6.4 DENSITY AND PRESSURE

The density of a substance is defined as its mass per unit volume. The symbol used for density is the greek letter ρ (rho).

thus,

$$\text{density} = \frac{\text{mass}}{\text{volume}} \text{ or } \rho = \frac{m}{V} \qquad (6.7)$$

The SI unit of density is kg m^{-3}.

Pressure Pressure is defined as the force acting normally per unit area

$$\text{pressure} = \frac{\text{thrust}}{\text{area}} \qquad (6.8)$$

The SI unit of pressure is 1 newton per metre square (Nm^{-2}) also known as the Pascal.

3.4.1 Calculation of pressure of a column of liquid

Suppose we consider a horizontal area A square metres at a depth of h metres below the surface of liquid of density ρ kg m^{-2} (figure 3.1). Standing on this area is a vertical column of liquid of volume hA m^3, the mass of which (volume times density) is given by h A ρ kg f (where 1 kgf = 9.8 N) then,

thrust on area = 9.8 h A ρ N

$$\text{since pressure} = \frac{\text{thrust}}{\text{area}} = \frac{9.8hA\rho}{A} Nm^{-2} = 9.8h\rho\ Nm^{-2} \qquad (6.9)$$

It is important to note that the area A does not appear in the final expression for the pressure. Thus the pressure at any point in a liquid at rest depends only on the depth and density.

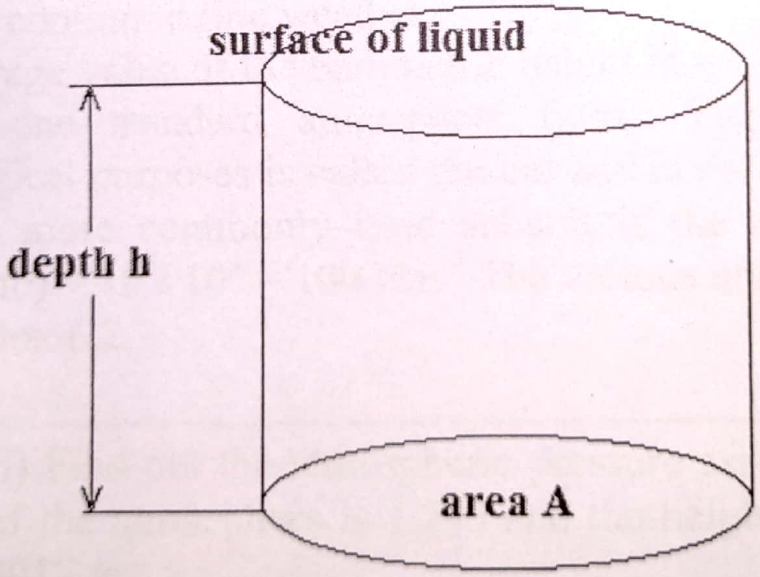

Figure 6.1 Pressure of a liquid column

6.4.2 Atmospheric Pressure

Owing to its weight the atmosphere exerts a pressure of about 1000 kgf per metre square. If we assume that, to a close approximation 1kgf = 10 N, then the atmospheric pressure in SI units is equal to 100 000 Nm^{-2} or 10^5 Nm^{-2} or 10^5Pascals.

The atmospheric pressure can be measured accurately using a Fortin's barometer (figure 3.2). It consists essentially of a tube with mercury which is protected by enclosing it in a brass tube, the upper part of which is made of glass so that the mercury surface may be seen. Readings are taken by a vernier moving over a millimeter scale of sufficient length to cover the full range of variation in barometric height.

To overcome errors due to alteration in the lower mercury level a leather bag is provided which may be raised or lowered by a screw. Before taking a reading, this screw is adjusted until the lower mercury surface just touches an ivory pointer. This pointer has been fixed so as to coincide with the zero of the vertical millimeter scale. A Fortin's barometer thus measures atmospheric pressure in millimeters of mercury (mm Hg). The normal pressure at the sea level is 760 mm Hg.

Variations in the atmospheric pressure are due to changes in the density of air consequent upon the changes in temperature and water vapour of the atmosphere. Water vapour is lighter than air, its density being 5/8 of that of dry air. Thus, when the proportions of water vapour in the atmosphere increases, the density and hence the pressure of the atmosphere decreases and consequently, the barometer reading falls. A considerable fall in the reading indicates that rain is imminent. On the contrary, a steady rise indicates a continued fine weather.

The average value of the barometric height at sea level is 760 mm Hg and is called one standard atmosphere (atm). The unit of pressure for meteorological purposes is called the bar and is defined as a pressure of 10^5 Nm^{-2}. The more commonly used subunit is the millibar (1/1000 bar). 1 millibar (mb) = $10^5/10^3 = 100$ Nm^{-2}. The various units and their relations are shown in Box 6.2.

Box 6.2(i) Find out the atmospheric pressure assuming that the density of the atmosphere is 1.293 and the height of the atmosphere is 8012 m.

(ii) Express one standard atmosphere in (a) newtons per metre square (Pascals), (b) bars and (c) millibars

Solution (i) Pressure = ρgh

Atmospheric pressure = $1.293 \times 9.81 \times 8012$ Nm^{-2}

= 101626 N or approximately 10^5 Nm^{-2}

(ii) 1 atm = 760 mm Hg = 0.76 m Hg

density of mercury = 13.6 g cm^{-3} = 13.6×1000 kg m^{-3}

hence 1 atm = $0.76 \times 13.6 \times 1000 \times 9.81$ = 101400 Nm^{-2} (Pascals)

= $101400/10^5$ bar = 1.014 bar = 1014 millibar

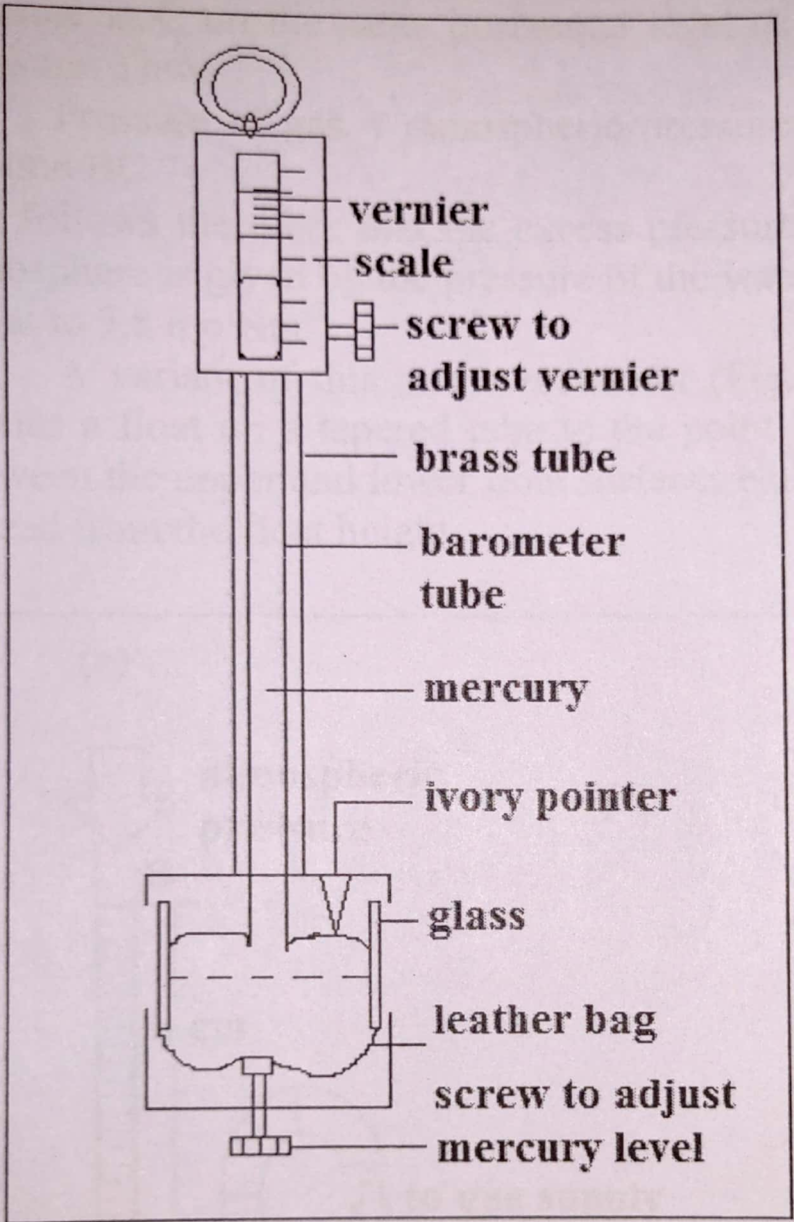

Figure 6.2 Fortin's barometer

In the sea the pressure increases by one atmosphere for a depth of 10 m and this sequence continues as one goes deeper into the sea. Above the sea level the pressure decreases by 0.06 atmospheres for every 1000 metres of altitude in the first 15,000 metres. Above this the decrease is less rapid.