Physical Quantities & Measurements

Measurement of Density

Take an iron ball and a wooden ball of the same radius. Now can you say which one is heavy?

The answer is very simple—the iron ball. Why is it so despite the equal volumes of the balls?

This is because of the difference of the masses present in a unit volume of iron and wood. Both the balls have the same volume, but their masses are different. Therefore, we can say that the mass per unit volume of iron is more than that of wood. This is called **density**.

Hence we define **density** of a matter as the **mass per unit volume** present in it.

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

Density is the primary property of a matter. Every substance has different density. Densities of different substances vary on how closely the molecules are packed. In a substance having high density such as iron, the molecules are densely packed.

Units of Density

As density is defined as the mass per unit volume, the unit of density is also defined as

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

In **CGS System,** mass is measured in grams and volume in cubic centimetres. Therefore, the unit of density is CGS system is **g/cm^3** or **$g\ cm^{-3}$**.

In **SI System,** mass is measured in kilograms and volume in cubic metres. Therefore, the unit of density is SI system is **kg/m^3** or **$kg\ m^{-3}$**.

Relation Between S.I. and C.G.S units

$$1\ \text{kg m}^{-3} = 10^{-3}\ \text{g cm}^{-3}$$
$$\text{or, } 1\ \text{g cm}^{-3} = 1000\ \text{kg m}^{-3}$$

Measurement of Density

(i) Density of a Regular Solid

For measuring the density of a regular solid, we require the measurements of its mass and volume.

- Mass of the regular solid can be measured using a physical balance.

- For measuring the volume *V* of the given regular solid, we can use the formula given below
- Volume of cube, $V = (\text{side})^2$
- Volume of cuboid, V = length × breadth × height
- Volume of sphere, $V = 4/3\pi r^3$; where *r* is the radius of the spherical solid
- Volume of cylinder, $V = \pi r^2 h$; where *r* and *h* are the radius and height of cylindrical solid

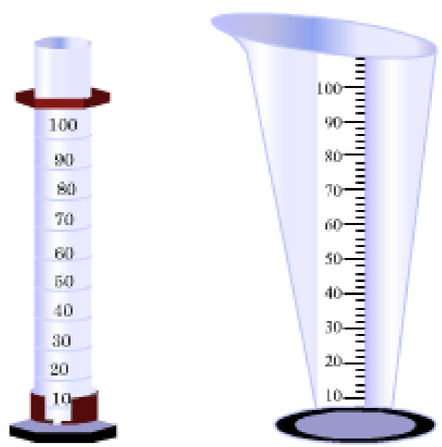
Dimensions of the regular solids can be measured using a metre rule.

(ii) Density of an Irregular Solid

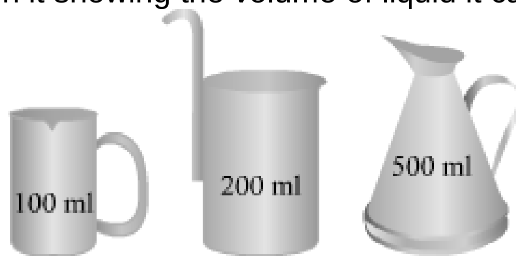
- Mass of the irregular solid can be measured in the similar way by a physical balance.

- To find the volume of the solid, the displacement method is used. In this method, when a solid is immersed in a liquid, it displaces volume of liquid equal to its own volume. Now for measuring the volume of a liquid, various types of vessels are used. Some of them are:

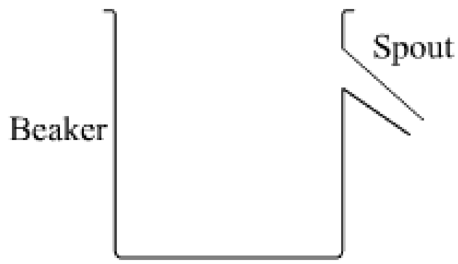
(a) Measuring cylinder: Glass or plastic is used for its making. It has graduations in millilitre (ml) with zero mark at the bottom. The graduations increase upwards as shown in the figure below.



(b) Measuring beaker: Glass, plastic or metal is used for its making. Also, the capacity of the beaker is marked on it showing the volume of liquid it can hold.



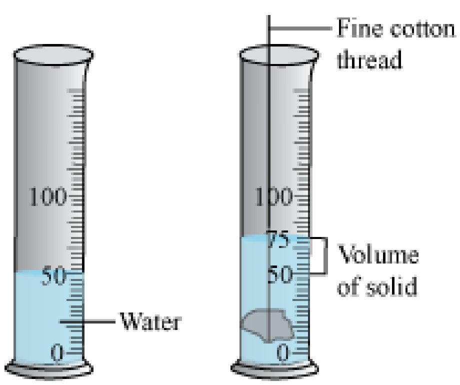
(c) Eureka can: Eureka can, made up of glass, plastic or metal, is used to hold a volume of liquid upto its spout.



Let us see how to find the volume an irregular solid using a measuring cylinder. Take a measuring cylinder and pour some water in it. Note the level of water. Let the level be V_1. Now, tie the solid to a thin thread and dip it into the water.

When the solid is completely submerged in the water, note the water level from the measuring cylinder. Let it now be say V_2. Then the difference $V_2 - V_1$ i.e. the rise in the water level will give you the volume of the solid. Thus, the volume of the solid is $V = (V_2 - V_1)$

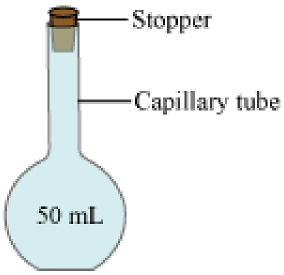
If mass of the solid measured using beam balance is *M,* then the density of the solid is $D = \frac{M}{V}$



- Now you can easily calculate the density of the solid by using the formula:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{\text{Mass of the solid}}{\text{Volume of the displaced water}}$$

Density of Liquid



For measuring the density of a liquid, a specially designed bottle is used. This bottle is called **density bottle**. It is a small glass bottle having capacity of 50 mL and a close-fitting round stopper at its neck. The stopper has a small capillary glass tube attached to it.

When the bottle is completely filled with some liquid and the stopper is inserted, the excess liquid rises up through the capillary tube. This ensures that the bottle is always filled with exactly 50 mL of liquid.

- First, the bottle is washed with distilled water and then dried with hot air. Then the stopper is inserted and the mass of the bottle is measured.
- The bottle is then completely filled with distilled water. After attaching the stopper, the bottle is wiped properly from the outside. Now, the mass of the bottle is measured.
- Distilled water is poured off the density bottle and then the bottle is again dried with hot air. The liquid (density of which has to be measured) is then filled into the bottle. After attaching the stopper, the mass of the density bottle is measured.

Calculations

Let the mass of the empty bottle be m_0 g.

Mass of the empty bottle + Water = m_1 g

Therefore, mass of water = $(m_1 - m_0)$ g

Now, density of water = 1 g cm^{-3}

Hence, the volume of 1 g of water is 1 cm^3.

Therefore, volume of ($m_1 - m_0$) g of water = ($m_1 - m_0$) cm^3

As the bottle is completely filled with water,

Volume of water = Volume of the bottle

Hence, volume of the bottle = ($m_1 - m_0$) cm^3

Let the mass of empty bottle + liquid be m_3 g.

Now,

Volume of water = Volume of the liquid = Volume of the bottle

As density = $\frac{\text{Mass}}{\text{Volume}}$,

Density of the liquid = $\left(\frac{m_3 - m_0}{m_1 - m_0}\right)$ g cm^{-3}

Variation of Density with Temperature

- **Solids:** All forms of matter expand on heating; but in solids, heating has very little effect on the volume of the solid. Solids do not expand significantly to bring any considerable change in their volumes. As a result, the density of a solid does not change much with temperature variation.

- **Liquids and Gases:** When liquids and gases are heated, their volume increases. As the volume is inversely proportional to density, an increase in volume decreases density. Hence, **with the increase in temperature, densities of liquids and gases decrease and with the decrease in temperature, densities increase.**

Consequence of Density Variation with Change in Temperature

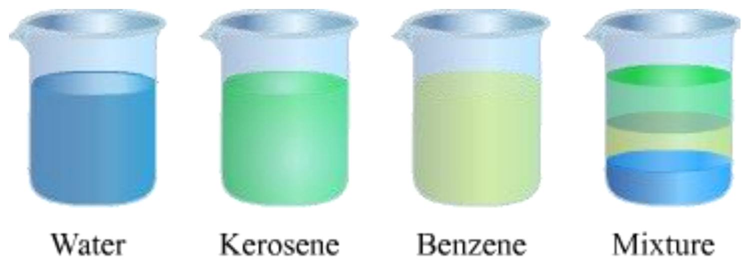
Let us take the example of water. When we heat a beaker filled with water, the density of the water near the bottom of the beaker decreases and rises up. To take its place, cold water from the top goes down. Thus, a current is set in the water. This current is called convection current. This process is the same for any liquid when it is heated.

As in liquids, convection current also sets up in gases because of variation in density with temperature change. In atmosphere, when air is heated up, hot air rises up. Denser and cooler air from the upper level of the atmosphere starts settling down at the bottom. As a result of this, convection current sets up in the atmosphere.

Relative Density

Relative Densities − An Overview

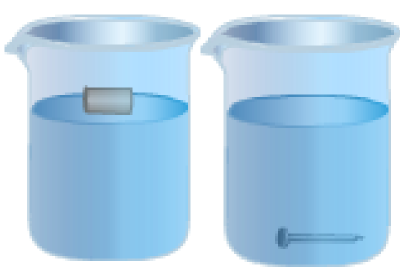
Whenever we use the term ‘relative’ to describe something, a sense of comparison comes to our mind. ‘Relative’ when used with ‘density’ also implies a comparison. It means the comparison of the density of matter.



Knowing the relative density of a substance with respect to that of a liquid helps one figure out whether it will float in the liquid or not. In this lesson, we will learn the concept of relative density in detail.

Question: Have you ever wondered why a cork floats while a nail sinks in water?

Solution: The density of a cork is less than that of water, whereas the density of a nail is greater than that of water. A substance whose density is less than that of a liquid will float on the surface of that liquid. Thus, a cork floats in water. On the other hand, a substance whose density is greater than that of a liquid will sink in that liquid. Thus, a nail sinks in water.



Density

The density of a substance is defined as the mass per unit volume of that substance.

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

The SI unit of density is kilogram per cubic metre (kg/m^3). Sometimes a smaller unit of density - gram per cubic centimetre (g/cm^3) is also used.

The following table shows the densities of some common substances.

Substances	**Densities (kg/m^3)**	**Substances**	**Densities (kg/m^3)**
Water	1000	Mercury	13600
Kerosene	810	Ice (0°C)	916
Cork	240	Sea water	1025
Iron	7870	Wood	800
Glycerine	1260	Alcohol	790

Know More

The density of the Dead Sea (also called the Salt Sea) is about 1.25 times greater than that of pure water. This density is so high that no human can sink in the Dead Sea. So, one can easily float on the surface of the Dead Sea.

Solved Examples

Easy

Example 1:

The mass of 2 m^3 of aluminium is 5400 kg. Calculate its density in SI unit.

Solution:

It is given that:

Volume of aluminium = 2 m^3

Its mass = 5400 kg

We know that:

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

$$\therefore \text{Density of aluminium} = \frac{5400 \text{ kg}}{2 \text{ m}^3} = 2700 \text{ kg/m}^3$$

Relative Density: In Depth

Raju is studying in the light of a kerosene lantern. Suddenly, the light of the lantern goes out because the lower end of the wick is not able to reach the kerosene in the fuel container (as shown in **Figure A**). Not knowing what to do, Raju asks his father. His father tells him to carefully pour some water in the fuel container, making sure that the wick does not come in contact with the water. Raju does as told and is surprised to see the light of the lantern become bright again.

What do you think happens in the fuel container? Does the water start acting as a fuel?

The answer to the second question is NO. Water does not act as a fuel for the lantern. What really happens is this. When poured into the fuel container, the water settles down and causes the kerosene to rise and float on its surface.

The lower end of the wick is once again immersed in kerosene and hence, the lantern becomes bright again. A clear partition arises between kerosene and water (as shown **Figure B**). This happens because the density of kerosene (810 kg/m^3) is less than that of water (1000 kg/m^3). In other words, since the relative density of kerosene is less than that of water, it floats in water.

Figure A Figure B

Relative Density: In Depth

The relative density of a substance is defined as its density with respect to that of water (water at 4 ^{o}C).

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

Relative density is also called **specific gravity**. It should be remembered that because **relative density is a ratio of the same physical quantities, it has no unit. It is a pure number.**

The following table shows the relative densities of a few substances.

Substances	**Relative densities**	**Substances**	**Relative densities**
Water	1	Mercury	13.6
Kerosene	0.81	Ice (0°C)	0.916
Cork	0.24	Sea water	1.025
Iron	7.87	Wood	0.8
Glycerine	1.26	Alcohol	0.79
Aluminium	2.7	Gold	19.3

The Relative density of a substance can also be given as the ratio of the mass of the substance to the mass of an equal volume of water at 4 ^{o}C i.e.

Relative density of a substance (R.D.) =

$$\frac{\text{Mass of substance}}{\text{Mass of an equal volume of water at } 4\,^{o}\text{C}}$$

Relative Density of a Solid Substance by Archimedes' Principle

Using Archimedes' principle, we can find the relative density of a solid substance as

$$\text{R.D.} = \frac{W_1}{W_1 - W_2}$$

Where W_1 is the weight of the body in air and W_2 is the weight of the body in water.

(1) Relative density of a solid denser than water and insoluble in it

$$\text{R. D.} = \frac{\text{Weight of solid in air}}{\text{Loss in weight of solid in water}} = \frac{W_1}{W_1 - W_2}$$

(2) Relative density of a solid denser than water and soluble in it

$$\text{R. D.} = \frac{\text{Weight of solid in air}}{\text{Loss in weight of solid in liquid}} \times \text{R. D. of liquid}$$

Relative Density of a Liquid Substance by Archimedes' Principle

By definition, relative density of a liquid is

$$\text{R. D.} = \frac{\text{Weight of given volume of the liquid}}{\text{Weight of the same volume of water}}$$

We know by archimedes' principle that if a solid is immersed in a liquid or water, it displaces the liquid or water equal to its own volume.

$$\text{R. D.} = \frac{\text{Weight of a liquid displaced by a body}}{\text{Weight of water displaced by the same body}}$$

$$\frac{\text{Weight of the body in air} - \text{Weight of the body in liquid}}{\text{Weight of the body in air} - \text{Weight of the body in water}} = \frac{W_1 - W_2}{W_1 - W_3}$$

Solved Examples

Medium

Example 1:

What is the significance of relative density?

Solution:

Relative density helps us to determine the density of an unknown substance by using the density of a known substance. It enables geologists to calculate the mineral content in rocks.

Example 2:

What are the differences between density and relative density?

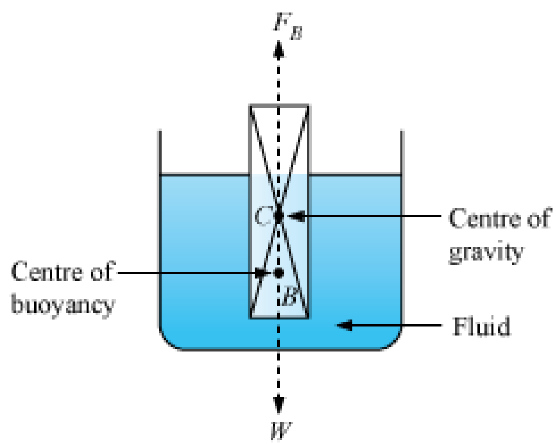
Solution:

The density of a substance is defined as the mass per unit volume of that substance. The SI unit of density is kg/m^3.

The relative density of a substance is the ratio of its density to that of a reference material. Usually, the reference material is water. Relative density is also known as specific gravity. It is a pure number, and has no unit.

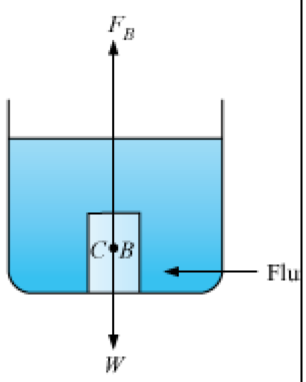
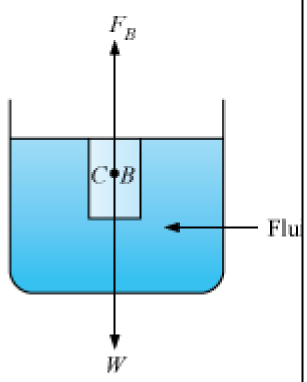
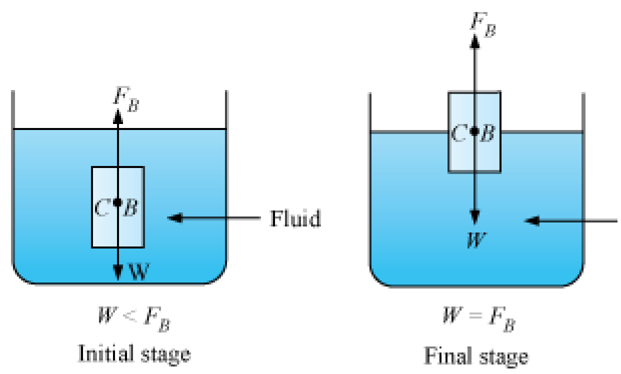
Law of Floatation

A body, when immersed in a liquid, experiences two forces—the weight of its own and the counteracting buoyant force. The figure shows the forces and their point of action.



These forces can give rise to the following situations as shown in the table below.

CASE − I	CASE − II	CASE − III
When $W > F_B$	**When $W = F_B$**	**When $W < F_B$**

In this case, the body sinks to the bottom.	In this case, the body floats below the surface.	In this case, the body floats above the surface.
		

Law of Floatation: The weight of the solid floating in a fluid is equal to the weight of the fluid displaced by immersed part of the solid.

The law of floatation can be represented as:

Volume of body × Density of body = Volume of displaced liquid × Density of liquid

Application of Law of floatation

- An iron ship floats easily
- If an iron nail is placed on the surface of water, it sinks while a ship made up of iron does not. This is because the density of iron nail is greater than that of water. Hence, the weight of the nail would be more than the upthrust of water on it due to which the nail sink in water.

  Whereas, the ship has large empty space in it which is occupied by air. This makes its volume large and average density less than that of water. Therefore, the weight of water displaced by the submerged part of the ship becomes equal to the total weight of the ship and hence it floats.
- An iceberg floats on water

- The density of ice is 0.917 g cm^{-3} and that of water is 1 g cm^{-3}. Hence, big masses of ice, also called icebergs, float on water with their major part inside the water surface and only a small part above the water surface.

- Volume of the iceberg above the surface of water when floating: Weight of water displaced by the submerged part of iceberg = Total weight of iceberg.
  Thus, $\frac{v}{V} = \frac{\rho_{\text{ice}}}{\rho_{\text{water}}}$, where *V* is the total volume of iceberg and volume of iceberg submerged in water is *v.*

Application of Law of Floatation

Let us see some applications of Archimedes principle or, you can also say, the law of floatation.

- **Floatation of fish**: Fishes have floating tubes, which are generally filled with air and hence displace more water than their weight. This amount of air is adjustable and hence can be used to gain or lose height.

- **Floatation of submarine**: A submarine in normal condition floats on water, but when water is sucked in, it gains weight and gets submerged in water.

- **Floatation in sea water:** It is easier to float in sea water than in fresh water because the density of sea water (1.04 g cm^{-3}) is more than that of the fresh water. Hence, in sea water, the displaced water is much heavier than the normal water.

- **Floatation of man in fresh water:** The density of human body without the head is lesser than that of the water. But we drown because the density of human head is very high. This makes the density of the whole body, including the head, higher than that of water. When we swim, we displace more water by pushing it downwards to make the weight of the body equal to the weight of the displaced water.

- **Floatation of icebergs:** Icebergs float in water with $11/12^{th}$ part of its volume under water and $1/12^{th}$ part above it. This happens because the density of ice is 0.917 g cm^{-3} and that of sea water is 1.04 g cm^{-3}. Icebergs can be very dangerous for ships as under water, ice can hit the ships and sink it.

Archimedes Principle is also used in lactometers to determine the purity of milk and in hydrometers to determine the density of a liquid.