

CHAPTER – 10



Floatation

In the previous chapters we have discussed and studied about motion, the cause of motion, gravitation and work done by an agent along with power. Another concept that helps us to understand thrust and pressure exerted by a force shall be studied. We shall also discuss the conditions of objects to float in a liquid.

10.1 Thrust and Pressure

Have you ever wondered why heavy duty trucks have much wider tyres than those of motorbikes? Why cutting tools have sharp edges? In order to answer these questions and understand the phenomena involved, we need to know the net force in a particular direction on a surface (thrust) and the force per unit area (pressure) acting on the surface of any object concerned.

Let us try to know the meanings of thrust and pressure by examining the following observations:

Observation 1

Suppose you are trying to fix a drawing sheet or a poster on the black board or on a plank using drawing pins. In doing so, you have to press the head of the pins with your thumb with a force. This force is directed perpendicular to the surface where the drawing sheet or poster is to be fixed. The same force now acts on the smaller area at the tip of the pin.

Observation 2

When you stand on loose sand or mud your feet go deep into them. If you lay down with your back side in contact with the sand or mud your body will not go as deep as in earlier case. In both cases the force exerted on the sand or mud are the same, being the weight of your body.

Observation 3

Take a brick and place it on the freshly prepared cement and sand mixture in different configurations of the brick. At first, you place with the widest area of the brick and next with the smallest area of the same brick on the mixture. You will find that the brick goes deeper in the later case. Here also, the same force is exerted in the two cases, the weight of the brick.

In the above observations you have seen that the force is acting vertically downwards i.e. perpendicular to the surface concerned and is called the thrust. Now you have seen that when you stand on the loose sand, the force which is the weight of your body is acting on an area equal to the area of your feet but when you lay down the same force acts on an area equal to the contact area of the whole backside of your body, which is of larger area than your feet. Thus the effects of the force of same magnitude are different. Similarly, in the other observations thrust is the same but effects are

different. Therefore the effect of a given thrust depends on the area on which it acts, being smaller with wider area. The thrust on unit area is called "pressure". Thus

$$\text{Pressure} = \frac{\text{Thrust}}{\text{Area}} = \frac{F}{A} \dots\dots\dots 10.1$$

Here, F is the thrust and A is the area where thrust acts.

Putting the SI units for thrust and area in the above equation, the SI unit for pressure becomes Nm^{-2} or pascal (Pa) in honour of scientist Blaise Pascal. Let us consider the following example to understand the effect of thrust on different areas.

Example 10.1.

A brick of mass 3 kg is kept on a table. The dimensions of the brick are 30 cm × 12 cm × 7 cm. Calculate the pressure exerted on the table when the brick lies with its sides of dimensions (a) 30 cm × 12 cm and (b) 12 cm × 7 cm. (Take $g = 10 \text{ ms}^{-2}$)

Solution:

The mass of the brick = 3 kg

Thus the weight of the brick = $3 \text{ kg} \times 10 \text{ ms}^{-2} = 30 \text{ N}$.

Case (a) Area of the contact side = 30 cm × 12 cm = 360 cm^2

$$= \left(\frac{360}{100 \times 100} \right) \text{m}^2 = 0.036 \text{ m}^2$$

$$\begin{aligned} \text{From Eq (10.1), Pressure} &= \frac{30 \text{ N}}{0.036 \text{ m}^2} = 833.3 \text{ Nm}^{-2} \\ &= 833.3 \text{ Pa} \end{aligned}$$

Case (b) Area of the contact side = 12 cm × 7 cm = 84 cm^2

$$= \left(\frac{84}{100 \times 100} \right) \text{m}^2 = 0.0084 \text{ m}^2$$

$$\begin{aligned} \text{From Eq (10.1), Pressure} &= \frac{30 \text{ N}}{0.0084 \text{ m}^2} = 3571.4 \text{ Nm}^{-2} \\ &= 3571.4 \text{ Pa.} \end{aligned}$$

From the above example we have seen that the same force acting on smaller area exerts a larger pressure and a smaller pressure on a larger area. This is the reason why drawing pin or iron nail has pointed tip, knives have very sharp edges, buildings have wide foundations and heavy duty trucks have wider tyres.

10.1.1 Buoyancy

Have you ever tried to lift water from pond, household reservoir or from a well with a bucket? Have you felt that the bucket of water is heavier when it is out of the water? Have you ever felt lighter when you go deeper into the water on the steps of the pond? Have you ever had a swim in a pond and felt lighter? Have you ever thought why a ship made of iron does not sink in water but while the same amount of iron in the form of a sheet or bulk would sink in water? These questions can be answered by taking buoyancy into consideration. At first let us try to know the meaning of buoyancy by performing an activity.

Activity 10.1

Take an empty glass or plastic bottle whose mouth is closed with air tight stopper. Put it in water contained in a bucket. You will see that it floats. Submerge it into the water forcibly. You will feel an upward push exerted by the bottle. The upward push will increase as you submerge the bottle, deeper and deeper till it is immersed completely. Now, release the bottle and see what happens? It will bounce back to the surface. This shows that water exerts a force on the bottle in the upward direction. The above activity can also be done in other non-volatile and stable liquid, if available. In spite of gravitational force acting on the bottle in the downward direction, the bottle does not stay inside water when it is released. How can you immerse the bottle in water?

In the above activity, you have learnt that water exerts an upward force on the bottle. That is why the bottle comes up to the surface of water in the original position. This shows that the upward force exerted on the bottle by water is larger than the weight of the bottle due to the gravitational attraction of the earth.

To keep the bottle completely immersed, the upward force exerted on the bottle must be balanced using an externally applied force on the bottle in the downward direction, having a magnitude at least equal to the difference between the upward force on the bottle and its weight acting vertically downwards.

The upward force exerted by the water on the bottle is known as upthrust or buoyant force. In fact, as cited above, all objects experience a force of buoyancy when they are immersed in a fluid (liquid or gas). This phenomenon is known as buoyancy. The magnitude of the buoyant force depends on the density of the fluid and volume of the immersed body.

10.1.2 Why objects float or sink when placed on the surface of a liquid say water?

Let us perform the following activity in order to get an answer to the above question.

Activity10.2

Take a beaker and fill with water. Put an iron nail on the surface of water. Observe what happens.

The iron nail sinks because the upthrust of water acting on the nail is less than the force on the nail due to the gravitational attraction i.e. the weight of the nail acting in the downward direction. That is why the nail sinks, shown in Fig.10.1.

In the above activity, if the liquid were mercury (Hg) the nail will float on the surface of mercury by submerging a small portion.

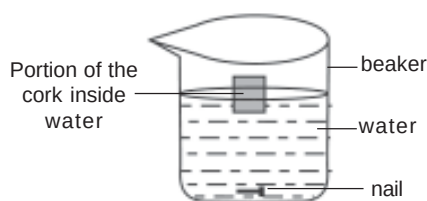


Fig. 10.1: An iron nail sinks in water while the cork floats

Activity 10.3

Take water in a beaker. Put an iron nail and a piece of cork having equal masses. Observe what happens.

You will see that the cork floats while the nail sinks. This happens because of the difference in their densities, which is the mass per unit volume of each of them. This shows that the density of cork is less than that of water, as shown in the figure (10.1). This also shows that the upthrust of water on the cork is greater than the weight of the cork. In the case of iron nail, the density of iron is greater than the density of water. This means that the upthrust of water on the *iron nail* is less than the weight of the nail acting vertically downwards. That is why the iron nail sinks.

Thus we have learnt that objects of density less than that of the liquid floats on the liquid by submerging some portion of the body, while the objects whose density is greater than that of the liquid will sink in the liquid.

Try to answer:

1. Kitchen knives have very sharp edges and if the edge is not so sharp it is not easy to cut vegetables. Give reason why?
2. Why is it difficult to hold school bags and heavy canvas bags with straps made of thin and strong strings.
3. What is buoyancy?
4. Can we use objects which dissolve in water or in the experimental liquid? Can we use objects which absorb the liquid?

10.2 Archimede's Principle

Activity 10.4

Take a piece of stone or a glass marble and tie it to one end of a light spring.

Suspend the stone or marble by fixing the other end of the spring at a rigid support as shown in Fig:10.2. Note the position of the pointer 'A', which is the elongation of the spring due to the weight of the marble. Now slowly dip the marble in the water in a container as shown in the Fig:10.2.

Observe what happens to the position of the pointer on the scale.

You will observe that the pointer goes up, i.e. elongation of the spring decreases as the marble is gradually lowered into the water. However, no further change in the position of the pointer will be observed as soon as the marble gets fully immersed in water. What have you learnt from the decrease in the elongation of the spring?

It is already learnt that the elongation produced in the spring is due to the *weight of body* suspended at the lower end of the spring. Since the decrease in the extension can also be made if you push up the marble slightly, you could infer that some force acts

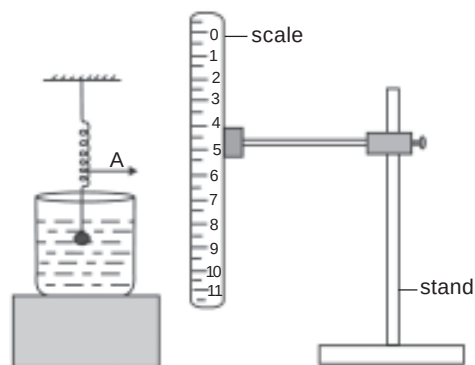


Fig. 10.2: Pointer goes up when the marble is immersed in water

on the marble in the upward direction. As a result the net force acting on the spring decreases and hence the elongation also decreases. This upward force exerted by the liquid (water) is known as the force of buoyancy.

Let us try to know the answers to the following questions. What is the magnitude of the buoyant force experienced by a body when immersed in a liquid? Is it the same for a given solid body, in all fluids? Do all bodies of same mass experience the same buoyant force when immersed completely in a liquid? etc. The answer to these questions can be given after going through Archimede's Principle, stated as follows:

When a solid body is immersed partly or fully in fluid (liquid as well as gas), it experiences an upward force that is equal to the weight of the fluid displaced by the body.

Thus you can explain, now why a further decrease in the elongation of the spring was not observed in activity 10.4, as soon as the marble was immersed fully in water. You must also note that marble or stone is solid and does not dissolve in water and does not absorb water also.

Archimede's Principle has many applications. It is used in designing ships and submarines. Lactometers which are used to determine the purity of a sample of milk, hydrometers for determining the density of liquids, are based on this principle.

Example 10.2

A cubical block of metal is of mass 1.5 kg volume 150 c.c. If the density of water is 1000 kg. m^{-3} . Will it immerse or float? What will be its weight in water?

Solutions:

Mass of the block, $m = 1.5 \text{ kg}$.

$$\begin{aligned}\text{Vol. of the block, } v &= 150 \text{ c.c.} = \frac{150}{100 \times 100 \times 100} \text{ m}^3 \\ &= 1.5 \times 10^{-4} \text{ m}^3\end{aligned}$$

$$\begin{aligned}\text{Thus, density of the metal} &= \frac{m}{v} = \frac{1.5 \text{ kg}}{1.5 \times 10^{-4} \text{ m}^3} \\ &= 10^4 \text{ kg m}^{-3}.\end{aligned}$$

Thus, the block will immerse completely in the water, since its density is greater than that of water.

From Archimede's Principle, the weight of the displaced water = $(1.5 \times 10^{-4} \text{ m}^3 \times 1000 \text{ kg. m}^{-3} \times g) \text{ N}$.

Taking density of water as 1000 kg m^{-3} .

Thus, upthrust on the block = $(1.5 \times 10^{-1} \times g) \text{ N}$.

The downward force, which is the weight of block = $1.5 \times g \text{ N}$

$$\begin{aligned}\therefore \text{The resultant downward force} &= (1.5 g - 1.5 \times 10^{-1} g) \text{ N} \\ &= (1.5 - 0.15)g \text{ N} = (1.35g) \text{ N}.\end{aligned}$$

Hence, the block would weigh 1.35 kg.

10.2.1 Experimental Demonstration of Archimede's Principle

Take a solid block of a substance which sinks in a liquid say, water and also does not dissolve in water; a spring balance; two measuring cylinders and a cylindrical container A having volume larger than the volume of the solid.

Fix the spring balance at a suitable support and suspend the arrangement to the spring balance as shown in Fig.10.3 (a) and record the reading of the balance accurately. Now, immerse the solid in water contained in measuring cylinder and record the reading of the spring balance and the increase in volume of water in the measuring cylinder as accurately as possible, as shown in the Fig.10.3. (b). The reading of the spring balance will be smaller than that in the earlier case [Fig.10.3 (a)]. The difference in the readings of spring balance is the loss in weight of the solid when immersed in water.

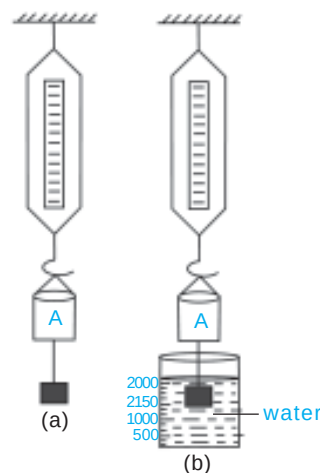


Fig. 10.3: Experimental arrangement to verify Archimede's principle

Now, take water equal in volume to that of increase in the volume when the solid is completely immersed in water as shown in (b), using another measuring cylinder. Then, pour the water into the container A. Record the new reading of the spring balance. Certainly, you will observe that this reading on the spring balance will be equal to that in fig. 10.3 (a). This shows that the loss in weight of the solid due to buoyancy is exactly equal to the weight of the displaced water, after completely immersing the solid in water. Thus, Archimede's Principle is verified.

10.3 Floatation

You have learnt that some body floats while some body sinks in the same liquid, activity 10.2 and 10.3. Why does a bowl prepared from a sheet of metal float whereas the same sheet in the form of a plate sinks?

You have learnt that when a body is placed in a fluid two forces act on the body. They are (i) weight of the body acting in downward direction and (ii) upthrust equal to the weight of the displaced liquid in the upward direction. If the force mentioned in (i) is greater than that mentioned in (ii) the resultant is acting downwards and the body will sink. On the other hand, if the condition is reversed i.e. downward force due to the weight is smaller than the upward force due to the upthrust or buoyancy then resultant force is in upward direction and body floats. This is the situation for the floating cork in activity 10.3. Thus in the case of cork, activity 10.3, has a weight equal to the weight of the displaced liquid. That is why the cork floats on water.

The weight of a body in a fluid is called its apparent weight. For a body floating in a liquid, its weight is equal to the weight of the liquid displaced. Similarly a solid body whose density is smaller than the density of the liquid where it is placed it floats in the liquid.

Let us try to answer

1. Your weight is 50 kg on a weighing machine. Is your mass more or less than 50 kg.
2. You have a bagful of cotton and iron rod of the same mass, say 50 kg, when measured using a weighing machine. In reality one is of heavier mass than the other. Can you say which one is heavier? Explain why.

10.4 Relative density

You have learnt in previous classes that density of a substance is defined as mass of a unit volume of it and is expressed in kg m^{-3} (kilogram per metrecube) and remains constant. Therefore density of a substance is one of its many characteristic properties. It is different for different substances. For example the density of mercury is 13600 kgm^{-3} while that of water is 1000 kgm^{-3} . The density of a given sample of a substance can help us to determine its purity e.g. the density of pure gold sample is 19300 kg m^{-3} .

Very often, the density of a substance is expressed in comparison with that of water as a convenient means. Thus, the relative density of a substance is the ratio of its density to that of water. The relative density of a substance is also called its specific gravity.

$$\text{Relative density or specific gravity of a substance} = \frac{\text{Density of the substance}}{\text{Density of water}}$$

Since, the relative density is a ratio of similar quantities, it has no unit i.e. a pure number.

Example 10.3.

The relative density of a substance is 10.8. The density water is 10^3 kgm^{-3} . What is the density of the substance?

Solution:

$$\text{Relative density of the substance} = 10.8$$

$$\text{From, Relative density} = \frac{\text{Density of the substance}}{\text{Density of water}}, \text{ we get}$$

$$\begin{aligned} \text{Density of the substance} &= \text{Relative density of the substance} \times \text{density of water.} \\ &= 10.8 \times 1000 \text{ kgm}^{-3} \\ &= 10800 \text{ kgm}^{-3} \\ &= 1.08 \times 10^4 \text{ kgm}^{-3}. \end{aligned}$$

POINTS TO REMEMBER

- (i) Pressure on a surface or at a point is thrust per unit area and its SI unit is Pa (pascal).
- (ii) All objects experience a force of buoyancy when they are immersed in a fluid.
- (iii) All bodies in solid form having density less than that of the liquid in which they are immersed, float on the surface of the liquid by projecting some portion above the surface. If the bodies are of density larger than that of the liquid in which they are immersed then they sink in the liquid.
- (iv) Whenever any body floats in a liquid, the weight of the floating body is equal to the weight of the liquid displaced by the body.
- (v) Density of a substance is equal to the product of its relative density by the density of water. The unit for density is the same as that for the water.

EXERCISES

1. *What is thrust? State its direction of action.*
2. *In which direction does the buoyant force on an object immersed in a liquid act? State the magnitude of buoyant force.*
3. *Why does a block of plastic or cork come up to the surface of water when they are released under water?*
4. *The volume of a solid block of mass 180 gm is 100 cm^3 . If the block is placed in water of density 1 gm/cm^3 , will it float or sink? Explain.*
(sink; density of substance of block is 1.8 gm cm^{-3}
which is larger than that of water)
5. *A lump of plastic of relative density 0.4 has a mass of 10 gm. It is placed in water. Calculate the volume of the lump projecting above the surface of water. (Take the density of water as 1 gm cm^{-3}).*

(15 cm^3)