CHAPTER II

PHOTOMETRY OF AIRGLOW

CONSTRUCTION AND CALIBRATION OF PHOTOMETER

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CHAPTER II

PHOTOMETRY OF AIRGLOW

CONSTRUCTION AND CALIBRATION OF PHOTOMETER

1. General description

It is known that even in low and middle latitudes where aurorae are rare, there is a permanent faint airglow coming from excited atoms and molecules in the upper atmosphere and that this glow undergoes periodic and nonperiodic variations. For the detection and identification of the spectrum of the airglow, spectrographs with large apertures have to be employed and long exposures have to be given. The study of the short period changes in the intensity of the airglow has in recent years been greatly facilitated by the use of the photomultipliers and appropriate interference filters.

In the work done by the author at Mount Abu attention was concentrated on the measurement of the intensities of light on three wavelengths (1) the oxygen green line OI 5577 A, (2) the oxygen red line OI 6300-6364 A and (3) the sodium
yellow lines Na-D 5890-5896 A. In addition, the radiation in a narrow band at 5300 A where there are no important lines was also studied for estimating the continuous background radiation from stars.

Figure 1 shows a block diagram of the equipment used. The photometer converts the light signal from the sky to an electrical current. The high-tension voltage for the phototube is obtained from a stabilized H.T. supply. The output voltage of the phototube is amplified by a three-stage d.c. amplifier. The filaments of the amplifier valves are heated from a 6 V accumulator to ensure good stability. The power for the amplifier valves is derived from a low tension electronically stabilized power supply. The amplified signal is finally fed to a 0-1 mA d.c. Svershad pen recorder.

**Fig.1.** Schematic diagram of the airglow equipment.

2. **Airglow photometer**

The different constituents of the airglow equipment are described in detail in the following.
(a) Basic operation of a photomultiplier

The basic operation of a photomultiplier tube is shown in Figure 2. It consists of a photocathode, a series of target electrodes or dynodes at increasing potentials and a collector.

![Diagram of a photomultiplier](image)

**Fig. 2.** Operation of a photomultiplier.

When the light beam falls on the photocathode, a photocurrent $i_0$ is drawn from it to the first target. The target emits a secondary electron current $i_0R$ where $R$ is the secondary emission ratio of the surface. This current in turn strikes the second target and ejects from it a current $i_0R^2$. Thus for $n$ target-electrodes the current reaching the collector is $i_0R^n$. So a photomultiplier with 10 dynodes and each with an yield of $R = 4$ has an output current one million times as great as the current leaving the photocathode.
Usually all electrons leaving one target do not reach the successive target. This reduces the gain of the photomultiplier. This is avoided by an appropriate design of the photomultiplier. There are two classes of photomultipliers: (1) magnetic multiplier phototubes and (2) electrostatic multiplier phototubes.

In magnetic multiplier phototubes the photocathode and the dynodes are all in one plane. The increasing voltages are applied to the successive dynodes and a magnetic field is maintained by a pair of soft iron pole pieces outside the tube envelope. Even though the performance of the magnetic multiplier is satisfactory, the requirement of the external magnetic field makes the multiplier unit complicated and unwieldy.

The electrostatic multiplier consists of a sequence of secondary emission activated fine mesh screens at increasing potentials, a transparent cathode at one end and a collector at the other. For more efficiency and compactness, instead of the screens, electrodes with appropriate shapes are used for guiding of electrons from cathode to cathode. A more compact multiplier phototube is obtained by arranging the electrodes in a circular array as in an RCA 33L-A phototube.

(b) Dark current of the multiplier

A multiplier will pass a certain amount of current
when the voltage is applied to the dynodes even when the photocathode is unilluminated. Such dark currents have to be allowed for when the device is used for the measurement or detection of very weak lights.

The sources of the dark current are (1) leakage between the electrodes both inside and outside the envelope, (2) thermionic emission from the photocathode to dynodes which is multiplied along with the signal light current, (3) the current generated by the positive ion impact on the photocathode and dynodes, which is augmented by field emission currents from the projecting points of electrodes. The ohmic leakage is reduced by the proper design of the multiplier. The dark current due to thermionic emission can be reduced by operating the multiplier at a lower temperature, for instance by immersing it in solid CO₂ or in liquid air. To avoid instability due to the dark current arising from the impact of a positive ion on photocathode or dynodes, the dynodes are fed with appropriate voltage.

(c) Photometers used for airglow observations

For the night airglow observations two photomultipliers were used (1) RCA 96L-A and (2) EMI 6095. RCA 96L-A has a side on photocathode with nine stages of multiplication. The multiplier has a maximum response at 4000 Å. Its typical sensitivity is 20 A/L with 100 v per stage. EMI 6095 is
an end on photomultiplier with a large size photocathode and eleven stages of multiplication. Its sensitivity at 180 v per stage is 300 A/L.

RCA 931-A was used for studying the regions 5300 and 5677 A. EMX 6095 which has a higher gain and higher relative response was used for the study of 5300, 5577, 5393, and 6300 A regions.

For the RCA 931-A photomultiplier the voltage per stage was -95 v with -190 v between the final dynode and the anode. The EMX 6095 photomultiplier was operated at -1150 v, with the voltage between the final dynode and anode, double the voltage per stage.

Figure 3(a) shows a schematic diagram of the photometer in which an RCA 931-A photomultiplier is the sensing element. The phototube is housed in an earthed copper tube T. B is a box which contains a chain of resistances appropriately connected to an H.T. supply to furnish appropriate voltages to the dynodes of the phototube P. S is a shutter which can cut out the light from the phototube and can be operated by the knob K. The tube T with the box B is fitted in a wooden box W. Two filters F₁ and F₂, one transmitting a narrow band near 5577 A and the other a band near 5300 A are mounted on the disc D. The disc D is fitted on the axle X and can be rotated by a motor through intermittent gears G. When exposed, the light
falls on the phototube through one of the filters for about \(3\frac{1}{2}\) minutes, one after the other. The disc acts as a shutter. When the shutter cuts off the light, the dark current level is recorded. The projecting cylindrical tube contains the aperture A, which defines the angle subtended by the photometer. The inside of the tube is coated with lampblack. The photometer covers a circular field of \(11^\circ.2\) diameter. The plugs for the H.T. voltage and the output signal are mounted on the side of the box B.

![Diagram of Polar Air Glow Photometer]

**Fig.3(a)** Polar airglow photometer used at Mt. Abu for 5577 and 5800 Å radiation.
The wooden box is mounted on a platform which can be suitably turned so as to point the photometer towards the celestial pole.

![Diagram of Alt-Azimuth Air Glow Photometer]

Fig. 3(b). Alt-azimuth airglow photometer for the airglow observations at 5300, 5577, 5893 and 6300 Å.

Figure 3(b) shows the other photometer which uses an EMI 6095 photomultiplier. The lens L with the focal length 4" and aperture 2" forms the objective. It is fitted in such a way that the photocathode lies in its focal plane. S is a shutter which can cut off the light from the phototube P. A small radioactive source is fitted in the shutter S. Two interference filters are used, one for selecting the sodium
yellow lines at 5390-5396 Å and the other for the OI red lines 6300-6364 Å. The filters are rotated by a motor M through the gears G. The photometer is provided with an alt-azimuth mounting. θ shows the altitudinal scale and φ shows the azimuthal scale. The aperture A situated just above the photocathode defines the cone of reception of the photometer. It covers a circular field of 7°.2 diameter.

For routine observations, the photometer was turned towards the celestial pole.

For the full-sky scanning observations the disc D could be replaced by another disc which could hold four filters. The motor M was removed and the filters could be changed manually by rotating the axle X. A metal knob with notches was mounted on the axle X and was held rigid by a spring mounted on the cover G. This system was used to maintain the appropriate position of the filter above the aperture A.

(d) Characteristics of optical filters

Figure 4 represents the transmission characteristics of the optical interference filters. Filters I and II are used with the RCA 361-A phototube and III to VI with the EMI 6035 photomultiplier. The continuous curve represents the dependence of the transmission of the filter upon wavelength, whereas the dotted curve shows the transmission of the filter

multiplied by the response of the photomultiplier. An OS 16 Corning glass filter is used in conjunction with the 5577 A filter (XII) to cut off some of the unwanted yellow region of the spectrum. Along with 5890 A filter (V) OSK is used to cut off the red region and with 6800 A filter (VI) a 'plastic red' filter is used to cut off the unwanted yellow region. The use of these appropriate filters allows the selection of the oxygen green line, sodium yellow lines and the oxygen red lines respectively. The 5800 A filter allows the estimation of the background radiation.

Fig A. Dependence of filter transmission on wavelength.
The interference filters used were made by Neasra Barr and Stroud. Their peak transmissions and the band widths are summarised in table I.

### Table I

<table>
<thead>
<tr>
<th>Filters</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Filter combination</td>
<td>5300A</td>
<td>5577A</td>
<td>5300A</td>
<td>5577A</td>
<td>6392A</td>
<td>6300A</td>
</tr>
<tr>
<td></td>
<td>inf.</td>
<td>inf.</td>
<td>inf.</td>
<td>inf.</td>
<td>inf.</td>
<td>inf.</td>
</tr>
<tr>
<td></td>
<td>4056</td>
<td></td>
<td></td>
<td>4056</td>
<td></td>
<td>621</td>
</tr>
<tr>
<td></td>
<td>+red</td>
<td></td>
<td></td>
<td>+red</td>
<td></td>
<td>plastic</td>
</tr>
<tr>
<td>2. Emission selected</td>
<td>OI</td>
<td>5577A</td>
<td>OI</td>
<td>5577A</td>
<td>Na-D</td>
<td>OI</td>
</tr>
<tr>
<td>3. Peak transmission</td>
<td>0.206</td>
<td>0.223</td>
<td>0.231</td>
<td>0.212</td>
<td>0.253</td>
<td>0.237</td>
</tr>
<tr>
<td>4. Transmission at selected wavelength</td>
<td>0.190</td>
<td>0.130</td>
<td>0.122</td>
<td>0.210</td>
<td>0.255</td>
<td>0.237</td>
</tr>
<tr>
<td>5. Half transmission band-width in Å</td>
<td>55</td>
<td>30</td>
<td>60</td>
<td>60</td>
<td>95</td>
<td>90</td>
</tr>
<tr>
<td>6. Equivalent band-width* in Å</td>
<td>91</td>
<td>136</td>
<td>152</td>
<td>30</td>
<td>150</td>
<td>140</td>
</tr>
<tr>
<td>7. Photomultiplier used</td>
<td>RCA 931-A</td>
<td>EMI 6095</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Equivalent band-width is defined by \[ W = \frac{\int_{R_{\text{em}}}^{R_{\text{em}}}}{t_{\lambda} R_{\lambda}} \, d\lambda. \]

- \( t_{\lambda} \) = transmission of the filter at wavelength \( \lambda \).
- \( R_{\lambda} \) = relative response of the photomultiplier at \( \lambda \).
- \( R_{\text{em}} \) = transmission of the filter at the emission wavelength.
- \( R_{\text{em}} \) = response of the photomultiplier at the emission wavelength.
3. The circlevol amplifier

(a) General considerations

The output current of the photomultiplier has usually a very small magnitude. For amplifying weak signal currents of this order, the amplifier should take a sufficiently high resistance in the grid circuit, so as to build a sufficient voltage signal across it. This demands the introduction of high resistances of the order of 1000 megohms in the grid circuit of an ordinary d.c. amplifier. But in the normal amplifier the grid current itself is of the same order as that of the current involved in the present measurements. This offsets the usability of normal amplifiers. So it is essential to reduce the grid current to a minimum.

The grid current may be due to any one of the following phenomena:

1. The cathode of the valve can emit positive ions, which flow to the grid.

2. The electrons flowing from grid to plate can ionize the residual gas left in the tube, in which case some of the positive ions produced will flow to the grid.

3. The plate or some part of the tube may emit electrons, which is known as photoelectric effect.

4. The electrons impinging on the plate may have enough energy to cause the emission of soft X-rays. These
in turn can bombard the grid and emit electrons.

5. Electrons may reach the grid from cathode by
virtue of the finite velocity with which they
are emitted.

6. Leakage currents can occur over the inside or
the outside of the tube.

All these sources of grid current should be
minimised so that the amplifier can take a high resistance
in its input circuit. The use of a special tube maintained
under specific conditions for reducing all the above mentioned
sources of grid current is known as electrometer operation.

(b) Design of the amplifier

Figure 5 shows the circuit of the three stage d.c.
amplifier. The first stage of this consists of the electrometer
operation followed by two successive push-pull stages. For
the electrometer operation an acorn tube 954 is used. The
operating conditions are as mentioned below.

The plate is run at low voltage of ±6 v. The screen
grid is operated at +15 v. The filament of the valve is
rated at 4.2 v. The conventional control grid is connected
to the filament, the suppressor grid is biased at -3 v, and
used as the control grid. For reducing the surface leakage
current the high meg resistor and the tube with its base are
cleaned with petrol. These are kept dry and free of moisture
by means of a desiccator. The effects of stray electric and magnetic fields are eliminated by properly shielding the amplifier. All the connection leads are run as direct as possible and are made by use of shielded wire. In the input circuit a glass sealed high megohm Vistoreen resistor is employed.

To suppress the steady part of the plate current of the 264 tube from further amplification, the electrometer tube is put in a Wheatstone's bridge as shown in the figure.

![D.C. Amplifier for Airoglow](image)

**Fig. 5. Three stage d.c. amplifier.**

The tube with its plate lead forms one arm of the bridge and a potential divider with a variable resistance forms the other arm. The double ended output of the bridge circuit is amplified by using two 6SN7 push-pull stages. The use of the push-pull amplifier minimises the harmful
changes introduced due to the change in the filament and the plate voltages of the valves. The filaments of the valves are heated from a 6 v accumulator to ensure better stability. The potential divider in the plate circuit of the push-pull stages enables an appropriate matching of the two sections of each amplifier stage. The common resistance in the cathodes of each stage furnishes the necessary bias. It also provides a negative feed back and improves the stability of the amplifier.

(c) Calibration of the amplifier

![Graph](image)

Fig.6. Calibration curve of the d.c. amplifier.

The amplifier was tested to find its sensitivity and range of linearity by feeding an arbitrary signal from a 2 v accumulator. The results are presented in Fig.6. It is
seen from the graph that the amplifier is linear in the range ± 1 mA. The overall current gain of the amplifier is

\[ 3 \times 10^3 / 10^{-5} = 3 \times 10^6 \]

4. The recorder

The output signal from the d.c. amplifier is fed to a pen recorder. It is a recording milliammeter with 0.1 mA full scale sensitivity, obtained from Evershed and Vignoles Co., England. It has a synchronous motor drive, with the chart speed of 1 inch per hour. It has a time constant of the order of one second, but is slightly variable with the magnetic damping arrangement provided in the instrument.

5. The H.T. supply

The high tension needed for the dynodes of the photomultiplier is derived from an H.T. supply. Its circuit diagram is shown in Fig. 7. The power-pack portion of the supply consists of two 5 R 4 valves forming a voltage doubler circuit. The input a.c. voltage is 230 v. The voltage doubler furnishes about 1300 v d.c. The remaining part of the circuit makes up the regulating system. The GL6 tube plays the role of a variable resistance. The high gain, sharp cut off pentode 6SR7 forms the amplifier part and works on the principle of degenerative circuit. The plate resistance of the amplifier is connected to the cathode of GL6 tube, and
its voltage is fed to the grid of 6L6. The reference voltage for the amplifier is obtained from a VR tube. The current for the VR tube is provided from the input side of the regulating circuit. A part of the output voltage is tapped from the bank of resistances and is fed to the grid of the amplifier. This serves as an error voltage. The screen of the amplifier is maintained at a steady potential from the output side as shown in the figure.

*Fig.7. Electronically stabilized H.T. supply for the photomultiplier.*
The H.T. supply has a ripple voltage of 10 mV at an output voltage of 1000 V. The variable resistance in the bleeder chain provides a range of 50 V on either side.

6. Power supply for the amplifier

An electronically stabilized model 50 power supply circuit was suitably modified to deliver 250 V d.c. for furnishing the power to the plates of the amplifier. Fig. 8
The R.F. supply has a ripple voltage of 10 mV at an output voltage of 1000 v. The variable resistance in the bleeder chain provides a range of 50 v on either side.

6. Power supply for the amplifier

An electronically stabilized model 50 power supply circuit was suitably modified to deliver 250 v d.c. for furnishing the power to the plates of the amplifier. Fig. 8
shows the circuit of this power supply. The full wave rectification by a 5A4 valve of 350-0-350 v a.c., with choke and condensers form the power pack of the supply. The remaining constitutes the stabilization circuit. Three 6L6 valves are used in parallel as the variable resistance to get sufficient current from the output side. This variable resistance is controlled by a two stage amplifier. The first stage consists of a difference amplifier followed by another stage of amplification. The reference voltage to the grid of the difference amplifier of 6C67 valve is obtained from a VR tube. The current for VR tube 6C3 is furnished from the plate side. This ensures that the reference voltage will not be subjected to the changes caused by the varying current through the VR tube. The error voltage for the second grid of the difference amplifier is tapped from the output side. A steady voltage is fed to the plates of the difference amplifier from the cathode side of the variable resistance. The signal of the difference amplifier is further amplified by another 6C67 valve. The plate load of this amplifier is returned to the power-pack side. This allows the potential of the grid of 6L6 to approach that of its cathode without any reduction in the current of the amplifier stage, thus the gain of the amplifier does not reduce. The use of the difference amplifier reduces the drifts of the supply voltages which are due to the changes in the heater voltages. The power supply has a low r.m.s. ripple of 3 mV for an output voltage of 250 v.
7. **Stability of the airglow equipment**

The stability of the airglow equipment was checked by the use of proper radioactive sources. For RCA 381-A photometer the procedure was to expose the photometer to the radioactive source and note the deflections caused for both the filters, at the beginning and at the end of the observations. For EMI 6026 photometer, the photometer could be directly exposed to the radioactive source by means of the shutter S (in Fig. 2b). The observed intensities were then appropriately corrected according to the deflections caused by the signal from the radioactive source.

8. **Sample records**

![NIGHT AIRGLOW (MT ABU)](image)

*Figs. 8(a) & (b). Sample records of nocturnal variations of the airglow at 5500, 5577, 5528 and 6300 Å.*
Figs. 9(a) and 9(b) show the sample records of the observations taken at Mount Abu with these photometers.

In Fig. 9(a) the curve with higher amplitude refers to the intensity of the OI green line and the one with lower amplitude to 5300 Å region. The record in Fig. 9(b) with higher amplitude relates to the Na-D lines and the other with the lower amplitude to the OI red lines. The smaller amplitude of the OI red lines is due to the lower response of the photomultiplier at that wavelength.

9. Calibration of the photometers

(a) General considerations

For the intercomparison of the observations at different stations, it is advisable to express all the observations in some standard unit. Therefore Hunten, Reach and Chamberlain suggested that the intensities should be expressed in a unit "Rayleigh". The Rayleigh is defined by an expression \( R = 4 \pi B \) where \( B \) refers to the surface brightness of the sky in \( 10^6 \) quanta / cm\(^2\) / sec. sterad.

(b) Methods of calibration

There are three methods to calibrate the airglow photometers. These are:

1. Calibration from star deflections.
2. Calibration from the mean zenith intensity of the integrated starlight and the zodiacal light, and
3. Calibration against a standard source, whose spectral energy distribution is known.

The first two methods have been discussed in detail by Roach\textsuperscript{3}. It should be noted that both these methods involve some basic assumptions, and demand quite a large number of observations. The last mentioned method is reproducible and involves fewer assumptions. This method was used for calibrating the airglow equipment.

(c) \textit{Experimental set up}

The photometers were calibrated against a tungsten W-4 type ribbon filament lamp obtained from Messrs Philips. The arrangement of the calibration set up is shown schematically in figure 10. \(S\) is a screen coated with magnesium oxide. \(F\) is the tungsten filament lamp which illuminates the screen. The filament is heated by a d.c. current which is measured with accuracy. The colour temperature of the filament is found out from its calibration curve from the knowledge of the heating current. The slit \(T\) just above the lamp defines the area of the filament which illuminates the screen. \(P\) is the photometer kept at a distance \(D\) from the screen and it covers a small portion of the screen.
Fig.10. Experimental set up for the calibration of the airglow photometer against a standard tungsten filament lamp.

For taking the observations the airglow equipment was run at the usual voltages, with the only difference that the photometer was exposed to the MgO screen instead of the sky. For a known temperature of the filament the signal deflections were noted for different distances $D'$ of the filament from the screen. Appropriate neutral filters were introduced on the photometer aperture to obtain reduced illumination from the screen. The observations were taken with an Avo S meter for the sake of convenience and accuracy. Two different temperatures of the lamp were used for calibration purposes. All the observations are summarised in tables IIa and IIb.

The last two columns of these tables give the product $D'^2\Delta$. From mean values of $D'^2\Delta$, the signal deflections are
### Table IIIa.

Calibration observations for RCA 931-A photometer.

Photomultiplier voltage: \( V = 950 \text{ V} \). \( D = 76.9 \text{ cms} \).

Power supply for amplifier \( +250 \text{ V} \).

Amplifier filaments \( +6.1 \text{ V} \).

Neutral filter used \( 07 \text{ 32l} \).

<table>
<thead>
<tr>
<th>Distance ( D ) in cm.</th>
<th>Deflection (( \mu \text{A} )) caused for filters</th>
<th>( D^{12} \Delta )</th>
<th>for</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5300A</td>
<td>5577A</td>
<td>5300A</td>
</tr>
<tr>
<td>(Current in the lamp 2,785 Amps.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. 170.3</td>
<td>235</td>
<td>500</td>
<td>( 5.265 \times 10^6 )</td>
</tr>
<tr>
<td>2. 152.4</td>
<td>350</td>
<td>605</td>
<td>( 3.363 \times 10^6 )</td>
</tr>
<tr>
<td>3. 136.5</td>
<td>420</td>
<td>765</td>
<td>( 7.324 \times 10^6 )</td>
</tr>
<tr>
<td>4. 121.3</td>
<td>535</td>
<td>920</td>
<td>( 7.870 \times 10^6 )</td>
</tr>
<tr>
<td>Mean</td>
<td>200</td>
<td>202</td>
<td>( 3.090 \times 10^6 )</td>
</tr>
<tr>
<td>(Current in the lamp 2,930 Amps.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. 243.5</td>
<td>215</td>
<td>230</td>
<td>( 1.275 \times 10^7 )</td>
</tr>
<tr>
<td>2. 212.7</td>
<td>235</td>
<td>500</td>
<td>( 1.239 \times 10^7 )</td>
</tr>
<tr>
<td>3. 139.9</td>
<td>390</td>
<td>655</td>
<td>( 1.406 \times 10^7 )</td>
</tr>
<tr>
<td>4. 161.3</td>
<td>525</td>
<td>215</td>
<td>( 1.366 \times 10^7 )</td>
</tr>
<tr>
<td>Mean</td>
<td>200</td>
<td>232</td>
<td>( 1.337 \times 10^7 )</td>
</tr>
</tbody>
</table>
Table IIb(1)

Calibration observations for EMI 6095 photometer.

Photomultiplier voltage $\pm$ 1100 v.  $D = 96.5$ cm.
Power supply for amplifier $\pm$ 250 v.
Amplifier filaments $\pm$ 6.1 v.
Neutral filter used $\pm$ ON 321 + ON 321a.

<table>
<thead>
<tr>
<th>Distance D' (in cm)</th>
<th>Deflection (μA)</th>
<th>$D'^2 \Delta$ for filters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>caused for 5300A</td>
<td>5377A 5300A 5377A</td>
</tr>
<tr>
<td>1. 212.7</td>
<td>330</td>
<td>330 $1.719 \times 10^7$ $1.719 \times 10^7$</td>
</tr>
<tr>
<td>2. 177.1</td>
<td>520</td>
<td>520 $1.631$ $1.631$</td>
</tr>
<tr>
<td>3. 151.3</td>
<td>625</td>
<td>625 $1.563$ $1.563$</td>
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<tr>
<td>4. 135.5</td>
<td>800</td>
<td>780 $1.472$ $1.472$</td>
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<tr>
<td>Mean</td>
<td>200</td>
<td>400 $1.602 \times 10^7$ $1.593 \times 10^7$</td>
</tr>
</tbody>
</table>

(Current in the lamp 2.725 Amps.)

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 224.0</td>
<td>450</td>
<td>455 $2.309 \times 10^7$ $2.333 \times 10^7$</td>
</tr>
<tr>
<td>2. 200.4</td>
<td>555</td>
<td>560 $2.259$ $2.249$</td>
</tr>
<tr>
<td>3. 170.3</td>
<td>750</td>
<td>770 $2.232$ $2.233$</td>
</tr>
<tr>
<td>4. 154.4</td>
<td>900</td>
<td>830 $2.146$ $2.128$</td>
</tr>
<tr>
<td>Mean</td>
<td>200</td>
<td>552 $2.246 \times 10^7$ $2.223 \times 10^7$</td>
</tr>
</tbody>
</table>

(Current in the lamp 2.325 Amps.)
<table>
<thead>
<tr>
<th>Distance D' in cm.</th>
<th>Deflection (µA) caused for filters 5393A</th>
<th>D'^2Δ for 5393A</th>
<th>D'^2Δ for 6300A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Current in the lamp 2.325 Amps.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>197.9</td>
<td>410</td>
<td>296</td>
</tr>
<tr>
<td>2.</td>
<td>155.9</td>
<td>570</td>
<td>410</td>
</tr>
<tr>
<td>3.</td>
<td>146.9</td>
<td>695</td>
<td>500</td>
</tr>
<tr>
<td>4.</td>
<td>131.0</td>
<td>385</td>
<td>620</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>505</td>
<td>219</td>
</tr>
<tr>
<td></td>
<td>(Current in the lamp 2.725 Aamps.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>152.3</td>
<td>535</td>
<td>335</td>
</tr>
<tr>
<td>2.</td>
<td>133.4</td>
<td>665</td>
<td>475</td>
</tr>
<tr>
<td>3.</td>
<td>116.7</td>
<td>320</td>
<td>590</td>
</tr>
<tr>
<td>4.</td>
<td>105.2</td>
<td>410</td>
<td>670</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>227</td>
<td>164</td>
</tr>
</tbody>
</table>
calculated for \( D' = 200 \text{ cms} \). These also are included in the tables.

(d) **The derivation of the formula**

The aim in deriving the formula is to calculate the effective surface brightness \( B \) of the screen in unit mega quanta \( \text{cm}^{-2} \text{ sec}^{-1} \text{ sterad}^{-1} \), which causes unit deflection on the recorder. This can be converted to Rayleigh by the simple relation \( R = 4 \pi B \).

The procedure would be to calculate the effective energy radiated by the screen (\( \text{cm}^{-2} \text{ sec}^{-1} \text{ sterad}^{-1} \)) corresponding to unit deflection on the photometer. This energy of the continuous spectrum band is compared with the equivalent energy from a monochromatic source to estimate the surface brightness \( B \) of the sky. Finally \( B \) is converted to Rayleighs.

Starting from the source and (refer Fig.10) the spectral energy distribution of the tungsten filament, according to Planck’s radiation law would be

\[
J_\lambda \, d\lambda = c_1 \, e^{c_2/\lambda^5} \, \lambda^5 \, d\lambda \quad \text{erg cm}^{-2} \text{ sec}^{-1}
\]

where \( c_1 \) is the 1st radiation constant,

\( c_2 \) = 2nd radiation constant,

\( \lambda \) = the wavelength under consideration,

\( d\lambda \) = the wavelength interval chosen,

\( J_\lambda \) = the energy radiated at wavelength \( \lambda \),
\[ T \text{ - the colour temperature of the filament in } ^\circ\text{K}. \]
\[ c_1 = 3.74 \times 10^{-5} \text{ ergs cm}^{-2} \text{ sec}^{-1}. \]
\[ c_2 = 1.433 \text{ cm}^2 \text{ deg}. \]

Taking into account the area of the filament used for illumination and the transmission coefficient of its envelope, the energy radiated from the filament would be
\[ 0.9 J_\lambda d\lambda A \text{ ergs sec}^{-1}. \]

The energy in a unit solid angle perpendicular to the plane of the filament would be
\[ \frac{0.9 J_\lambda d\lambda A}{\pi} \text{ ergs sec}^{-1} \text{ sterad}^{-1}. \]

The illumination by this source on the screen at a distance \( d' \) from the filament and inclined at an angle \( \theta \) would be
\[ \frac{0.9 J_\lambda d\lambda A \cos \theta}{\pi d'^2} \text{ ergs cm}^{-2} \text{ sec}^{-1}. \]

The screen with the diffusion coefficient 0.975 would radiate the energy
\[ \frac{0.9 \times 0.975 J_\lambda d\lambda A \cos \theta}{\pi^2 d'^2} \text{ ergs cm}^{-2} \text{ sec}^{-1} \text{ sterad}^{-1}. \]

Now the dependence of the transmission of the filters and the response of the photomultiplier upon wavelength should be considered. The energy at wavelength \( \lambda \) in the interval \( d\lambda \) would then be
\[ 0.9 \times 0.975 \int_{\lambda_1}^{\lambda_2} \frac{\lambda \cos \theta}{\pi^2 d^2} \text{ergs cm}^{-2} \text{sec}^{-1} \text{sterad}^{-1} \]

where \( t_\lambda \) is transmission of the interference filter at wavelength \( \lambda \).

\( T_\lambda \) = transmission of neutral filter at \( \lambda \).

\( R_\lambda \) = relative response of the photomultiplier at \( \lambda \).

The integration of the above expression in the interval \( \lambda_1 \) to \( \lambda_2 \) would give the effective energy in ergs cm\(^{-2} \) sec\(^{-1} \) sterad\(^{-1} \) of the screen causing a deflection \( \Delta \) on the recorder. Hence, the energy per unit deflection would be

\[ 0.9 \times 0.975 \int_{\lambda_1}^{\lambda_2} \frac{\lambda \cos \theta}{\pi^2 d^2} \Delta \]

For a monochromatic source the equivalent energy in mega quanta would be

\[ E_2 = n \times 10^{-6} \quad \text{H} \]

where \( T_{\text{em}} \) is filter transmission at emission wavelength,

\( R_{\text{em}} \) = photomultiplier response at emission wavelength,

\( W \) = equivalent bandwidth.

Equating (1) and (2) \( E_1 = E_2 \) or

\[ n = \frac{\frac{E_1}{\lambda} \times 10^{-6}}{\text{H} \times T_{\text{em}} R_{\text{em}} W} \text{megaquanta cm}^{-2} \text{sec}^{-1} \text{sterad}^{-1} \]
which is the surface brightness S of the screen.

Now \( R = 4 \pi B \)

\[
= 4 \pi n
\]

\[
= 4 \pi B_1 \lambda \cdot 10^{-6}
\]

\[
= \frac{hc T_{em} R_{em} \lambda}{hc T_{em} R_{em} \lambda - \lambda^2} \quad \cdots \quad \cdots \quad \cdots \quad (4)
\]

substituting \( B_1 \) from (2) in (4) we get

\[
R/\mu A = \frac{4 \cdot 0.9 \cdot 0.975 \cdot 10^{-6} \Lambda \cos \theta \int \frac{\lambda}{t \lambda \lambda^{\lambda}} \Delta^{\lambda}}{hc T_{em} R_{em} \lambda - \lambda^2 \Delta}
\]

with \( \cos \theta = 0.9351 \) and

\( d^1 = 200 \text{ cm (with } \lambda \text{ in cm}) \),

\( \Lambda = 0.0125 \text{ cm}^2 \)

\[
R/\mu A = \frac{6.595 \cdot 10^{-9} \lambda S}{T_{em} R_{em} \lambda - \lambda^2 \Delta} \quad \cdots \quad \cdots \quad \cdots \quad (5)
\]

where \( S = \int \frac{t}{\lambda} \lambda^{\lambda} \frac{d \lambda^2}{\lambda} \), and \( \lambda \) now expressed in Angstroms.

\( S \) is evaluated by numerical integration.

\( V \) is defined as \( W = \frac{1}{T_{em} R_{em}} \cdot \)

The quantities involved in the above derivation are presented in table III.
Roach\textsuperscript{4} and Muruhata have brought to notice that the laboratory calibration and stellar calibration are not identical, but are related to each other as: stellar \( q/d = 1.25 \) laboratory \( q/d \), which they had derived empirically. Therefore the last row of table III was obtained by multiplying the laboratory calibration by a factor 1.25.

The RCA 33L-A photometer was calibrated against Roach's travelling photometer in May 1958. This yielded an empirical relation

\[
R_{5577} = 2.37 \left( d_{5577} - 65 \right) \quad \text{.. .. .. .. (a)}
\]

where \( R_{5577} \) is the intensity in Rayleighs corrected for the background and \( d_{5577} \) is the deflection caused by the signal for the 5577 A filter.

It can be seen that the calibration factor 2.37 of (a) agrees fairly well with the corresponding value 2.49 of the last row of table III.

The factors in the last row of table III were used for converting the readings in arbitrary units (\( \mu \)A deflections) to Rayleighs.

10. \textbf{Contamination due to background and its elimination}

The interference filters which are used to select the appropriate emissions under study transmit along with these emissions, the continuous background radiation, the light of
the astronomical origin and also some unwanted radiations. All these radiations contaminate the observations.

For eliminating the background radiation, it is assumed that the spectral energy distribution of the background is that of a G2 star. With this assumption the background is estimated by employing a 5300 A filter. The energy transmitted by this filter is removed from the total energy transmitted by the filter used for selecting the emission, with appropriate correction for filter transmission etc. As the background radiation in the direction of the celestial pole was found to remain fairly steady the following relations were used for eliminating the background.

\[ R_{5577} = 3.37 \ (d_{5577} - 65) \quad \cdots \cdots \cdots \quad (a) \]

as obtained from the calibration with Roach's\(^4\) photometer.

\[ R_{5533} = 0.73 \quad d_{5533} - 115 \quad \cdots \cdots \cdots \quad (b) \]

\[ R_{6200} = 1.33 \quad d_{6200} - 115 \quad \cdots \cdots \cdots \quad (c) \]

where R's give intensity in Rayleighs corrected for the background and d's represent the deflections produced by signal on the recorder.

In addition to the background, 5300 A filter transmits the weak bands of OH (6-0 and 9-2). The 5577 A allows the weak band (7-1) of OH. The 5533 A and 6200 A filters
transmit the strong OH bands (5-2) and (3-0) respectively. No correction was made for the effect of the contamination due to OH bands.

The observations are summarised in the next chapter.

REFERENCES

<table>
<thead>
<tr>
<th>Filter No.</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>The radiation under study</td>
<td>5300A background</td>
<td>5577A green line</td>
<td>5300A background</td>
<td>5577A green line</td>
<td>5893A Na-D lines</td>
<td>6300A red line</td>
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<tr>
<td>Photomultiplier used</td>
<td>RGA 931-A</td>
<td>EMI 6095</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photomultiplier response R\text{em} at emission ( \lambda )</td>
<td>0.50</td>
<td>0.323</td>
<td>0.82</td>
<td>0.69</td>
<td>0.516</td>
<td>0.27</td>
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<td>Equivalent bandwidth ( W ) of the filter in ( \AA )</td>
<td>91.2</td>
<td>135.3</td>
<td>152.4</td>
<td>79.5</td>
<td>150.3</td>
<td>139.7</td>
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<tr>
<td>Transmission of filter T\text{em} at emission ( \lambda )</td>
<td>0.19</td>
<td>0.18</td>
<td>0.122</td>
<td>0.21</td>
<td>0.255</td>
<td>0.287</td>
</tr>
<tr>
<td>Inclination of the lamp with the screen</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>( S ) for (a) 2075°K</td>
<td>8.295 ( \times 10^7 )</td>
<td>1.214 ( \times 10^8 )</td>
<td>7.150 ( \times 10^7 )</td>
<td>7.650 ( \times 10^7 )</td>
<td>6.804 ( \times 10^7 )</td>
<td>4.709 ( \times 10^7 )</td>
</tr>
<tr>
<td>(b) 2155°K (for RGA 931-A)</td>
<td>1.342 ( \times 10^8 )</td>
<td>1.920 ( \times 10^8 )</td>
<td>9.013 ( \times 10^7 )</td>
<td>9.635 ( \times 10^7 )</td>
<td>8.990 ( \times 10^7 )</td>
<td>5.812 ( \times 10^7 )</td>
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<td>2115°K (for EMI 6095)</td>
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<td></td>
</tr>
<tr>
<td>Deflection on ( \Delta ) for (a) ( \mu A ) (( D^1 = 200 \text{ cm} ))</td>
<td>202</td>
<td>352</td>
<td>400</td>
<td>400</td>
<td>286</td>
<td>206</td>
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<td>(b)</td>
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<td>579</td>
<td>562</td>
<td>556</td>
<td>384</td>
<td>276</td>
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<td>160</td>
<td>279</td>
<td>317</td>
<td>317</td>
<td>227</td>
<td>164</td>
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<td>(b)</td>
<td>264</td>
<td>460</td>
<td>446</td>
<td>441</td>
<td>305</td>
<td>219</td>
</tr>
<tr>
<td>( S/\Delta )</td>
<td>5.184 ( \times 10^5 )</td>
<td>4.351 ( \times 10^5 )</td>
<td>2.257 ( \times 10^5 )</td>
<td>2.413 ( \times 10^5 )</td>
<td>2.997 ( \times 10^5 )</td>
<td>2.871 ( \times 10^5 )</td>
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<tr>
<td>(b)</td>
<td>5.084 ( \times 10^5 )</td>
<td>4.174 ( \times 10^5 )</td>
<td>2.021 ( \times 10^5 )</td>
<td>2.184 ( \times 10^5 )</td>
<td>2.948 ( \times 10^5 )</td>
<td>2.654 ( \times 10^5 )</td>
</tr>
<tr>
<td>( S/\Delta ) (mean)</td>
<td>5.134 ( \times 10^5 )</td>
<td>4.263 ( \times 10^5 )</td>
<td>2.139 ( \times 10^5 )</td>
<td>2.229 ( \times 10^5 )</td>
<td>2.973 ( \times 10^5 )</td>
<td>2.763 ( \times 10^5 )</td>
</tr>
<tr>
<td>Constant term</td>
<td>6.596 ( \times 10^{-9} )</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>( y )-leaks / ( \mu A ) (Laboratory method)</td>
<td>2.100</td>
<td>1.992</td>
<td>0.491</td>
<td>0.734</td>
<td>0.583</td>
<td>1.061</td>
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<tr>
<td>( y )-leaks / ( \mu A ) (Astronomical) ( (R_{lab} = 1.25) )</td>
<td>2.625</td>
<td>2.490</td>
<td>0.614</td>
<td>0.918</td>
<td>0.729</td>
<td>1.326</td>
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