

# Determination of Refractive Index by Brewster Angle Method

## Aim

To determine the refractive index of a transparent material (microscope glass slide) by measuring the Brewster angle.

## Apparatus

Breadboard, Laser diode, Polarizer with rotator / analyser, Transparent glass plate (microscope slide), Rotation stage, Photodetector, Detector output unit.

## Theory

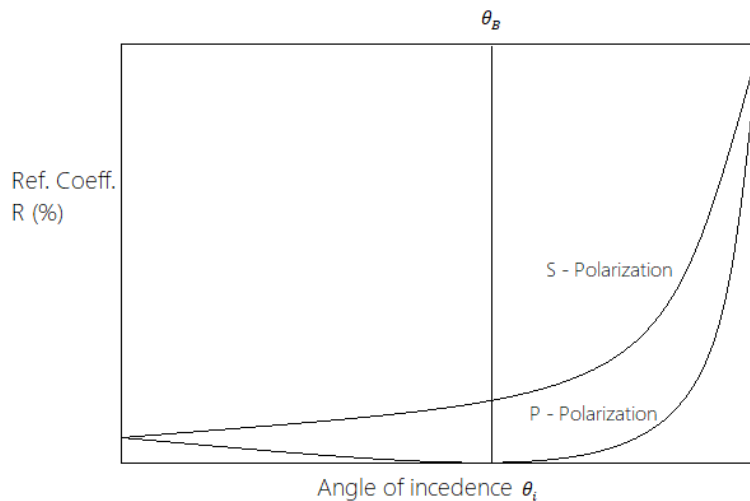
When a light beam is incident on a dielectric surface, its electric field can be resolved into:

p-polarized component (parallel to plane of incidence)

s-polarized component (perpendicular to plane of incidence)

These components have different reflection coefficients.

At a particular angle of incidence, called the Brewster angle  $\theta_B$ , the reflection coefficient of the p-polarized component becomes zero. At this angle, the reflected and transmitted beams are mutually perpendicular.



From Snell's law, the Brewster angle relation is

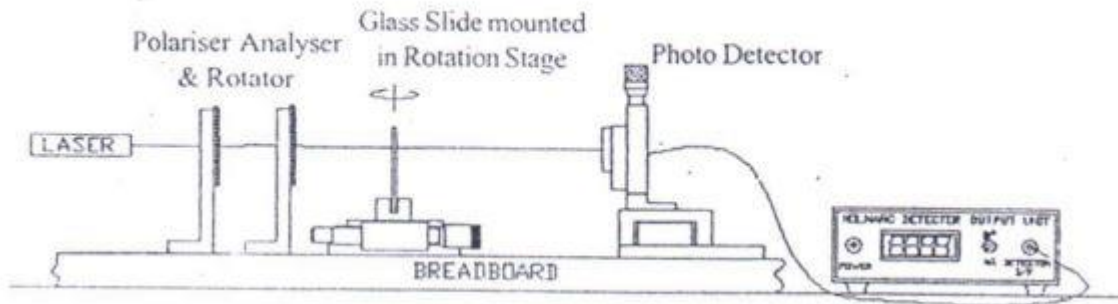
$$\tan \theta_B = n$$

Where -

$n$  is the refractive index of the transparent material.

Thus, by measuring  $\theta_B$ , the refractive index is obtained.

## Procedure



Mount the diode laser on the laser mount and switch it on.

Place the polarizer rotator (analyser) in front of the laser so that the electric field is parallel to the breadboard (p-polarization).

Mount the microscope glass slide on the rotation stage.

Adjust the slide so that the reflected beam initially returns toward the laser aperture.

Rotate the glass slide slowly and observe the intensity of the reflected beam on the detector.

Note the angle corresponding to the minimum reflected intensity, this is the Brewster angle  $\theta_B$ .

Calculate the refractive index using relation

$$n = \tan \theta_B$$

## Precautions

Ensure proper alignment of laser and detector.

Avoid vibration or movement during readings.

Take slow angular steps near Brewster angle.

Keep the glass slide clean.

# Michelson Interferometer

## Aim

1. To determine the wavelength of a laser beam.
2. To measure the refractive index of a transparent material (glass slide).
3. To determine the refractive index of air.

## Theory

### 1. Michelson Interferometer

The Michelson interferometer splits a laser beam into two beams using a partially silvered beam splitter. The beams reflect from two mirrors (M1 and M2) and recombine to form an interference pattern on a screen. The wavelength of the laser can be determined from the mirror displacement and the number of fringes observed:

$$\lambda = \left( \frac{2d}{N} \right) \times \delta$$

where:

$d$  = displacement of mirror for  $N$  fringes

$N$  = number of fringes counted

$\delta$  = calibration constant of the micrometre

### 2. Refractive Index of a Transparent Material

$$n = \frac{(2t - N\lambda)(1 - \cos\theta)}{2t(1 - \cos\theta) - N\lambda}$$

where:

$t$  = thickness of glass slide

$N$  = number of fringes shifted

$\theta$  = rotation angle of the glass slide

$\lambda$  = wavelength of the laser

### 3. Refractive Index of Air

$$n = \left( \frac{2d(n-1)}{\lambda} \right) \left( \frac{\delta P}{P} \right)$$

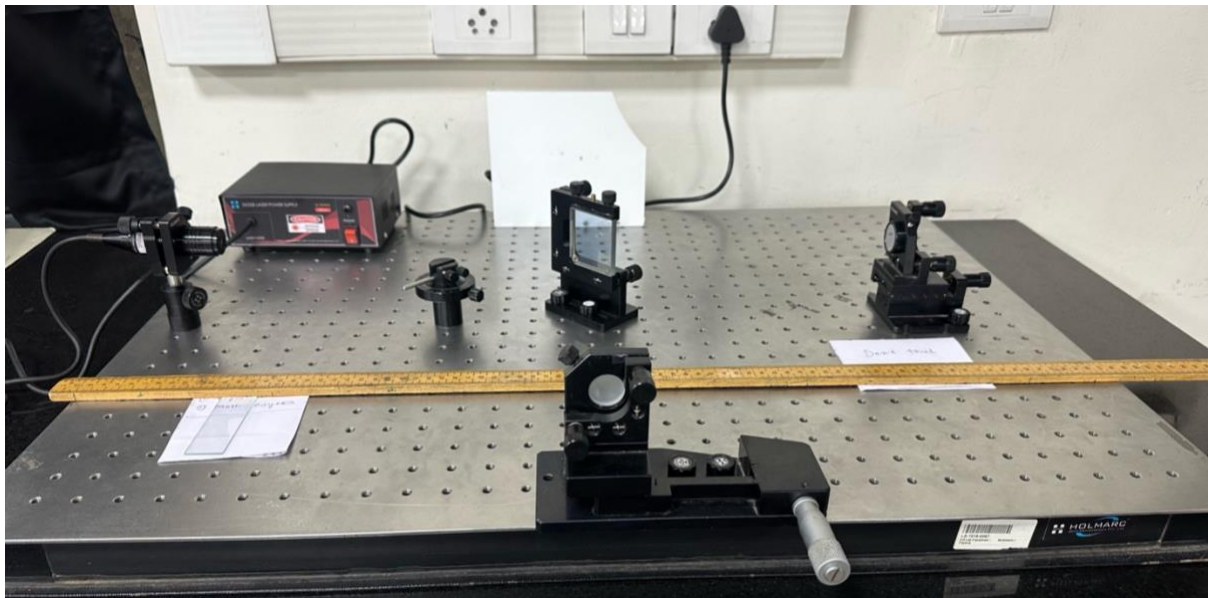
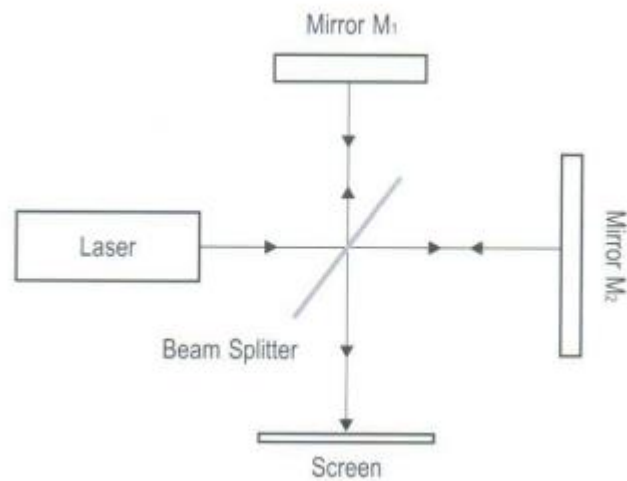
where:

$d$  = length of the air cell

$P$  = atmospheric pressure

$\delta P$  = change in pressure

## Experimental Setup



1. Place the laser mount on the optical breadboard and insert the laser.
2. Place the beam splitter at 45° in front of the laser.
3. Place mirror M<sub>1</sub> with translation in one arm and mirror M<sub>2</sub> with precision translation in the perpendicular arm. Adjust distances so mirrors are equidistant from the beam splitter.
4. Place the screen to capture the interference pattern.
5. Align the laser and mirrors carefully until the reflected beams coincide on the screen.
6. Insert the divergence lens to expand the laser beam and observe clear fringes.
7. Use the micrometre for precise mirror movements.

## Procedure

1. Count sufficient number of fringes (preferably  $\geq 20$ ) for better accuracy and calculate the calibration constant.
2. Using the calibrated micrometre arrangement, find the wavelength of the red laser by noting the mirror displacement and the corresponding number of fringes observed.
3. Using the wavelength obtained from the red laser measurement, determine the refractive index of (a) Glass — by inserting the glass plate in one arm and observing the fringe shift on rotation of the plate. (b) Air — by using the pressure cell and counting the number of fringes for a measured change in pressure.

## Safety Instructions/Precautions

- Avoid looking directly into the laser beam.
- Conduct the experiment in low-light, dust-free conditions.
- Handle optical components by their edges, avoid touching their surfaces.
- Keep all equipment moisture-free and dust-free.
- Do not exceed the pressure limit of the pressure cell (300 mm Hg).

# MILLIKAN'S OIL DROP EXPERIMENT

## Aim

To determine the elementary charge of the electron (e) and to verify the quantization of electric charge using Millikan's oil drop experiment.

## Theory

Millikan's oil drop experiment is one of the most important experiments in modern physics. It provides direct evidence that electric charge is quantized and occurs in discrete units. Tiny oil droplets are introduced between two horizontal parallel plates. Due to friction during spraying, the droplets acquire electric charge. During free fall the oil droplet experiences gravitational, buoyant, and viscous drag forces, and when an electric field is applied it experiences these same forces along with an additional electric force.

By measuring the terminal velocities of the droplet during free fall and during motion in an electric field, the charge carried by the droplet can be calculated.

The forces acting on an oil drop are as follows -

Gravitational force

$$F_g = \frac{4}{3}\pi r^3 \rho_a g$$

Buoyant force

$$F_b = \frac{4}{3}\pi r^3 \rho_o g$$

Viscous force (Stokes' law)

$$F_v = 6\pi\eta r v$$

Electric force

$$F_e = qE = q \frac{V}{d}$$

where

$r$  = radius of oil drop

$\rho$  = density of oil

$\rho_a$  = density of air

$\eta$  = coefficient of viscosity of air

$v$  = terminal velocity

$V$  = Applied voltage

$d$  = separation between plates

Free fall of the drop (Voltage OFF):

At terminal velocity  $v_f$  the net force is zero

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

Hence,

$$v_f = \frac{2r^2 g(\rho - \rho_0)}{9\eta} \quad (2)$$

Cunningham's correction:

Stokes' law assumes a continuous medium and no slip at the surface of the droplet. In this experiment, the oil droplet radius ( $\sim 10^{-6}$ ) is comparable to the mean free path of air molecules, resulting in slip at the surface.

Therefore, Stoke's law must be corrected using Cunningham's correction factor.

The corrected viscous force is given by:

$$F_v = \frac{6\pi\eta r v}{C}$$

where

$$C = 1 + \frac{b}{P r}$$

$$b = 6.17 \times 10^{-8} \text{ m of Hg} - \text{m}$$

$$P = \text{Atm pressure}$$

$$r = \text{radius of the droplet}$$

Corrected terminal velocity

Including Cunningham's correction, Eq. (1) becomes:

$$v_f = \frac{2r^2 g(\rho - \rho_a)}{9\eta} \left(1 + \frac{C}{P r}\right) \quad (3)$$

Rearranging:

$$r^2 + \frac{b}{P} r - \left(\frac{9\eta v_f}{2g(\rho - \rho_0)}\right) = 0 \quad (4)$$

This quadratic equation is solved for  $r$ .

Motion under electric field (Dynamic Method)

When the droplet rises with terminal velocity  $v_r$

$$q \frac{V}{d} = \frac{4}{3}\pi r^3(\rho - \rho_0)g + 6\pi\eta r v_r \quad (5)$$

Subtracting the free-fall equation (1) from eq. (5) and solve for  $q = ne$ .

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

Dividing eq (6) by equation (2)

$$q = ne = \frac{4\pi g d}{3V} (\rho - \rho_a) \left(1 + \frac{v_r}{v_f}\right)$$

Where,  $v_f = \frac{L}{t_f}$   $v_r = \frac{L}{t_r}$

Calculate  $r$  from equation (3) and estimate the value of  $q = ne$ .

### Balancing Method (Static Method)

When the droplet remains stationary:

Charge on the droplet can be calculated using the balancing voltage  $V_b$ .

$$q \frac{V_b}{d} = \frac{4}{3} \pi r^3 (\rho - \rho_a) g$$

$$q = \frac{4}{3} \pi r^3 (\rho - \rho_a) g \cdot \frac{d}{V_b} \quad (5)$$

Fixed parameters to be used during the experiment

Plate separation,  $d = 5 \times 10^{-3} \text{ m}$

Distance between reference lines,  $L = 1 \times 10^{-3} \text{ m}$

Density of oil,  $\rho = 928 \text{ kg m}^{-3}$

Density of air,  $\rho_a = 1.2 \text{ Kg m}^{-3}$

## **Apparatus**

The Millikan Oil Drop apparatus is designed to observe and control the motion of extremely small oil droplets under gravity and an electric field. The complete setup consists of the following components:

### 1. Oil Drop Chamber

The oil drop chamber is mounted on the top of the main control panel. It consists of:

#### (a) Parallel Plate Electrodes

Two horizontal, circular metal plates arranged parallel to each other. The plates are separated by a 5 mm thick ebonite ring. The ebonite ring has a central viewing hole that allows observation of oil droplets between the plates.

#### (b) Upper Plate Aperture



The upper electrode has a very small hole at its centre. Oil droplets produced by an atomizer enter the space between the plates through this hole

#### (c) Illumination System

A built-in LED illumination device uniformly lights the region between the plates. This makes the tiny oil droplets visible through the microscope

#### 2. Levelling Arrangement

Two levelling screws are provided at the base of the panel. These screws are used to ensure that the electrode plates are perfectly horizontal, i.e., perpendicular to the direction of gravity. A spirit level (water level) mounted on the top of the panel helps to check proper levelling. Correct levelling is essential to prevent sideways drift of oil droplets during observation.

#### 3. Microscope with CCD Camera

A microscope with approximately  $30\times$  magnification is used to observe the oil droplets. The microscope is fitted with a CCD camera head, which transmits the image of the droplets to a monitor. The droplets appear as bright, unresolved points of light on the screen

#### 4. High-Voltage Power Supply

A regulated DC power supply provides a continuously variable voltage in the range 0–800 V. The voltage is applied to the upper plate, while the lower plate is permanently grounded. Applying voltage produces a uniform electric field between the plates

#### 5. Digital Voltmeter

A built-in  $3\frac{1}{2}$ -digit LED voltmeter displays the voltage applied across the plate. This allows accurate measurement of the electric field strength

#### 6. Time Meter

A digital time meter measures the time taken by an oil droplet to move between two preset positions. The meter has two keys: Clear (Reset) Key: Sets the display to 0.00 s. Start/Stop Key: Starts and stops the timing operation

#### 7. Monitor with Graduated Screen

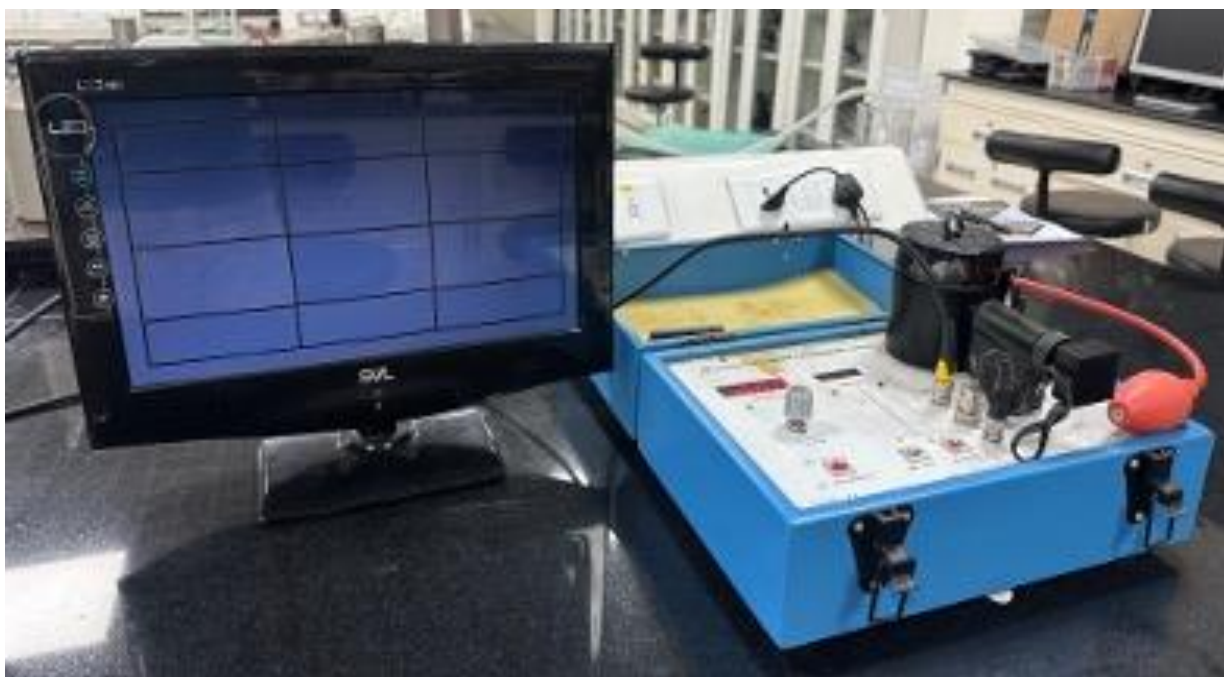
The monitor displays the magnified image of the droplets. Horizontal reference lines on the screen are used to define a known distance for timing the droplet's motion

#### 8. Atomizer

A small atomizer sprays fine oil droplets into the chamber. The droplets become electrically charged due to friction during spraying

#### 9. Thermometer

A thermometer is used to measure the room temperature, which is required to determine the viscosity of air



*Figure 1 Experimental Setup*

#### **⚠ WARNING**

High voltage is present inside the apparatus.  
Non-technical persons must not open the instrument.

## **Procedure**

### **A. Preliminary Steps**

Measure and note the room temperature and atmospheric pressure.. Switch ON the main power supply. Adjust the levelling screws until the spirit level indicates that the plates are horizontal.

### **B. Setting Reference Lines**

Select two horizontal reference lines on the monitor screen. A good choice is the second line from the top and the second line from the bottom. This gives sufficient space to control the droplet without losing it. Press the Clear key to reset the time meter to 0.00 s.

### **C. Producing and Observing Oil Droplets**

Spray oil droplets gently using the atomizer (1–2 short sprays are sufficient). Some droplets pass through the hole in the upper plate into the region between the electrodes. Observe the droplets on the monitor as small bright spots. With no electric field applied, droplets drift downward slowly under gravity.

### **D. Identifying Charged Droplets**

Apply a voltage between the plates: If a droplet falls more slowly or rises, it is negatively charged. If a droplet falls faster, it is positively charged (ignore such droplets). Select a suitable negatively charged droplet, which takes about 10–15 seconds to fall freely and does not show excessive random motion (Brownian motion), and can be made to rise with a voltage of about 500 V.

### **E. Isolating a Single Droplet**

Remove unwanted droplets by switching the electric field ON and OFF. Focus on a single droplet for measurements.

## F. Measurement Methods

### **1. Dynamic Method (Rise and Fall Method)**

Measure free-fall time with voltage OFF. Measure rise time with voltage ON. Repeat several times and calculate average values.

Steps:

Pull the droplet above the top reference line using voltage. Switch OFF voltage and start timer as droplet crosses the top line. Stop timer when droplet crosses the bottom line. Apply voltage again to stop the droplet. Repeat for upward motion and record voltage.

### **2. Balancing Method (Static Method)**

Measure free-fall time as before. Apply voltage and adjust it until the droplet remains stationary. Record the balancing voltage. Take several readings and calculate the average.

## G. Final Steps

Record the room temperature and atmospheric pressure again. Enter all observations in the data tables. Repeat the experiment for multiple droplets to improve accuracy.

### **Note to Students**

This is a precision experiment that requires patience and careful observation. More droplets and repeated measurements lead to better results.

### **Precautions**

Use minimal oil spray.

Select droplets with slow steady motion.

Ensure plates are perfectly horizontal.

High voltage, do not open instrument casing and handle it very carefully.

# Photoelectric Effect: Determination of Planck's Constant

## Aim

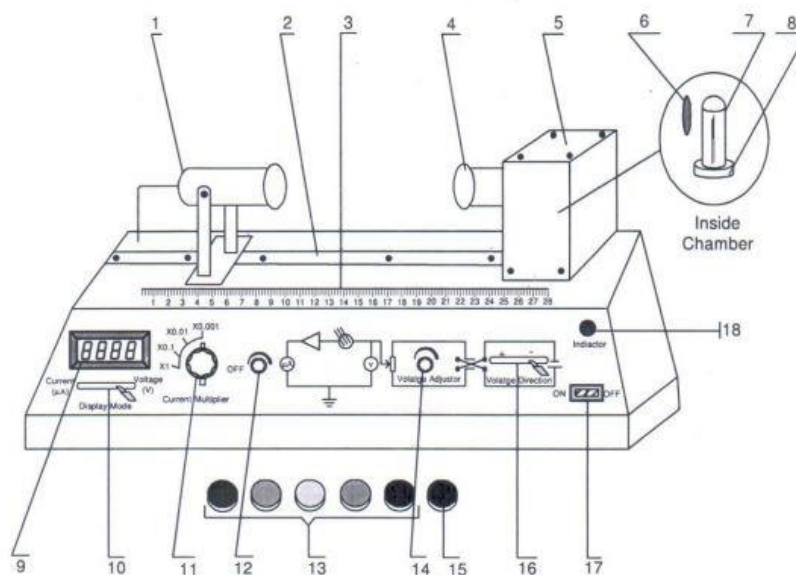
To determine Planck's constant ( $h$ ) using the photoelectric effect by measuring the stopping potential corresponding to monochromatic light of different wavelengths.

## Theory

When light of sufficiently high frequency falls on a metal surface, electrons are emitted, a phenomenon called the photoelectric effect. The maximum kinetic energy of emitted electrons depends only on the frequency of incident light and not on its intensity. According to Einstein, light consists of photons of energy  $E = h\nu$ . A part of this energy overcomes the work function ( $\phi$ ) and the remaining appears as electron kinetic energy. Using a retarding (stopping) potential  $V$ ,  $eV = h\nu - \phi$ . A plot of  $V$  versus  $\nu$  is a straight line whose slope gives  $h = e(\Delta V / \Delta \nu)$ .

## Panel Diagram of Experimental Setup

The instrument consists of a vacuum photocell, monochromatic filter set, light source, nanoammeter and variable accelerating/retarding voltage supply.



1-Light source, 2-Guide, 3-Scale, 4-Drawtube, 5-Cover, 6-Focus lens, 7-Vacuum Phototube, 8-Base for holding the Phototube, 9-Digital Meter, 10-Display mode switch, 11-Current range selector, 12-Light intensity switch, 13-Filter set, 14-Accelerate voltage adjuster, 15-Lens cover, 16-Voltage direction switch, 17-Power switch, 18-Power indicator.

Panel Diagram of Planck's Constant Experiment, PC-101

Light from the source is focused on the cathode of the phototube through a selected colour filter. The emitted electrons are collected at the anode. A variable retarding potential is applied. The stopping potential is the value of  $V$  at which the photocurrent becomes zero, corresponding to the maximum kinetic energy of emitted electrons.

## Procedure

1. Switch on the instrument and allow warm-up.
2. Set display to current mode.
3. Insert the Red filter (635 nm) and focus the light on the cathode.
4. Select current range  $\times 0.001 \mu\text{A}$ .
5. Increase retarding voltage slowly until the current becomes zero; note  $V$ .
6. Repeat for Yellow-I, Yellow-II, Green and Blue filters.

## Precautions

- Perform the experiment in dim light and avoid strong illumination.
- Use the lens cover when the apparatus is idle.
- Keep filters and lens clean and dust-free.
- Take readings slowly near zero-current condition.
- Allow sufficient stabilization time before recording readings.

# Determination of Rydberg Constant

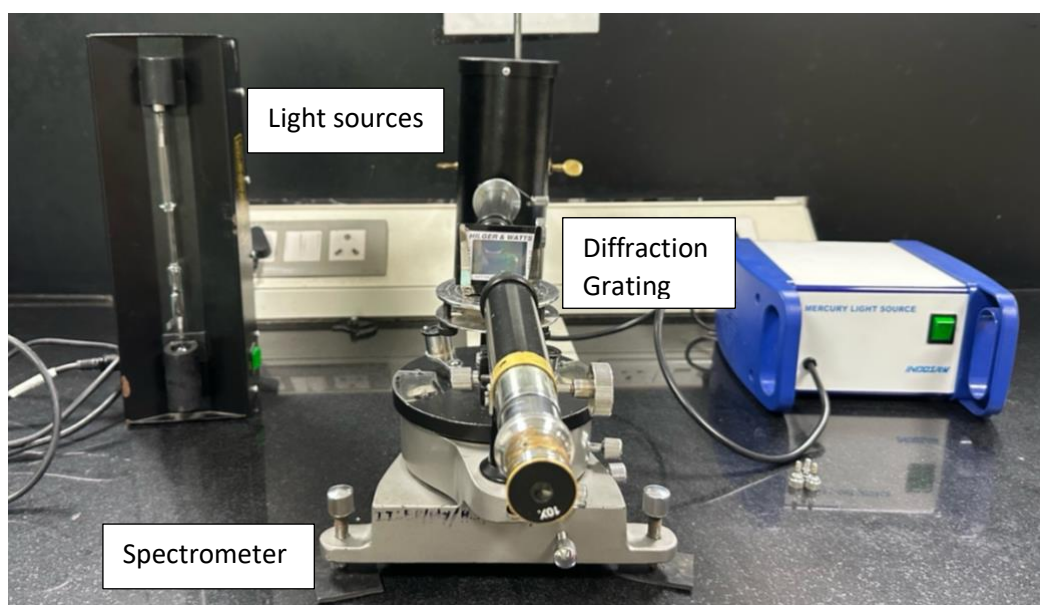
## Motivation and Aim

When atoms are excited they emit light at discrete wavelengths. In hydrogen these lines form distinct spectral series corresponding to electronic transitions between quantized states. The visible part of the spectrum is called the Balmer series, arising from transitions to the level  $n = 2$ .

In this experiment, the wavelengths of the Balmer lines are determined using a diffraction spectrometer. These data are then used to determine the Rydberg constant.

## Apparatus

Student spectrometer with diffraction grating, Hydrogen discharge lamp and power supply, Magnifier and blackout cloth (for reducing stray light).



## Procedure

Align the spectrometer so that the slit is narrow and sharply focused, and the telescope is focused at infinity. Place the hydrogen discharge source near the collimator slit and obtain a bright, well-defined central image of the slit.

Insert the diffraction grating such that its plane is approximately perpendicular to the optical axis. Identify the undiffracted central image and set this as the reference angle.

Rotate the telescope to either side of the central image and locate the first-order spectral lines corresponding to: red ( $H\alpha, \lambda = 656.28nm$ ), blue-green ( $H\beta, \lambda = 486.13nm$ ), violet ( $H\gamma, \lambda = 434.05nm$ ) and if visible, the weak violet ( $H\delta, \lambda = 410.17nm$ ) line.

For each line, bring the slit image to the vertical cross-hair and note the angular reading. Record the angles on both the left and right sides of the central image. Repeat the measurement (and where visible, also for the second diffraction order).

Ensure that the tube is allowed to stabilize in brightness before readings are taken, and avoid widening the slit, as this degrades line sharpness.

## Theory

The emission lines in hydrogen arise from transitions between bound electronic states. For a transition from an initial level  $n_i$  to a final level  $n_f$ , the wavelength is given by the Rydberg relation

$$\frac{1}{\lambda} = R \left( \frac{1}{n_f^2} - \frac{1}{n_i^2} \right), n_i > n_f.$$

For the Balmer series,

$$n_f = 2 \text{ and } n_i = 3, 4, 5, 6, 7, \dots$$

so the measured lines correspond to specific integer values of  $n_i$ .

In the diffraction spectrometer, the wavelength is related to the measured diffraction angle by

$$d \sin \theta = m \lambda$$

where  $d$  is the grating spacing and  $m$  is the order of diffraction.

Combining the two relations allows the experimentally determined wavelengths to be used to obtain a value of the Rydberg constant  $R$ .

The angular positions of each Balmer line are first recorded on the left and right sides of the central image, and the diffraction angle is obtained as half of the difference between these readings. Using this angle, the wavelength of each line is calculated from the grating relation  $\lambda = d \sin \theta / m$ , where  $d$  is the grating spacing and  $m$  is the diffraction order. For every measured line, the quantities  $1/\lambda$  and  $\left(\frac{1}{4} - \frac{1}{n_i^2}\right)$  are evaluated, with  $n_i$  denoting the initial quantum number of the transition. A plot of  $1/\lambda$  against  $\left(\frac{1}{4} - \frac{1}{n_i^2}\right)$  is then obtained. As the dependence is expected to be linear for the Balmer series, the slope of the best-fit straight line yields the experimental value of the Rydberg constant.

## Precautions

The hydrogen discharge lamp operates at high voltage and becomes hot so please do not touch the glass tube.

Handle the grating only by the edges of the glass plate.

# Specific heat of solids

## Motivation and Aim

The change in temperature ( $\Delta T$ ) of a material when supplied with a certain (fixed) amount of heat ( $\Delta Q$ ) depends on the type of material and is inversely proportional to the mass  $m$  of the material. The material dependence is given the quantity called the specific heat  $c$  of the substance. The interdependence of these quantities is summarised by the equation

$$\Delta Q = cm\Delta T$$

To measure the specific of a substance we supply a fixed amount of heat and measure the rise in its temperature.

## Apparatus

1. Dewar
2. Thermometers
3. Weighing Balance
4. Shots of various materials
5. Steam Generator

## Procedure

Measure the mass of the shots of each material. Place as many shots of a given material into the steam chamber and leave them there long enough for them to come to equilibrium with steam temperature (20 min). Then drop the shots (which are now at  $100^\circ\text{C}$ ) into the transfer mesh and insert them in the Dewar that has about 180 g water at room temperature. Keep the Dewar closed. Thoroughly mix the water and observe the maximum rise in temperature of the water. Repeat with shots of different materials and measure the temperature change in each case.

## Theory

The amount of heat required to raise the temperature of a unit mass of a substance by 1 degree is called the specific heat of the substance. The SI unit of specific heat is  $[\text{J/kg/K}]$ . The specific heat of water is among the highest of all substances. Historically the specific heat of water is arbitrarily set as  $1 \text{ cal/g/}^\circ\text{C}$ . The equivalent SI value is  $4184 \text{ J/kg/K}$ . A related quantity is the molar specific heat, which is the specific heat for 1 mol of a substance. Metals have very low specific heats, in comparison. At room temperature the molar heat capacity of all crystalline solids is more or less the same. This is because the vibrational energy levels in a solid are more or less similar and the main contribution to the specific heats are from vibrations of the atoms in a solid. Exceptions to this are for instance diamond, which has extremely low specific heat.

## Analysis

Heat lost by the shots is

$$\Delta Q_s = c_s m_s (\theta_s - \theta_m)$$

where  $\theta_s$  is the initial temperature of the shots,  $\theta_m$  is the final temperature of the mixture of water and shots.

Heat gained by the water is

$$\Delta Q_w = c_w m_w (\theta_w - \theta_m),$$

assuming that no heat is absorbed by the flask. However, this is not correct, and we make a correction by replacing  $m_w$  by  $m_w + m_f$ , where  $m_f$  is the equivalent mass of water that would have absorbed the same amount of heat as the flask. Since  $Q_1 = Q_2$ , and  $c_w = 1$ , we have

$$c_s = \frac{(m_w + m_f)(\theta_w - \theta_m)}{m_s(\theta_s - \theta_m)}$$

## Points to Ponder

1. How would you determine the water equivalent of the Dewar, if it were not given to you?



# Stefan's law of radiation

## Motivation and Aim

A body at an absolute temperature  $T$  is found to radiate heat at a rate that is proportional to the fourth power of  $T$ . In this experiment a heated tungsten filament is taken to be a blackbody source of radiation. Since the filament is in vacuum, the only source of heat dissipation is by radiation. By measuring the electrical power consumed by the filament as a function of temperature, we determine whether the fourth power law holds.

## Apparatus

1. A tungsten filament in an evacuated glass bulb
2. Constant voltage source
2. Millimameter
4. Voltmeter

## Procedure

A tungsten filament is heated using a constant voltage source. Setting a voltage, the current in the filament is allowed to stabilise and measured in a steady state. The voltage is increased in steps and from the measured steady current, the resistance of the filament is determined at each setting.

Finally, we carefully measure the current at which the filament just starts glowing, and determine  $R_G$ , the resistance at the temperature at which the filament just starts glowing.

## Theory

Based on the equation for the spectral distribution of blackbody radiation, we can determine the total power radiated by the blackbody:

$$P_{\text{rad}} \propto T^4$$

This law is called Stefan's law. All bodies at finite temperature constantly radiate and simultaneously absorb heat from their surroundings. If the temperature of the body is  $T$  and the ambient temperature is  $T_a$ , the rate of heat exchange is given by the expression

$$\dot{Q} = \epsilon \sigma (T^4 - T_a^4)$$

where  $\sigma$  is a universal constant called the Stefan's constant and  $\epsilon$  is a factor less than 1, which accounts for non-ideal behaviour of the body. For a blackbody,  $\epsilon = 1$ .

## Analysis

The resistance  $R$  of heated tungsten filament changes as a function of temperature  $T$ , so the electrical power dissipated by the filament at a constant voltage also changes. The power dissipated is  $P = VI$  where  $V$  and  $I$  are the voltage across and the current through the filament. The resistance of the filament is  $R = V/I$ . Since the resistance depends on the temperature of a substance, the temperature can be determined from the measured resistance at each stage.

The temperature dependence of resistance is given by the equation

$$R(T) = R_0(1 + \alpha T + \beta T^2)$$

For tungsten  $\alpha = 5.21 \times 10^{-3} \text{ [K]}^{-1}$  and  $\beta = 7.2 \times 10^{-7} \text{ [K]}^{-2}$ .

1. Using the measured value of  $R_G$  and the known glowing temperature  $T_G = 800 \text{ K}$ , we calculate  $R_0$  using the above equation.
2. Plot the electrical power dissipated  $P (= VI)$  at each setting vs. the temperature  $T$  calculated from the measured value of the resistance ( $V/I$ ) at each setting.
3. Using the graph verify the fourth power law and determine the constant of proportionality in the equation for the radiated power for the tungsten filament.

# Thermal conductivity by Lee's Method

## Motivation and Aim

In this experiment the thermal conductivity of a bad conductor is measured.

## Apparatus

1. Lee's Apparatus
2. Bad conductor samples (glass and ebonite discs).
3. Two thermometers
4. Boiler and Heater
5. Stop watch
6. Weighing balance
7. Vernier Calliper

## Procedure

Fill the boiler with water to nearly half and heat it to produce steam. In the mean time, weigh the disc  $D_1$  on which the apparatus rests. Further, measure the diameter of specimen disc  $d$  with a vernier calliper and its thickness using a screw gauge at several spaces and determine the mean thickness.

Clamp the glass specimen between the base disk  $D_2$  of the steam jacket and the auxiliary brass disk  $D_1$ . Insert the thermometers (either mercury thermometer or thermocouples) in the two brass disks  $D_1, D_2$ . Check if they show the same readings at room temperature. If not, note the difference  $T'$ .

Connect the boiler outlet with the inlet of the steam chamber by a rubber tube. Continue passing steam until the two brass disks reach a steady temperature. Note down the temperatures  $T_1$  and  $T_2$  of the two discs.

The second part of the experiment involves the determination of the cooling rate of disc  $D_1$  alone. Remove the sample disc. Heat the disc  $D_1$  directly by the steam chamber till its temperature is about  $T_1 + 10^\circ \text{C}$ . Remove the steam chamber and place the insulating disk on it. Record the temperature of the brass disc at half minute intervals. Continue till the temperature falls to about  $T_1 - 7^\circ \text{C}$ .

## Theory

Fourier's Law of heat conductance gives the rate of transfer of heat between two objects at temperatures  $T_2$  and  $T_1$  connected by a conductor with conductivity  $k$  and cross-sectional areas  $A$  (assumed uniform) and length  $l$  as

$$\frac{\Delta Q}{\Delta t} = k \frac{A}{l} (T_2 - T_1)$$

This equation governs the rate of heat transfer from disc  $D_2$  to  $D_1$  in the first half of the experiment.

The instantaneous rate at which a warm body loses heat to surroundings is given by Newton's law of cooling (which is a special case of Stefan's law, when the temperature differences are small, and there are losses other than radiative losses).

$$\frac{dT}{dt} = -b(T - T_a),$$

where  $T_a$  is the ambient temperature.

This law governs the rate at which the disc  $D_1$  cools in the second half of the experiment. If  $m$  is the mass of the disk and  $s$  is the specific heat of the material of  $D_1$  (brass in this case), then the rate at which heat is lost by the disc  $D_1$

$$\frac{\Delta Q_1}{\Delta t} = ms(dT_1/dt)$$

## Analysis

In the steady state achieved in the first half of the experiment, the heat supplied by the steam is lost by cooling of disc  $D_1$ . Hence the heat balance in the experiment is given by combining equations two heat transfer equations.

$$ms \frac{dT}{dt} = k \frac{A}{l} (T_2 - T_1)$$

$dT/dt$  for  $D_1$  can be determined from the cooling curve obtained in the second part of the experiment. As an approximation a single value of  $dT/dt$  can be used for this calculation. It is calculated at the value  $T_1$  during the cooling of the disc  $D_1$  from  $T_1 + 10^\circ \text{C}$  to  $T_1 - 10^\circ \text{C}$ . From the known value of  $s = 0.380 \text{ J/g/K}$  for brass,  $k$  can be determined.

Note that if the two thermometers do not initially show the same reading, the difference  $T_2 - T_1$  will have to be corrected by the quantity  $T'$  determined at the beginning of the experiment.

### Points to Ponder

1. Why is it necessary to have a thin disk in the experiment?
2. Would this method work for measuring the conductivity of a good conductor?
3. In the cooling part of the experiment, why is the brass disc  $D_1$  covered by the glass disc? Is it crucial to do so?
4. Why do we take the cooling data asymmetrically around  $T_1$  in the second half of the experiment?

# Thermal Expansion

## Motivation and Aim

All materials expand when heated and contract when cooled. Heating changes the length, area, as well as the volume of the substance. The rate of change of length of a substance with temperature is called the coefficient of thermal expansion  $\alpha$  of that material. In this experiment  $\alpha$  is measured for three metals.

## Apparatus

- |                          |                                     |
|--------------------------|-------------------------------------|
| 1. Pullinger's Apparatus | 3. Brass, Aluminium and Copper rods |
| 2. Thermometer           | 4. Steam bath                       |

## Procedure

Place the brass rod in the apparatus along with the thermometer. Ensure that the thermometer is in contact with the rod. Note the position of the top end of the rod by moving the spherometer and getting it to just touch the end face of the rod. Contact will be indicated by the buzzer or LED connected to the spherometer. After noting the spherometer reading move the spindle away from the rod face.

Heat the rod by passing steam through the jacket of the apparatus. Wait until the temperature of the rod becomes steady, and reaches close to the steam temperature.

Turn the spherometer spindle downwards until it just touches the rod and note the temperature of the rod. Repeat this as the rod cools down and note the spherometer reading each time, until the rod returns to room temperature.

## Theory

It is empirically observed that the change in length due to temperature depends on both, the initial length and the change in temperature of a substance. For solids close to room temperature, the dependence can be taken to be linear, thereby obtaining the equation:

$$\Delta L = L_0 \alpha (T - T_0)$$

However this linear dependence is not universal. There are exceptions to this, a prime example being the behaviour of water near 4 °C.

## Analysis

1. Plot a graph of spherometer reading vs. Temperature.
2. From the slope of this graph determine the coefficient of thermal expansion.

## Points to Ponder

1. It is possible to note the rod length as the rod is heating up and while it is cooling down. Which readings will be more reliable? Why?
2. What are the major sources of systematic errors in this experiment?
3. To what extent does the error in initial length measurement affect the outcome of the experiment?

# Thermistor Characteristics

## Motivation and Aim

Resistivity of materials is a function of temperature. For certain semiconductors, the change in resistivity with temperature can be very rapid. Such materials can be used to make resistors with high temperature sensitivity, and are called thermistors. They can be used as temperature sensors.

## Apparatus

1. A thermistor
2. A mercury thermometer
3. A water bath
4. Electric heater
5. Ice

## Procedure

The thermistor is connected to a voltage source and placed in a water bath. The temperature of the water bath is changed and at each steady temperature its resistance is determined using a precision multimeter. Measurements are repeated for several temperatures, both as the water heats up and then again as it cools down. Further, the temperature is reduced by introducing ice to the bath and taking readings as the water cools and then as it return to room temperature.

## Theory

The temperature dependence of the resistance of a semiconductor can be modelled as

$$\frac{1}{T} = A + B \ln(R) + C [\ln(R)]^3$$

## Analysis

After plotting a graph of  $1/T$  vs.  $\ln(R(T))$  where  $R_T$  is the room temperature, the coefficients can be determined by a cubic fit to the data.

## Points to Ponder

1. On the basis of observations can you find a range in which a thermistor is a linear device device?
2. Is a thermistor more useful for measuring accurately small changes, or large changes, in temperature?