
5005
4803 (1/1)
3755
6583 6547
ns
np
nd
nf
2s2p³
$^1P^0$ ^1S ^1P ^1D $^1P^0$ $^1D^0$ $^1F^0$ ^1D ^1F ^1G $^1P^0$ $^1D^0$
$^3P^0$ ^3S ^3P ^3D $^3P^0$ $^3D^0$ $^3F^0$ ^3D ^3F ^3G
^5P $^5S^0$ $^5P^0$ $^5D^0$ ^5P ^5D ^5F

Fig. 5b.

The number of lines of this origin, which are found to coincide in a satisfactory way with auroral lines, are given in table 2.

Table 2.

Origin of Lines	Number of Lines	
	Interval 8860–6364	Interval 6364–3114
OI	7	36
OII	4	125
NI	13	102
NII	6	114

In the table we have for each of these lines given the term symbols for the lower and upper atomic energy state. The transitions, which may give lines observed in the auroral spectrum are illustrated by means of the term diagrams fig. 4a and 4b for OI and OII and in fig. 5a and 5b for NI and NII.

The term symbols are on each diagram arranged in a horizontal row. The energy states are indicated by a short and fat horizontal line. The symbol corresponding to any energy state is found by imagining a vertical line drawn from the state to the row of symbols.

The transitions are indicated by a line drawn between the energy states, and the wavelength of the line resulting from the transition is written close to the "line of transition".

In the case of multiple states the separation due to variations of the quantum number (j) is too small to be given on the diagram. In this case a multiplet is indicated by a single "line of transition", and only the wavelength of one of the principal components is given. In the bracket on the right side of the written wavelength value, the fraction of the number of observed lines to the total number of multiple components is given. If e.g. the fraction is (6/6) it means that all 6 components of the multiplet have been detected or may be present in the auroral spectrum, and if the fraction is (4/6) it means that only 4 out of 6 possible components have been detected.

The "transition lines" corresponding to auroral lines which are most accurately determined and identified are drawn as fat lines. Those which are less certain or the existence of which are probable are drawn as thin lines.

In view of the fact that the lines corresponding to the forbidden transitions from the metastable ground states are so conspicious in the case of OI, makes it a matter of interest to know whether corresponding forbidden lines from OII, NI and NII appear in the auroral luminescence.

In the case of OII, it has been previously found (1, 7, 8) that the doublet 3729, 3726 (corresponding to transitions $^4S_{3/2} - {}^2D_{5/2,\,3/2}$) within the limit of error, coincides with observed auroral lines, which, however, are comparatively weak.

A multiplet corresponding to the transition $({}^2D_{j'} = {}^2P_{j''})$ and a wavelength of the principal component of about 7330 fall in the infra red region, where the spectrum is dominated by broad bands, e.g. from $(N_2 1P)$. Therefore at present it is doubtful whether the lines corresponding to these transitions appear in the auroral luminescence.

In the case of NI, a line 3466—corresponding to the transition $({}^4S - {}^2P)$ may be said to coincide in a satisfactory way with an auroral line of moderate intensity previously measured on several auroral spectrograms (cfr. paper 8 p. 9 and 10).

The forbidden transitions $({}^4S_{3/2} - {}^2D_{5/2,\,3/2})$ would give a doublet (5202, 5197), but as the components would not be separated even by the new spectrograph, the doublet would give a somewhat broadened line with an apparent wavelength 5199.5 if the components were equally strong. On our Oslo spectrogram a somewhat broad line of moderate intensity with a wavelength 5199 appeared. This would seem to prove that this forbidden green NI-line appears in the auroral spectrum. But now it happens that a doublet corresponding to the allowed transitions $3p^2S_{1/2} - 5d^2P_{3/2,\,1/2}$ gives components with about the same wavelengths, 5201.8, 5197.1 and the mean 5199.5. The fact that the observed auroral line 5199 is moderately strong, while the allowed lines are very weak, speaks decidedly in favour of the assumption that the auroral line 5199 essentially originates from the forbidden transition. The doublet $({}^2D_{5/2,\,3/2} - {}^2P_{3/2})$ (10395. 10404) lies outside the infra red region as yet explored.

In the case of NII the transition ($^1D—^1S$) would give a line 5755, which may possibly be identified with the faint auroral line 5754. The doublet ($^3P_{2.1}—^1D_2$) (6583, 6548) corresponding to the red OI-doublet falls in a region where the auroral luminescence has strong and broad bands, and if the doublet is very weak it might be masked by the bands.

Thus it is not excluded that the forbidden NII-lines may be present in the auroral luminescence, but if so they must as a rule be very weak.

§ 3. Detailed Study of the Doppler Spreading of the Hydrogen Lines.

As mentioned in the preliminary communications the H_β-line appears quite distinctly on the auroral spectrogram from Oslo, but it is broad and diffuse on account of Doppler effect. A closer inspection of the photometer curves shows, that also H_γ appears and is spread out in a similar way.[1]

An enlarged copy of the photometer curve of the diffuse H_β line and its nearest surroundings is shown on fig. 6. The undisplaced H_β-line (4861.3 Å) is seen to fall near the place, where the "H_β-band" has its maximum. The maximum merely shows a relatively small Doppler-displacement towards shorter wavelengths. This is better seen from fig. 7, where an intensity curve is drawn, for which the irregularities of the photometer curve (fig. 6) have been dropped.

The medium line (b) passing through the intensity maximum is seen to be displaced $\Delta\lambda_m = 1$ Å towards shorter waves relative to the undisplaced H_β-line (a).

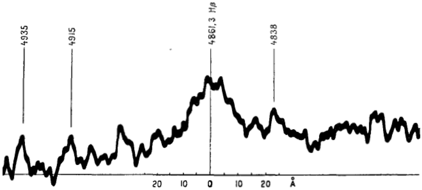


Fig. 6.

When we take into account that the instrument was kept in the same position relative to the magnetic lines of force through the whole exposure, the type of Doppler spreading shown on fig. 6 and 7, is easily explained, when we assume that protons are coming into the atmosphere, where they will move in spirals round the magnetic lines of force.

According to theory, the angle between the orbit of a proton and the magnetic lines of force will as a rule increase downwards and if the proton is not absorbed the angle may reach 90° after which it turns upwards. This means that there is a probability for orbits to move approximately in circles perpendicular to the lines of force, and when also the instrument is directed nearly perpendicular to the lines of force, the H_β-line will be displaced almost equally in both directions relative to the undisplaced line. The situation is illustrated in fig. 8.

The magnetic inclination at Oslo is about 70°. The elevation angle of the instrument was about 25°. This means that the angle between the downwards directed magnetic lines of force and the axis of the instrument is about 85°, which explains the small average Doppler displacement $\Delta\lambda_m$ fig. 7.

Finally it must be remembered that at the moment when the light emission takes place, the protons are neutralised, and the influence of the magnetic field on the motion of the hydrogen atoms vanishes. *Thus from the incoming*

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[1] The H_α-line falls outside the sensitivity range of the photographic plate.

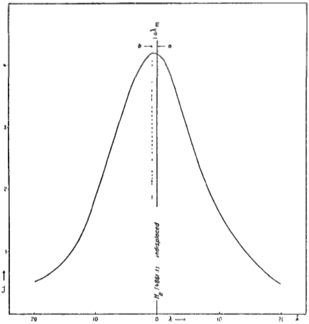

Fig. 7.

proton bundle hydrogen atoms will spread out in various directions as indicated by the arrows fig. 8. The distribution of velocities is symmetrical relative to the lines of force, but the components of the velocities along the lines of force are mainly directed downwards.

On some previous spectrograms from Tromsoe (9) the H_β-line was mainly displaced towards shorter waves, showing that the instrument during the exposure had mostly been held nearly in the direction of the lines of force.

As seen from fig. 7, the maximum Doppler displacement is about 18 Å. From the conception we have of the process it is legitimate to assume that there will always be some hydrogen atoms of maximum velocity, which will move towards the observer or in the opposite direction. Consequently the maximum velocity should be determined by the equation:

$$V_{\max} = \frac{\Delta\lambda_{\max}}{\lambda} \cdot C \qquad (1a)$$

Putting $\lambda_{\max} = 18$ Å we find $V_{\max}$ equal to about 1000 km/sec.

The average velocity of the hydrogen atoms downwards along the lines of force is found by the equation:

$$V_m = \frac{\Delta\lambda_m}{\lambda} \cdot \frac{C}{\cos\varphi} \qquad (1b)$$

Putting $\Delta\lambda_m = 1$ Å, $\varphi = 85°$, we get V_m equal about 700 km/sec. As $\Delta\lambda_m$ and φ are not very accurately determined the value found for V_m is merely to be regarded as a rough estimate.

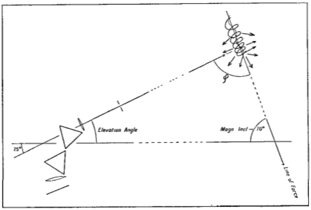

Fig. 8.

§ 4. Determination of the Ionospheric Temperature by means of the N_2^+ Band 3914.

As shown in previous papers (12, 13, 14) an upper limit for the ionospheric temperature can be found from the intensity distribution of the rotational components of the R-branch of a negative nitrogen band. If the dispersion of the spectrograph is so great that the rotational components are separated, an absolute determination of the temperature of the emitting molecular ions can be determined quite accurately.

Even when the rotational components are not separated, the method can be used, but in that case the correction for overlapping has to be determined by means of spectrograms of about the same dispersion and from the same bands emitted from a light source of varied, known temperatures.

As seen from the photometer curves of the negative nitrogen bands, particularly 3914, the components of the R-branch appear separated, so the intensity of each individual component can be measured. As the photographic density is suitable for intensity measurements the band 3914 should give favourable conditions for an accurate absolute temperature determination.

The temperature may be derived either by determining the rotational quantum number (K_m), which corresponds to the intensity maximum of the R-branch, or by determining the way in which the intensity of the components of the R-branch vary with the rotational quantum number.

Let I_k be the intensity of a rotational component corresponding to the quantum number K, then

$$\log_{10}\left(\frac{I_k}{K}\right) = -\varkappa_1 (K+1) K \qquad (2a)$$

where

$$\varkappa_1 = \frac{h^2 \log_{10}\varepsilon}{8\pi^2 JkT_\varkappa} \qquad (2b)$$

$T_\varkappa$ is the absolute temperature of the emitting N_2^+ ions, the moment of inertia (J) of the N_2^+ ions in the upper state is equal to $13.4 \cdot 10^{-14}$ (gr.cm^2), h and k are Planck's and Boltmann's constant respectively. The equation (2b) gives

$$T_\varkappa = \frac{1.2855}{\varkappa_1} \qquad (3)$$

From the quantum number (K_m) corresponding to the maximum of the intensity distribution curve, the absolute temperature T_m is found from the formula (14):

$$T_m = 2.96\, K_m\, (2\, K_m + 1) \qquad (4)$$

If the intensities of the rotational components follow the Maxwell law of energy distribution, we should have:

$T_\varkappa = T_m$ = absolute temperature T of the emitting ions.

A photometer curve (fig. 9) of the 3914 band shows distinctly the maxima of the rotational bands of odd quantum numbers.

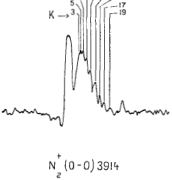

Fig. 9.

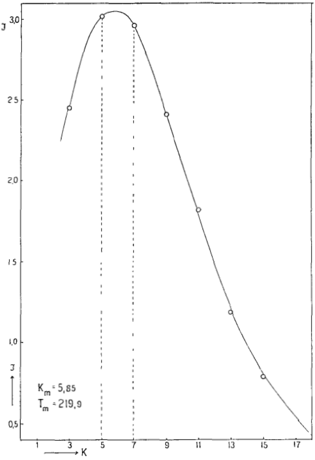

Fig. 10.

The curve fig. 10 gives the relation between intensity (I) and rotational quantum number. From this we find:

$$K_m = 5.85$$

and by means of equation (4)

$$\underline{T_m = 219.9 \text{ Kelvin}}$$

According to equation (2a) $\log_{10}(I_k/k)$ should be a linear function of $K(K+1)$. This relation is represented by the straight line fig, 11, the slope of which gives the quantity $\varkappa_1 = \frac{1}{169.5}$ and equation (3) gives

$$\underline{T_\varkappa = 217.9 \text{ Kelvin}}$$

Thus within the limit of error we have $T_\varkappa \approx T_m$. Taking the mean value we get:

$$T = 218.9 \text{ K}$$

or $$t = -54.1° \text{ C}$$

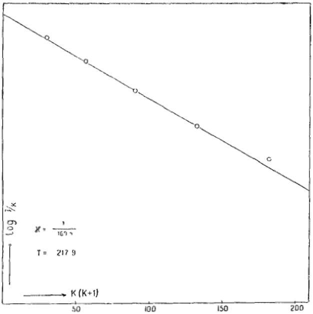

Fig. 11.

The ionospheric temperature, derived from this spectrogram, is somewhat lower than the mean tempeture from our earlier measurements.

During this winter some very successful spectrograms, covering also the long wave region into the infra red, have been taken at the Tromsoe Observatory with the new spectrograph. The results will be given later.

Summary of Results.

1. A new two prism glass spectrograph combining considerable dispersion with a light power F : 1.2, had been obtained from Société générale d'optique where it was built by Dr. Cojan in accordance with given specifications.
2. The spectrograph was designed to meet the requirements for the detection and measurement of faint and closely packed lines known to be present in the auroral luminescence.
3. An auroral spectrogram was obtained at Oslo with the new spectrograph during the night Feb. 23—24 1950, and in addition to the usual somewhat strong lines and bands, a great number of weak but sharp and distinct lines appeared.
4. About 114 bands and lines could be measured with a comparator directly from the negative, more than 50 of which were not previously detected.
5. By means of photometer curves of great magnification a still greater number of weak lines could be detected and quite accurately measured.
6. In the spectral region (6300—3880) covered, the total number of measured bands and lines amounted to about 375, and about 310 of these had not been previously detected and measured. By far the greater part of these lines were shown to originate from O-and N-atoms in the neutral or ionized state.

   In addition to the nitrogen bands earlier observed, it was found that bands from the negative group of oxygen (O_2^+-bands) appeared and that a number of auroral lines gave satisfactory coincidence with Goldstein bands from N_2, Schumann-Runge bands from O_2, and β-bands from NO.
7. The H_β-line appeared quite marked, but was spread out into a diffuse band through Doppler effect. The undisplaced line was situated near the middle of the band. Taking into account that the instrument was directed nearly perpendicular to the lines of force, this spreading in both directions was explained by assuming that the protons were moving in spirals round the magnetic lines of force, and when they were neutralized, the atoms would have velocity components in all directions perpendicular to the magnetic lines of force.

   Also the much weaker H_γ-line was seen to be spread out in the same way.
8. The fact that the rotational components of the R-branch of the band 3914 were distinctly separated, greatly favoured an accurate temperature determination. We found $T_m = 219.9°$ K and $T_x = 217.9°$ K, which gives a mean value:

$$T = 218.9° \text{ K or } t = -54.1° \text{ C}$$

In conclusion we wish to express our thanks to Mr. A. Omholt and Mr. O. Øiseth for most valuable assistance in connection with the accomplishment of this paper. Our thanks are also due to "The Scientific Government Fund" for valuable economic support of the research work forming the basis of this paper.

Physical Institute, University Oslo, Feb. 1951.

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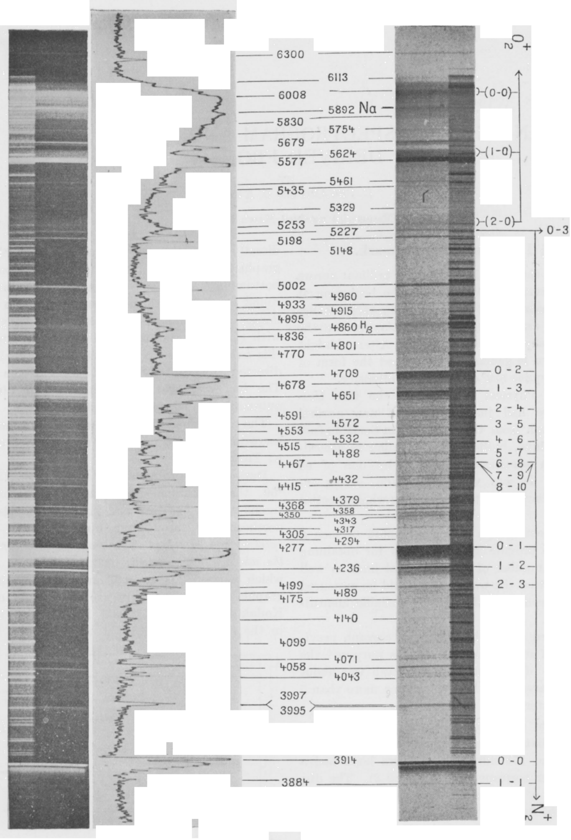
O_2^+
6300
6113
6008
5892 Na
5830
5754
5679
5624
5577
5461
5435
5329
5253
5227
5198
5148
5002
4960
4933
4915
4895
4860 H_β
4836
4801
4770
4709
4678
4651
4591
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3995
3914
3884
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(1-0)
(2-0)
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1-3
2-4
3-5
4-6
5-7
6-8
7-9
8-10
0-1
1-2
2-3
0-0
1-1
N_2^+

Fig. 2.