CHAPTER III

THE EXPERIMENTAL SET- UP AND TECHNIQUES

3.1. INTRODUCTION

This Chapter deals with some of the instrumentation work done by the author. The description of the apparatus, the experimental techniques employed and a brief analysis of errors involved in the present investigation are also discussed in detail.

Three discharge tubes were fabricated for different studies. A stabilized high voltage dc power supply and a solenoid (air core) were designed and constructed by the author. A search coil was also fabricated for the purpose of measuring the intensity of the magnetic fields.

3.2. THE DISCHARGE TUBES

3.2.1. Description of the discharge tubes

All the tubes were made of corning glass. The electrodes were made of aluminium. Type 1(DTI) was fitted with plane parallel electrodes with rounded edges and is shown in Figures 3.1. a,b.\]
Type 2 (DT2) was fitted with two Langmuir probes (Figures 3.2, a,b) and Type 3 (DT3) with only one Langmuir probe (Figure 3.3, a,b). Langmuir probes help us to determine the electron temperature and positive ion number density.

3.2.2. Construction of Langmuir Probes

Cylindrical Langmuir probes were used for the investigation. Glass sleeve was used to insulate the unwanted part of the probe wire.

During the fabrication of the probe its relative size with respect to the systems should be given due consideration, since the introduction of the probe, no matter how small it is, always perturbs the plasma. If it is too large, it may not measure the true parameters in its neighbourhood. In particular, the drain of the carriers from the plasma to the probe must be negligible. Then the rate of loss in this way must be clearly very small compared with the other loss mechanisms, occurring in the absence of the probe, for example, the ambipolar diffusion. These considerations put the upper limit to the probe radius.
3.2.3. Cleaning of the Discharge tubes

The discharge tube was cleaned with water and then with distilled water. It was dried and then cleaned with acetone. Any oxide formation on the electrodes was cleaned using an alkali. Once the discharge tube was put in the vacuum system, the electrodes were cleaned by a discharge current of $1.60 \, \mu A/mm^2$, for about 15 minutes.

3.3. VACUUM SYSTEM

A schematic diagram of the vacuum system is shown in Figure 3.7. The vacuum unit consisted of an oil diffusion pump backed by a double stage rotary pump of capacity 100 l/min. The ultimate vacuum of the system was $2 \times 10^{-6}$ torr.

All the present investigations were done in dry air. The full length of a burette and a drying tower contained anhydrous calcium chloride, over layers of glass wool. Free atmospheric air was let into the discharge tube, through the burette and the drying tower, and through a needle valve. The glass wool filtered the dust particles from air and the anhydrous calcium chloride removed the moisture from the air.
Thick walled polythene (PVC) tubes were used to connect the different units of the vacuum system. Epoxy (araldite) was used for air tight joints. Vacuum grease was also used wherever necessary.

Care was taken to see that the discharge gas (air) was completely removed off its moisture content.

First, using rotary and diffusion pumps, low pressure of the order of $10^{-6}$ torr was produced in the discharge tube and dry air was let in, to fill it. This was done a number of times so that the discharge tube was completely removed of moisture.

Low pressures were measured by a closed tube mercury monometer and by a McLeod gauze.

3.4. STABILIZED DC POWER SUPPLY AND THE POTENTIAL DIVIDER

The required high voltages were obtained from a stabilized power pack (1100 V - 100 mA dc unit) fabricated by the author. The design of the circuit is shown in Figure 3.5.

When the mains voltage changed by 10%, the output variation was only 0.75% as measured by
a calibrated electrometer (Philips Universal electrometer PP9000) whose accuracy was 3%. In addition to the stabilizing action of the power supply, the mains voltage was controlled by an ac stabilizer and a variable autotransformer. The maximum variation in the mains was less than ± 2.5 V and hence the maximum variation in the output of the power-pack was less than ± 0.09%. The ripple factor of the power supply, as measured on an oscilloscope was 0.16%.

A potential divider arrangement was used to tap the required potential from the power supply. Two potential dividers were used one with a total resistance of 25 meg ohm - consisting 24 resistors of one meg ohm each and 100 of 10 k ohm, each in series and the other with a total resistance of 20 meg.ohm - 19 resistors of one meg ohm each and 100, 10 k ohm each in series. Hence, with a supply of 1100 V, the potential could be varied in steps of 0.44 V and 0.55 V respectively, by the potential dividers.

The resistors were made of carbon, with a temperature coefficient of $-5 \times 10^{-4}/\circ C$. Before selection, each individual resistor was measured and those with departures of more than 0.33% were
Resistors were checked periodically for their correct values. Potential divider and the power supply circuit is shown schematically in Figure 3.6.

3.5. SOLENOID

3.5.1. Construction of the Solenoid

The measurement of electron temperature of plasma has to be made under the influence of uniform longitudinal magnetic fields. Hence a solenoid was constructed as detailed below:

The dimensions of the solenoid were decided by taking into account the following considerations:

(i) A uniform magnetic field for a length of about 6 cm was required.

(ii) The diameter of the bore must be large enough to accommodate the discharge tubes lengthwise (maximum transverse dimension = 9.5 cm). Hence the following dimensions were decided for the solenoid:

Length of the solenoid = 30 cm.
Inner diameter of the Solenoid = 10 cm.

(Approximately).
A suitable material has to be selected for the solenoid former. The properties required of a solenoid former are that the material should be

(i) non-magnetic: If the material is magnetic
   (1) it will be a disturbance for the free handling of magnetically sensitive equipments near it and
   (2) it will alter the field pattern of that due to the solenoid.

(ii) a good conductor of heat, so that it can conduct away the ohmic heat produced in the windings.

(iii) Sturdy: The former for small thickness must be able to support the weight of the windings and

(iv) available easily.

Brass is the only metal satisfying all the above requirements and so it was chosen to make the solenoid former.

A brass sheet of thickness 1.84 mm of the required dimensions was used for the construction of the solenoid former. A press board was cut to the required dimensions, varnished and pasted on the external area of the cylinder, and the
inner sides of the annular plates. The press board, pasted perfectly, insulates the metal former from the windings. This is in addition to the double insulation provided on the coil itself.

The following considerations were made in selecting the winding coil. Suitable coil must be used for producing maximum intensity of the magnetic field. The heat dissipation should be small, so that the resistance of the coil and hence field current does not change appreciably. Detailed calculations were made with the above considerations. For optimum advantage the copper wire of Swg No. 18 was chosen for the windings. About 25 Kg of copper wire was used for the winding. The copper coil was wound over the solenoid former uniformly, in tact, layer by layer and end to end. The solenoid former was fixed on a wooden base using brass plates. Sections of the solenoid are shown in Figures 3.7.1 and 3.7.2. The solenoid fixture is shown in Figure 3.7.3. The leads of the solenoid were provided with additional insulation using polythene sleeves. The leads were connected to the terminals fixed on the wooden board. The surface of the solenoid was wrapped with cambric cloth.
3.5.2. Magnetic Field of the Solenoid

The intensity of the magnetic field in the bore of the solenoid was calculated using the formula

\[ F = \frac{2\pi n I}{10} (\cos \varphi_1 - \cos \varphi_2) \]  

(3.1)

which may be derived from the Biot and Savart law (1820). Here,

- \( F \) is the strength of the magnetic field in Gauss, at any point on the axis of the Solenoid,
- \( n \) is the number of turns per Cm length of the Solenoid,
- \( I \) is the current through the solenoid in Amperes and
- \( \varphi_1 \) and \( \varphi_2 \) are the angles described in Figure 3.8.7.

It was found that for a length of 6 Cm at the middle of the solenoid, the intensity of the magnetic field was uniform up to ± 0.5%. Also it is obvious that the field will be the same, throughout any cross section, perpendicular to the axis, inside the solenoid.

The magnetic field of the solenoid was
experimentally determined by first principles as described in Section 3.8.4. Arrangement was made to keep the search coil coaxially with the solenoid at any point in the bore. The intensity of the magnetic field was determined at many points on the axis of the solenoid.

The purpose of the experiment was to verify the calculated values of the magnetic field. It was observed that when the change in current was doubled, the magnetic flux was also doubled. Hence it was decided to determine the magnetic flux for only one value of current.

The experimental and calculated values of the strength of the magnetic fields at points along the axis of the solenoid are plotted in Figure 3.9. The intensity of the magnetic fields at the midpoint of the solenoid are plotted against the energising current in Figure 3.10.

3.5.3. Comparison of Experimental and Calculated results

The calculated and experimental results are compared in Table 3.1 as well as in Figure 3.9. One can observe that the agreement between the two values improves as one moves towards the
centre of the solenoid. At the centre of the solenoid, it is seen that the two values agree within 0.33%. In view of the good agreement, only the calculated values were used for the intensity of the magnetic field, wherever necessary.

3.6. SEARCH COIL

A small wooden cylinder of length about 0.4 cm and a diameter of about 0.6 cm and with annular projections at the edges was chosen as the solenoid former. A very thin copper wire (Swg No. 33) was wound uniformly on the former. The resistance of the search coil was found to be 16.8 ohm.

3.7. RESEARCH ELECTROMAGNET

A research electromagnet was used for the study of breakdown potentials, electron temperature, positive ion number density and current-voltage characteristics—all in magnetic fields.

3.7.1. Description of the Research Electromagnet

The particulars of the research electromagnet are:

Number of energising coils : 2
Energising supply: 110 V, 5 A
Resistance when cold: 42 ohm
Resistance when hot: 45 ohm (After one hour)
Diameter of pole faces: 82 mm (Flat faces)
Air gap between pole faces: 95 mm

3.7.2. Magnetic field due to the Research Electromagnet

The strength of the magnetic field in the space between the pole faces was determined by a calibrated fluxmeter (Hall probe type). The intensity of the magnetic field was determined at different points along the axis, and along the transverse direction through the mid point of the air gap, for a few different currents. Since the nature of variation was the same for all the currents, the results are reported only for one value of current, (Figure 3.11)

It was observed that the magnetic field was uniform for a length of 0.75 Cm at the middle region along the axis and for a diameter of 2 Cm perpendicular to the axis. Therefore the magnetic field was homogeneous in a volume of 2.36 Cm$^3$. 
The strength of the magnetic field at the centre of the air gap was also determined for different currents. The measurements by fluxmeter were checked by measurements using the search coil. The intensity of the magnetic field at the midpoint of the air gap versus the energising current is shown in Figure 3.12.

3.8. MEASURING SYSTEMS

3.8.1. Measurement of Pressure

The low pressures were measured by a closed tube mercury monometer and a McLeod gauze. For pressures less than 0.6 torr, the McLeod gauze was used and for pressures greater than 0.6 torr, the mercury monometer was used.

3.8.2. Measurement of Voltages

The voltages were measured

(i) by a calibrated vacuum tube voltmeter (VTVM)
   (Philips: Universal Electrometer PP 9000).

(ii) on a potential divider and

(iii) by a calibrated voltmeter.
(i) Measurement by VTVM

In the study of electron temperature and positive ion density and, current and voltage characteristics, the VTVM was used for the measurement of voltages. It was calibrated according to the recommendations of the manufacturer.

(ii) Measurements on the potential divider

In the study of breakdown potentials, voltages were measured on the potential divider.

(iii) Measurements by a calibrated voltmeter

In the study of electron temperature and ion density, the probe voltages were measured by a calibrated voltmeter.

3.8.3. Measurement of Current

The glow discharge and electrical probe currents were measured by the same standardised galvanometer used for flux measurement. The sensitivity of galvanometer was $2.95 \times 10^{-8}$ A cm$^{-1}$.

The solenoid and electromagnet energising currents were measured by a calibrated ammeter.
3.8.4. Measurement of Magnetic Fields

The intensities of the magnetic fields were measured (i) by a search coil and ballistic galvanometer combination (method of first principles) and (ii) by a calibrated fluxmeter (Hall probe).

The strength of the magnetic field by the method of first principles is given by (Worsnop and Flint, 1967)

$$ F_E = \frac{T}{N} \cdot \frac{I}{\phi} \cdot \frac{r}{2\pi a} \cdot \sigma (1 + \frac{a}{2}) $$

(3.2)

where

$ F_E $ is the intensity of the magnetic field in Gauss,

$ T $ is the period of oscillation of the galvanometer in seconds,

$ i $ is the steady current in emu

$ \phi $ is the steady deflection due to current $ i $ in Cm

$ r $ is the total resistance in the circuit in emu

$ a $ is the area of one turn of the search coil in Cm$^2$

$ n $ is the total number of turns in the search coil.
\( \alpha \) is the throw produced on the scale by the ballistic galvanometer in Cm, due to the change in flux in the search coil and \( \lambda \) is the logarithmic decrement.

The circuit diagram for the measurement of the magnetic field is shown in Figure 3.13. A calibrated ammeter was used to measure the energising current. It was found that two tap keys used separately in the circuits gave better results than the use of a compound key. Hence the work was done with tap keys. For each determination of the magnetic field, the experiment was repeated a number of times to obtain the maximum induced current. The intensity of the magnetic field was calculated using the relation (3.2).

The general experimental set up is shown in Figure 3.14.

3.9. ANALYSIS OF ERRORS

A brief analysis of the various errors involved in the measurement of pressure, voltage, current and intensity of the magnetic field reported in this thesis is given in this section.
3.9.1. **Errors in the Measurement of Pressure**

When the pressure is measured by a McLeod gauze, the pressure is proportional to the square of the length of the air column above the mercury meniscus in the closed capillary tube. Maximum error in the measurement of length of the air column was 1 mm. Based on this the maximum error in the measurement of pressure by McLeod gauze was found to be 0.0016 torr. For the lowest pressure measured this was 2%. For higher pressures, this was very much less.

When the pressure was measured by the closed tube mercury monometer, the length of the mercury column was measured by a travelling microscope of accuracy 0.01 mm. Therefore the maximum error in the measurement of pressure could be just 0.01 torr which was 1% for the measured pressure of 1 torr. For higher pressures percentage error was very much less.

3.9.2. **Errors in the Measurement of Voltage**

The maximum error in the measurement of voltages by VTVM was 3%.

When the voltages were measured on the
potential divider, the error in the measurement was due to the inaccuracy in the resistances of the resistors and the possible fluctuation in the supply voltage. The maximum inaccuracy in the resistances was 0.33% (Section 3.4). Since higher and lower values are equally probable, the maximum relative difference among the resistances is 0.66%. This, together with the maximum variation in the supply voltage of 0.09% (Section 3.4), gives the error in the measurement of voltage to be 0.75%. The supply voltage was measured by the VTVM, whose accuracy was 3%. Therefore the overall error in the measurement of voltages on the potential divider was <4%. The error is not uncommon in breakdown potential studies, because often the accuracies in breakdown potential measurements are no better than 3 or 5% (Loeb, 1955).

3.9.3. Error in the Measurement of current

Based on the error in the measurement of sensitivity of the galvanometer and its resistance, the error in the measurement of current by the galvanometer was <0.5%.

3.9.4. Error in the Measurement of the Intensity of the Magnetic Field

Error in the measurement of the intensity
of the magnetic field by the calibrated flux meter was < 1%. The error in the measurement of the same by the search coil, on the basis of relation (3.2) was found to be < 6%.
TABLE 3.1

Intensity of magnetic field of the solenoid
Experimental and Calculated values

<table>
<thead>
<tr>
<th>S.No</th>
<th>Distance from one end (Cm)</th>
<th>Intensity of the magnetic field Experimental (G)</th>
<th>Intensity of the magnetic field Calculated (G)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>42.10</td>
<td>44.59</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>55.21</td>
<td>56.84</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>67.02</td>
<td>66.76</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>73.03</td>
<td>73.57</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>77.76</td>
<td>77.87</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>80.78</td>
<td>80.58</td>
</tr>
<tr>
<td>7</td>
<td>12</td>
<td>82.06</td>
<td>82.06</td>
</tr>
<tr>
<td>8</td>
<td>14</td>
<td>82.69</td>
<td>82.77</td>
</tr>
<tr>
<td>9</td>
<td>15</td>
<td>83.14</td>
<td>82.87</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
<td>82.69</td>
<td>82.77</td>
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<tr>
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</tr>
<tr>
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<td>22</td>
<td>77.56</td>
<td>77.87</td>
</tr>
<tr>
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<td>24</td>
<td>73.03</td>
<td>73.57</td>
</tr>
<tr>
<td>15</td>
<td>26</td>
<td>66.59</td>
<td>66.76</td>
</tr>
<tr>
<td>16</td>
<td>28</td>
<td>55.43</td>
<td>56.84</td>
</tr>
<tr>
<td>17</td>
<td>30</td>
<td>42.10</td>
<td>44.59</td>
</tr>
</tbody>
</table>
Fig[3.1a] DISCHARGE TUBE-1.
1. Discharge tube: Corning glass.
2. Electrodes: Aluminium discs.
3. Electrode leads: Tungsten.

Fig[3.1b] Electrode.
1. Electrode with rounded edges.
2. Electrode - lead joint.
3. Tungsten lead.

Dimensions in mm.
Fig 3.2(a) DISCHARGE TUBE:
1. Discharge tube: corning glass.
2. Electrodes: Aluminium disc of thickness 1.32.
3. Electrode leads: copper.

Fig 3.2(b) Langmuir probe:
1. Probe: copper.
2. Glass sleeve.

Dimensions in mm
Fig[3.3] DISCHARGE TUBE-3.
1. Discharge tube. Corning glass.
2. Electrodes. Aluminium discs.
3. Electrode leads. Tungsten.

Fig[3.3b] Langmuir probe.
1. Probe tungsten.
2. Glass sleeve.

Dimensions in mm.
Fig.[3.4] VACUUM SYSTEM.

1. Stop cock. 2. Burette. 3. Drying tower.
7. Anhydrous CaCl₂.
FIG[35]  HIGH VOLTAGE STABILIZED DC POWER SUPPLY.
Fig [3.6] POTENTIAL DIVIDER AND THE POWER SUPPLY.

1 to 24 1 Mega ohm resistors.
1 to 100 10 Kilo ohm resistors.
Fig [3.7] SOLENOID.

1. Axis of the solenoid.
2. Solenoid former Brass thickness 1.84 mm.
3. Cambric cloth.
4. Press board.
5. Layers of windings 30 layers.
6. Turns in a winding approx. 180 turns per layer.
7. Total no of turns 5334, 177.8 turns/cm.
Fig[3.8] DESCRIPTION OF ANGLES $\theta_1$ and $\theta_2$

S- Solenoid
a- Axis of the solenoid.
Fig. [3.9]. Magnetic field strength Vs distance on the axis from one end of the solenoid for a current of 0.41 Amp.
Fig. [3.10] Magnetic field strength at the mid-point of the solenoid Vs Solenoid current.
Fig[3.11] Intensity of the magnetic field Vs axial distance.

(ELECTROMAGNET)
Fig[3.12] Intensity of the magnetic field Vs energising current

(ELECTROMAGNET)
Fig. [3.13] Circuit diagram for the determination of the intensity of the magnetic field.

S-Solenoid  Sc-Search coil  P-Power supply
A-Ammeter  R-Series resistance  BG-Ballistic galvanometer
C-Commutator (Reversible key)  $T_1$, $T_2$-tap keys
Fig. [3.14] General Experimental Set up.
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