2 Physical Quantities and Measurement

Theme : Previous learning demonstrated the measurement of the density of regular solids. In this class children will develop the ability to measure the density of an irregular solid and also of a given liquid. They will also understand that due to the difference in the value of densities of a solid and liquid, a piece of solid can float or sink in a liquid.

In this chapter you will learn to

- measure density of an irregular solid
- measure density of a liquid
- discuss the concept of floatation based on relative densities of solid and liquid
- express result of measurement in proper unit with proper symbol
- solve simple numerical problems based on formula of density
- compare densities of matter in three states, solid, liquid and gas
- make careful observations including measurements
- gather data using formal units
- make conclusions from collected data
- make predictions using scientific knowledge and effectively communicating the same.

LEARNING OBJECTIVES

- Revising previous concepts learnt by children.
- Building on children's previous learning.
- Demonstrating the process of measurement of density of an irregular solid.
- Demonstrating the process of measurement of density of a liquid.
- Engaging children in practical tasks involving measurement of density of an irregular solid and a liquid.
- Engaging children (in group/pairs/individually) in an investigation to find out which object floats in which liquid, given solids of different densities and liquids of different densities. This is to be followed by discussion.
- Guiding children to predict the result of the previous investigation and compare predictions with the outcomes.

KNOWING CONCEPTS

- Measurement of density of irregular solids using:
  - Eureka can
  - Measuring cylinder
- Measurement of density of fluids:
  - Basic concept
  - Concept of floatation and sinking of a substance (relate to density)
- Comparison of densities in the three states of matter.

DENSITY

Each body has a certain mass and a definite volume. The volume occupied by a body increases, if its mass is increased. Similarly, the mass of a body increases on increasing its volume. Further, it is found that

1. Equal masses of different substances have different volumes. *For example*, the volume of cotton is much larger than the volume of an equal mass of lead. This is because the particles of lead are closely packed while those of cotton are very loosely packed. In other words, lead is denser than cotton.
2. Equal volumes of different substances have different masses. *For example*, the mass of iron is much more than the mass of an equal volume of wood. This is because the particles of iron are more closely packed than those of the wood. In other words, iron is denser than wood.

Thus, to explain that equal volumes of different substances have different masses or equal masses of different substances have different volumes, we use a term called density. It is defined as follows :

The density of a substance is its mass per unit volume *i.e.*

Density of a substance

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

The density of a substance is represented by the symbol d. If mass of a substance is M and its volume is V, its density will be

$$\boxed{d = \frac{M}{V}}$$

UNIT OF DENSITY

$$\text{Unit of density} = \frac{\text{Unit of mass}}{\text{Unit of volume}}$$

In the S.I. system, unit of mass is kg and unit of volume is m^3, so S.I. unit of density is kg m^{-3} (kilogram per cubic metre). In the C.G.S. system unit of mass is g and unit of volume is cm^3, so CGS unit of density is g cm^{-3} (gram per cubic centimetre).

Relationship between S.I. and C.G.S. units :

$$1 \text{ kg m}^{-3} = \frac{1\text{ kg}}{1\text{ m}^3} = \frac{1000\text{ g}}{(100\text{ cm})^3}$$

$$= \frac{1}{1000} \text{ g cm}^{-3}$$

Thus,

$$1 \text{ kg m}^{-3} = 10^{-3} \text{ g cm}^{-3}$$

$$\text{or} \quad 1 \text{ g cm}^{-3} = 1000 \text{ kg m}^{-3}$$

Examples : 1. The mass of an iron cube of volume 10 cm^3 is equal to 78 g.

$$\text{Therefore, density of iron} = \frac{78\text{ g}}{10\text{ cm}^3}$$
$$= 7{\cdot}8 \text{ g cm}^{-3}.$$

2. The mass of 1 cm^3 of water is 1 g, hence, density of water $= \frac{1\text{ g}}{1\text{ cm}^3} = 1 \text{ g cm}^{-3}$.

3. A piece of copper of mass 8·9 kg has volume 0·001 m^3. The density of copper $= \frac{8{\cdot}9\text{ kg}}{0{\cdot}001\text{ m}^3} = 8900 \text{ kg m}^{-3}$.

Do You Know ?

1. The density of a substance does not change with any change in its shape or size.

2. Almost all substances expand on heating and contract on cooling, but their mass does not change. So, the density of a substance decreases with the increase in temperature and increases with the decrease in temperature. Exception is water which contracts on heating from 0°C to 4°C and expands on heating above 4°C. So the density of water increases from 0°C to 4°C and then decreases above 4°C (*i.e.* the density of water is maximum at 4°C which is equal to 1000 kg m^{-3}).

DETERMINATION OF DENSITY OF A REGULAR SOLID

1. First measure the mass M of the given regular solid by using a beam balance.
2. Now, to find the volume V of the given regular solid, use the following formula :

   Volume of a cube = $(\text{one side})^3$

   Volume of a cuboid

   $$= \text{length} \times \text{breadth} \times \text{height}$$

   Volume of a sphere = $\frac{4}{3}\pi\,(\text{radius})^3$

   Volume of a cylinder = $\pi\,(\text{radius})^2 \times \text{height}$

   (where $\pi = 3{\cdot}14$)

   The side of a cube or length, breadth and height of a cuboid or radius of a sphere or radius and height of a cylinder can be measured with the use of a metre ruler.
3. Knowing mass M and volume V, calculate density d of the substance of the given regular body by using the formula

   $$d = \frac{M}{V}$$

   For example, if mass of a cube of iron is

   $$M = 210 \text{ g}$$

   One side of cube = 3 cm

   $\therefore$ Volume of cube V = $(\text{one side})^3$

   $$= (3)^3 = 27 \text{ cm}^3$$

   $$\text{Density of iron } d = \frac{M}{V} = \frac{210\text{g}}{27\text{cm}^3}$$

   $$= 7{\cdot}78 \text{ g cm}^{-3}$$

VESSELS FOR MEASURING VOLUME

In class VII, you have read that we use different vessels for measuring the volume of liquids. Some of the vessels are given below.

(i) **Measuring cylinder :** It is made up of glass or plastic and is graduated in millilitre (mL) with its zero mark at the bottom. The graduations then increase upwards as shown in Fig. 2.1. We have measuring cylinders available of different capacities, such as 50 mL, 100 mL, 200 mL, 500 mL etc. The capacity of a measuring cylinder is marked on it.

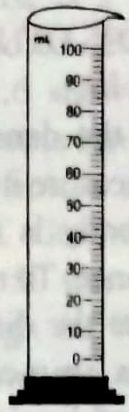

Fig. 2.1 Measuring cylinder

(ii) **Measuring beaker :** A measuring beaker is made up of glass, plastic or metal like aluminium. It is used to take out a fixed volume of liquids (say milk, oil, etc.) such as 50 mL, 100 mL, 200 mL, 500 mL, 1 litre from a large container. The capacity of a measuring beaker is marked on it.

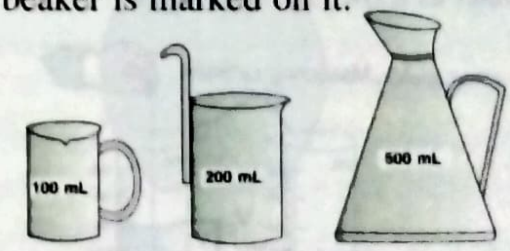

Fig. 2.2 Measuring beakers

(iii) **Eureka can :** A Eureka can is a glass (or polythene or metal) beaker with a side opening near its mouth which is known as spout. Thus, the beaker can contain a volume of liquid up to the spout. Any excess of liquid overflows through the spout. It is shown in Fig. 2.3.

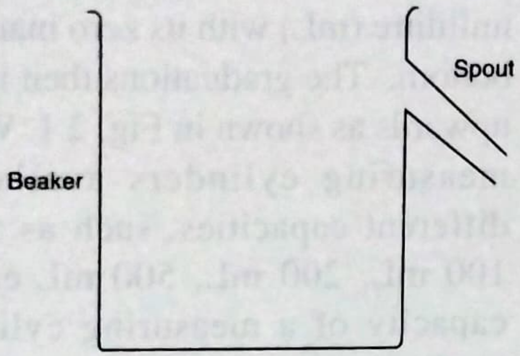

Fig. 2.3 Eureka can

DETERMINATION OF DENSITY OF AN IRREGULAR SOLID

To determine the density of an irregular solid, we have to measure its mass and volume. The mass of the body is measured with the help of a beam balance. To measure the volume of the solid, we use the displacement method *i.e.* a solid when immersed in a liquid, displaces volume of liquid equal to its own volume. The measurement of volume of an irregular body by displacement method can be understood by the following activities.

ACTIVITY 1

1. Measure the mass of the given solid using a common beam balance. Note the mass. Let it be M gram.
2. Take a measuring cylinder. Fill it partly with water as shown in Fig. 2.4 (a)

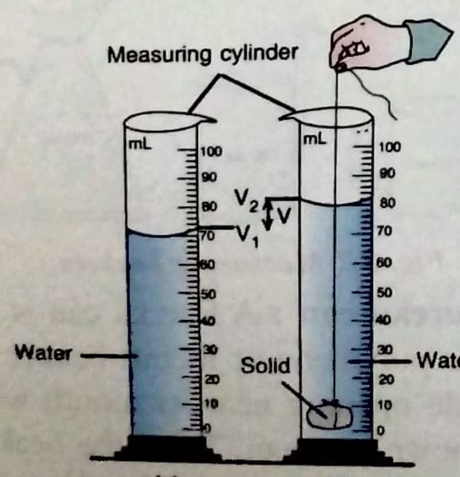

Fig. 2.4 Measurement of volume of a solid using a measuring cylinder

3. Note the level of water. Let it be V_1 mL.
4. Now, tie the given solid with a thread and gently lower the solid in water contained in the measuring cylinder as shown in Fig. 2.4 (b). Take care that no water splashes out. Note the level of water again. Let it be V_2 mL.
5. Find the difference, $V_2 - V_1$. It gives the volume V of the solid *i.e.*

$$V = (V_2 - V_1)\ \text{cm}^3$$

6. Then, calculate the density of the solid by using the following formula:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{M}{V}\ \text{g cm}^{-3}$$

If $M = 78$ g, $V = 10\ \text{cm}^3$, then

$$\text{Density} = \frac{78\ \text{g}}{10\ \text{cm}^3} = 7{\cdot}8\ \text{g cm}^{-3}.$$

Note : $1\ \text{mL} = 1\ \text{cm}^3$.

ACTIVITY 2

1. Take an Eureka can. Place the Eureka can on the table with a measuring cylinder under its spout as shown in Fig. 2.5 (a). Pour water into the can until it starts overflowing through the spout. When the water has stopped dripping, remove the measuring cylinder. Empty it, dry it and again place it under the spout.
2. Now tie the given irregular solid by a thread. Immerse the solid gently into the water contained

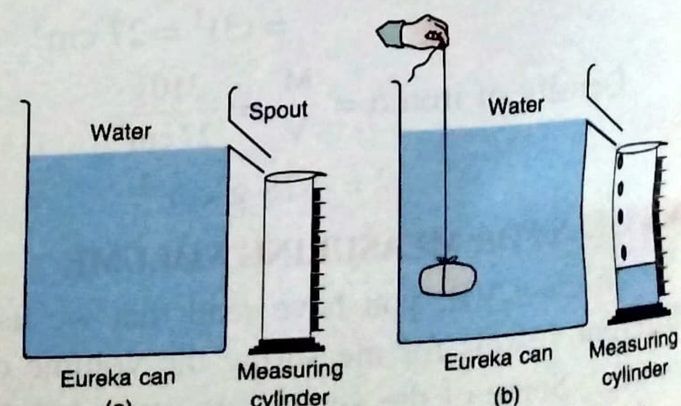

Fig. 2.5 Measurement of volume of a solid using Eureka can

in the beaker can as shown in Fig. 2.5(b). The solid displaces water equal to its own volume which overflows through the spout and gets collected in the measuring cylinder. When water stops dripping out through the spout, note the volume of water collected in the measuring cylinder.

4. Dry the solid. Measure the mass M of the given solid with a beam balance.
Let mass of solid M = 110 g
Volume of solid V = volume of water collected in the measuring cylinder = 40 cm^3

$$\text{Density } d = \frac{\text{Mass M}}{\text{Volume V}}$$

$$= \frac{110\text{ g}}{40\text{ cm}^3} = 2.75\text{ g cm}^{-3}$$

DETERMINATION OF DENSITY OF A LIQUID

To determine the density of a liquid (say milk, oil, etc.), its mass M is measured by a common beam balance and its volume V is measured by a measuring cylinder. Then density is calculated by using the relation $d = \frac{M}{V}$.

ACTIVITY 3

To determine the density of milk.

1. Take a beaker. Measure the mass of the empty beaker using a common beam balance. Let the mass be M_1 gram.
2. Now take a measuring cylinder and pour milk into it to a certain level say 50 ml. Thus, volume of milk V = 50 ml or 50 cm^3.
3. Transfer the milk into the empty beaker. Measure its mass again. Let the mass of beaker with milk be M_2 gram.
4. Find the difference $M_2 - M_1$ which gives the mass M of the milk. Thus, mass of the milk $M = (M_2 - M_1)$ gram. Let M = 51.5 gram.
5. Calculate the density of milk using the following formula :

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{M}{V}$$

$$= \frac{51.5\text{ g}}{50\text{ cm}^3} = 1.03\text{ g cm}^{-3}$$

DENSITY BOTTLE

A density bottle is a specially designed bottle which is used to determine the density of a liquid. Fig. 2.6 shows a density bottle. It is a small glass bottle having a glass stopper at its neck. The bottle can store a fixed volume of a liquid. Generally the volume of bottle is 25 mL or 50 mL. The stopper has a narrow hole through it. When the bottle is filled with the liquid and stopper is inserted, the excess liquid rises through the hole and drains out. Thus, the bottle always contains the same volume of liquid each time when it is filled.

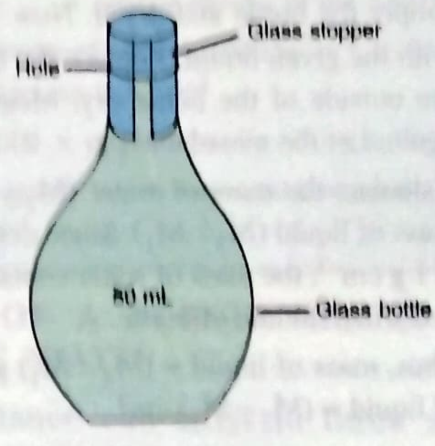

Fig. 2.6 Density bottle

Note : 1. Since the density of water is 1 g cm^{-3}, so the mass (in g) of water needed to fill the bottle completely, will give the volume (in mL) of bottle.

2. Nowadays, it is not named as specific gravity bottle.

DETERMINATION OF DENSITY OF A LIQUID USING THE DENSITY BOTTLE

To determine the density of a liquid using the density bottle, we have to measure the mass of liquid and mass of water taken in it by using the common balance, the mass of water in the density bottle gives the volume of liquid.

This can be understood by the following activity.

ACTIVITY 4

To determine the density of a liquid using a density bottle.

1. First wash the bottle and dry it. Then measure the mass of empty bottle using a beam balance. Let the mass be M_1 g.
2. Remove the stopper of the bottle and fill it with water. Replace the stopper. Wipe the outside of the bottle dry. Measure its mass again. Let the mass be M_2 g.
3. Empty the bottle and dry it. Now fill the bottle with the given liquid. Replace the stopper. Wipe the outside of the bottle dry. Measure its mass again. Let the mass be M_3 g.
4. Calculate the mass of water $(M_2 - M_1)$ and the mass of liquid $(M_3 - M_1)$. Since density of water is 1 g cm^{-3}, the mass of water contained in bottle gives the volume of bottle.

Thus, mass of liquid = $(M_3 - M_1)$ g and volume of liquid = $(M_2 - M_1)$ cm^3

$$\therefore \text{ Density of liquid} = \frac{\text{Mass of liquid}}{\text{Volume of liquid}}$$

$$= \frac{(M_3 - M_1)\,\text{g}}{(M_2 - M_1)\,\text{cm}^3}$$

For example,

Mass of empty bottle $M_1 = 30$ g

Mass of bottle filled with water $M_2 = 60$ g

Mass of bottle filled with liquid $M_3 = 54$ g

The mass of liquid $M = 54\text{ g} - 30\text{ g} = 24\text{ g}$

Volume of liquid $V = 60 - 30 = 30\text{ cm}^3$

$$\text{Density of liquid} = \frac{M}{V} = \frac{24\text{ g}}{30\text{ cm}^3}$$

$$= 0{\cdot}8\text{ g cm}^{-3}$$

RELATIVE DENSITY

The relative density of a substance is defined as the ratio of the density of the substance to the density of water. The symbol used for relative density is R.D. Thus,

Relative density of a substance

$$\text{R.D.} = \frac{\text{Density of the substance}}{\text{Density of water}}$$

For example, density of iron is 7·8 g cm^{-3} and density of water is 1 g cm^{-3}. Hence,

Relative density of iron

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

$$= \frac{7{\cdot}8\text{ g cm}^{-3}}{1\text{ g cm}^{-3}} = 7{\cdot}8$$

But density of a substance is the mass of 1 cm^3 of that substance, therefore we can also express the relative density of a substance as follows :

Relative density of a substance

$$= \frac{\text{Mass of 1 cm}^3\text{ of the substance}}{\text{Mass of 1 cm}^3\text{ of water}}$$

$$= \frac{\text{Mass of V cm}^3\text{ of the substance}}{\text{Mass of V cm}^3\text{ of water}}$$

$$= \frac{\text{Mass of any volume of the substance}}{\text{Mass of the same volume of water}}$$

Thus, *relative density of a substance can also be defined as the ratio of the mass of any volume of the substance to the mass of an equal volume of water.*

For example, if we say that the relative density of iron is 7·8, we mean that a piece of iron of any volume has mass 7·8 times that of an equal volume of water.

UNIT OF RELATIVE DENSITY

Relative density is just a number. It has no unit. It is a dimensionless quantity. It is a ratio of same quantities.

MEASUREMENT OF RELATIVE DENSITY OF A LIQUID

The relative density of a liquid is measured by using a density bottle. This can be understood by the following activity.

ACTIVITY 5

To determine the relative density of a liquid using a density bottle.

1. Take an empty dry density bottle. Find its mass M_1 g by using a beam balance.
2. Now fill the bottle completely with water and insert the stopper. The extra water overflows through the hole in the stopper. Dry the outer surface with a blotting paper and then measure the mass of bottle again on a beam balance. Suppose, the mass is M_2 g.
3. Now empty the bottle and dry it. Fill the bottle again completely with the given liquid, and insert the stopper. Again, the extra liquid, if any, will overflow through the hole in the stopper. Dry and measure the mass of bottle again. Suppose the mass now is M_3 g. Thus

Mass of empty bottle = M_1 g

Mass of bottle + water = M_2 g

Mass of bottle + liquid = M_3 g

Mass of water = $(M_2 - M_1)$ g

Mass of liquid = $(M_3 - M_1)$ g

Relative density of liquid

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

$$= \frac{(M_3 - M_1)\,g}{(M_2 - M_1)\,g} = \frac{M_3 - M_1}{M_2 - M_1}$$

For example, if $M_1 = 25$ g

$M_2 = 55$ g

$M_3 = 49$ g

Then R.D. of liquid $= \dfrac{(49 - 25)\,g}{(55 - 25)\,g}$

$$= \frac{24}{30} = 0{\cdot}8$$

Do You Know ?

1. Density bottle measures the relative density of a liquid.
2. Since density of water is 1 g cm^{-3}, so density of a substance in g cm^{-3}
   = relative density of the substance.
3. Since density of water is 1000 kg m^{-3}, so density of a substance in kg m^{-3}
   = 1000 × relative density of that substance.
4. Specific gravity usually means relative density with respect to water.

DENSITY OF A SUBSTANCE IN ITS DIFFERENT STATES

A substance can exist in three states (i) solid, (ii) liquid and (iii) gas. *For example*, ice, water and steam are the three states of the same substance, water. According to the molecular model, we have read that the molecules of a solid are closely packed, molecules of a liquid are loosely packed while those of a gas are very loosely packed. Therefore, a substance is highly dense in solid state, less

Density and Relative density of some common substances

Substance	Density		Relative density
	in g cm^{-3}	in kg m^{-3}	
Solid			
Cork	0·25	250	0·25
Wood	0·7	700	0·7
Ice	0·92	920	0·92
Glass	1·97	1970	1·97
Aluminium	2·7	2700	2·7
Iron	7·8	7800	7·8
Brass	8·4	8400	8·4
Silver	10·3	10300	10·3
Lead	11·5	11500	11·5
Liquid			
Turpentine oil	0·87	870	0·87
Alcohol	0·8	800	0·8
Water	1·0	1000	1·0
Milk	1·03	1030	1·03
Glycerine	1·26	1260	1·26
Mercury	13·6	13600	13·6

dense in liquid state and still less dense in gaseous state. Thus, the density of a substance in solid state is more than that in liquid state and density of a substance in liquid state is more than that in gaseous state.

Exception : The density of ice is less than water. The density of ice is 0·917 g cm^{-3}, that of water is 1·00 g cm^{-3} and that of steam is 0·00057 g cm^{-3}.

The table above gives the density and relative density of some common substances.

FLOATING AND SINKING

If we place a piece of cork and an iron nail on the surface of water, we notice that the cork floats while the nail sinks. This is because the density of cork is less than the density of water, while the density of iron (of which the nail is made up of) is more than the density of water. Thus, a body floats on a liquid if its density is less than the density of the liquid while a body sinks in a liquid if its density is more than the density of the liquid.

Some examples :

1. A solid iron ball with a density of 7·86 g cm^{-3} will sink in water which has a density of 1·0 g cm^{-3}. The same iron ball will float in mercury which has a density of 13·6 g cm^{-3}.
2. A small cork will float on water because the density of cork is less than the

density of water, whereas an iron nail will sink in water because the density of iron nail is more than the density of water.

PRINCIPLE OF FLOATATION

When a body is completely or partially immersed in a liquid, the following two forces act on it :

(1) The weight of the body W acting vertically downwards. This force has a tendency to sink the body.

(2) The buoyant force of the liquid F_B acting vertically upwards. The buoyant force is equal to the weight of the liquid displaced by the immersed part of the body. This force has a tendency to move the body up. This is why buoyant force is also called upthrust.

Now there can be the following three possibilities :

Case 1 : The weight of the body W is greater than the buoyant force F_B. In this case, the resultant force on the body is ($W - F_B$) which acts downwards. The body will sink in the liquid to the bottom under the influence of the resultant force ($W - F_B$). This is shown in Fig. 2.7. This happens when the density of the solid is greater than the density of the liquid.

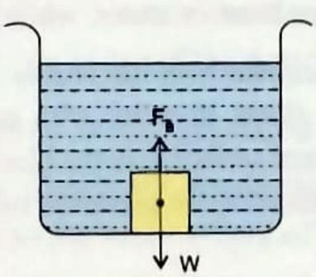

Fig. 2.7 When density of body is greater than the density of liquid, the body sinks

Case 2 : The weight of the body W is equal to the buoyant force F_B. In this case, the resultant force on the body is zero, *i.e.* the apparent weight of the body is zero. The body will float just inside the surface of liquid. This is shown in Fig. 2.8. This happens when the density of the solid is equal to the density of the liquid.

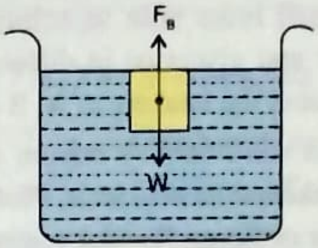

Fig. 2.8 When density of body is equal to the density of liquid, the body floats just inside the liquid surface

Case 3 : The weight of the body W is less than the buoyant force. In this case, the resultant force acts on the body upwards. The body will float partially above the surface of liquid. *Only that much portion of the body will immerse inside the liquid by which the weight of the liquid displaced F_B balances the total weight of the body.* This is shown in Fig. 2.9. This happens when the density of the solid is less than the density of the liquid. Now while floating, $F_B = W$, so apparent weight is zero.

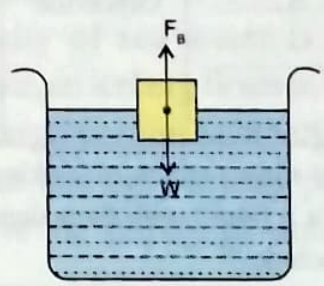

Fig. 2.9 The body floats partly submerged when density of body is less than the density of liquid

Thus, *a body of density greater than the density of liquid, sinks inside the liquid, while a body of density equal or less than the density of liquid, floats on the liquid.*

The dependence of a solid/liquid on its density to float/sink in a liquid can be understood by the following activity.

ACTIVITY 6

1. Take a cork, a piece of wood, an ice cube, an iron nail, a small brass coin as solids. Take water, turpentine and glycerine in different beakers as liquids. Label the beakers as A, B and C.
2. Place each solid one by one on the surface of liquid contained in beaker A. Note whether the solid sinks or floats. Record your observations.
3. Repeat step 2 with the liquid of beaker B and C respectively.

Beaker	Cork	Wood	Ice	Iron	Coin
Water	....	....	......	....	....
Turpentine	....	....	......	....	....
Glycerine	....	....	......	....	....

From the table of density of some substances, record the density of solids and liquids used above.

Density of solid		Density of liquid	
Cork	....	Water	....
Wood	....	Turpentine	....
Ice	....	Glycerine	....
Iron	....		
Brass	....		

Relate your observations of sinking or floating of a solid in a liquid with their densities. What do you conclude ?

Conclusion : ....

LAW OF FLOATATION

When a body floats in a liquid, the weight of the liquid displaced by its immersed part is equal to the total weight of the body. This is the law of floatation, *i.e.* while floating,

Weight of the floating body = Weight of the liquid displaced by its immersed part (*i.e.*, buoyant force).

In other words, according to the law of floatation, the apparent weight of a floating body is zero. A body floats with its major portion outside the surface of a liquid of higher density than that of a liquid of low density. This can be demonstrated by the following activity.

ACTIVITY 7

1. Take two identical small blocks of wood. Label them as A and B. Take water in a beaker labelled as P and glycerine in another beaker labelled as Q.
2. Place the wooden block A on the surface of water in beaker P and the wooden block B on the surface of glycerine in beaker Q (Fig. 2.10).

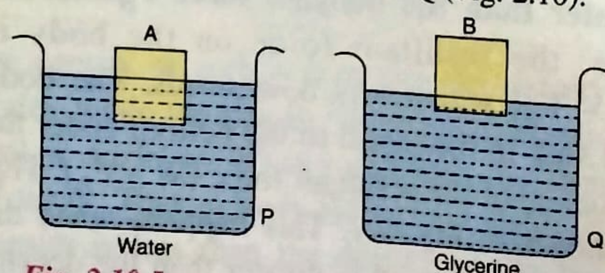

Fig. 2.10 Less portion of wood submerged in glycerine than in water, while floating

You will notice that both the blocks A and B float. The block A floats in water with its less portion outside the water surface than the block B which has its major portion outside glycerine surfac

Conclusion :

1. The density of wood is less than the d water as well as the density of glycerine.
2. The density of glycerine is more than the densit of water.

SOME APPLICATIONS OF FLOATATION

(i) **Floatation of an iron ship :** A nail made of iron sinks in water, but a ship made of iron does not. The reason is that a nail is solid and the density of iron is greater than that of water. The weight of the nail is more than the buoyant force of water on it. So the nail sinks in water. On the other hand, the ship is hollow and its empty space contains air. This makes the average density of ship less than that of water. Therefore, a ship floats on water.

(ii) **Floatation of man :** It is easier for a person to swim in sea water than in river water. The reason is that sea water contains salt and so its density is more than the density of river water. The weight of a man gets balanced by the less immersed part of his body in sea water as compared to that in river water. Thus, it is easier to swim in sea water than in river water.

(iii) **Floatation of ice on water :** A piece of ice floats on water with its $\frac{9}{10}$th part inside the water and only $\frac{1}{10}$th part of it outside the water. The reason is that the density of ice is 0·9 g cm^{-3} (or 900 kg m^{-3}) while the density of water is 1 g cm^{-3} (or 1000 kg m^{-3}). Hence, the weight of water displaced by $\frac{9}{10}$th part of ice immersed inside water becomes equal to the total weight of the ice piece.

(iv) **Submarine :** A submarine can be made to dive or to rise to the surface of water as and when desired. The reason is that a submarine is a water-tight boat which can travel under water like a ship

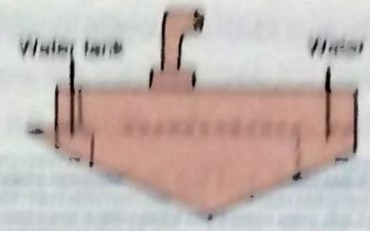

Fig. 2.11 A submarine

(Fig. 2.11). A submarine is provided with water tanks. To make the submarine dive, the tanks are filled with water so that the average density of the submarine becomes greater than the density of sea water and it sinks. To make the submarine rise to the surface of water, these tanks are emptied. This makes the average density of the submarine less than the density of sea water, so the submarine rises up to the surface of water.

(v) **Icebergs :** Very huge and large pieces of ice floating on sea water, are called icebergs. They are dangerous for ships. The reason is that the density of ice is less than the density of sea water. The density of ice is 0·9 g cm^{-3} and the density of sea water is 1·02 g cm^{-3}. Hence, an iceberg floats in sea water with its large portion submerged inside the water and only a little portion of it is above the surface of water (Fig. 2.12).

Fig. 2.12 An iceberg floating on sea water

Thus, a ship can collide with the invisible part of iceberg under the surface of water. Hence, it is dangerous for ships.

(vi) **Whales** : The whales can sink or rise at their will. Whales are sea animals. They have a special organ in their body which is called swim bladder. In order to come to the surface of water, they fill the bladder with air. This decreases the average density of the whale and so it rises to the surface. To dive into the sea, they empty the bladder. This increases the average density of the whale and it goes down.

(vii) **Balloons** : A hydrogen or helium filled balloon rises in air. The reason is that the density of these gases is less than the density of air. Therefore, the buoyant force experienced by the balloon due to air, becomes greater than the weight of the balloon. Hence, the balloon rises up under the influence of the net upward force.

SOLVED EXAMPLES

1. A block of glass is 30 cm long, 25 cm wide and has a thickness of 2 cm. Find its density if its mass is 7·5 kg.

Solution : Volume of glass block

= length × breadth × thickness

= 30 cm × 25 cm × 2 cm

= 1500 cm^3

Mass of block = 7·5 kg = 7500 g

$$\text{Density } d = \frac{M}{V} = \frac{7500 \text{ g}}{1500 \text{ cm}^3} = 5 \text{ g cm}^{-3}$$

2. A piece of iron of volume 30 cm^3 has mass of 234 g. Find the density of iron.

Solution : *Given*, mass M = 234 g

Volume V = 30 cm^3

$$\text{Density } d = \frac{M}{V} = \frac{234 \text{ g}}{30 \text{ cm}^3} = 7{\cdot}8 \text{ g cm}^{-3}$$

3. The mass of 10 cm^3 of silver is 103 g. Find : (a) the density of silver in kg m^{-3} (b) relative density of silver. State the assumption made in part (b).

Solution : *Given*, mass M = 103 g and volume V = 10 cm^3

(a) $$\text{Density } d = \frac{M}{V} = \frac{103 \text{ g}}{10 \text{ cm}^3} = 10{\cdot}3 \text{ g cm}^{-3}$$

$= 10{\cdot}3 \times 1000 \text{ kg m}^{-3}$

$= 10300 \text{ kg m}^{-3}$.

(b) Relative density of silver

$$= \frac{\text{Density of silver}}{\text{Density of water}} = \frac{10300 \text{ kg m}^{-3}}{1000 \text{ kg m}^{-3}} = 10{\cdot}3$$

Assumption : The density of water is 1000 kg m^{-3}.

4. A piece of iron when immersed in water taken in a Eureka can displaces 25 ml of water. Its mass is 195 g. Find the density of iron in kg m^{-3}.

Solution : *Given*, Mass of iron piece M = 195 g

= 0·195 kg

Volume of iron piece, V

= volume of water displaced

= 25 cm^3 = 25 × 10^{-6} m^3

Density of iron $d = \frac{M}{V}$

$= \frac{0.195 \text{ kg}}{25 \times 10^{-6} \text{ m}^3}$

$= 7800 \text{ kg m}^{-3}$.

5. A block of silver displaces 200 mL of water in a measuring cylinder. If the density of silver is 10300 kg m^{-3}, find the mass of block.

Solution : *Given*, density of silver $d = 10300 \text{ kg m}^{-3}$

Volume of block V

= volume of water displaced

or $V = 200 \text{ cm}^3 = 200 \times 10^{-6} \text{ m}^3$

Since $d = \frac{M}{V}$

$\therefore$ Mass of block $M = V \times d$

$= (200 \times 10^{-6} \text{ m}^3) \times (10300 \text{ kg m}^{-3})$

$= 2.06$ kg.

6. The mass of a copper piece is 44 g. A measuring cylinder contains water to a level of 12 mL. The water level rises to 17 mL mark when the copper piece is dipped in the measuring cylinder. Find : (i) the volume of copper piece, and (ii) the density of copper.

Solution : *Given* : Initial level of water $V_1 = 12$ mL. Final level of water $V_2 = 17$ mL

Mass M = 44 g

Volume of copper piece $V = V_2 - V_1$

$= 17 - 12 = 5$ mL (or 5 cm^3)

Density of copper $d = \frac{M}{V} = \frac{44 \text{ g}}{5 \text{ cm}^3}$

$= 8.8 \text{ g cm}^{-3}$

7. The mass of density bottle is 51·50 g when empty, 76·50 g when full of water and 71·85 g when full of an oil. Find : (a) capacity of density bottle, and (b) density of oil.

Solution : *Given*, Mass of empty density bottle $M_1 = 51.50$ g

Mass of bottle with water $M_2 = 76.50$ g and mass of bottle with oil $M_3 = 71.85$ g

(a) Mass of water in bottle $= M_2 - M_1$

$= 76.50 - 51.50 = 25.00$ g

Since density of water is 1 g cm^{-3}, therefore, capacity of density bottle V = 25·00 mL.

(b) Mass of oil in bottle $M = M_3 - M_1$

$= 71.85 - 51.50 = 20.35$ g

Density of oil d

$= \frac{\text{Mass of oil M}}{\text{Volume of oil V}} = \frac{20.35 \text{ g}}{25 \text{ cm}^3} = 0.814 \text{ g cm}^{-3}$

8. The mass of a density bottle is 35 g when empty, 65 g when filled with water, and 59 g when filled with alcohol. Find the relative density of alcohol.

Solution : *Given*, Mass of empty density bottle $M_1 = 35$ g

Mass of bottle + water $M_2 = 65$ g

Mass of bottle + alcohol $M_3 = 59$ g

Relative density of alcohol

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

$= \frac{M_3 - M_1}{M_2 - M_1} = \frac{59 - 35}{65 - 35} = \frac{24}{30} = 0.8$

9. The table below gives the density of some solids and liquids. For each solid, list the name of liquids in which that solid will (a) float, (b) sink.

Solid	Density in kg m^{-3}	Liquid	Density in kg m^{-3}
1. Iron	7800	Mercury	13600
2. Wood	700	Water	1000
3. Cork	250	Glycerine	1260

(i) Iron — (a) floats on mercury
(b) sinks in water and glycerine.

(ii) Wood — (a) floats on mercury, wa and glycerine
(b) sinks in none.

(iii) Cork — (a) floats on mercury, wa and glycerine
(b) sinks in none.

RECAPITULATION

- Equal masses of different substances have different volumes.
- Equal volumes of different substances have different masses.
- The density of a substance is defined as the mass of a unit volume of that substance.
- If a body has mass M and volume V, its density d is given as $d = \frac{M}{V}$.
- Density = $\frac{\text{Mass}}{\text{Volume}}$, Mass = Volume × Density, Volume = $\frac{\text{Mass}}{\text{Density}}$.
- The S.I. unit of density is kg m^{-3} and the C.G.S. unit is g cm^{-3}.
- 1 g cm^{-3} = 1000 kg m^{-3}.
- The density of a substance is not changed by the change in its size or shape.
- The density of a substance decreases with increase in its temperature if the substance expands on heating. This decrease is more in gases, less in liquids and still less in solids for the same rise in temperature. However, the density of water increases when heated from 0°C to 4°C and then decreases when heated above 4°C.
- The density of a substance is more in its solid state, less in liquid state and still less in its gaseous state. Exception is ice whose density is less than the density of water.
- A density bottle is a specially designed bottle to store a fixed volume of liquid. It is used to find the density and relative density of a liquid.
- The relative density of a substance is defined as the ratio of the density of the substance to the density of water. Thus,

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

- The relative density of a substance is the ratio of the mass of any volume of the substance to the mass of an equal volume of water.
- The relative density is just a number. It has no unit as it is a ratio of same quantities.
- When a body is partially or completely immersed in a liquid, it experiences an upward force due to the liquid which is called buoyant force or upthrust.
- The buoyant force is equal to the weight of the liquid displaced by the body.
- When a body is immersed in a liquid, the buoyant force on it depends on : (i) the volume of the body immersed in the liquid (larger the volume of the body immersed in a liquid, greater is the buoyant force). (ii) the density of the liquid in which the body is immersed (more the density of liquid, greater is the buoyant force).

- If the density of body is more than the density of liquid, the body sinks.
- If the density of body is equal to or less than the density of liquid, the body floats.
- A body floats with only that much portion of it submerged inside the liquid by which the weight of the liquid displaced (or buoyant force) balances the total weight of the body.
- According to the law of floatation, the weight of a floating body is equal to the weight of the liquid displaced by its submerged part (*i.e.*, buoyant force on it).
- The apparent weight of a floating body is zero.
- More the density of liquid, more is the portion of the floating body outside the surface of liquid.
- If a body floats in different liquids, its different volumes get submerged in different liquids, but in each liquid the weight of liquid displaced by the submerged part of body (*i.e.*, buoyant force) remains same (equal to the weight on the body).

TEST YOURSELF

A. OBJECTIVE TYPE QUESTIONS

1. Choose the correct answer from the multiple choices given below.

(a) The correct relation is :

(i) Density = Mass × Volume
(ii) Mass = Density × Volume
(iii) Volume = Density × Mass
(iv) Density = Mass + Volume

(b) The relative density of alcohol is 0·8. Its density is :

(i) 0·8 (ii) 800 kg m^{-3}
(iii) 800 g cm^{-3} (iv) 0·8 kg m^{-3}

(c) A block of wood of density 0·8 g cm^{-3} has a volume of 60 cm^3. The mass of block is :

(i) 60·8 g (ii) 75 g
(iii) 48 g (iv) 0.013 g

(d) The density of aluminium is 2·7 g cm^{-3} and that of brass 8·4 g cm^{-3}. The correct statement is :

(i) Equal masses of aluminium and brass have equal volumes.
(ii) The mass of a certain volume of brass is more than the mass of equal volume of aluminium.
(iii) The volume of a certain mass of brass is more than the volume of equal mass of aluminium.
(iv) Equal volumes of aluminium and brass have equal masses.

(e) A density bottle has a marking 25 mL on it. It means that :

(i) the mass of density bottle is 25 g
(ii) the density bottle will store 25 mL of any liquid in it
(iii) the density bottle will store 25 mL of water, but more volume of liquid denser than water
(iv) the density bottle will store 25 mL of water, but more volume of a liquid lighter than water.

(f) The correct statement is :

(i) The buoyant force on a body is equal to the volume of the liquid displaced by it.
(ii) The buoyant force on a body is equal to the volume of the body.
(iii) The buoyant force on a body is equal to the weight of the liquid displaced by it.
(iv) The buoyant force on a body is always equal to the weight of the body.

(g) A piece of wood floats on water. The buoyant force on wood will be :

(i) zero

(ii) more than the weight of the wood piece

(iii) equal to the weight of the wood piece

(iv) less than the weight of the wood piece.

(h) The weight of a body is more than the buoyant force experienced by it, due to a liquid. The body will :

(i) sink

(ii) float with its some part outside the liquid

(iii) float just below the surface of liquid

(iv) float with whole of its volume above the surface of liquid.

(i) **Assertion (A)** : In order to come to surface of water, whales fill their swim bladder with water.

Reason (R) : A body floats when the density of the body is less than the density of the liquid.

(1) Both A and R are true and R is the correct explanation of A

(2) Both A and R are true and R is not the correct explanation of A

(3) Assertion is true but reason is false

(4) Assertion is false but reason is true

Ans: (a)–(ii), (b)–(ii), (c)–(iii), (d)–(ii), (e)–(ii), (f)–(iii), (g)–(iii), (h)–(i), (i)–(iv)

2. Fill in the blanks :

(a) 1 kg is the mass of .... mL of water at 4°C.

(b) Mass = density × ....

(c) The S.I. unit of density is ....

(d) Density of water is .... kg m^{-3}.

(e) 1 g cm^{-3} = ... kg m^{-3}.

(f) The density of a body which sinks in water is .... than 1000 kg m^{-3}.

(g) A body sinks in a liquid A, but floats in a liquid B. The density of liquid A is .... than the density of liquid B.

(h) A body X sinks in water, but a body Y floats on water. The density of the body X is .... than the density of body Y.

(i) The buoyant force experienced by a b when floating in salt-water is .... when floating in pure water.

(j) The apparent weight of a body floating liquid is ....

Ans: (a) 1000 (b) volume (c) kg m^{-3} (d) 10 (e) 1000 (f) more (g) less (h) m (i) equal to (j) z

3. Write **true** or **false** for each statement :

(a) Equal volumes of two different substanc have equal masses.

(b) The density of a piece of brass will chang by changing its size or shape.

(c) The density of a liquid decreases wit increase in its temperature.

(d) Relative density of water is 1·0.

(e) Relative density of a substance is expresse in g cm^{-3}.

(f) When a body is immersed in a liquid, th buoyant force experienced by the body is equa to the volume of the liquid displaced by it.

(g) If a body floats in different liquids, differe volumes of the body get submerged i different liquids, but in each liquid th weight of the liquid displaced by th submerged part of body remain the same.

(h) A body experiences the same buoyant forc when it floats or sinks in water.

(i) A body floats in a liquid when its weigh becomes equal to the weight of the liqui displaced by its submerged part.

(j) A body while floating, sinks deeper in a liqui of low density than in a liquid of high densit

Ans: True—(c), (d), (g), (i), (j

False—(a), (b), (e), (f), (h

4. Match the following :

Column A	Column B
(a) kg m^{-3}	(i) relative density
(b) No unit	(ii) sinks in alcohol
(c) Relative density	(iii) floats on water
(d) Iron	(iv) density
(e) Wood	(v) density bottle

Ans: (a)–(iv), (b)–(i), (c)–(v), (d)–(ii), (e)–(iii

B. SHORT ANSWER TYPE QUESTIONS

1. Define the term density of a substance.
2. Name the S.I. unit of density. How is it related to g cm^{-3} ?
3. The density of brass is 8·4 g cm^{-3}. What do you mean by this statement ?
4. Arrange the following substances in order of their increasing density :

   Iron, Cork, Brass, Water, Mercury.
5. How does the density of a liquid (or gas) vary with temperature ?
6. A given quantity of a liquid is heated. Which of the following quantity will vary and how ?

   (a) mass, (b) volume or (c) density.
7. Define the term relative density of a substance.
8. What is the unit of relative density ?
9. Explain the meaning of the statement 'Relative density of aluminium is 2·7'.
10. State the law of floatation.
11. For a floating body, how is its weight related to the buoyant force ?

C. LONG ANSWER TYPE QUESTIONS

1. Describe an experiment to determine the density of the material of a coin.
2. Describe an experiment to determine the density of a liquid.
3. What is a density bottle ? How is it used to find the density of a liquid ?
4. Distinguish between density and relative density.
5. How does the density of a body and that of a liquid determine whether the body will float or sink into that liquid ?
6. Explain why an iron needle sinks in water, but a ship made of iron floats on water.
7. It is easier to swim in sea water than in river water. Explain the reason.
8. Icebergs floating on sea water are dangerous for ships. Explain the reason.
9. Explain why it is easier to lift a stone under water than in air.
10. What is a submarine ? How can it be made to dive in water and come to the surface of water ?
11. A balloon filled with hydrogen rises in air. Explain the reason.

D. THINK AND ANSWER

1. A cork piece floats on water surface while an iron nail sinks in it. Explain the reason.
2. Which of the following will sink or float on water ? (Density of water = 1 g cm^{-3})

   (a) Body A having density 500 kg m^{-3}

   (b) Body B having density 2520 kg m^{-3}

   (c) Body C having density 1100 kg m^{-3}

   (d) Body D having density 0·85 g cm^{-3}.

   Ans: Sink–(b) and (c), Float–(a) and (d)
3. The density of water is 1·0 g cm^{-3}. The density of iron is 7·8 g cm^{-3}. The density of mercury is 13·6 g cm^{-3}. Answer the following :

   (a) Will a piece of iron float or sink in water ?

   (b) Will a piece of iron float or sink in mercury ?
4. The diagram given below shows a body floating in three different liquids A, B and C at different levels.

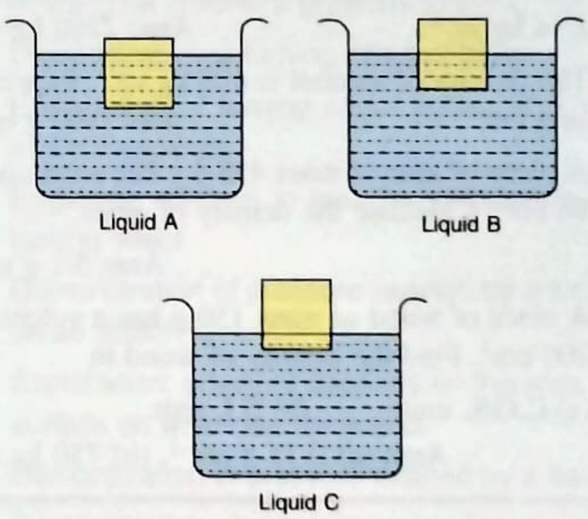

Fig. 2.13

   (a) In which liquid does the body experience the greatest buoyant force ?

   (b) Which liquid has the least density ?

   (c) Which liquid has the highest density ?

   Ans: (a) same in each, (b) A, (c) C