1 Mass, Weight and Density

The common objects around you are made of different materials, such as iron, cement, wood, plastic and glass. All these materials are collectively called matter. The entire world, with all the living beings and nonliving things, in fact, the whole universe, is made up of matter. In this chapter, we will study a few characteristics of anything made of matter.

MASS AND WEIGHT

Mass is a basic property of all material objects, or of all things made of matter. The mass of a body is the amount of matter in the body. To begin with, you must be clear about one thing. Mass is not always related to size. To take an example, a ball of candy floss made from a spoonful of sugar takes up much more space than the sugar. However, the two have the same mass because they contain the same amount of matter. Similarly, if you compress some loose cotton, it takes up less space, but its mass remains the same.

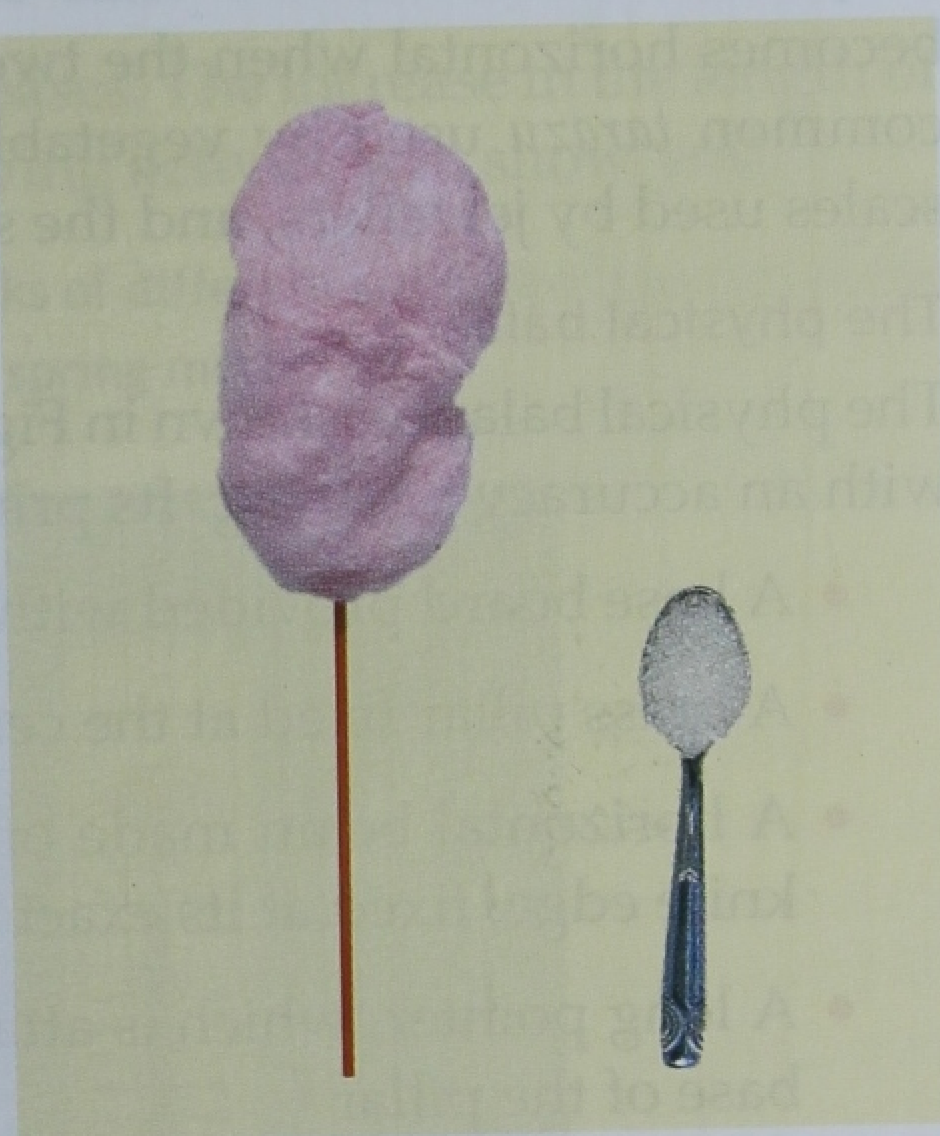


Fig. 1.1 A ball of candy floss made from a spoonful of sugar contains the same amount of matter as the sugar.

The weight of a body is its property of being heavy or light. It depends on the mass of the body. A body of greater mass appears heavier than a body with less mass. You know that the earth attracts all objects towards itself. This pull, called the force of gravity, depends on the mass of the object. And it is this force that we call the weight of an object. Thus, the weight of a body is the force with which it is attracted by gravity.

Comparing Mass and Weight

We can now compare the two quantities mass and weight.

1. Both mass and weight are physical quantities, with magnitudes that can be measured and expressed in terms of numbers and units. Although they are closely related to each other, the two are different physical quantities, and not two names for the same physical quantity.
2. The SI unit of mass is the kilogram (kg). Since weight is, by definition, a force, its SI unit is the newton (N).

3. The weight and mass of a body are related.

$$\text{Weight} = \text{constant} \times \text{mass}$$

You will learn about this constant later. It is called the acceleration due to gravity and is written as '*g*'. It may be different at different places. For example, it is different on the earth and on the moon. Thus, though the mass of a body remains constant, its weight may be different at different places.

4. Ordinarily, when we speak of weighing an object, we mean measuring its mass. Thus, when we say that an object weighs 1 kg, we mean that its mass is 1 kg. The weight of an object of mass 1 kg is 9.8 N, as you already know.

Measurement of Mass

The mass of a body can be measured using different methods. In the common beam balance, the unknown mass is compared directly with a known mass. The two masses are placed on pans suspended from the two ends of a horizontal beam. This beam is supported at the middle and becomes horizontal when the two masses are equal. Balances which work on this principle are the common *tarazu* used by vegetable and fruit sellers, the physical balance used in laboratories, the scales used by jewellers, and the scales used in grocery stores and sweet shops.

The physical balance

The physical balance, shown in Figure 1.2, is used for scientific work. It can measure masses up to 1 kg with an accuracy of 10 mg. Its principal parts are as follows.

- A base board provided with levelling screws
- A brass pillar fixed at the centre of the base board
- A horizontal beam made of brass or aluminium, with a triangular piece, called the knife edge, fixed at its exact centre
- A long pointer, which is attached to the beam and can move over a scale fixed at the base of the pillar
- Two identical pans suspended from knife edges at the ends of the beam
- A case made of wood and glass to cover the entire device

A weight box is provided along with the balance. It contains weights from 500 g to 10 mg, such that they can be combined to obtain any weight between 10 mg and 1 kg.

When the balance is not in use, the beam rests on supports fixed to the pillar. To make the balance ready for use, a knob or handle on the base board is rotated clockwise. The beam then moves up from its supports and can swing about the knife edge. When the pans are empty, the pointer should swing equally to both sides of the scale at the bottom.

To weigh an object (or measure its mass), the pans are brought down and the object is placed on the left pan. Suitable weights are placed on the right pan and the pans are moved up. The weights are adjusted till the pointer swings equally. At this position, the total weight on the right pan is equal to the weight of the object.

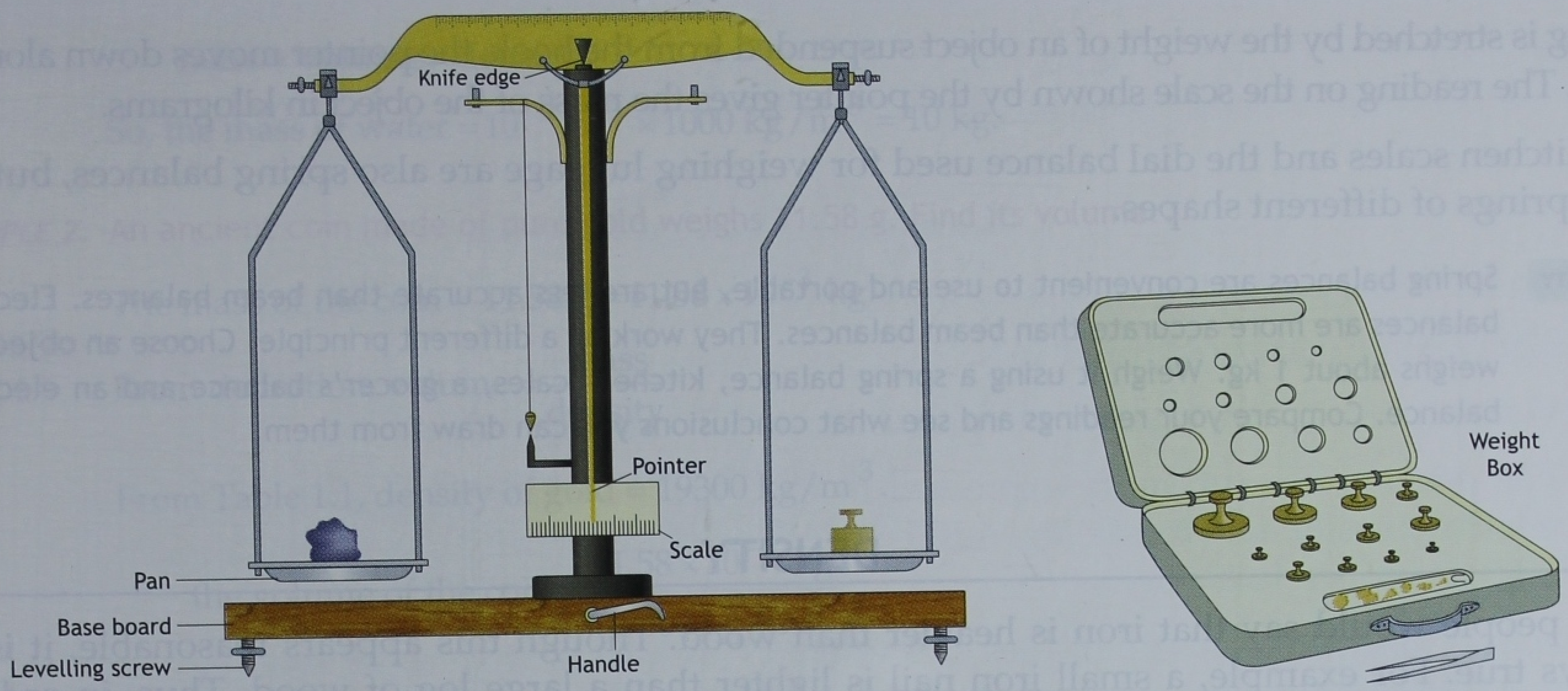
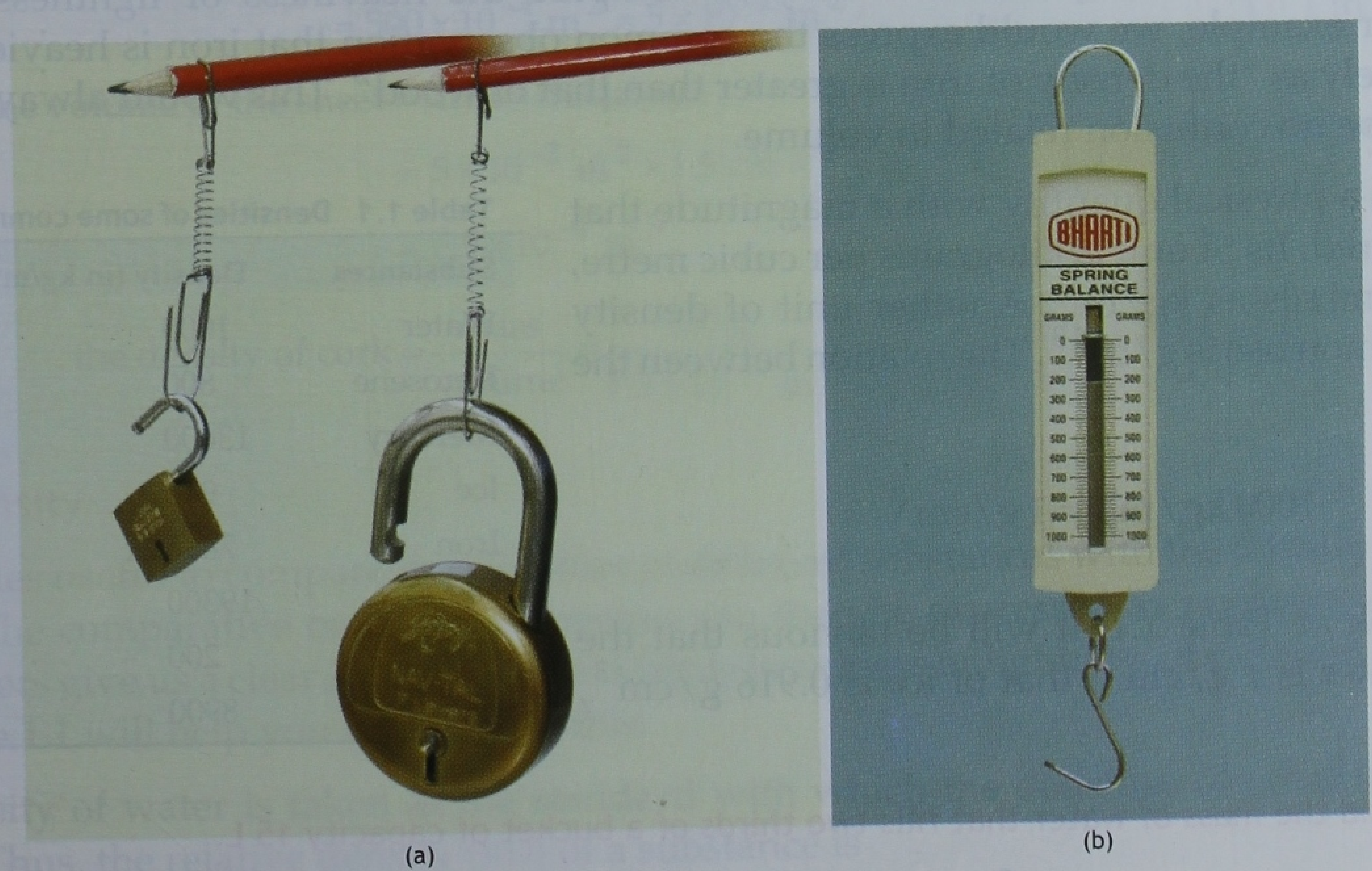


Fig. 1.2 Physical balance and weight box

The spring balance

If you fix one end of a spring and pull at its other end, its length increases. The increase in the length of the spring is proportional to the force you apply on it, as the following activity will show you.

ACTIVITY Fix paper clips to the ends of a spring (use one from a pen). Hang locks of different sizes from the clip at the lower end, as shown in Figure 1.3(a). Heavier locks will stretch the spring more.



(a) (b)

Fig. 1.3 (a) When you hang a heavier weight, the spring stretches more. (b) A spring balance works on this principle.

A spring balance works on the principle illustrated by this activity. A steel spring is placed inside a cover. It can be suspended from a ring fixed at its upper end. The object to be weighed is attached to a hook at its lower end. A small pointer attached to the spring can move over a scale marked on the cover. When the spring is stretched by the weight of an object suspended from the hook, the pointer moves down along the scale. The reading on the scale shown by the pointer gives the mass of the object in kilograms.

Kitchen scales and the dial balance used for weighing luggage are also spring balances, but they use springs of different shapes.

ACTIVITY Spring balances are convenient to use and portable, but are less accurate than beam balances. Electronic balances are more accurate than beam balances. They work on a different principle. Choose an object that weighs about 1 kg. Weigh it using a spring balance, kitchen scales, a grocer's balance and an electronic balance. Compare your readings and see what conclusions you can draw from them.

DENSITY

Most people would say that iron is heavier than wood. Though this appears reasonable, it is not always true. For example, a small iron nail is lighter than a large log of wood. Thus, in order to compare the 'heaviness' or 'lightness' of two different materials, we need to compare the masses of objects of the same size or volume. We do this with the help of a quantity called density. The density of a material is equal to its mass per unit volume.

This can also be expressed as $$\text{density} = \frac{\text{mass}}{\text{volume}}$$

The definition of density makes it easy to compare the heaviness or lightness of different materials. For example, we would express the common observation that iron is heavier than wood more accurately as "the density of iron is greater than that of wood". This would always be true and there would be no confusion related to volume.

Density is a physical quantity with a magnitude that can be measured. Its SI unit is kilograms per cubic metre, written in symbols as kg/m^3. Another unit of density that is in common use is g/cm^3. The relation between the two units is

$$1000\ kg/m^3 = 1\ g/cm^3$$

If you look at Table 1.1, it will be obvious that the density of water is 1 g/cm^3, that of ice is 0.916 g/cm^3, and so on.

Table 1.1 Densities of some common substances

Substances	Density (in kg/m^3)	RD
Water	1000	1
Kerosene	800	0.8
Mercury	13600	13.6
Ice	916	0.916
Iron	7800	7.8
Gold	19300	19.3
Cork	200	0.2
Copper	8900	8.9

EXAMPLE 1. Find the mass of water that fills two thirds of a bucket of capacity 15 L.

The volume of water $= \frac{2}{3} \times 15\ L = 10\ L$.

You know that $1\ L = 10^{-3}\ m^3$.

$\therefore\quad 10\ L = 10 \times 10^{-3}\ m^3 = 10^{-2}\ m^3$.

According to definition, density $= \frac{\text{mass}}{\text{volume}}$.

$\therefore$ mass = volume × density.

So, the mass of water $= 10^{-2}\ \text{m}^3 \times 1000\ \text{kg/m}^3 = 10\ \text{kg}$.

EXAMPLE 2. An ancient coin made of pure gold weighs 11.58 g. Find its volume.

The mass of the coin $= 11.58\ \text{g} = 11.58 \times 10^{-3}\ \text{kg}$.

From definition, volume $= \dfrac{\text{mass}}{\text{density}}$.

From Table 1.1, density of gold $= 19300\ \text{kg/m}^3$.

$$\therefore \quad \text{the volume of the coin} = \frac{11.58 \times 10^{-3}\ \text{kg}}{19300\ \text{kg/m}^3}$$

$$= \frac{11.58 \times 10^{-3}\ \text{kg}}{19.3 \times 10^{3}\ \text{kg/m}^3} = 0.6 \times 10^{-6}\ \text{m}^3$$

$$= 0.6\ \text{cc}. \qquad [\because\ 1\ \text{m}^3 = 10^6\ \text{cc}]$$

EXAMPLE 3. A rectangular sheet of cork measures 25 cm × 20 cm and has a thickness of 1.5 cm. If it weighs 150 g, find the density of cork.

The area of the sheet $= 25\ \text{cm} \times 20\ \text{cm} = 500\ \text{cm}^2$

$$= 500 \times 10^{-4}\ \text{m}^2 = 5 \times 10^{-2}\ \text{m}^2. \qquad [\because\ 1\ \text{m}^2 = 10^4\ \text{cm}^2]$$

The volume of the sheet = area × thickness

$$= 5 \times 10^{-2}\ \text{m}^2 \times 1.5\ \text{cm} = 5 \times 10^{-2}\ \text{m}^2 \times 1.5 \times 10^{-2}\ \text{m}$$

$$= 7.5 \times 10^{-4}\ \text{m}^3.$$

$$\therefore \quad \text{the density of cork} = \frac{\text{mass}}{\text{volume}} = \frac{150\ \text{g}}{7.5 \times 10^{-4}\ \text{m}} = \frac{150 \times 10^{-3}\ \text{kg}}{7.5 \times 10^{-4}\ \text{m}^2} = 200\ \text{kg/m}^3.$$

Relative Density

It is sometimes useful to compare the densities of different substances with the density of a standard substance. The comparative or relative densities can then be expressed as numbers without units. These numbers give us a clear idea about the relative heaviness or lightness of different substances. A look at Table 1.1 will help you understand this.

The density of water is taken as the standard with which the densities of other substances are compared. Thus, the relative density (RD) of a substance is

$$\text{RD} = \frac{\text{density of substance}}{\text{density of water}}$$

Since the density of a substance is its mass per unit volume,

$$\text{RD} = \frac{\text{mass of unit volume of substance}}{\text{mass of unit volume of water}}$$

$$= \frac{\text{mass of any volume of substance}}{\text{mass of same volume of water}}.$$

Here are a few points that you need to remember.

- The relative density of water is 1.
- Relative density is a number without units.
- The density of a substance expressed in g/cc has the same numerical value as its relative density. Obviously, the numerical value of the density of a substance in SI is 1000 times its relative density.
- Substances with relative densities greater than 1 are heavier than water and those with relative densities less than 1 are lighter than water. Thus, steel, gold and mercury are heavier than water, while ice, cork and kerosene are lighter than water.

Specific Gravity Bottle

Relative density is also called specific gravity (SG). A relative density bottle or a specific gravity bottle is a small, thin-walled glass bottle used to measure the density or relative density of a liquid. It has a fixed capacity, which is usually 50 cc and sometimes 25 cc. The capacity is marked on the wall of the bottle. The bottle has a glass stopper with a thin hole. When it is filled with a liquid and the stopper is pushed in, some liquid flows out through the hole. The liquid remaining in the bottle has the exact volume marked on it.

ACTIVITY To find the density of a liquid using an SG bottle, you will require an SG bottle, some blotting paper, a physical balance and a weight box. Make sure that the bottle is clean, empty and dry.

Weigh the empty bottle along with its stopper. Let this mass be m_1. Then fill the bottle with the liquid whose density you wish to measure and insert the stopper gently. Some liquid will spill out through the hole in the stopper and spread over the outer surface of the bottle. Dry the bottle with a blotting paper and weigh it again. Let the mass of the bottle and liquid be m_2. Let the capacity of the bottle be V. Calculate the density of the liquid as follows.

The mass of the liquid $= m_2 - m_1$.

The volume of the liquid $= V$.

$\therefore$ the density of the liquid $= \dfrac{m_2 - m_1}{V}$.

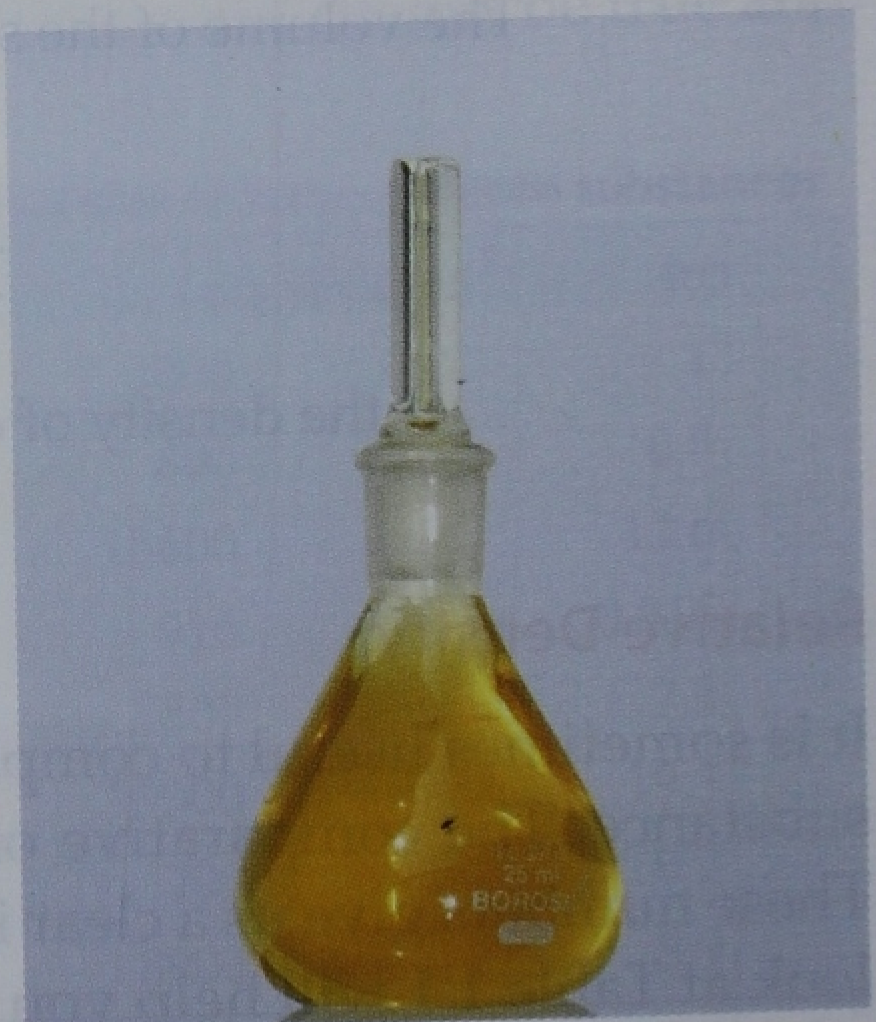


Fig. 1.4 Specific gravity bottle

You can also use an SG bottle to find the relative density of a liquid. In this case you do not need to know the capacity of the SG bottle. Follow the steps mentioned in the preceding activity. Let the mass of the empty bottle be m_1 and the mass of the bottle filled with the liquid be m_2.

Then the mass of the liquid $= m_2 - m_1$. ... (1)

Empty the bottle, clean and dry it. Then fill it with water and weigh the bottle.

Let the mass of the bottle and water be m_3.

Then the mass of water $= m_3 - m_1$. ... (2)

The quantities calculated in (1) and (2) are the masses of the same volume of the liquid and water respectively. It follows that

$$\text{RD of the liquid} = \frac{m_2 - m_1}{m_3 - m_1}.$$

Floating and Sinking

A piece of wood floats in water but a stone sinks in it. An iron nail sinks in water but a piece of cork floats in it. Suppose we ask ourselves, "When does a solid float or sink in a liquid?" The answer would be: A solid floats in a liquid whose density is greater than its own and sinks in a liquid whose density is less than its own.

A look at Table 1.1 will tell you the following.

1. Ice will float in water but sink in kerosene.
2. Iron will sink in water but float in mercury.
3. Gold will sink in mercury but copper will float in mercury.

What about liquids? If two liquids of different densities are poured into the same container, the liquid with the greater density moves down (sinks) and the liquid with lower density moves up (rises). For example, if kerosene and water are poured into the same container, kerosene rises and floats over water.

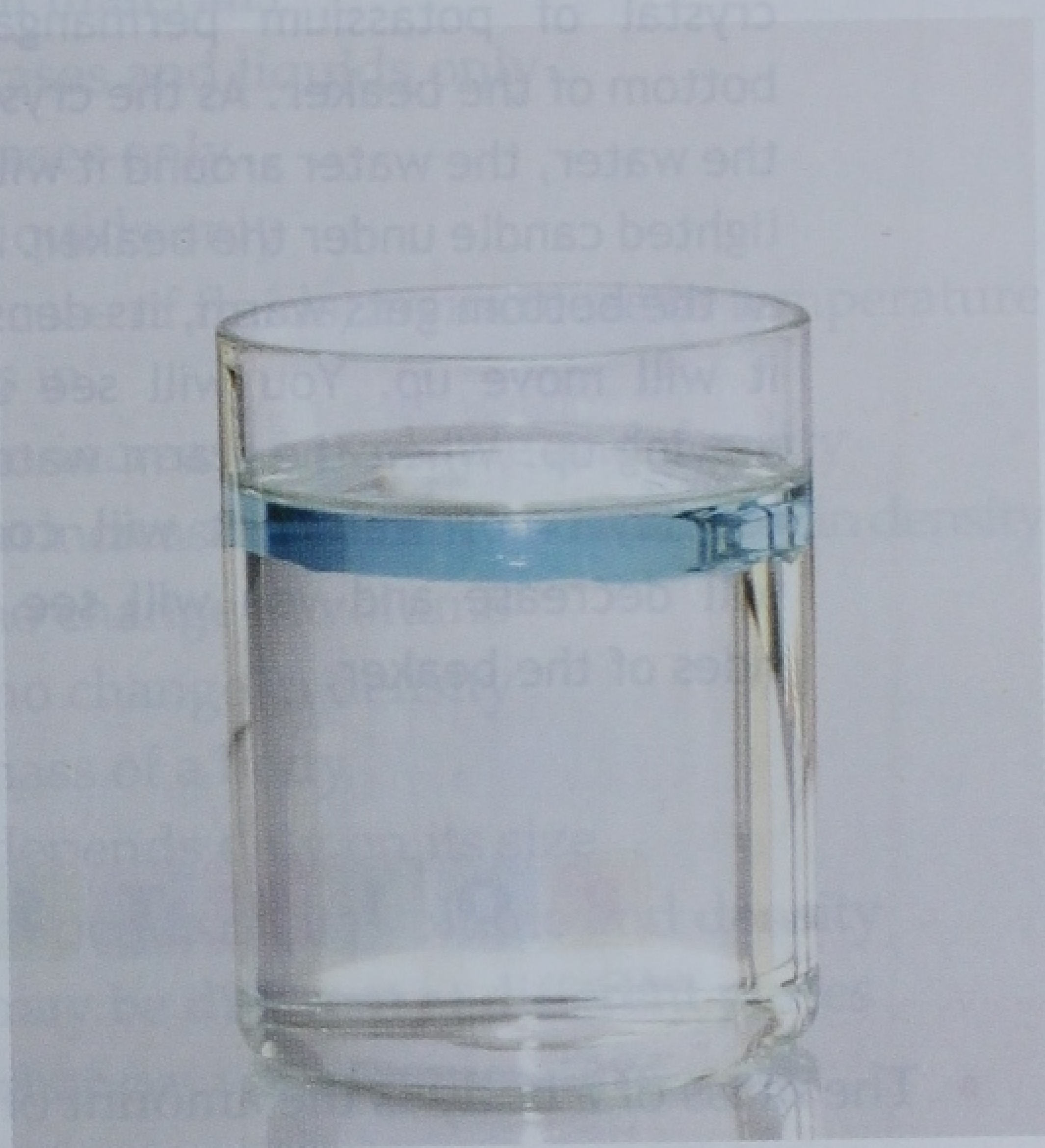


Fig. 1.5 Kerosene is lighter than water, so it moves up.

Variation of Density with Temperature

You may have heard that metals expand in summer and contract in winter. This is true not only of metals, but of most substances, whether solid, liquid or gas. In general, the volume of a substance increases with rise in temperature and decreases with fall in temperature. This is called thermal expansion and contraction. (The word 'thermal' always refers to heat.) Thermal changes in volume are the maximum in gases, less in liquids, and the least in solids.

Though the volume of a substance changes with temperature, its mass does not. You know that density = mass/volume. It follows that if mass remains constant and volume changes, density must change. When the temperature increases, the volume of a substance increases. Therefore, its density decreases. When the temperature decreases, the volume decreases and the density increases.

Liquids and gases are together called fluids. Changes in density with temperature are much more marked in fluids than in solids. If different parts of the same fluid are at different temperatures, they will have different densities. Such differences in density are responsible for a large number of natural processes and also have many practical applications.

Convection currents

When different sections of a fluid are at different temperatures, and hence have different densities, they move either up or down. The cooler sections, being heavier, move down while the hotter sections, being lighter, move up. This kind of movement is very common in both gases and liquids, and is called a convection current. The movement of different sections of a fluid due to differences in temperature is called a convection current. You will read more about this in Chapter 4.

ACTIVITY Stand a beaker of water on a tripod (stand) and place a crystal of potassium permanganate gently at the bottom of the beaker. As the crystal starts dissolving in the water, the water around it will become red. Place a lighted candle under the beaker. As the coloured water at the bottom gets warm, its density will decrease and it will move up. You will see streaks of red water moving up. When the warm water reaches the cooler top layers of water, it will cool down. Its density will decrease and you will see it moving down the sides of the beaker.

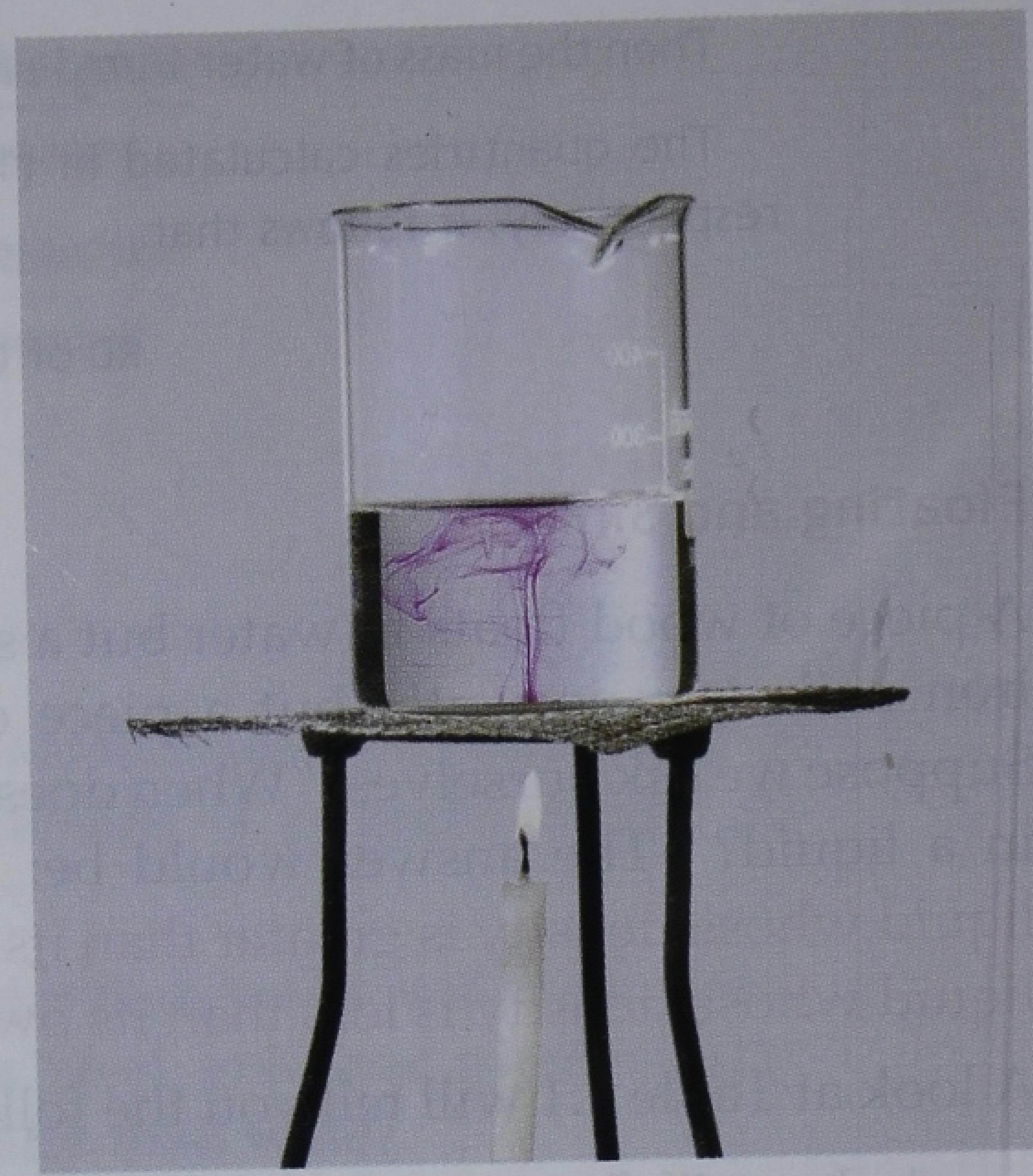


Fig. 1.6 Convection current in a beaker of water

POINTS TO REMEMBER

- The mass of a body is the amount of matter in the body.
- The weight of a body is the force with which it is attracted by gravity.
- The SI units of mass and weight are the kilogram (kg) and the newton (N) respectively.
- In a beam balance, the mass of a body is compared directly with a known mass.
- In a spring balance, a mass is measured by the distance through which a spring is stretched when the mass is suspended from the spring.
- Spring balances are convenient and portable. Beam balances are more accurate.
- The density of a material is equal to its mass per unit volume. The SI unit of density is kg/m^3. $1000\ kg/m^3 = 1\ g/cc$.
- The relative density or specific gravity of a substance = the density of the substance/the density of water.
- Relative density is a number and does not have any units.
- The density or relative density of a liquid can be measured by a specific gravity bottle.
- A solid will float in a liquid whose density is greater than its own and sink in a liquid whose density is less than its own. When two liquids are poured into a container, the one with the greater density will move down.
- Almost every substance undergoes thermal expansion and contraction. The effect is the greatest in gases and the least in solids.
- Liquids and gases are together called fluids. Fluids show marked changes in volume and density with changes in temperature.
- The movement of different sections of a fluid due to differences in temperature is called a convection current.

EXERCISE

Short-Answer Questions

1. What is meant by the mass of a body? What is the SI unit of mass?
2. What is meant by the weight of a body? What is the SI unit of weight?
3. What is the working principle of a spring balance?
4. What is meant by the density of a body? What is the SI unit of density?
5. What is the relative density of a substance?

Long-Answer Questions

1. Briefly describe the process of weighing an object using a physical balance. You can use a sketch to explain your answer.
2. How is an object weighed using a spring balance? State one advantage and one disadvantage of a spring balance.
3. What is a relative density bottle? How is the relative density of a liquid measured with it?
4. State the conditions under which a body floats or sinks in a liquid. Use the examples of three solids and three liquids to explain your answer.
5. What is a convection current? Describe an experiment to show a convection current in a liquid.

Objective Questions

Choose the correct option.

1. Which of the following statements is incorrect regarding the quantities mass and weight?
   (a) Both are physical quantities.
   (b) The two are different physical quantities.
   (c) They have different SI units.
   (d) Their ratio always remains constant.
2. How many 'knife edges' are used in a physical balance?
   (a) 1 (b) 2
   (c) 3 (4) 4
3. Which of the following statements is correct regarding density and relative density?
   (a) They have the same units.
   (b) They always have the same numerical value.
   (c) They have the same numerical value when density is expressed in g/cc.
   (d) Relative density is 1000 times the density in g/cc.
4. Convection currents occur in
   (a) all materials .
   (b) gases and liquids only
   (c) gases only
   (d) liquids only
5. In the case of fluids, an increase in temperature results in
   (a) an increase in volume and density
   (b) an increase in volume and decrease in density
   (c) no change in volume
   (d) no change in density
6. The mass of a body
   (a) depends only on its size
   (b) depends on its volume and density
   (c) may be different at different places
   (d) changes with temperature

Fill in the blanks.

1. A spring balance is less ...... than a beam balance.
2. A solid floats in a liquid when its density is ...... than the density of the liquid.
3. Liquids and gases are together called ....
4. Convection ...... are set up in a liquid when different parts of it are at different temperatures.
5. The relative density of water is ....

Write true or false.

1. Mass and weight are two names for the same physical quantity.
2. The weight of a body may be different at different places and under different conditions.
3. The relative density and density of a material have the same numerical value in SI units.
4. Convection currents occur due to differences in density in different sections of a liquid or gas.
5. Ice floats in water but sinks in kerosene.
6. A substance with a relative density of less than 1 is heavier than water.

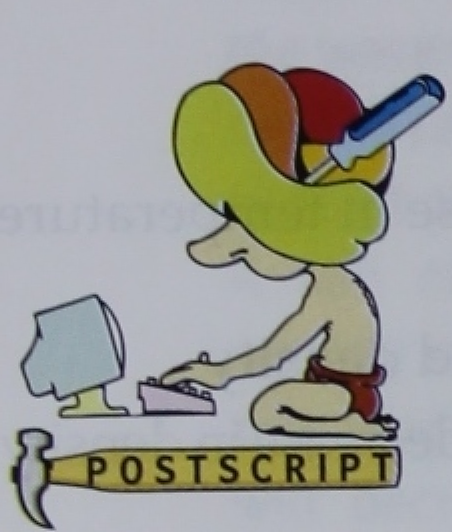
Numericals

1. Find the mass of an ice cube of edge 2 cm. The density of ice = 900 kg/m^3.

2. A beaker weighs 120 g when empty and 280 g when filled with kerosene. Find the volume of the beaker. The density of kerosene = 800 kg/m^3.
3. A metal ball weighs 1.8 kg. The volume of the ball is 250 cc. Find the density of the metal.
4. The capacity of an RD bottle is 50 cc and its mass is 24.5 g when empty. Find its mass when it is filled with a liquid of density 800 kg/m^3.
5. The mass of an empty RD bottle is 24.5 g. Its mass is 74.4 g when filled with water and 87 g when filled with a liquid. Find the relative density of the liquid.

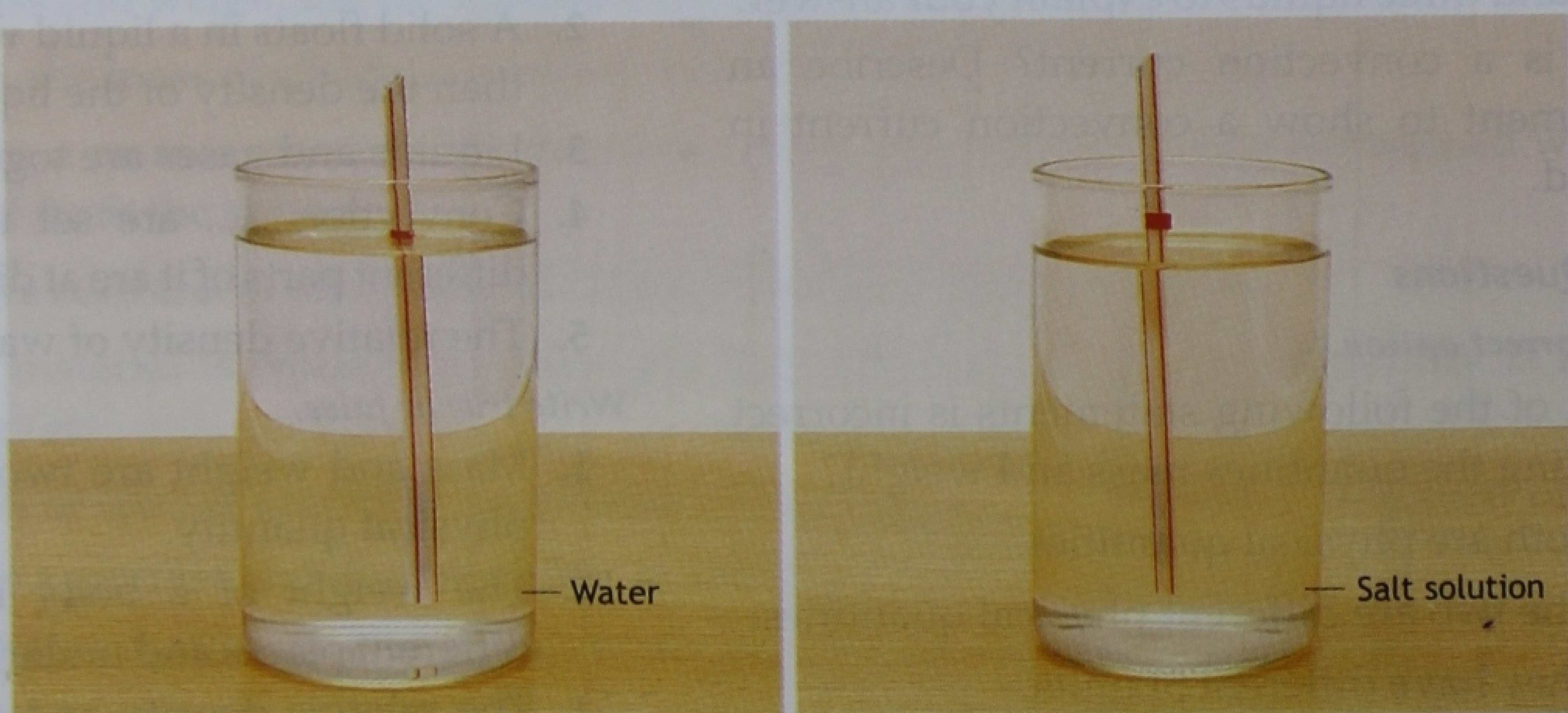
Answers

1. 7.2 g 2. 200 cc 3. 7200 kg/m^3
4. 64.5 g 5. 1.253 kg/m^3



A hydrometer is an instrument used to measure the density or relative density of a liquid. It has a weighted bulb (made heavy) and a thin stem. The weighted bulb helps it float vertically in the liquid being tested. The length of the stem above the surface of the liquid depends on the density of the liquid. Naturally, more of the stem shows in liquids of high density. Graduations on the stem show the density of the liquid.

ACTIVITY Put a few drops of candle wax on a plate. Seal one end of a drinking straw by dipping it into the wax. Stand the straw in a glass of water, with the sealed end at the bottom. Drop pins into the straw till it floats vertically. Use a ballpoint pen or a thin strip of coloured tape to mark the level up to which the straw sinks in water. You now have a hydrometer. Place it in different liquids, such as a concentrated solution of common salt, and kerosene. In liquids that are denser than water (salt solution, for example), the hydrometer will rise higher (the mark on the hydrometer will be above the liquid surface). And in liquids such as kerosene, which are less dense than water, the hydrometer will sink lower (the mark will be below the liquid surface). Mark your hydrometer as it floats in milk. What happens when you put it in milk mixed with water?



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