UNIT 1

Fluids

G8JNLI

Learning Objectives

After completing this lesson, students will be able to

- define pressure in terms of weight.
- explain the variation of pressure with respect to depth in a fluid.
- learn the fact that water exerts an upward force on objects immersed in it.
- recall and state the Archimedes' principle.
- calculate density when pressure and altitude are given.
- learn the formula for finding the relative density of an object and apply the same.
- understand the behaviour of floating bodies.

Introduction

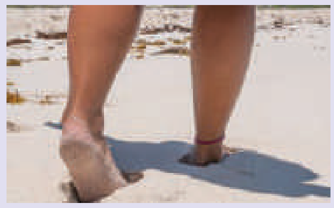
A small iron nail sinks in water, whereas a huge ship of heavy mass floats on sea water. Astronauts have to wear a special suit while traveling in space. All these have a common reason called 'pressure'. The intermolecular forces in solids are strong, so that the shape and size of solids do not easily change. But this force is less in liquids and gases (together known as fluids) so that their shape is easily changed. If the pressure increases in a solid, based on its inherent properties it experiences tension and ultimately deforms or breaks. In the case of fluids it however causes it to flow rather than to deform. Although liquids and gases share some common characteristics, they have many distinctive characteristics on their own. It is easy to compress a gas whereas liquids are incompressible. Learning of all these facts helps us to understand pressure better. In this lesson you will study about the pressure in fluids, density of fluids and their application in practical life.

1.1 Thrust and Pressure

Try to fix a paper with the help of a drawing pin. Push the pin into the board by its head. Did you succeed? Try now to push the pin by the pointed end. Could you do it this time? Have you ever wondered why a camel can run in a desert easily? Why a truck or a motorbus has wider tyre? Why cutting tools have sharp edges? In order to answer these questions and understand the phenomena involved, we need to learn about two interrelated physical concepts called thrust and pressure.

Activity 1

Stand on loose sand. Your feet go deep into the sand. Now, lie down on the sand. What happens? You will find that your body will not go that deep into the sand.



Bed of nail

If a single nail pricks our body it is very painful. How is it possible for people to lie down on a bed of nails, still remain unhurt?

In both the cases of the above activity, the force exerted on the sand is the weight of your body which is the same. This force acting perpendicular to the surface is called thrust. When you stand on loose sand, the force is acting on an area equal to the area of your feet. When you lie down, the same force acts on an area of your whole body, which is larger than the area of your feet. Therefore the effect of thrust, that is, pressure depends on the area on which it acts. The effect of thrust on sand is larger while standing than lying.

The net force in a particular direction is called thrust. The force per unit area acting on an object concerned is called pressure. Thus, we can say thrust on an unit area is pressure.

$$\text{Pressure} = \frac{\text{Thrust}}{\text{Area of contact}}$$

For the same given force, if the area is large pressure is low and vice versa. This is shown in Figure 1.1.

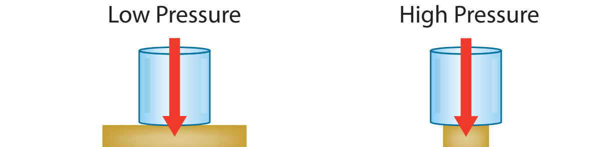


Figure 1.1 Pressure depends on area of application

In SI units, the unit of thrust is newton denoted as N. The unit of pressure is newton per square metre or newton metre^{-2} denoted as Nm^{-2}. In the honour of the great French scientist, Blaise Pascal, 1 newton per square metre is called as 1 pascal denoted as Pa. 1 Pa = 1 N m^{-2}

In CGS system force is measured in dyne and area in square cm. Thus the unit of pressure in CGS system is dyne per square cm (dyne cm^{-2}). The relation between the two units is,

$$1 \text{ N m}^{-2} = 10 \text{ dyne cm}^{-2}.$$

Example 1.1

A man whose mass is 90 kg stands on his feet on a floor. The total area of contact of his two feet with the floor is 0.036 m^2. (Take, g = 10 ms^{-2})

a. How much is the pressure exerted by him on the floor?

b. What pressure will he exert on the floor if he stands on one foot?

Solution

The weight of the man (thrust),

$F = mg = 90 \text{ kg} \times 10 \text{ m s}^{-2} = 900 \text{ N}$

a) Pressure, $P = \frac{F}{A} = \frac{900 \text{ N}}{0.036 \text{ m}^2} = 25000 \text{ Pa}$

b) Area of one foot, $A_{1foot} = \frac{A}{2} = 0.018 \text{ m}^2$

Pressure, exerted by 1foot

$= \frac{F}{A_{1foot}} = \frac{900 \text{ N}}{0.018 \text{ m}^2} = 50000 \text{ Pa}$

DO YOU KNOW?

- Cutting edges of knife and axes are sharpened, because as the area decreases the pressure increases. Hence, small force is enough to cut an object.
- Heavy trucks are fitted with six to eight wheels. As area increases pressure decreases. So weight of the truck exerts less pressure on the road.
- Animals' jaws can exert a pressure of more than 750 pounds per square inch as they are very sharp.

1.2 Pressure in fluids

All the flowing substances, both liquids and gases are called fluids. Like solids, fluids also have weight and therefore exert pressure. When filled in a container, the pressure of the fluid is exerted in all directions and at all points of the fluid. Since the molecules of a fluid are in constant, rapid motion, particles are likely to move equally in any direction. Therefore the pressure exerted by the fluid acts on an object from all directions. It is shown in Figure 1.2. Pressure in fluids is calculated as shown below.

$$\text{Fluid Pressure} = \frac{\text{Total force exerted by the fluid}}{\text{Area over which the force is exerted}} = \frac{F}{A}$$

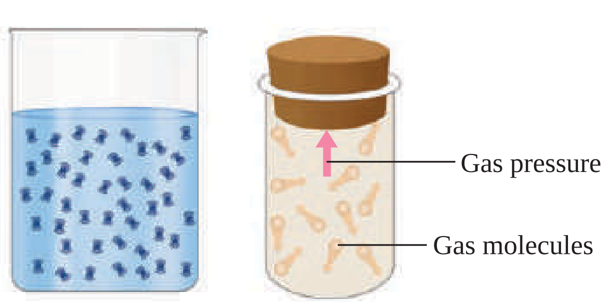


Figure 1.2 Collision of molecules gives rise to pressure

We shall first learn about the pressure exerted by liquids and then learn about the pressure exerted by gases.

1.2.1 Pressure due to liquids

The force exerted due to the pressure of a liquid on a body submerged in it and on the walls of the container is always perpendicular to the surface. In Figure 1.3, we can see the pressure acting on all sides of the vessel.

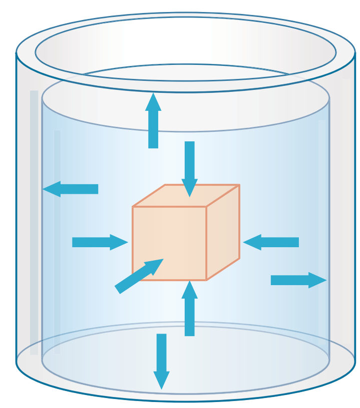
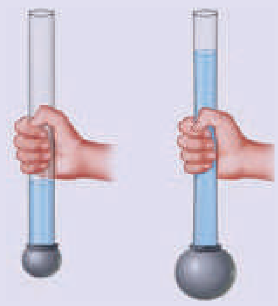


Figure 1.3 Force due to pressure of a liquid

When an air filled balloon is immersed inside the water in a vessel it immediately comes up and floats on water. This shows that water (or liquid) exerts pressure in the upward direction. It is shown in Figure 1.4.

Figure 1.4 Liquid pressure exerts force upwards

Activity 2



Take a transparent plastic pipe. Also take a balloon and tie it tightly over one end of the plastic pipe. Keep the pipe in a vertical position with its closed end at the bottom. Pour some water in the pipe from the top. What happens?

We will find that on pouring water in the pipe, the balloon tied at the bottom stretches and bulges out. The bulging out of balloon demonstrates that the water poured in the pipe exerts a pressure on the bottom of its container.

Similarly, liquid pressure acts in lateral sides also. When a bottle having water is pierced on the sides we can see water coming out with a speed as in Figure 1.5. This is because liquid exerts lateral pressure on the walls the container.

Figure 1.5 Liquid pressures on lateral sides of the container

1.2.2 Factors determining liquid pressure in liquids

Pressure exerted by a liquid at a point is determined by,

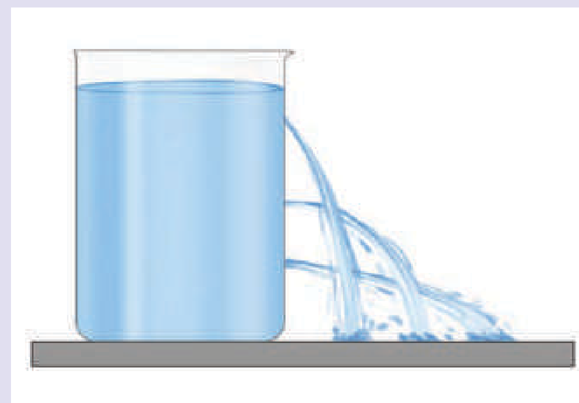
(i) depth (h)

(ii) density of the liquid (ρ)

(iii) acceleration due to gravity (g).

Activity 3

Take a large plastic can. Punch holes with a nail in a vertical line on the side of the can as shown in figure. Then fill the can with water. The water may just dribble out from the top hole, but with increased speed at the bottom holes as depth causes the water to squirt out with more pressure.



From this activity we can see that pressure varies as depth increases. But, it is same at a particular depth independent of the direction. In Figure 1.6, we see the gauge reads the same value because the pressure is being measured at the same depth (red line).

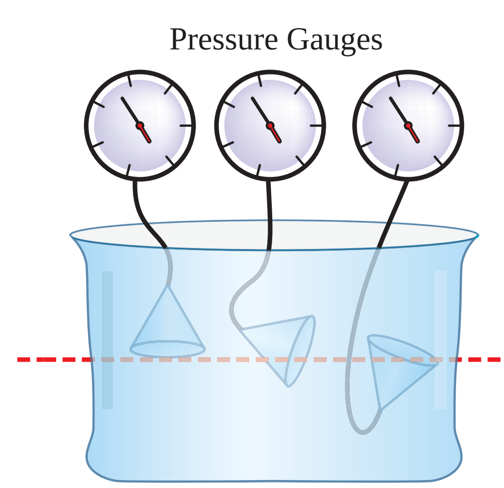
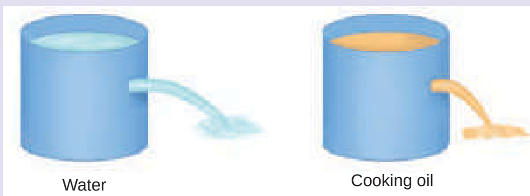


Figure 1.6 Pressure at a depth is same independent of directions

Activity 4

Take two liquids of different densities say water and oil to a same level in two plastic containers. Make holes in the two containers at the same level. What do you see? It is seen that water is squirting out with more pressure than that of oil. This indicates that pressure depends on density of the liquid.



Water Cooking oil

1.2.3 Pressure due to a liquid column

A tall beaker is filled with liquid so that it forms a liquid column. The area of cross section at the bottom is A. The density of the liquid is ρ. The height of the liquid column is h. In other words the depth of the water from the top level surface is 'h' as shown in Figure 1.7.

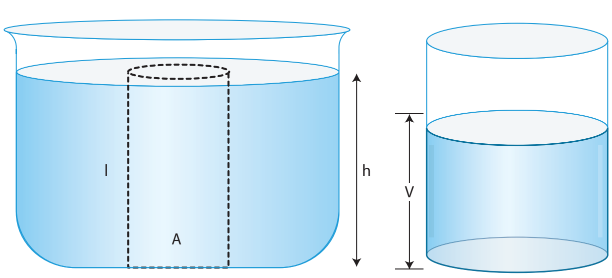


Figure 1.7 Pressure due to a liquid column

We know that thrust at the bottom of the column (F) = weight of the liquid.

Therefore, $F = mg$ (1)

We can get the mass of the liquid by multiplying the volume of the liquid and its density.

Mass, $m = \rho V$ (2)

Volume of the liquid column, V = Area of cross section (A) × Height (h) = Ah (3)

Substituting (3) in (2)

Hence, mass, $m = \rho Ah$ (4)

Substituting (4) in (1)

Force = $mg = \rho Ahg$

$$\text{Pressure, } P = \frac{\text{Thrust (F)}}{\text{Area (A)}} = \frac{mg}{A} = \frac{\rho(Ah)g}{A} = \rho hg$$

∴ Pressure due to a liquid column, $P = h\rho g$

This expression shows that pressure in a liquid column is determined by depth, density of the liquid and the acceleration due to gravity. Interestingly, the final expression for pressure does not have the term area A in it. Thus pressure at a given depth does not depend upon the shape of the vessel containing the liquid or the amount of liquid in the vessel. It only depends on the depth. In Figure 1.8, the pressure is the same even though the containers have different amounts of liquid in them, and are of different shapes.

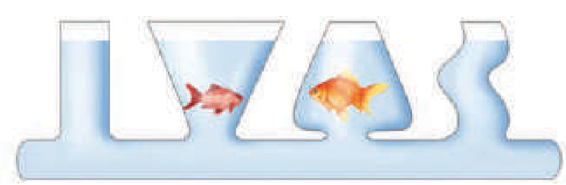


Figure 1.8 Pressure does not depend on shape and size of the container

Example 1.2

Calculate the pressure exerted by a column of water of height 0.85 m (density of water, ρ_w = 1000 kg m^{-3}) and kerosene of same height (density of kerosene, ρ_k = 800 kg m^{-3})

Solution:

Pressure due to water

$= h\rho_w g = 0.85 \text{ m} \times 1000 \text{ kg m}^{-3} \times 10 \text{ m s}^{-2}$

= 8500 Pa.

Pressure due to kerosene

$= h\rho_k g = 0.85 \text{ m} \times 800 \text{ kg m}^{-3} \times 10 \text{ ms}^{-2}$

= 6800 Pa.

1.3 Atmospheric pressure

Earth is surrounded by a layer of air up to certain height (nearly 300 km) and this layer of air around the earth is called atmosphere of the earth. Since air occupies space and has weight, it also exerts pressure (Fig. 1.9). This pressure is called atmospheric pressure. The atmospheric pressure we normally refer is the air pressure at sea level.

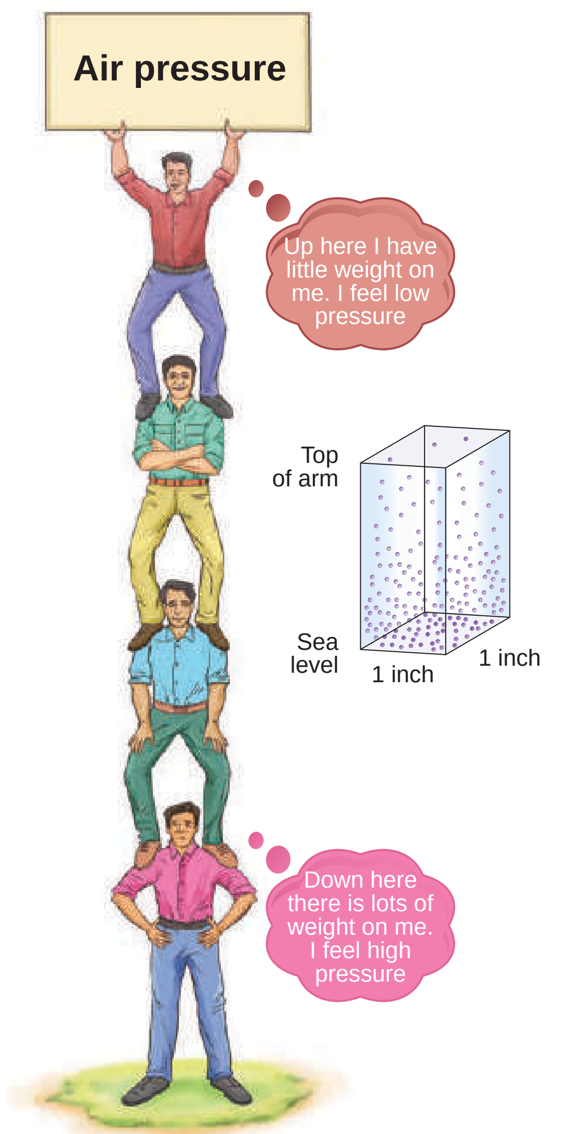


Figure 1.9 Atmospheric pressure

Figure 1.10 shows that air gets 'thinner' with increasing altitude. Hence, the atmospheric pressure decreases as we go up in mountains. On the other hand air gets heavier as we go down below sea level like mines. Table 1.1 gives the value of atmospheric pressure at some places above and below sea level.

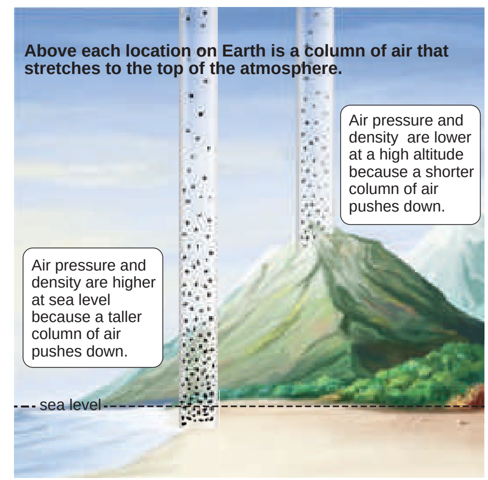


Figure 1.10 Atmospheric pressure acts like a column

DO YOU KNOW?

Human lung is well adapted to breathe at a pressure of sea level (101.3 k Pa). As the pressure falls at greater altitudes, mountain climbers need special breathing equipments with oxygen cylinders.

Similar special equipments are used by people who work in mines where the pressure is greater than that of sea level.

Table 1.1 Atmospheric pressure at different places

Atmospheric pressure	k Pa
Mount Everest summit	33.7
Earth sea level	101.3
Dead sea (below sea level)	*106.7*

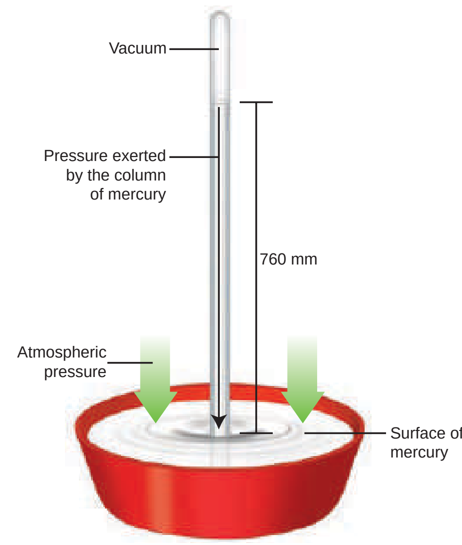


Figure 1.11 Mercury barometer

1.3.1 Measurement of atmospheric pressure

The instrument used to measure atmospheric pressure is called barometer. A mercury barometer, first designed by an Italian Physicist Torricelli, consists of a long glass tube (closed at one end, open at the other) filled with mercury and turned upside down into a container of mercury. This is done by closing the open end of the mercury filled tube with the thumb and then opening it after immersing it in to a trough of mercury (Fig. 1.11). The barometer works by balancing the mercury in the glass tube against the outside air pressure. If the air pressure increases, it pushes more of the mercury up into the tub and if the air pressure decreases, more of the mercury drains from the tube. As there is no air trapped in the space between mercury and the closed end, there is vacuum in that space. Vacuum cannot exert any pressure. So the level of mercury in the tube provides a precise measure of air pressure which is called atmospheric pressure. This type of instrument can be used in a lab or weather station.

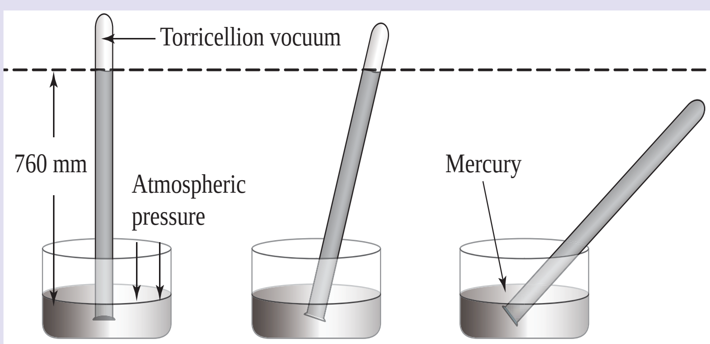
More to Know

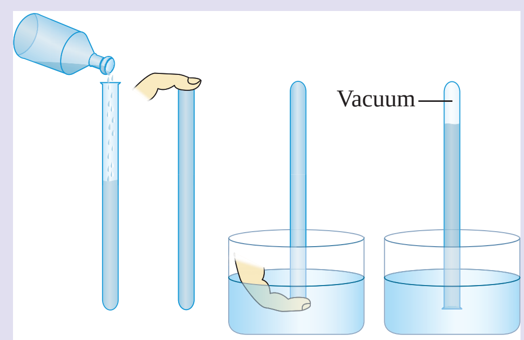
Two puzzling questions accidentally led to the discovery of the idea of air pressure and an instrument barometer, to measure it. During the time of Galileo, in Italy many were perplexed that a suction pump could not pump water from rivers and wells if the depth of the water was more than 11 meter. Another question that troubled philosophers in Europe was if there is an actual vacuum.

Galileo incorrectly suggested that the limit of the suction pump was imposed by the weight of water. The idea was put to test by Gasparo Berti around 1640. He took a glass tube of about 12 metres in length. He placed it vertically. Then he covered the bottom of the tube. Filled it with water and he sealed the top. Now he opened the top at the bottom. The water fell down and when it reached the level of 11 meter high the flow stopped. There was an empty space at the top above the water column. Was it really empty? Vacuum? Without examining the question, Berti died soon. The dramatic demonstration caught the attention of another Italian scientist, Evangelista Torricelli.

Torricelli took several glass tubes, each with different diameters, but all about one meter length, sealed at one end. He filled them with mercury. After placing a finger over the opening, they were upturned into a basin containing more mercury. When the finger was removed and the mercury was released, the level fell and stopping at the height of about 76 centimetre. This occurred irrespective of the diameter of the tube.

Above the 76 cm level the glass tube looked empty. Was it really empty? Torricelli tilted the tubes. As the tubes were tilted the mercury rushed into the empty space. If that space was filled with say air, bubbles should come out. None came. Therefore Torricelli reasoned that the empty space above the mercury column is real vacuum. But why the column remained at 76 cm?





In 1647, Marin Mersenne and Blaise Pascal, two scientists from France performed an interesting experiment. They made two identical barometers and placed them parallel at the base of a mountain in France, the Puy de Dôme. Both of them showed the same level of mercury. They carried one to the summit of the mountain. To their astonishment as they climbed the mountain, the level of the mercury dropped. They reasoned that air exerts pressure and as we go higher the air column above our head, the air pressure drops. The barometer helps to measure the invisible air pressure.

On a typical day at sea level, the height of the mercury column is 760 mm. Let us calculate the pressure due to the mercury column of 760 mm which is equal to the atmospheric pressure. The density of mercury is 13600 kg m^{-3}.

Pressure, $P = h\rho g$

$= (760 \times 10^{-3} m) \times (13600\ kgm^{-3}) \times (9.8\ ms^{-2})$

$= 1.013 \times 10^5$ Pa.

This pressure is called one atmospheric pressure (atm). There is also another unit called (bar) that is also used to express such high values of pressure.

1 atm = 1.013×10^5 Pa.

1 bar = 1×10^5 Pa.

Hence, 1 atm = 1.013 bar.

Expressing the value in kilopascal gives 101.3 k Pa. This means that, on each 1 m^2 of surface, the force acting is 1.013 k N.

1.3.2 Types of barometers

As the mercury is not in a closed vessel in the mercury barometer, moving the instrument without spilling the mercury is difficult. Hence, we have other sophisticated instruments which are handy. They also work on the same principle like a mercury barometer but instead of mercury they use diaphragms and other precise components which respond for variation in atmospheric pressure. Table 1.2 shows some of the barometers used frequently.

Example 1.3

A mercury barometer in a physics laboratory shows a 732 mm vertical column of mercury. Calculate the atmospheric pressure in pascal. [Given density of mercury, $\rho = 1.36 \times 10^4$ kg m^{-3}, g = 9.8 m s^{-2}]

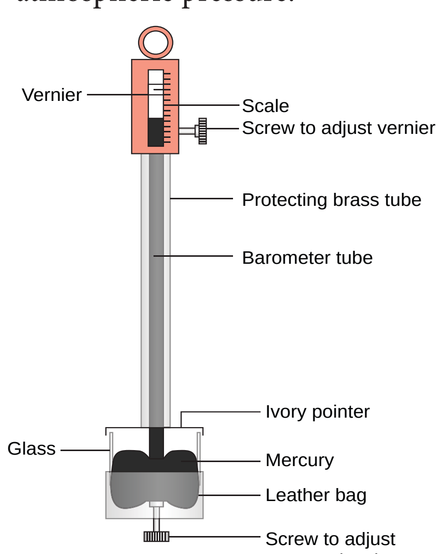
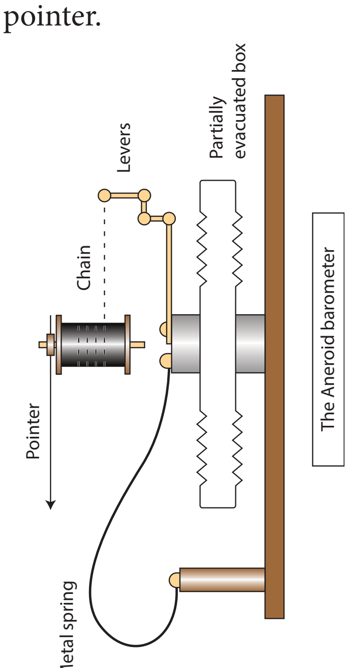
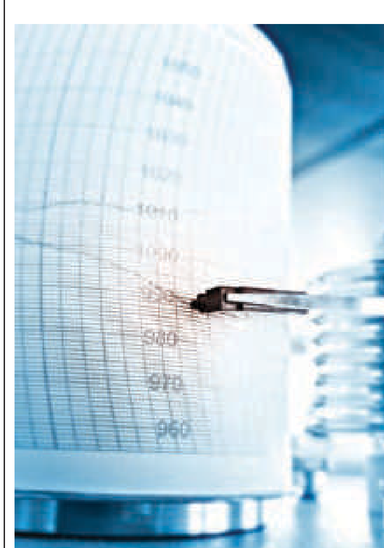
Solution:

Atmospheric pressure in the laboratory,

$P = h\rho g = 732 \times 10^{-3} \times 1.36 \times 10^4 \times 9.8$

$= 9.76 \times 10^4$ Pa (or) 0.976×10^5 Pa

Table 1.2 Types of barometers

<table>
<tr><th>Fortin's barometer</th><th>Aneroid barometer</th><th>Barograph</th></tr>
<tr>
<td>It is a mercury barometer in which the mercury bath along with mercury and barometer tube is covered with a flexible leather case so that spilling of mercury during transport is averted. The amount of movement of a screw at the bottom to maintain the mercury level same is a measure of the atmospheric pressure.

Fortin barometer</td>
<td>It is a device for measuring atmospheric pressure without the use of liquids. It consists of a partially evacuated metal chamber and a thin corrugated lid which is displaced by variations in the external air pressure. A lever connected to the diaphragm of the chamber moves a pointer.
</td>
<td>It is a barometer that records the atmospheric pressure variations over time. One or more aneroid cells sense the pressure changes. The variations are recorded through a lever and pen arrangement on a moving graph sheet attached to a rotating drum.
</td>
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1.3.3 Gauge pressure and absolute pressure

Our daily activities are happening in the atmospheric pressure. We are so used to it that we do not even realise. When tyre pressure and blood pressure are measured using instruments (gauges) they show the pressure over the atmospheric pressure. Hence, absolute pressure is zero-referenced against a perfect vacuum and gauge pressure is zero-referenced against atmospheric pressure.

For pressures higher than atmospheric pressure,
absolute pressure = atmospheric pressure + gauge pressure

For pressures lower than atmospheric pressure,
absolute pressure = atmospheric pressure – gauge pressure

Example 1.4

Find the absolute pressure on a scuba diver (deep sea diver) when the diver is 12 metres below the surface of the ocean. Assume standard atmospheric conditions. [Take density of water as 1030 kg m^{-3}, g = 9.8 m s^{-2}]

Solution:

Pressure due to sea water, $P_{water} = h\rho g$

$= (12\ m) \times (1.03 \times 10^3\ kgm^{-3}) \times (9.8\ m\ s^{-2})$

$= 1.21 \times 10^5$ Pa

$P_{absolute} = P_{atmosphere} + P_{water}$

$= (1.01 \times 10^5) + (1.21 \times 10^5)$

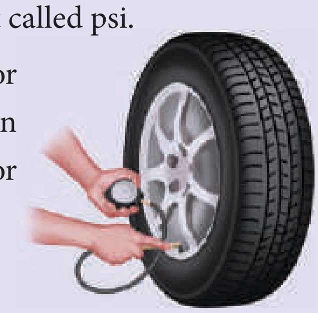
$P_{absolute} = 2.22 \times 10^5$ Pa

This is more than twice the atmospheric pressure. Parts of our body, especially blood vessels and soft tissues cannot withstand such high pressure. Hence, scuba divers always wear special suits and equipment to protect them (Fig. 1.12).

Figure 1.12 Scuba divers with special protecting equipment

DO YOU KNOW?

In petrol bunks, the tyre pressure of vehicles is measured in a unit called psi.



It stands for pascal per inch, an old system of unit for measuring pressure.

1 psi = 6895 Pa

1 psi = 0.06895×10^5 Pa

A tire pressure of 30 psi means 2.0685×10^5 Pa. It is almost twice the atmospheric pressure.

More to Know

Mass of the Atmosphere

The global mean pressure at the surface of the Earth (P_S = 984 hPa) is slightly less than the mean sea-level pressure because of the elevation of land. We can deduce the total mass of the atmosphere (m_a) as shown below.

$$Pa = \frac{F}{A} = \frac{(m_a g)}{4\pi R^2};\ m_a = \frac{(P_a 4\pi R^2)}{g} = 5.2 \times 10^{18}\ kg$$

where R = 6400 km is the radius of the Earth.

Activity 5

Press a good quality rubber sucker hard on a plane smooth surface. It sticks to the surface. Now pull it off the surface. When you press the sucker, most of the air between its cup and the plane surface escapes out. The sucker sticks to the plane surface since the pressure due to the atmosphere pushes on it. The sucker can be removed off the plane surface by applying a large external force that overcomes the atmospheric pressure. By this principle only, lizards and monitor lizards (udumbu) are able to get good grip over surfaces.

1.4 Pascal's Law

Pascal's principle is named after Blaise Pascal (1623-1662), a French mathematician and physicist. The law states that the external pressure applied on an incompressible liquid is transmitted uniformly throughout the liquid. Pascal's law can be demonstrated with the help of the glass vessel having holes all over its surface. Fill it with water. Push the piston. The water rushes out of the holes in the vessel with the same pressure. The force applied on the piston exerts pressure on water. This pressure is transmitted equally throughout the liquid in all directions (Fig. 1.13). This principle is applied in various machines used in our daily life.

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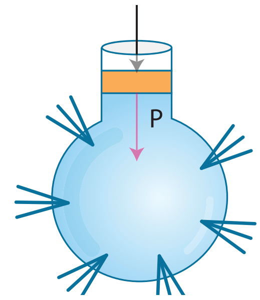


Figure 1.13 Demonstration of Pascal's Law

Activity 6

Take a tooth paste available in your home. Squeeze it. What happens? When any part of the tube is squeezed toothpaste squirts out through the open end. The pressure applied at one part of the tooth paste (through tube) is transmitted equally throughout the toothpaste. When the pressure reaches the open end, it forces toothpaste out through the opening.

1.4.1 Hydraulic press

Pascal's law became the basis for one of the important machines ever developed, the hydraulic press. It consists of two cylinders of different cross-sectional areas as shown in Figure 1.14. They are fitted with pistons of cross-sectional areas “a” and “A”. The object to be compressed is placed over the piston of large

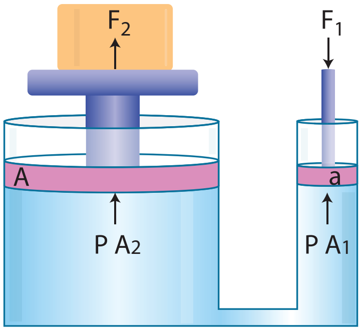


Figure 1.14 Hydraulic press

cross-sectional area A. The force F_1 is applied on the piston of small cross-sectional area a. The pressure P produced by small piston is transmitted equally to large piston and a force F_2 acts on A which is much larger than F_1. Pressure on piston of small area 'a' is given by,

$$P = \frac{F_1}{A_1} \qquad (1)$$

Applying Pascal's law, the pressure on large piston of area A will be the same as that on small piston. Therefore, $P = \frac{F_2}{A_2}$ (2)

Comparing equations (1) and (2),we get $\frac{F_1}{A_1} = \frac{F_2}{A_2}$. or $F_2 = F_1 \times \frac{A_2}{A_1}$

Since, the ratio $\frac{A_2}{A_1}$ is greater than 1, the force F_2 that acts on the larger piston is greater than the force F_1 acting on the smaller piston. Hydraulic systems working in this way are known as *force multipliers*.

Example 1.5

A hydraulic system is used to lift a 2000 kg vehicle in an auto garage. If the vehicle sits on a piston of area 0.5 m^2, and a force is applied to a piston of area 0.03 m^2, what is the minimum force that must be applied to lift the vehicle?

Given: Area covered by the vehicle on the piston $A_1 = 0.5\ m^2$

Weight of the vehicle, $F_1 = 2000\ kg \times 9.8\ m\ s^{-2}$

Area on which force F_2 is applied, $A_2 = 0.03\ m^2$

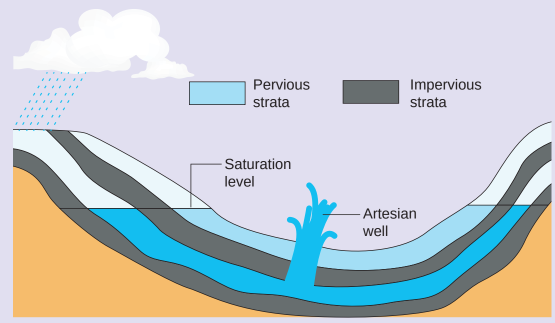
Solution:

$$P_1 = P_2;\ \frac{F_1}{A_1} = \frac{F_2}{A_2} \text{ and } F_2 = \frac{F_1}{A_1} A_2;$$

$$F_2 = (2000 \times 9.8)\frac{0.03}{0.5} = 1176\ N$$

Info bits

An artesian aquifer is a confined aquifer containing groundwater that will flow upwards out of a well without the need for pumping. In recharging aquifers, this happens because the water table at its recharge zone is at a higher elevation than the head of the well.



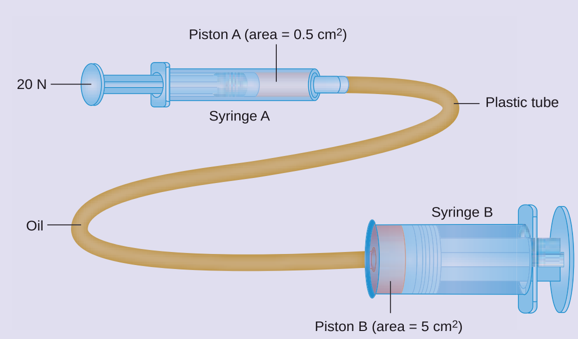
Example 1.6

Two syringes are connected together as shown in the diagram below.

A force of 20 N is applied to the piston in syringe A.

(a) Calculate the pressure that the piston in syringe A exerts on the oil.

(b) Calculate the force needed to just prevent the piston in syringe B from moving out.



Solution:

(a) A force of 20 N is applied to the piston in syringe A.

The pressure that the piston in syringe A exerts on the oil,

$$P = \frac{F}{A} = \frac{20N}{0.5\ cm^2} = 40\ N\ cm^{-2}$$

(b) $P = \frac{F}{A}$. So F = PA

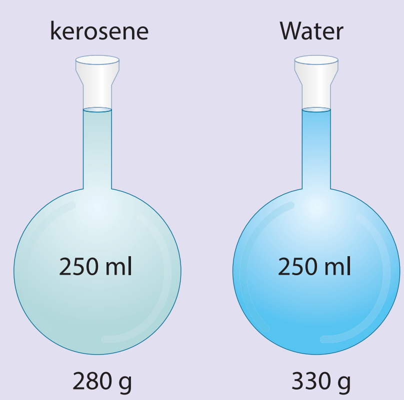
The force needed to just prevent the piston in syringe B from moving out,

F = 40 N $cm^{-2} \times 5\ cm^2$ = 200 N

1.5 Density

Activity 7

Take two identical flasks and fill one flask with water to 250 cm^3 mark and the other with kerosene to the same 250 cm^3 mark. Measure them in a balance. The flask filled with water will be heavier than the one filled with kerosene. Why? The answer is in finding the mass per unit volume of kerosene and water in respective flasks.



To understand density better, let us assume that the mass of the flask be 80g. So, the mass of the flask filled with water is 330g and the mass of flask filled with kerosene is 280g. Mass of water only is 250g and kerosene only is 200g. Mass per unit volume of water is 250/250cm^3. This is 1g/cm^3. Mass per unit volume of kerosene is 200g/250cm^3. This is 0.8g/cm^3. The result 1g/cm^3 and 0.8gcm^3 are the densities of water and kerosene respectively. *Therefore the density of a substance is the mass per unit volume of a given substance.*

The SI unit of density is kilogram per meter cubic (kg/m^3) also gram per centimeter cubic (g/cm^3). The symbol for density is rho (ρ).

Example 1.7

A silver cylindrical rod has a length of 0.5 m and radius of 0.4 m. Find the density of the rod if its mass is 2640 kg.

Solution:

Mass of the cylinder = 2640 kg

Volume of the cylinder = $\pi r^2 h = 3.14 \times (0.4)^2 \times 0.5 = 0.2512\ m^3$

Density = mass/volume = 2640 kg/0.2512 m^3 = 10509 kg m^{-3}

1.5.1 Relative Density

We can compare the densities of two substances by finding their masses. But generally density of a substance is compared with the density of water at 4°C because density of water at that temperature is 1g/cm^3. Density of any other substance with respect to the density of water at 4°C is called the relative density. Thus relative density of a substance is defined as ratio of density of the substance to density of water at 4°C. Mathematically, relative density (R.D)

$$= \frac{\text{Density of the substance}}{\text{Density of water at 4°C}}$$

We know that, Density $= \frac{\text{Mass}}{\text{Volume}}$

∴ Relative density

$$= \frac{\text{Mass of the substance/Volume of the substance}}{\text{Mass of water/Volume of water}}$$

Since the volume of the substance is equal to the volume of water,

Relative density

$$= \frac{\text{Mass of certain volume of substance}}{\text{Mass of equal volume of water}}$$

Thus, the ratio of the mass of a given volume of a substance to the mass of an equal volume of water at 4°C also denotes relative density.

1.5.2 Measurement of relative density

Relative density can be measured using Pycnometer (Fig. 1.15) also called density bottle. It consists of ground glass stopper with a fine hole through it. The function of the hole in a stopper is that, when the bottle is filled and the stopper is inserted, the excess liquid rises through the hole and runs down outside the bottle. By this way the bottle will always contain the same volume of whatever the liquid is filled in, provided the temperature remains constant. Thus the density of a given volume of a substance to the density of equal volume of referenced substance is called relative density or specific gravity of the given substance. If the referenced substance is water then the term specific gravity is used.

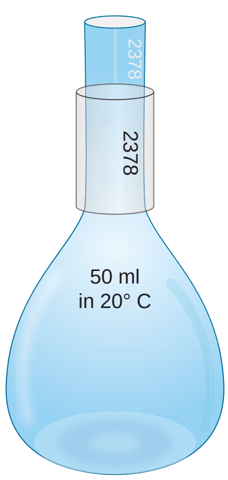


Figure 1.15 Specific gravity bottle

1.5.3 Floating and sinking

Whether an object will sink or float in a liquid is determined by the density of the object compared to the density of the liquid. If the density of a substance is less than the density of the liquid it will float. For example a piece of wood which is less dense than water will float on it. Any substance having more density than water (for example, a stone), will sink into water.

Example 1.8

You have a block of a mystery material, 12 cm long, 11 cm wide and 3.5 cm thick. Its mass is 1155 grams. (a) What is its density? (b) Will it float in a tank of water, or sink?

Solution:

(a) $\text{Density} = \dfrac{\text{Mass}}{\text{Volume}} = \dfrac{1155\text{g}}{12\text{ cm} \times 11\text{ cm} \times 3.5\text{ cm}}$

$= \dfrac{1155\text{ g}}{462\text{ cm}^3} = 2.5\text{ g cm}^{-3}$

(b) The mystery material is denser than the water, so it sinks.

1.5.4 Application of principle of flotation

Hydrometer

A direct-reading instrument used for measuring the density or relative density of the liquid is called hydrometer. Hydrometer is based on the principle of flotation, i.e., the weight of the liquid displaced by the immersed portion of the hydrometer is equal to the weight of the hydrometer.

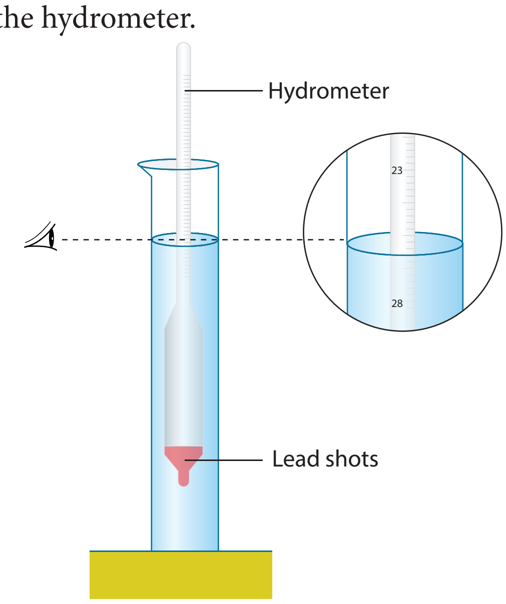


Figure 1.16 Hydrometer

Hydrometer consists of a cylindrical stem having a spherical bulb at its lower end and a narrow tube at is upper end. The lower spherical bulb is partially filled with lead shots or mercury. This helps hydrometer to float or stand vertically in liquids. The narrow tube has markings so that relative density of a liquid can be read directly.

The liquid to be tested is poured into the glass jar. The hydrometer is gently lowered in to the liquid until it floats freely. The reading against the level of liquid touching the tube gives the relative density of the liquid.

Hydrometers may be calibrated for different uses such as lactometers for measuring the density (creaminess) of milk, saccharometer for measuring the density of sugar in a liquid and alcoholometer for measuring higher levels of alcohol in spirits.

Lactometer

One form of hydrometer is a lactometer, an instrument used to check the purity of milk. The lactometer works on the principle of gravity of milk.

The lactometer consists of a long graduated test tube with a cylindrical bulb with the graduation ranging from 15 at the top to 45 at the bottom. The test tube is filled with air. This air chamber causes the instrument to float. The spherical bulb is filled with mercury to cause the lactometer to sink up to the proper level and to float in an upright position in the milk.

Inside the lactometer there may be a thermometer extending from the bulb up into the upper part of the test tube where the scale is located. The correct lactometer reading is obtained only at the temperature of 60°C. A lactometer measures the cream content of milk. More the cream, lower the lactometer floats in the milk. The average reading of normal milk is 32. The lactometers are used highly at milk processing units and at dairies.

1.6 Buoyancy

We already saw that a body experiences an upward force due to the fluid surrounding, when it is partially or fully immersed in to it. We also saw that pressure is more at the bottom and less at the top of the liquid. This pressure difference causes a force on the object and pushes it upward. This force is called buoyant force and the phenomenon is called buoyancy (Fig.1.17).

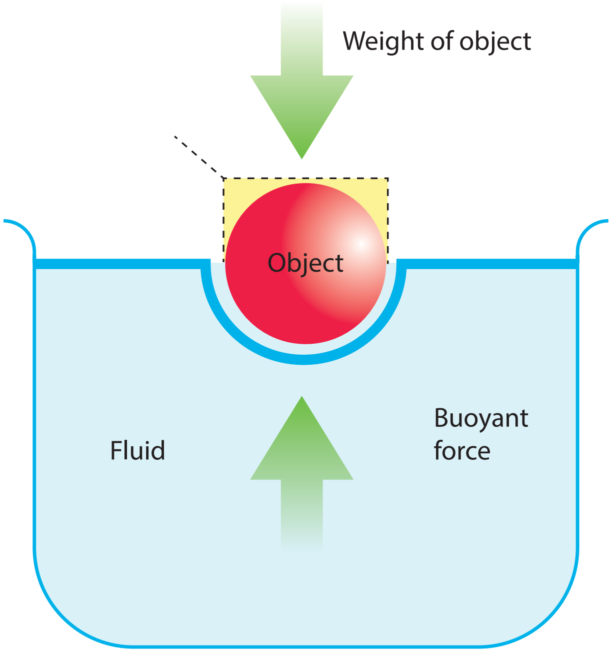


Figure 1.17 Buoyant force

Most buoyant objects are those with a relatively high volume and low density. If the object weighs less than the amount of water it has displaced (density is less), buoyant force will be more and it will float (such object is known as positively buoyant). But if the object weighs more than the amount of water it has displaced (density is more), buoyant force is less and the object will sink (such object is known as negatively buoyant).

More to Know

- ✓ Salt water provides more buoyant force than fresh water. Because buoyant force depends as much on the density of fluids as on the volume displaced.
- ✓ Hydrogen, helium and hot air are much less dense than ordinary air and this gives them buoyancy.

Cartesian diver

Cartesian diver is an experiment that demonstrates the principle of buoyancy. It is a pen cap with clay. The Cartesian diver contains just enough liquid that it barely floats in a bath of the liquid; its remaining volume is filled with air. When pressing the bath, the additional water enters the diver, thus increasing the average density of the diver, and thus it sinks.

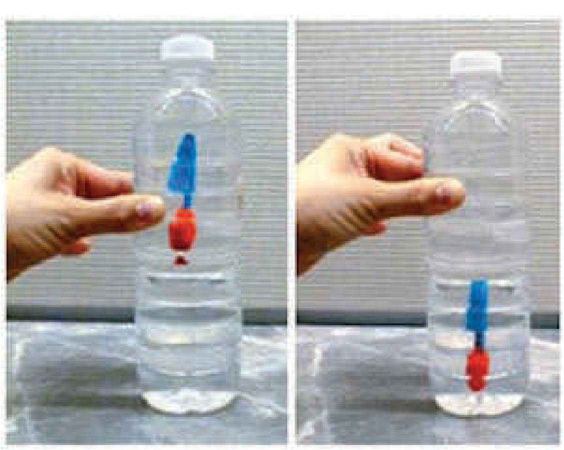


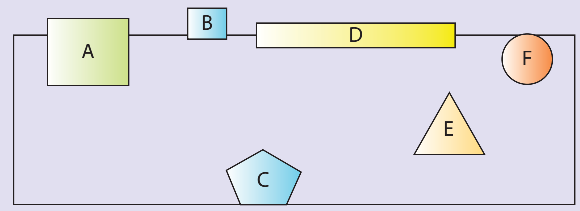
Figure 1.18 Cartesian diver

DO YOU KNOW?

- Fish has an internal swim bladder which is filled with gas. When it needs to rise or descend, it changes the volume and its density.
- Human swimmers, icebergs and ships stay afloat due to buoyancy.
- Petroleum-based products typically float on the surface of water, because their specific gravity is low.

Examples 1.9

Six objects (A-F) are in a liquid, as shown below. None of them are moving. Arrange them in order of density, from lowest to highest.



Solution:

The more of an object's volume is above the water surface, the less dense it is. Object B must therefore be the least dense, followed by D, A, and F. Object E is next, because it is neutrally buoyant and equal in density to the liquid. Object C is negatively buoyant because it is denser than the fluid.

Therefore the order of density from lowest to highest is B,D,A,F, E,C.

1.6.1 Mathematical representation of Buoyant force

For an object submerged in a fluid, there is a net force on the object, because the pressure at the top and bottom of it are different.

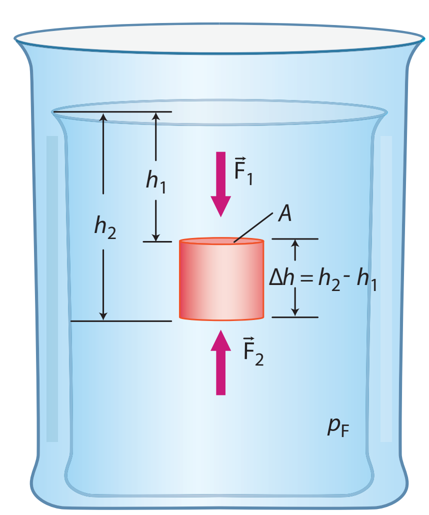


Figure 1.19 Net force acting on an object

We know that pressure, $P = \frac{F}{A}$

$$F = P\,A$$

$F_{buoyancy} = F_2 - F_1 = P_2A_2 - P_1A_1$

Since area is same, $A_2 = A_1 = A$

Therefore,

$$F_{buoyancy} = P_2A - P_1A$$
$$= A(P_2 - P_1)$$

Since, $P = h\rho g$,

$$F_{buoyancy} = A(\rho g h_2 - \rho g h_1)$$
$$= A\rho g(h_2 - h_1) = \rho g A(h_2 - h_1)$$
$$F_{buoyancy} = \rho g(A\Delta h) = (\rho_{fluid})\, g\, (V_{displaced})$$

Example 1.10

A golden crown has been placed in a tub of water. The volume of water displaced is measured to be 1.50 liters. The density of water is 1000 kg m^{-3}, or 1.000 kg L^{-1}. What is the buoyant force acting on the crown?

Solution:

The buoyant force is, $F_b = \rho g V$

First, we ensure that the units used for volume are the same.

If 1 m^3 = 1000 L, then 1.50 L = 0.00150 m^3.

$F_b = (1000 \text{ kg m}^{-3})(9.80 \text{ m s}^{-2})(0.00150 \text{ m}^3)$

$= 14.7 \text{ kg m s}^{-2} = 14.7 \text{ N}$

The buoyant force acting on the golden crown is 14.7 N.

1.7 Archimedes' Principle

Archimedes principle is the consequence of Pascal's law. According to legend, Archimedes devised the principle of the "hydrostatic balance" after he noticed his own apparent loss in weight while sitting in his bath. The story goes that he was so enthused with his discovery that he jumped out of his bath and ran through the town, shouting "eureka". Archimedes principle states that 'a body immersed in a fluid experiences a vertical upward buoyant force equal to the weight of the fluid it displaces'.

Figure 1.20 Archimedes and eureka

When a body is partially or completely immersed in a fluid at rest, it experiences an upthrust which is equal to the weight of the fluid displaced by it. Due to the upthrust acting on the body, it apparently loses a part of its weight and the apparent loss of weight is equal to the upthrust.

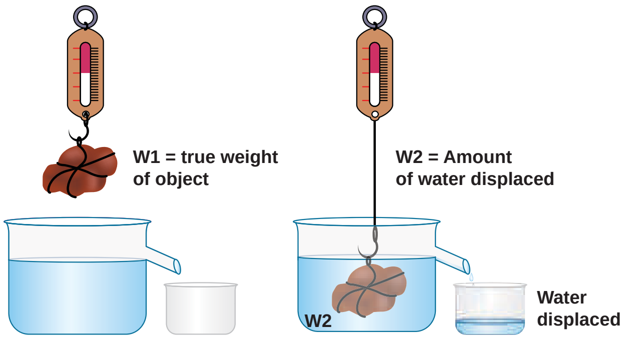


Figure 1.21 Upthrust is equal to the weight of the fluid displaced

Thus, for a body either partially or completely immersed in a fluid,

Upthrust = Weight of the fluid displaced

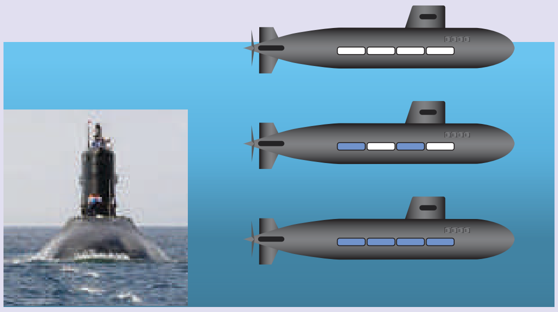
= Apparent loss of weight of the body.

Apparent weight of an object =

True weight of an object in air

– Upthrust (weight of water displaced)

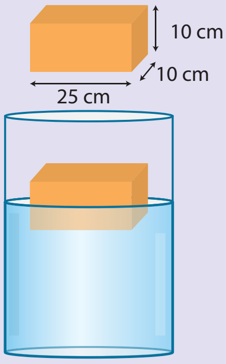
Info bits



Submarines change the level of floating by pumping in and pumping out water in to its compartments.

Example 1.11

What is the mass of the object floating in the given diagram?



Solution:

Weight of the object = Buoyant force

$\rho = 1000\ \text{kg m}^{-3}$

$V = (25 \text{x} 10 \text{x} 10)\ \text{cm}^3 = 2500 \text{ x } 10^{-6}\ \text{m}^3$

$m = \rho V = 1000 \text{ x } 2500 \text{ x } 10^{-6} = 2.5\ \text{kg}$

1.8 Laws of flotation

Laws of flotation are,

1. The weight of a floating body in a fluid is equal to the weight of the fluid displaced by the body.
2. The centre of gravity of the floating body and the centre of buoyancy are in the same vertical line.

The point through which the force of buoyancy is supposed to act is known as centre of buoyancy. It is shown in Figure 1.22.

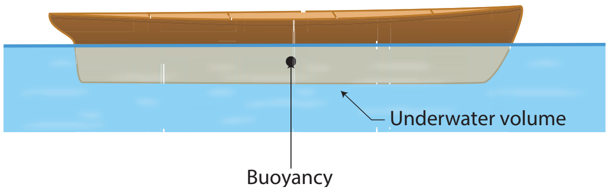


Figure 1.22 Centre of buoyancy

Info bits

Flotation therapy uses water that contains Epsom salts rich in magnesium. As a floater relaxes, he or she is absorbing this magnesium through the skin. Magnesium helps the body to process insulin, which lowers a person's risk of developing Type 2 Diabetes.

Points to Remember

- The force which produces compression is called thrust. Its S.I. unit is newton.
- Thrust acting normally to a unit area of a surface is called pressure. Its S.I. unit is pascal.
- The pressure exerted by the atmospheric gases on its surroundings and on the surface of the earth is called atmospheric pressure. 1 atm is the pressure exerted by a vertical column of mercury of 76 cm height.
- Barometer is an instrument used to measure atmospheric pressure.
- The upward force experienced by a body when partly or fully immersed in a fluid is called upthrust or buoyant force.
- Cartesian diver is an experiment which demonstrates the principle of buoyancy and the ideal gas law.
- Pascal's law states that an increase in pressure at any point inside a liquid at rest

is transmitted equally and without any change, in all directions to every other point in the liquid.

- Archimedes' Principle states that when a body is partially or wholly immersed in a fluid, it experiences an up thrust or apparent lose of weight, which is equal to the weight of the fluid displaced by the immersed part of the body.
- Density is known as mass per unit volume of a body. Its S.I. unit is kg m^{-3}.
- Relative density is the ratio between the density of a substance and density of water. Relative density of a body is a pure number and has no unit.
- Relative density of a liquid

$$= \frac{\text{Apparent loss of weight of a body in liquid}}{\text{Apparent loss of weight of the same body in water}}$$

- Hydrometer is a device used to measure the relative density of liquids based on the Archimedes' principle.
- Lactometer is a device used to check the purity of milk by measuring its density using Archimedes' Principle.
- Laws of flotation are given as: i) Weight of a floating body = Upthrust or buoyant force = Apparent loss of weight of the body in the fluid. ii) The centre of gravity and the centre of buoyancy lie in the same vertical line.

A-Z GLOSSARY

Altitude	Vertical distance in the up direction.
Astronaut	Person who is specially trained to travel into outer space.
Axes	Simple machine to cut, shape and split wood.
Deformation	Changes in an object's shape or form due to the application of a force or forces.
Fossils water	Preserved water.
Iceberg	Large piece of ice floating in water.
Hydraulic systems	Device that uses fluids and work under the fluid pressure to control valves.
Incompressible	No change in volume if a pressure is applied.
Meteorological	Weather condition.
Piston	Movable disc fitted inside a cylinder.
Propellers	Fan that transmits power in the form of thrust by rotation.
Syringe	Simple pump made of plastic or glass to inject or withdraw fluid.
Therapy	Treatment.
Velocity	Speed with direction.

G93FPT

TEXTBOOK EVALUATION

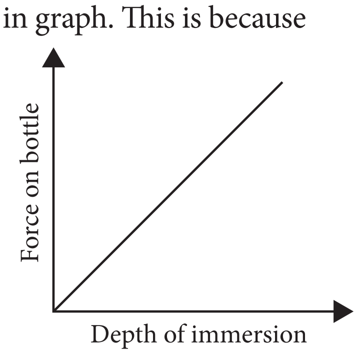
I. Choose the correct answer.

1. The size of an air bubble rising up in water
   (a) decreases
   (b) increases
   (c) remains same
   (d) may increase or decrease

2. Clouds float in atmosphere because of their low
   (a) density (b) pressure
   (c) velocity (d) mass

3. In a pressure cooker, the food is cooked faster because
   (a) increased pressure lowers the boiling point
   (b) increased pressure raises the boiling point
   (c) decreased pressure raises the boiling point
   (d) increased pressure lowers the melting point

4. An empty plastic bottle closed with an airtight stopper is pushed down into a bucket filled with water. As the bottle is pushed down, there is an increasing force on the bottom as shown in graph. This is because



   (a) more volume of liquid is dispaced
   (b) more weight of liquid is displaced
   (c) pressure increases with depth
   (d) all the above

II. Fill in the blanks.

1. In a fluid, buoyant force exists because pressure at the __________ of an object is greater than the pressure at the top.
2. The weight of the body immersed in a liquid appears to be ________ than its actual weight.
3. The instrument used to measure atmospheric pressure is __________.
4. The magnitude of buoyant force acting on an object immersed in a liquid depends on __________ of the liquid.
5. A drinking straw works on the existence of __________.

III. True or False.

1. The weight of fluid displaced determines the buoyant force on an object.
2. The shape of an object helps to determine whether the object will float.
3. The foundations of high-rise buildings are kept wide so that they may exert more pressure on the ground.
4. Archimedes' principle can also be applied to gases.
5. Hydraulic press is used in the extraction of oil from oil seeds.

IV. Match the following.

Density	-	hρg
1 gwt	-	Milk
Pascal's law	-	$\frac{\text{Mass}}{\text{Volume}}$
Pressure exerted by a fluid	-	Pressure
Lactometer	-	980 dyne

V. Answer in brief.

1. On what factors the pressure exerted by the liquid depends on?
2. Why does a helium balloon float in air?

3. Why it is easy to swim in river water than in sea water?
4. What is meant by atmospheric pressure?
5. State Pascal's law.

VI. Answer in detail.

1. With an appropriate illustration prove that the force acting on a smaller area exerts a greater pressure.
2. Describe the construction and working of mercury barometer.
3. How does an object's density determine whether the object will sink or float in water?
4. Explain the construction and working of a hydrometer with diagram.
5. State the laws of flotation.

VII. Assertion and Reason.

Directions: In each of the following questions, a statement of Assertion (A) is given followed by a corresponding statement of Reason (R) just below it. Of the statements, mark the correct answer as

(a) If both assertion and reason are true and reason is the correct explanation of assertion.

(b) If both assertion and reason are true but reason is not the correct explanation of assertion.

(c) If assertion is true but reason is false.

(d) If assertion is false but reason is true.

1. **Assertion:** To float, body must displace liquid whose weight is equal to the actual weight.

   Reason: The body will experience no net downward force in that case.

2. **Assertion:** Pascal's law is the working principle of a hydraulic lift.

   Reason: Pressure is thrust per unit area.

3. **Assertion:** The force acting on the surface of a liquid at rest, under gravity, in a container is always horizontal.

   Reason: The forces acting on a fluid at rest have to be normal to the surface.

4. **Assertion:** A sleeping mattress is so designed that when you lie on it, a large area of your body comes in its contact.

   Reason: This reduces the pressure on the body and sleeping becomes comfortable.

5. **Assertion:** Wide wooden sleepers are kept below railway lines to reduce pressure on the railway tracks and prevent them from sinking in the ground.

   Reason: Pressure is directly proportional to the area in which it is acting.

VIII. Comprehension type.

1. While passing nearby a pond, some students saw a drowning man screaming for help. They alerted another passerby, who immediately threw an inflated rubber tube in the pond. The man was saved. Respond to the given questions using the information provided above.

   a. Why the passerby did use inflated rubber tube to save the drowning man?

   b. Write the principle involved herein.

   c. Which qualities shown by the students and the passerby do you identify that helped in saving the drowning man.

2. A balloon displaces air and it results in buoyant force. This buoyant force is more than the weight of the balloon and hence the balloon moves up.

   a. As the balloon moves up what happens to the density of it?

   b. Write the condition for floating of balloon.

   c. Buoyant force depends on the density of ________.

3. Two different bodies A and B are completely immersed in water and undergo the same loss in weight.
   a. Will the weight of the body A and body B in air be the same?
   b. If 4 kg of material occupy 20 cm^3 and 9 kg of material be occupy 90 cm^3, which has greater density A or B?
   c. What vertical height of mercury will exert a pressure of 99960 Pa? (Density of mercury = 136000 kg m^{-3}).

IX. Numerical Problems.

1. A block of wood of weight 200 g floats on the surface of water. If the volume of block is 300 cm^3 calculate the upthrust due to water.
2. Density of mercury is 13600 kg m^{-3}. Calculate the relative density.
3. A body of voloume 100 cc is immersed completely in water contained in a jar. The weight of water and the jar before immersion of the body was 700 g. Calculate the weight of water and jar after immersion.
4. The density of water is 1 g cm^{-3}. What is its density in S.I. units?
5. Calculate the apparent weight of wood floating on water if it weighs 100g in air.

X. HOTS

1. How high does the mercury barometer stand on a day when atmospheric pressure is 98.6 kPa?
2. How does a fish manage to rise up and move down in water?
3. If you put one ice cube in a glass of water and another in a glass of alcohol, what would you observe? Explain your observations.
4. You have a bag of cotton and an iron bar, each indicating a mass of 100 kg when measured on a weighing machine. In reality, one is heavier than other. Can you say which one is heavier and why?
5. Why does a boat with a hole in the bottom would eventually sink?

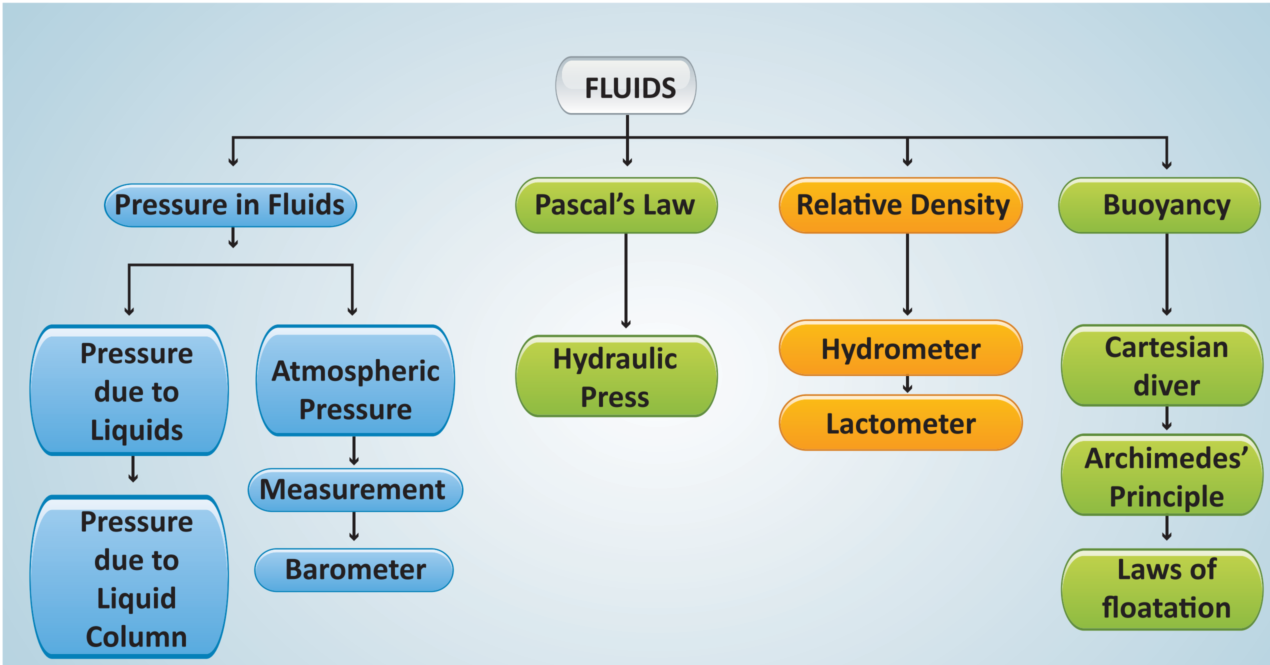
REFERENCE BOOKS

1. Fundamentals of Physics - By David Halliday and Robert Resnick.
2. I.C.S.E Concise Physics - By Selina publisher.
3. Physics - By Tower, Smith Tuston & Cope.

INTERNET RESOURCES

https://www.sciencelearn.org.nz/resources/390-rockets-and-thrust
https://www.teachengineering.org/lessons/view/cub_airplanes_lesson04
http://www.cyberphysics.co.uk/topics/earth/atmosphr/atmospheric_pressure.htm
http://discovermagazine.com/2003/mar/featscienceof
http://northwestfloatcenter.com/how-flotation-can-help-your-heart/

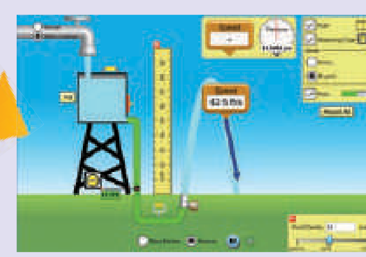
Concept Map



ICT CORNER

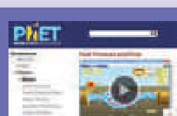
Fluid

Experiment with Fluid Pressure and Flow using virtual simulator.

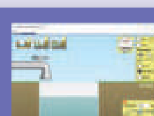


Steps

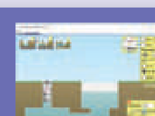
- Type the given URL to reach "pHET Simulation" page and download the "java" file of "Fluid Pressure and Flow".
- Open the "java" file. Open the water tap and observe the "Pressure" fluctuations by increasing "Fluid density" and "Gravity".
- Select the third picture and drop down a weight scales to transform weight into pressure.
- Switch to "Flow" tab from the top to simulate fluid motion under a given shape and pressure. Click the "red" button to drop dots into the fluid and alter the pipe shape by dragging the yellow holders.



Step1



Step2



Step3

Step4

Fluid Pressure and Flow Simulator

URL: https://phet.colorado.edu/en/simulation/fluid-pressure-and-flow or Scan the QR Code.

*Pictures are indicative only

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