EXPERIMENT 11

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.

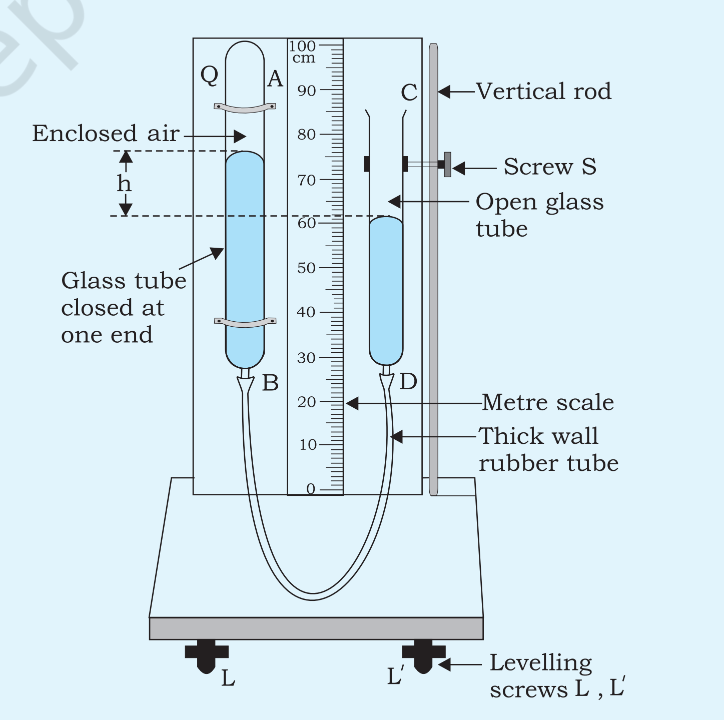

Fig. E11.1: *Boyle's law apparatus*

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 (Pressure of enclosed air) = $H \pm h$

where H is the atmospheric pressure.

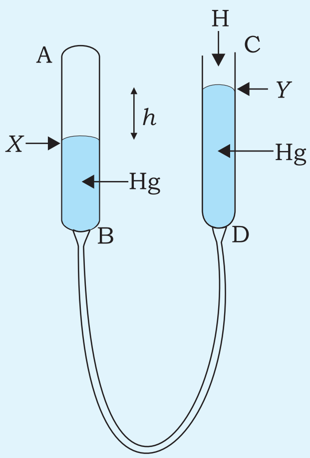

Fig. E 11.2 : *Pressure of air in tube AB = H + h*

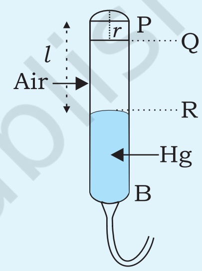

Fig. E 11.3 : *Volume of trapped air in tube AB*

(b) Measurement of volume of trapped air

In case the closed tube is not graduated.

Volume of air in tube

= Volume of air in length PR – 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

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

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

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

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

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.

$$P \, \alpha \frac{1}{V}$$

or $PV =$ 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.

1. Note the temperature of the room with a thermometer.
2. Note the atmospheric pressure using Fortin's Barometer (Project P-9).
3. Set the apparatus vertically using the levelling screws and spirit level.
4. 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.
5. 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.
6. 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.
7. 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.
8. Use the Vernier Callipers to determine the diameter of the closed tube AB and hence find 'r', its radius $\frac{1}{3}$ PQ = $\frac{1}{3}r$.
9. Record your observations in the Table E 11.1.
10. 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.

Correction = $\frac{1}{3}r$ = ...

OR

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

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

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 ± h (cm of Hg)	Volume of air XA $l-\frac{1}{3}r$	PV or P× 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.

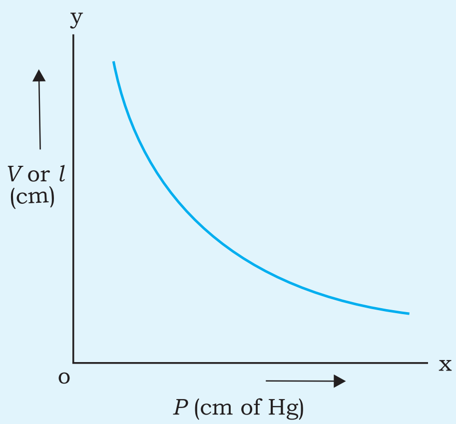

Fig. E11.4 : *Graph between Volume, V and pressure, P*

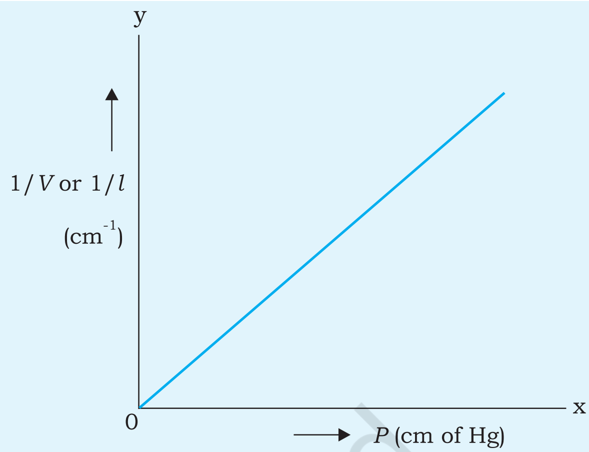

Fig. E11.5 : *Graph between $\frac{1}{V}$ and pressure P*

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).

3. 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.

PRECAUTIONS

1. The apparatus should be kept covered when not in use.
2. The apparatus should not be shifted in between observations.
3. While measuring the volume of the air, correction for the curved portion of the closed tube should be taken into account.
4. 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.
5. The set square should be placed tangential to the upper meniscus of the mercury for determining its level.

SOURCES OF ERROR

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

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

DISCUSSION

1. The apparatus should be vertical to ensure that the difference in level (h) is accurate.
2. The diameter of the two glass tubes may or may not be the same but the apparatus should be vertical.
3. The open tube CD should be raised or lowered gradually to ensure that the temperature of the enclosed air remains the same.
4. 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.
5. Why should the upper meniscus of mercury in the two tubes recorded carefully using a set square?

SELF ASSESSMENT

1. 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.
2. 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?
3. If the diameter of tube AB is large, why would the estimation of the curved portion be unreliable?
4. 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

1. Tilt apparatus slightly and note the value of 'h' for two or three values of X and Y.
2. 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?