

AIM

To study the variation in volume (V) with pressure (P) for a sample of air at constant temperature by plotting graphs between P and V , and between P and $\frac{1}{V}$.

APPARATUS AND MATERIAL REQUIRED

Boyle's law apparatus, Fortin's Barometer, Vernier Callipers, thermometer, set square and spirit level.

DESCRIPTION AND APPARATUS

The Boyle's law apparatus consists of two glass tubes about 25 cm long and 0.5 cm in diameter (Fig. E11.1). One tube AB is closed at one end while the other CD is open. The two tubes are drawn into a fine opening at the other end (B and D). The ends B and D are connected by a thick walled rubber tubing. The glass tube AB is fixed vertically along the metre scale. The other tube CD can be moved vertically along a vertical rod and may be fixed to it at any height with the help of screw S.

The tube CD, AB and rubber tubing are filled with mercury. The closed tube AB traps some air in it. The volume of air is proportional to the length of air column as it is of uniform cross section.

The apparatus is fixed on a horizontal platform with a vertical stand. The unit is provided with levelling screws.

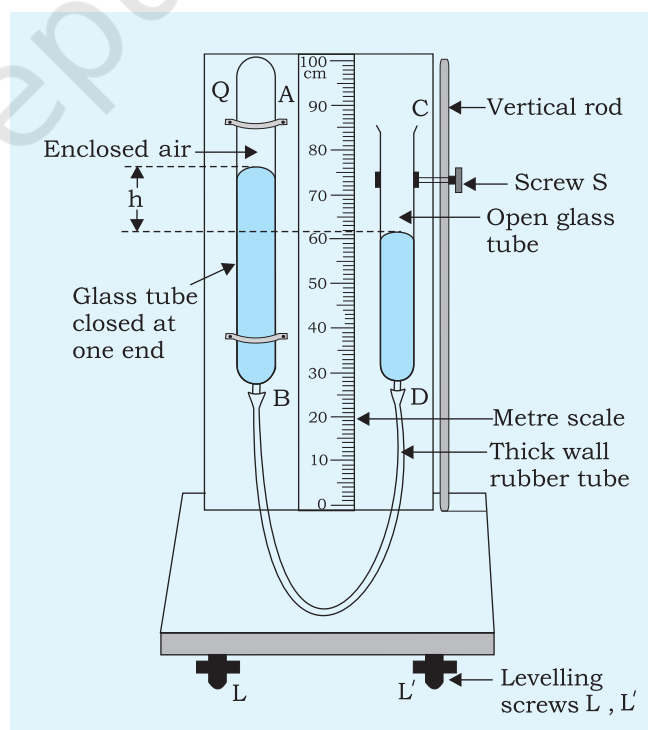


Fig. E11.1: Boyle's law apparatus

PROCEDURE

(a) Measurement of Pressure:

The pressure of the enclosed air in tube AB is measured by noting the difference (h) in the mercury levels (X and Y) in the two tubes AB and CD (Fig. E11.2). Since liquid in interconnected vessels have the same pressure at any horizontal level,

(E 11.1)

$$P \text{ (Pressure of enclosed air)} = H \pm h$$

where H is the atmospheric pressure.

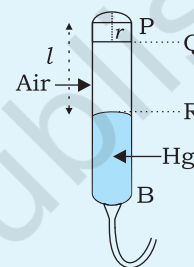
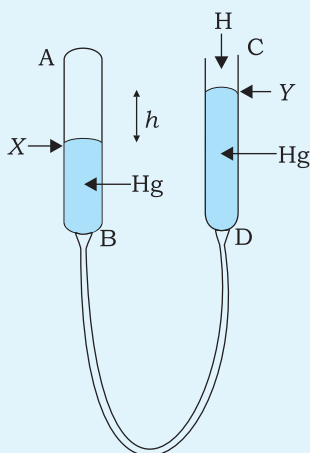


Fig. E 11.2 : Pressure of air in tube AB = $H + h$ **Fig. E 11.3** : Volume of trapped air in tube AB

(b) Measurement of volume of trapped air

In case the closed tube is not graduated.

Volume of air in tube

$$= \text{Volume of air in length PR} - \text{Volume of air in curved portion PQ}$$

Let r be the radius of the tube

Volume of curved portion = volume of the hemisphere of radius r

$$= \frac{1}{2} \times \frac{4}{3} \pi r^3 = \frac{2}{3} \pi r^3$$

$$\text{Volume of PQ} = \pi r^2 \times r = \pi r^3$$

$$\text{error in volume} = \pi r^3 - \frac{2}{3} \pi r^3 = \frac{1}{3} \pi r^3$$

$$\text{resulting error in length} = \frac{1}{3} \pi r^3 / \pi r^2 = \frac{1}{3} r$$

$$\text{correction in length} = -\frac{1}{3}r = -\frac{1}{3}PQ$$

(E 11.2)

This should be subtracted from the measured length l .

Boyle's law: At a constant temperature, the pressure exerted by an enclosed mass of gas is inversely proportional to its volume.

$$P \propto \frac{1}{V}$$

$$\text{or } PV = \text{constant}$$

(E 11.3)

Hence the P - V graph is a curve while that of $P - \frac{1}{V}$ is a straight line.

- (c) Measurement of volume of air for a given pressure.
- Note the temperature of the room with a thermometer.
 - Note the atmospheric pressure using Fortin's Barometer (Project P-9).
 - Set the apparatus vertically using the levelling screws and spirit level.
 - Slide the tube CD to adjust the mercury level at the same level as in AB. Use set square to read the upper convex meniscus of mercury.
 - Note the reading of the metre scale corresponding to the top end of the closed tube P and that of level Q where its curvature just ends. Calculate $\frac{1}{3}PQ$ and note it.
 - Raise CD such that the mercury level in tubes AB and CD is different. Use the set square to carefully read the meniscus X and Y of mercury in tube AB and CD. Note the difference h in the mercury level.
 - Repeat the adjustment of CD for 5 more values of ' h '. This should be done slowly and without jerk. Changing the position of CD with respect to AB slowly ensures that there is no change in temperature, otherwise the Boyle's law will not be valid.
 - Use the Vernier Callipers to determine the diameter of the closed tube AB and hence find ' r ', its radius $\frac{1}{3}PQ = \frac{1}{3}r$.
 - Record your observations in the Table E 11.1.
 - Plot graphs (i) P versus V and (ii) P versus $\frac{1}{V}$, interpret the graphs.

OBSERVATIONS AND CALCULATIONS

1. Room temperature = ... °C.
2. Atmospheric pressure as observed from the Fortins Barometer = ... cm of Hg.
3. For correction in level l due to curved portion of tube AB

(a) Reading for the top of the closed tube AB (P) = ... cm.

Reading where the uniform portion of the tube AB begins (or the curved portion ends) (Q) = ... cm.

Difference (P - Q) = r = ... cm.

$$\text{Correction} = \frac{1}{3}r = \dots$$

OR

(b) Diameter of tube AB = d = ... cm.

$$\text{radius } r = \frac{1}{2}d = \dots \text{ cm.}$$

$$\text{correction for level } l = \frac{1}{3}r$$

RESULT

1. Within experimental limits, the graph between P and V is a curve.
2. Within experimental limits, the product PV is a constant (from the calculation).

Table E 11.1 : Measurement of Pressure and Volume of enclosed air

S. No.	Level of mercury in closed tube AB X (cm of Hg)	Level of mercury in open tube CD Y (cm of Hg)	Pressure difference $h = X - Y$ (cm of Hg)	Pressure of air in AB = $H \pm h$ (cm of Hg)	Volume of air XA $\left(l - \frac{1}{3}r\right)$	PV or $P \times l$	1/V or $\frac{1}{l}$
1							
2							
3							
4							

Note: $H \pm h$ must be considered according to the levels X and Y taking into account whether the pressure of air in AB will be more than atmospheric pressure or less.

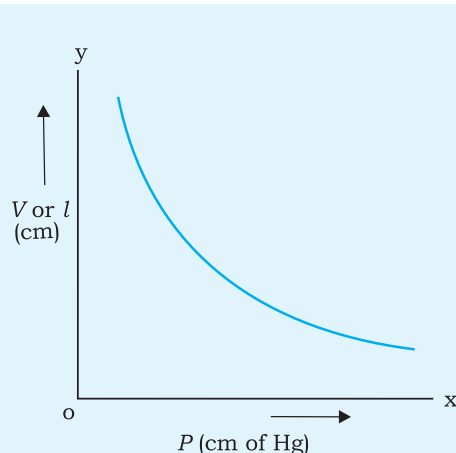


Fig. E11.4 : Graph between Volume, V and pressure, P

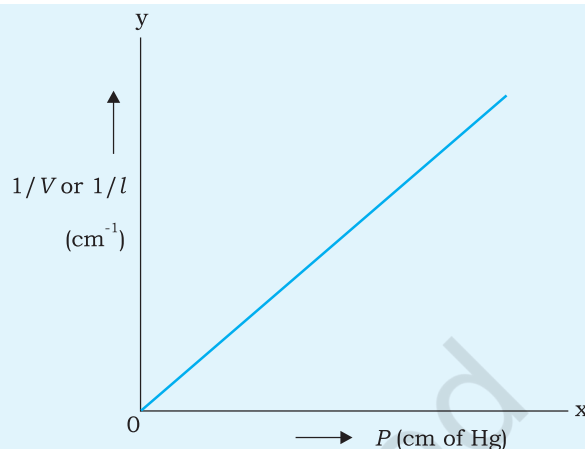


Fig. E11.5 : Graph between $\frac{1}{V}$ and pressure P

Note that Fig. E 11.4 shows that the graph between P and V is a curve and that between P and $\frac{1}{V}$ is a straight line (Fig. E 11.5).

- The graph P and $\frac{1}{V}$ is a straight line showing that the pressure of a given mass of enclosed gas is inversely proportional to its volume at constant temperature.

P RECAUTIONS

- The apparatus should be kept covered when not in use.
- The apparatus should not be shifted in between observations.
- While measuring the volume of the air, correction for the curved portion of the closed tube should be taken into account.
- Mercury used should be clean and not leave any trace on the glass. The open tube should be plugged with cotton wool when not in use.
- The set square should be placed tangential to the upper meniscus of the mercury for determining its level.

SOURCES OF ERROR

- The enclosed air may not be dry.
- Atmospheric pressure and temperature of the laboratory may change during the course of the experiment.

- The closed end of the tube AB may not be hemispherical.
- The mercury may be oxidised due to exposure to atmosphere.

DISCUSSION

- The apparatus should be vertical to ensure that the difference in level (h) is accurate.
- The diameter of the two glass tubes may or may not be the same but the apparatus should be vertical.
- The open tube CD should be raised or lowered gradually to ensure that the temperature of the enclosed air remains the same.
- The readings should be taken in order (above and below the atmospheric pressure). This ensures wider range of consideration, also if they are taken slowly the atmospheric pressure and temperature over the duration of observation remain the same. So time should not be wasted.
- Why should the upper meniscus of mercury in the two tubes recorded carefully using a set square?

SELF ASSESSMENT

- Plot $\frac{1}{V}$ versus ' h ' graph and determine the value of $\frac{1}{V}$ when $h = 0$. Compare this to the value of atmospheric pressure. Give a suitable explanation for your result.
- Comment on the two methods used for estimation of the volume of the curved portion of the closed tube. What are the assumptions made for the two methods?
- If the diameter of tube AB is large, why would the estimation of the curved portion be unreliable?
- The apparatus when not in use should be kept covered to avoid contamination of mercury in the open tube. How will oxidation of mercury affect the experiment?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

- Tilt apparatus slightly and note the value of ' h ' for two or three values of X and Y.
- Take a glass U tube. Fill it with water. Pour oil in one arm. Note the difference in level of water, level of oil and water in the two arms. Deduce the density of oil. What role does atmospheric pressure play in this experiment?

EXPERIMENT 12

AIM

To determine the surface tension of water by capillary rise method.

APPARATUS AND MATERIAL REQUIRED

A glass/plastic capillary tube, travelling microscope, beaker, cork with pin, clamps and stand, thermometer, dilute nitric acid solution, dilute caustic soda solution, water, plumb line.

PRINCIPLE

When a liquid rises in a capillary tube [Fig. E 12.1], 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

$$2\pi rT = \pi r^2 h \rho g \quad (\text{approx}) \text{ for water}$$

$$\text{or } T = \frac{h\rho gr}{2}$$

where T = surface tension of the liquid,
 h = height of the liquid column and
 r = inner radius of the capillary tube

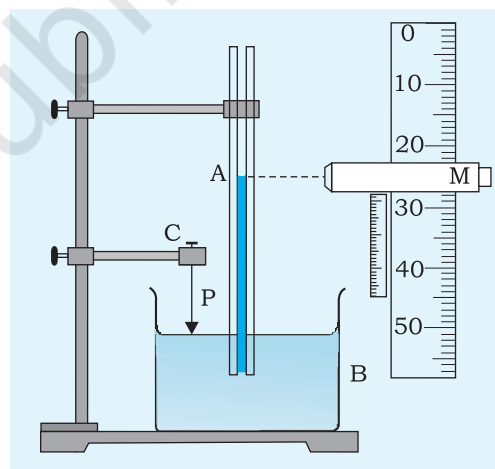


Fig.E 12.1: Rise of liquid in a capillary tube

PROCEDURE

1. Do the experiment in a well-lit place for example, near a window or use an incandescent bulb.
2. Clean the capillary tube and beaker successively in caustic soda and nitric acid and finally rinse thoroughly with water.
3. Fill the beaker with water and measure its temperature.
4. Clamp the capillary tube near its upper end, keeping it above the beaker. Set it vertical with the help of a plumb line held near it.

Move down the tube so that its lower end dips into the water in the beaker.

5. 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 Fig. E 12.1. Ensure that the pin does not touch the capillary tube. Slowly lower the pin till its tip just touches the water surface. This can be done by coinciding the tip of the pin with its image in water.
6. 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 focussing the meniscus, hold a piece of paper at the lowest point of the meniscus outside the capillary tube and focus it first, as a guide. Note the reading of travelling microscope.
7. 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.
8. Focus the microscope on the tip of the pin and note the microscope reading.
9. 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 readings to measure the internal diameter of the tube in two mutually perpendicular directions.

OBSERVATIONS

Determination of h

Least count (L.C.) of the microscope = ... mm

Table E 12.1 : Measurement of capillary rise

S. No.	Reading of meniscus h_1 (cm)			Reading of tip of pin touching surface of water h_2 (cm)			$h = h_1 - h_2$
	M.S.R. S (cm)	V.S.R. n	$h_1 = (S + n \times \text{L.C.})$	M.S.R. S' (cm)	V.S.R. n'	$h_2 = (S' + n' \times \text{L.C.})$ (cm)	
1							
2							
3							

Table E 12.2 : Measurement of diameter of the capillary tube

S. No.	Reading along a diameter (cm)		Diameter $d_1 (x_2 - x_1)$	Reading along perpendicular diameter (cm)		Diameter $d_2 (y_2 - y_1)$	Mean diameter d
	One end	other end	(cm)	One end	other end	(cm)	$= \frac{d_1 + d_2}{2}$ (cm)
1	x_1	x_2		y_1	y_2		
2							
3							

Mean radius $r = \dots$ cm; Temperature of water $\theta = \dots$ °C;

Density of water at θ° C = \dots g cm⁻³

CALCULATION

Substitute the value of h and r and ρg in the formula for T and calculate the surface tension.

RESULT

The surface tension of water at \dots °C = $\dots \pm \dots$ Nm⁻¹

PRECAUTIONS

1. To make capillary tube free of contamination, it must be rinsed first in a solution of caustic soda then with dilute nitric acid and finally cleaned with water thoroughly.
2. The capillary tube must be kept vertical while dipping it in water.
3. To ensure that capillary tube is sufficiently wet, raise and lower water level in container by lifting or lowering the beaker. It should have no effect on height of liquid level in the capillary tube.
4. Water level in the capillary tube should be slightly above the edge of the beaker/dish so that the edge does not obstruct observations.
5. Temperature should be recorded before and after the experiment.
6. Height of liquid column should be measured from lowest point of concave meniscus.

SOURCES OF ERROR

1. Inserting dry capillary tube in the liquid can cause gross error in the measurement of surface tension as liquid level in capillary tube may not fall back when the level in container is lowered.

2. Surface tension changes with impurities and temperature of the liquid.
3. Non-vertical placement of the capillary tube may introduce error in the measurement of height of the liquid column in the tube.
4. Improper focussing of meniscus in microscope could cause an error in measurement of the height of liquid column in the capillary tube.

DISCUSSION

1. In a fine capillary tube, the meniscus surface may be considered to be semispherical and the weight of the liquid above the lowest point of the meniscus as $\frac{1}{3}\rho r^3\pi g$. Taking this into account, the formula for surface tension is modified to $T = \frac{1}{2}\rho gr\left(h + \frac{r}{3}\right)$. More precise calculation of surface tension can be done using this formula.
2. If the capillary is dry from inside the water that rises to a certain height in it will not fall back, so the capillary should be wet from inside. To wet the inside of the capillary tube thoroughly, it is first dipped well down in the water and raised and clamped. Alternatively, the beaker may be lifted up and placed down.

SELF ASSESSMENT

1. Suppose the length of capillary tube taken is less than the height upto which liquid could rise. What do you expect if such a tube is inserted inside the liquid? Explain your answer.
2. Two match sticks are floating parallel and quite close to each other. What would happen if a drop of soap solution or a drop of hot water falls between the two sticks? Explain your answer.

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Experiment can be performed at different temperatures and effect of temperature on surface tension can be studied.
2. Experiment can be performed by adding some impurities and effect of change in impurity concentration (like adding NaCl or sugar) on surface tension can be studied.
3. Study the effect of inclination of capillary tube on height of liquid rise in the capillary tube.

AIM

To determine the coefficient of viscosity of a given liquid by measuring the terminal velocity of a spherical body.

APPARATUS AND MATERIAL REQUIRED

A wide bore tube of transparent glass/acrylic (approximately 1.25 m long and 4 cm diameter), a short inlet tube of about 10 cm length and 1 cm diameter (or a funnel with an opening of 1 cm), steel balls of known diameters between 1.0 mm to 3 mm, transparent viscous liquid (castor oil/glycerine), laboratory stand, forceps, rubber bands, two rubber stoppers (one with a hole), a thermometer (0-50 °C), and metre scale.

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 v , then the sum of the upward buoyant force and viscous drag, force F , is balanced by the downward weight of the ball (Fig. E13.1).

= Buoyant force on the ball + viscous force

$$\frac{4}{3}\pi r^3 \sigma g = \frac{4}{3}\pi r^3 \rho g + 6\pi\eta r v \quad \text{(E 13.1)}$$

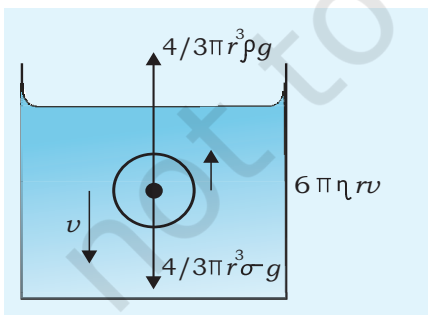


Fig.E 13.1: Forces acting on a spherical body falling through a viscous liquid with terminal velocity

$$\text{or } v = \frac{\frac{4}{3}\pi r^3 (\sigma - \rho) g}{6\pi\eta r} = \frac{2 r^2 (\sigma - \rho) g}{9 \eta} \quad \text{(E 13.2)}$$

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

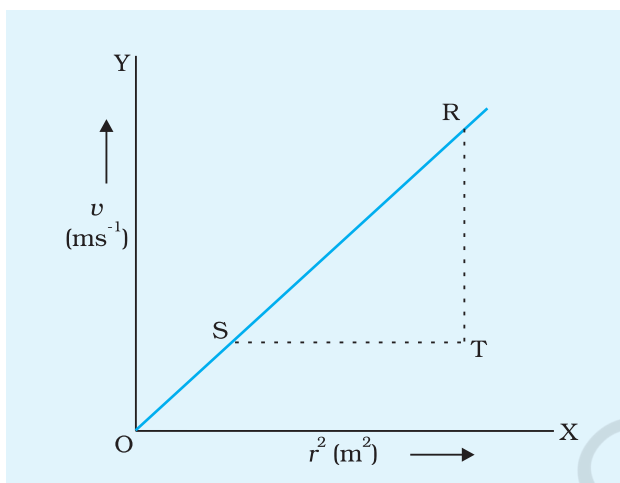
The terminal velocity depends directly on the square of the size (diameter) of the spherical ball. Therefore, if several spherical balls of different radii are made to fall freely through the viscous liquid then a plot of v vs r^2 would be a straight line as illustrated in Fig. E 13.2.

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

(E 13.3)

$$\eta = \frac{2}{9} g(\sigma - \rho) \cdot \frac{r^2}{v} = \frac{2}{9} \frac{(\sigma - \rho)g}{(\text{slope of line})}$$

$$= \dots \text{Nsm}^{-2} \text{ (poise)}$$



The relation given by Eq. (E 13.3) holds good if the liquid through which the spherical body falls freely is in a cylindrical vessel of radius $R \gg r$ and the height of the cylinder is sufficient 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.

P ROCEDURE

Fig.E 13.2: Graph between terminal velocity v , and square of radius of ball, r^2

1. Find the least count of the stop-watch.
2. Note the room temperature, using a thermometer.
3. Take a wide bore tube of transparent glass/acrylic (of diameter about 4 cm and of length approximately 1.25 m). Fit a rubber stopper at one end of the wide tube and ensure that it is airtight. Fill it with the given transparent viscous liquid (say glycerine). Fix the tube vertically in the clamp stand as shown in Fig. E 13.3. Ensure that there is no air bubble inside the viscous liquid in the wide bore tube.
4. Put three rubber bands A, B, and C around the wide bore tube dividing it into four portions (Fig. E 13.3), such that $AB = BC$, each about 30 cm. The rubber band A should be around 40 cm below the mouth of the wide bore tube (length sufficient to allow the ball to attain terminal velocity).
5. 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 thoroughly with the experimental viscous liquid (glycerine) in a petridish or a watch glass. Otherwise

these balls may develop air bubble(s) on their surfaces as they enter the liquid column.

6. Fix a short inlet tube vertically at the open end of the wide tube through a rubber stopper fixed to it. Alternately one can also use a glass funnel instead of an inlet tube as shown in Fig. E 13.3. 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. The ball, after passing through the inlet tube, will fall along the axis of the liquid column.
7. 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 stop-watch to continue and stop it when the ball crosses the band C.
8. 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 attained before the ball crosses A, then $t_2 = 2 t_1$. If it is not so, repeat the experiment with steel ball of same radii after adjusting the positions of rubber bands.
9. Repeat the experiment for other balls of different diameters.
10. Obtain terminal velocity for each ball.
11. Plot a graph between terminal velocity, v and square of the radius of spherical ball, r^2 . It should be a straight line. Find the slope of the line and hence determine the coefficient of viscosity of the liquid using the relation given by Eq. (E 13.3).

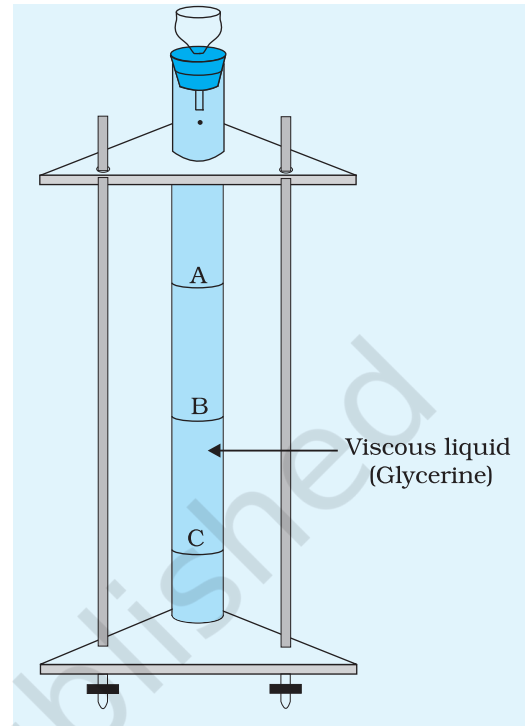


Fig.E 13.3: Steel ball falling along the axis of the tube filled with a viscous liquid.

OBSERVATIONS

1. Temperature of experimental liquid (glycerine) $\theta = \dots^\circ\text{C}$.
2. Density of material of steel balls $\sigma = \dots \text{kg m}^{-3}$
3. Density of the viscous liquid used in the tube = $\dots \text{kgm}^{-3}$
4. Density of experimental viscous liquid $\rho = \dots \text{kg m}^{-3}$

5. Internal diameter of the wide bore tube = ... cm = ... m

6. Length of wide bore tube = ... cm = ... m

7. Distance between A and B = ... cm = ... m

8. Distance between B and C = ... cm = ... m

Average distance h between two consecutive rubber bands
= ... cm = ... m

9. Acceleration due to gravity at the place of experiment, = ... gms^{-2}

10. Least count of stop-watch = ... s

Table E 13.1: Measurement of time of fall of steel balls

S. No.	Diameter and radius of spherical balls		Square of the radius of the balls r^2 (m^2)	Time taken for covering distance $h = \dots$ cm between rubber bands				Terminal Velocity $v = \frac{h}{t}$ (m^{-1})
	d (cm)	$r = d/2$ (m)		A and B t_1 (s)	A and C t_2 (s)	B and C $t_3 = t_2 - t_1$ (s)	Mean time $t = \frac{t_1 + t_3}{2}$ (s)	
1								
2								
3								

GRAPH

Plot a graph between r^2 and v taking r^2 along x -axis and v along y -axis. This graph will be similar to that shown in Fig. E 13.2.

Slope of line $\frac{v}{r^2} = \frac{RT}{ST}$

So $\eta = \frac{2}{9} \frac{r^2 (\sigma - \rho) g}{(\text{slope of line})}$

Error $\frac{\Delta \eta}{\eta} = \frac{2 \Delta r}{r} + \frac{\Delta \text{slope}}{\text{slope}}$

Standard value of $\eta = \dots \text{Nsm}^{-2}$

% error in $\eta = \dots \%$

RESULT

The coefficient of viscosity of the given viscous liquid at temperature θ °C = ... \pm ... Nsm^{-2}

PRECAUTIONS AND SOURCES OF ERROR

1. In order to minimise the effects, although small, on the value of terminal velocity (more precisely on the value of viscous drag, force F), the radius of the wide bore tube containing the experimental viscous liquid should be much larger than the radius of the falling spherical balls.
2. The steel balls should fall without touching the sides of the tube.
3. The ball should be dropped gently in the tube containing viscous/liquid.

DISCUSSION

1. Ensure that the ball is spherical. Otherwise formula used for terminal velocity will not be valid.
2. Motion of falling ball must be translational.
3. Diameter of the wide bore tube should be much larger than that of the spherical ball.

SELF ASSESSMENT

1. Do all the raindrops strike the ground with the same velocity irrespective of their size?
2. Is Stokes' law applicable to body of shapes other than spherical?
3. What is the effect of temperature on coefficient of viscosity of a liquid?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Value of η can be calculated for steel balls of different radii and compared with that obtained from the experiment.
2. To find viscosity of mustard oil [**Hint:** Set up the apparatus and use mustard oil instead of glycerine in the wide bore tube].
3. To check purity of milk [**Hint:** Use mustard oil in the tall tube. Take an eye dropper, fill milk in it. Drop one drop of milk in the oil at the top of the wide bore tube and find its terminal velocity. Use the knowledge of coefficient of viscosity of mustard oil to calculate the density of milk].
4. Study the effect of viscosity of water on the time of rise of air bubble [**Hint:** Use the bubble maker used in an aquarium. Place it in the wide bore tube. Find the terminal velocity of rising air bubble].