Example 10.4 Mass of an object is 10 kg. What is its weight on the earth?

Solution:

Mass, m = 10 kg
Acceleration due to gravity, g = 9.8 m s^{-2}
$W = m \times g$
W = 10 kg × 9.8 m s^{-2} = 98 N
Thus, the weight of the object is 98 N.

Example 10.5 An object weighs 10 N when measured on the surface of the earth. What would be its weight when measured on the surface of the moon?

Solution:

We know,
Weight of object on the moon
= (1/6) × its weight on the earth.
That is,

$$W_m = \frac{W_e}{6} = \frac{10}{6}\text{ N.}$$

$$= 1.67\text{ N.}$$

Thus, the weight of object on the surface of the moon would be 1.67 N.

Questions

1. *What are the differences between the mass of an object and its weight?*
2. *Why is the weight of an object on the moon $\frac{1}{6}^{th}$ its weight on the earth?*

10.5 Thrust and Pressure

Have you ever wondered why a camel can run in a desert easily? Why an army tank weighing more than a thousand tonne rests upon a continuous chain? Why a truck or a motorbus has much wider tyres? Why cutting tools have sharp edges? In order to address these questions and understand the phenomena involved, it helps to introduce the concepts of the net force in a particular direction (thrust) and the force per unit area (pressure) acting on the object concerned.

Let us try to understand the meanings of thrust and pressure by considering the following situations:

Situation 1: You wish to fix a poster on a bulletin board, as shown in Fig 10.3. To do this task you will have to press drawing pins with your thumb. You apply a force on the surface area of the head of the pin. This force is directed perpendicular to the surface area of the board. This force acts on a smaller area at the tip of the pin.

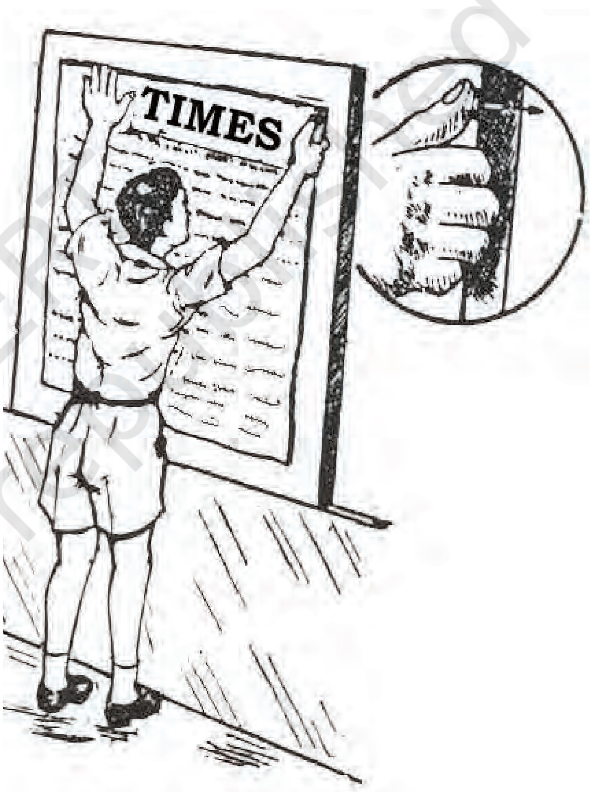

Fig. 10.3: *To fix a poster, drawing pins are pressed with the thumb perpendicular to the board.*

Situation 2: You stand on loose sand. Your feet go deep into the sand. Now, lie down on the sand. You will find that your body will not go that deep in the sand. In both cases the force exerted on the sand is the weight of your body.

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You have learnt that weight is the force acting vertically downwards. Here the force is acting perpendicular to the surface of the sand. The force acting on an object perpendicular to the surface is called thrust.

When you stand on loose sand, the force, that is, the weight of your body is acting on an area equal to area of your feet. When you lie down, the same force acts on an area equal to the contact area of your whole body, which is larger than the area of your feet. Thus, the effects of forces of the same magnitude on different areas are different. In the above cases, thrust is the same. But effects are different. Therefore the effect of thrust depends on the area on which it acts.

The effect of thrust on sand is larger while standing than while lying. The thrust on unit area is called pressure. Thus,

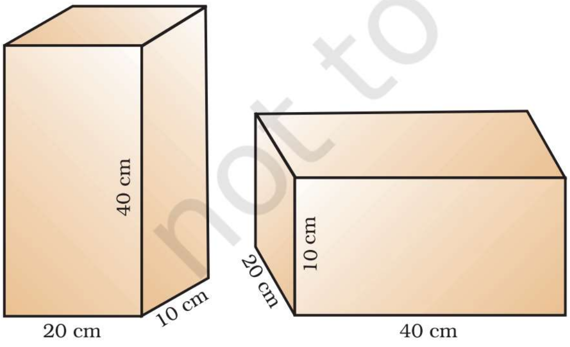
$$\text{Pressure} = \frac{\text{thrust}}{\text{area}} \qquad (10.20)$$

Substituting the SI unit of thrust and area in Eq. (10.20), we get the SI unit of pressure as N/m^2 or $N\ m^{-2}$.

In honour of scientist Blaise Pascal, the SI unit of pressure is called pascal, denoted as Pa.

Let us consider a numerical example to understand the effects of thrust acting on different areas.

Example 10.6 A block of wood is kept on a tabletop. The mass of wooden block is 5 kg and its dimensions are 40 cm × 20 cm × 10 cm. Find the pressure exerted by the wooden block on the table top if it is made to lie on the table top with its sides of dimensions (a) 20 cm × 10 cm and (b) 40 cm × 20 cm.



(a) (b)

Fig. 10.4

Solution:

The mass of the wooden block = 5 kg

The dimensions

= 40 cm × 20 cm × 10 cm

Here, the weight of the wooden block applies a thrust on the table top.

That is,

$$\begin{aligned} \text{Thrust} = F &= m \times g \\ &= 5\ \text{kg} \times 9.8\ \text{m s}^{-2} \\ &= 49\ \text{N} \end{aligned}$$

$$\begin{aligned} \text{Area of a side} &= \text{length} \times \text{breadth} \\ &= 20\ \text{cm} \times 10\ \text{cm} \\ &= 200\ \text{cm}^2 = 0.02\ \text{m}^2 \end{aligned}$$

From Eq. (10.20),

$$\text{Pressure} = \frac{49\,\text{N}}{0.02\,\text{m}^2}$$

$$= 2450\ \text{N m}^{-2}.$$

When the block lies on its side of dimensions 40 cm × 20 cm, it exerts the same thrust.

$$\begin{aligned} \text{Area} &= \text{length} \times \text{breadth} \\ &= 40\ \text{cm} \times 20\ \text{cm} \\ &= 800\ \text{cm}^2 = 0.08\ \text{m}^2 \end{aligned}$$

From Eq. (10.20),

$$\text{Pressure} = \frac{49\,\text{N}}{0.08\,\text{m}^2}$$

$$= 612.5\ \text{N m}^{-2}$$

The pressure exerted by the side 20 cm × 10 cm is 2450 N m^{-2} and by the side 40 cm × 20 cm is 612.5 N m^{-2}.

Thus, the same force acting on a smaller area exerts a larger pressure, and a smaller pressure on a larger area. This is the reason why a nail has a pointed tip, knives have sharp edges and buildings have wide foundations.

10.5.1 PRESSURE IN FLUIDS

All liquids and gases are fluids. A solid exerts pressure on a surface due to its weight. Similarly, fluids have weight, and they also

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exert pressure on the base and walls of the container in which they are enclosed. Pressure exerted in any confined mass of fluid is transmitted undiminished in all directions.

10.5.2 BUOYANCY

Have you ever had a swim in a pool and felt lighter? Have you ever drawn water from a well and felt that the bucket of water is heavier when it is out of the water? Have you ever wondered why a ship made of iron and steel does not sink in sea water, but while the same amount of iron and steel in the form of a sheet would sink? These questions can be answered by taking buoyancy in consideration. Let us understand the meaning of buoyancy by doing an activity.

Activity 10.4

- Take an empty plastic bottle. Close the mouth of the bottle with an airtight stopper. Put it in a bucket filled with water. You see that the bottle floats.
- Push the bottle into the water. You feel an upward push. Try to push it further down. You will find it difficult to push deeper and deeper. This indicates that water exerts a force on the bottle in the upward direction. The upward force exerted by the water goes on increasing as the bottle is pushed deeper till it is completely immersed.
- Now, release the bottle. It bounces back to the surface.
- Does the force due to the gravitational attraction of the earth act on this bottle? If so, why doesn't the bottle stay immersed in water after it is released? How can you immerse the bottle in water?

The force due to the gravitational attraction of the earth acts on the bottle in the downward direction. So the bottle is pulled downwards. But the water exerts an upward force on the bottle. Thus, the bottle is pushed upwards. We have learnt that weight of an object is the force due to gravitational attraction of the earth. When the bottle is immersed, the upward force exerted by the water on the bottle is greater than its weight. Therefore it rises up when released.

To keep the bottle completely immersed, the upward force on the bottle due to water must be balanced. This can be achieved by an externally applied force acting downwards. This force must at least be equal to the difference between the upward force and the weight of the bottle.

The upward force exerted by the water on the bottle is known as upthrust or buoyant force. In fact, all objects experience a force of buoyancy when they are immersed in a fluid. The magnitude of this buoyant force depends on the density of the fluid.

10.5.3 WHY OBJECTS FLOAT OR SINK WHEN PLACED ON THE SURFACE OF WATER?

Let us do the following activities to arrive at an answer for the above question.

Activity 10.5

- Take a beaker filled with water.
- Take an iron nail and place it on the surface of the water.
- Observe what happens.

The nail sinks. The force due to the gravitational attraction of the earth on the iron nail pulls it downwards. There is an upthrust of water on the nail, which pushes it upwards. But the downward force acting on the nail is greater than the upthrust of water on the nail. So it sinks (Fig. 10.5).

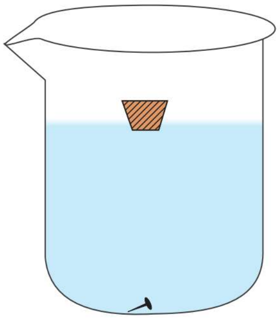

Fig. 10.5: *An iron nail sinks and a cork floats when placed on the surface of water.*

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Activity 10.6

- Take a beaker filled with water.
- Take a piece of cork and an iron nail of equal mass.
- Place them on the surface of water.
- Observe what happens.

The cork floats while the nail sinks. This happens because of the difference in their densities. The density of a substance is defined as the mass per unit volume. The density of cork is less than the density of water. This means that the upthrust of water on the cork is greater than the weight of the cork. So it floats (Fig. 10.5).

The density of an iron nail is more than the density of water. This means that the upthrust of water on the iron nail is less than the weight of the nail. So it sinks.

Therefore objects of density less than that of a liquid float on the liquid. The objects of density greater than that of a liquid sink in the liquid.

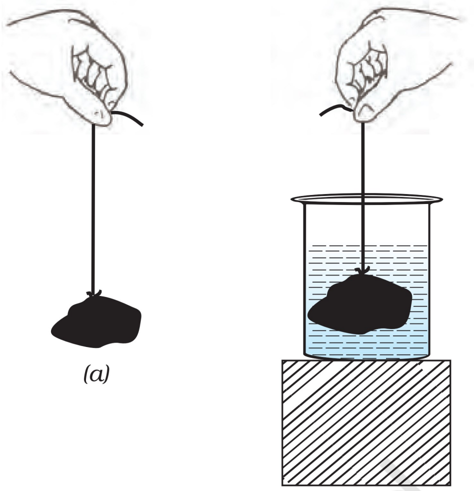
Questions

1. *Why is it difficult to hold a school bag having a strap made of a thin and strong string?*
2. *What do you mean by buoyancy?*
3. *Why does an object float or sink when placed on the surface of water?*

10.6 Archimedes' Principle

Activity 10.7

- Take a piece of stone and tie it to one end of a rubber string or a spring balance.
- Suspend the stone by holding the balance or the string as shown in Fig. 10.6 (a).
- Note the elongation of the string or the reading on the spring balance due to the weight of the stone.
- Now, slowly dip the stone in the water in a container as shown in Fig. 10.6 (b).



(a) (b)

Fig. 10.6: *(a) Observe the elongation of the rubber string due to the weight of a piece of stone suspended from it in air. (b) The elongation decreases as the stone is immersed in water.*

- Observe what happens to elongation of the string or the reading on the balance.

You will find that the elongation of the string or the reading of the balance decreases as the stone is gradually lowered in the water. However, no further change is observed once the stone gets fully immersed in the water. What do you infer from the decrease in the extension of the string or the reading of the spring balance?

We know that the elongation produced in the string or the spring balance is due to the weight of the stone. Since the extension decreases once the stone is lowered in water, it means that some force acts on the stone in upward direction. As a result, the net force on the string decreases and hence the elongation also decreases. As discussed earlier, this upward force exerted by water is known as the force of buoyancy.

What is the magnitude of the buoyant force experienced by a body? Is it the same in all fluids for a given body? Do all bodies in a given fluid experience the same buoyant force? The answer to these questions is

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contained in Archimedes' principle, stated as follows:

When a body is immersed fully or partially in a fluid, it experiences an upward force that is equal to the weight of the fluid displaced by it.

Now, can you explain why a further decrease in the elongation of the string was not observed in activity 10.7, as the stone was fully immersed in water?

Archimedes

Archimedes was a Greek scientist. He discovered the principle, subsequently named after him, after noticing that the water in a bathtub overflowed when he stepped into it. He ran through the streets shouting "Eureka!", which means "I have got it". This knowledge helped him to determine the purity of the gold in the crown made for the king.

His work in the field of Geometry and Mechanics made him famous. His understanding of levers, pulleys, wheels-and-axle helped the Greek army in its war with Roman army.

Archimedes' 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 and hydrometers used for determining density of liquids, are based on this principle.

Questions

1. *You find your mass to be 42 kg on a weighing machine. Is your mass more or less than 42 kg?*
2. *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?*

10.7 Relative Density

As you know, the density of a substance is defined as mass of a unit volume. The unit of density is kilogram per metre cube (kg m^{-3}). The density of a given substance, under specified conditions, remains the same. Therefore the density of a substance is one of its characteristic properties. It is different for different substances. For example, the density of gold is 19300 kg m^{-3} while that of water is 1000 kg m^{-3}. The density of a given sample of a substance can help us to determine its purity.

It is often convenient to express density of a substance in comparison with that of water. The relative density of a substance is the ratio of its density to that of water:

$$\text{Relative density} = \frac{\text{Density of a substance}}{\text{Density of water}}$$

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

Example 10.7 Relative density of silver is 10.8. The density of water is 10^3 kg m^{-3}. What is the density of silver in SI unit?

Solution:

Relative density of silver = 10.8

Relative density

$$= \frac{\text{Density of silver}}{\text{Density of water}}$$

Density of silver

$= \text{Relative density of silver}$

$\times \text{density of water}$

$= 10.8 \times 10^3 \text{ kg m}^{-3}$.

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