

$$E = mc^2$$



# DBT-STAR COLLEGE SCHEME Revised Practical Protocol Manual



## Volume 4: PHYSICS



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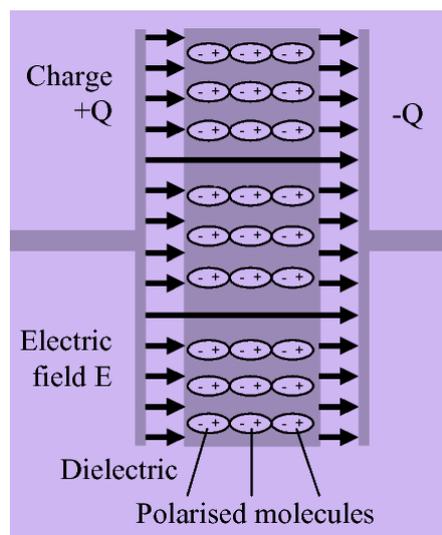
# MEASUREMENT OF DIELECTRIC CONSTANT OF SOLIDS AND LIQUIDS USING LCR METER

## 1. Aim

To determine the dielectric constant of the given solid and liquids using LCR meter.

## 2. Introduction

Dielectric or electrical insulating materials are the substances in which electrostatic field can persist for long times. When a dielectric is placed between the plates of a capacitor and the capacitor is charged, the electric field between the plates polarizes the molecules of the dielectric (Figure 1). This produces concentration of charges on its surface that creates an electric field which is antiparallel to the original field (which has polarized the dielectric). This reduces the electric potential difference between the plates. Considered the reverse, this means that, with a dielectric between the plates of capacitor, it can hold a large charge. This extend of this effect depends on the dipole polarisability of molecules of the dielectric, which in turn determines the dielectric constant of the material.



**Figure 1. Electric field between capacitor plates with a dielectric**

The electrons in the molecules shift towards the positively charged plate. The molecules then create a leftward electric field that partially annuls the field created by the charged plates. (The air gap is shown for clarity; in a real capacitor, the dielectric is in direct contact with the plates).

The method for determination of dielectric constants of liquids consists in the successive measurement of capacitance, first in a vacuum, and then when the capacitor is immersed in the liquid under investigation. A cylindrical capacitor has been used for liquid samples and different size parallel plate capacitor for solid samples.

## 2.1 Parallel Plate Capacitor

The capacity of a parallel plate capacitor is given by

$$C = \kappa \frac{\epsilon_0 A}{d} \text{ farad} \quad (1)$$

Where A is plate area and d is distance between the plates. It is assumed that the dielectric is completely fills the space between the capacitor plates.

## 2.2 Cylindrical Capacitor

The capacitance per unit length of a long cylindrical capacitor immersed in a medium of dielectric constant  $\kappa$  is given by

$$C = \kappa \frac{(2\pi\epsilon_0)}{\left(\ln\frac{r_1}{r_2}\right)} \text{ farad / m} \quad (2)$$

Here  $\epsilon_0 = 8.854 \times 10^{-12} \text{ C}^2 \text{ m}^{-2} \text{ N}^{-1}$  is permittivity of free space;  $r_1$  is external radius of the inner cylinder, and  $r_2$  is internal radius of the outer cylinder.

In actual practice, there are errors due to stray capacitances at the end of the cylinders and the leads. In any accurate measurement, it is necessary to eliminate these. It has been done in the following ways.

Consider a cylindrical capacitor of length L (in meter) filled to a height  $h < L$  with a liquid of dielectric constant  $\kappa$ . Its total capacitance is given by

$$C = \frac{2\pi\epsilon_0}{\ln\left(\frac{r_2}{r_1}\right)} [\kappa h + \kappa_0(L - h)] + C_0 \quad (3)$$

Here  $\kappa$  is the dielectric constant of air and C is sum total of stray capacitances. A simplification of Eq.(2) leads to

$$C = \frac{2\pi\epsilon_0}{\ln\left(\frac{r_2}{r_1}\right)} (\kappa - \kappa_0)h + C_0 \quad (4)$$

Where

$$C_0 = C_s + \frac{2\pi\epsilon_0}{\ln\left(\frac{r_2}{r_1}\right)} \kappa_0 L$$

Eq.(3) shows that the measured capacity C is a linear function of h(the height up to which the liquid is filled in the capacitor). If we vary the liquid height h, and measure it, together with the corresponding capacitance C, the plot of the data should be a straight line.

$$\frac{dC}{dh} = \frac{2\pi\epsilon_0}{\ln\left(\frac{r_2}{r_1}\right)} (\kappa - \kappa_0) \text{ farad/m} \quad (5)$$

The slope will yield a value for  $\kappa$  if  $\kappa_0$ ,  $r_1$  and  $r_2$  are known. The uncertainty due to  $C_s$ , has thus be eliminated.

### 3. Materials Required

Dielectric constant of solids and liquids set up, sample jar, Solid samples: glass plate, Bakelite sheet, Teflon, PZT (Lead Zirconate Titanate), Liquid sample: Carbon tetrachloride

### 4. Formula

$$\text{i) Solid Sample, } \kappa = \frac{Cd}{\epsilon_0 A}$$

$$\text{ii) Liquid Sample, } \kappa - \kappa_0 = \frac{dC/dh}{2\pi\epsilon_0} \ln\left(\frac{r_2}{r_1}\right)$$

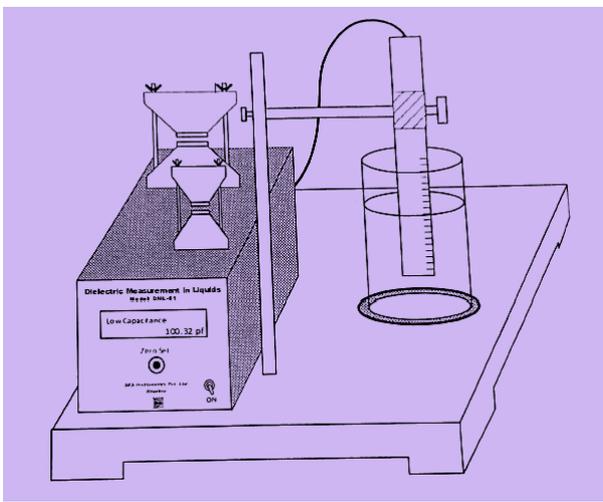
Where,

<b>C</b>	<b>Capacitance of the sample (farad)</b>
<b>d</b>	<b>Thickness of the sample (meter)</b>
<b>A</b>	<b>Area of the sample (meter)</b>
<b><math>\kappa</math></b>	<b>Dielectric constant of the sample</b>
<b><math>\kappa_0</math></b>	<b>Dielectric constant of air</b>
<b><math>\frac{dc}{dh}</math></b>	<b>Concentration gradient known from graph</b>
<b><math>\epsilon_0</math></b>	<b>Permittivity of free space (<math>\epsilon_0 = 8.854 \times 10^{-12} \text{ C}^2 \text{ m}^{-2} \text{ N}^{-1}</math>)</b>
<b><math>r_1, r_2</math></b>	<b>Inner and outer radius of the cylinder (meter)</b>

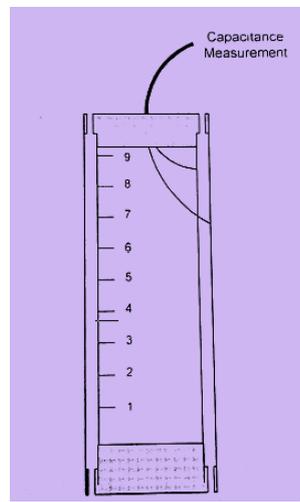
### 5. Procedure

#### 5.1. Probes Arrangement for Solids

It consists of two circular parallel plate setups of diameters 10mm and 50mm to cater to smaller and bigger samples respectively. One of the plates of the pair is fixed on the mount while the other can be moved up and down for inserting the sample between the plates and making the metallic plate surfaces touch the dielectric sample surface.



**Figure 2: Dielectric measurement of Solid and Liquids (Non contacting)**



**Figure 3: Co-axial cylinder set-up**

### 5.2. Probes Arrangement for Liquids

It consists of two polished brass cylinders fixed coaxially using threaded insulating gaskets the two ends. These gaskets have holes, in the lower one for allowing the experimental liquid to flow in between the cylinders, and in the upper one for communication with the atmosphere. Care has been taken to make the cylindrical electrodes of uniform cross section. This arrangement is mounted vertically and can be moved up and down with a rack and pinion set up. It is put in a vessel containing the experimental liquids. The outer surface of the outer cylinder has a vertical scale to measure the height of the liquid within the cylinders. Proper leads are provided for connections to the capacitance meter.

### 5.3. Digital Capacitance Meter

This is compact direct reading microcontroller based high resolution instrument for the measurement of capacitance of the sample.

Specifications	
Range	0 pf - 50 $\mu$ f auto range
Resolution	0.01 pf
Display	16 $\times$ 2 LCD display with back light
Accuracy	Better than 1%
Zero setting	Push button zero setting

#### 5.4. Solid Sample

The upper plate of the appropriate parallel plate capacitor of the arrangement for solids is raised by turning the top screw anticlockwise to keep/insert the sample. The plate is then lowered by turning the top screw clockwise till the capacitor plates touch the sample surface. The arrangement is then connected to the Digital capacitance meter. The meter is switched on and the reading is recorded.

- i. Room temperature : 26 °C
- ii. Diameter of smaller capacitor plate:10 mm
- iii. Diameter of bigger capacitor plates:50 mm
- iv. Thickness of lead zirconate titanate pallet:2.55 mm
- v. Thickness of Bakelite sheet sample=1.5 mm
- vi. Thickness of glass plate sample=1.5 mm
- vii. Thickness of Teflon sample =1.0 mm

#### 5.5. Capacity Measurement of Solid sample

S. No	Sample	C( $\mu$ f)
1	PZT (Lead Zirconate Titanate)	
2	Glass	
3	Bakelite	
4	Teflon	

#### 5.6. Liquid Sample

The glass container is put on the stand below the coaxial cylinder set-up (CCS) as shown in Figure. The container is filled with the experimental liquid up to a height of about 12 cm. The CCS is now lowered until the liquid touches the zero mark on the scale. The capacity meter is now adjusted to zero value by pushing zero set button for about a second (pressing it for longer duration will automatically set it to auto calibration mode, which is not desirable for this experiment). Remember, the result depends not on the actual value of the capacitance, but on its variation with the height of the liquid. The CCS is then lowered in step of 1cm and the reading on the Capacity meter are taken and recorded.

### 5.7. Capacity measurement of Liquid Sample: CCl<sub>4</sub>

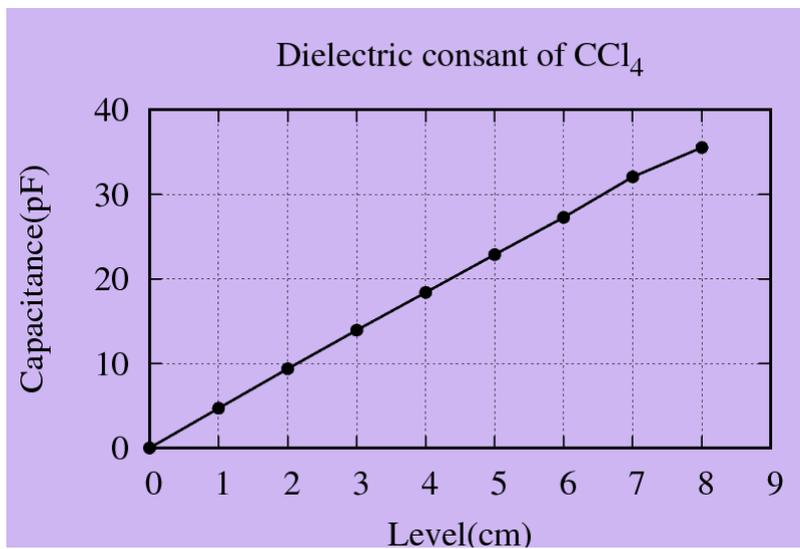
Dielectric Constant of free air ( $\kappa_0$ ): 1.0059

External radius of the inner cylinder: 25.4mm

Internal radius of the outer cylinder: 30.6 mm

S. No	Liquid Level (cm)	Capacity (pf)
1.	0.0	
2.	1.0	
3.	2.0	
4.	3.0	

### 5.8 Graph



### 6. Result

The dielectric constant of various solids and liquids samples are measured and their values are listed below as follows

#### For solid sample

- i. PZT =
- ii. Glass =
- iii. Bakelite =
- iv. Teflon =

#### For liquid sample

CCl<sub>4</sub> =

## 7. Precautions

- i. The spring loaded probe should be allowed to rest on the sample very gently; otherwise it may damage the conducting surface of the sample or even break the sample.
- ii. The reading of capacitance meter should be taken when the oven is OFF. This would be indicated by the green LED. In ON position there may be some pickups.
- iii. Avoid touching of the plates while connected to high voltage supply.

### Suggested Reading(s)

- i. C. Kittel, Introduction to Solid State Physics, Wiley Publisher, 8<sup>th</sup> Edition 2012.
- ii. Ch.V.V Ramana, Dielectric Constant Measurement for Liquids and Solids, LAP Lambert Academic Publishing, 2010.
- iii. [https://www.engineeringtoolbox.com/liquid-dielectric-constants-d\\_1263.html](https://www.engineeringtoolbox.com/liquid-dielectric-constants-d_1263.html)

# MEASUREMENT OF THE CHARGE OF AN ELECTRON BY MILLIKAN'S OIL DROP METHOD

## 1. Aim

To measure the charge of an electron by observing the effect of an electric field on a cloud charged oil droplets using Millikan's oil drop method.

## 2. Introduction

This method is based on the study of the motion of uncharged oil drop under free fall due to gravity and charged oil drop in a uniform electric field. By adjusting uniform electric field suitably, a charged oil drop can be made to move up or down or even kept balanced in the field of view for sufficiently long time and a series of observations can be made. Consider a spherical oil droplet of radius 'r' and density  $\rho$  falling under the gravitational force. This droplet in air is acted upon by a constant force and soon reaches a terminal velocity given by Stokes law,  $F_\eta = 6\pi r \eta v_f$ , where  $\eta$  is the coefficient of viscosity of air and  $v_f$  is the terminal velocity during the fall. The gravitational and buoyancy forces acting on the droplet are balanced by  $F_\eta$

$$\frac{4}{3}\pi r^3 \rho g - \frac{4}{3}\pi r^3 \rho_a g = 6\pi \eta r v_f \quad (1)$$

Here  $\rho_a$  is the density of the air. The falling velocity  $v_f$  is thus given by

$$v_f = \frac{2}{9} \frac{g r^2}{\eta} (\rho - \rho_a) \quad (2)$$

If the droplet carries a charge 'ne' and is moving upward with terminal velocity  $v_r$  under the influence of the applied electric field  $\frac{V}{d}$  between the parallel plate electrodes separated by the distance d and potential difference V, the force balance equation is, Figure

$$\frac{4}{3}\pi r^3 (\rho - \rho_a) + 6\pi \eta r v_r = \frac{V n e}{d} \quad (3)$$

Subtracting equation (1) from equation (3) and solving for 'ne', we get

$$n e = \frac{6\pi \eta r d}{V} (v_f + v_r) \quad (4)$$

Dividing equation 4 by equation 2 gives

$$n e = \frac{4\pi g d}{3 V} (\rho - \rho_a) r^3 \left( 1 + \frac{v_r}{v_f} \right) \quad (5)$$

The Stokes law used in obtaining equations (1)–(5) assumes that the droplets are moving slowly, that there is no slipping of the medium over the surface of the droplet, that the medium is of quite large extent compared to the size of the droplet and that the inhomogeneity in the medium are of a size small compared to the size of the droplets. In the present case all the assumptions except the last one are reasonable valid. The radii of the droplets are of the order of one micron and therefore not much greater than the mean free path of the air molecules. The droplets will tend to fall more quickly in the free space between the air molecules. The expression for the falling velocity  $v_f$  corrected for this effect, on the basis of kinetic theory is

$$v_f = \frac{2}{9} \frac{g r^2}{\eta} (\rho - \rho_a) \left(1 + \frac{c}{P r}\right) \quad (5)$$

Where  $c$  ( $=6.17 \times 10^{-8}$  m of Hg-m) is a correction factor and  $P$  (in m of Hg) is the atmospheric pressure. Writing

$$\xi = \frac{9\eta}{2g} \frac{v_f}{\rho - \rho_a} \quad (6)$$

$$\zeta = \frac{c}{2P} \quad (7)$$

Equation 6 now reduces to

$$r^2 + 2\zeta r - \xi = 0 \quad (8)$$

The radius of the droplet is given by the positive root of this equation

$$r = -\zeta + \sqrt{\zeta^2 + \xi} \quad (9)$$

The charge  $ne$  may be obtained by first calculating  $\xi$  and  $\zeta$  from equation 7 and 8, then calculating the radius 'r' from equation 10 and finally 'ne' from equation 5.

Equation 5 above is for the “Dynamic” method. In the “Balancing” method, the droplet is kept stationary by adjusting the potential. The upward velocity is thus equal to zero. The final equation for 'ne' in the ‘Balancing’ method is therefore

$$ne = \frac{4\pi}{3} \frac{gd}{V_b} (\rho - \rho_a) r^3 \quad (10)$$

Where,  $V_b$  is the balancing potential.

### 3. Apparatus Required

Millikan Oil Drop Set Up, Monitor (14" LCD TV), Bottle of Oil, Video Output Cable.

### 4. Formula

- i. By dynamic method

$$ne = \frac{4\pi}{3} \frac{gd}{V} (\rho - \rho_a)r^3 \left(1 + \frac{v_r}{v_f}\right)$$

- ii. By balance method

$$ne = \frac{4\pi}{3} \frac{gd}{V_b} (\rho - \rho_a)r^3$$

Where,

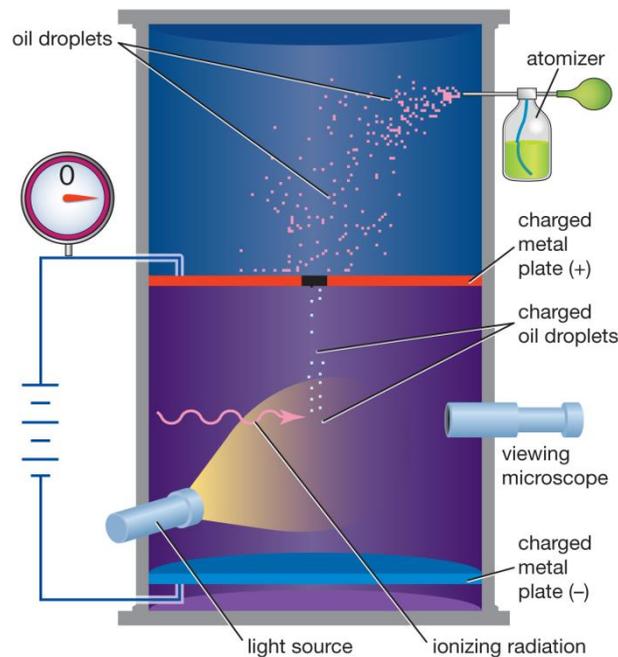
<b>g</b>	<b>Acceleration due to gravity (9.8 m/sec<sup>2</sup>)</b>
<b>d</b>	<b>Distance between the parallel plate electrode (meter)</b>
<b>V</b>	<b>Potential applied between the parallel plate -Dynamic method (volt)</b>
<b>V<sub>d</sub></b>	<b>Potential applied between the parallel plate -Balance method (volt)</b>
<b>ρ</b>	<b>Density of the liquid used in atomisation (kg/m<sup>3</sup>)</b>
<b>ρ<sub>a</sub></b>	<b>Density of the air medium (kg/m<sup>3</sup>)</b>
<b>r</b>	<b>Radius of the droplet (meter)</b>

### 5. Procedure

- i. Note the atmospheric pressure and the room temperature.
- ii. Switch on the power supply.
- iii. Wait for about ten minutes to let the system stabilize.
- iv. Fix two horizontal lines on the monitor. These are the present lines. The rise and fall times of the droplets to move from one line to the other are to be recorded, a good choice is to choose the second line from the top and the last but one line from the bottom. This will leave some room at the top and at the bottom for manoeuvring and preventing the droplet from getting lost.
- v. Press the 'clear key' to make the 'time meter' read zero.
- vi. Spray droplets of oil from the atomizer. One or two are squirts are usually sufficient.
- vii. As the droplets drift down, some of them pass through the hole in the upper parallel plate and reach the region in between the plates where they are illuminated.
- viii. These are viewed by the microscope /camera as unresolved points of diffracted light and the images are transmitted to the monitor screen.
- ix. These droplets drift down slowly under gravitational force.

- x. Under the influence of the electric field between the plates, the motion of the droplets will get affected if they are charged. If a droplet moves downward more slowly under the influence of the electric force (corresponding to the upper plate at a positive potential) the drop is negatively charged. Its motion can be arrested or even reversed (made to rise) by an increase in the potential. If the downward drifting of the droplet increases under the action of electric forces, the droplet is positively charged. Such droplets are ignored in the present set-up
- xi. Suitable negatively charged droplet is selected. 'Suitable' means that it drifts downward slowly (about 10-15 s free fall time) under gravitational field indicating that the droplet is not too heavy. Its mass should also not be too small; otherwise it will bounce around due to random collisions with air molecules. Brownian motion and it will be difficult to estimate when the droplet actually crosses a line. A very small droplet may cross a line 10~20 times. It should also be possible to make it rise by applying a Voltage of about 500 V indicating that there are only a few charge quanta on the droplet. Fix some value of the voltage.
- xii. This selection is done by concentrating on one or two droplets and removing all others from the field by switching on and switching off the electric field.
- xiii. Once a droplet has been chosen, measurements can begin. There are two approaches
  - (a) **Dynamic:** measure the free fall time with the voltage off and the rise time with some suitable voltage on for the droplet to move between the two above chosen lines on the monitor. For these measurements following procedure may be followed
    - ❖ Pull the droplet above the top chosen line on the monitor by adjusting the voltage.
    - ❖ Press the clear key to make the time meter read zero.
    - ❖ Switch off the voltage, the droplet will begin to fall freely.
    - ❖ Start the time meter by pressing the start/stop key when the droplet crosses the top chosen line on the monitor.
    - ❖ Stop the time meter by pressing the start/stop key again when the droplet crosses the bottom chosen line on the monitor.
    - ❖ Stop the downward motion of the droplet by switching on the voltage.
    - ❖ Note the fall time from the time meter.
    - ❖ Press the clear key to make time meter read zero.
    - ❖ Allow the droplet to come below the bottom line by switching off the voltage.
    - ❖ Switch on the voltage (its value already fixed earlier), the droplet will begin to rise.
    - ❖ Start the time meter when the droplet crosses the top chosen line on the monitor.
    - ❖ Stop the time meter when the droplet crosses the top chosen line on the monitor.

- ❖ Stop the upward motion of the droplet by switching off the voltage.
- ❖ Note the rise time and the voltage.



**Figure 1: Millikan's Oil Drop Experiment Set-up**

Repeat these measurements of free fall time and rise time several times. Take the average of these timings for the free fall and the rise and note the voltage. Take another suitable droplet if it is there. If not, spray droplets again. Choose a suitable one and proceed as above to get data on several droplets.

**(b) Balancing:** measuring the free fall times as in the above 'dynamic method' for the droplet to move between the two chosen lines on the monitor. Apply the voltage and adjust its value such that the electric force on the droplet just balances other forces on it and the droplet hangs (does not move up or down). The droplet should remain stationary for several minutes. The voltage may have to be adjusted again and again. Take the average value of these voltages and the average of the free fall timings. Take another suitable droplet if it is there. If not, spray droplet again. Choose a suitable one and proceed as above to get on several droplets

- ❖ Note the atmospheric pressure and the room temperature at the end to the experiment as well.
- ❖ Record your date in the format given in tabulation.

This is slightly difficult experiment and need some patience to achieve high accuracy. The more droplets on measures upon the more data one takes on each droplet, the accurate will be the final result.

- ❖ Distance between the parallel plate  $d = 5 \times 10^{-3} \text{m}$
- ❖ Distance between the chosen top and bottom lines on the monitor  $l = 1 \times 10^{-3} \text{m}$
- ❖ Density of the oil  $\rho = 929 \text{ kg/m}^3$
- ❖ Density of the air  $\rho_a = 1 \text{ kg/m}^3$
- ❖ Room temperature  $T = 24^\circ \text{C}$
- ❖ Atmospheric pressure  $P = \text{mm of Hg} = 0.75 \text{m}$
- ❖ Coefficient of viscosity of air  $= 1.8432 \times 10^{-5} \text{ kg/m sec}$

### 5.1. Observational Data (Dynamic method)

Droplet No	S. No	Free-fall Time	Rise Time	Mean Free Fall Time (tr)	Mean Rise Time (tr)	Mean free fall Velocity $V_f = L / t_f$ (m/s)	Voltage (V) Volt
1	1						
	2						
	3						
	4						
	5						
2	1						
	2						
	3						
	4						
	5						
3	1						
	2						
	3						
	4						
	5						
4	1						
	2						
	3						
	4						
	5						
5	1						
	2						
	3						
	4						
	5						

### 5.2. Observational Date (Balancing method)

Droplet No	S. No	Free-fall Time	Rise Time	Mean Free fall Time (tr)	Mean Free fall Velocity $V_f = L / t_f$ (m/s)	Voltage (V) Volt
1	1					
	2					
	3					
	4					
	5					
2	1					
	2					
	3					
	4					
	5					
3	1					
	2					
	3					
	4					
	5					
4	1					
	2					
	3					
	4					
	5					
5	1					
	2					
	3					
	4					
	5					

### 5.3. Calculation of common constant to be used with the entire droplet

$$C = \frac{4}{3} \pi d g (\rho - \rho_a) = 190.13$$

$$D = \frac{9\eta}{2g(\rho - \rho_a)} = 9.04 \times 10^{-9}$$

$$\zeta = \frac{c}{2P} = 4.06 \times 10^{-8}$$

Where,  $c = 6.17 \times 10^{-8}$

## 5.4. Calculation from the droplet data

### Dynamical Method

Droplet Number	$\xi$ (= $Dv_f$ )	$r$ (= $-\zeta + \sqrt{\zeta^2 + \xi}$ )	$r^3$	$T$ (= $1 + \frac{t_f}{f_r}$ )	$ne =$ ( $\frac{CTr^3}{V}$ )

### Balancing method

Droplet Number	$\xi$ (= $Dv_f$ )	$r$ (= $-\zeta + \sqrt{\zeta^2 + \xi}$ )	$r^3$	$ne =$ ( $\frac{CTr^3}{V}$ )

Analysis and treatment of the charge (ne) on the droplet

- ❖ Identify the minimum value of the charge ne on the droplets
- ❖ Divide the value of the charge ne on all the droplets by this minimum value.
- ❖ The result will be numbers close to integers for all the droplets
- ❖ Now extrapolate all these numbers or the earlier ones if no multiplication has been done to the nearest integer
- ❖ Divide the value of the charge ne on all the droplets by the respective integers
- ❖ This gives the values of the charge on an electron by different droplets
- ❖ Take the average of these values. This gives the final result

## 6. Result

The charge of an electron is measured by using Milliken's oil drop method and its values are tabulated as follows

### Dynamic Method

ne	ne divided by the lowest	Nearest integer $n_{eff}$	$ne/n_{eff}$
			<b>Mean (ne/n<sub>eff</sub>) =</b>

## Balancing Method

<b>ne</b>	<b>ne divided by the lowest</b>	<b>Nearest integer <math>n_{\text{eff}}</math></b>	<b>ne/<math>n_{\text{eff}}</math></b>
			<b>Mean (ne/<math>n_{\text{eff}}</math>) =</b>

### 7. Precautions

- i. Measure the voltage at the plate voltage connectors and not across the capacitor plates.
- ii. There is a ten megaohm resistor in series with each capacitor plate to prevent electric shock.
- iii. The temperature inside the droplet viewing chamber should be determined periodically (about fifteen minutes).
- iv. Always handle the plastic spacer and capacitor plates carefully to avoid scratching them. Solvents that might attack the plastic should be avoided.

### Suggested Reading(s)

- i. Millikan, R.A, On the elementary electrical charge and the Avogadro constant. The Physical Review, 32(4), 349-397, 1911.
- ii. <https://courses.lumenlearning.com/introchem/chapter/millikans-oil-drop-experiment/>
- iii. [http://ffden-2.phys.uaf.edu/212\\_fall2003.web.dir/ryan\\_mcallister/slide3.htm](http://ffden-2.phys.uaf.edu/212_fall2003.web.dir/ryan_mcallister/slide3.htm)

# MEASUREMENT OF SPECIFIC CHARGE OF AN ELECTRON BY THOMSON'S METHOD

## 1. Aim

To measure the ratio of the electron charge to mass ratio ( $e/m$ ) by studying the electron trajectories in a uniform magnetic field using Thomson's Method.

## 2. Introduction

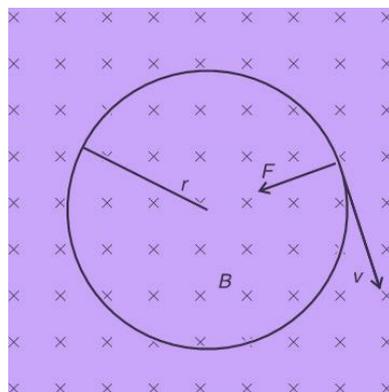
J. J. Thomson first determined the specific charge (charge to mass ratio  $e/m$ ) of the electron in 1887. In his experiment, J. J. Thomson had found a charged particle that had a specific charge two thousand times that of the hydrogen ion, the lightest particle known at that time. Once the charge on the particles was measured he could conclude with certainty that these particles were two thousand times lighter than hydrogen. This explained how these particles could pass between atoms and make their way out of thin sheets of gold. Measurement of the specific charge of cathode rays for different metals made him conclude that the particles that constituted cathode rays form a part of all the atoms in the universe. For his work J. J. Thomson received the Nobel Prize in Physics in 1906, "in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases". The direct measurement of mass of the electron is difficult by experiments. It is easier to determine the specific charge of the electron  $e/m$  from which the mass  $m$  can be calculated if the elementary charge  $e$  is known.

### 2.1 Charged particle in a magnetic field accelerated by a potential

An electron moving at velocity  $\mathbf{v}$  perpendicularly to a homogenous magnetic field  $\mathbf{B}$ , is subject to the Lorentz force  $\mathbf{F}$ :

$$\mathbf{F} = e(\vec{v} \times \vec{B}) \quad (1)$$

This is perpendicular to the velocity and to the magnetic field. The electron takes a circular orbit with axis of the circle defined by the direction of the magnetic field. The Lorentz force is thus equal to the centripetal force which forces an electron into an orbit  $r$  (see Fig.1).



**Figure 1: The path of the electron in amagnetic field**

$$F = m_e \cdot \frac{v^2}{r} \quad (2)$$

$$\text{Thus, } \frac{e}{m_e} = \frac{v}{r \cdot B} \quad (3)$$

## 2.2 Electrons accelerated by a Potential (U)

In the experiment, the electrons are accelerated in a fine beam tube by the potential U.

The resulting kinetic energy is

$$e \cdot U = \frac{m_e \cdot v^2}{2} \quad (4)$$

Combining equation (3) and (4), the specific charge of the electron thus is

$$\frac{e}{m_e} = \frac{2 \cdot U}{(r \cdot B)^2} \quad (5)$$

## 2.3 The magnetic field generated in a pair of Helmholtz coils

The magnetic field generated by a pair of Helmholtz coils is twice the field generated by a single coil. The magnetic field generated by a single coil of radius R carrying current I having N turns is given by

$$B = \frac{\mu_0 I R^2}{2 (R^2 + x^2)^{\frac{3}{2}}} \quad (6)$$

We need to calculate the magnetic field due to both the coils at  $x = R/2$  each coil. This is given by

$$B = \frac{2\mu_0 I N R^2}{2 (R^2 + x^2)^{\frac{3}{2}}} = \left(\frac{4}{5}\right)^{\frac{3}{2}} \frac{\mu_0 I N}{R} = kI \quad (7)$$

Where  $k = \left(\frac{4}{5}\right)^{\frac{3}{2}} \frac{\mu_0 N}{R}$ ,  $\mu_0 = 1.2566 \times 10^{-6} \text{ N / A}^2$

The field B generated in a pair of Helmholtz coils is proportional to the current I in the coils.

$$B = k \cdot I \quad (8)$$

The magnetic field should be parallel or anti-parallel to the magnetic field due to earth  $B_e$ . If the expression for magnetic field is plugged into equation (5), the resulting expression is

$$\frac{e}{m_e} = \frac{2 \cdot U}{(r \cdot k \cdot I)^2} \quad (9)$$

The proportionality factor  $k$  can be calculated either from the coil radius  $R = 0.2$  m and the winding factor  $n = 154$  per coil. The fine tube in the discharge tube setup contains hydrogen molecules at low pressure, which through collisions with electrons are caused to emit light. This makes the orbit of the electrons indirectly visible and their orbiting radius can be directly measured.

### 3. Apparatus Required

e/m tube, Helmholtz coil, Power supplies, Permanent magnet, Electronic control box.

### 4. Formula

The specific charge of the electron

$$\frac{e}{m} = \left( \frac{125a^2}{128\pi^2 n^2} \times 10^{14} \right) \frac{V}{I^2 d^2} \text{ coul/kg}$$

Where,

<b>V</b>	<b>Accelerating Potential (volt)</b>
<b>a</b>	<b>Radius of the Helmholtz coil (0.14 m)</b>
<b>n</b>	<b>Number of turns of each Helmholtz coil (160)</b>
<b>I</b>	<b>Current through the Helmholtz coil (amp)</b>
<b>d</b>	<b>Diameter of the electron beam path (meter)</b>

After substituting the standard values on the above formula, it becomes

$$\frac{e}{m} = (7.576 \times 10^6) \times \frac{v}{I^2 d^2} \text{ coul/kg}$$

### 5. Procedure

- i. Before the power is switched to “ON”, make sure all the control knobs are at their minimum position
- ii. Turn the power switch to “ON”. The indicator lamp will glow
- iii. Wait a little for the cathode to heat up.
- iv. Turn the accelerator voltage adjust knob clockwise to increase the voltage. Rectilinear electron beam emerging from the cathode will be visible. Adjust the accelerator voltage at about 200 volt.
- v. It should be clear that the electrons themselves in the beam are not visible. What is observed is the glow of the helium gas in the tube when the electrons collide with the atoms of the gas. We actually see the glow of gas atoms which have been excited by collisions with electrons.

- vi. Rotate the e/m tube so that the electron beam is parallel to the plane of the Helmholtz coils. (Do not take it out of its socket).
- vii. Earth's magnetic field interferes with the measurements. However this magnetic field is weak compared to the field generated by the Helmholtz coils and we could ignore its effects as a first approximation.
- viii. Slowly turn the current adjust knob clockwise to increase the current for the Helmholtz coils. The electron beam will be curved. Increasing the current will increase the curvature of the beam (see Fig.2).



**Figure 2: Experimental set-up for determining the specific charge of the electron**

- ix. In case the electron beam does not make a complete circle and the circular path is skewed, rotate the socket of the tube until the path is a closed circle. This happens when the tube pointer is set at about  $90^\circ$ .
- x. Measure the diameter of the electron beam. This measurement has been facilitated by fixing a hollow tube (fitted with cross wires at its both ends) on the slider of the scale. This tube fixes the line of sight during measurements.
- xi. Note the ammeter reading for the current to the Helmholtz coils and the voltmeter reading for the accelerating voltage.
- xii. Decrease the accelerating voltage by a small amount (20 volt, say) and measure the diameter of the electron beam path.

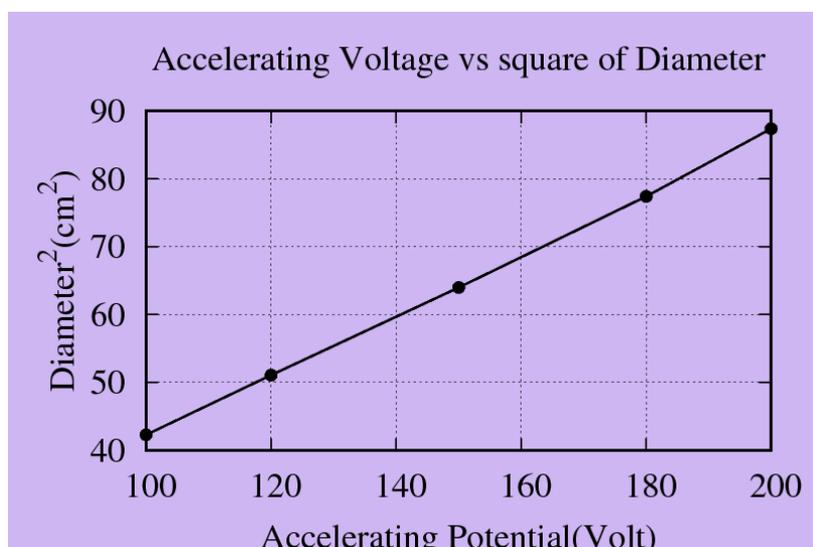
- xiii. Carry on the observations. The voltmeter reading should not be increased beyond 250 volt. A value lower than 80 volt is also not advisable. Similarly the current to the Helmholtz coils should not be more than 2 amp.
- xiv. Do not leave the beam ON for long period of time.

**5.1 Measurement of accelerating voltage V, magnetizing current I and diameter d of the electron beam path**

Accelerating voltage (Volt)	Current to the Helmholtz coils (amp)	Diameter of the beam path (m)	(Diameter) <sup>2</sup> (m <sup>2</sup> )	$\frac{V}{I^2 d^2}$
200				
180				
160				
140				
120				
100				
				Mean $\left(\frac{V}{I^2 d^2}\right) =$

**5.2 Graph**

The value of  $\frac{\Delta v}{\Delta d^2}$  is obtained from the slope of the following graph



**6. Result**

The value of the specific charge of an electron (e/m) is .....coul / kg

## 7. Precautions

- i. The Helmholtz coils should be connected with proper polarity else the circular path of the electrons will appear distorted.
- ii. The voltage should never exceed the maximum values 250 V mentioned else it might damage the walls of the discharge tube.
- iii. The maximum anode voltage should go beyond 45 V.
- iv. If the setup is should be aligned along the east-west direction else the trajectory of the electrons might not be perfectly circular.
- v. Do not exceed the current in the coils beyond 1.8A.

### Suggested Reading(s)

- i. D. Halliday and R. Resnick, Fundamentals of Physics, John Wiley & Sons, New York, Second Edition, 1981.
- ii. Manu Kumar Khattry, Manoj Kumar Thapa, Principle of Physics, Kathmandu: Ayam Pulication PVT LTD, 2010.
- iii. [http://lampx.tugraz.at/~hadley/num/apps/numerical\\_integration/thomson.en.php](http://lampx.tugraz.at/~hadley/num/apps/numerical_integration/thomson.en.php)

# DETERMINATION OF MAGNETORESISTANCE OF SEMICONDUCTORS

## 1. Aim

To study the magnetic field dependence of the transverse magnetoresistance of a given semiconductor sample.

## 2. Introduction

Magnetoresistance is a phenomenon in which the electrical resistivity of a material changes in the presence of an external magnetic field. Magnetoresistance was discovered by Lord Kelvin (William Thomson) in 1851. Albert Fert and Peter Grunberg were jointly awarded the Nobel Prize for the discovery of Giant Magnetoresistance in 2007.

The magnetoresistance is defined as the ratio of change in resistance of a substance due to application of magnetic field to its resistance in zero fields. Under the influence of a magnetic field, the electrons in a solid material do not follow the exact direction of superimposed electric field, instead take a curved path. This result shows decrease of the mean free path and hence an increase in the resistivity of the sample. When magnetic field is applied normal to the current flow, the effect is termed as transverse magnetoresistance and when field is applied parallel to the current flow, it is termed as longitudinal magnetoresistance.

## 3. Apparatus Required

Four Probe Set-up, Sample (n-type germanium), Magnetoresistance Set-up, Electromagnet, Constant Power Supply, Digital Gaussmeter.

## 4. Formula

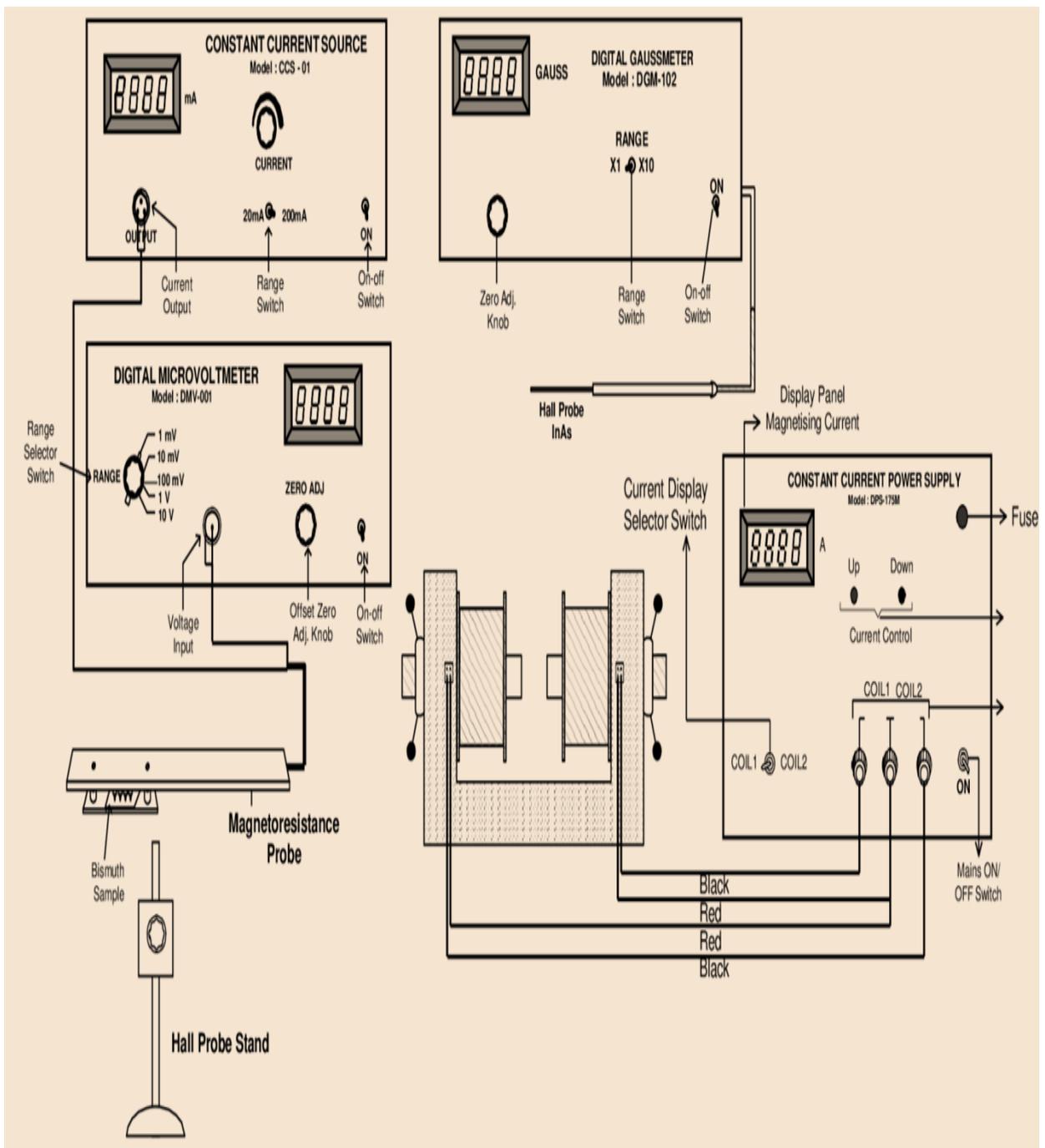
$$\frac{\Delta R}{R} = \frac{R_m - R}{R}$$

Where,

<b>R</b>	<b>Sample resistance without magnetic field (42.98 Ω)</b>
<b>R<sub>m</sub></b>	<b>Resistance of the sample with the magnetic field (Ω)</b>

## 5. Procedure

- i. Set the pole piece distance of the electromagnet to nearly 19 mm.
- ii. Now place the hall probe of gauss meter the magnetic field as shown in figure 1 and switch on the electromagnet power supply and set it to maximum (4A). Rotate the Hall probe till it become perpendicular to magnetic field. Magnetic field will be maximum in this adjustment.

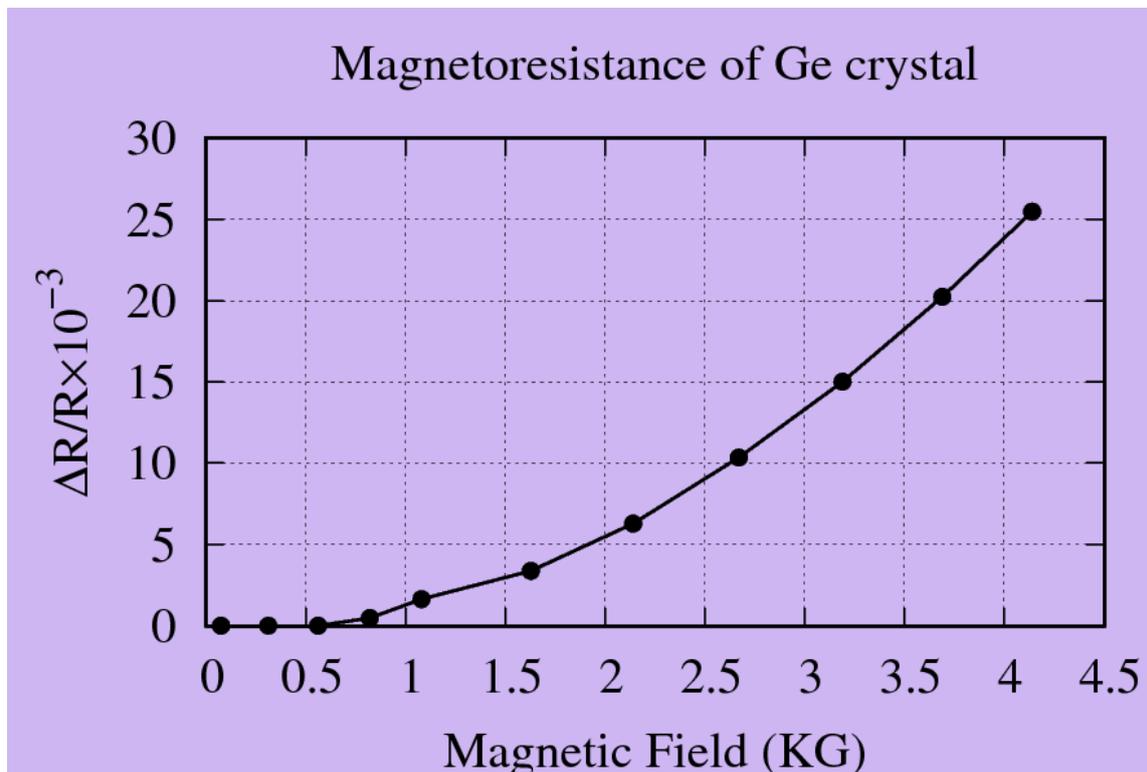


**Figure 1: Panel diagram of Magnetoresistance Set-up**

- iii. Now lower the current in constant power supply to minimum and slowly increase the current and tabulate the magnetic field as in Table 1.
- iv. Next unscrew the screws given at the top of probe to lower the case plate. Put the sample on the base plate of the four probe arrangement. Slowly screw both screws evenly to apply a very gentle pressure on the four spring probes. Check the continuity between the probes for proper electrical contacts.
- v. Connect the outer pair of probes (red/black) leads to the current terminals and the inner pair (yellow and green lead) to the probe voltage terminals.



## 5.1 Graph



## 6. Result

The dependence of resistivity with external applied magnetic field was studied.

## 7. Precautions

- i. Ensure that the specimen is located at the centre between the pole faces and is exactly perpendicular to the magnetic field.
- ii. To measure the magnetic flux the four probes should place at the center the pole faces, parallel to the crystal.
- iii. Check the direction of electromagnet coils so that it generates the maximum magnetic field, this can be check by placing the soft iron near the generated magnetic field, if soft iron attracts forcefully the magnetic field produced is strong, otherwise magnetic field is weak.

## Suggested Reading(s)

- i. B. Pippard, Magnetoresistance in Metals, Cambridge University Press (1989).
- ii. <https://www.iiserkol.ac.in/~ph324/ExptManuals/Magnetoesistance>.

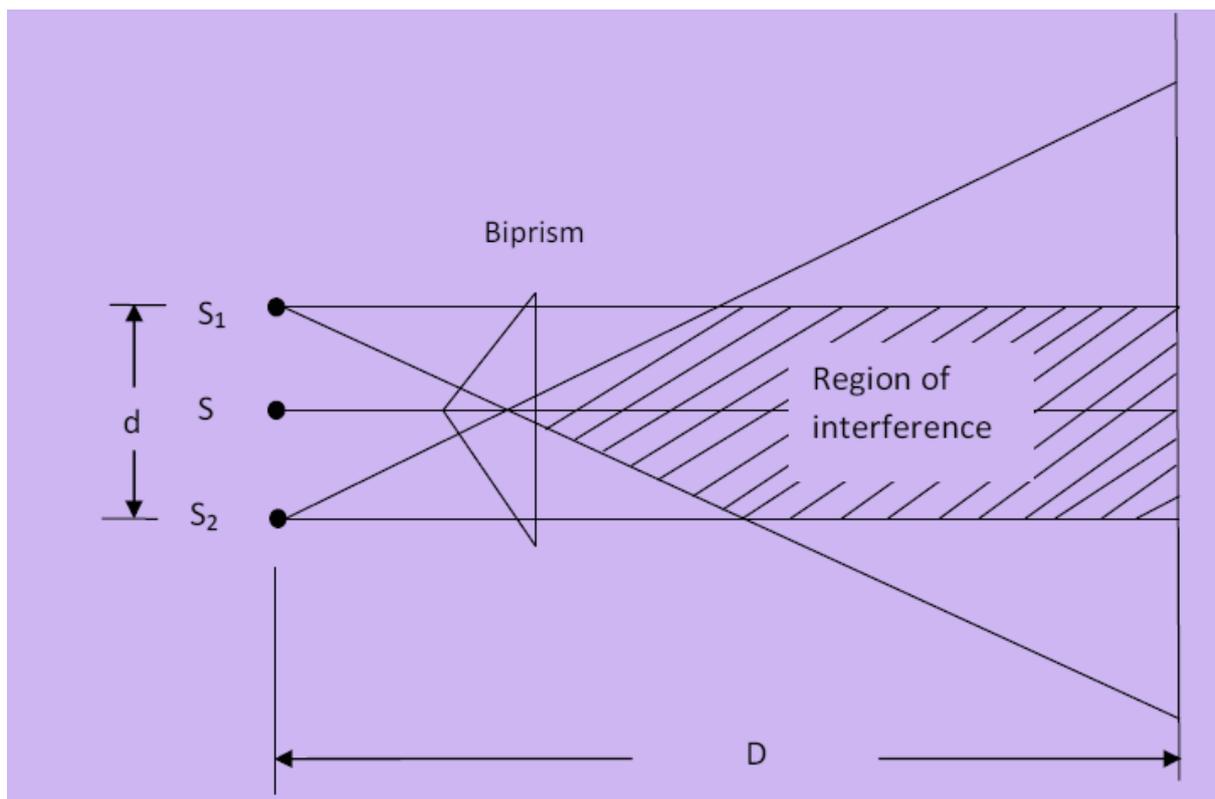
# MEASUREMENT OF WAVELENGTH OF MONOCHROMATIC LIGHT USING FRESNEL'S BIPRISM

## 1. Aim

To determine the wavelength of sodium light using Fresnel's Biprism method.

## 2. Introduction

A Fresnel Biprism is a thin double prism placed base to base and have very small refracting angle ( $0.5^\circ$ ). This is equivalent to a single prism with one of its angle nearly  $179^\circ$  and other two of  $0.5^\circ$  each. The interference is observed by the division of wave front. Monochromatic light through a narrow slit  $S$  falls on biprism, which divides it into two components. One of these components is refracted from upper portion of biprism and appears to come from  $S_1$  where the other one refracted through lower portion and appears to come from  $S_2$ . Thus  $S_1$  and  $S_2$  act as two virtual coherent sources formed from the original source. Light waves arising from  $S_1$  and  $S_2$  interfere in the shaded region and interference fringes are formed which can be observed on the screen as shown in figure 1.



**Figure 1. Fresnel Biprism Experiment Set-up**

## 3. Apparatus Required

Optical bench, Biprism, Slit, Micrometer eye-piece, Monochromatic source of light (Sodium lamp), Convex lens.

## 4. Formula

The wavelength of the sodium light is given by the formula in case of biprism experiment

$$\lambda = \beta \frac{2d}{D} \text{ meter}$$

$$2d = \sqrt{d_1 d_2} \text{ meter}$$

Where,

<b><math>\beta</math></b>	<b>Fringe width (metre)</b>
<b><math>2d</math></b>	<b>Distance between two virtual sources (meter)</b>
<b><math>D</math></b>	<b>Distance between the slit and the eyepiece (meter)</b>
<b><math>d_1</math></b>	<b>Distance between two image formed by the convex lens in the first (meter)</b>
<b><math>d_2</math></b>	<b>Distance between the two image formed by the convex lens in the second position (meter)</b>

## 5. Procedure

### 5.1 Adjustments

- i. The height of the slit, biprism and the eyepiece is adjusted at the same level.
- ii. The biprism upright is placed near the slit. The slit is made narrow and vertical. It is illuminated with sodium light. Looking through the biprism two images of the slit will be seen. The eye is moved sideways when one of the images will appear to cross the edge of the biprism from one edge to the other. If refracting edge of the biprism is parallel to the slit, the images as a whole will appear to cross the edge. Otherwise when the adjustment is faulty, either the top or the bottom of the image will cross the edge first. The biprism is adjusted by rotating it in its own plane to effect the sudden transition of the full image.
- iii. The eyepiece is placed near the biprism and the biprism upright is moved perpendicular to the biprism bed till fringes or a patch of light is visible. If the fringes are not seen the biprism is rotated in its cross plane with the help of tangential screw till fringes are obtained.
- iv. If fringes are not clear reduce the fringe width slightly.
- v. The vertical cross wire is adjusted on one of the bright fringe at the centre of the fringe system and the eyepiece is moved away from the biprism. In doing so, if fringes give a lateral shift, it must be removed in the following way.

From any position, the eyepiece is moved away from the biprism and at the same time lateral shift is given to the biprism with its base screw so that the vertical crosswire remains on the same fringe on which it was adjusted. The eyepiece is now moved towards the biprism and this procedure is repeated for few times till the lateral shift is removed.

### 5.2 Measurement of $\beta$ (Fringe width)

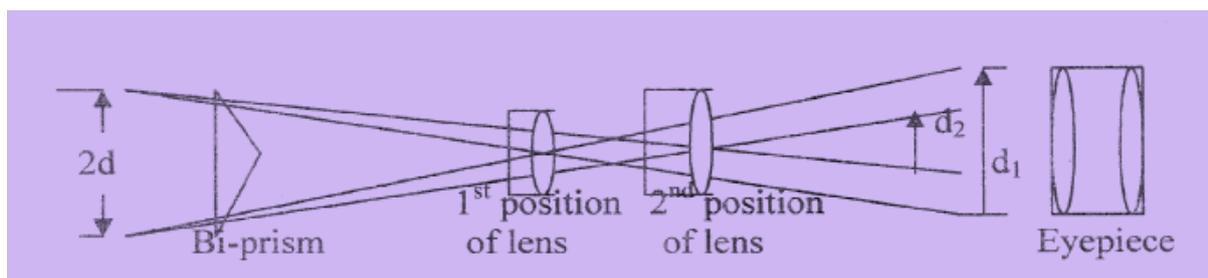
- i. The eyepiece is fixed about 100 cm away from the slit.
- ii. The vertical cross wire is set on one of the bright fringes and reading on eyepiece scale is noted.
- iii. The cross wire is moved on the next bright fringe and the reading is noted. In this way observations are noted for about 20 fringes.

### 5.3 Measurement of $D$ (Distance between Source and Screen)

The distance between the slit and the eyepiece uprights is noted. This distance gives 'D'. The value of 'D' is corrected for the bench error.

### 5.4 Measurement of $2d$ (Distance between the two Sources on Screen)

- i. For this part the distance between the eyepiece and slit should be kept slightly more than four times the focal length of lens. If necessary the position of the slit and the biprism should not be altered.
- ii. The convex lens is introduced the biprism and eyepiece and is placed near to the eyepiece. The lens is moved towards the biprism till two sharp images of the slit are seen. The distance  $d_1$  is measured by the micrometer eyepiece as shown in figure 2.
- iii. The lens is moved towards the biprism till two images are again seen the distance between these two images give  $d_2$ .
- iv. At least two sets of observation for  $d_1$  and  $d_2$  are taken.



**Figure 2. Determination of Distance between two sources**



### 6.3 Measurement of D

This distance between source and eyepiece is directly measured on the optical bench scale.

### 7. Result

The wavelength of the sodium light is determined by Fresnel biprism experiment ( $\lambda$ ) = ---- m

### 8. Precautions

- i. The setting of uprights at the same level is essential.
- ii. The slit should be vertical and narrow.
- iii. Crosswire should be fixed in the center of the fringe while taking observations for fringe width.
- iv. The micrometer screw should be rotated only in one direction to avoid backlash error.
- v. The fringe width should be measured at a fairly large distance.
- vi. Convex lens of shorter focal length should be used ( $f = 25$  cms. approx.)
- vii. Motion of eyepiece should be perpendicular to the lengths of the bench.

### Suggested Reading(s)

- i. Ajoy Ghatak, Optics, Mc Graw Hill, 7<sup>th</sup> Edition, 2020.
- ii. <https://bop-iitk.vlabs.ac.in/exp/fresnel-biprism/index.html>
- iii. <https://www.maths.tcd.ie/~robinson/labs/fresnel.pdf>

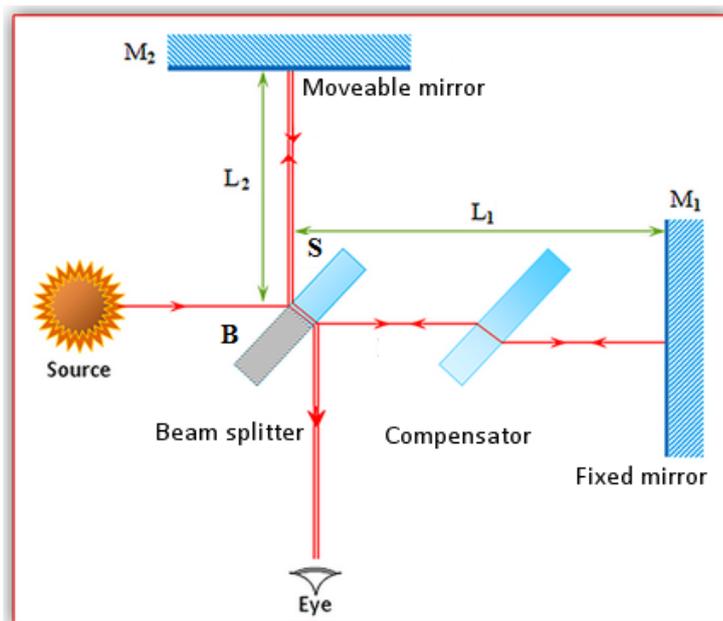
# MEASUREMENT OF WAVELENGTH OF MONOCHROMATIC LIGHT USING MICHELSON INTERFEROMETER

## 1. Aim

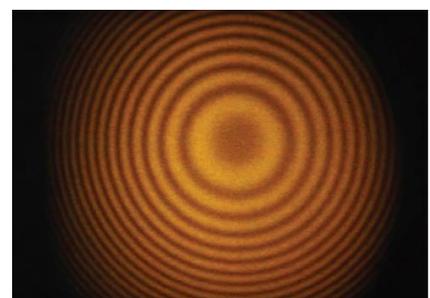
To determine the wavelength of monochromatic light using a Michelson Interferometer.

## 2. Introduction

The Michelson interferometer is a device that produces interference between two beams of light. A diagram of the apparatus is shown in Fig. 1. The basic operation of the interferometer is as follows. Light from a light source is split into two parts. One part of the light travels a different path length than the other. After traversing these different path lengths, the two parts of the light are brought together to interfere with each other. The interference pattern can be seen on a screen. Light from the source strikes the beam splitter. The beam splitter allows 50% of the radiation to be transmitted to the translatable mirror  $M_1$ . The other 50% of the radiation is reflected to the fixed mirror  $M_2$ . The compensator plate is introduced along this path to make each path have the same optical path length when  $M_1$  and  $M_2$  are the same distance from the beam splitter. After returning from  $M_1$ , 50% of the light is reflected toward the frosted glass screen. Likewise, 50% of the light returning from  $M_2$  is transmitted to the glass screen. At the screen, the two beams are superposed and one can observe the interference between them as shown in Fig. 2.



**Fig 1. Schematic diagram of the Michelson Interferometer**



**Fig 2. Interference pattern**

### 3. Apparatus Required

A Michelson Interferometer, Sodium Vapour Lamp, He –Ne laser.

### 4. Formula

The wavelength of monochromatic light using circular fringes

$$\lambda = \frac{2(\Delta d)}{N} \quad (\text{m})$$

Where,

$\Delta d$	The distance moved by moveable mirror $M_1$	(m)
N	The number of rings appear/disappear at the centre	(m)

### 5. Procedure

#### 5.1 Observation of circular fringes using sodium light as the light source

- i. Set the Michelson Interferometer on the table with coarse adjustable knob pointing towards you.
- ii. Set the lab jack in front of microscopic objective holder and set the height using lifting knob.
- iii. Place the sodium light source on lab jack, pointing the source towards the centre of fixed mirror.
- iv. Turn the sodium light on and adjust the sodium beam height using lab jack lifting knob until the beam is approximately parallel with the top of the interferometer and strikes the mirror at the centre.

- v. Set the viewing screen opposite of the adjustable mirror  $M_2$ . Note that the viewing screen should be placed at 1-2 meter from the adjustable mirror to get better resolution.
- vi. To get circular fringes,  $M_1$  should be exactly perpendicular to  $M_2$ . In this position, Michelson interferometer is said to be in normal adjustment. The setting needs that the plane of beam splitter BS exactly bisects the angle ( $45^\circ$ ) between the two mirrors.
- vii. Using coarse adjustment knob makes the distance of  $M_1$  and  $M_2$  from BS nearly equal.
- viii. When sodium light beam will be passing through beam splitter (BS) at  $45^\circ$  and observed in the direction  $M_2$ , four spots of the sodium light beam are seen on the viewing screen; two of which are faint and two are intense as shown in figure 2. The faint spots are due to reflection from un-silvered surface of BS and then from  $M_1$  and  $M_2$  respectively. The intense spots are due to reflection from silvered surface of BS and  $M_1$ ,  $M_2$ . (Note: Two spots of sodium light beam also been seen on the viewing screen other than four spots, which are ignorable because these two spots are formed by compensating plate).
- ix. The tilting screws at the back of  $M_1$  and  $M_2$  are adjusted to obtain only two images as shown in fig 2. This happens only when the mirrors  $M_1$  and  $M_2$  are exactly perpendicular to each other.
- x. Now place the beam expander and adjust its height to get circular fringes. A fringe pattern should appear on the screen and only fine adjustments of the movable mirror should be necessary. We can also view the pattern with naked eye or attaching a telescope near coarse adjustment knob.

## **5.2 Determination of the Wavelength of Sodium Light**

- i. Obtain the circular fringes are obtained as already explained.
- ii. Move the mirror  $M_2$  using fine adjustment knob. The fringes appear or disappear in the field of view. (Always move the knob in one direction for precise measurement).
- iii. Note down the reading of coarse adjustment knob. Let it be 'm'. Multiply this reading with least count 0.01mm. Note the reading of fine adjustment knob. Let it be 'n'. Multiply this reading with least count 0.0001mm. Now add the above two readings of coarse and fine adjustment knobs. Let it be  $d_1$ .
- iv. Rotate the fine adjustment knob to count the number of fringes appearing or disappearing. Let it be N.
- v. Note the observations as already explained in step 3. Let it be  $d_2$ .
- vi. Subtract  $d_1$  from  $d_2$  to get the value of 'd' for 'm' fringes.
- vii. Use the formula to calculate the value of d.

### 5.3 Observations

Initial position of gauge ( $d_1$ ) = \_\_\_\_\_ mm

S. No	N	m	n	$d_2$ mm	$\Delta d = (d_2 - d_1)$ mm

### 6. Result

The wavelength of sodium light using Michelson Interferometer is ( $\lambda$ ) = \_\_\_\_\_ meter

### 7. Precautions

- i. When turning the fine adjustment knob to count fringes, always turn it one complete revolution before we start counting. This will almost entirely eliminate errors due to backlash in fine adjustment knob.
- ii. Always turn the fine adjustment knob in one direction either clockwise or anti-clockwise.
- iii. Direct eye exposure to laser should be avoided.
- iv. Observing laser interference fringes by reflecting mirror is prohibited.
- v. Avoid touching any of the optics with bare hand.

### Suggested Reading(s)

- i. Ajoy Ghatak, Optics, Mc Graw Hill Education (India) Private Limited, 6<sup>th</sup> Edition, 2016.
- ii. [http://web.physics.ucsb.edu/~phys128/experiments/interferometry/the\\_michelson\\_interferometer.pdf](http://web.physics.ucsb.edu/~phys128/experiments/interferometry/the_michelson_interferometer.pdf)
- iii. <https://opentextbc.ca/universityphysicsv3openstax/chapter/the-michelson-interferometer/>

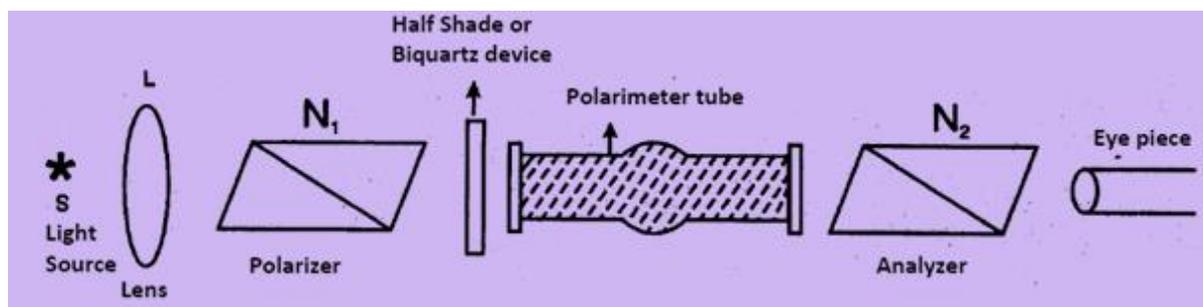
## DETERMINATION OF THE SPECIFIC ROTATORY POWER OF SOLUTION USING POLARIMETER

### 1. Aim

To determine the specific rotatory power of cane-sugar solution using the Laurent's Half shade polarimeter.

### 2. Introduction

A polarimeter consists of two Nicols termed as polariser and analyser. These can be rotated about a common axis and the substance, for which the rotation is to be determined, is placed in a tube in between these two. The half shade plate is placed between the polariser and the solution tube as shown in figure 1. This polarizer consists of a circular plate, one half of which is made of quartz plate cut parallel to the optic axis. It is of such a thickness that it produces a retardation of half-a-wavelength of sodium light between the ordinary and extraordinary rays. The other half of the plate is made-up of the glass and of such a thickness that the transmitted light is of the same intensity as that coming out from the quartz. Therefore, there will be two plane polarized light beams. One will be passing out of the glass portion and other pass out of the quartz. If these two beams of the polarized light of the same intensity are inclined on the principle section of the analyser then the two halves of the field-of-view (as observed through the eyepiece) will appear equally bright.



**Figure 1. Schematic diagram of the Polarimeter Set-up**

However, in between the polarizer and analyzer, we fill the sugar solution tube which causes the rotation of the plane of the polarization of incident lights. We estimate this property of the optically active compound by measuring the specific rotation ( $\alpha$ ) which is a property of a chiral chemical compound. It is defined as the change in orientation of monochromatic plane-polarized light, per unit distance concentration product, as the light passes through a sample of a compound in the solution. Compounds which rotate light clockwise are said to be dextrorotary, and correspond with positive specific rotation. On contrary, the compounds

which rotate light counter clockwise are said to be levorotary, and correspond with negative values of specific rotation.

A slight rotation in the plane of polarization in the clockwise or anticlockwise direction causes one component greater than the other. Therefore, either the quartz portion appears brighter than the glass or vice-versa. Thus, the analyzer can be set accurately so that the two halves of the field become equally bright.

### 3. Apparatus Required

Laurent's Half-Shade Polarimeter, Cane-Sugar solution, Sodium vapour lamp, Beakers etc.

### 4. Formula

The specific rotation of sugar solution is determined by the formula

$$S = \frac{\theta}{L \times C} \text{ degree / (decimeter) x (gm/cm}^3\text{)} \dots\dots\dots(1)$$

Where

<b><math>\theta</math></b>	<b>Rotation produced by the given solution (degree)</b>
<b>L</b>	<b>Length of the tube in the decimetre (1 decimeter = 10 cm)</b>
<b>C</b>	<b>Concentration of the solution <math>\left( \frac{10 \text{ gm}}{100 \text{ cc}} = 0.1 \text{ gm/cc} \right)</math></b>

If length of the solution (tube) is in centimetre then the formula will be

$$S = \frac{10 \times \theta}{L \times C} \dots\dots\dots(2)$$

$$\text{Also, } C = \frac{\text{Mass of the substance (M)}}{\text{Volume (V)}}$$

$$\text{So, Specific rotation (S) = } \frac{10 \times \theta \times V}{L \times M}$$

### 5. Procedure

- i) A 10 % or 0.1 N solution of cane sugar is prepared. This is done by dissolving 10 gms of cane-sugar in 100 ml of pure distilled water.
- ii) The solution is filtered and filled in the cylindrical glass tube. It is then closed water-tight by optically plane glass plates, washers and screws. Special care is taken to avoid air bubbles inside.

- iii) The sodium light is made to illuminate the collimator slit of the polarimeter. Without the cylindrical tube containing the solution, the light is observed. The analyzing Nicol is rotated such that the two halves of the Laurent's Half-shade are equally bright. The reading on the scale and vernier is noted as  $\theta_1$ .
- iv) The cylindrical tube containing the cane-sugar solution is now introduced. The analyzing Nicol prism is rotated until the two halves become equally bright. The reading on the scale and vernier is noted as  $\theta_2$ .

$$\text{Then } \theta = (\theta_2 - \theta_1)$$

- v) The procedure is repeated for different concentrations and the readings are tabulated.

### 5.1 Determination of specific rotation

Value of one division of the main scale = .....

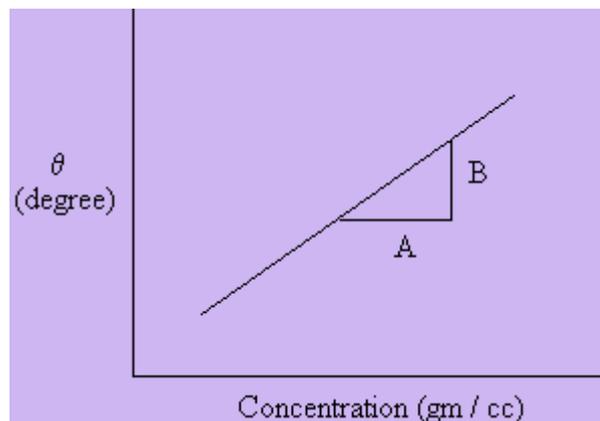
No. of division on vernier scale = .....

Least count of vernier = .....

$$\text{TR} = \text{MSR} + (\text{VSR} \times \text{LC})$$

Concentration C gms / cc	Scale Reading						Difference ( $\theta$ ) (degree)	
	With water ( $\theta_1$ ) A			With solution ( $\theta_2$ ) A'			A~A'	Mean
	MSR	VSR	TR	MSR	VSR	TR		
0.1								
0.05								
0.025								

### 5.2 Graph



## 6. Result

The Specific rotatory power of cane-sugar solution is determined by using polarimeter

$$S = \dots\dots\dots \text{deg/kg/m}^2$$

## 7. Precautions

- i. There should be no air-bubble in the tube while filling it with solution or distilled water.
- ii. While taking one set of the observations, the polarizer should not be disturbed.
- iii. The cap of the tube should not be tightened beyond a limit as it may strain the glass. Strained glass may produce elliptically polarized light which might interfere with the setting.
- iv. Two positions at  $\pm 90^\circ$  may appear where the equal illumination remains for a long range. These readings should not be taken.
- v. Switch off the lamp after completing the experiment.

### Suggested Reading(s)

- i. Ajoy Ghatak, Optics, Mc Graw Hill Education (India) Private Limited, 6<sup>th</sup> Edition, 2016.
- ii. <https://www.scribd.com/doc/70070450/Specific-Rotation-by-Polarimeter>
- iii. <https://vlab.amrita.edu/?sub=3&brch=208&sim=563&cnt=955>

## DETERMINATION OF RYDBERG'S CONSTANT USING A GRATING

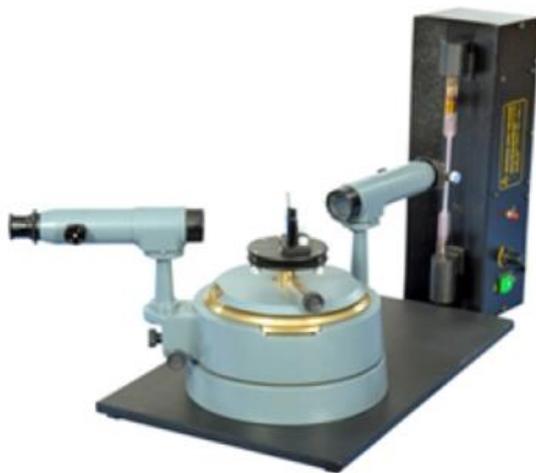
### 1. Aim

To determine the wavelengths of the visible spectral lines in Balmer Series of the Hydrogen atom and hence to find the value of Rydberg's constant.

### 2. Introduction

In this experiment, we will observe the visible wavelengths of light produced by an electric discharge in helium gas, using a diffraction grating. From knowledge of the wavelength values, we will be able to accurately calibrate the diffraction grating line spacing. Once calibrated, the grating is used to measure the wavelength of light produced by atomic hydrogen. By performing a curve fit to these measured wavelengths, we can determine the Rydberg constant, an important physical constant.

The helium and hydrogen gasses are contained in low-pressure discharge tubes that have metal electrodes at each end. When a high voltage is applied across the two electrodes, an electric current flows through the gas. High-energy electrons in the electric current collide with gas atoms and, in the process, can impart internal energy to the atoms. These excited atoms can then release energy in the form of electromagnetic radiation at specific wavelengths as shown in figure 1. Some of this electromagnetic radiation is in the visible range.



**Figure 1. Balmer Series and Rydberg's constant Experimental Set-up**

The spectral lines of Hydrogen atom are grouped as Lyman series, Balmer Series, Paschen Bracket and P fund series. Of these the Balmer series alone lies in the visible region.

In general, the wave lengths of Hydrogen spectral lines are given by the Rydberg's formula,

$$\frac{1}{\lambda} = R \left( \frac{1}{n_1^2} - \frac{1}{n_2^2} \right) m$$

Where, R= Ryberg's Constant ( $R = 1.09 \dots \times 10^7 \text{m}^{-1}$ )

Balmer series arises when transitions from higher orbits  $n_2 = 3, 4, 5, 6, \dots$  to the second orbit  $n_1 = 2$  occur, leading to the observation of the  $H_\alpha$ ,  $H_\beta$ ,  $H_\gamma$ ,  $H_\delta$  lines etc., The wavelengths of these lines are given as

<b><math>H_\alpha</math> line (red line - <math>n_2 = 3</math>)</b>	$\frac{1}{\lambda_\alpha} = R \left( \frac{1}{2^2} - \frac{1}{3^2} \right) = \frac{5}{36} R$
<b><math>H_\beta</math> line (blue green line - <math>n_2 = 4</math>)</b>	$\frac{1}{\lambda_\beta} = R \left( \frac{1}{2^2} - \frac{1}{4^2} \right) = \frac{3}{16} R$
<b><math>H_\gamma</math> line (blue line - <math>n_2 = 5</math>)</b>	$\frac{1}{\lambda_\gamma} = R \left( \frac{1}{2^2} - \frac{1}{5^2} \right) = \frac{21}{100} R$
<b><math>H_\delta</math> line (violet line - <math>n_2 = 6</math>)</b>	$\frac{1}{\lambda_\delta} = R \left( \frac{1}{2^2} - \frac{1}{6^2} \right) = \frac{2}{9} R$

### 3. Apparatus Required

Hydrogen discharge tube, High voltage power supply, Spectrometer, Mercury Vapour lamp, Diffraction grating etc.,

### 4. Procedure

The preliminary adjustments of the spectrometer are made.

- Telescope focus adjustment: The telescope of the spectrometer is directed to a distant object and its focal length is adjusted so as to get a distinct image.
- Collimator focus adjustment: The collimator slit is illuminated by a light source and the telescope is directed to view the illuminated slit. The focal length of the collimator is adjusted so as to get a clear image of the slit.
- Collimator slit width adjustment: The thickness of the collimator slit is made to be as thin as possible (hair line thickness).
- Spectrometer, grating table adjustment: The spectrometer, collimator, telescope and the grating table are made to be perfectly horizontal. For this purpose a spirit level may be used.



### 4.3 To find the Wavelengths of the Hydrogen Spectral lines

Hydrogen Lines	Spectrometer Reading				Difference $2\theta$		Mean $(\theta)$	$\lambda = \frac{\sin \theta}{mN}$	R
	Right		Left		$V_A$	$V_B$			
	$V_A$	$V_B$	$V_A$	$V_B$					
<b>H<sub>α</sub> line</b> (Red line)								$R = \frac{36}{5\lambda_\alpha}$	
<b>H<sub>β</sub> line</b> (Blue green )								$R = \frac{16}{3\lambda_\beta}$	
<b>H<sub>γ</sub> line</b> (Blue line)								$R = \frac{100}{21\lambda_\gamma}$	
<b>H<sub>δ</sub> line</b> (Violet line)								$R = \frac{9}{2\lambda_\delta}$	

Mean (R) =

### 5. Result

- The Wavelengths of the Balmer Series of Hydrogen atom are determined and tabulated.
- The Rydberg's Constant is found using a grating (R) = ..... m<sup>-1</sup>

### 6. Precautions

- Handle the spectral tube with utmost care.
- Never touch the surface of the grating by hand. Always hold it from the sides.
- Do not change the positions of the spectrometer and the spectral tube throughout the experiment.
- The hydrogen discharge lamp is powered by high voltage and the tube gets hot. DO NOT touches the tube anywhere especially near the ends where the electrical contacts are made.

### Suggested Reading(s)

- C.C. Ouseph, U.J. Rao & V. Vijayendran, Practical physics and electronics, S. Viswanathan, Pvt, Ltd, First Edition, 2007.
- M.N. Srinivasan, S. Balasubramaniyan, R. Ranganathan, A text book of Practical Physics, S.Chand & Sons, Reprint 2010.
- <https://hal.archives-ouvertes.fr/hal-00322372/document>