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NIGHTGLOW OBSERVATIONS AT ÅS DURING THE I.G.Y.

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Summary. A grating spectrograph with linear dispersion 35 and 50 Å/mm (dependent on grating and spectral order) has been used in the study of night airglow in the spectral range from 5100 *Å* to 7300 *Å*. Apart from the forbidden *OI* lines and the *NaI* doublet, the *NI* (5200 *Å*) doublet, the red *NII* forbidden lines (6548/83 *Å*) and a sharp H_α line seem to be permanently present in the nightglow. A covariance of the intensities of the *NII* and the H_α lines, possibly also with *OH* bands, is reported. The (0,0) and (0,1) bands of the N_2^+ negative system have been observed in the 4th order spectrum superposed on the 3rd. Accurate wavelengths of 8 *OH* bands in the visible region are given. From these, and previously published data, rotational energy levels for the vibrational states $v = 0$ to 9 of the *OH* $X^2\Pi$ state have been computed. Absolute intensities of 4 *OH* bands are estimated. The rotational temperature, derived from *OH* bands (6,1) and (9,3), is found to be 215° K.

1. Introduction. A new grating spectrograph, built by grants from the Norwegian Research Council for Science and the Humanities, has been used during the International Geophysical Year in the study of aurorae and nightglow at Ås, Southern Norway (10° 47′ E Gr, 59° 40′ N). Some results of the investigations have been given elsewhere (Kvifte 1959). In this paper the nightglow observations in the spectral range from about 5100 *Å* to just above 7300 *Å* will be dealt with in detail. The auroral material from the same region will be treated in a subsequent paper.

2. Instrumentation. The spectrograph shown in figure 1, a and b, was constructed by Mr. R. Markussen at the workshop of the Department of Physics at the Agricultural College of Norway during the winter 1957/58, as a joint project of cand. real. A. Omholt and the author. Before the instrument was finished, the optical parts were mounted provisionally and served in a satisfactory way as a spectrograph. Most of the spectra shown in plate I and II are taken with the provisional mounting (which hereafter will be denominated by spectrograph "*P*" as distinguished from the permanent mounting, spectrograph "*G*").

Both mountings have a fixed angle of about 30° between the optical axes of the collimator and the camera lens. The spectral range is altered by rotating the plane grating, placed with its center at the intersection point of the two optical axes, around a line perpendicular to the plane through these axes. The adjustment of the ruled grooves of the grating to parallelism with the same line is managed by small rotations of the grating around orthogonal axes.

Technical data of the essential parts of the spectrograph, marked in Fig. 1 by the capitals below, are as follows:

A. Slit: Type *F* 1386 symmetrical slit from Hilger et Watts Ltd., adjustable along the collimator axis.
B. Collimator lens in fixed position: "*P*" spectrograph: Fernbildlinse $F/5, f = 40$ cm from Astro Gesellschaft Bielicke et Co, Berlin. "*G*" spectrograph: Carl Zeiss, Jena, lens $F/5, f = 53$ cm.
C. Plane reflecting grating from Bausch and Lomb Optical Co. In "*P*": Ruled area 76×65 mm², 2160 grooves/mm and blaze wavelength 6000 Å (1st order spectrum used). In "*G*": 128×102 mm², 600 grooves/mm, blaze wavelength 1,6 μ. (3rd order spectrum used.)
D. Camera objective from Wray Optical Works Ltd, $F/0.71, f = 64$ mm. The adjustment of its focal plane relative to the plane of the photographic plate is done by screwing the lens along its optical axis. The position is reproduceable within 2.5μ.
E. The plateholder, for platesize 4×9 cm², is mounted on a slider which runs in an encased framework. The framework is adjustable around an axis in the plane of the plate emulsion.

The linear dispersion of spectrograph "*P*" was about 35 Å/mm in the 1st order, and the spectral range covered, by a fixed position of the grating, approximately 600 Å. The corresponding data of spectrograph "*G*" in the 3rd order spectrum are 50 Å/mm and 800 Å.

3. Observation procedure. The spectrograph was placed in a tower of a five storied building at The Agricultural College of Norway. The height above sea level is about 110 m. The tower has windows in eight directions, thus enabling observations towards all azimuths. The zenith angle of the observations is, however, limited to the interval 30° to 90°.

A roller table, with suitable arrangement for elevating the optical axis of the collimator, served as foundation for the spectrograph. By means of a field lens ($F/3, f =$ 17,5 cm) a portion of the sky was projected on the vertical slit.

Kodak photographic plates of emulsion types 103 a and *I* and sensitizing classes *G*, *T*, *E*, *F* and *N*, the *N* type hypersensitized with ammonia, were used in the different spectral regions. The exposure times varied from 2½ hour to 11½ hour with the 103a emulsion, the *IN* plate needed in the region around 7000 Å roughly 25 hours to yield a sufficiently dense spectrogram.

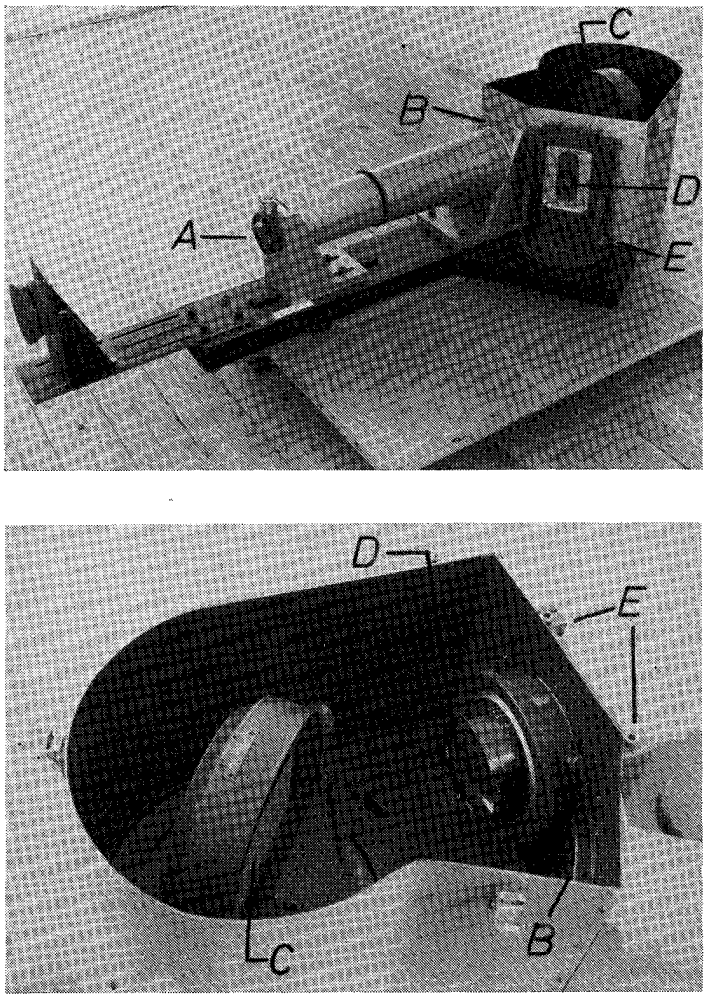


Fig. 1. Spectrograph «G». a: Exterior. b: Grating and Camera.

In all about 20 successful nightglow spectra were obtained during the periode from November 1957 to December 1958. The best ones are shown as negative reprints in Plate I and II. Relevant data for each spectrogram are given the in Explanation to the Plates.

The weather conditions were not always perfect. In some cases a slight haze reflected the light from buildings and the road-illumination, causing *Hg* lines and the stronger *Ne* lines to appear (see Plate I no 1 and 2, and Plate II no 2 and 4). These lines have served as a control of the wavelength measurements. As neon (in one case argon) was used for standard spectra, it was never difficult to distinguish between "false" and "real" lines in the nightglow.

4. Atomic lines.

OI, NaI. The presence in the nightglow of the atomic oxygen lines 5577 Å, 6300 Å and 6364 Å and of the sodium doublet at 5890/96 Å has since long been established with certainty (see e. g. Barbier 1955). They are all very intense as compared with other radiations in the nightglow. With the instrument here used, an exposure time of a few minutes was sufficient to obtain the *OI* 5577 Å line with measurable intensity. As the aim of the investigation was to study the fainter spectral features, the oxygen lines are usually heavily overexposed. No attempt has therefore been done to intercompare their intensities.

NI. The atomic nitrogen doublet at 5200 Å has been reported in the twilight spectrum (Courtès 1950). M. Dufay (1952) has studied this radiation in the twilight and the nightglow, and concludes that the doublet is probably not a normal component of the nightglow radiation.

Some spectra taken from this region, one of which is shown in Plate I, no 1, all contain the *NI* 5200 doublet. No auroral activity was visible on the nights when the spectra were taken, and the exposures were begun and stopped well after the end and before the onset of the twilight. The lines are faint, comparable in intensity with the stronger P_1 lines of the nearlying (9.2) *OH* band. There is no doubt of the correctness of the identification. The measured wavelengths coincide within a fraction of an Ångstrøm unit with the correct ones, and the doublet structure is visible on the original plate.

Even if the material is sparse, it seems probable that the forbidden nitrogen doublet usually is present in the nightglow at higher latitudes. Its intensity is, however, rather low.

NII. The forbidden *NII* lines have, to the author's knowledge, not been observed in the nightglow by others. Of the eight spectra taken from the region 6250—6650 Å, all shown in Plate II, six show distinctly the stronger component ($^3P_2$—$^1D_2$) at 6583 Å of the *NII* "doublet". On the two remaining spectra its presence is more doubtful. The weaker component ($^3P_1$—$^1D_2$) at 6548 Å is well visible only on three plates (Plate II no 1, 3 and 4).

The author is fairly confident that the identification of the *NII* forbidden lines is correct. The measured wavelengths coincide with the correct ones and the relative intensity of the lines is of the right magnitude (3 : 1). The absence of the line at 6548 Å when 6583 Å is present, is readily explained by its weakness compared with the latter. The simultanous variation of the intensities of the two lines, both from spectrum to spectrum, and *along* the spectral lines, shows that they must be closely related. The covariation along the spectral lines is well visible on spectrum no 1 and 3 of Plate II. A more intens patch on one line is accompanied by an increased intensity of the other, at the same distance from the line end (indicated by an arrow at the right hand side of the spectrum).

The *NII* line ($^1D_2$—$^1S_0$) at 5755 Å has not been observed in the nightglow spectra (although it appears in the aurorae, Kvifte (1959)). This *may* be due to the sparse

material from that region. As is apparant from the spectra of Plate II, the red *NII* doublet varies considerably in intensity from night to night, and the yellow-green line would presumably do the same. The line may on the other hand well be absent in analogy with the forbidden *NI* line at 3467 *Å* which does not appear in the nightglow (Barbier 1955) although the doublet at 5200 *Å* seems to be present.

H_a. Another interesting atomic feature appearing on the present spectra is a *sharp* H_a line (6563 *Å*). In three cases, spectrum no 1, 3 and 4 of Plate II, the line is relatively strong. Though fainter, it is visible on all spectra. The sharpness of the line in all cases shows conclusively that incoming protons cannot be the source of excitation, such as is usually the case with the H_a line in the aurorae. It should further be probable that the hydrogen atoms in the upper atmosphere must be excited by a process with little excess energy. Otherwise it should appear symmetrically broadened.

There seems to be a correlation between the intensities of the H_a line and the *NII* ($^3P_{2,1}$—$^1D_2$) lines. The spectra showing the strong H_a line (Plate II, 1, 3 and 4) also have the stronger *NII* lines. Patches, such as the ones on the *NII* lines mentioned above, appear also on the H_a line at the same place along the line. This close covariation of the intensities lead the author at first to believe that both the *NII* lines and the H_a line might originate from nebulae traveling past the line of observations during the exposure. It is, however, probably not so. In the first place the lines, although patchy in places, have the same transverse extension as the other lines and bands in the spectrum, an extension which can not be accounted for by the angular extension of a nebula. Secondly there appears to be patches of the same kind on the rotational lines of the *OH* bands in the same region, again in the same distance from the line ends. The patchiness of the *OH* band lines is, however, somewhat more diffuse.

In the authors opinion this spottiness of the lines must be explained as a simultaneous enhancement of the radiations in a comparatively restricted volume of the upper atmosphere. The covariance of the intensity indicates a close relation between the excitation of the *NII* lines and the H_a line, an excitation in which probably also the *OH* molecules play a role.

5. Molecular radiations.

N_2^+. There is, according to Barbier (1955), some doubt as to whether the N_2^+ 1st negative band system is a permanent component of the nightglow spectrum at low latitudes. Near the auroral zone, however, the presence of the bands in the nightglow seems well established (Small and Petrie 1952).

In the present material two extremely weak "lines" in the third order spectrum of spectrograph "*G*", at 5220 *Å* and 5705 *Å* may be interpreted as the *P* heads of the (0,0) and (0,1) bands at 3914 *Å* and 4278 *Å* in the 4th order spectrum. The "lines" are, however, not visible on all spectra from this region. If this is due to a lower efficiency of the grating in the 4th order compared to the 3rd, or if the bands are really absent, is still to be settled.

OH. The dominant band radiation in the investigated spectral region is the rotation-vibration $X^2\Pi$ system, or Meinel system (Meinel 1950 a, b), of the *OH* molecule. The band system has been extensively studied both in the nightglow (Meinel l. c., Cabannes et al (1950), J. Dufay (1951), M. Dufay (1951), Small & Petrie (1c), Chamberlain and Oliver (1953), Chamberlain and Roeslar (1954)), and in the laboratory (Herman and Hornbeck (1953), Dejardin et al (1953)).

Thanks to the precise measurements of the latter and to the determination by Dieke and Crosswhite (1948) of the rotational levels in the four lower vibrational states, the bands from the sixth vibrational level and downwards are well determined. Chamberlain and Roeslar (1c) have also measured a few rotational lines of the (8,3) and (9,4) bands from spectrograms with fair resolution, but otherwise bands from the vibrational levels $v_1 = 7,8$ and 9 are poorly determined.

The present material comprises two bands from each of these levels, and much care has been taken in the measurements to obtain precise wavelengths. Table 1 contains the values for the six bands mentioned, together with wavelengths of the (5,0) and (6,1) bands, which lie in the same spectral region.

Table 1. *Rotational lines of OH bands.*

[1]Line	Band							
	(9,2)	(7,1)	(8,2)	(5,0)	(9,3)	(6,1)	(7,2)	(8,3)
R_1 (2,3)		5541				6465,7	6828,1	7239,2
R_1 (1)	5188,5	44	5866,9	6143,8	6235,7	71,0	34,1	45,2
R_2 (1)			74,5	51,0	42,1	78,3		
Q_1 (1)	5203,5	63,5	[2]M : NaI	70,4	58,2	6498,7	63,5	76,6
Q_1 (2)			M : NaI		65,4	6505,1	M : O_2atm	84,4
Q_1 (3)						14,0	80,2	
P_2 (2)	18,0	M : OI	5906,8	6194,0	76,8	22,2	87,0	
P_1 (2)	24,3	88,3	15,3	6202,7	6287,8	32,8	M : O_2atm	7316,5
P_2 (3)	32,5	5597,0	25,3		M : OI	44,0	6911,5	
P_1 (3)	39,0	5604,5	33,2	21,5	6307,4	53,7	21,5	
P_2 (4)	49,5	15,5	45,3		21,7	69,1	38,0	
P_1 (4)	56,2	22,3	53,8	42,1	30,4	77,3	48,2	
P_2 (5)	70,0	38,5	70,7		49,0	6596,3	69,0	
P_1 (5)	5276,5	44,0	77,9	6268,4	56,8	6603,8	77,5	
P_2 (6)			5995,7		79,4	27,6		
P_1 (6)		5667,0	6004,6		6386,8	6633,5		
P_2 (7)					6414,1			
P_1 (7)			6037,5		20,7			
P_2 (8)					51,5			
P_1 (8)					6457,6			

[1] Terminology as in Herzberg (1951). The quantum number K refers to the lower level.
[2] M : = Masked by.

Wavelengths of the (9,2) band are, to the author's knowledge, not given before. The values of the other bands are systematically smaller, by one to five Ångström units, than those given by Small et al (1c), Cabannes et al (1c) and Dufay (1951), conform somewhat better with Chamberlain and Oliver's (1c) values.

From the energy levels, given by Dieke and Crosswhite (1c) and Herman and Hornbeck (1c) the wavelengths of the rotational lines of the (5,0) and (6,1) bands have been computed. These values agree within a fraction of an Ångström unit with the measured values. In view of this, the accuracy of the values given is estimated to be better than 0.5 *Å* for the stronger lines, and at least 1 *Å* for the weaker ones.

The line-notation in table 1 is in accordance with Herzberg (1951). The indices 1 and 2 refer to the sub-branches $^2\Pi_{3/2}$—$^2\Pi_{3/2}$ and $^2\Pi_{1/2}$—$^2\Pi_{1/2}$ respectively. The quantum number K, in brackets after the branch symbol, is equal to $(\mathcal{J} - \frac{1}{2})$ and $(\mathcal{J} + \frac{1}{2})$ for subbranch 1 and 2, $\mathcal{J}$ being the total angular momentum including spin of the molecule.

A few lines are masked by other radiations: The $P_2(2)$ line of the (7.1) band by *OI* 5577 *Å*, the Q lines of (8.2) by the sodium doublet, the $P_2(3)$ line of (9,3) by *OI* 6300 *Å*. Two lines of the (7,2) band are absorbed by lines in the (1,0) band of the O_2 Atmospheric system. Most of the P branches in the (8,3) band were outside the range of the spectrum (Plate I no 5).

The small splitting of the band lines, due to the Λ-type doubling of the energy levels, is only apparent in the P-lines with the greatest quantum number, K, as a slight diffusiness of the line. It has been disregarded in the measurements.

By means of the rotational energy levels of the vibrational levels $v = 1$ to 3, given by Dieke and Crosswhite (1c), energy levels for $v = 7$ to 9 have been computed from the data in Table 1.

Since the Λ-type doubling has been ignored in the wavelength measurements, this has also been done in the computation of the energy levels. This is, however, of minor importance when the values as intended, are used for calculating wavelengths of *OH* bands which are not, or only poorly, measured, with a view to clear up doubtful identifications in the nightglow and auroral spectrum.

Table 6 at the end of the paper contains energy levels for the $^2\Pi_{3/2}$ state (f_1) and the $^2\Pi_{1/2}$ state (f_2) for $v = 0$ to 9. The levels $v = 0$ to 6 are means of values (ignoring Λ-type doubling) given by Dieke and Crosswhite (1c) and Herman and Hornbeck (1c) ($v = 4$ to 6), the levels $v = 7$ to 9 are based on the present material. In column 4 and 6 of the same table are also entered the rotational term values, F_0, refered to the lowest terms for each vibrational level.

6. Temperature measurements. The rotational temperature of the *OH* bands has been measured by Meinel (1950 b) and Krassowsky et al (1958) with widely differing results. Meinel obtained a temperature of 260° *K* (250°*K* is probably more correct. This is the temperature obtained from his data by the method here adopted).

Krassowsky et al report temperatures ranging from 230° K to 330° K, dependent on the direction of observation.

In view of these discrepencies, it was deemed desirable to make some new temperature determinations. Eight spectrograms, those in Plate II, had a suitable density for measuring the rotational temperature from the P branches of the (6,1) band, four of them, no 1, 5, 6 and 8, also from the (9.3) band.

In the temperature determination by means of the OH bands a couple of details has to be considered, details which usually are of no importance in such computations. A short review of the method will therefore be given.

Assuming thermal equilibrium, the intensity, I, of a rotational line within a band is given by:

$$I(\mathcal{J}) = C\nu_J^4 \, s_J \, exp \, (-F(\mathcal{J}) \, hc/kT) \tag{1}$$

where ν_J is the wave number of the line and s_J the line strength. Theoretical expressions for s_J are derived for different electronic states of the molecule. $F(\mathcal{J})$ is the rotational term value in the upper vibrational level, $\mathcal{J}$ the rotational quantum number of same. h, c, k and T have the usual meaning.

Usually ν_J is regarded as a constant, and $F(\mathcal{J})$ is approximated by

$$F(\mathcal{J}) = B_{eff} \, \mathcal{J}(\mathcal{J}+1) \tag{2}$$

B_{eff} being the "effective" rotational constant of the upper level. A common procedure is then to plot ln (I/s) against $\mathcal{J}(\mathcal{J}+1)$ and derive the rotational temperature from the slope of the straight line obtained (if thermal equilibrium exists).

The lines in the P branches of the OH bands are fairly well spaced (see table 1), and ν_J^4 is therefore no constant. For the bands here used, the (6,1) and (9,3), the variation from $P(2)$ to $P(6)$ is about 6 %. Ignoration of this variation would tend to lower the temperature by 2 to 3 %. The variation of ν_J has been taken into account here.

The two sub-branches of a doublet band system have different "effective" rotational constants. They are not given in the literature, but can be approximated from the rotational constant B_v of the vibrational level by the formula (Mullikan (1931)):

$$B_{eff} = B_v \left(1 \pm \frac{1}{\gamma_\Lambda} + \ldots.\right) \tag{3}$$

γ is the coupling constant, Λ the electronic orbital angular momentum of the state and + or — gives the constant for one or the other of the branches. In the case under consideration $\Lambda = 1$, and γ is about — 10, i. e. the difference between B_v and B_1 or B_2 is about $\mp$ 10 %. The computed temperature, T, is directly proportional to the applied B, and an error in this constant will give a proportional error in T.

Equation (2), with B_{eff} determined by eq. (3), is however, in the case of the ground state of OH a rather poor approximation of $F(\mathcal{J})$, which will be apparent when the computed values are compared with the experimental values of the rotational levels.

Higher order terms of $\mathcal{J}(\mathcal{J}+1)$ are not negligable. It is therefore a safer procedure to use the experimental values of $F(\mathcal{J})$ directly. Here $ln\ (I/sv^4)$ has been plotted against $\frac{hc}{k}F(\mathcal{J})$, where $F(\mathcal{J})$ has been taken from table 6, column 4 and 6.

Expressions for s_J have been given by Hønl and London (1925) for Hund's coupling case (*a*). To a good approximation the $OH\ X^2\Pi$ state belongs to case (*a*) when $\mathcal{J}$ is small. In this investigation maximum five lines of the P branches have been utilised in the temperature determination. Hønl and London's linestrength values should therefore be applicable. They are:

$$(4) \qquad s_J = \begin{cases} \dfrac{(\mathcal{J}+1)^2 - 9/4}{\mathcal{J}+1} & \text{for the } P_1 \text{ branch} \\ \dfrac{(\mathcal{J}+1)^2 - 1/4}{\mathcal{J}+1} & \text{for the } P_2 \text{ branch} \end{cases}$$

In the experimental arrangement the slit of the spectrograph was placed vertically and an image of the sky projected on it by a field lens. Each point on the spectral lines such represents a corresponding point along a vertical line in the sky.

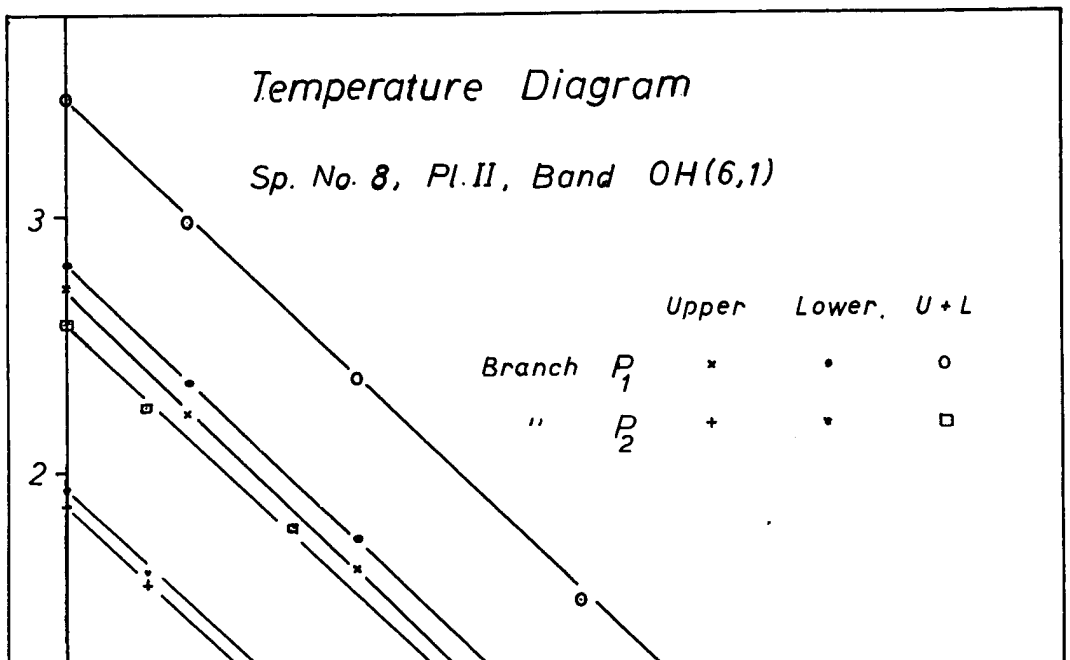
A microphotometer tracing was taken along each side of the spectrum, corresponding to the upper and lower parts of the observed area. The line intensities were derived from the photometer curve in the usual manner by means of a density — intensity calibration curve, and the intensities such obtained corrected for background, plate sensitivety and absorption in the spectrograph.

Each spectrogram yielded four independent sets of intensities, one from each subbranch on either side of the spectrum. In order to eliminate to some extend plate irregularities, two more sets were formed as the means of the line intensities from the two sides of the spectrum (''Upper + Lower'').

When $\ln(I_J/sv^4)$ is plotted against $\frac{hc}{k}F_J$, a diagram is obtained for each spectrum as the one shown in fig. 2 of spectrum no 8, Plate II. The points computed from intensities within a ''set'' fulfill satisfactory the straight-line condition, showing that temperature equilibrium exists. The value of the intersection point of a line with the abscisse axis divided by the corresponding value on the ordinate axis, gives the temperature directly for the set under consideration.

Table 2 and 3 contain the results from band (6,1) and (9,3) respectively. ''Upper'' and ''Lower'' refer to the side of the spectrum corresponding to upper and lower part of the observed area of the sky, $U + L$ to the mean intensity set, P_1 and P_2 to the respective branches of the band.

There is a comparatively small variation of the temperature values from branch to branch, spectrum to spectrum and band to band. The total variation of single values is from 205° K to 221° K, of plate means from 211° K to 218° K.



This consistency has lead the author to believe that the temperature mean, 215° K, should be fairly accurate. This value is, however, rather lower than previously published temperatures (see above). Although the observations have been carried out towards widely different parts of the sky (see explanation to plate II), the present material gives no indication of such a variation in temperature as the one reported by Krassowsky et al (1c). Since a detailed description of the latter's experimental and computational procedure is lacking, it is impossible to compare his data and those here given as to accuracy. It is felt that more precise temperature measurements are needed to settle this point.

Table 2. *Temperature (°K) of the atmospheric OH stratum measured from OH band (6,1).*

	Upper		Lower		U + L		
Sp. No.	P_1	P_2	P_1	P_2	P_1	P_2	Mean
1	219	214	216	209	217	212	214,5
2	215	214	214	214	215	216	215
3	218	215	213	213	217	214	215
4	219	218	205	214	211	215	214
5	211	219	210	212	208	218	213
6	217	219	211	214	214	219	215,5
7	215	217	214	214	214	217	215
8	211	217	212	214	212	217	214
Mean	216	217	212	213	214	216	214,5

Table 3. *Temperature (°K) of the atmospheric OH stratum measured from OH band (9,3).*

	Upper		Lower		U + L		
Sp. No.	P_1	P_2	P_1	P_2	P_1	P_2	Mean
1	215	218	216	218	215	218	216,5
5	210	218	212	220	211	219	215
6	218	221	215	214	217	219	217,5
8	213	209	213	209	212	212	211
Mean	214	216	214	215	214	216	215

If a temperature of 215° *K* is accepted, the height of the *OH* stratum in the atmosphere must, according to the temperature-height curve given by the Rocket Panel (1952), be either about 70 km or a little below 100 km (alternatively 90 km, dependent on assumption of variable or constant mean molecular weight of the air). The 70 km height is in good accordance with the height deduced for the *OH* stratum from the ozon-hydrogen theory of Bates and Nicolet (Bates et al 1956) for the *OH* formation in the atmosphere. The second alternative, a height of about 100 km, is however what should be expected if the theory of Krassowsky (1957) that hydroxyl molecules are formed from excited oxygen molecules and hydrogen atoms is correct.

7. The intensitity of *OH* bands. Intensities of the rotational lines of the *OH* bands (8,2), (5,0), (9,3) and (6,1) have been measured. The spectrogram giving the (9,2) and (7,1) bands (no 1, Plate I) was too dense to give reliable measurements, and the infrared spectrum (Pl I no 5) had an inhomogeneous background. No attempt has therefore been made to evaluate these spectrograms.

Owing to the limited extension of the spectral range of the spectrograph for a fix position of the grating, the four measured bands could not be photographed on one and the same spectrum. The range containing the (8,2) and (5,0) bands (Plate I, no 3

and 4) had, however, also some lines of the (9,3) band. These lines were used to standardize the intensities of the two ranges, the one containing the (8,2) and (5,0) bands and the one giving the (9,3) and (6,1) bands (Plate II). An uncertainly may have been introduced by this procedure between the relative intensities of the (8,2) — (5,0) group relative to the (9,3)— (6,1) group. The error should, however, not be great.

In table 4 are collected means of the line intensities measured. The values of the (8,2), (5,0), (9,3) and (6,1) bands are based on 3, 2, 4 and 8 spectra respectively. The "Sum Intensity" in the last row but one is computed from the theoretical expression for I, eq. (1), by summation over J. Mean expression for B_1 and B_2 have been found from the data in column 4 and 6 of table 6. T is put equal to 215° K and the constant C is normalized to give the best fit of the computed line intensities with the measured ones in table 4.

The sum intensities of the bands should be comparable with the relative intensities of the *NaI* and *OI* lines in table 5. It should, however, be noted that whereas the intensity ratio between the (8,2) band and the sodium doublet has been fairly constant in the present material, the ratio between the *OH* (6,1) and the *OI* (6300) has varied by a factor greater than 10. The intensities of the *OI* lines, given in table 5, are the means from two spectrograms (Pl. II no 1 and 3), exposed towards SW and which gave the lowest intensity (in this scale) of the lines.

Absolute intensities (in R = Megaquanta/cm², sec.) of the *NaI* and *OI* lines,

Table 4. *Intensities of OH band lines.*

Line	Band			
	(8,3)	(5,0)	(9,3)	(6,1)
R_1 (2,3)				5,6
R_1 (1)	6,0	2,9	12,2	5,0
R_2 (1)			3,6	2,1
Q_1 (1)	Masked	3,1	14	10
Q_2 (2)	—»—		3,9	4,2
Q_3 (3)				1,8
P_2 (2)	2,4		3,8	3,0
P_1 (2)	4,3	2,2	9,5	7,3
P_2 (3)	3,0		Masked	4,0
P_1 (3)	5,6	2,6	10,8	8,0
P_2 (4)	2,1		4,6	3,2
P_1 (4)	4,0		8,9	6,3
P_2 (5)	1,5		3,2	2,0
P_1 (5)	2,6		5,6	3,3
P_2 (6)			1,8	0,9
P_1 (6)			3,1	1,5
Sum Int.	60	25	125	80
Abs. Int. (R)	75	30	160	100

Table 5. *Intensities of NaI and OI lines.*

Atom	NaI		OI	
Line	5890Å	5896Å	6300Å	6364Å
Rel. Intensity	59	32	170	59
Abs. Intensity (R)	~ 150		~ 150	(~ 50?)

given by Roach (1956), are entered in the last row of table 5. From these values and the intensities in the next but last rows of both tables, the absolute intensities of the *OH* bands, in the last row of table 4, are estimated.

It is usually assumed that the sum intensity of the *OH* (8,2) band is weak as compared with the intensity of the sodium doublet (see e. g. Barbier 1955 b). Here the intensity ratio is found to be about 1/2.

Barbier (1955 b) has tentatively stipulated the absolute intensity of the (9,3) band to 70 *R*, as compared with 150 *R* for the 5890 *Å* radiation. According to the present investigation the (9,3) band intensity may be as high as that of the *OI* line and the sodium lines. The intensity of the *OI* (6300) line varies, however, considerably as mentioned above. A mean ratio of about 1/2 between the two radiations in the 6300 *Å* range may therefore be more probable.

The intensities here obtained of the *OH* bands seem to be rather higher than previously assumed. If these results should prove to be correct, the correlation reported between the intensities of the sodium doublet, the red oxygen lines and the *OH* bands (Barbier 1955 b, Roach 1956), found with photoelectric instruments, may to some extend be due to the "background" of *OH* bands. Even if a correction has been applied for the background, it is possible that its magnitude has been underrated. A photometer with a spectral resolution great enough to separate the atomic lines from the *OH* band lines should be the ideal apparatus for intercomparing the night glow radiations. It is intended to try to replace the photographic plate in spectrograph "*G*" with photoelectric cells with a view to such investigations.

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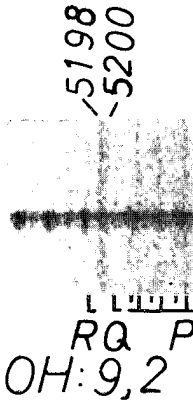
	Ω
v	K
0	1
	2
	3
	4
	5
	6
	7
	8
	9
	10
1	1
	2
	3
	4
	5
	6
	7
	8
	9
	10
2	1
	2
	3
	4
	5
	6
	7
	8
	9
	10
3	1
	2
	3
	4
	5
	6
	7
	8
	9
	10
4	1
	2
	3
	4
	5

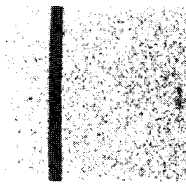
Table 6. *Energy levels of the $X^2\Pi$ state of OH. $f = G(v) + F(J)$ in cm^{-1}.*

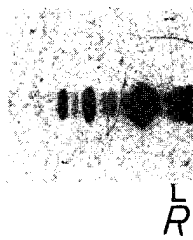
	Ω	3/2		1/2	
v	K	f_1	$F_{01}(J)$	f_2	$F_{02}(J)$
0	1	0	0	126,3	0
	2	83,8		187,6	61,3
	3	202,1		288,9	162,6
	4	355,5		429,3	303,0
	5	544,2		608,2	481,9
	6	768,3		824,6	698,3
	7	1027,9		1078,1	951,8
	8	322,7		368,1	1241,8
	9	652,6		694,0	1567,7
	10	2017,3		2055,4	1929,1
1	1	3568,4	0	3695,2	0
	2	649,2	80,8	754,1	58,9
	3	763,2	194,8	851,2	156,0
	4	910,9	342,5	986,1	290,9
	5	4092,5	524,1	4157,8	462,6
	6	308,2	739,8	365,7	670,5
	7	557,9	989,5	609,3	914,1
	8	841,5	1273,1	888,0	1192,8
	9	5158,8	1590,4	5201,2	1506,0
	10	509,4	1941,0	548,4	1853,2
2	1	6971,1	0	7097,3	0
	2	7049,0	77,9	155,2	57,9
	3	158,8	187,7	248,1	150,8
	4	300,9	329,8	377,4	280,1
	5	475,5	504,4	542,1	444,8
	6	682,9	711,8	741,8	644,5
	7	922,8	951,7	975,5	878,2
	8	8195,3	1224,2	8242,9	1145,6
	9	500,1	1529,0	543,5	1446,2
	10	836,9	1865,8	876,9	1779,6
3	1	10210,5	0	10336,6	0
	2	284,9	74,4	391,2	54,6
	3	390,8	180,3	481,0	144,4
	4	527,3	316,8	605,1	268,5
	5	695,0	484,5	763,0	426,4
	6	894,1	683,6	954,3	617,7
	7	11124,5	914,0	11178,3	841,7
	8	386,0	1175,5	434,6	1098,0
	9	678,3	1467,8	722,7	1386,1
	10	12001,3	1790,8	12042,2	1705,6
4	1	13287,0	0	13415,7	0
	2	358,9	71,9	467,0	51,3
	3	460,1	173,1	552,3	136,6
	4	591,2	304,2	670,6	254,9
	5	751,9	464,9	821,7	406,0
	6	943,0	656,0	14004,0	588,3
	7	14163,7	876,7	218,7	803,2
	8	414,2	1127,2	464,2	1048,5
	9	694,3	1407,3	739,9	1324,2
	10	15002,8	1715,8	15045,4	1629,7
5	1	16201,0	0	16330,3	0
	2	270,1	69,1	379,3	49,0
	3	367,1	166,1	460,3	130,0
	4	492,2	291,2	573,3	243,0
	5	646,2	445,2	717,4	387,1
	6	829,1	628,1	891,9	561,6
	7	17039,8	838,8	17096,9	766,6
	8	279,8	1078,8	331,2	1000,9
	9	547,5	1346,5	594,2	1263,9
	10	843,0	1642,0	885,8	1555,5
6	1	18952,1	0	19082,1	0
	2	19017,7	65,6	127,8	45,7
	3	110,3	158,2	205,3	123,2
	4	230,4	278,3	312,2	230,1
	5	377,1	425,0	449,5	367,4
	6	551,5	599,4	616,0	533,9
	7	752,9	800,8	811,4	729,3
	8	981,3	1029,2	20034,0	951,9
	9	20236,4	1284,3	284,9	1202,8
7	1	21538,0	0	21671,3	0
	2	601,0	63,0	712,9	41,6
	3	690,5	152,5	787,9	116,6
	4	804,4	266,4	887,8	216,5
	5	949,3	411,3		
	6				
	7				
8	1	23949,4	0	24080,1	0
	2	24009,3	59,9	118,5	38,4
	3	93,2	143,8	192,8	112,7
	4	198,2	248,8	285,9	205,8
	5	332,2	382,8	415,8	335,7
	6	481,4	532,0		
	7				
9	1	26184,3	0	26316,4	0
	2	240,5	56,2	353,3	36,9
	3	320,2	135,9	420,4	104,0
	4	422,0	237,7	510,7	194,3
	5	571,1	362,8	625,4	309,0
	6	694,8	510,5	764,7	448,3
	7	867,3	683,0	930,6	614,2

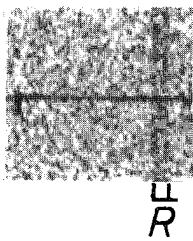
Explanation to Plate I.

Sp. No.	Date	Exposure		Elevation	Direction	Plate	Remark
		Interval	Duration				
1	11.12.58	$17^{40}-06^{35}$	12^h55^m	12°	W	103aG	"G"
2	12.10.58	$19^{20}-04^{35}$	9»15»	20°	SE	103aT	"P"
3	17.12.57	$17^{50}-04^{15}$	10»25»	25°	NE—W	103aE	»
4	21.12.57	$18^{05}-05^{45}$	11»40»	20°	W	103aE	»
5	9.12.58	$17^{25}-06^{45}$	26»55»	22°—27°	SE, NW	IN	"G"
	10.12.58	$17^{15}-06^{50}$					Sensitized





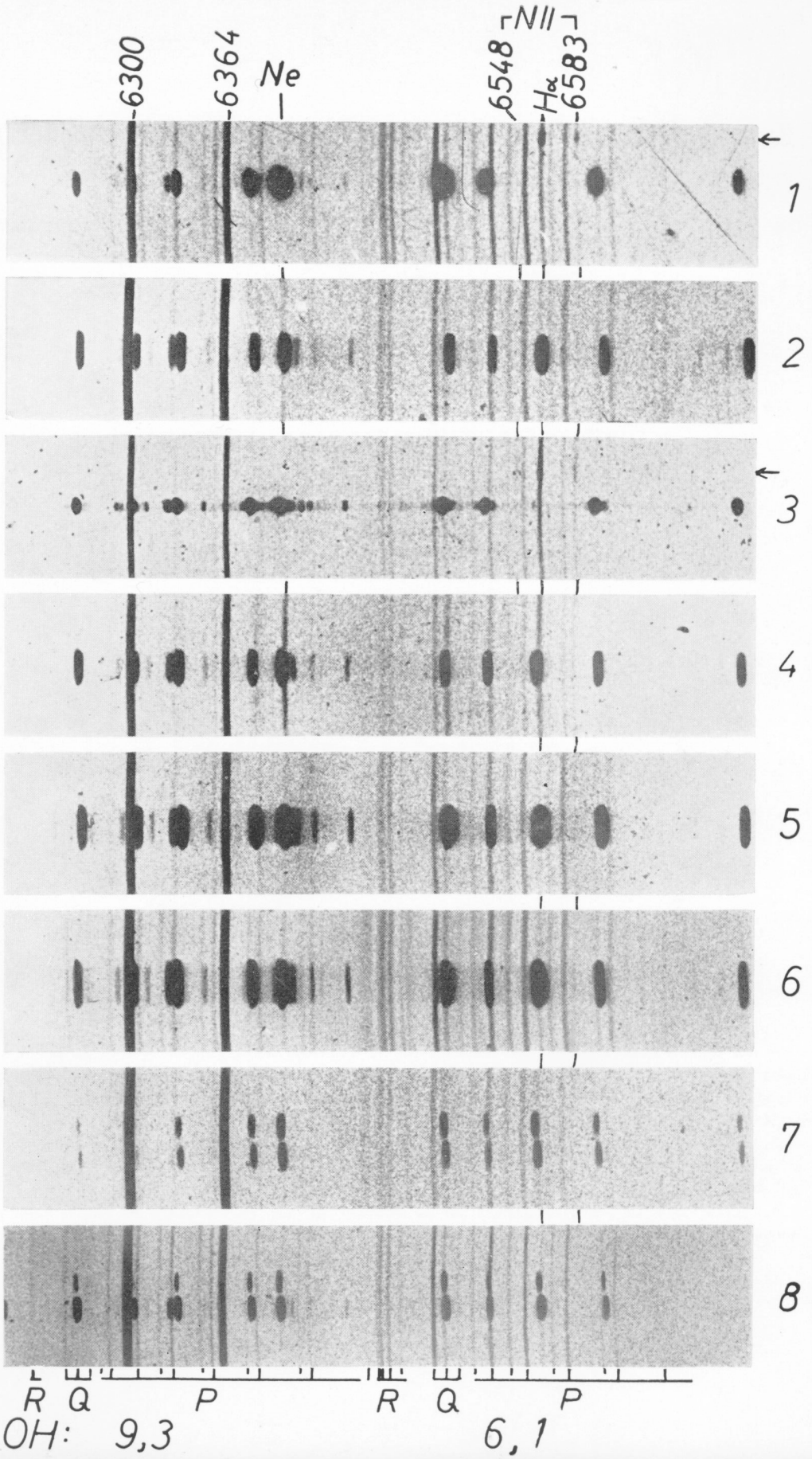




Explanation to Plate II.

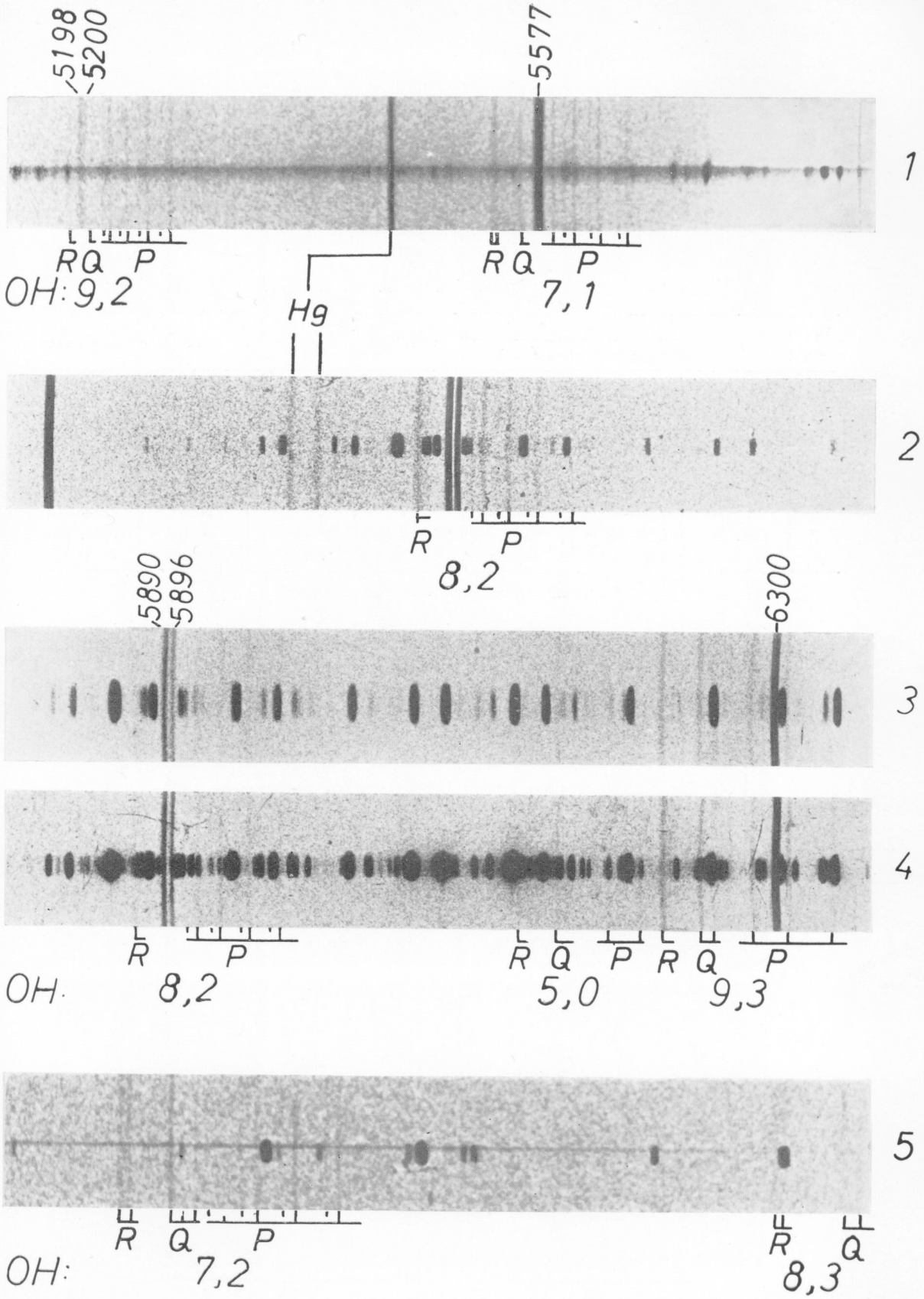
Sp. No.	Date	Exposure		Elevation	Direction	Plate	Remarks
		Interval	Duration				
1	16.1.58	$19^{00}-05^{00}$	10^h	20°—30°	SW—SE	103aE	
2	17.1.58	$18^{15}-05^{40}$	$11^h\,30^m$	18°- 22°	NW	103aF	Trace Au
3	20.1.58	$21^{30}-24^{00}$	2»30»	26°	SW	103aE	
4	21.1.58	$18^{30}-23^{40}$	4»50»	31°	NW	103aE	
5	13.2.58	$23^{00}-03^{00}$	4»	12°—18°	NW—N	103aE	1^h Au
6	17.2.58	$22^{50}-05^{10}$	6»20»	17°	N	103aE	Trace Au
7	13.3.58	$22^{50}-03^{10}$	4»40»	25°	N	103aE	Trace Au
8	27.3.58	$21^{00}-04^{15}$	7»15»	22°	NW	103aE	Trace Au

All spectrograms taken with spectrograph "P".



emarks

ace Au

Au
race Au
race Au
race Au

	Remark
1	"G"
2	"P"
3	»
4	»
5	"G" Sensitized