Class 12

2017-18

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27. EXPERIMENTAL PHYSICS

1. PREVIEW

This lesson aims to make the student familiar with the basic approach and observations of physics experiments and activities. It covers the basics of all the physics experiments for class 11^{th} and 12^{th} based on the latest NCERT pattern. This is indeed very beneficial for JEE aspirants as it has a direct 20% weightage in the JEE MAIN examination. Therefore, it is recommended that the student goes through this material thoroughly for his/ her benefit in JEE MAIN examination.

Experiment 1: Vernier Callipers – It is Used to Measure Internal and External Diameter and Depth of a Vessel

What is a vernier caliper?

(a) A vernier caliper has two scales - one main scale and a vernier scale - which slides along the main scale. The main scale and vernier scale are divided into small divisions of different magnitudes.

The main scale is graduated in cm and mm. It has two fixed jaws, A and C, projected at right angles from the scale. The sliding vernier scale has jaws (B.D) projecting at right angles from it as also the main scale and a metallic strip (N). The zero of the main scale and the vernier scale coincide when the jaws are made to touch each other. The jaws and metallic strip are designed to measure the distance/ diameter of objects. Knob P is used to slide the vernier scale on the main scale. Screw S is used to fix the vernier scale at a desired position.

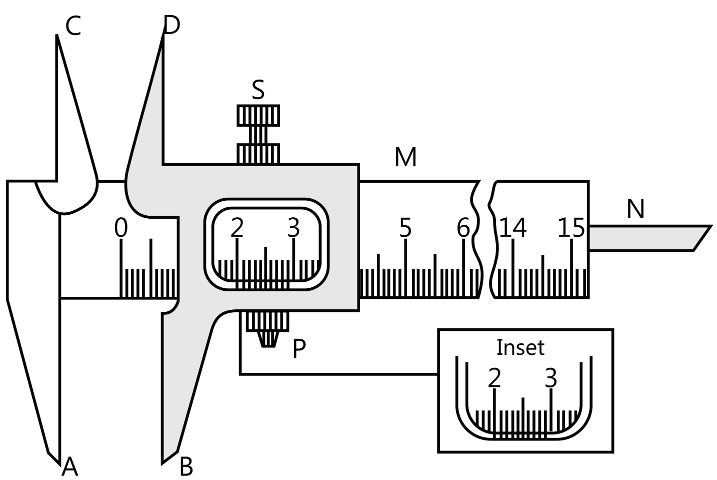


Figure 27.1

(b) The least count of a common scale is 1mm. It is difficult to further divide it to improve the least count of the scale. A vernier scale enables this to be achieved.

The difference in the magnitude of one main scale division (M.S.D) and one vernier scale division (V.S.D) is known as the least count of the instrument, as it is the smallest distance that can be measured using the instrument.

$n\,V.S.D. = (n-1)\,M.S.D.$

Procedure

(a) Measuring the diameter of a small spherical or cylindrical body.

(i) Keep the jaws of the Vernier Calipers closed. Observe the zero mark on the main scale; it must perfectly coincide with that of the vernier scale. If not, account for the zero error for all observations to be made while the instrument is being used. Look for the division on the vernier scale that coincides with a division of main scale. Use a magnifying glass, if available and note the number of division on the vernier scale that coincides with that on the main scale. Position your eyes directly over the division mark so as to avoid any parallax error.

(ii) Gently loosen the screw to release the movable jaw. Slide it enough to hold the sphere/ cylindrical body gently (without any undue pressure) between the lower jaws AB. The jaws should be perfectly perpendicular to the diameter of the body. Now, gently tighten the screw in order to clamp the instrument in this position to the body.

(iii) Carefully note the position of the zero mark of the vernier scale against the main scale. Usually, it will not perfectly coincide with any of the small divisions on the main scale. Record the main scale division just to the left of the zero mark of the vernier scale.

(iv) Start looking for exact coincidence of a vernier scale division with that of a main scale division in the vernier window from the left end (zero) to the right. Note its number (say) N, carefully.

(v) Multiply 'N' by the least count of the instrument and add the product to the main scale reading noted in step 4. Ensure that the product is converted into proper units (usually cm) for addition to be valid.

(vi) Repeat steps 3-6 to obtain the diameter of the body at different positions on its curved surface. Take three sets of readings in each case.

(vii) Record the observations in the tabular form with proper units. Apply zero correction if required.

(viii) Find the arithmetic mean of the corrected readings of the diameter of the body. Express the results in suitable units with appropriate number of significant figures.

(b) Measuring the internal diameter and depth of the given beaker (or similar cylindrical object) to find its internal volume.

(i) Adjust the upper jaws 'CD' of the Vernier Calipers so as to touch the inner wall of the beaker without exerting undue pressure on it. Gently tighten the screw to keep the Vernier Calipers in this position.

(ii) Repeat the steps 3-6 as in Part (a) to obtain the value of the internal diameter of the beaker/ calorimeter. Do this for two different (angular) positions of the beaker.

(iii) Keep the edge of the main scale of Vernier Calipers on the peripheral edge of the beaker in order to determine the depth of the beaker. This should be done in such a way that the tip of the strip is able to go freely inside the beaker along its depth.

(iv) Keep sliding the moving jaw of the Vernier Calipers until the strip just touches the bottom of the beaker. Take care that it does so while being perfectly perpendicular to the bottom surface. Now tighten the screw of the Vernier Calipers.

(v) Repeat steps 4-6 of Part (a) of the expertiment to obtain the depth of the given beaker. Take the readings for depth at different positions of the breaker.

(vi) Record the observations in tabular form with proper units and significant figures. Apply zero corrections, if required.

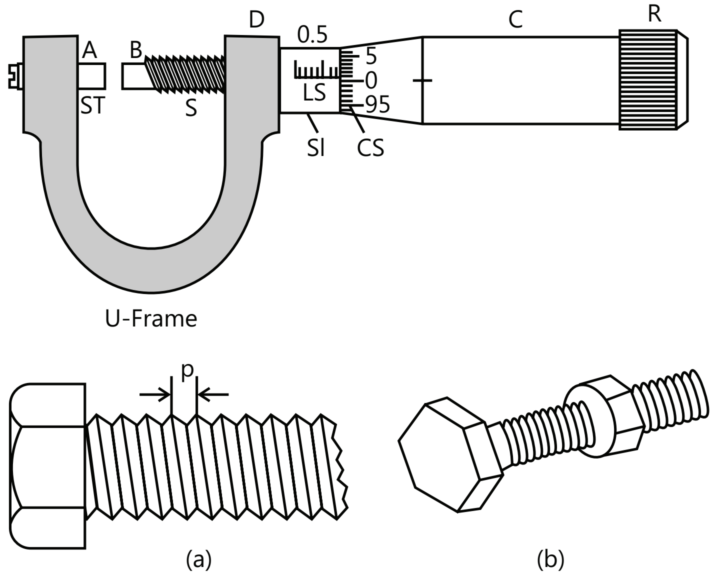
(vii) Find out the mean of the corrected readings of the internal diameter and depth of the given beaker. Express the result in suitable units and proper significant figures.

Follow similar procedure for calculating the external diameter and by adjusting the upper jaws CD of the Vernier Caliper so as to touch the walls of the beaker from the outside.

Experiment 2: Screw Gauge – Its Use to Determine Thickness/ Diameter of Thin Sheet/ Wire

What is a screw gauge?

With Vernier Calipers, you are usually able to measure length accurately up to 0.1mm. More accurate measurement of length up to 0.01mm or 0.005mm may be made by using a screw gauge. As such, a screw gauge is an instrument of higher precision than Vernier Calipers. You may have observed an ordinary screw [see Fig 27.2 (a)]. There are threads on a screw. The separation between any two consecutive threads is the same. The screw can be moved backward or forward in this nut by rotating it clockwise or anticlockwise [Fig 27.2. (b)].



A screw (a) without nut (b) with nut

Figure 27.2

The distance generated by the screw when it makes its one complete rotation is the separtation between two consecutive threads. This distance is called the pitch of the screw. Fig 27.2. (a) shows the pitch (p) of the screw. It is usually 1mm or 0.5mm. The first Fig 27.2 shows a gauge. It has a screw 'S' which advances forward or backward as one rotates the head 'C' through rachet 'R'. There is a linear scale 'LS' attached to limb 'D' of the U frame. The smallest division on the linear scale is 1mm (in one type of screw gauge). There is a circular scale 'CS' on the head which can be rotated. There are 100 divisions on the circular scale. When the end 'B' of the screw touches the surface 'A' of the stud 'ST', the zero marks on the main scale and the circular scale should coincide with each other.

ZERO ERROR: When the end of the screw and the surface of the stud are in contact with each other, the linear scale and the circular scale reading should be zero. In case this is not so, the screw gauge is said to have an error called zero error.

Fig 27.3. Shows an enlarged view of a screw gauge with its faces A and B in contact. Here, the zero mark of LS and CS coincide with each other.

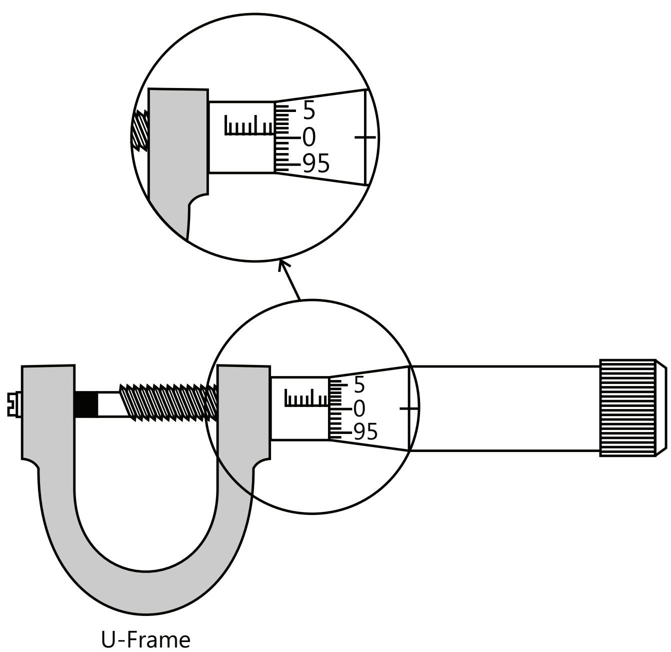
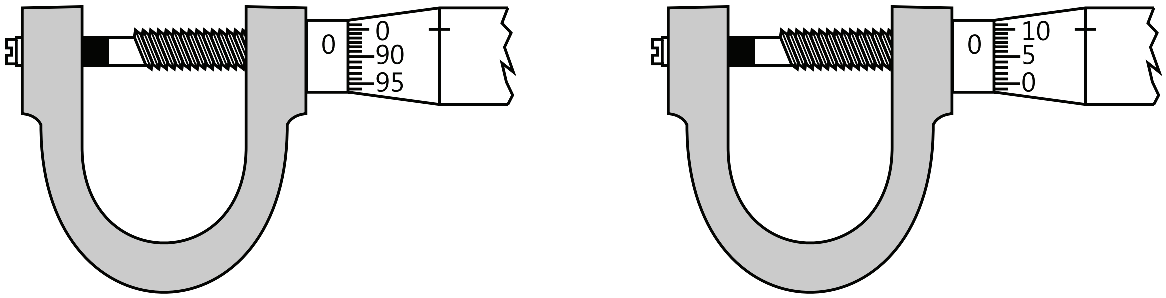


Figure 27.3

When the reading on the circular scale across the linear scale is more than zero (or positive), the instrument has **Positive Zero Error**, as shown in Fig 27.4. (a).

When the reading of the circular scale across the linear scale is less than zero (or negative), the instrument is said to have **Negative Zero Error**, as shown in Fig 27.4. (b).



(a)
Showing a positive zero error

(b)
Showing a positive zero error

Figure 27.4

Taking the Linear Scale Reading: The mark on the linear scale which lies close to the left edge of the circular scale is the linear scale reading. For example, the linear scale reading as shown in the Fig 27.5.

Taking Circular Scale Reading: The division of circular scale which coincides with the main scale line is the reading of circular scale. For example, in the adjacent Fig 27.5, the circular scale reading is 2.

Total Reading

Total reading

= linear scale reading + circular scale reading least count

= 0.5+2*0.001

= 0.502 cm

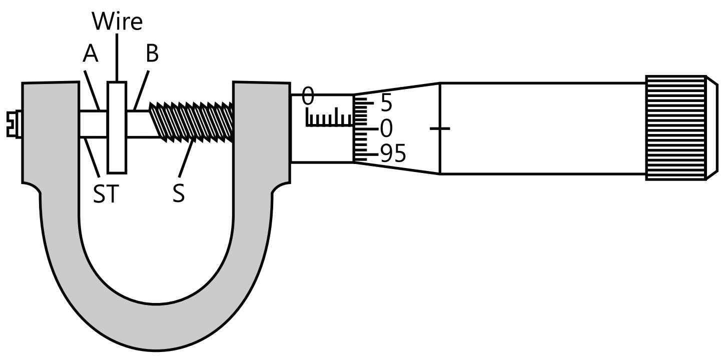


Figure 27.5

Principle: The linear distance moved by the screw is directly proportional to the rotation given to it. The linear distance moved by the screw when it is rotated by one division of the circular scale is the least distance that can be measured accurately by the instrument. It is called the least count of the instrument.

$$\text{Least count} = \frac{\text{pitch}}{\text{No. of divisions on circular scale}}$$

For example, for a screw gauge with a pitch of 1mm and 100 divisions on the circular scale, the least count is 1mm/100=0.01mm

This is the smallest length that can be measured with this screw gauge.

(a) Measurement of Diameter of a Given Wire

Procedure

(i) Take the screw gauge and make sure that the rachet R on the head of the screw functions properly.

(ii) Rotate the screw through, say, ten complete rotations and observe the distance through which it has receded. This distance is the reading on the linear scale marked by the edge of the circular scale. Then, find the pitch of the screw, i.e., the distance moved by the screw in one complete rotation. If there are n distance moved by the screw in one complete rotation. If there are n number of divisons on the circular scale, then distance moved by the screw when it is rotated thorugh one division on the circular scale is called the least count of the screw gauge, that is, $\text{Least count} = \frac{\text{pitch}}{\text{n}}$

(iii) Insert the given wire between the screw and the stud of the screw gauge. Move the screw forward by rotating the rachet till the wire is gently gripped between the screw and the stud as shown in the Fig 27.6. Stop rotating the rachet the moment you hear a click sound.

Take the readings on the linear scale and the circular scale.

(iv) From these two readings, obtain the diameter of the wire.

(v) The wire may not have an exactly circular cross section. Therefore, it is necessary to measure the diameter of the wire for two positions at right angles to each other. For this, first record the reading of diameter d_1 [Fig 27.6 (a)] and then rotate the wire through 90 at the same cross-sectional position. Record the reading for diameter d_2 in this position [Fig 27.6(b)].

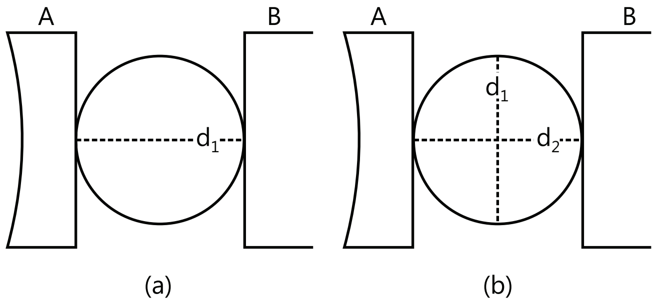


Figure 27.6

(vi) The wire may not be truly cylindrical. Therefore, it is necessary to measure the diameter at several different places and obtain the average value of the diameter. For this, repeat the steps 3-6 for three more positions of the wire.

(vii) Take the mean of the different values of the diameter so obtained.

(viii) Substract zero error, if any, with proper sign to get the correct value for the diameter of the wire.

(b) Measurement of Thickness of a Given sheet

Procedure

(i) Insert the given sheet between the studs of the screw gauge and determine the thickness at five different positions.

(ii) Find the average thickness and calculate the correct thickness by applying zero error by following the steps followed earlier.

Experiment 3: Simple Pendulum – Dissipation of Energy by Plotting a Graph between Square of Amplitude and Time

Principle: When a simple pendulum executes simple harmonic motion, the restoring force F is given by

$$F(t) = -kx(t) \quad \text{(i)}$$

Where x(t) is the displacement at time t and $k = mg/L$. The displacement is given by

$$x(t) = A_0 \cos(\omega t - \theta) \quad \text{(ii)}$$

Where ω is the (angular) frequency and θ is a constant. A_0 is the maximum ..displacement in each oscillation, which is called the amplititude. The total energy of the pendulum is given as

$$E = \frac{1}{2}kA_0^2 \qquad \text{...(iii)}$$

The total energy remains a constant in an ideal pendulum, because its amplitude remain constant.

But in a real pendulum, the amplitude never remains constant. It decreases with time due to serveral factors like air drag, some play at the point of suspension, imperfection in rigidity of the string and suspension, etc. Therefore, the amplitude of A_0 falls with time at each successive oscillation. The amplitude becomes a function of time and is given by

$$A(t) = A_0 e^{-\lambda t/2} \qquad \text{...(iv)}$$

Where A_0 is the initial amplitude and λ is a contant which depends on damping and the mass of the bob. The total energy of the pendulum at time t is then given by

$$E(t) = \frac{1}{2}kA^2(t) = E_0 e^{-\lambda t} \qquad \text{...(v)}$$

Thus, the energy falls with time, because some of the energy is being lost due to the surroundings.

The frequency of a damped oscillator does not depend much on the amplitude. Therefore, instead of measuring the time, we can also measure the number of oscillations n. At the end of n oscillations, $t = nT$, where T is the time period. Then Eq. (v) can be written in the form $E_n = E_0 e^{-\alpha n}$

where $\quad \alpha = \lambda T \qquad$ ...(vi)

and E_n is the energy of the oscillator at the end of n oscillations.

Procedure

(a) Find the mass of the pendulum bob.

(b) Fix a metre scale just below the pendulum, such that the zero mark of the scale is just below the bob at rest.

(c) When the pendulum oscillates, you have to observe the point on the scale above which the bob rises at its maximum displacement. When doing so, do not worry about millimeter marks. Take observations only upto 0.5cm.

(d) Pull the pendulum bob so that it is above the 15cm mark. Thus, the initial amplitude will be. $A_0 = 15\text{cm at } n = 0$. Leave the bob gently so that it starts oscillating.

(e) Keep counting the number of oscillations when the bob is at its maximum displacement on the same side.

(f) Record the amplitude A_n after every ten oscillations.

(g) Plot a graph of A_n^2 versus n, and interpret the graph.

(h) Stick a piece of cotton or a small strip of paper to the bob so as to increase the damping, and repeat the experiment.

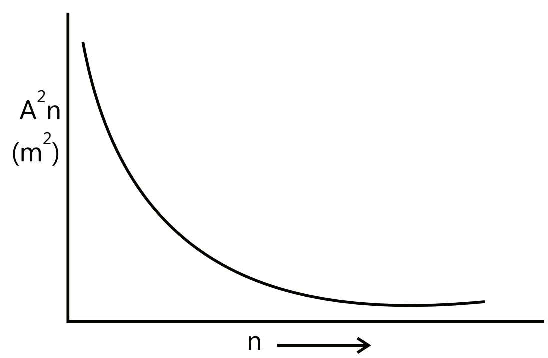


Figure 27.7

Experiment 4: Metre Scale – Mass of a Given Object by Principle of Moments

Principle: For a body free to rotate about a fixed axis in equilibrium, the sum of the clockwise moments is equal to the sum of the anticlockwise moments.

If M_1 is the known mass, suspended at a distance l_1 on one side from the centre of gravity of a beam and M_2 is the unknown mass, suspended at a distance l_2 on the other side from the centre of gravity, and the beam is in equilibrium, then $M_2 l_2 = M_1 l_1$

Procedure:

(a) Create a raised platform on a table. One can use a wooden or a metal block to do so. However, the platform must be a sturdy. Place a wedge on a laboratory stand about 20cm above the table top. With the help of a spirit level, set the level of the wedge horizontal.

(b) Use two loops of thread to suspend the unknown mass and the weights from the metre scale (beam). Insert the loops at about 10 cm from the edge of the metre scale from both sides.

(c) Place the metre scale with thread loops on the wedge and adjust it till it is balanced. Mark two points on the scale above the wedge where the scale is balanced. Join these two points with a straight line which would help pin point the location of balance position even if the scale topples off the wedge for some reason. This line is passing through the centre of gravity of the scale.

(d) Take the unknown mass in one hand. Pick a weight from the weight box that is nearly equal to the unknown mass when it is held in the other hand.

(e) Suspend the unknown mass from either of the two loops of thread attached to the metre scale. Suspend the known weight from the other loop as shown in Fig 27.8.

(f) Adjust the position of the known weight by moving the loop till the metre scale is balanced on the sharp wedge. Make sure that in the balanced position, the line drawn in Step 3 is exactly above the wedge. Also ensure that the thread of the two loops passing over the scale is parallel to this line.

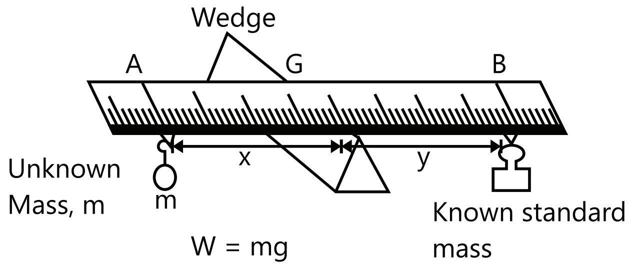


Figure 27.8: Experimental set up for determination of mass of a given body

(g) Measure the distance of the position of the loop from the line drawn in Step 3. Record your observations.

(h) Repeat the activity at least twice, each time with a slightly lighter and a heavier weight. Note the distance of unknown mass and weight from line drawn in Step 3 in each case.

Experiment 5: Young's Modulus of Elasticity of the Material of a Metallic Wire

Principle:

The apparatus works on the principle of Hookes' Law. If l is the extension in a wire of length L and radius r due to force F (=mg), the Young's Modulus of the material of the given wire, Y, is $Y = \dfrac{MgL}{\pi r^2 l}$

Procedure:

(a) Suspend weights from both the hooks so that the two wires are stretched and become free from any kinks. Attach only the constant weight W on the reference wire to keep it tight.

(b) Measure the length of the experimental wire from the point of its support to the point where it is attached to the frame.

(c) Find the least count of the screw gauge. Determine the diameter of the experimental wire at about five points, and at each point in two mutually perpendicular directions. Find the mean diameter and subsequently, the radius of the wire.

(d) Find the pitch and the least count of the miocrometer screw attached to the frame. Adjust it such that the bubble in the spirit level is exactly in the centre. Take the reading of the micrometer.

(e) Place a load on the hanger attached to the experimental wire and increase it in increments of 0.5kg. For each load, bring the bubble of the spirit level to the centre by adjusting the micrometer screw and the note its reading. Take precautions to avoid backlash error.

(f) Take about 8 observations for increasing load.

(g) Decrease the load in reductions of 0.5kg, and each time, take a reading on the micrometer screw as in step 5.

Experiment 6: Surface Tension of Water by Capillary Rise and Effect of Detergents

Principle

When a liquid rises in a capillary tube [Fig 27.9], the weight of the column of the liquid of density ρ below the meniscus is supported by the upward force of surface tension acting around the circumference of the points of contact. Therefore,

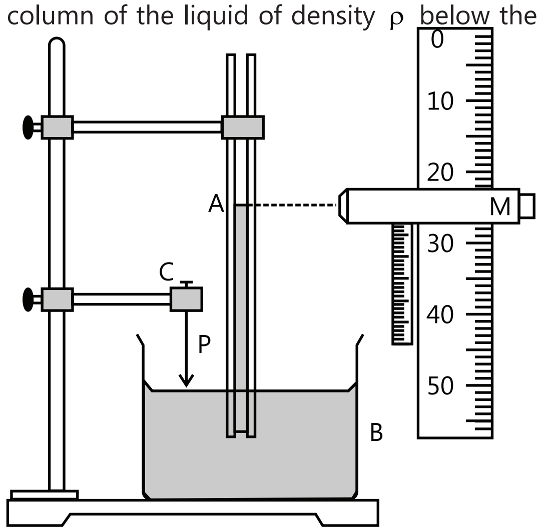
$2\pi rT = \pi r^2 h\rho g$ (approx.) for distilled water in contact with a clean glass capillary.

or $\quad T = \dfrac{h\rho gr}{2}$

where $\quad$ T = Surface tension of the liquid

h = Height of the liquid column and

r = Inner radius of the capillary tube



Rise of liquid in capillary tube

Figure 27.9

Procedure

(a) Do the experiment in a well-lit place. For example, near a window or use an incandescent bullb.

(b) Clean the capillary tube and beaker successively in caustic soda and nitric acid and rinse thoroughly with water.

(c) Fill the beaker with water and measure its temperature.

(d) Clamp the capillary tube near its upper end, keeping it above the beaker. Set it up vertically with the help of a plumbline held near it. Move down the tube so that its lower end dips into the water in the beaker.

(e) Push a pin P through a cork C, and fix it on another clamp such that the tip of the pin is just above the water surface as shown in the Fig 27.9. Ensure that the pin does not touch the capillary tube. Slowly, lower the pin till the tip just about touches the water surface. This can be done by matching the tip of the pin with its image in water.

(f) Now, focus the travelling microscope M on the meniscus of the water in capillary A, and move the microscope until the horizontal crosswire is tangential to the lowest point of the meniscus, which is seen inverted in M. If there is any difficulty in focusing the meniscus outside the capillary tube, then focus it first, as a guide. Note the reading of the travelling microscope.

(g) Mark the position of the meniscus on the capillary with a pen. Now carefully remove the capillary tube from the beaker, and then the beaker without disturbing the pin.

(h) Focus the microscope on the tip of the pin and note the microscope reading.

(i) Cut the capillary tube carefully at the point marked on it. Fix the capillary tube horizontally on a stand. Focus the microscope on the transverse cross section of the tube and take a reading to measure the internal diameter of the tube in two mutually perpendicular directions.

AIM: To study the effect of detergent on surface tension of water by observing capillary rise.

Principle: Substances that can be used to separate grease, dust and dirt sticking to a surface are called detergents. When added to water, detergents lower its surface tension due to additional intermolecular interactions.

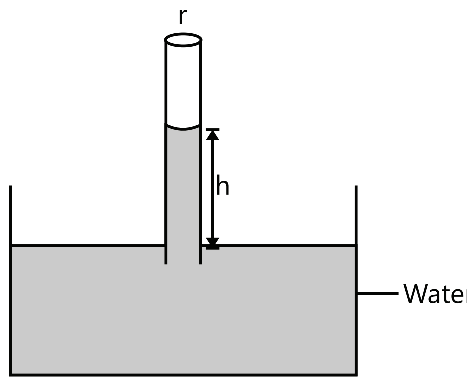
The lowering of surface tension by addition of detergent in water can be observed by capillary rise method.

For a vertically placed capillary tube of radius r in a water – filled shallow vessel, the rise of water in capillary tube h (Fig. 27.10) is given by: $h = \dfrac{2S\cos\theta}{\rho gr}$ or $s = \dfrac{h\rho gr}{2\cos\theta}$

Where S is surface tension of the water vapour film; θ is the contact angle (Fig. 27.10), ρ is the density of water and g is the acceleration due to gravity. For pure or distilled water in contact with a clean glass capillary tube $\theta = 0^0$ or cos $\theta = 1$. Thus, $S = \frac{1}{2}h\rho gr$

Using this result, the surface tension of different detergent solutions (colloidal) in water can be compared. In a detergent solution, the capillary rise (or the surface tension) would be lower than that for pure and distilled water. And an increase in a detergent's concentration would result in a further lowering of the rise of the solution in the capillary.

A detergent for which the capillary rise is minimum (or the one that causes maximum lowering of surface tension), is said to be more cleansing.



Rise of water in capillary tube

Figure 27.10

Procedure

(a) Take a capillary tube of uniform bore, and clean and rinse it with distilled water. Use water to clean and rinse the beaker as well. Pour enough water to fill half the beaker. Make sure that the capillary tube is dry and free of grease, oil, etc. Also cleck that the top of the capillary tube is open and not blocked by anything.

(b) Take a plastic scale and mount the capillary tube on it using rubber bands.

(c) Hold the scale with the capillary in the vertical position with the help of a clamp stand.

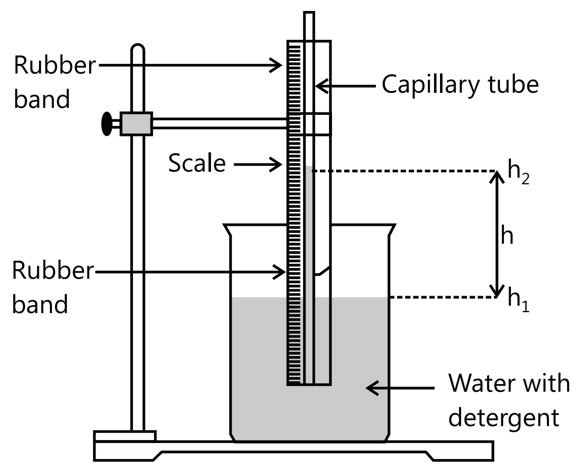
(d) Place the half-filled beaker below the lower end of the scale and gradually lower the scale till its lower end is immersed below the surface of water in the beaker as shown in the Fig 27.11.

(e) Read the position of the water level inside and outside the capillary tube on the scale. Let the position be $h = h_2 - h_1$.

(f) Rinse the capillary thoroughly in running water and dry it.

(g) Take a small amount of the given detergent and mix it with the water in the beaker.

(h) Repeat the experiment with detergent solution and find the capillary rise again. Let it be h'.



To study capillary in water and detergent mixed in it

Figure 27.11

Experiment 7: Coefficient of Viscosity of a Given Viscous Liquid by Measuring Terminal Velocity of a Given Spherical Body

Principle: When a spherical body of radius r and density σ falls freely through a viscous liquid of density ρ and viscosity η with terminal velocity υ, then the sum of the upward buoyant force and viscous drag, force F, is balanced by the downward weight of the ball (Fig 27.12).

Gravitational force = Buoyant force on the ball + viscous force

$$\frac{4}{3}\pi r^3 \sigma g = \frac{4}{3}\pi r^3 \rho g + 6\pi\eta r \upsilon \qquad \text{... (i)}$$

or $$\upsilon = \frac{\frac{4}{3}\pi r^3 (\sigma - \rho) g}{6\pi\eta r} = \frac{2}{9}\frac{r^2(\sigma-\rho)g}{\eta} \qquad \text{...(ii)}$$

where υ is the terminal velocity, the constant velocity acquired by a body while moving through viscous fluid under application of constant force.

The terminal velocity depends directly on the square of the size (diameter) of the spherical ball. Therefore, if several spherical balls of different radii are made to fall freely through the viscous liquid, then a plot of υ vs r^2 would be a straight line as illustrated in Fig 27.12.

The shape of this line will give an average value of $\frac{\upsilon}{r^2}$ which may be used to find the coefficient of viscosity η of

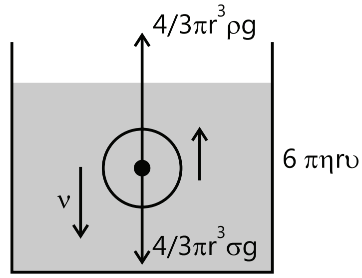


Figure 27.12

the given liquid. Thus $\eta = \frac{2}{9}(\sigma - \rho)g.\frac{r^2}{\upsilon} = \frac{2}{9}\frac{(\sigma - \rho)g}{(\text{slope of line})}$ Nsm^{-2}(poise) ...(iii)

The relation given by Eq. (iii) holds good if the liquid through which the spherical body falls freely is in a cylindrical vessel of radius R>>r, and the height of the cylinder is enough to let the ball attain terminal velocity. At the same time, the ball should not come in contact with the walls of the vessel.

Procedure: Graph between terminal υelocity υ, and square of radius of ball r^2

(a) Find the least count of the stop-watch.

(b) Note the room temperature, using a thermomerter.

(c) Take a wide bore tube of transparent glass or acrylic (of diameter about 4cm and of length approximately 1.25m). Fit a rubber stopper at one end of the tube and ensure that it is air-tight. Fill it with the given transparent viscous liquid (say glycerine). Fix the tube vertically in the clamp stand as shown in the Fig 27.13. Ensure that there are no air bubbles inside the viscous liquid in the wide bore tube.

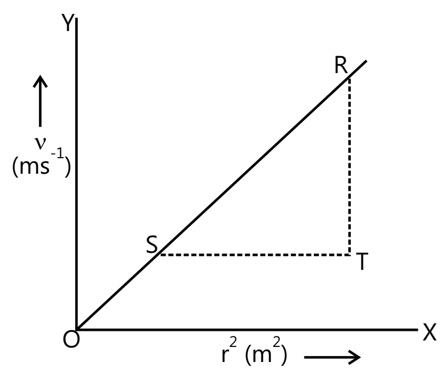


Figure 27.13

(d) Put three rubber bands A, B, and C around the wide bore tube, thus dividing it into four portions (Fig. 27.13), such that AB=BC, each about 30cm. The rubber band A should be around 40cm below the mouth of the wide bore tube (length sufficient to allow the ball to attain terminal velocity).

(e) Separate a set of clean and dry steel balls of different radii. The set should include four or five identical steel balls of same known radii (r_1). Rinse these balls thorughtly with the experimental viscous liquid (glycerine) in a petridish or a watch glass, else these balls may develop air bubbles on their surface as they enter the liquid column.

(f) Fix a short inlet tube vertically at the open end of the wide tube through a rubber stopper fixed to it. Alternatively, one may also use a glass funnel instead of an inlet tube as shown in the Fig 27.14. With the help of forceps, hold one of the balls of radius r_1 near the top of tube. Allow the ball to fall freely. After passing through the inlet tube, the ball will fall along the axis of the liquid column.

(g) Take two stop watches and start both of them simultaneously as the spherical ball passes through the rubber band A. Stop one the watches as the ball passes through the band B. Allow the second stopwatch to continue and stop it when the ball crosses the band C.

(h) Note the times t_1 and t_2 as indicated by the two stop watches. t_1 is then the time taken by the falling ball to travel from A to B and t_2 is the time taken by it in falling from A to C. If terminal velocity had been

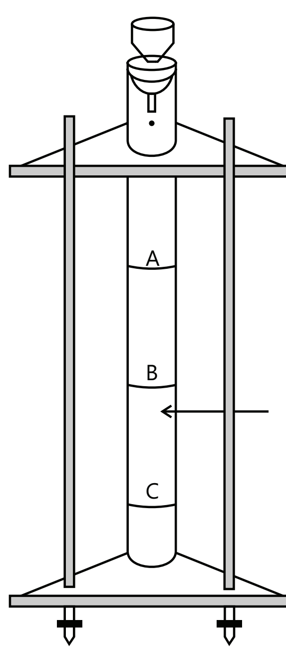


Figure 27.14

attained before the ball crosses A, then $t_2 = 2t_1$. If it is not so, repeat the experiment with a steel ball of same radii after adjusting the position of rubber bands.

(i) Repeat the experiment for other balls of different diameters.

(j) Obtain terminal velocity for each ball.

(k) Plot a graph between terminal velocity υ and square of the radius of spherical ball, r^2. It should be a straight line. Find the slope of the line and thus determine the coefficient of viscosity of the liquid using the relation given by Eq. (iii).

Experiment 8: Plotting a Cooling Curve for the Relationship between the Temperature of a Hot Body and Time

Desctription of Apparatus: As shown in the Fig 27.15, the Newton's law of cooling apparatus has a double-walled container, which can be sealed by an insulating lid. Water filled between these double walls ensures that the temperature of the environment surrounding the calorimeter remains constant. Temperature of the liquid and the calorimeter also remains constant for a fairly long period of time, so that temperature measurement is feasible. Temperature of water in calorimeter is feasible. Temperature of water in calorimeter and that of water between the double walls of the container is recorded by two thermometers.

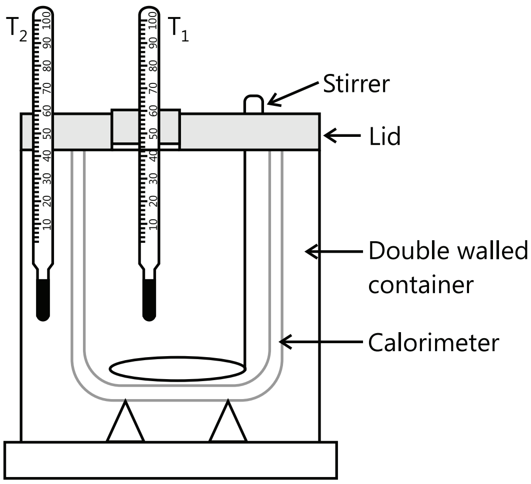


Figure 27.15

Theory: The rate at which a hot body loses heat is directly proportional to the difference between the temperature of the hot body and that of its surroundings, and depends on the nature of the material and the surface area of the body. This is Newton's law of cooling.

For a body of mass m and specific heat s, at its initial temperature θ higher than the temperature of its surroundings θ_0, the rate of loss of heat is $\frac{dQ}{dt}$, where dQ is the amount of head lost by the hot body to its surroondings in a small interval of time.

Following Newton's law of cooling we have

Rate of loss of heat, $\frac{dQ}{dt} = -k(\theta - \theta_0)$ ... (i)

Also $\frac{dQ}{dt} = ms\left(\frac{d\theta}{dt}\right)$ ... (ii)

Using Eqs and the rate of fall of termperature is given by

$$\frac{d\theta}{dt} = -\frac{k}{ms}\left(\theta - \theta_0\right) \quad \text{... (iii)}$$

Where k is the constant of proportionality and $k' = k/ms$ is another constant (The term 'ms' also includes the water equivalent to the calorimeter with which the experiment is performed). Negative sign appears in Eqs. (ii) and (iii) because loss of heat implies temperature decrease. Eq. (iii) may be rewritten as

$$d\theta = -k'\left(\theta - \theta_0\right)dt$$

on intergrating, we get $\int \frac{d\theta}{\theta - \theta_0} = -k' \int dt$

or $\ln\left(\theta - \theta_0\right) = \log_e\left(\theta - \theta_0\right) = k't + c$

or $\ln(\theta-\theta_0)=2.303\log_{10}(\theta-\theta_0)=k't+c$ ... (iv)

Where c is the constant of integration.

Eq. (iv) shows that the shape of a plot between $\log_{10}(\theta-\theta_0)$ and t will be a straight line.

Procedure T_1

(a) Find the least counts of thermometers T_1 and T_2. Take some water in a beaker and measure its temperature (at room temperature θ_0) with one (say T_1) of the thermometers.

(b) Find the least count of the stopwatch/ clock by examining its functions.

(c) Pour water into the double-walled container (enclosure) at room temperature. Insert the other thermometer T_2 in the water contained in it, with the help of the clamp stand.

(d) Heat some water separately to a temperature of about 40^0C above the room temperature θ_0. Pour hot water in the calorimeter right to the top.

(e) Put the calorimeter filled with hot water back into the enclosure and cover it using the lid with holes. Insert the thermometer T_1 and the stirrer in the calorimeter through the holes provided in the lid.

(f) Note the initial temperature of the water between the enclosures of double wall with the thermometer T_2. When the difference of readings of two thermometers . T_1 and T_2 is about 30^0C, note the initial reading of the thermometer.

(g) Keep on stirring the water gently and constantly. Note the reading of thermometer T_1 – first, after about every half a minute, then after about one minute and finally after two minutes duration or so.

(h) Keep on simultaneously noting the reading of the stopwatch and that of the thermometer T_1, while stirring water gently and constantly, till the temperature of the water in the calorimeter falls to a temperature of about 5^0C above that of the enclosure. Note the temperature of the enclosure, by the thermometer T_2.

(i) Record observations in tabular form. Find the excess of temperature $(\theta-\theta_0)$ and also $\log_{10}(\theta-\theta_0)$ for each reading, using logarithmic tables. Record these values in the corresponding columns in the table.

(j) Plot a graph between time t, taken along x-axis and $\log_{10}(\theta-\theta_0)$ taken along y-axis. Interpret the graph.

Plotting Graph

(i) Plot a graph between $(\theta-\theta_0)$ and t as shown in the Fig 27.16, taking t along x-axis and $(\theta-\theta_0)$ along y-axis. This is called cooling curve.

(ii) Also plot a graph between $\log_{10}(\theta-\theta_0)$ and time t, as shown in Fig 27.16, taking time t along x-axis and $\log_{10}(\theta-\theta_0)$ along y-axis. Choose suitable scales on these axes. Identify the shape of the cooling curve and the other graph.

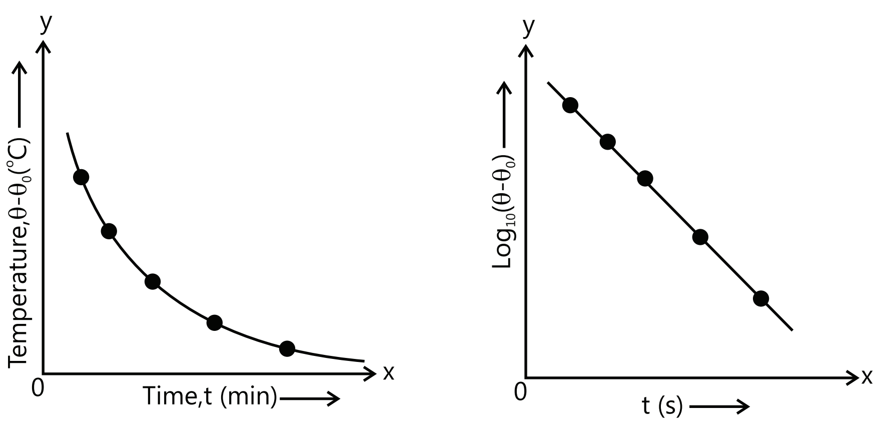


Figure 27.16

Experiment 9: Speed of Sound in Air at Room Temperature Using a Resonance Tube

Principle: When a vibrating tuning fork of known frequency V is held over the top of an air column in a glass tube AB (Fig 27.17), a standing wave pattern can be formed in tube. Under the right conditions, a superposition between a forward moving and reflected wave occurs in the tube to cause resonance. This gives a very noticeable rise in the amplitude, or loudness, of the sound. In a closed organ pipe like a resonance tube, there is a zero amplitude point at the closed end (Fig 27.17). For resonance to occur, a node must be created at the closed end and an antinode must be created at the open end. Let the first loud sound be heard at length l_1 of the air column [Fig 27.17. (a)], i.e., when the natural frequency of the air column of length l_1 becomes equal to the natural frequency of the tuning fork, so that the air column vibrates with maximum amplitude. In fact, the length of the air column vibrates is slightly longer than the length of the air column in tube AB.

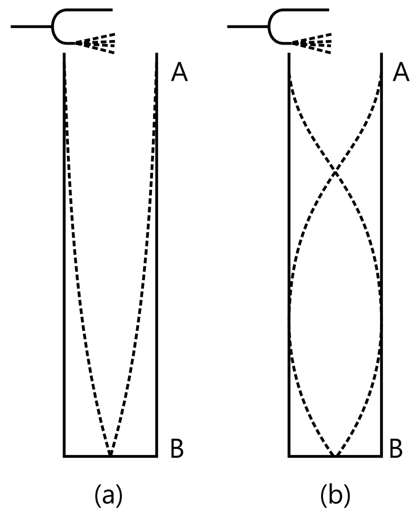


Figure 27.17

Thus, $\frac{\lambda}{4} = l_1 + e$

Where e (= 0.6r, where r = radius of the glass tube) the end correction for the resonance is tube and λ is the wavelength of the sound produced by the tuning fork.

Now, on further lowering the closed end of the tube AB, let the second resonance positon be heard at length l_2 of the air column in the tube.

$\frac{3\lambda}{4} = l_2 + e$ [Fig 27.18 (b)]. This length l_2 would approximately be equal to three quarters of the wavelength. That is, ... (ii)

Subtracting Eq. (1) from Eq. (2) gives $\lambda = 2(l_2 - l_1)$ ...(iii)

Thus, the velocity of sound in air at room temperature $(\upsilon = v\lambda)$ would be $\upsilon = 2v(l_2 - l_1)$.

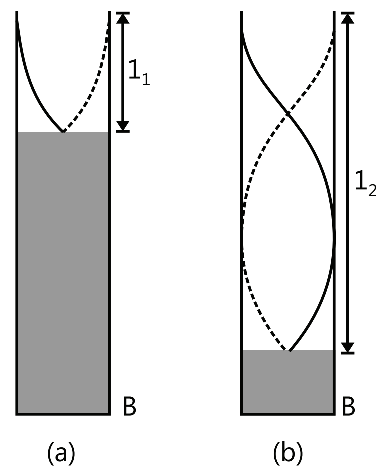


Figure 27.18

Procedure

Adjustment Of Resonance Tube: The apparatus usually consists of a narrow glass tube about a metre long and 5cm in diameter, rigidly fixed in its vertical position with a wooden stand. The lower end of this tube is attached to a reservoir by a rubber tube. Using a clamp, the reservoir can be made to slide up or down along a vertical rod. In order to keep the water level (or the length of air column) fixed in the tube, a pinch cock is provided with the rubber tube. A metre scale is also fixed along the tube. The whole apparatus is fixed on a horizontal wooden base that can be levelled using the screws provided at the bottom. There is water in both the reservoir and the tube. When the reservoir is raised, the length of the air column in the tube goes up. Now:

(a) Set the resonance tube vertical with the help of a spirit level, and level the screws provided at the bottom of the wooden base of the apparatus.

(b) Note the room temperature with a thermometer.

(c) Note the frequency v of given tuning fork.

(d) Fix the reservoir to the highest point of the vertical rod with the help of the clamp.

Determination of First Resonance Position

(e) Fill the water in the reservoir such that the level of water in the tube reaches the top.

(f) Close the pinch clock and lower the position of the reservoir on the vertical rod.

(g) Gently strike the given tuning fork on a rubber pad and put it nearly one cm above the open end of the tube. Keep both the prongs of the tuning fork parallel to the ground and place one above the other so that the prongs vibrate in the vertical plane. Try to listen the sound being produced in the tube. It may not be audible in the position.

(h) Slowly loosen the pinch cock to let the water level fall in the tube very slowly. Keep bringing the tuning fork near the open end of the resonance tube; notice the increasing volume of the sound.

(i) Repeat steps 7 and 8 till you get the exact position of water level in the tube for which the intensity of sound being produced in the tube is maximum. This corresponds to the first resonance postion or fundamental node, if the length of the air column is minimum. Close the pinch cock at this position and note the positon of the water level or length l_1 of the air column in the tube. This is the determination of first resonance positions while the level of water is falling in the tube.

(j) Repeat steps 5-9 to confirm the first resonance position.

(k) Next, find out the first resonance postion by gradually raising the level of water in resonance tube, and holding the vibrating tuning fork continuously on top of its open end. Fix the tube at the position by gradually raising the level of water in resonance tube, and holding the vibrating tuning fork continuously on top of its open end. Fix the tube at the position where the sound of maximum intensity is heard.

Determination of second resonance position

(l) Lower the position of the water level further in the resonance tube by sliding down the position of the reservoir on the vertical stand and opening the pinch cock till the length of the air column in the tube increases about three times of the length l_1.

(m) Find out the second resonance position and determine the length of air column l_2 in the tube with the same tuning fork with frequency v_1 and confirm the length l_2 by taking four readings – two when the water level is falling and the other two when the level of water is rising in the tube.

(n) Repeat steps 5-13 with a second tuning fork of frequency v_2 and determine the first and second resonance positions.

(o) Calculate the velocity of sound in each case.

Experiment 10: Specific Heat Capacity of a Given (i) Solid and (ii) Liquid by Method of Mixtures

Principle/ Theory: For a body of mass m and specific heat s, the amount of heat Q lost/ gained by it when its temperature falls/ rises by Δt is given by $\Delta Q = ms\Delta t$

Specific heat capacity: It is the amount of heat required to raise the temperature of unit mass of a substance through 1 C. Its S.I. unit is $Jkg^{-1}K^{-1}$.

Principle of calorimetry: If bodies of different temperatures are brought in thermal contact, the amount of heat lost by the body at higher termperature is equal to the amount of heat gained by the body at lower temperature at thermal equilibrium, provided no heat is lost to the surrounding.

(a) Specific heat capacity of given solid by method of mixtures.

Procedure

(i) Set the physical balance and make sure there is no zero error.

(ii) Weigh the empty calorimeter with a stirrer and lid with the physical balance/ spring. Ensure that the calorimeter is clean and dry.

Note the mass m_1 of the calorimeter. Pour the given water in the calorimeter. Make sure that the quantity of water taken is sufficient to completely submerge the given solid in it. Weigh the calorimeter with water along with the stirrer and the lid and note it's mass m_2. Place the calorimeter in its insulating cover.

(iii) Dip the solid in water and take it out. Now shake it out to get rid of the water sticking to its surface. Weigh the wet solid with the physical balance and note its mass m_3.

(iv) Tie the solid tightly with the thread in the middle. Ensure that it can be lifted by holding the thread without slipping.

Place a 250mL beaker on the wire gauze kept on a tripod stand as shown in the Fig 27.19 (a).

Fill the beaker containing water by tying the other end of the thread to a laboratory stand. The solid should be completely submerged in the water and should be atleast 0.5cm below the surface. Now, heat the water with the solid suspended in it [Fig 27.19 (a)].

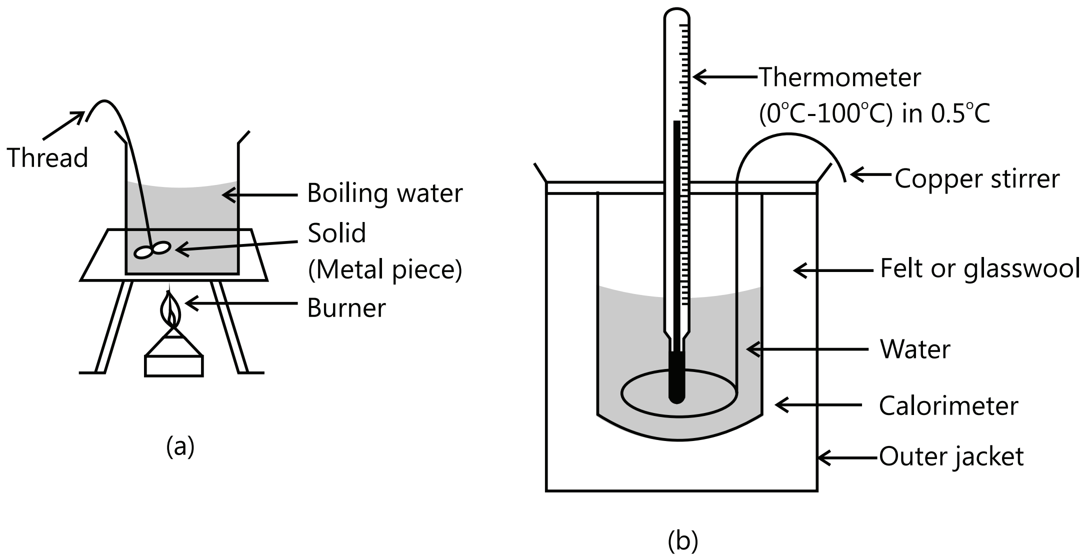


Figure 27.19

(v) Note the least count of the thermometer. Measure the temperature of the water taken in the calorimeter. Record the temperature t_1 of the water.

(vi) Let the water in the beaker boil of about 5-10 minutes. Now measure the temperature t_2 of the water with the other thermometer, and record the same. Holding the solid with the thread tied to it, remove it from the boiling water, and shake it to get rid of the water on it and quickly put it the water in the calorimeter, immediately replacing the lid [Fig. 27.19(b)]. Stir the water with the stirrer. Measure the temperature of the mixture till it becomes constant. Record this temperature as t_3.

(b) Specific heat capacity of given liquid by method of mixtures.

Procedure

(i) Set the physical balance and make sure there is no zero error.

(ii) Weigh the empty calorimeter with the stirrer and the lid with the physical balance/ spring balance. Ensure that the calorimeter is clean and dry. Note the mass m_1 of the calorimeter. Pour the given liquid in the calorimeter. Make sure that the quantity of liquid taken would be sufficient to completely submerge the solid in it. Weigh the calorimeter with liquid along with the stirrer and the lid and note its mass m_2. Place the calorimeter in its insulating cover.

(iii) Take a metallic cylinder whose specific heat capacity is known. Dip it in water in a container and shake it to get rid of the water sticking to its surface. Weigh the wet solid with the physical balance and note down its mass m_3

(iv) Tie the solid tightly with the thread at its middle. Make sure that it can be lifted by holding the thread without slipping.

Place a 250 ml beaker on the wire gauze kept on a tripod stand as shown in Fig 27.19 (a). Fill the beaker halfway with water. Now suspend the solid in the beaker containing water by tying the other end of the thread to a laboratory stand. The solid should be completely submerged in water and should be atleast 0.5cm below the surface. Now heat the water with the solid suspended in it.

(v) Note the least count of the thermometer. Measure the temperature of the water taken in the calorimeter. Record the temperature t_1 of the water.

(vi) Let the liquid in the beaker boil for about 5-10 minutes. Now measure the temperature t_2 of the liquid with the other thermometer and record the same. Holding the solid with the thread tied to it, remove it from the boiling water, shake it to get rid of the excess water on it and quickly put it in the liquid in the calorimeter, replacing the lid immediately. Stir with the stirrer. Measure the temperature of the mixture becomes constant. Record this temperature as t_3.

Experiment 11: Resistivity of the Material of a Given Wire Using Meter Bridge

Description of Apparatus Meter Bridge

It consists of one metre long constantan wire 'AC' of uniform cross-sectional area, mounted on a wooden board with a scale (Fig 27.20). The two ends of the wire are attached to terminals A and C. Thick metal strips bent at right angles are used to provide two gaps E and F to connect resistors forming a Wheatstone bridge (Fig 27.20). The terminal B between the gaps is used for connecting the galvanometer, and the other end of the galvanometer is connected to a jockey J.

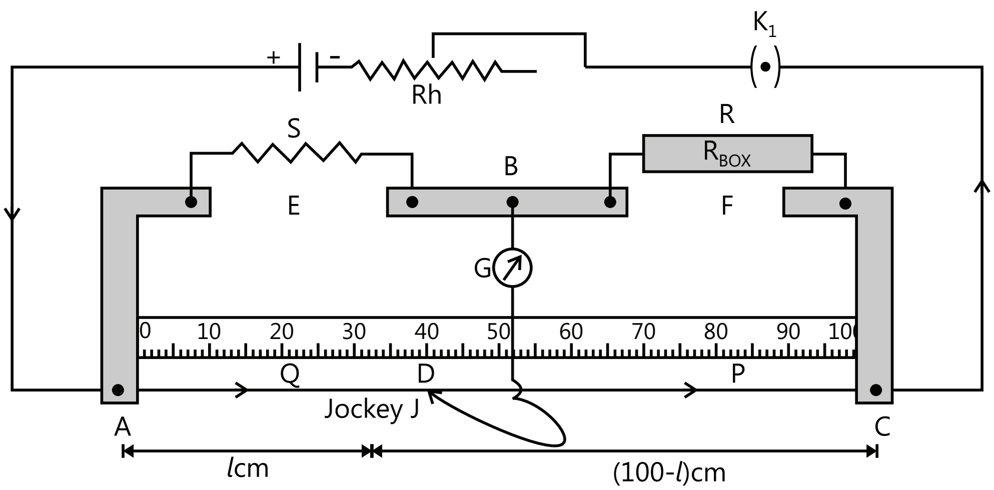


Figure 27.20

Principle: A meter bridge works on the principle of Wheatstone's bridge. As shown in the Fig 27.21, it consists of four resistors P, Q, R and S connected in the form of a network ABCD. The terminals A and C are connected to two terminals of a cell through a key K_1. Terminals B and C are connected to a sensitive galvanometer G through a key K_2.

If there is no deflection in the galvanometer G,

Then balance condition for Wheatstone's bridge is $\frac{P}{Q} = \frac{R}{S}$

We use this relation to determine S, as P, Q and R are known. The unknown resistance S is connected in the gap E and a resistance box (R_{BOX}) in gap F of the meter bridge. The terminal B is connected to one terminal of the galvanometer G. The other terminal of the galvanometer is connected to a jockey J which slides along the wire AC. A source of dc voltage is connected between A and C through a key K_1 so as to provide a constant potential drop along AC (Fig 27.21).

A resistor (or wire) of known resistance is inserted in the gap F by taking out corresponding key from the resistance box $\left(R_{BOX}\right)$. The jockey is moved on the wire AC to obtain a condition of no-deflection in the galvanometer. It happens when the jockey is kept at a point D called the null point. In this condition:

$$\frac{P}{Q}=\frac{R}{S}=\frac{\text{Resistance wire of length DC}}{\text{Resistance of wire of length AD}}$$

Unknown resistance S of the wire, having uniform cross-sectional area, is then given by $S=R\frac{l}{100-l}$ ... (i)

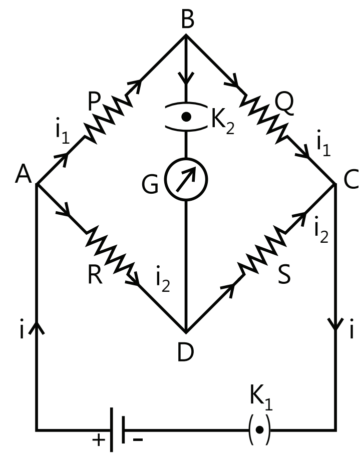


Figure 27.21

The reason for this is that for a wire of uniform cross-sectional area, resistance is proportional to length.

Thus, knowing l and R, and using Eq. (1), the unknown resistance S can be determined.

Resistivity: The specific resistance or resistivity ρ of the material of the given wire is $\rho=S\frac{a}{l}$ where S is the resistance of the wire of length L and $a=\pi r^2$ (r being the radius) is the area of cross-section.

Procedure

(a) Find the average diameter of the wire with a screw gauge. From this, obtain the value of its radius r.

(b) Clean the insulation at the ends of the connecting wires with a piece of sand paper. Tighten all plugs of the resistance box $\left(R_{BOX}\right)$ by pressing each plug.

(c) Set up the circuit as shown in Fig 27.21 with unknown resistance wire of known length in gap E.

(d) Next, introduce some resistance R in the circuit from the resistance box. Bring the jockey J in contact with terminal A first and then with terminal C. Note the direction in which pointer of the galvanometer gets deflected in each case. Make sure that the jockey remains in contact with the wire for a fraction of a second. If the galvanometer shows deflection on both sides of its zero mark for these two points of contact of the jockey, null point will be somewhere on the wire AC. If it is not so, adjust resistance R so that the null point is somewhere in the middle of the wire AC, say between 30cm and 70cm.

(e) If there is one-sided deflection, check the circuit again, especially junctions, for their continuity.

(f) Repeat step 4 for four different values of resistance R.

(g) Interchange the position of the resistances S and R and repeat steps 4 to 6 for the same five values of R. While interchanging S and R, ensure that the same length of wire of resistance S is now in the gap F. The interchange takes care of unaccounted resistance offered by terminals.

Experiment 12: Resistance of a Given Wire Using Ohm's Law

Principle: Ohm's Law states that the electric current flowing through a conductor is directly proportional to the potential difference across its ends, provided that the physical state of the conductor remains uncharged.

If I is the current flowing through the conductor and V is the potential difference across its ends, then according to Ohm's Law

$$V\propto I \text{ and hence } \quad V=RI \qquad \text{... (i)}$$

Where R is the constant of proportionality, and is termed as the electrical resistance of the conductor. If V is expressed in volts and I in amperes, then R is expressed in Ohm's. The resistance R depends upon the material and dimensions of the conductor. For a wire of uniform cross-section, the resistance depends on the length l and the area of cross-section A. It also depends on the temperature of the conductor. At a given temperature, the resistance

$$R = \rho \frac{l}{A} \quad \text{... (ii)}$$

Where ρ is the specific resistance or resistivity and is characteristic to the material of wire.

Combining Eqs. (1) and (2), we have

$$V = \rho \frac{l}{A} I \quad \text{... (iii)}$$

A linear relationship is obtained between V and I, i.e., the graph between V and I will be a straight line passing through the origin as shown in Fig 27.22. The slope of the graph is 1/ R from Eq. 1 (equation of straight line passing through origin is y = mx where m is the slope of graph)

$$\text{Slope} = \frac{1}{R} \quad \Rightarrow R = \frac{1}{\text{slope}}$$

If l is the length of wire then the resistance per unit length of the wire $\frac{R}{l}$.

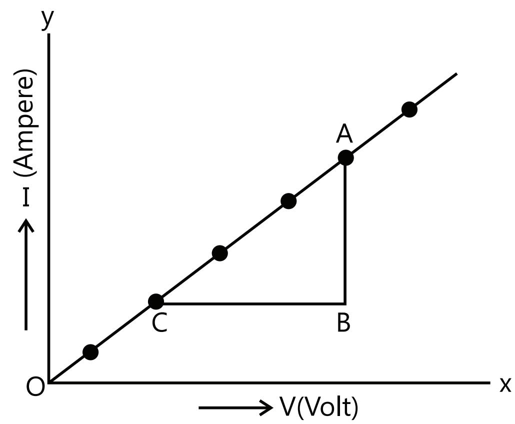


Figure 27.22

Procedure

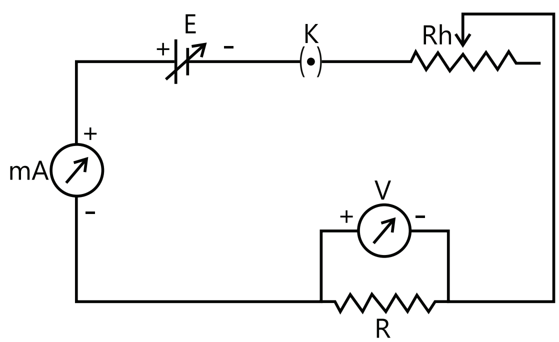
(a) Clean the ends of the connecting wires with the help of sand paper in order to remove any insulating coating on them.

(b) Connect various components – resistance, rheostat, battery, key voltmeter and ammeter as shown in Fig 27.23.

(c) Note whether pointers in milliammeter and voltmeter coincide with the zero mark on the measuring scale. If it is not so, adjust the pointer to coincide with the zero mark by adjusting the screw provided near the base of the needle using a screw driver.

(d) Note the range and least count of the given voltmeter and milliammeter.

(e) Insert the key K and slide the rheostat contact to one of its extreme ends, so that the current passing through the resistance wire is minimum.



Circuit to find the relation between current I and potential difference, V for a give wire

Figure 27.23

(f) Note the milliammeter and voltmeter readings.

(g) Remove the key K and allow the wire to cool, if heated. Once again, insert the key. Shift the rheostat contact slightly to increase the applied voltage. Note the milliammeter and voltmeter reading.

(h) Repeat step 7 for four different settings of the rheostat. Record your observation in a tabular form.

Experiment 13: Potentiometer

(a) Comparison of EMF of Two Primary Cells

In the circuit shown, the cell of emf E_1 is balanced for a length l_1 on the potentiometer wire by connecting A to C. In the next event, the cell of emf E_2 is balanced for a length l_2 on the potentiometer wire by connecting B to C. Let x be the potential gradient across the potentiometer wire. Then $E_1 = l_1 x$ and $E_2 = l_2 x$ $\therefore$ $\frac{E_1}{E_2} = \frac{l_1}{l_2}$

The e.m.f of a cell can be determined only when e.m.f of another cell is known to us.

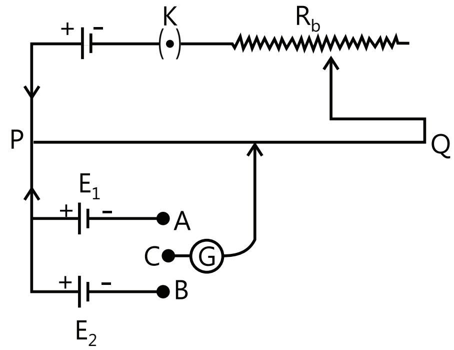


Figure 27.24

(b) Determination of Internal Resistance of a Cell

Principle: When a resistance R is connected across a cell of emf E and internal resistance r, then the current I in the circuit is $I = \frac{E}{R+r}$ ... (i)

The potential difference V (=RI) across the two terminals of the cell is

$$V = \frac{E}{R+r}R \quad \text{... (ii)}$$

Thus $\frac{E}{V} = 1 + \frac{r}{R}$ or $r = \left(\frac{E}{V} - 1\right)R$ Also $\frac{E}{V} = \frac{l_0}{l}$ ... (iii)

From the above equations, $r = \frac{l_0 - l}{l}R$ ... (iv)

Procedure

(a) Connect different electrical components as shown in the circuit (Fig 27.25.). After checking the circuit connections, close key K_1.

(b) With keys K_2 and K_3 open and a protective high resistance P form the $R_{BOX\,2}$, find the position of the balance point. For final reading, short circuit the resistance P by closing the key K_3 and find the balance length l_0.

(c) Take R = 10 Ω $\left(\text{from } R_{BOX1}\right)$, close the key K_2 and quickly measure the new balance length l. Open K_2 as soon as this has been done.

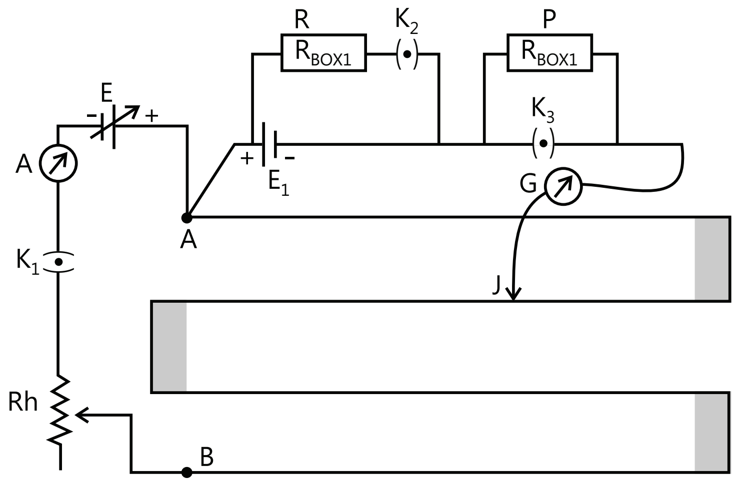


Figure 27.25

(d) Keep the reading in the ammeter constant throughout the above observation.

(e) Reduce the value of R in equal steps of 1 Ω and for each value of R obtain the balance length l.

(f) At the end of the experiment, open key K_2 and repeat step 2 to find l_0 again.

Experiment 14: Resistance and Figure of Merit of a Galvanometer by Half Deflection Method

Principle Galvanometer: Galvanometer is a sensitive device used to detect very low current. Its working is based on the principle that a coil placed in a uniform magnetic field experiences a torque when an electric current is set up in it. The deflection of the coil is determined by a pointer attached to it, moving on the scale.

When a coil carrying current I is placed in a radial magnetic field, the coil experiences a deflection θ which is related to I as $I = k\theta$ ... (i)

Where k is a constant of proportionality and is termed as Figure of merit of the galvanometer.

The circuit arrangement required for finding the resistance G of the galvanometer by half deflection method is shown in Fig 27.26.

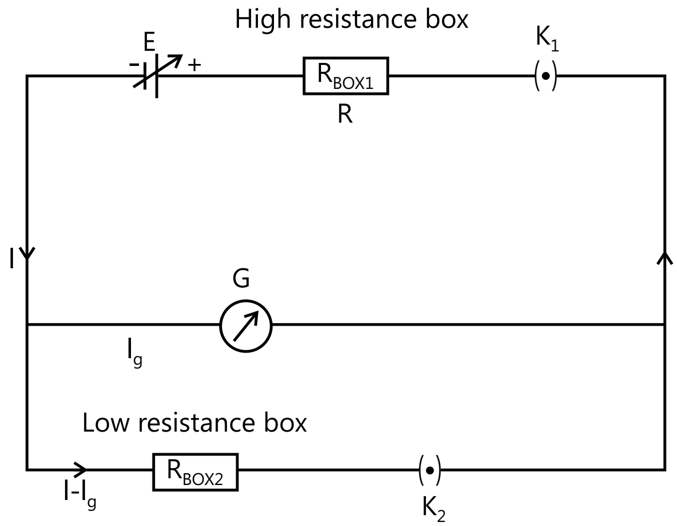


Figure 27.26

When a resistance R is introduced in the circuit, the current I_g flowing through it is given by $I_g = \frac{E}{R+G}$ ... (ii)

In this case, the key K_2 is kept open. Here E is the emf of battery, G is the resistance of the galvanometer whose resistance is to be determind.

If the current I_g produces a deflection θ in the galvanometer, then from equation (i) we get $I_g = k\theta$ ... (iii)

Combining equations (ii) and (iii) we get $\frac{E}{R+G} = k$ ... (iv)

On keeping both the keys K_1 and K_2 closed and by adjusting the value of shunt resistance S, the deflection of the galvanometer needle becomes $\frac{1}{2}$ (half). As G and S are in parallel combination and R in series with it, the total resistance of the circuit. $R' = R + \frac{GS}{G+S}$ ... (v)

The total current, I due to the emf E in the circuit is given by $I = \frac{E}{R + \frac{GS}{G+S}}$ ... (vi)

If I'_g is the current through the galvanometer of resistance G, then $GI'_g = S(I - I'_g)$ $I_g = \frac{IS}{G+S}$ ... (vii)

Substituting the value of I from Equation (v), in equation (vii) the current I'_g is given by

$$I'_g = \frac{IS}{G+S} = \frac{E}{R + \frac{GS}{G+S}} \cdot \frac{S}{G+S} \Rightarrow I'_g = \frac{ES}{RG + GS + RS} \quad \text{... (viii)}$$

For galvanometer current I'_g if the deflection through the galvanometer is reduced to half of its initial value $= \frac{1}{2}$ then $I'_g = k\left(\frac{\theta}{2}\right) = \frac{ES}{R(G+S) + GS}$

On dividing Eq. (ii) by Eq. (viii), $\frac{I_g}{I'_g} = \frac{E}{R+G} \times \frac{R(G+S) + GS}{ES} = 2$

$\Rightarrow R(G+S)+GS = 2S(R+G)$

$\Rightarrow RG=RS+GS$

$\Rightarrow G(R-S)=RS$

$$\text{or, } G=\frac{RS}{R-S} \quad \text{... (ix)}$$

By knowing the values of R and S, the galvanometer resistance G can be determined. Normally R is chosen very high $(10k\Omega)$ in comparison to $S(100\Omega)$.

The Figure of merit (k) of the galvanometer is defined as the current requied for deflecting the pointer by one division.

For determining the Fig of merit of the galvanometer the key K_2 is opened in the circuit arrangement. Using Eqs (ii) and (iii) the Figure of merit of the galvanometer is given by

$$k=\frac{1}{\theta}\frac{E}{R+G} \quad \text{... (x)}$$

By knowing the values of E, R, G and θ the Figure of merit of the galvanometer can be calculated.

Procedure

(a) Clean the connecting wires with sand paper and make neat and tight connections as per the circuit diagram.

(b) From the high resistance box $(R_{BOX\,1})$ $(1-10k\Omega)$, remove $5k\Omega$ key and then close the key K_1. Adjust the resistance R from this resistance box to get full scale deflection on the galvanometer dia. Record the values of resistance, R and deflection θ.

(c) Insert the key K_2 and keep R fixed. Adjust the value of shunt resistance S to get the deflection in the galvanometer which is exactly half of θ. Note down S. Remove plug K_2 after noting down the value of shunt resistance, S.

(d) Take five sets of observations by repeating steps 2 and 3 so that θ is even number of divisions and record the observations for R,

S, θ and $\frac{1}{2}$ in tabular form.

(e) Calculate the galvanometer resistance G and Figure of merit k of galvanometer using Eqs (ix) and (x) respectively.

Experiment 15: Focal Length of Different Mirrors

(i) Convex Lens (ii) Convex Mirror (iii) Concave Mirror Using Parallax Method

Convex lens

Parallax: This is employed in the location of image of an object. For example, as shown in the Fig.27.27 (a) O and I are the object and image points for a mirror / lens.

An object point O and its real image 'I' are conjugate points i.e., any of the two may be considered as object and the other as its image. Thus it helps in accurate adjustment to check for no parallax at both the points. If we say there is no parallax between an object O (pin) and its image I, then by moving the eye through which we are observing to the left and then to the right, object and its image both appear to move together relative to the lens / mirror. It implies that the position of both are same on the optical bench [Fig 27. 27. (d) and (e)]. If their positions are not same then in one position they may appear to coincide and in another they will appear separate [Fig 27. 27. (b) and (c)].

This method of locating the position of an image on the optical bench by a pin, is called the method of parallax.

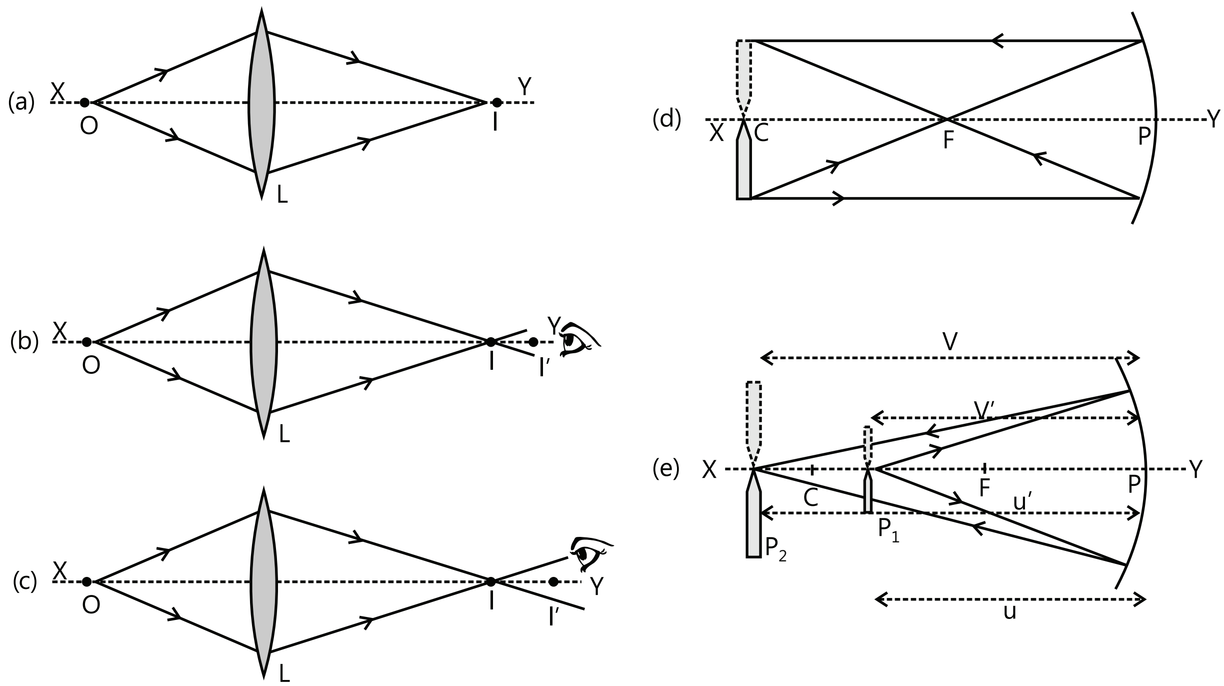


Figure 27. 27

Principle: For an object placed at a distance u from the pole of a concave mirror of focal length f, the image is formed at a distance v from the pole. The relation between these distances (for a concave mirror) is

$$\frac{1}{f}=\frac{1}{u}+\frac{1}{v} \quad \text{or} \quad f=\frac{uv}{u+v}$$

If an object (say, a pin) is placed in front of the reflecting surface of the concave mirror such that the object's position lies in between the principal focus of the mirror, F and the centre of curvature C, then a real, inverted and magnified image is formed in between the centre of curvature C of the mirror and infinity (Fig 27.28).

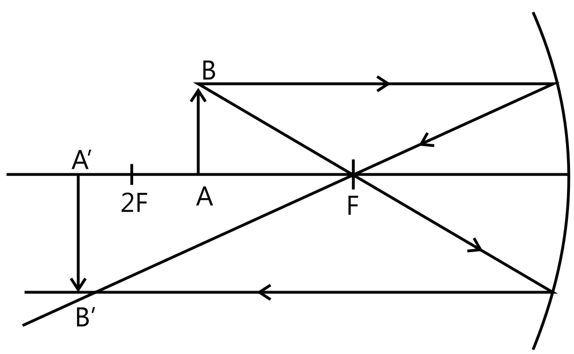


Figure 27.28

Thus, the image formed in such a case would be clearer and easier to be seen. The focal length of the mirror, using the above relation, can be determined by placing the object in between the point 2F and focus F.

Procedure

(a) Obtain approximate value of the focal length of the concave mirror, by focusing the image of a distant object. Obtain bright and clear image of distant building or tree on a plane wall or a sheet of paper and measure the distance between the mirror and the image which gives the approximate focal length of the concave mirror.

(b) Place the optical bench on a rigid table. Make it horizontal using a spirit level and levelling screws.

(c) Clamp the concave mirror on an upright and mount it vertically near one end of the optical bench. Move an object pin P_1 on the optical bench back and forth so that its image is formed at the same height. Make slight adjustments of the height of the pin or the mirror inclination. This procedure ensures that the principal axis of the mirror is parallel to the optical bench.

(d) Place another vertically mounted sharp and bright pin P_2 in front of the reflecting surface of the concave mirror. Adjust the pins P_1 and P_2 so that the height of the tips of these pins become equal to the height of the pole P of mirror from the base of the optical bench.

(e) To determine index correction, a thin straight index needle is placed so that its one end A_1 touches the tip of the pin and the other end B_1 touches the pole P of the mirror. The positions of the uprights are read on the scale. Their difference gives the observed distance between the tip of the pin and the pole of the mirror. Lenth of the needle A_1B_1 is measured by placing it on the scale which is the actual distance between the points in question. The difference between the two gives the correction to be applied to the observed distance. Find the index correction for both the pins P_1 and P_2 for all measurements.

(f) Move the pin P_1 away from the mirror and place it almost at 2F. An inverted image of same size as the pin should be visible.

(g) Now place another pin P_2 on the bench. Adjust its height to be almost the same as the earlier pin. Place a piece of paper on the tip of one pin, take this as the object pin.

(h) Place the pin with paper at a distance lying between F and 2F.

(i) Locate the image of the pin using the other pin. Remember that parallax has to be removed between the image and the pin.

(j) Note the values of u and v i.e. the distances of the object and image pins from the mirror respectively.

(k) Repeat the experiment for at least five different positions of the object and determine the corresponding values of V. Record your observations in tabular form.

(l) After doing index correction, record the corrected values of u and v. Find the value of focal length, f.

Focal length of a convex mirror: Since a convex mirror always forms a virtual image, its focal length cannot be found directly. For this purpose, an indirect method is used as described below.

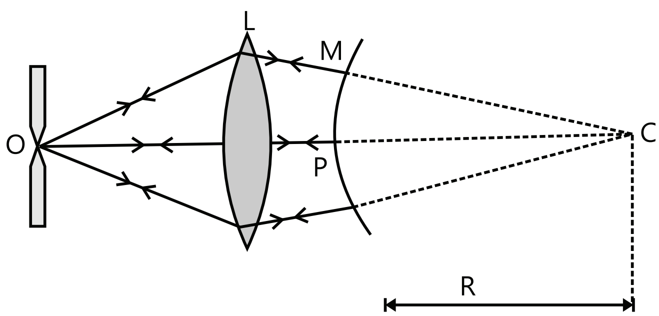


Figure 27.29

An auxiliary convex lens L is introduced between the convex mirror M and object needle O. Now the object needle is kept at a distance which is roughly 1.5 times the focal length of the convex lens. The position of the convex mirror is now adjusted, such that a real inverted image of object needle O is formed at O itself. This will be possible only when the rays incident on the convex mirror are incident normally on it, hence retrace their path and when produced rightward must pass through the centre of curvature C of the mirror.

To locate the position of C, convex mirror is removed (without disturbing the object needle O and convex lens L). An image needle I is put behind the convex lens and moved to a position at which there is no parallax between tip of the inverted image of the object needle I gives position of centre of curvature C of the mirror M.

Then, $\quad PC=PI=R$ and $f=\frac{R}{2}=\frac{PI}{2}$

Focal length of concave mirror: We can calculate the focal length of a concave mirror by using the following three graphical methods.

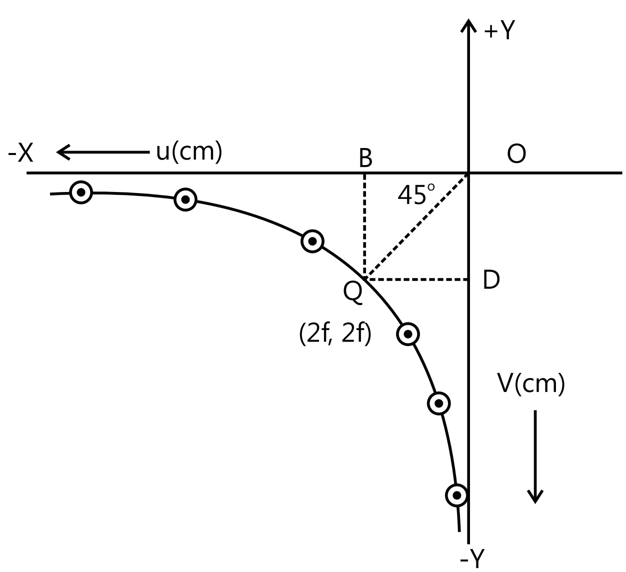


Figure 27.30

Method 1: u-v Method

Let us select a suitable but the same scale to represent u along-X axis and v along-Y axis. According to sign convention, in this case, u and v are both negative. Plot the various points for different sets of values of u and v from the observation table. The graph then comes out to be a rectangular hyperbola as shown.

Draw a line OQ making an angle of 45° with either axis and meeting the curve at point Q. Draw QB and QD perpendicular on X and Y axes respectively. The values of u and v will be same for point Q. So the coordinates of point Q must be (2f, 2f). This is due to the fact that, for a concave mirror, u and v are equal only when the object is placed at the centre of curvature. So, u=v=R=2f

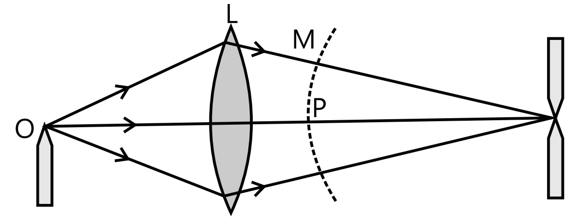


Figure 27.31

From mirror formula applied to point Q $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}=\frac{2}{R}$;

Since u=v $\therefore$ $\frac{1}{f}=\frac{2}{u}=\frac{2}{v}$ $\quad\therefore\quad f=\frac{u}{2}$ or $\frac{v}{2}$

Hence, half the values of either coordinates of Q (i.e., distance OD or OB) gives the focal length of the concave mirror.

$f=-\frac{OD}{2}=-\text{...cm}=f_1(\text{say});$

Also $\quad f=-\frac{OB}{2}=-\text{...cm}=f_2(\text{say})$

So, mean value of $f=\left(\frac{f_1+f_2}{2}\right)=-\text{...cm}$

Method 2: u-v Graph Method

Select a suitable but the same scale to represent u along X axis (or X′ axis) and v along-Y axis (or Y′ axis). Mark the points at distance u_1, u_2, u_3,..... etc. along the OX′ axis and the corresponding points at distance v_1, v_2, v_3,....etc. along the OY′ axis for different sets of observations.

Draw straight lines joining u_1 with v_1, u_2 with v_2, u_3 with v_3 etc. These lines will intersect at a point K as shown in the graph. Draw KL and KM perpendicular on X′ and Y′ axis respectively, then

OL=OM= − f $\quad\therefore\quad$ f = −...........cm

The above argument can be justified from the fact that the mirror formula, $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ is satisfied by extreme values (f, ∞) and (∞, f). The straight lines corresponding to extreme values intersect at a point K having co-ordinates (f, f). For lines LK, u=f, $v\to\infty$ and for line MK, v=f, $u\to\infty$.

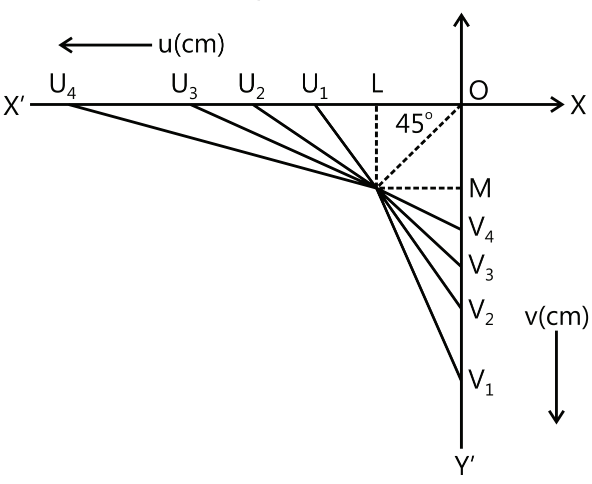


Figure 27.32

Method 3: $\frac{1}{u}$ and $\frac{1}{v}$ Graph Method

Select a suitable but the same scale to represent $\frac{1}{u}$ along – X axis (or X′ axis) and $\frac{1}{v}$ along-Y axis (or Y′ axis). By sign convention, both $\frac{1}{u}$ and $\frac{1}{v}$ are negative (for real images). For different sets of values of $\frac{1}{u}$ and $\frac{1}{v}$ plot the graph, which comes to be a straight line as shown in Fig 27.33.

The straight line cuts the two axes X′ and Y′ at an angle of $45°$ at points A and B respectively and also has equal intercepts for both the axis. Measures are distance OA and OB.

The focal length, $f = -\frac{1}{OA} = -\frac{1}{OB} = f_0$ (say)

$\therefore \quad f = f_0 - cm$

The above agreement can be explained as follows.

From mirror formula, $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

(a) If object is placed at infinity, then $u \to \infty$

$\therefore \quad \frac{1}{v} = \frac{1}{f}$

So, intercept $OB = \frac{1}{v} = \frac{1}{f}$

(b) If image is formed at infinity, then $v \to \infty \ \therefore \quad \frac{1}{u} = \frac{1}{v}$

So, intercept $OA = \frac{1}{u} = \frac{1}{f}$

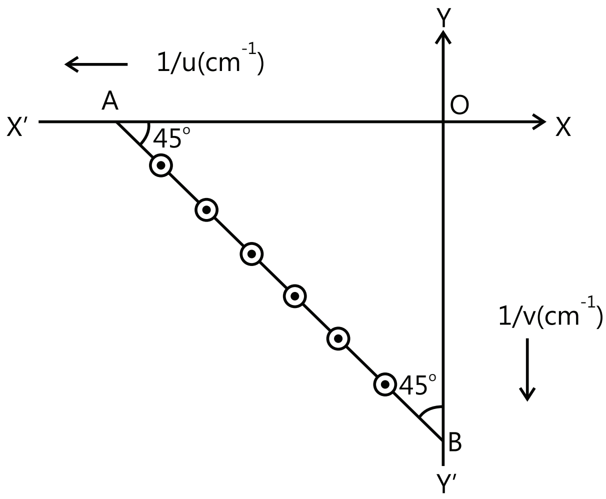
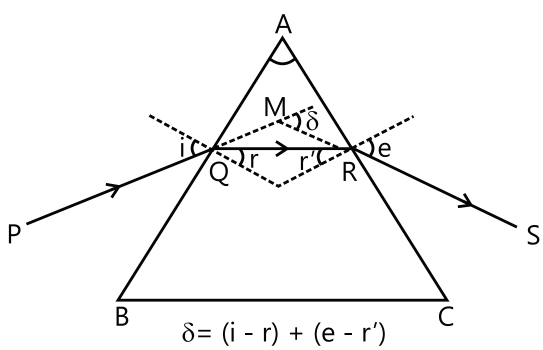


Figure 27.33

Experiment 16: Plot of Angle of Deviation vs. Angle of Incidence for a Triangular Prism

Principle: A triangular prism has three rectangular lateral surfaces and two triangular bases. The line along which any two faces (refracting surfaces) of the prism meet, is the refracting edge of the prism and the angle between them is the angle of the prism. For this experiment, it is convenient to place the prism with its rectangular surfaces vertical. The prinicipal section ABC of the prism is obtained by a horizontal plane perpendicular to the refracting edge (Fig. 27.34).



$\delta = (i - r) + (e - r')$
$= i + e - A$

Figure 27.34

A ray of light PQ (from air to glass) incident on the first face AB at an angle is refreacted at angle r along QR and finally, emerges along RS. The dotted lines in the Fig 27.34 represent the normal to the surfaces. The angle of incidence (from glass to air) at the second face AC is r′ and the angle of refraction (or emergence) is e. The angle between the direction of incident ray PQ (produced forward) and direction of emergent ray RS (produced backward) is the angle of deviation δ .

From geometrical considerations we have $r + r' = A$ ... (i)

$\delta = (i - r) + (e - r') = i + e - A$ ... (ii)

At the position of the prism for minimum deviation $\delta_{m'}$ the light ray passes through the prism symmetrically, i.e. parallel to the base so that when

$\delta = \delta_{m'}\, i = e$ which implies $r = r'$.

The advantage of putting the prism in minimum deviation position is that the image is brightest in this position.

Procedure

(a) Fix a white sheet of paper on a drawing board with the help of cellotape or drawing pins.

(b) Draw a straight line XY, using a sharp pencil nearly in the middle and parallel to the length of the paper.

(c) Mark points O_1, O_2, O_3,......... on the straight line XY at suitable distance of about 8 to 10cm and draw normal N_1O_1, N_2O_2, N_3O_3...... on these point (Fig. 27.35).

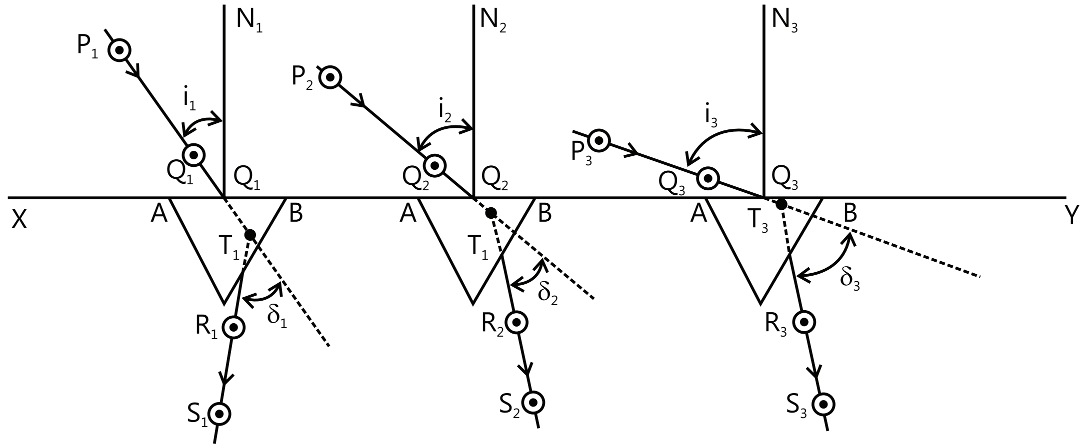


Figure 27.35

(d) Draw straight lines, P_1O_1, P_2O_2, P_3O_3,......... corresponding to the incident rays, making angles of incidence at $35^0, 40^0, 45^0, 50^0, ...60^0$ respectively with the normal, using a protractor. Write the values of the angles $\angle P_1O_1N_1, \angle P_2O_2N_2, \angle P_3O_3N_3$,....... on the white paper sheet (Fig. 27.35)

(e) Place the prism with its refracting face AB on the line XY with point O_1 in the middle of AB as shown in the Fig 27.35. Draw the boundary of the prism with a sharp pencil.

(f) Fix two alpins P_1 and Q_1 with sharp tips vertically about 10cm apart, on the incident ray line P_1Q_1 such that pin Q_1 is close to point O_1. Close one eye (say left) and looking through the prism, bring your right eye in line with the images of the pins P_1 and Q_1. Fix alpins R_1 and S_1 about 10cm apart vertically on the white paper sheet, with their tips in line with the tips in line with the tips of the images of pins P_1 and Q_1. In this way pin R_1 and S_1 will become collinear with the images of pin P_1 and Q_1.

(g) Remove the pins R_1 and S_1 and encircle their pin pricks on the white paper sheet with the help of a sharp pencil. Remove the pins P_1 and Q_1 and encircle their pin pricks also.

(h) Join the points (or pin pricks) R_1 and S_1 with the help of a sharp pencil and scale, to obtain the emergent ray R_1S_1. Produce it backwards to meet the incident ray P_1Q_1 (produced forward) at T_1. Draw arrowheads on P_1Q_1 and R_1S_1 to show the direction of the rays.

(i) Measure the angle of deviation δ_1 and the angle BAC (angle A) of the prism (Fig. 27.36) with a protractor and write the values of these angles indicated in the diagram.

(j) Repeat steps 5 to 9 for different values of angle of incidence (40°, 45°, 50° .....) and measure the corresponding angles of deviation δ_2, δ_3..... with the protractor, and indicate them in the respective diagrams.

(k) Record observation in tabular form with proper units and significant Fig 27.36. Sample graph looks like the adjacent Fig 27.36.

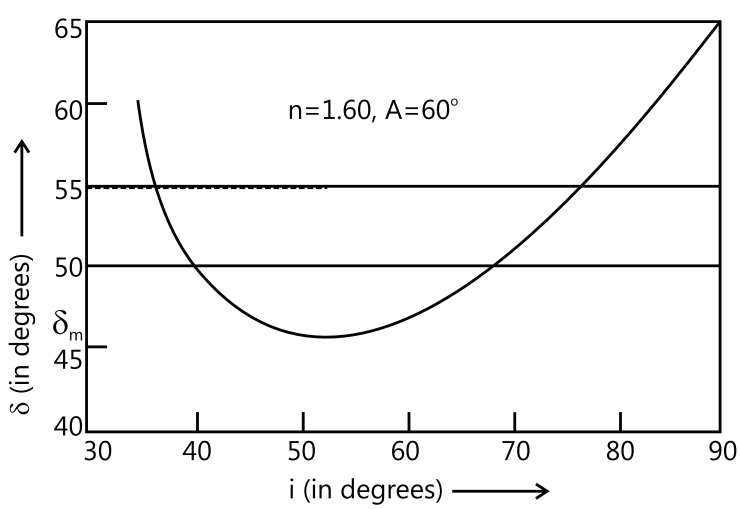


Figure 27.36

Experiment 17: Refractive Index of a Glass Slab Using a Travelling Microscope

Principle

(a) A travelling microscope (Fig 27.37) consists of an ordinary compound microscope M which is capable of moving along both vertical and horizontal directions. The movement in any direction can be read by a fixed main scale S and a sliding vernier scale V. There is a horizontal metal platform which can be levelled by means of the levelling screws L and a small spirit level over the base. The vertical motion is controlled by two screws, one is called the fixing screw and other as tangent screw, and the later imparts slow motion only when the former is fixed. Similarly, there are two screws for the horizontal motion.

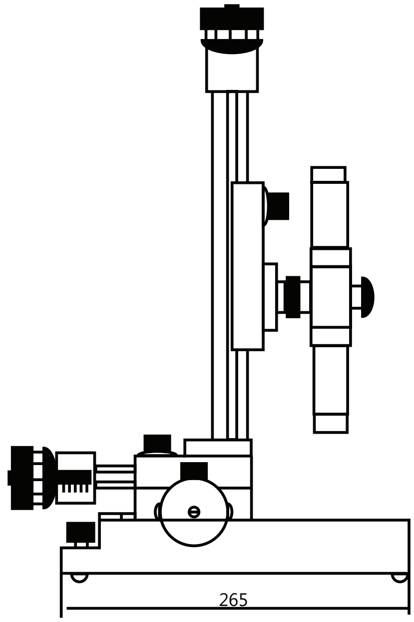


Figure 27.37

(b) The compound microscope has the usual objective O and eyepiece E. There is a cross-wire which can be sharply focused by the eyepiece in the field of view. While focusing the microscope, adjustments are to be made so that there is no parallax between the cross wire and the image of the object to be seen.

(c) When a ray of light is allowed to travel from the rarer medium (air) to the denser medium (glass) obliquely, there is a change in both, the path, as well as speed of the light. The ratio of the speed of light in air medium to that in the glass medium is called refractive index of glass medium with respect to air medium.

(d) Let abcd be a glass slab (Fig 27.38) below which a mark A is put. After refraction, the rays from A will appear to come from B. As a result, B is the apparent image of A. Then refractive index of air w.r.t glass is given by

$$ {}_g\mu_a = \frac{\sin i}{\sin r} = \frac{CD/AD}{CD/BD} = \frac{BD}{AD} $$

Hence refractive index of glass w.r.t air will be ${}_a\mu_g = \frac{1}{{}_g\mu_a} = \frac{AD}{BD}$

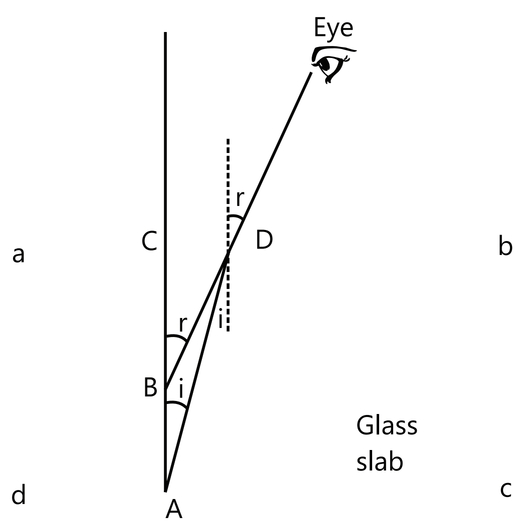


Figure 27.38

(e) If the point D is considered to be very close to point C, then

ADAC=Real thickness and $BD \cong BC$ = Apparent thickness

(f) So, the refractive index of glass with respect to air is

$$ {}_a\mu_g = \frac{AC}{BC} = \frac{\text{Real Thickness}}{\text{Apparant Thickness}} $$

Procedure

(a) The platform of the travelling microscope is levelled by a spirit level by adjusting the levelling screws.

(b) The least count of the vertical scale is determined by using the common principle of the vernier scale.

Example: LG=1MSD-1VSD=$\frac{S}{n}$

Where S = smallest main scale division and n = total number of divisions in the vernier scale.

If $S = \frac{1}{2}$ mm=0.05cm, n=50, then $LC = \frac{0.05}{50}$ =0.001 cm R_1

(c) The eyepiece is focused to get the distinct images of the cross wires in the field of view. At first, the microscope is focused to a cross mark O on a piece of paper fixed on the platform. The corresponding reading R_1 is noted on the vernier scale.

(d) The glass slab is then placed on the mark O and the cross wire is focused through the microscope which has to be raised up. The corresponding reading R_2 is noted on the vernier scale.

(e) Without disturbing the slab, a small quantity or lycopodium powder is sprinkled on the upper surface of the glass slab. Microscope is raised further up, to focus the granules of lycopodium powder on the surface of the glass slab. The final reading R_3 is noted.

(f) Repeat steps 3 to 5 three times by putting mark A at different places on the paper.

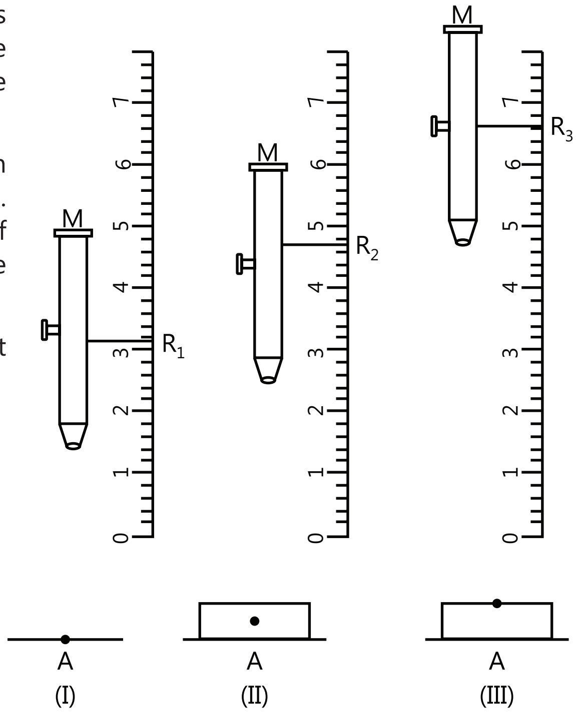


Figure 27.39

Experiment 18: Characteristic Curves of a P-N Junction Diode in Forward and Reverse Bias

Theory:

Characteristics of diode: Graphical relationship between the voltage applied across a diode and the current through the diode is called characteristics of diode. The graph plotted with current as ordinate and potential applied across it ends as abscissa, shows the characteristics of the diode.

Forward biasing: A p-n junction diode gets forward biased when its p side is connected to the positive terminal of the supply voltage and n to the negative terminal. Initially for voltages up to 0.4V, there is not much rise in current due to the opposition by barrier potential. Beyond this, the current starts rising in a p-n junction.

Knee Voltage: The forward voltage when the current starts rising, i.e., is termed as the knee voltage. It is represented as V_k. It is about 0.7V for silicon.

Reverse biasing : A p-n junction is reverse biased when the p side of the junction is connected to the negative terminal of supply voltage and n side terminal is connected to positive terminal of battery.

Reverse saturation current: As the applied voltage is increased in the reverse bias, starting from zero value, the current increases, but soon becomes constant. This current is very small (a few microamperes). It is called the reverse saturation current.

PN Junction Diode and its characteristics

PN junction diode is symbolically represented as shown in the picture. The direction of the arrow is the direction of conventional current flow (under forward bias). Now let's try applying an external voltage to the pn junction diode. The process of applying an external voltage is called "biasing". There are two ways in which we can bias a pn junction diode.

(1) Forward bias and (2) Reverse bias

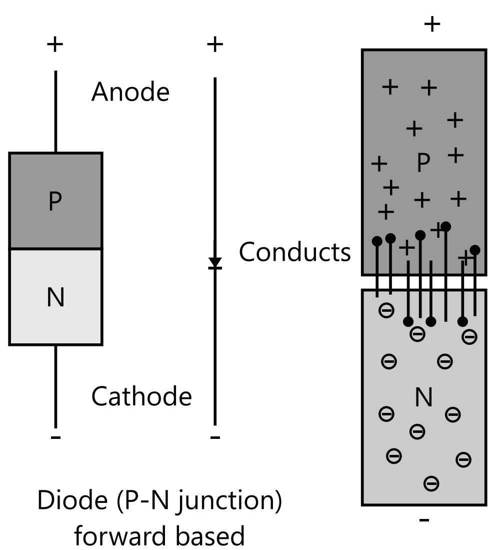


Figure 27.40

The basic difference between a forward bias and reverse bias is in the direction of applying external voltage. The direction of external voltage applied in reverse bias is opposite to that of external voltage applied in forward bias.

Forward biasing a PN Junction diode

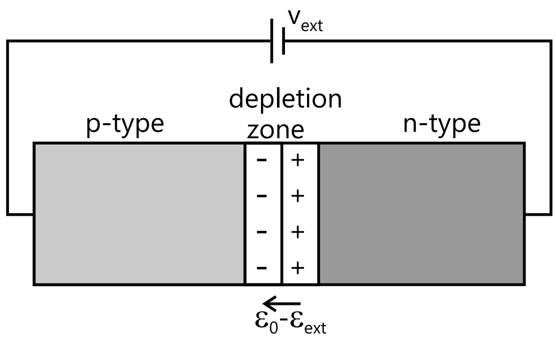


Figure 27.41

Plotting the characteristics of a p-n junction

What we are going to do is, vary the voltage across diode by adjusting the battery. We start from 0 volts, then slowly move 0.1 volts, 0.2 volts and so on till 10 volts. Let's note the readings of voltmeter and ammeter each time we adjust the battery (in steps of 0.1 volts). Finally, after taking the readings, plot a graph with voltmeter readings on X-axis and corresponding Ammeter readings on Y axis. Join all the dots in the graph paper and you will see a graphical representation as shown below. This is what we call "characteristics of a pn junction diode" or the "behavior of diode under forward bias".

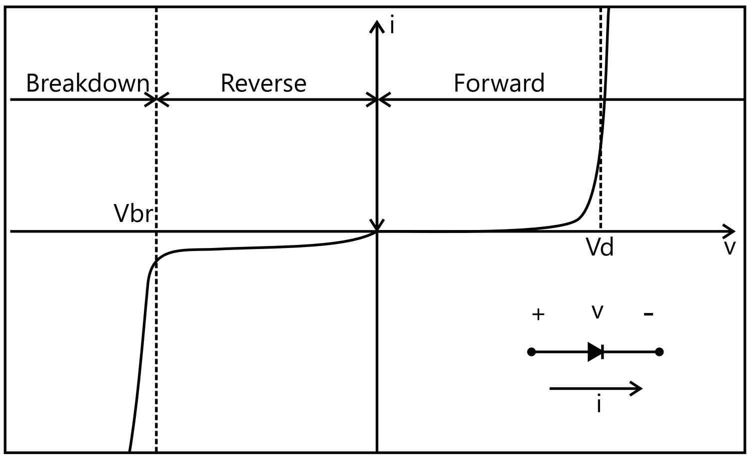
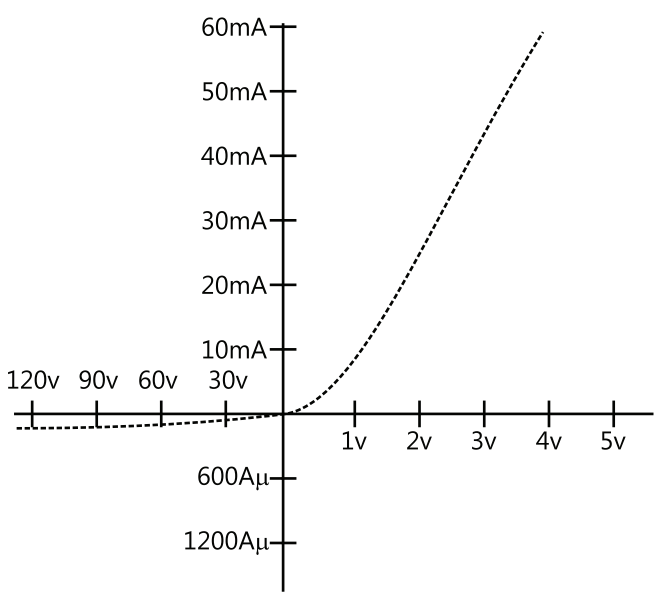


Figure 27.42

How to analyse the characteristics of a pn junction diode?

From the *"characteristics graph"* we have just drawn, we are going to make conclusions about the behavior of pn junction diode. The first thing that we will be interested in, is "barrier potential". From the graph, we observe that the diode does not conduct at all in the initial stages. From 0 volts to 0.7 volts, we are seeing the ammeter reading as zero! This means the diode has not started conducting current through it. From 0.7 volts and up, the diode starts conducting and the current through diode increases linearly with increase in voltage of battery. The barrier potential of silicon diode is 0.7 volts. The diode starts conducting at 0.7 volts and current through the diode increases linearly with increase in voltage. So that's the forward bias characteristics of a pn junction diode. It conducts current linearly with increase in voltage applied across the 2 terminals (provided the applied voltage crosses barrier potential).



Junction diode characteristics

Figure 27.43

What happens inside the pn junction diode when we apply forward bias?

We have seen the characteristics of pn junction diode through its graph. We know a diode has a depletion region with a fixed barrier potential. This depletion region has a predefined width, say W. This width will vary for a Silicon diode and a Germanium diode. The width highly depends on the type of semiconductor used to make pn junction, the level of doping etc. When we apply voltage to the terminals of diode, the width of the depletion region slowly starts decreasing. The reason for this is, in forward bias we apply voltage in a direction opposite to that of barrier potential. We know the p-side of diode is connected to positive terminal and n-side of diode is connected to negative terminal of battery. So the electrons in n-side gets pushed towards the junction (by force of repulsion) and the holes in p-side gets pushed towards the junction. As the applied voltage increases from 0 volts to 0.7 volts, the depletion region width reduces from 'W' to zero. This means depletion region vanishes at 0.7 volts of applied voltage. This results in increased diffusion of electrons from n-side to p-side region and the increased diffusion of holes from p-side to n-side region. In other words, "minority carrier" injection happens on both p-side (in a normal diode (without bias) electrons are a minority on p-side) and n-side (holes are a minority on n-side) of the diode.

How does the current flow take place in a pn junction diode?

This is another interesting factor, to explain. As the voltage level increases, the electrons from n-side gets pushed towards the p-side junction. Similarly holes from p-side gets pushed towards the n-side junction. Now there arises a concentration gradient between the number of electrons at the p-side junction region and the number of electrons at the region towards the p-side terminal. A similar concentration gradient develops between the number of holes at the n-side junction region and the number of holes at region near the n-side terminal. This results in movement of charge carriers (electrons and holes) from a region of higher concentration to a region of lower concentration. This movement of charge carriers inside pn junction gives rise to current through the circuit.

Reverse biasing a pn junction diode

Why should we reverse bias a pn diode? The reason is, we want to learn its characteristics under different circumstances. By reverse biasing, we mean applying an external voltage which is opposite in direction to forward bias. So here we connect positive terminal of battery to n-side of the diode and negative terminal of the battery to p-side of the diode. This completes the reverse bias circuit for pn junction diode. Now to study its characteristics (change in current with applied voltage), we need to repeat all those steps again. Connect voltmeter, ammeter, vary the battery voltage, note the readings etc etc. Finally we will get a graph as shown.

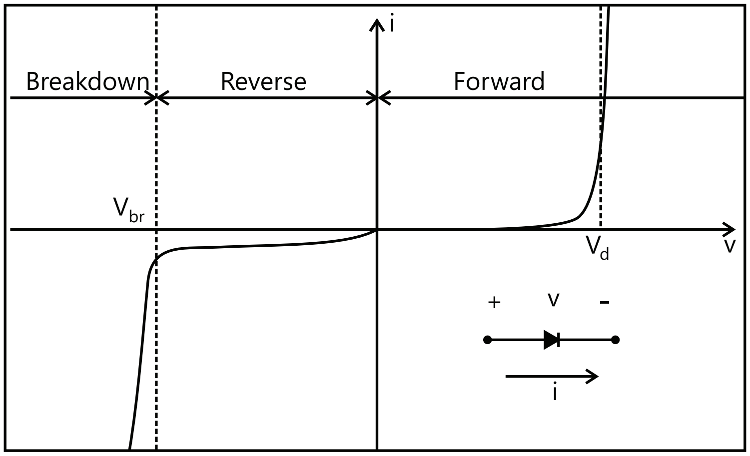


Figure 27.44

Analysing the reverse bias characteristics

Here the interesting thing to note is that, diode does not conduct with change in applied voltage. The current remains constant at a negligibly small value (in the range of micro amps) for a long range of change in applied voltage. When the voltage is raised above a particular point, say 80 volts, the current suddenly shoots (increases suddenly). This is called as "reverse current" and this particular value of applied voltage, where reverse current through diode increases suddenly is known as "break down voltage".

What happens inside the diode?

We connected p-side of the diode to the negative terminal of the battery and n-side of the diode to the positive terminal of the battery. One thing is clear, we are applying external voltage in the same direction of barrier potential. If applied, external voltage is V and barrier potential is V_x , then total voltage across the pn junction will be V+Vx. The electrons at n-side will get pulled from junction region to the terminal region of n-side and similarly the holes at p-side junction will get pulled towards the terminal region of p-side. This results in increasing the depletion region width from its initial length, say 'W' to some 'W+x'. As width of depletion region increases, it results in increasing the electric field strength.

How does reverse saturation current occur and why does it exist?

The reverse saturation current is the negligibly small current (in the range of micro amperes) shown in the graph, from 0 volts, to break down voltage. It remains almost constant (negligible increase do exist) in the range of 0 volts, to reverse breakdown voltage. How does it occur? We know, as electrons and holes are pulled away from junction, they dont diffuse each other across the junction. So the net "diffusion current" is zero! What remains is the drift due to the electric field. This reverse saturation current is the result of drifting of charge carriers from the junction region to the terminal region. This drift is caused by the electric field generated by depletion region.

What happens at reverse breakdown?

At breakdown voltage, the current through the diode shoots rapidly. Even for a small change in applied voltage, there is a high increase in net current through the diode. For each pn junction diode, there will be a maximum net current that it can withstand. If the reverse current exceeds this maximum rating, the diode will get damaged.

Conclusion about PN junction characteristics

To conclude about pn junction characteristics, we need to get an answer to the first question we have raised – what is the use of pn junction? From the analysis of both, forward bias and reverse bias, we can arrive at one fact – a pn junction diode conducts current only in one direction – i.e., during forward bias. During forward bias, the diode conducts current with increase in voltage. During reverse bias, the diode does not conduct with increase in voltage (break down usually results in damage of diode).

Experiment 19: Characteristic Curves of a Zener Diode and Finding Reverse Breakdown Voltage

Theory and Circuit diagram

On application of reverse bias to a diode, depletion layer widens and the bias increases the barrier potential. As a result of this, there is no flow of current in the diode. As the reverse bias increases to a certain value, the applied electric field pulls electrons directly out of their bonds and an increased current flow occurs. The effect is called Zener effect and the reverse voltage applied is called Zener current. At breakdown voltage, the current suddenly increases to a high value (maintaining the voltage constant). That is why zener diodes are used in voltage regulators. Zener diodes with breakdown voltage 2.7V to a few hundred volts are available.

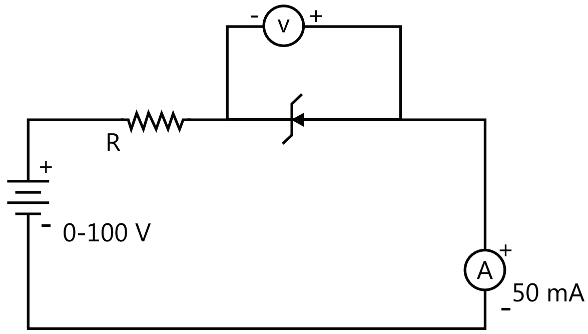


Figure 27.44

Experiment 20: Characteristic Curves of a Transistor and Finding Current Gain and Voltage Gain

Theory:

In most of the transistor circuits, out of the common base, common collector and common emitter, the configuration generally used is common emitter. In such connections, the emitter is common to both the input and the output. For ascertaining the common emitter characteristics, the variables studied are:

(a) $I_{B\ vs}$. V_{BE} keeping V_{CE} constant (Input characteristics)

(b) $_{Ic\ vs}$. V_{CE} keeping I_B constant. (Output characteristics)

(c) $I_{C\ vs}$. I_B keeping V_C constant. (Transfer characteristics)

Transistor is said to be a current device.

Input Characterisitcs: Input characteristics show interdependence of the base current on the base potential for fixed values of as shown in the figure.

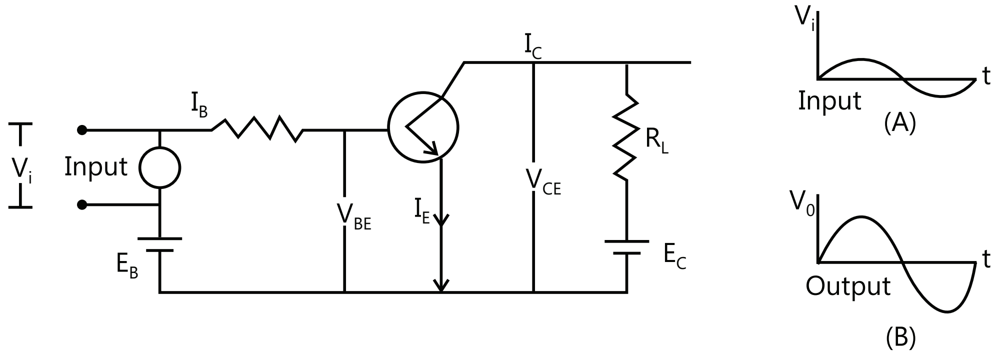


Figure 27.46

The a.c. input resistance (r_i) of the transistor in common emitter circuit is

$$r_i = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right) v_c = \text{constant} \qquad r_i \text{ is only a few 100 ohms.}$$

Output characteristics: These characteristics show the dependence of I_c on V_{CE} when I_B value is fixed as shown in figure and is generally operated beyond the sharp change of slope. The a.c. output resistance (r_o) of transistor in common emitter circuit is

$$r_o = \left(\frac{\Delta V_C}{\Delta I_C}\right) I_B = \text{constant}$$

The value of r_o varies from a 1000 ohms to a few 10 kilo-ohms.

Transfer characteristics: These characteristics show the variation of I_c to base current I_B corresponding to a point P on the transfer characteristics is termed as direct current gain β.

Therefore,

$$\text{Current gain} - \beta = \frac{\text{Collector current at given value of } V_c}{\text{Base current at same value}} \quad \text{or} \qquad \beta = \frac{I_C}{I_B}$$

Alternating current Amplification –

In transfer characteristics, a small change in base current ΔI_B at a given value of V_c produces a large change ΔI_C in collector current, then,

$$\text{A.C. Current gain, } \beta' = \frac{\Delta I_C}{\Delta I_B} = \frac{QR}{PR} \text{ as shown in Fig} = \ldots\ldots\ldots\ldots\ldots \qquad \text{(ii)}$$

Voltage Gain –

Corresponding to a small voltage change Δv_i in the emitter base (i.e., input), if the change in the output voltage at the collector is ΔV_o, then the ratio of ΔV_o to ΔV_i is termed as voltage gain, i.e.,

But $\quad \Delta V_i = r_i \Delta I_B$ and $\Delta V_o = r_o \Delta I_C \Rightarrow$ Avg. gain $= \dfrac{r_o}{r_i} \cdot \dfrac{\Delta I_c}{\Delta I_B} = \dfrac{r_o}{r_i}\beta$

Where r_i is input resistance and r_o is the output resistance of the transistor and β is the current gain,

$$\therefore \qquad Av = \frac{r_o}{r_i} \cdot \frac{\Delta I_c}{\Delta I_B} = \beta \frac{r_o}{r_i}$$