Department of Physics
Indian Institute of Technology Madras

B.Tech. Laboratory Manual
PH 1030 (November- February 2022)

List of experiments:

1. **Young's modulus of wood using a strain gauge**
2. **Radiation from a hot filament – Stefan's Law**
3. **Variable 'g' pendulum**
4. **Transmission grating**
5. **Cathode Ray Oscilloscope**
6. **Mapping equipotential lines**
7. **Sonometer**
8. **Wavelength of light by interference - Newton's rings**
9. **Transistor Characteristics**
10. **Magnetic field along the axis of the coil.**

PH1030: Instructions to students(January-May2018)

Laboratory classes commence on 01-11-2022(Tuesday)

1. **Details about the course:**

- Number of experiments :-10
- List of experiments :- given in the laboratory manual
- Batch wise allotment of experiments :- it will be announced in the lab

2. **Preparation for the experiments:**

- Students should procure the laboratory manual from the moodle (https://courses.iitm.ac.in) and 10 sets of stapled laboratory record sheets during the first week when you come to the lab) The 10 sets of record sheets will be used for 10 different experiments and students should use only these sheets. Students should come prepared with the aim, apparatus required for the experiment, circuit/ray/schematic diagram, formula, tabular columns, etc. written down (before coming to the laboratory sessions) on the record sheets-set. **One credit will be evaluated based on the assignments that should be carried out "outside the lab hours". This included the above mentioned write up and answers to the questions given at the end of each experiment in the manual book.**
- **Marks will be reduced for those who come to laboratory without preparation**

3. **How to carry out the experiments**:

- Experiments should be completed on the same day and marks can be obtained from the teacher at the end of the laboratory session.
- The record sheets set used by the student for the experiment should not be carried out of the laboratory. Failure to return the set will be considered as the experiment being incomplete and no marks will be given.
- Student should inform the concerned teacher and also the laboratory staff (**return the issued experimental accessories to the staff**) before leaving the laboratory.

4. **Repeat classes:**

- No repetition of an experiment is allowed except in the event of the student being absent due to medical emergency and unforeseen circumstances. Repeat classes (for various batches) will be held at the end of the experiments-cycle. Please note that we have only limited days for the repeat classes for entire sessions.

5. **Evaluation Procedure:**

- Each experiment will be evaluated for 30 marks for in-lab activities and 10 marks for "outside the lab hours activities" and the grand total (10x40) will be normalized to 75 marks. The end semester practical examination will be conducted at the end of the cycle and it carries 25 marks.

“IT IS MANDATORY FOR ALL STUDENTS TO WEAR SHOES FOR THE LABORATORY CLASSES”

Graphs

A graph is simply a diagram illustrating the relationship between two quantities, one of which varies as the other is changed. The quantity that is changed is called “independent variable”, the other is called the “dependent variable”. The following general points should be noted:

1. Scale must not be too small – loss of accuracy, scale should not be too large – exaggeration of accidental errors. Scales on each axis are chosen usually the same unless one variable changes much more rapidly than the other, in which case it is plotted on a smaller scale.

2. The independent variable is plotted on the horizontal axis and dependent variable plotted on the vertical axis.

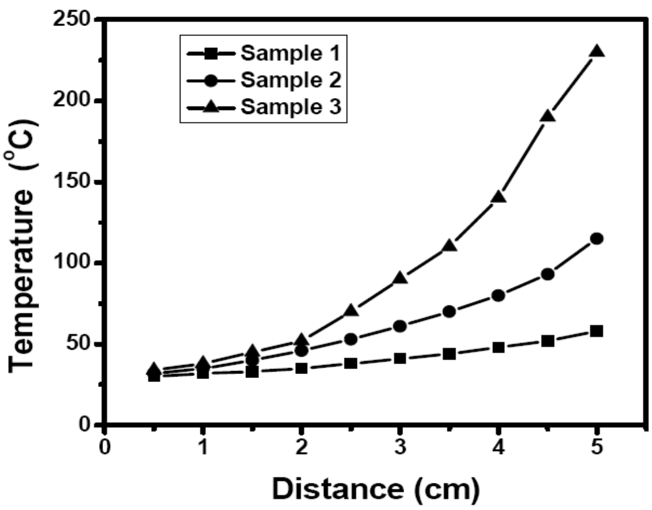
3. The origin need not represent the zero values of variables – unless definite reference to the origin is required.

4. Graph should be titled. It should have captions containing:- *a*) standard name of variable, *b*) its symbol, if such a thing exists, and *c*) standard abbreviation for the unit of measure.

5. Numerals representing scale values should be placed outside the axis. Values less than unity should be written as 0.47, not .47. Use of too many ciphers should be avoided. Thus if scale numbers are 10,000; 20,000; 30,000 etc. They should be written as 1.0, 2.0, 3.0 with the symbol and unit, *say*, pressure should be represented as ***P*** (10^4 N/m^2). Similarly scale numbers such as 0.0001; 0.0002; 0.0003 etc. should be written as 1.0, 2.0, 3.0 with the symbol and units, *say*, pressure should be represented as ***P*** (10^{-4} N/m^2).

6. Axes should be easily marked as shown in the graph below.

Example:



AN INTRODUCTION TO ERROR ANALYSIS

Suppose the length of an object is measured with a meter scale and the result is given as 11.3 cm. Does it mean that the length is exactly 11.3 cm? The chances are that the length is slightly more or slightly less than the recorded value as the *least count* of the scale is one mm (it cannot read as a fraction of a *mm*) the observer rounds off the result to the nearer full *mm* value. Thus, any length measuring greater than 11.25 cm and less than 11.35 cm may be erroneously represented as the length anywhere between 11.25 and 11.35 cm. The maximum uncertainty (on either side) or the maximum possible error, $\boldsymbol{\delta l}$, is 0.05 cm which is half of the lesser count on the scale.

Let the object under consideration be a glass plate with certain dimensions. To obtain the volume of the plate, suppose we measure the width '*b*' with a slide calipers and the thickness'*t*' with a screw gauge, whose least counts are 0.1 mm and 0.01 mm respectively. Let the result obtained, after averaging over many measurements, be

$b = 2.75$ cm

$t = 2.52$ mm $= 0.252$ cm

and the length (l) = 11.3 cm as measured by a meter scale with one end at zero exactly!

You may note that the coincidences on the vernier scale and the main scale of the screw gauge might not have been exact and represent only the nearest exact readings. Hence these measurements also include the corresponding uncertainties each equal to half the least count. So we have,

$l = 11.30 \pm 0.05$cm

$B = 2.75 \pm 0.005$ cm

$t = 0.252 \pm 0.0005$ cm

Note that ± 0.05 cm, ± 0.005 cm, ± 0.0005 cm are actually instrumental errors. Personal errors like reading 11.3 as 11.2 or 11.4 are not taken into account. To avoid personal errors, average values of many readings have to be used. The volume calculated from the recorded values of l, b and t is,

$V = (11.3 \times 2.75 \times 0.252) = 7.8309$ cm^3

Care has to be taken to avoid writing *cm* as *mm*, *mm* as *cm* etc. This is also a personal error, which can be certainly avoided if care is taken by the experimenter.

However, since each observation is subject to an uncertainty, there should also be an uncertainty in evaluating the volume (V). How can the cumulative effect of the individual uncertainties on the final result be estimated?

Let the maximum error in V due to $\boldsymbol{\delta l}$, $\boldsymbol{\delta b}$, and $\boldsymbol{\delta t}$ be $\boldsymbol{\delta V}$. Then,

$$(V \pm \delta V) = (l \pm \delta l)(b \pm \delta b)(t \pm \delta t)$$

$V + \delta V$ corresponds to maximum positive values of δl, δb and δt,

$$(V + \delta V) = (l + \delta l)(b + \delta b)(t + \delta t)$$

[or]

$V(1 + \delta V/V) = lbt\,(1+\delta l/l)(1 + \delta b/b)(1 + \delta t/t)$

Cancelling $V = lbt$ on both sides and using the approximation,

$(1 + x)(1 + y)(1 + z) = 1 + x + y + z$ *as* $x<<1, y<<1, z<<1,$

We obtain

$\boldsymbol{\delta V/V = \delta l/l + \delta b/b + \delta t/t}$

The relative error in the product of a number of quantities is the sum of the relative errors of the individual quantities.

$\delta l/l = 0.05/11.3 = 0.0044$

$\delta b/b = 0.005/2.75 = 0.0018$

$\delta t/t = 0.0005/0.252 = 0.002$ and

$\delta V/V = 0.0082$

From the value, $V = 7.8309$, we have

$\delta V = 7.8309 \times 0.0082 = 0.064213$ cm^3

(rounded off to one significant digit).

The result of the measurements is therefore

$V = 7.8309 \pm 0.06$ cm^3

An important point to be noted is that writing the volume as 7.8309 cm^3 would convey the idea that the result is measured accurate to 0.0001 cm^3. We know from the calculated error that this is not the case and error is in the second decimal place itself. We are not certain that the second decimal is 3 but it may be 3 + 6. The volume may be anywhere in the range 7.77 to 7.89 cm^3. As the second decimal place is subject to such an uncertainty, it is meaning lessto specify the subsequent digits. This result should therefore be recorded only up to the second decimal place. [The error could be much larger if the least counts themselves are taken into account].

Thus $V = (7.83 \pm 0.06)$ cm^3

It is the calculation of the maximum error in the result, based on the least counts of the different instruments used that can indicate the number of significant digits to which the final result is accurate. Suppose we now measure the mass of a plate correct to a milligram and the result is

$m = (18.34 \pm 0.005)g$

The density 'd' can be calculated from m and V.

$d = m/ V = 18.34/ 7.83 = 2.3423\ gcm^{-3}$

$$d(1 + \delta d/d) = \frac{m}{v}\frac{(1+\delta m/m)}{1-\frac{\delta v}{v}}$$

$$1 + \delta d/d = (1 + \delta m/m)\,(1 - \delta v/v)^{-1}$$

As $\frac{\delta v}{v}$ and $\frac{\delta m}{m}$ are very much less than 1,

$\delta d/d = \frac{\delta m}{m} + \frac{\delta v}{v}$

The relative error in the quotient of two quantities is (also equal to the sum of the individual relative errors),

$$\frac{\delta m}{m} = \frac{0.005}{18.34} = 0.0003$$

$$\frac{\delta d}{d} = 0.0085$$

$\delta d = 0.0085 \times 2.3423 = 0.02$ gcm^{-3}

Therefore d= (2.3423 ± 0.02) or (2. 34 ± 0.02) gcm^{-3}

[The error in measurements may be many times the least count if the instrument is not properly designed. Least count may often signify readability/resolution and not the accuracy. Repeated measurements falling outside the least counts are indicative of this].

Other situations

1. Suppose x is the difference of two quantities a and b, whose measurements have maximum possible errors as δa and δb. What is δx?

   $x = a - b$
   $(x \pm \delta x) = (a \pm \delta a) - (b \pm \delta b)$

The maximum value of the difference x corresponds to maximum a and minimum b

$(x + \delta x) = (a + \delta a) – (b - \delta b)$

$= (a - b) + (\delta a + \delta b)$

Cancelling $x = a – b$,

$\underline{\delta x = \delta a + \delta b}$

In a sum or difference of two quantities, the uncertainty in the result is the sum of the actual uncertainties in the quantities – (Not the relative uncertainties).

2. If p $= \frac{xy^2}{ab}(1+m)$, *what is* $\frac{\delta p}{p}$?

   First $\delta(1 + m) = \delta l + \delta m$

   Y^2 can be dealt with as a product of y and y.

   $$\frac{\delta y^2}{y^2} = \frac{\delta y}{y} + \frac{\delta y}{y} = 2\frac{\delta y}{y}$$

   $$\frac{\delta p}{p} = \frac{\delta x}{x} + \frac{\delta (y)^2}{y^2} + \frac{\delta a}{a} + \frac{\delta b}{b} + \frac{\delta 1 + \delta m}{(1+m)}$$

   $$= \frac{\delta x}{x} + 2\frac{\delta y}{y} + \frac{\delta a}{a} + \frac{\delta b}{b} + \frac{\delta 1 + \delta m}{(1+m)}$$

Questions:

1. Suppose $x = (a + b)/(c\text{-}d)$. To minimize the uncertainty in x, which of the four quantities must be measured to greatest accuracy, if all four quantities a, b, c, and d are of the same order of magnitude?

2. The period of a simple pendulum is measured with a stop watch of accuracy 0.1 second. In one trial, 4 oscillations are found to take 6.4 s, in another 50 oscillations take 81 s. In this measurement, the relative uncertainty depends only on the least count of the instrument – in this case the stop watch? How can the relative uncertainty in the period be minimized?

3. The refractive index of a glass slab may be determined using a vernier microscope as follows. The microscope is focused on a marking on an object placed on a platform and the reading, a, on the vertical scale is noted. The glass slab is placed over the object. The object appears raised. The microscope is raised to get the image to focus and the position on the scale, b, is again noted. The last reading, c, is found raising the microscope to focus on a tiny marking on the top surface of the slab. The least count of the vernier scale is 0.01mm. The readings a, b, and$c$ are 6.128 cm, 6.497 cm, and

6.128 cm respectively. Calculate the refractive index and the percentage error in the result. Express the result to the accuracy possible in the experiment, along with the range of error.

Note:

In the above case cited, we have used our judgment, *i.e.* the ability to estimate the reading to ONE HALF the least count of the instrument. If we take that the actual error is ONE least count on either side of the measured quantity all the errors calculated in the above cases would be doubled.

References:

1. Practical physics – by G.L.Squires, Cambridge University Press, 4th edition, 2001.

2. A text book of Practical Physics by M.N. Srinivasan, S. Balasubramanian and R. Ranganathan, Sultan Chand and Sons, First edition, 1990.

1. Young's modulus of wood using a strain gauge

Aim: To determine the Young's modulus of a half-meter wooden scale

Apparatus: A half meter scale with two identical strain gauges attached to each end of the scale with one strain gauge at the top and the other at the bottom, thick wire, a clamp, a circuit board with appropriate terminals to constitute a Wheatstone network hanger and slotted weights, digital millivoltmeter, callipers, screw gauge, rheostats, a constant current source and connecting wires.

Young's modulus:

$y = \left(\frac{F/A}{\Delta L/L}\right)$When an external force, F, is applied along a long bar of length L, (and perpendicular to the cross-sectional area A), internal forces in the bar resist distortion and the bar attains an equilibrium when the external force is exactly balanced by the internal forces with a change in length, ΔL. The tensile stress is force per unit area (in N/m^2) and the longitudinal strain is the change in length to the original length and it is a dimensionless quantity. The ratio of the tensile stress (F/A) to the tensile strain (ΔL/L) is given by,

$$y = \frac{F/A}{\Delta L/L}$$

where *Y* is the Young's modulus of the bar.

Strain Gauge:
A strain gauge is a transducer whose electrical resistance varies in proportion to the amount of strain in the device. The most widely used gauge is a metallic strain gauge which consists of a very fine wire or, more commonly, metallic foil arranged in a grid pattern. The grid pattern maximizes the amount of metallic wire or foil subject to strain in the parallel direction (Figure 1). The cross sectional area of the grid is minimized to reduce the effect of shear strain and Poisson strain. The grid is bonded to a thin backing, called the carrier, which is attached directly to the test specimen. Therefore, the strain experienced by the test specimen is transferred directly to the strain gauge, which responds with a linear change in electrical resistance.

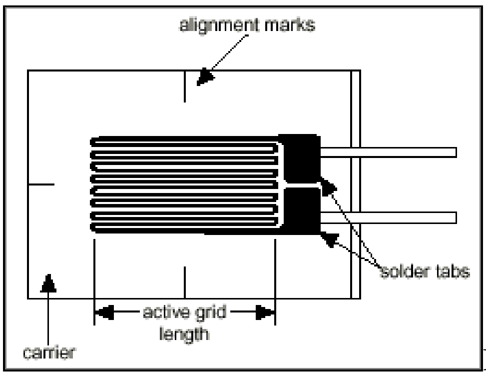


Figure 1: A strain gauge

A fundamental parameter of the strain gauge is its sensitivity to strain, expressed quantitatively as the gauge factor (λ). Gauge factor is defined as the ratio of fractional change in electrical resistance to the fractional change in length (strain):

The gauge factor for metallic strain gauge is typically around 2.

Wheatstone Bridge:

Measuring the strain with a strain gauge requires accurate measurement of very small changes in resistance and such small changes in R can be measured with a Wheatstone bridge. A general Wheatstone bridge consists of four resistive arms with an excitation voltage, V_{ex}, that is applied across the bridge (Figure 2.)

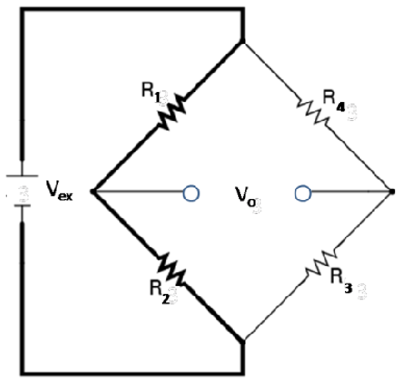


Fig. 2 Wheatstone bridge

The output voltage of the bridge, V_o, will be equal to:

$$V_o = \left[\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2}\right] V_{ex}$$

From this equation, it is apparent that when $R_1/R_2 = R_4/R_3$, the voltage output V_o will be zero. Under these conditions, the bridge is said to be balanced. Any change in resistance in any arm of the bridge will result in a nonzero output voltage. Therefore, if we replace R_4 in Figure 2 with an active strain gauge, any changes in the strain gauge resistance will unbalance the bridge and produce a nonzero output voltage. If the nominal resistance of the strain gauge is designated as R_G, then the strain-induced change in resistance, ΔR, can be expressed as $\Delta R = R_G \times \lambda \times$ Strain.

Assuming that $R_1 = R_2$ and $R_3 = R_G$, the bridge equation above can be rewritten to express V_o/V_{ex} as a function of strain.

Ideally, we would like the resistance of the strain gauge to change only in response to applied strain. However, strain gauge material, as well as the specimen material on which the gauge is mounted, will also respond to changes in temperature. Strain gauge manufacturers attempt to minimize sensitivity to temperature by processing the gauge material to compensate for the thermal expansion of the specimen material for which the gauge is intended. While compensated gauges reduce the thermal sensitivity, they do not totally remove it. By using two strain gauges in the bridge, the effect of temperature can be further minimized. For example, in a strain gauge configuration, one gauge is active (R_G+ΔR), and a second gauge is placed transverse to the applied strain. Therefore, the strain has little effect on the second gauge, called the dummy gauge. However, any changes in temperature will affect both gauges in the same way. Because the temperature changes are identical in the two gauges, the ratio of their resistance does not change, and hence the voltage V_o does not change, and thus the effects of the temperature change are minimized.

The sensitivity of the bridge to strain can be doubled by making both gauges active in a half-bridge configuration. Figure 3 illustrates a bending beam application with one bridge mounted in tension (R_G+ΔR) and the other mounted in compression (R_G-ΔR). This half-bridge configuration, whose circuit diagram is also illustrated in Fig.3, yields an output voltage that is linear and approximately doubles the output of the quarter-bridge circuit.

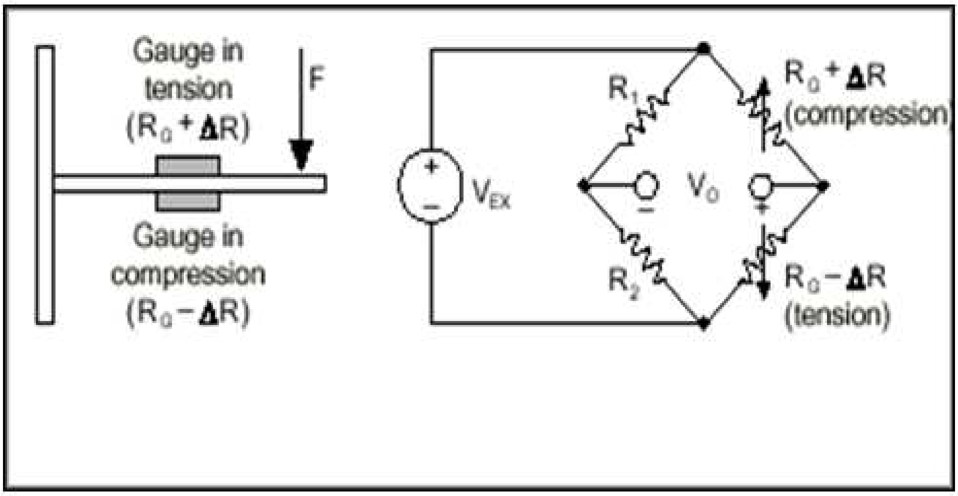


Figure 3.

And in this experiment we aim to determine the Young's modulus of a half-meter wooden bar by loading it with a mass of "*m*" in gram. For a beam of rectangular cross-section with breadth *b* and thickness *d*, the moment of inertia *I*, is the moment of force/restoring couple and is = *Y.I*/*R*, where *R* is the radius of curvature of the bending beam and *Y* is the Young's modulus. The Young's modulus (*Y)* can be calculated by assuming that at equilibrium, the bending moment is equal to the restoring moment.

Procedure:

1. Clamp the beam to the table in such a way that the strain gauges are close to the clamped end. Load and unload the free end of the beam a number of times.

2. Make the connections as given in the circuit diagram (Fig. 4.)

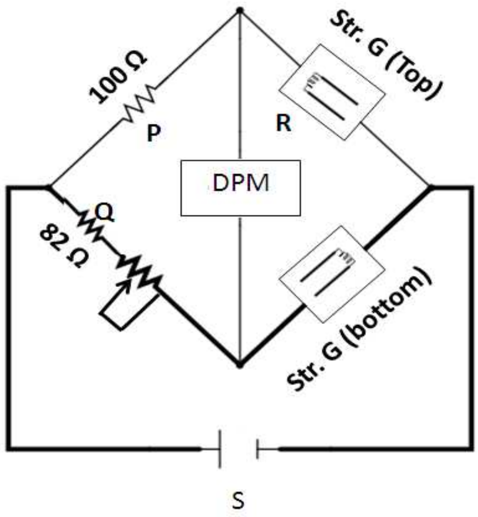


Figure 4

3. Switch on the constant current source and the DPM.
4. Balance the bridge using the variable resistance box. At this stage the DPM will read 0 or very nearly zero. Note that this is done at no load.
5. Load the beam with a hanger of mass m gm suspending it as close to the free end as possible. Note the DPM reading. Note that as you are about to take a reading, the last digit will be changing about the actual steady value. Take a few reading and get the average.
6. Increase the load in steps of *m* gm, up to 5*m* gm and take the readings each time.
7. Unload the beam from 5*m* down to zero in steps of *m* gm at a time and note the DPM reading each time.
8. To check reproducibility, repeat all the above processes taking readings while loading and unloading in steps of *m* gm.
9. Draw a graph between *m* along x-axis and unbalanced voltage *dV* along y-axis. Determine the slope of this graph (*dV/m*).
10. Note the distance between the centre of the strain gauges and the pint of application of the load (L).
11. Measure the breadth of the beam using slide calipers (b).
12. Measure the thickness of the beam using a screw gauge (d).
13. Young's Modulus of the material of the beam, which is nothing but the stress to strain ratio, is given by the following expression: $Y = \left(\frac{6gL\lambda RI}{bd^2\left[1+\left(\frac{R}{P}\right)\right](dV/m)}\right)$

Where g is acceleration due to gravity, λ the gauge factor (to be obtained from the teacher), I is the output current from source S and R is the resistance of strain gauge.

Tabulations:

Load/gm →	0	m	2m	3m	4m	5m
DPM reading						
1) Loading V_1/mV						
2) Unloading V_2/mV						
Mean of V_1+V_2						

2. Radiation from a hot filament – Stefan's Law

Aim: Verification of Stefan's law

Apparatus: Low voltage bulb, Variable power supply, Cobra3 basic unit, Connection box, Resistor (100 Ω), Digital multimeter, Thermopile, Measuring scale and connecting wires.

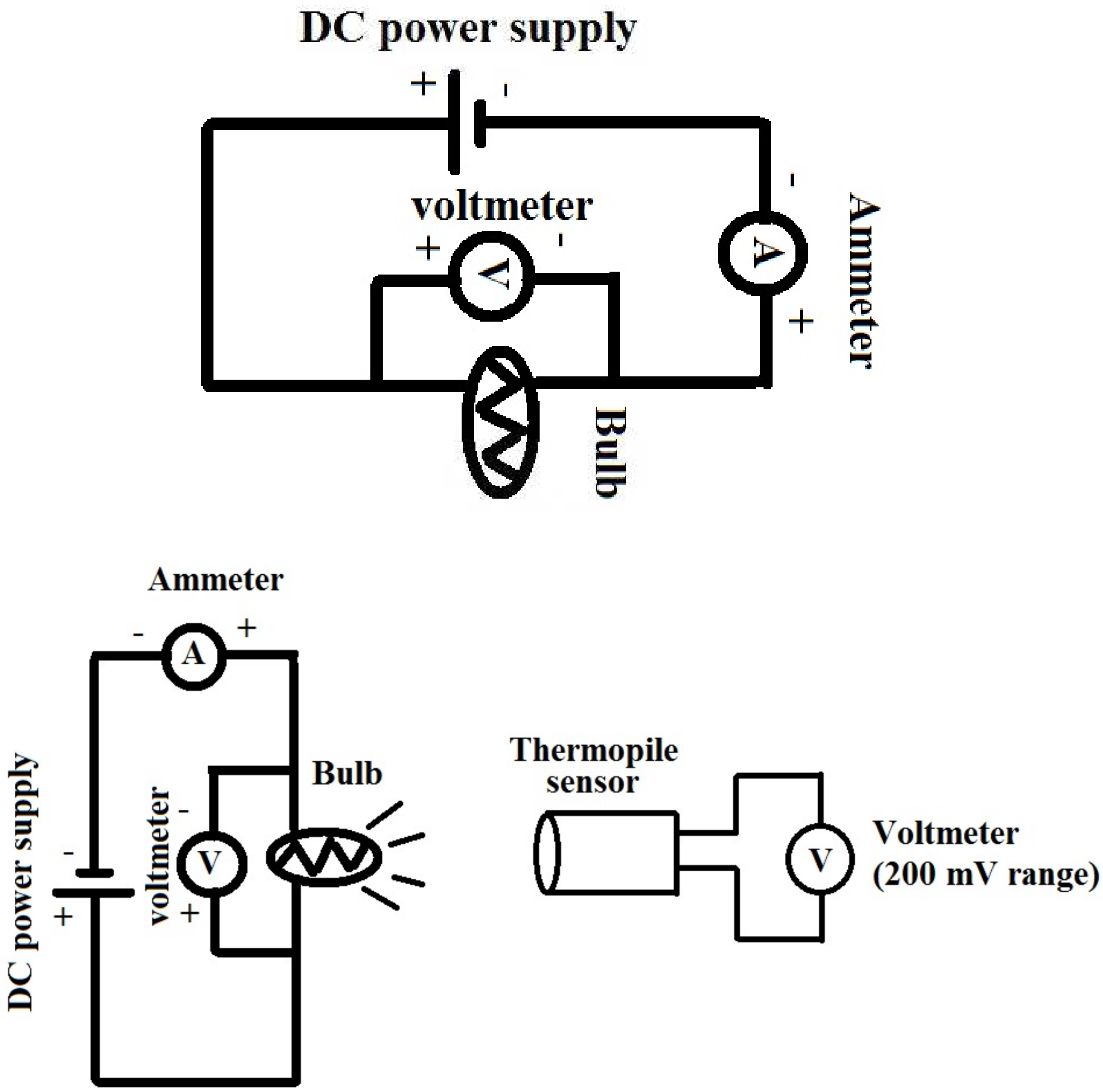


Fig. 1: Circuit diagrams for measuring the resistance of the filament (when the bulb is not glowing) and determining filament temperature (when the filament starts glowing).

Theory:

If the energy flux density L of a black body, *e.g.*, energy emitted per unit area and unit time at temperature T and wavelength λ within the interval dλ, is designated by $dL(T,\lambda)/d\lambda$, which can be integrated over all wavelength range to yield the flux density $L(T, \lambda)$:

$$L(T,\lambda) = \frac{2\pi^5}{15}\frac{k^5}{c^2h^3}T^4$$

where, c = velocity of light (3.00 x 10^8 m/s), h = Planck's constant (6.62 x 10^{-34} J·s) and$k$ = Boltzmann's constant (1.381 x 10^{-23} J·K^{-1}). This is called Stefan-Boltzmann law and can be written as

$$L(T,\lambda) = \sigma T^4$$

withσ= 5.67 x 10^{-8} W·m^{-2}·K^{-4}

The proportionality L~T^4 is also valid for a 'grey' body, the surface of which shows a wavelength-independent absorption-coefficient of less than one.

To prove the validity of Stefan-Boltzmann's law, we measure the radiation emitted by the filament of an incandescent lamp which represents a 'grey' body fairly well. For a fixed distance between filament and thermopile, the energy fluxΦ which hits the thermopile is proportional to $L(T)$.

$$\Phi \sim L(T)$$

Because of the proportionality between $\Phi$and the thermoelectric e.m.f.,V_{TC} of thethermopile, we can also write:

$$V_{TC} \sim T^4$$

if the thermopile is at a temperature of zero degrees Kelvin.Since the thermopile is at room temperature, T_R also radiates due to the T^4 law so that we can write:

$$V_{TC} \sim (T^4 - T_R^4)$$

Under the present circumstances, we can neglect T_R^4 against T^4so that we get a straight line with slope "4" when representing the function V_{TC}= f(T) double logarithmically.

$$\lg V_{TC} = 4 \lg T + \text{constant}$$

The absolute temperature T = t + 273 of the filament is calculated from the measured resistances R(t) of the tungsten filament (t = temperature in centigrade). For the tungsten filament resistance, we have the following temperature dependence:

$$R(t) = R_o(1 + \alpha\, t + \beta\, t^2)$$

where, R_0 = resistance at 0 °C, $R(t)$ = resistance at temperature t, α = 4.82 x 10^{-3} K^{-1} andβ = 6.67 x 10^{-7} K^{-2}.

The resistance R_0 at 0°C can be found by using the relation:

$$R_0 = \left(\frac{R(t_R)}{1+\alpha \cdot t_R + \beta \cdot t_R^2}\right) \qquad (5)$$

Solving R(t) with respect to t and using the relation T = t + 273 gives:

$$T = 273 + \frac{1}{2\beta}\left[\sqrt{\alpha^2 + 4\beta\left(\frac{R(t)}{R_0} - 1\right)} - \alpha\right] = 273 + \frac{\alpha}{2\beta}\left[\sqrt{1 + \frac{4\beta}{\alpha^2}\left(\frac{R(t)}{R_0} - 1\right)} - 1\right] \quad (6)$$

R(t) and R_0 are found by applying Ohm's law, e. g. by voltage and current measurements across the filament.

Procedure:

Part 1: Measurement of the resistance of the filament at room temperature.

1. Connect the circuit as shown in Fig.1.
2. Voltage and current should be measured using digital multimeters.
3. Switch ON the DC source. Adjust the voltage (V) to 0.1 V and measure the corresponding current (I). Records these values in the tablular column.
4. Calculate the resistance of the filament (V/I) and use it as R_o. Note: The current can be measured for few different voltages (measured in steps of 0.1 V) and an average R_O can be calculated. This measurement should be done at room temperature (i.e. under cold condition) of the filament. Larger current can heat up the coil and therefore modifying the actual $R_O$at room temperature.

Part 2. Measurement of the resistance at different currents

5. Use the same circuit in Fig.1. Connect the lamp to a DC power supply together with an ammeter and voltmeter to record filament current and voltage respectively.
6. Place a radiation sensor as shown in the Fig.2 and connect the radiation sensor (Thermopile) to a digital multimeter that should be set on a 100 or 200-millivolt DC range.
7. For filament voltages of between 1V and ~ 15 V, in steps of about 0.2 V, record the filament voltage (V), current (I) and the sensor millivoltmeter reading (V_{TC}).
8. Calculate the resistance of the filament R_T (=V/I) for the various readings taken in step 7. Now calculate the temperature using the formula (6).
9. Draw a graph between log (V_{TC}) and log(T) and measure the slope.

Tables:

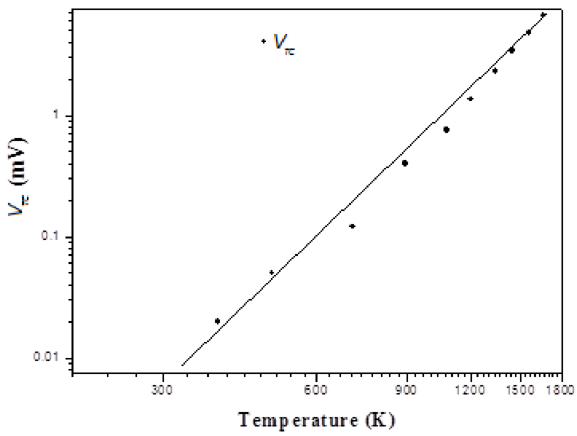
Table 1. Measurement of resistance (R_T) at 50 mA and 100 mA.

S. No.	Current I (A)	Voltage (V)	Resistance R(T) (Ω)

Table 2. Measurement of energy flux and temperature as a function of current (I_{max} = 2 A and V_{max} = 15 V)

S. No.	Current I (A)	Voltage (V)	Resistance R(T) (Ω)	Energy flux V_{TC}(mV)	log (V_{TC})	Temperature T (K)	log(T)

Example:



Precautions:

1. Handle the thermopile only with the given rod.

2. Never touch the thermopile detector by hand.

3. Do not apply current more than 2.0 A through the filament.

3. Variable effective 'g' pendulum

Aim: (i) To determine the acceleration due to gravity (g) by means of a compound pendulum and the radius of gyration about an axis through the center of gravity for the compound pendulum.
(ii) To investigate the dependence of the value of 'g' on the plane of oscillations of the pendulum.
Apparatus: A 1 m long stainless steel rod as a compound pendulum with provision to tilt the plane of oscillations and a timer.

Theory:

A simple pendulum consists of a small body called a "bob" (usually a sphere) attached to the end of a string of negligible mass and of length large compared with the respective quantities of the bob. Under these conditions the mass of the bob may be regarded as concentrated at its center of gravity, and the length of thependulum is the distance of this point from the axis of suspension. When the dimensions of the suspended body are not negligible in comparison with the distance of the center of gravity from the axis of suspension, the pendulum is a compound, or physical pendulum. A rigid body mounted upon a horizontal axis so as to vibrate under the force of gravity is a compound pendulum.

In Fig.1 a body of irregular shape is pivoted about a horizontal frictionless axis through P and is displaced from its equilibrium position by an angle θ. In the equilibrium position the center of gravity G of the body is vertically below P. The distance GP is $l$and the mass of the body is m. The restoring torque for an angular displacement $\theta$is

$$\tau = -mgl\sin\theta \qquad (1)$$

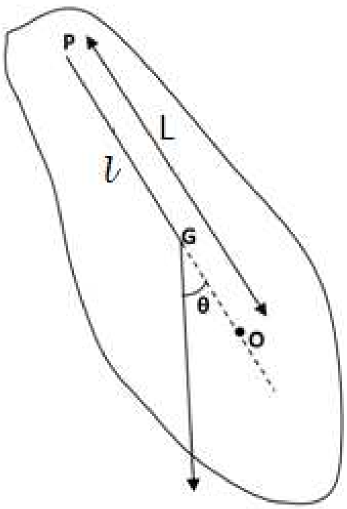


Fig. 1

For small amplitudes ($\theta \approx 0$),

$$I\frac{d^2\theta}{dt^2} = -mgl\,\theta \qquad (2)$$

where $I$is the moment of inertia of the body through the axis P.
Eq. (2) represents a simple harmonic motion and hence the period of oscillations is given by

$$T = 2\pi\sqrt{\frac{I}{mgl}} \qquad (3)$$

Now $I = I_G + ml^2$, where $I_G$is the moment of inertia of thebody about an axis parallel to the axis through P and passingthrough the center of gravity G.

$$I_G = mK^2 \qquad (4)$$

where K is the radius of gyration about the axis passing through G.

Thus,

$$T = 2\pi\sqrt{\frac{mK^2+ml^2}{mgl}} = 2\pi\sqrt{\frac{\frac{K^2}{l}+l}{g}} \qquad (5)$$

The period of a simple pendulum of length *L*, is given by

$$T = 2\pi\sqrt{\frac{\mathrm{L}}{g}} \qquad (6)$$

where

$$\mathrm{L} = l + \frac{K^2}{l} \qquad (7)$$

This is the length of an “equivalent simple pendulum”. If the mass of the body were concentrated at a point O (See Fig.1) such that $\mathrm{OP} = l + \frac{K^2}{l}$, this would correspond to a simple pendulum with period *T*. The point O is called the ‘Centre of Oscillation’. Now, from (5) and (6),

$$l^2 - lL + K^2 = 0 \qquad (8)$$

Equation (8) has two roots l_1 and l_2 such that;

$$l_1 + l_2 = L \qquad (9)$$

and

$$l_1 l_2 = K^2 \qquad (10)$$

Thus, both l_1 and l_2 are positive. This means that on one side of the CG, there are two positions of suspension for which the periods are the same and there will be another pair of positions on the other side of the CG for which the periods are same as above. Thus there are four positions of suspension, two on either side of the CG, about which the time periods of the pendulum would be the same. The distance between two such positions of the centers of suspension asymmetrically located on either side of CG, is the length L of the simple equivalent pendulum. Thus, if the body was supported on a parallel axis through the point O (see Fig. 1), it would oscillate with the same time period *T* as when supported at P.

From Eqs.(6) and (10), the value of g and K are given by;

$$g = 4\pi^2 \frac{L}{T^2} \qquad (11)$$

$$K = \sqrt{l_1 l_2} \qquad (12)$$

By determining L, l_1 and l_2 graphically for a particular value of T, the acceleration due to gravity g at that place and the radius of gyration K of the compound pendulum can be determined.

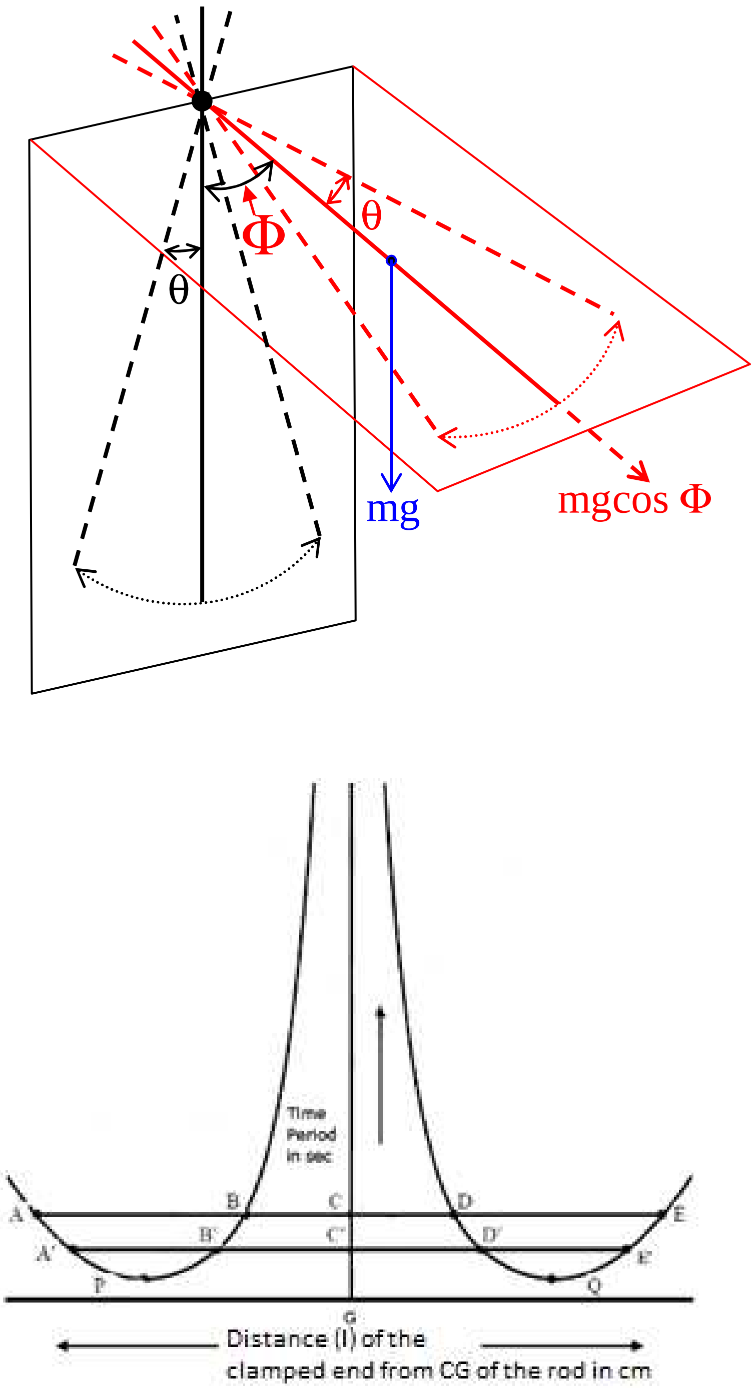


Fig. 2: The physical pendulum set up for variable 'g' configuration and the corresponding time period *vs* distance plot of the clamped end from CG of the rod

If theplane of oscillations is at an angle Φwithrespect to the vertical plane, the components of the accelerationof gravity $g(\Phi)$ which are effective in its oscillation planeare reduced to $g(\Phi) = g \cos\Phi$and eqn. (3) becomes

$$T(\Phi) = 2\pi\sqrt{\frac{I}{mgl\ \cos\Phi}} \qquad (13)$$

In accordancewith this formula, the increase in the oscillation period, whichis proportional to the square root of $1/\cos\Phi$, can be confirmed experimentally.

Procedure:

In the present case, the pendulum is a rod of 10 mm diameter and 1 m length.

(i) Clamp the rod into the support stand using a clamping set up and suspend the rod in a vertical plane.

(ii) Allow the rod to oscillate in the vertical plane ($\Phi = 0$) with a small amplitude ($\theta < 10^o$).

(iii)Measure the time taken for 10 oscillations using a precision stopwatch. Repeat this three times and find the mean time t for 10 oscillations and then determine the time period T. Give estimates for the error ΔT.

(iv)Measure the distance d of the ends of the rod from the axis of suspension, using a meter scale.

(v) Repeat (i) to (iv) for different lengths (in steps of 2 cm) till the CG of the bar is approached where the time period becomes very large.

(vi) Draw a graph with the distance $l = d - D/2$, where D is the total length of the rod, as x-axis and the time period T as y-axis. The graph will be as shown in Fig. 1. (note: $l$is the distance from the pivot point to the centre of mass of the rod. The center of mass of the rod is located at D/2 for a straight cylindrical rod.)

(vii) Draw a line ABC parallel to the x-axis. The length L of the equivalent simple pendulum is $L = AC + BC$ and $K = \sqrt{AC \times BC}$. Find also the time period T corresponding to the line ABC. Repeat the above for several lines parallel to the x-axis. For each line, obtain the values of L, T and K and draw a graph with T^2 as x-axis and L as y-axis. The graph would be a straight line whose slope will be $g/4\pi^2$ from which, g must be calculated. Estimate the error Δg.

For studying the dependence of g on Φ, repeat (i) to (iii) for a length where T is minimum,for values of Φ from 75^o to 15^o. Plot $4\pi^2(K^2 + l^2)/l\cos\Phi$ vs T^2 for various Φ. Explain what you get and what you expect. (Use K obtained from previous part).

Table 1: Measurements for $\Phi = 0$. (The table shows four measurements just for guide. You will have more measurements to do.)

Serial no of holes from one end		Distance d of the hole from one end (cm)	Time for 10 oscillations (sec)	Mean time t for 10 oscillations (sec)	Time period T = t/10 (sec)
One side of C.G					

Table 2: Calculation of 'g' and 'K' from the plot time period vs distance plot of the clamped end from one end of the rod.

No. of obs.	**L (cm)**	**T (sec)**	**$g=4\pi^2\frac{L}{T^2}$ (cm/sec^2)**	**K (cm)**
			Mean'g' (cm/sec^2)	**Mean 'K'(cm)**

Give K $\pm\Delta$K and from a graph of L vs T^2 find g $\pm\Delta$g.

4. Transmission grating

Aim: Determination of the wavelength of the spectral lines of Mercury spectrum.

A grating is a transparent film or glass sheet on which a number of closely lying, equidistant parallel lines are ruled. The ruled spaces are rendered opaque while the inter spaces remain transparent. In effect, therefore, the grating comprises of a large number of closely lying, parallel slits separated by equal distances.

Considering interference of parallel waves passing through slits, imagine a wave front is incident on the grating normal to the plane of the grating. The each slit becomes a secondary source of waves that spread out on the other side of the grating (Fig.1).

The path difference between the rays S_1A and S_2B from successive slits traveling in the particular direction, at an angle θ with the normal to the grating is $d\sin\theta$ where d is the separation of successive slits. If this path difference happens to be multiple of the individual waves from different slits, when they arrive at a plane ABCDE, will all be in phase and their amplitudes will all add up if their amplitudes are superposed. But they are all traveling in parallel direction and no superposition takes place unless the waves affect a common point. By placing a convex lens in the path of the beam, all the waves are converged at the focal point of the lens. As the paths AF, BF, CF etc. are optically equal and the waves are already in phase in the plane ABCDE, the wave reinforce one another at F and we get an image of maximum intensity. The amplitude is N times the amplitude of each wave and intensity will be N^2 times the intensity due to one slit, if there are on the whole N silts. The condition for obtaining maximum intensity is $d\sin\theta = m\lambda$, where m is an integer. At these values of *viz.* θ = 0, $\sin^{-1}\lambda/d$, $\sin^{-1}3\lambda/d$ *etc*., we will have maximum intensity in the image. These are called the principal maxima of orders 0,1,2,3,…*etc*.

If the light that illuminates the grating is composite (consists of many wave lengths)- then each order m have the different angles. For each other, we will have a spectrum, provided we know the distance between the rulings in the grating, we can determine the wavelength of the light from any source.

Experimental procedure:

To determine the wavelengths of the lines present in a given radiation, we measure, using a spectrometer, the angles at which the different orders (of maxima) are produced, with respect to the incident beam. The grating can be standardized, *i.e.* the value of the grating element ‘d’ determined using a standard monochromatic light source of known wavelength. Using this, the wavelength of any other source can be calculated.

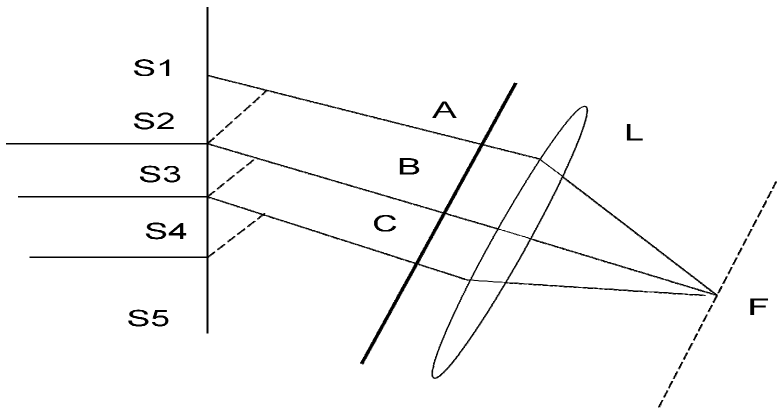


Fig. 1

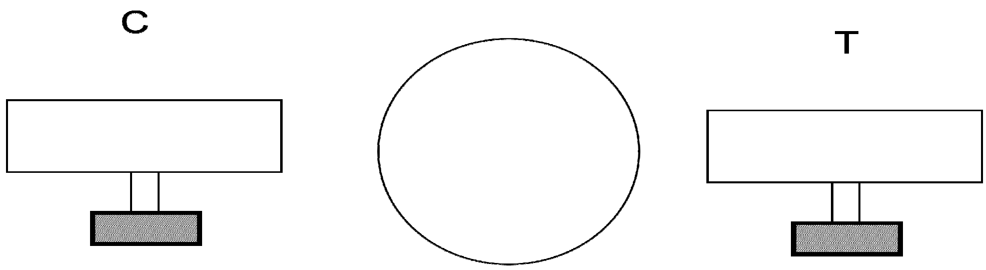


Fig. 2

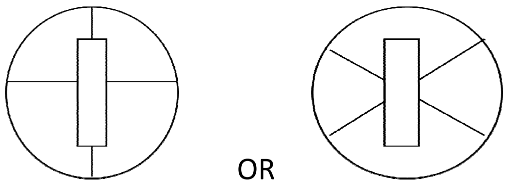


Fig. 3

1. First the preliminary adjustments are made in the spectrometer.

2. To adjust the incident beam from the collimator to be normal to the plane of the grating (Fig. 1 and 2), the telescope is placed along the axis of the collimator and image of the slit obtained exactly at the intersection of the cross-wires (Fig. 3). The reading in the circular scale corresponding to this position screw of the telescope is noted (R1) – Fig .4. The fixing screw of the telescope is released and the telescope rotated to another position which reads (R1 + 90°) or (R1 - 90°). Then the grating is mounted vertically on the central table. The central table is disengaged from the disc carrying the verniers and rotated till the image of the slit after reflection at the grating surface obtained exactly at the intersection of the cross wires. As the axes of the collimator and the telescope have been set up to be perpendicular, this means that the beam from the collimator is incident on the grating at an angle 45°. The levelling screws may be adjusted if the image of the slit is not at the centre of the field of view (Fig.5).

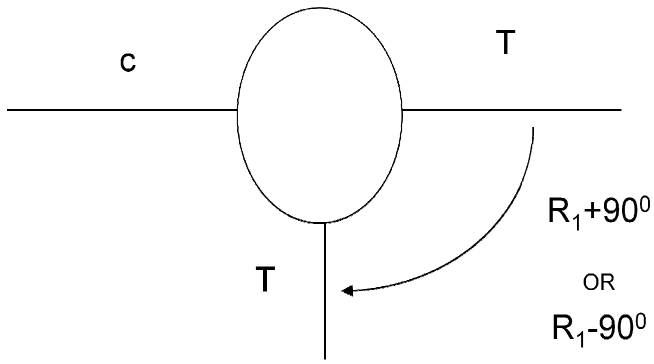

c
T
T
R1+90⁰
OR
R1-90⁰

Fig. 4

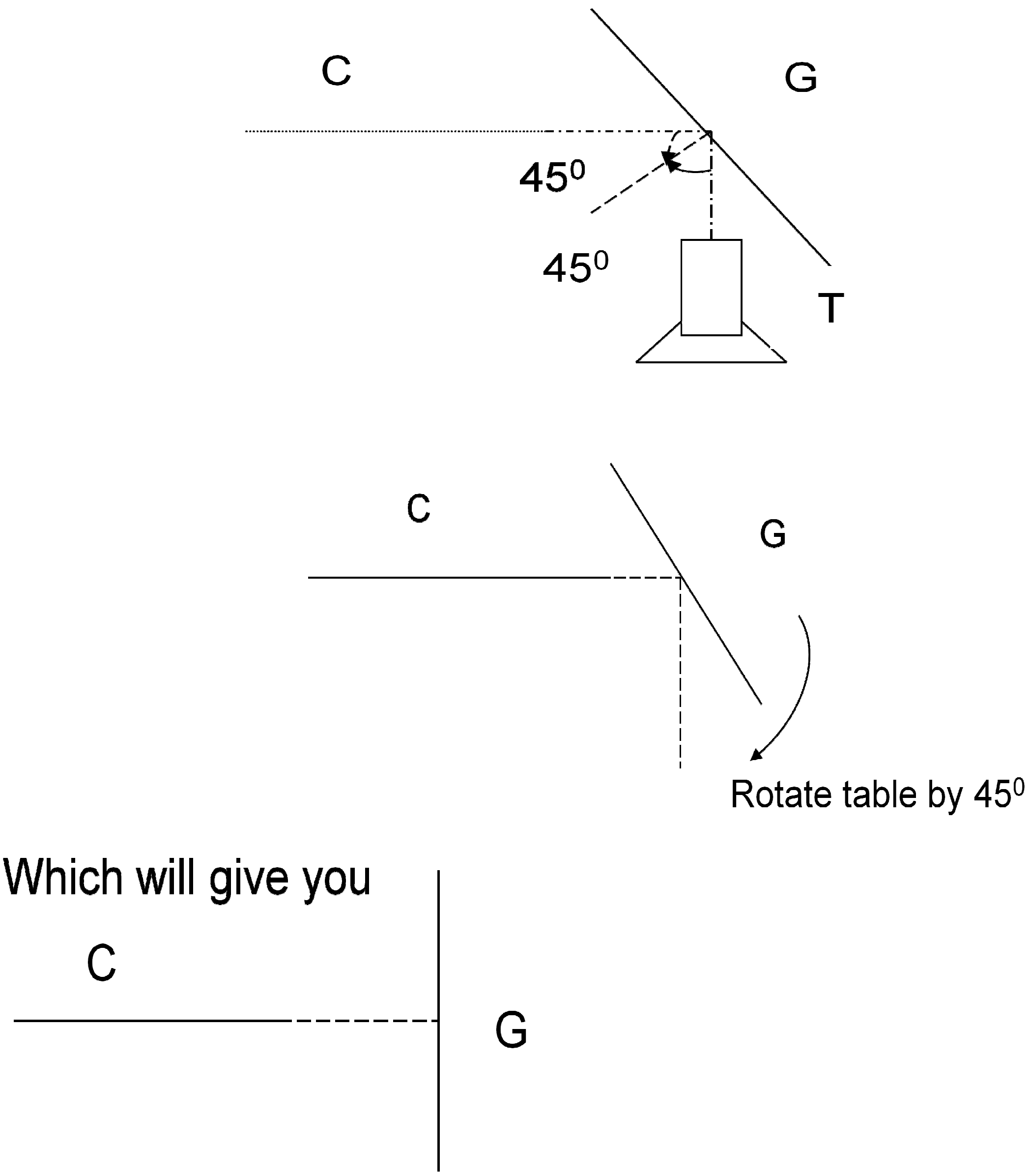

C
G
45⁰
45⁰
T
C
G
Rotate table by 45⁰
Which will give you
C
G

Fig. 5

From the present reading, the central table is rotated exactly by 45^0 with the aid of the vernier scale in the proper direction, to make the source of the grating normal to the direction of the incident beam from the collimator (Fig 5).The slit of collimator is illuminated by the mercury vapour lamp. The telescope is moved to one side of the original direction and the angle with the direct beam is gradually increased, different colored lines are seen, constituting the spectrum of the mercury source (Fig .6).

Readings:

The reading corresponding to the position of the telescope when it is in line with the collimator is again noted. This is bound to be different from the direct ray reading 'R' taken at the start, as the position of the vernier has been changed in the meantime). Then the intersection of the cross wires is placed on the successive (prominent) lines of the first order spectrum and the reading (R) are taken for each line. The telescope is moved to the other side of the direct ray and the readings obtained for the same lines of the first order spectrum (R). In the case of mercury spectrum it consists of the following lines (Fig .7). Y_1, Y2, G and B are quite bright. The greenish-blue line is less intense. The two violet lines are of feeble intensity, the extreme violet line being relatively brighter one. It is a common mistake to assume the very bright blue line as the violet line. Once the violet lines are specially looked for and identified, the difference in shape can be appreciated. As noted in Fig.8, we see that (R-R') gives 2θ; θ can be found.

The same experiment may be repeated with the second order spectra on either side.

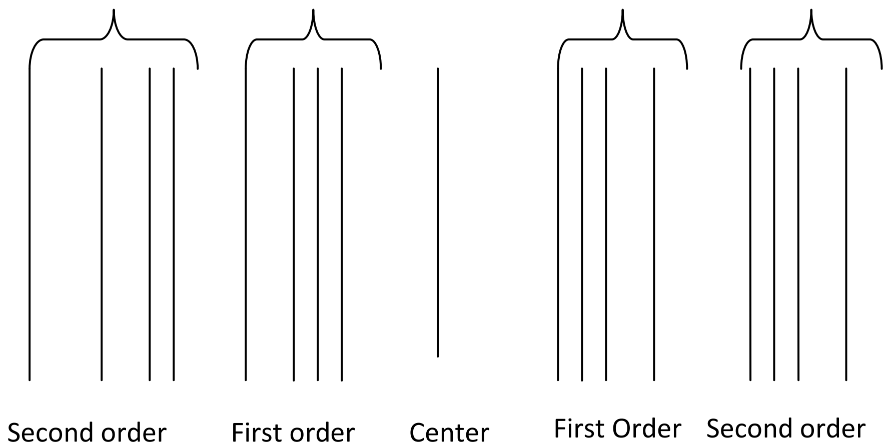


Fig. 6

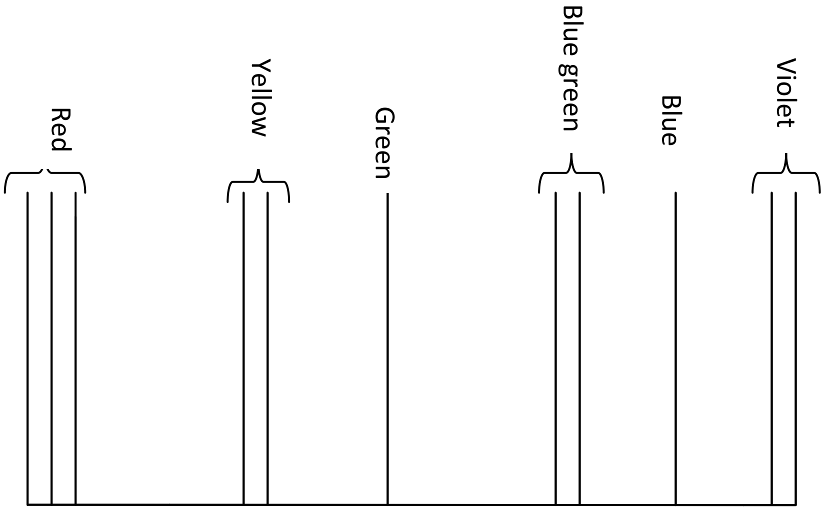

Red
Yellow
Green
Blue green
Blue
Violet

Fig.7

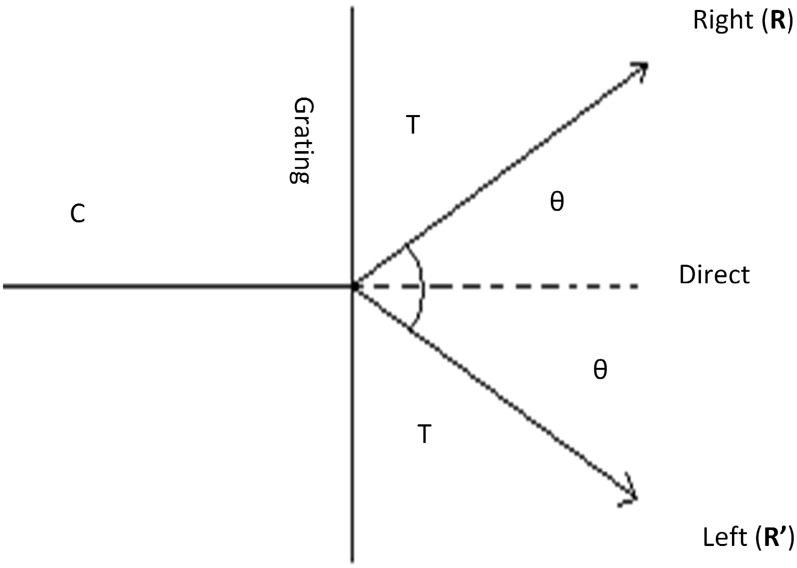

Right (**R**)
Grating
T
θ
C
Direct
θ
T
Left (**R'**)

Fig. 8

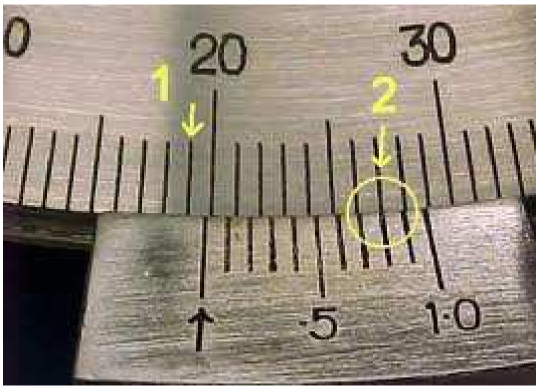


Figure 5

Reading a Circular Vernier Scale:

Main Scale is the fixed scale (at the top, in picture) which has 0-360^{O} marked on it.
Vernier Scale is the small movable scale (at the bottom, in the picture) which has 0-10^{O} marked on it.

Least Count (L.C.) = 1 M.S.D – 1 V.S.D

M.S.D = Main Scale Division

V.S.D = Vernier Scale Division

In this example:

1 M.S.D = 1^{O}

10 V.S.D's coincide with 9 M.S.D's.

1 V.S.D = $\frac{9}{10}$ M.S.D

L.C. = 1 M.S.D – 0.9 M.S.D

L.C. = 0.1 M.S.D = 6'

Reading = Main Scale Reading + Vernier Scale Reading * L.C.

In this example:

Main Scale Reading (marked "1" in the figure 5 – the reading of the main scale just below the Vernier scale zero) = 19^{O}

Vernier Scale Reading (the line on Vernier Scale coinciding with the Main Scale, shown as "2" in the figure 5) = 8

Reading = 19^{O} + 8 x 6' = 19^{O} 48'

Note that the least count of the spectrometer provided to you it will be in the order of seconds.

1. Standrardization of the grating:

Wavelength known= *Least count=*

Colour	Order	Left (R)						Right(R')						$R- R'$ = 2Θ (deg)	$\sin\Theta$	λ = $\sin\Theta/mN$ (A°)
		Vernier A (Θ_A)(deg)			Vernier B(Θ_B) (deg)			Vernier A($\Theta_{A'}$) (deg)			Vernier B ($\Theta_{B'}$) (deg)					
	(m)	Main Scale Reading	Vernier Scale Reading (VSCxLC)	Total Reading	Main Scale Reading	Vernier Scale Reading (VSCxLC)	Total Reading	Main Scale Readin g	Vernier Scale Reading (VSCxLC)	Total Reading	Main Scale Reading	Vernier Scale Reading (VSCxLC)	Total Reading			

Vernier A (Θ_A) - Vernier A($\Theta_{A'}$) = 2Θ Vernier B(Θ_B) - Vernier B ($\Theta_{B'}$) = 2Θ

Mean 2Θ =

From the Equation, $\mathrm{Sin}\theta = \mathrm{Nm}\lambda$

$N = (\mathrm{Sin}\theta/m\lambda)$

2. *Determination of other wavelengths(at least four different colours)*

<table>
<tr><td rowspan="3">Colour</td><td rowspan="3">Order

(m)</td><td colspan="6">Left (R)</td><td colspan="6">Right(R ′)</td><td rowspan="3">R- R ′ = 2Θ

(deg)</td><td rowspan="3">sinΘ</td><td rowspan="3">λ = sinΘ/mN

(A˚)</td></tr>
<tr><td colspan="3">Vernier A (Θ_A) (deg)</td><td colspan="3">Vernier B(Θ_B) (deg)</td><td colspan="3">Vernier A($\Theta_{A'}$) (deg)</td><td colspan="3">Vernier B ($\Theta_{B'}$) (deg)</td></tr>
<tr><td>Main Scale Reading</td><td>Vernier Scale Reading (VSCxLC)</td><td>Total Reading</td><td>Main Scale Reading</td><td>Vernier Scale Reading (VSCxLC)</td><td>Total Readin g</td><td>Main Scale Reading</td><td>Vernier Scale Reading (VSCxLC)</td><td>Total Reading</td><td>Main Scale Reading</td><td>Vernier Scale Reading (VSCxLC)</td><td>Total Reading</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

$$\lambda = sin\Theta / mn$$

Summarize your results.

5.Cathode Ray Oscilloscope

Aim: To use the CRO for voltage and frequency measurements and study the wave shapes/Lissajous figures.

Apparatus required: A cathode ray oscilloscope, audio frequency generators, an RC circuit

General Description of a CRO:

In a cathode ray oscilloscope, a beam of electrons produced in the electron gun is accelerated by an anode and focused onto a fluorescence screen. This beam can be deflected horizontally or vertically by applying a suitable voltage across the x-plates or y-plates respectively. A linear time-base of any desired frequency can be applied across the x-plates, under whose influence the electron beam travels back and forth horizontally. These x- and y-inputs can also be amplified internally.

FUNCTIONS OF SELECT SWITCHES/KNOBS IN CRO:

A. Power and general control

Power: This is a push-button type switch that turns on the power when pressed. Pressing it again turns off the power.

Intensity: This knob adjusts the brightness (intensity). Brightness increases as knob is rotated clockwise. All measurements should be performed with the lowest possible intensity that is comfortable to your eyes. Important note: Keeping the spot at high for long may damage the phosphor coating on the screen.

Focus: Knob to vary the size of the electron beam (and hence the spot size) striking the screen. After choosing appropriate brightness by adjusting the intensity control knob, adjust the focus until the display is sharpest.

B. Vertical (amplitude) control

Pos: This is used to move the CH1 and CH2 trace vertically on the display. The Pos control of CH2 also controls the Y (vertical) position in the X-Y mode.

Volt/Div: Each position of this switch indicates the number that tells the scale used for the vertical axis. For example, the position corresponding to 1 V shows 1 cm on the vertical scale corresponds to 1 V. Thus, a 2 V_{PP} sine wave, for example, will occupy 2 cm on the vertical scale. The knob on the switch should be kept fully in the clockwise direction

AC-GND-DC: Used for choosing the coupling system for the input AC: ac coupled (dc component is blocked), DC: dc coupled (both ac and dc and components are allowed) and GND: The input the vertical axis is grounded.

Vert Mode: This selects the mode for vertical deflection. CH1: displays only the input to CH1 alone. CH2: displays the input to CH2 alone. Dual: Displays both CH1 and CH2 inputs.

Input: The BNC inputs 1 and 2 accept signals (BNC cable) for CH1 and CH2 respectively.

C. Horizontal (time base) control

H Pos: It is used to move the CH1 or CH2 trace horizontally on the display. The HPos control of CH1 also controls the X (horizontal) position in the X-Y mode.

Time/Div: Each position of this switch indicates the number that tells the scale for the horizontal axis. For example, the position corresponding to 1 ms shows 1 cm on the horizontal scale corresponds to 1 ms. Thus one cycle of, for example, 1 kHz sine wave will occupy a "length" of 1 cm on the horizontal scale.

Var Sweep: This knob is used to vary the sweep time between the present position (as indicated by the Time/Div switch) and the next.

D. Trigger controls

Trig Level: This knob selects the starting point at which the sweep is triggered. Keep it in fully counter clockwise position for fixed level. The positions + or – indicates triggering the signal when it is rising (+ve slope) or falling (-ve slope) respectively.

Coupling: When this switch is in AC position, the signal is capacitively coupled to vertical amplifier and a base line will be displayed (spot becomes line). TV-V and TV-H are meant for composite video signals and rejects high frequency signals or dc and low frequency signals respectively.

Source: When this switch is in CH1/CH2 mode, the signal at CH1/CH2 becomes triggering signal. When it is in ALT mode CH1 and CH2 signals become triggering signals alternately.

Norm/Auto: Leave the switch in NORM position for normal display.

FUNCTIONS OF SELECT SWITCHES/KNOBS IN FNG

Power: This switch turns on or turns off the power to the system

Frequency: Particular range is selected by the corresponding push button. Continuous variation is selected by the "Freq" knob. In older models, a knob (with graduated scale) with selector switch performs this operation.

Signal amplitude: When this switch is in pressed mode it shows amplitude and in the normal released reads frequency. In older models a selector switch is used for this purpose.

Wave type: Appropriate wave (sine/square triangle) can be chosen by pressing the corresponding button. An associated knob allows variation of duty cycle of square/triangle waves.

DC offset: This allows adding a dc level. It is turned off when it is in the extreme CCW direction.

Measurement of AC voltages and study of wave shapes:

1. Switch the power ‘On”.
2. Keep the intensity of the CRO low so that the trace on the screen is just visible. High intensities may spoil the screen’s coating material.
3. Go to ‘XY’ mode.
4. Keep the VOLT/DIV knobs of both Channels [CH.1(X) and CH.2(Y)] at the same position (say), at 0.2 Volts/Divn.
5. Adjust the X-position control and the Y-position control knobs to place the trace at the center of the screen.
6. Switch the FUNCTION GENERATOR (FNG) ON. Keep the frequency of the FNG at 1 kHz.
7. Connect the output of the FNG to the input of CH.1(X) of the CRO using the BNC connector.
8. Keep to the function switch corresponding Sine Wave switched ON.
9. Keep the Amplitude Coarse control knob at 2 V position and the continuous variation knob at some specific angle so that you see a vertical line trace by the electron beam with a length of about 4 large divisions on the screen.

   Can you guess why we are getting a vertical line?

   The applied Sine Wave on the Y plates keep changing polarity 1000 times per second in a sinusoidal fashion and hence the electron beam also, being negatively charged, keep moving up and down at this frequency. Hence due to persistence of vision we see a continuous line. If you reduce the frequency of the applied Sine Wave using the push button switch on top to very low values (say 0.1 Hz) then you can follow the beam movement.
10. The magnitude of the line is proportional to the Peak-toPeak voltage of the applied wave (V_{PP}). Calculate the peak voltage of the sinusoid using the formula V_P = (Number of divisions x voltage sensitivity)/2 in Volts. The voltage sensitivity is read from the knob position of CH.1 (X) in Volt/Divn or mV/Divn.
11. Calculate $V_{RMS} = V_P/\sqrt{2}$
12. In the digital multimeter (DMM) set the function dial to AC voltage and the range to 20 V (say). Read the output voltage from the FNG directly.
13. Repeat such measurements for two more values.

14. Release the XY mode and adjust the Time/Divn such that you observe some two or three complete Sine Waves within the screen. This is possible because now the Time base (Sweep Voltage) is applied to the X plates.
15. Set the function knob of FNG to First Square and then to triangle & observe the shape on the CRO screen changes first to square and then to triangle one after another. As before the different voltages applied from the FNG in these Square/Triangle modes circulate the V_{RMS} voltages using both the CRO and the DMM and tabulate the results.

(Set a frequency with particular amplitude, do the measurement for Sine, Square and Triangle. Repeat it for different amplitude)

Table 1.Measurement of AC voltages.

S.No	*Shape of wave*	*No of divisions*	V_P	V_{RMS} *CRO*	V_{RMS} *DMM*
1 *2* *3*	*Sine*				
1 *2* *3*	*Square*				
1 *2* *3*	*Triangle*				

SINE $$V_{RMS} = \frac{V_P}{\sqrt{2}}$$

SQUARE $$V_{RMS} = V_P$$

TRIANGLE $$V_{RMS} = \frac{V_P}{\sqrt{3}}$$

16. The data V_{RMS} (CRO) for square and triangle waves will not agree with those of DMM. Why? Perform integration over one period for the case of sine, square and triangle and derive the relationship between Peak voltage and RMS voltage for the different cases given above. Use the correct relationship obtained by calculation and evaluates the RMS voltage for the measurements using CRO. The DMM results will be erroneous for these cases as it is calibrated only for Sine Waves.

II. Lissajous pattern

Set the CRO in XY mode as before. Keep the sensitivity of both CH.1(X) and CH.2(Y) same (say, 0.2 V/Divn.)

Switch both the Function Generators. Set them both at 1 kHz (say). Also set the output amplitudes of both about the same using the Coarse and Fine control knobs.

Apply the two outputs from the two FNGs to the two plates CH.1(X) and CH.2(Y) using BNC cables.

Adjust the continuous Frequency Control dial of one of the FNGs and obtain a CIRCLE on the screen. The CIRCLE will keep changing to ellipse and momentarily into a straight line etc. continuously (why?). This is called the **LISSAJOUS PATTERN**. The figure CIRCLE shows that the two frequencies applied to X & Y plates are in the ratio 1:1. Sketch the Lissajous figures obtained for other ratios (1:2, 2:1, 2:3 etc.) by keeping the frequency of one FNG fixed and changing the other continuously. Repeat the experiment for different frequencies and tabulate the results as below in table 2:

Table 2. Lissajous patterns.

S. No.	*FNG 1 (kHz)*	*FNG2(kHz)*	*Figure*	*Ratio*
1	*1*			
2	*1*			
3	*1*			
4	*1*			
5	*1*			

Experiment 2

Lissajous figures and relative phase measurement

Consider two sinusoidal voltage signals, $V_1(t)$ = A sinωt and $V_2(t)$ = B sin(ωt + φ). A simple way to produce a phase-shifted signal with different amplitude from the given signal is t use a simple RC circuit. See figure 1. The signal across the capacitor will be shifted in phase with respect to the input signal and also it will have different amplitude, depending on the frequency. If these two signals are connected to a CRO such that $V_1(t)$ is given to Ch.1 and $V_2(t)$ to Ch.2 (this order is important for the following discussions), and the display is set **to XY mode**, then the display may like the pattern shown in figure 2. This pattern is called Lissajous Pattern

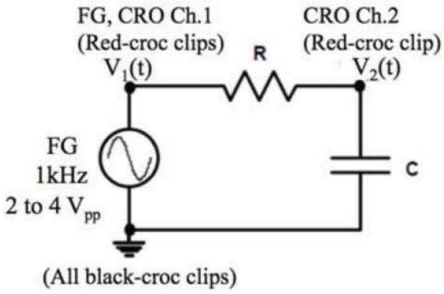


Figure 1. RC circuit to produce a Phase-shifted signal

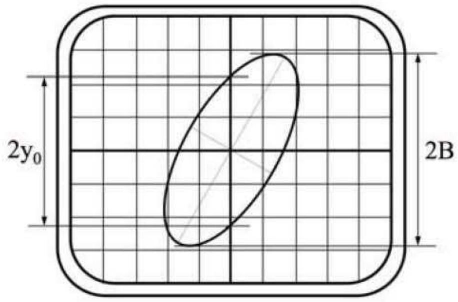


Figure 2. Pattern in CRO. In XY mode Ch.1 is X and Ch.2 is Y.

It is possible to eliminate "ωt" and write $V_2(t)$ in terms of $V_1(t)$

$$V_2(t) = B[\frac{V_1^2}{A}\cos\varphi + \frac{1}{A}Sqrt[(1-\frac{V_1^2}{C^2})\sin\varphi]$$

At $t = 0$; $V_1 = 0$ and $V_2 = B\sin\varphi$

From figure 2, $V_2 = y_0 \Rightarrow \sin\varphi = \frac{y_0}{B}$

Thus the relative phase difference can be calculated. Take R = 220 Ω and C = 1 μF and complete the measurement. Repeat the same for another frequency (about 2 KHz). Note if the ellipse is aligned in the opposite direction, then $\varphi = 180 - \sin^{-1}\left(\frac{y_0}{B}\right)$. The phase difference can also be read directly from the CRO.

Table 2 R = ; C = ; Frequency = ; V_{PP} =

Phase difference (measured)	Phase difference (calculated)

Note: Try to analyze the circuit in terms of Phasors. If you have time repeat the experiment at a different frequency. Depending on the Phase difference the Lissajous pattern can vary from line to circle to ellipse. Try seeing them in the oscilloscope. If you replace the capacitor with a resistor how will the Lissajous pattern look? Think about the above.

Summarize your results.

6. Mapping equipotential lines

Aim

To map regions of equipotential for a given set of electrode configuration.

Apparatus

A circular glass container with KCl solution (0.1 g of KCl in 250 ml distilled water should be prepared), two pairs of electrodes with (i) circular and (ii) parallel plate configuration, ac voltage source, multimeter and connecting wires.

Introduction

A simple way to understand the force of interaction between electric charges is to consider that a charge produces a field in the space surrounding it. Any other charge kept in this field would experience a force, the Coulomb force. Hence, the action at a distance can be thought of as being facilitated by the electric field. Electric field is defined as the force per unit charge exerted on a test positive charge. An associated concept is the potential energy, similar to the potential energy of a mass in gravitational field. The electric potential energy at a given point is defined as the work done in bringing a unit test positive from infinity up to that point. The work done per unit charge is the electrostatic potential. Thus, it is not the absolute potential, but the potential difference is what one measures. For instance, in a common 1.5 V dry cell the positive terminal is at a higher potential of 1.5 V than its negative terminal. Note carefully the use of potential and not potential energy. The primary difference is that potential is independent of the magnitude of the test charge, just as the gravitational potential does not depend on the magnitude of the test mass.

Another related concept is regions of constant potential or equipotential regions. The potential difference between any two points at regions of constant potential is zero. When a charge is moved along an equipotential region, the change in potential energy of the charge is zero which means the work done by the field on the charge is zero. Further no work is done when a charge is moved such that the displacement is normal to the electric field at any point. Hence, the lines of electric field and equipotential lines form set of orthogonal curves. In three dimensions regions of constant potential are surfaces and are termed equipotential surfaces. What is obvious from these discussions is the ease with which the equipotential regions can be identified: Connect the two probes of a voltmeter (multimeter set in voltage mode) across any two points and if the meter reads 0V, then both points are at the same potential.

Experimental Procedure

A Photograph of the experimental arrangement is displayed in Fig.1, while a schematic of the electrode configuration is shown in Fig.2 and Fig.3. To begin with use the circular configuration. The goal is to locate a region, all the points of which are at constant potential with respect to one of the electrodes.

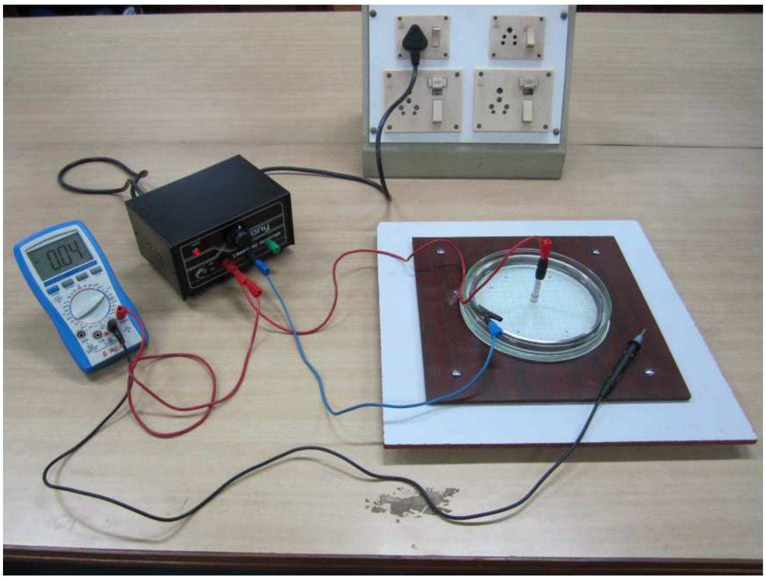
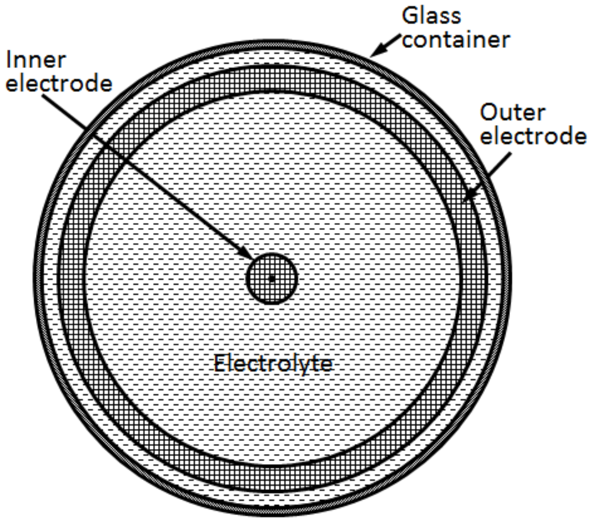


Fig. 1: Experimental set up for mapping equipotential lines

Procedure

1. Apply a suitable voltage of about 6 V (rms) between the inner electrode and the outer annular electrode which is kept concentric with the inner electrode. The outer electrode must be at ground potential.
2. Set the multimeter to read **ac voltage**. Note one of the probes (black) of the multimeter is insulated completely but for a small portion at the tip of the probe. This probe should be used for measurements, while the other probe (red) should be connected to the inner electrode.
3. Immerse the “black probe” in the solution until it comes into contact with the bottom and move it until the voltmeter reads 2.5V. Essentially, this tells you that the voltage difference between inner electrode and the point where the probe is located is 2.5V.
4. Read the coordinates of the point from the graph sheet placed at the bottom and transfer the same to the graph sheet in the booklet. Prior to this, two concentric circles must be drawn on the graph sheet such that, the radius of the inner circle as the radius of the inner electrode and the radius of the outer circle as the inner radius of the outer electrode.
5. Repeat the experiment by locating several points that are at the same potential of 2.5V with respect to the outer electrode. Take as many points as possible so that you can connect all the points by a meaningful smooth curve. This curve gives you an equipotential region.
6. Repeat the above for the voltage differences in steps of 1 V until 6.5 V.
7. Once the experiments are completed, take out both the electrodes and place the two parallel electrodes in the solution. See Fig.3 for the placement of the electrodes. There are two protrusions below the electrodes and they must fit inside the two slots on the

base. This will provide mechanical stability. Apply a potential of about 6 V between the two electrodes and repeat the steps 2-6 for this electrode configuration.



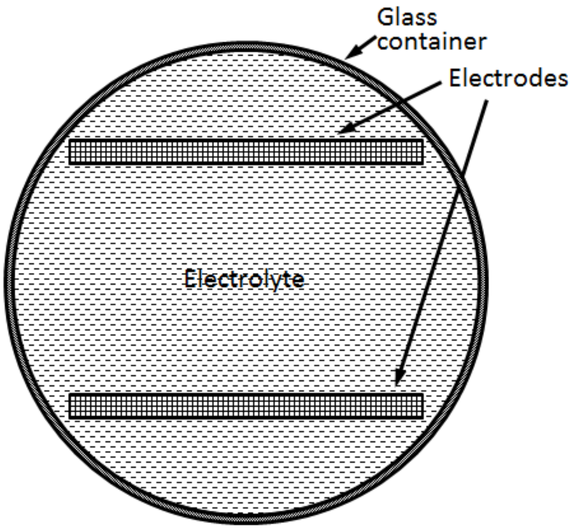


Fig. 2 Fig. 3

Electrode placement for circular (Fig.2) and parallel plate (Fig.3) configurations

Theory

The potential distribution in a given region can be obtained by solving the Laplace's equation under suitable boundary conditions. The circular symmetry of the electrodes used in the first experiment implies that the Laplace's equation be considered in polar coordinates. In this coordinates and with the understanding that there is no angular dependence, the Laplace's equation becomes

$$\frac{1}{\rho}\frac{d}{d\rho}\left(\rho\frac{dV}{d\rho}\right)=0 \qquad (1)$$

Excluding the ρ= 0, from the solution and integrating Eqn.1 twice yields

$$V = A\ln\rho + B \qquad (2)$$

where, A and B are constant of integration. Let the outer electrode be at the potential V_o and the inner electrode be at the potential 0, The boundary conditions can be written as

$$V(a) = V_0 \text{ and } V(b) = 0 \tag{3}$$

Where, a is the radius of the inner electrode and b is the inner radius of the outer electrode. Note here that $b>a$.
Substitution of the boundary conditions yields the solution for the potential at any point in between the electrodes as:

$$V(\rho) = V_0 \frac{\ln(b/\rho)}{\ln(b/a)} \tag{4}$$

Not that the solutions correctly predicts the potential difference between the electrodes.

Setting V to be constant lead to the equation that gives the equipotential curves as

$$\rho = const \tag{5}$$

which are circles of constant radii.

The electric field can be found as $\vec{E} = -\vec{\nabla} V$ (6)

$$\vec{E}(\rho) = \frac{V_0}{\rho} \frac{1}{\ln(b/a)} \hat{e}_\rho \tag{7}$$

The electric field is along the radial direction and its magnitude decreases with radial distance. Electric lines of force are defined as curves, tangent to which at any point gives the direction of the electric field. This definition can be used to get equation for electric lines of force. Fig.4 shows a sketch of equipotential lines and electric lines of force.

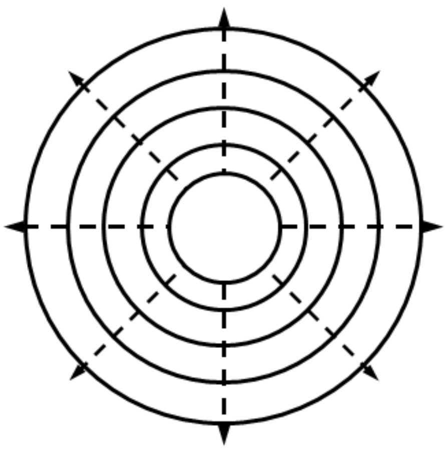


Fig.4 Equipotentials (circles) and electric lines of force (dashed radial lines) for the electrode geometry considered.

Uniqueness Theorem

It is important at this stage to know the uniqueness theorem. In a rather simplified form it can be stated that given the boundary conditions, the potential at any point in between closed boundaries is uniquely and completely determined by the Laplace equation and is independent of the potential outside the boundary. In other words, given the potentials on the electrodes (boundaries) the potential at any point in between the electrodes can be uniquely determined.

Draw now few radial lines in the graph sheet. You may draw dashed lines to differentiate them from equipotential lines.

Also use equation 4 to get equation for the equipotential for at least one circle.

The equation for equipotential can be developed for the parallel configuration. Assuming the potential to be function of *y* coordinate alone, the Laplace's equation can be written as

$$\frac{d^2V}{dy^2} = 0 \tag{8}$$

Replacing the partial derivative with total derivative and integrating it twice yields

$$V = Cy + D \tag{9}$$

Where *C* and *D* are constants of integration. Assuming the boundary conditions,

$$V(d) = V_0 \text{ and } V(0) = 0 \tag{10}$$

Where *d* is the distance between the electrodes, leads to

$$V(y) = V_0 \frac{y}{d} \tag{11}$$

Thus y = const (horizontal lines) are the equations that generate the equipotentials. The electric field this case can be found as $\vec{E} = -\vec{\nabla} V$

$$\vec{E}(y) = -\frac{V_0}{d}\hat{e}_y \tag{12}$$

The electric field is constant and it points along the negative y axis and the electric lines of force are vertical lines (x = const). See Fig. 5 for equipotentials and electric lines of force.

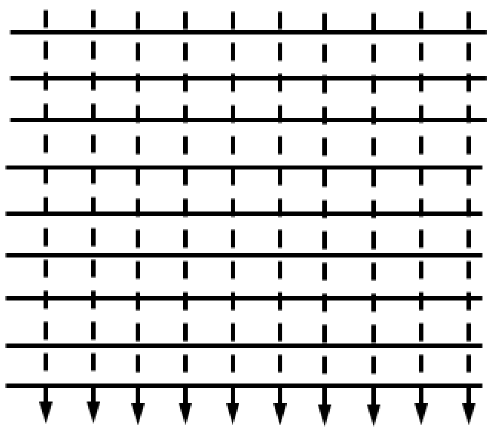


Fig.5 Equipotentials (continuous horizontal lines) and electric lines of force (dashed vertical lines) for the parallel plate electrode geometry.

Sketch few vertical lines in the graph sheet. You may draw dashed lines to differentiate them from equipotential lines.
Also use equation 11 to get the equation for the equipotential for at least one case.

You may have noticed that the equipotentials are not straight lines as predicted by the theory. Try to find the reason for this

7. Sonometer

Aim : To determine the frequency of the alternating current using sonometer.

Appratus required: A sonometer with soft iron wire, slotted weights, meter scale. Magnet

Theory:

A sonometer is a hollow wooden box used in lab to study the transverse vibrations of string. It is also called the monochord because it often has only one string. On the wooden rectangular box are two fixed bridges, near the ends, and at one end is a pulley. A string, often a metallic and non-magnetic wire of length l is fastened at one end and it is made to run over the bridges and the pulley, and attached to a weight holder hanging below the pulley. Weights can be added to the holder to produce tension in the wire, and the bridges can be moved to change the length of the vibrating section of the string.

Basically a Sonometer is a device based on the principle of Resonance. It is used to verify the laws of vibration of stretched string and also to determine the frequency of a tuning fork. "When the frequency of the applied force is equal to the natural frequency of the body, the body vibrates with very large amplitude. The magnet is placed at the middle of the Sonometer wire and the magnetic field is applied perpendicular to the Sonometer wire in a horizontal plane and alternating current is applied to the Sonometer wire. Since we pass linear current, we get circular oscillating magnetic field, that interacts with the the permanent magnet at the centre of the wire and the magnetic field. When the length 'l' of the sonometer wire vibrates with maximum amplitude, the frequency of the applied A.C. is equal to the natural frequency of the wire.

Every object has a natural frequency of vibration. If kinetic energy is applied to an object at a rate that matches its natural frequency, resonance occurs and the object vibrates. In this experiment a small current, produced by a signal generator, causes the sonometer wire to move up and down due to interaction with the magnetic field of a magnet. When the rate of movement due to the current matches the fundamental frequency of the wire, resonance occurs causing noticeable vibration. For small amplitude vibration, the frequency is proportional to

a) The square root of the tension of the string,
b) The reciprocal of the square root of the linear density of the string,
c) The reciprocal of the length of the string.

$$f = \frac{1}{2l}\sqrt{T/m} \qquad (1)$$

where

T is the tension of the wire.(=product of mass suspended and acceleration due to gravity)

m is the mass per unit length of the wire

l is the resonating length of the wire.

Procedure:

1. Before starting the experiment make sure that the pulley is without friction.

2. Add maximum weights in the weight hanger and can be reduced one by one.

3. Place the magnet in the centre of the sonometer. Switch on the AC main supply.

4. Move both the bridges outwards so that the maximum length of the wire can be included.

5. Move both the bridges inwards equally till sonometer starts vibrating.

6. Adjust the distance between the bridges so that we will get maximum amplitude of the string.

7. Measure the length of the wire between the bridges and record it as (L).

8. Now the experiment can be repeated by decreasing the weight in the weight hanger in steps and each time measure the length between the bridges when the wire shows maximum vibration.

8. Plot square root of tension Vs resonating length and measure the slope.

9. Measure the diameter of the given wire using screw gauge and tabulate it in Table 2.

10. By knowing the value of acceleration due to gravity (g) ,mass per unit length (m), frequency of ac supply can be found.

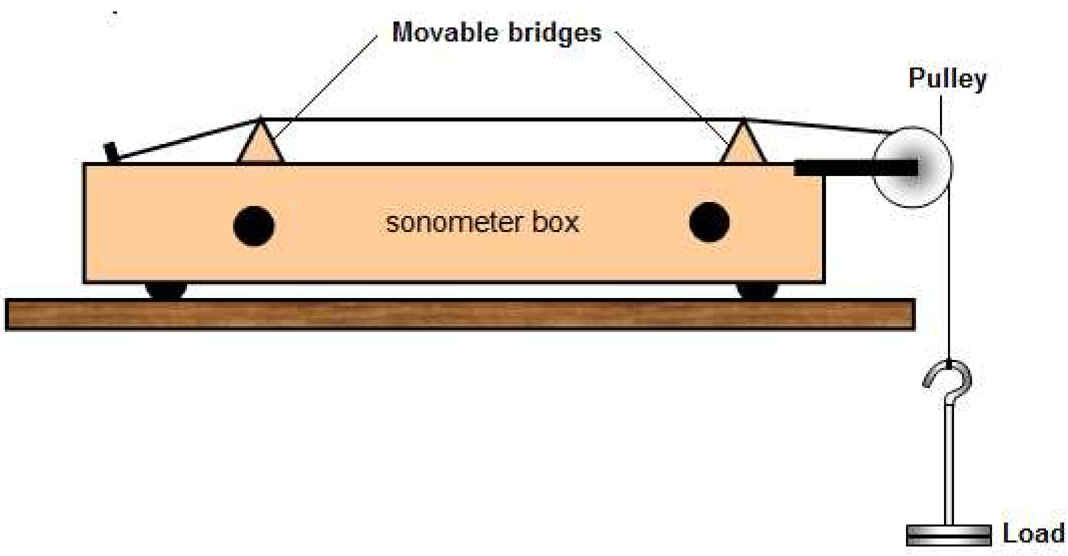


Fig 1.

$$\mathbf{f=(1/2).(\sqrt{T}/L)(1/\sqrt{m})}$$

Precaution:

1.The wire should be of a uniform area of cross-section, free from kinks.
2. The resonance position should obtained by first lowly increasing the distance between the wedges and then slowly decreasing it.
3. The weight of hanger should always be included in the load.
4. The pulley should be free from friction.

Table 1. To find the value of ($\sqrt{T}/L$)

Sl.No.	Load (g)	Length of the vibrating segment		Mean	T=mg	Ratio ($\sqrt{T}$ /L)
		Trail I L1 (cm)	Trail II L2 (cm)	L (cm)		

Mean ($\sqrt{T}$ /L)= ....

Table 2: To find the diameter of the wire:

Sl.No.	PSR	HSC	HSR(HSCxLC)	TR= PSR+HSR

Diameter of the wire: .... mm
Radius of the wire: .... mm
Density of the steel wire: 8000 Kg/m^3
Linear density of the given wire (m) = ... kg

***Linear density (m) can be found by two methods. It can measured by weighing one meterlength of wire or by measuring the diameter of the given wire* and $m=\pi r^2\rho$

.

8.Wavelength of light by interference - Newton's rings

Aim: To determine the wavelength of a monochromatic light by forming Newton's rings.

Apparatus: A plano-convex lens of large focal length, glass plate, monochromatic light source (sodium vapor lamp), a traveling microscope.

Interference:

Interference effects are observed when, in a certain regions of space, two waves of the same frequency are superposed and the two waves reach the same point with some phase difference. Depending on the amount of phase difference at any point, the effect of superposition is to produce varying intensities-varying from a maximum of $(a_2+a_1)^2$ to minimum of $(a_2-a_1)^2$, where a_2 and a_1 are the amplitudes of the individual waves. For the interference pattern to be observed, the intensities at different points and hence the phase differences between the individual waves should be constant in time. Such waves having a phase relation, which is independent of time, are said to be coherent. The light waves from two different sources of light do not have this phase relationship. So it is necessary that the two waves that is made to travel different paths and get superposed to produce interference, is derived from a single original wave-front. The splitting of a single wave-front into two portions to produce interference may be achieved in two ways.

(a) By wave-front division as is done in double slit experiment.

(b) To make the rays undergo partial reflection and reflected/refracted waves to interfere. Here it is the energy of the original wave that is divided into the interfering waves. This method is called "division of amplitude" (as the energy depends on the amplitude) an example is the production of interference bands by partial reflection at the two faces of a thin transparent film as shown in fig. 1.

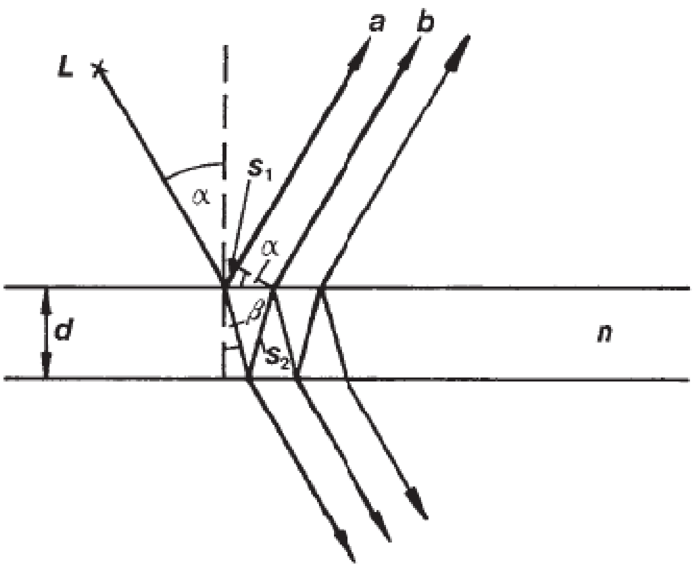


Figure 1.

An example is the production of interference bands by partial reflection from thin transparent film. Compared to ray *a*, ray *b* has gone through a longer path and therefore has a phase lag. It can be proved from the geometry that the phase difference is δ={2nd cosφ'(2π/λ)}. Depending on the value of δ, there will be a maximum, minimum or intermediate illumination at the point where the rays a and *b* meet.

Any variation in the phase difference δ can arise only due to the variation in the separation *d*. In the case of an air wedge between two glass plates, we obtain a series of parallel equidistant bright and dark bands. The rays reflected by the two bounding faces of the air film intersect very close to the surface of the glass plate, the interference bands are formed close to the air wedge. By focussing a microscope on the surface of the glass plate, one would be able to view the pattern. Such fringe systems formed close to the air wedge arising mainly due to the variation in the φ' thickness of the film are called fringes of equal thickness because each fringe of a given intensity corresponds to the locus points having the same value of thickness *d*.

NEWTON'S RINGS:

Referring to Fig. 2, a convex lens is placed over a plane glass plate. The system is illuminated from above by a monochromatic light from a sodium lamp. Interference fringes are formed due to the superposition of light reflection by the upper and lower boundaries of the air film. Loci of constant *d* will be concentric circles around the point of contact a band of minimum intensity is obtained if the separation satisfied the relation 2nd cosφ'=(2mλ/2) which yields 2*d*=mλ or *d*=mλ/2 (for normal incidence φ'=0, n=1 for air, and cosφ'=1). The center correspoonds to *d*=0 and this condition is satisfied with m=0. At a small distance away from the center, where the air thickness is ½ wavelength we have the first order dark ring. When *d*=mλ/2, we have the mth order dark ring. Midway between successive dark rings, we have rings of maximum intensity corresponding to *d*=(2m-1)λ/4. To obtain the radii of the different rings, we must relate the separation d to the distance from the centre. Consider fig.2, *r* is the radius of the ring and *R* radius curvature of the convex surface.

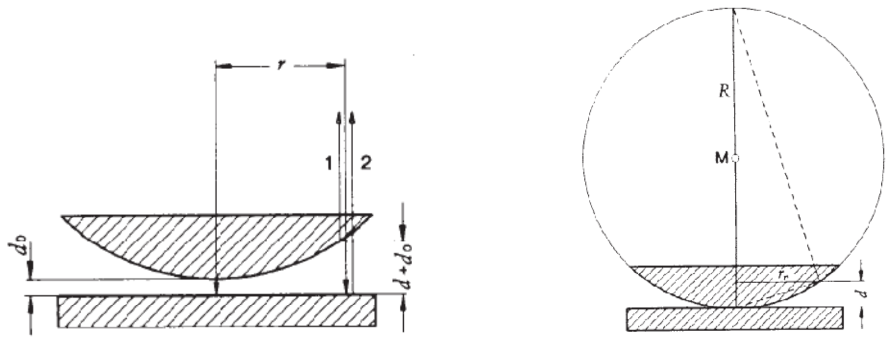


Figure 2.

$r^2 = R^2 - (R-d)^2$ or $d = r^2/2R$.

Hence, $r_m^{\ 2} = m\lambda R$ for dark rings

and $r_m^{\ 2} = (2m-1)\lambda R/4$ for bright rings

Measuring the diameters of different orders of the dark rings in the pattern, we may find λ, if R is known.

Experiment:(The convex lens should have focal length of 75 cm or larger).

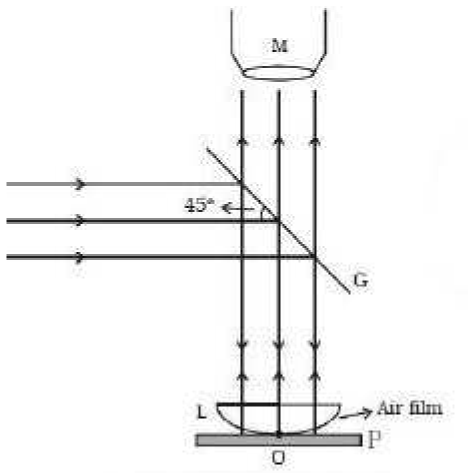


Figure 3.

1. Place the biconvex or plano-convex lens over a plane glass plate. It will be better if the lower portion of the glass plate is a ground surface to avoid reflection from the lower surface.
2. Mount a transparent glass plate above the centre of the lens at about $45^o$to the horizontal.
3. Mount the whole arrangement on the horizontal platform of a vernier microscope.
4. Keep the microscope along with the lens system on it facing the sodium vapor lamp. When the lens is viewed from above, through the 45^o plate, the reflected image of the lamp will be seen at the centre of the lens. (A slight change in the orientation of the microscope base with respect to the lamp may be necessary to get the bright patch of light over the centre of the lens). Even with the naked eye, a tiny dark spot (a small ring system) can be seen inside the bright patch.
5. If the same is viewed through the microscope a number of alternately bright and dark concentric rings can be seen. The microscope must be adjusted so that there is no parallax between the cross wires and the rings. The eyepiece is rotated to make one of the cross wires pass through the central spot of the ring system and the other

tangential to one of the rings. As the microscope carrier is moved along the horizontal scale, the tangential cross wire coincides with the different successive rings.

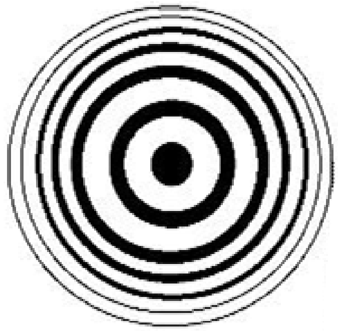


Fig. 4. Newton's rings

6. By placing the cross wire tangential to a particular ring at the two extremities and noting the scale readings, the diameter of the ring may be determined. Starting from the central spot as order n, move the cross wire outward to one side counting the rings. Place the cross wire tangential to,for instance, the $(n+12)^{th}$ dark ring. Take the reading on the horizontal scale $[X^R]$ (n+12). Move the cross wire towards the centre and take readings at the position of every alternate ring n+10 n+8 etc. [R-right]. After the centre, moving in the same direction, take the readings, on the opposite side, at the same orders of rings, n+2, n+4, ..., n+12. Let the readings be $X^L(n+2)$, $X^L(n+4)$, ... (L-left). Then $X^R{}_m$ - $X^L{}_m$ = diameter of the m^{th} ring. Tabulate the readings
7. Draw a graph with order m on x-axis and the $(\text{diameter})^2$ along y-axis.

$$\frac{r_m^{\ 2}}{m} = R\lambda$$

Focal length of the given plano convex lens ----------------------

Least count of the vernier-------------------

Order of the ring	Travelling microscope Reading						Diameter of the ring (cm) $X_L \sim X_R$	Diameter square of the ring $(cm)^2$
	Left(X_L) cm			Right (X_R) cm				
	MSR	VSR	TR	MSR	VSR	TR		

7. Transistor Characteristics

Aim:

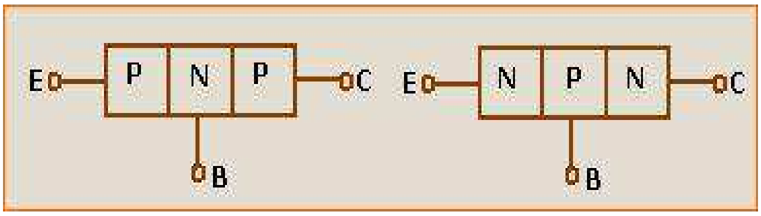
To study the static characteristics of a Transistor (common emitter configuration)

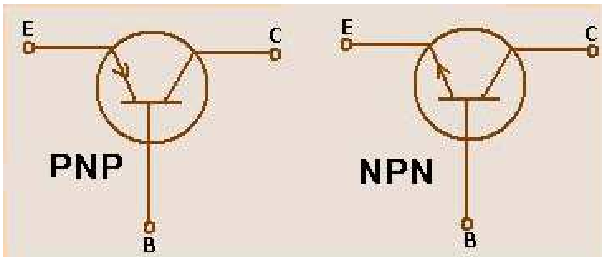
Apparatus required:

NPN transistor, power supply, voltmeter, ammeter.

Theory:

A transistor is a solid state device used to amplify or switch electronic signals and electric power. A transistor consists of two pn junctions formed by sandwiching either P-type or N-type semiconductor between a pair of opposite types. There are two types of transistors, namely, N-P-N transistor and P-N-P transistor. The transistor can be regarded as a combination of two diodes connected back to back. There are three terminals taken from each type of semiconductor. The emitter, base and collector are provided with terminals which are labeled as E, B and C. The symbols employed for P-N-P and N-P-N transistor is as shown below. The arrow head is always at the emitter (not at the collector) and in each case, its direction indicates conventional direction of current flow. For a PNP transistor, the arrow head points emitter to base(emitter is positive with respect to base and also to the collector). And for a NPN transistor, arrow head points base to emitter(base is positive with respect to emitter and also with collector terminal)





1. **Emitter**: It forms left hand section of the transistor. It is more heavily doped than any other regions because its main function is to supply majority charge carriers, either electrons or holes.(electrons if emitter is N-type and holes if emitter is P-type)
2. **Base**: It forms the middle section of the transistor. It is very thin (of the order of 10^{-6}m) when compared with other sections, emitter and collector and is very lightly doped.
3. **Collector**: It forms the right hand section of the transistor and is lightly doped. Its main function as the name implies that to collect the majority charge carriers through base. The collector region is made physically larger when compared with other regions because it has to dissipate much greater power. And because of this reason, we cannot interchange the regions emitter to collector and vice versa. However, for the sake of convenience, it is customary to show emitter and collector to be of equal size.

There are 3 leads in a transistor viz emitter, base and collector terminals, However when a transistor is to be connected in a circuit, we require four terminals, two for input and two for the output. It can be done by making one transistor terminal as common to both input and output terminals. The input is fed between this common terminal and one of the other two terminals. Accordingly, a transistor can be connected in a circuit in three different ways. Each circuit has its own advantages and disadvantages.

(i) common base configuration (CB)
(ii) common emitter configuration (CE)
(iii) common collector configuration(CC)

For proper working of a transistor, it is essential to apply voltages of correct polarity across its two junctions. The proper flow of zero signal collector current and the maintenance of proper collector-emitter voltage during the passage of signal is known as transistor biasing.

Cutoff mode*: both junctions are reverse biased.*

Saturation mode: *both junctions are forward biased*

Active mode: *base - emitter junction is forward biased and collector –base is reverse biased.*

When the emitter-base junction is forward biased, majority charge carriers are repelled from the emitter and the junction offers very low resistance to the current and when the collector-base junction is reverse biased, the majority carriers are attracted and the junction offers a high resistance to the current.

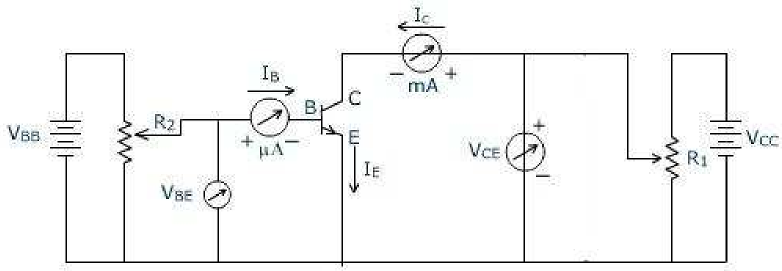
The fundamental relation between the currents in a transistor circuit can be obtained by Kirchhoff's current law and is given by,

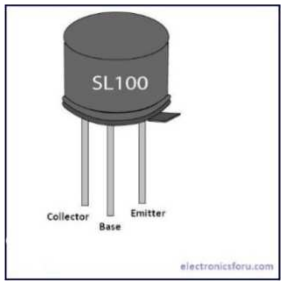
$$I_E = I_B + I_C$$

which is true for all types of transistors and of all transistor configurations.

Common Emitter Static Characteristics:

The static characteristicsof a transistor in CE configuration are determined by the following circuit. A micro ammeter is connected in series with the base to measure I_B , base current. Similarly, a milli ammeter is connected in series to the collector circuit to measure I_C, collector current. A voltmeter is connected across base and emitter terminals for measuring V_{BE} and second voltmeter is connected across collector-emitter terminals to measure the output of collector –emitter voltage, V_{CE} . The rheostats R2 and R1 were used to vary the base voltage(input voltage) and collector voltage(output voltage)





Circuit for obtaining the characteristics of a npn transistor

Procedure:

(I). Input Characteristics: It shows how base current, I_B varies with changes in V_{BE} when V_{CE} is kept constant.

1. Switch on the unit. Initially keep the knob R2 to minimum position and adjust the collector voltage V_{CE} as 5 V by R1 and keep it constant for the whole experiment.

2. Increase the base - emitter voltage V_{BE} in steps, and in each time measure I_B.

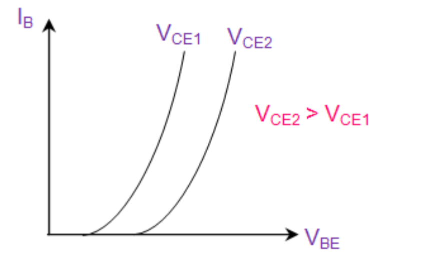
3. Plot I_B (in µA)vs. V_{BE} (in volts)

4. Repeat the above experiment for different values of V_{CE}.

The input impedance of the transistor is defined as the ratio of small change in base-emitter voltage to the corresponding change in the base current at a given V_{CE}.

The overall shape resembles the forward characteristics of a PN diode and as shown below. The reciprocal of the slope gives the input resistance R_{in} of the transistor. Due to initial non-linearity of the curve R_{in}varies considerably from a value of 4kΩ near the origin to a value of 600Ω over the more linear part of the curve.

$$R_{in} = \left.\frac{\Delta V_{BE}}{\Delta I_B}\right|_{V_{CE}=constant}$$



Input Characteristics for CE Configuration

II.Output characteristics: It shows how collector current, I_C varies with changes in $V_{CE}$when I_B is held constant.

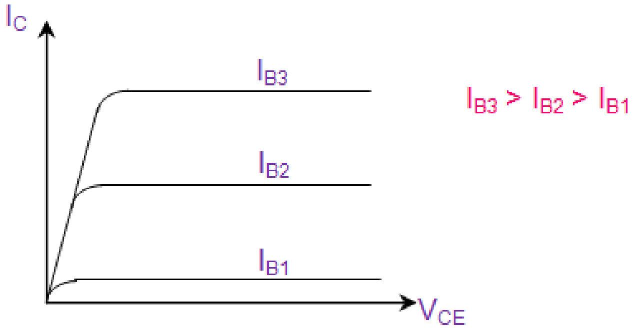
1. Keep the base current, I_B to some convenient value (say 20µA) and maintained constant.

2. Increase V_{CE} from zero in steps and measure collector current, I_C in each time.

3. Plot I_c (in mA) vs. V_{CE} (in volts)

3. Repeat the above experiment for different values of collector current, I_B. and family of curves are obtained in this way.

$$R_{out} = \left.\frac{\Delta V_{CE}}{\Delta I_C}\right|_{I_B=constant}$$



Output Characteristics for CE Configuration

The output impendence is defined as the ratio of variation in the collector-emitter voltage to the corresponding variation in the collector current at a constant base current.

It is seen from the plot that as V_{CE} increases from zero, I_C rapidly increases to a near saturation value of I_B. *(It is observed that a small collector current flows even when base current I_B is zero which is called common emitter leakage current, I_{CEO} which is equals to $(1+\beta)I_{CO}$, where I_{CO} is due to the flow of minority carriers across the reverse biased collector base junction)*

The value of output resistance over the near horizontal part of the characteristic varies from 10kΩ to 50 kΩ

III. Current transfer characteristics: It shows how collector current I_C varies with changes in I_B when V_{CE} is kept constant.

1. Keep collector emitter voltage V_{CE} constant.

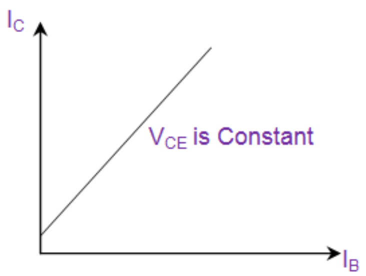
2. Increase the base current, I_B and measure collector current, I_C.

3. Plot the base current I_B Vs collector current I_C.

4. Repeat the above experiment with different values of V_{CE}.

The current gain is defined as the ratio of a small change in the collector current to the corresponding change in the base current at constant V_{CE}.

$$\beta = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}=constant}$$



Transfer Characteristics for CE Configuration

Table. 1. Input Characteristics.

Sl.No.	V_{CE} = (V)		V_{CE} = (V)		V_{CE} = (V)	
	V_{BE} (V)	I_B (μA)	V_{BE} (V)	I_B (μA)	V_{BE} (V)	I_B (μA)

Table. 2 Output Characteristics.

Sl.No.	I_B =(μA)		I_B =(μA)		I_B =(μA)	
	V_{CE} (V)	I_C (mA)	V_{CE} (V)	I_C (mA)	V_{CE} (V)	I_C (mA)

Table.3 Current Transfer Characteristics.

Sl.No.	V_{CE}= (V)		V_{CE}= (V)		V_{CE}= (V)	
	I_B(μA)	I_C(mA)	I_B(μA)	I_C(mA)	I_B(μA)	I_C(mA)

Write a summery and comment on your results

10. Magnetic field along the axis of the coil

Aim: Plot the graph showing the variation of magnetic field with distance along the axis of a circular coil carrying current.

Apparatus required: Tangent galvanometer placed on a bench, DC power supply, a rheostat, a commutator, plug key and connecting wires and an ammeter.

Formula used: The magnitude of the magnetic field, F, along the axis of a coil is given by,

$$F = \frac{\mu_0 n i r^2}{2(r^2 + x^2)^{3/2}}.$$

where n = number of turns in the coil,

r = radius of the coil,

i = current in amperes flowing in the coil,

x = distance of the point from the center of the coil and

μ_0 = magnetic permeability in vacuum.

If $\boldsymbol{F}$ is made perpendicular to $\boldsymbol{H}$, the horizontal component of the earth's magnetic field, the deflection θ of the needle is given by, $F = H \tan\theta$. Thus, one has

$$F = \frac{\mu_0 n i r^2}{2(r^2 + x^2)^{3/2}} = H \tan\theta$$

Description of the apparatus:

It consists of a circular coil of many turns of insulated thin copper wire. It is fixed with its plane vertical on a horizontal bench. A magnetometer compass box is placed inside the coil such that it can slide on the bench in such a way that the center of the needle always lies on the axis of the coil. The distance of the needle from the center can be read on the graduated scale fixed on the arms of the magnetometer.

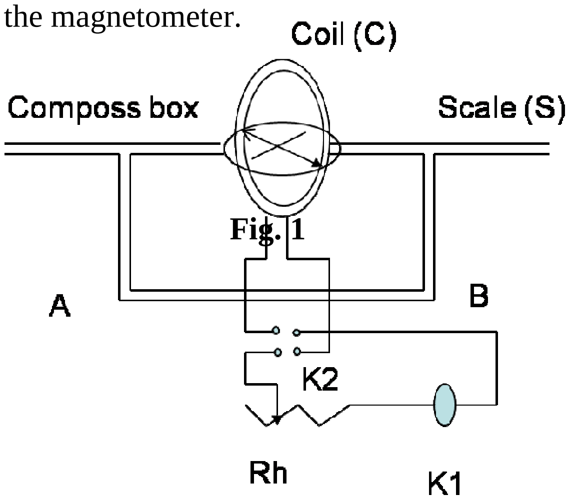


Fig. 1

Procedure:

1. Place the magnetometer box on the sliding bench such that its magnetic needle is at the centre of the coil. By rotating the whole apparatus in the horizontal plane, set the coil in the magnetic meridian. In this case the coil, needle and its image all lie in the same vertical plane. Rotate the compass box until the pointer ends read 0-0 on the circular scale.
2. To set the coils exactly in the same magnetic meridian, setup the electrical connections as in the figure. Pass the current in one direction by the help of commutator. Note the readings of the ends of the pointer. Reverse the current direction. Again note the readings. If both the readings are the same then the coil is in the magnetic meridian. Otherwise adjust again.
3. Assign *sensible* least counts to all readings as well as constants such as radius of the coil, the current as well as the displacement and deflections.
4. Using the rheostat adjust the current such that the deflection of 50^o to 70^o is produced in the compass needle placed at the center of the coil. Read both ends of the pointer. Reverse the direction of the current and again note the readings. The mean of four readings give the mean deflection at x= 0.
5. Now displace the compass box through 1-4 cm such that the change is deflection is around 4-5^o and repeat the experiment keeping the current unchanged throughout. Carry out the experiment for displacements on both sides of the coil assigning negative displacement to a side.
6. Repeat the experiment by shifting the compass box to the other side of the coil.
7. Plot a graph taking displacement along the x- axis and $\tan\theta$ along the y-axis with the centre of the coil as the origin.
8. Next compute the magnetic field F. for each deflection/displacement and plot the magnetic field vs $\tan\theta$ (on the x-axis). Estimate the horizontal component of the earth's magnetic field from the slope of the best fit straight line for the plotted data. Using the various least counts, estimate the errors in F as well as $\tan\theta$ and indicate them as error bars in the plot.

Table 1

x	Deflection on east arm(degrees)						Deflection on west arm(degrees)					
	Current in one way		Reverse		Mean	$\tan\theta$	Current in one way		Reverse		Mean	$\tan\theta$

where θ is the mean of four deflections for the east and west arms respectively.

Table 2

$\tan\theta$	$\delta\tan\theta$	F	δF