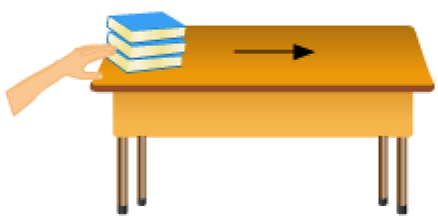
Fluids

Thrust and Pressure: An Overview

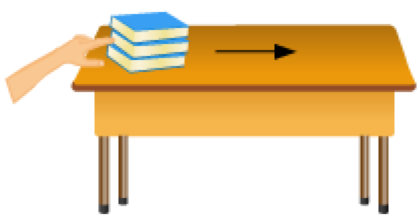
Thrust and **pressure** are two physical quantities related to force. Take, for example, a plastic ball immersed in water. A force is used to submerge it. At the same time, water exerts pressure on the submerged ball. Now, as soon as the force is removed, the upward thrust acting on the ball brings it back to the surface of water.

Go through this lesson to learn about thrust and pressure in detail.

Thrust and Pressure: In Depth



Case (i)



Case (ii)

Supose we have a pile of three books on a table. If we try pushing the pile with all the fingers of one hand, we will be able to move the books easily. However, this will not be the case if we try pushing the pile with only the index finger.

In 'Case (i)', the effort needed to displace the pile of books is taken care of by the force applied by the fingers. In 'Case (ii)', the force applied by the single finger is not enough; a greater force is needed to displace the books. Thus, the force per unit area exerted by the pile on all the fingers is lesser than that exerted by the same books on the index finger. Consequently, the books move easily in the first case, but not in the second.

This force per unit area is called pressure. It is given by the following relation:

$$\boxed{\text{Pressure} = \frac{\text{Force applied}}{\text{Contact area}} = \frac{\text{Thrust}}{\text{Contact area}}}$$

For a constant magnitude of thrust, if the contact area is greater, then the pressure will be lesser, and vice versa.

Since the SI units of thrust and contact area are N and m^2 respectively, **the SI unit of pressure is pascal (N/m^2)**.

Know More

Heavy vehicles have more than four tyres. Let us understand why this is so.

A wheel of a heavy vehicle has to support a large load. As a result, the consequent pressure on the road due to the wheel is very large. Extra wheels reduce the load carried by the individual wheels, which in turn reduces the pressure on the road due to each wheel. This prevents the wheels from causing damage to the road or sinking into the ground.

Solved Examples

Easy

Example 1:

A force, acting on an area of 0.5 m^2, produces a pressure of 500 Pa. Find the value of the force.

Solution:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$
$$\Rightarrow \text{Force} = \text{Pressure} \times \text{Area}$$
$$= 0.5\ \text{N/m}^2 \times 500\ \text{m}^2 = 250\ \text{N}$$

Example 2:

A force of 100 N is applied on an area of 2 m^2. What is the pressure resulting from this force?

Solution:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$
$$= \frac{100\ \text{N}}{2\ \text{m}^2} = 50\ \text{N/m}^2$$

Medium

Example 3:

A block of wood has a mass of 20 kg. Its length, breadth and height are 30 cm, 25 cm and 10 cm respectively. On which of its sides should it rest so that it exerts the least pressure on the ground? Also, calculate this pressure. (Take g = 10 m/s^2)

Solution:

The side of the block that has the greatest surface area will exert the least pressure on the ground, and vice versa. Therefore, in order to exert the least pressure on the ground, the block should rest on the side having the dimensions 30 cm × 25 cm.

We can compute the least pressure exerted by the block as follows

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$
$$\text{Force} = \text{Mass of the wooden block} \times g = 20 \times 10 = 200\ \text{N}$$
$$\text{Area} = \frac{30}{100} \times \frac{25}{100} = 0.075\ \text{m}^2$$
$$\text{Pressure} = \frac{200}{0.075} = 2666.7\ \text{N/m}^2$$

Example 4:

Explain why the wheels of an army tank are covered over by a wide steel belt?

Solution:

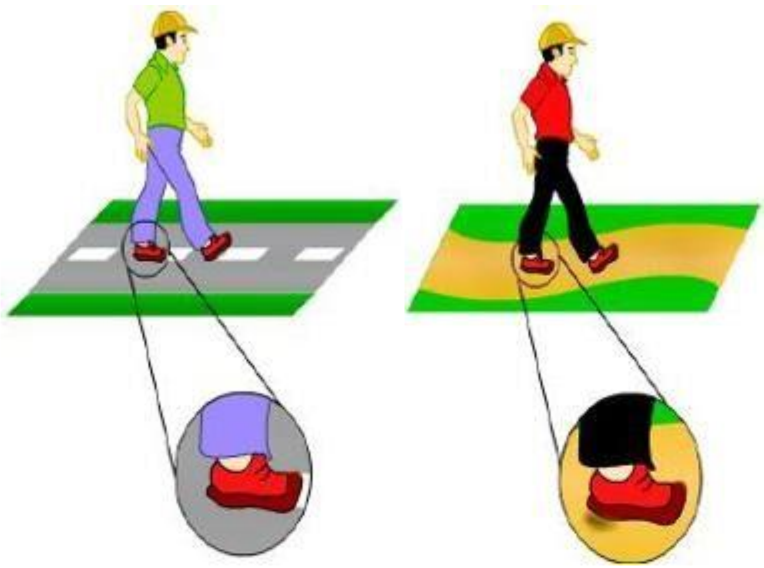
The steel belt covering the wheels of an army tank has a large surface area. This reduces the pressure exerted by the tank on the ground. As a result, the tank can move easily without damaging the ground or sinking in it.

Know Your Scientist

Blaise Pascal (1623−1662) was a great mathematician and physicist. He worked in the field of geometry and helped in the development of calculators. He also contributed to studies relating to fluids and the pressure distribution in them. The SI unit of pressure is named after him. One pascal is equal to the amount of pressure exerted by a force of one newton on one-square-metre area.

Walking on a Sand Bed

Have you ever wondered why walking on a sand bed is more difficult than walking on a hard road? Let us understand the reason for this phenomenon.



You already know that we push the ground with some force while walking, and the ground in turn applies the same force on our feet. The concrete or soil particles comprising a hard road are tightly bound and immovable. As a result, the reaction force of the ground on our feet is almost equal to the force of our feet on the ground.

A sand bed, on the other hand, consists of loose and movable particles of sand. While walking, these particles get displaced by the force applied by our feet. Consequently, the reaction force of the ground on our feet reduces, which makes walking difficult.

In other words, a hard, rigid surface is able to sustain the pressure applied upon it. Hence, such a surface allows easy movement. However, a soft, loose surface gets deformed under the applied pressure. Hence, such a surface hampers movement.

This phenomenon shows how the same pressure applied by the same force on the same surface area of different surfaces leads to different results.

Applications of Pressure

A few applications of the pressure are discussed here.

1. If you observe a knife used for cutting vegetables, you will notice that the edge of the knife is made very sharp and the area of the edge is very small. Therefore, the pressure on the edge is very high which allows us to cut the materials very easily and with little effort.

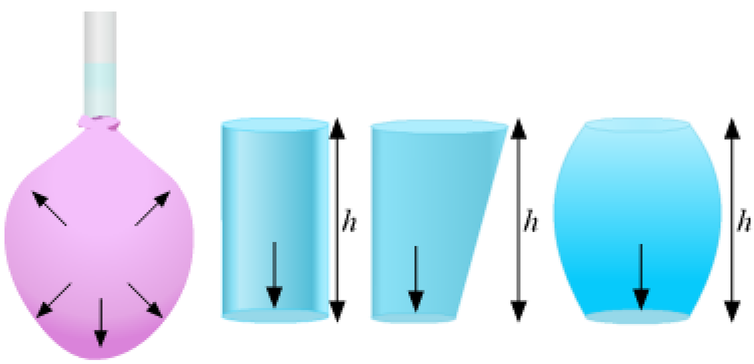
2. The area over which the weight of a skier is distributes is greatly increased by the skis. This reduces the pressure on the snow, and thus, allows the skier to move over snow without sinking into it.

3. While using a straw to drink anything, air is sucked out of the straw. Due to this, the pressure inside the straw is decreased. Hence, the atmospheric pressure outside, forces the liquid to go into the straw.

4. The straps of shoulder bags are generally made broad. The larger area of the strap reduces the pressure on the shoulder of the person who is carrying the bag which makes the bag easier and more comfortable to carry.

Pressure Exerted by Fluids

A fluid is a substance that doesn't have any fixed shape and yields easily to external pressure. Like solids, fluids (liquids and gases) have weight and can exert pressure on the walls of the container in which they are enclosed. When you exert pressure on the surface of a liquid or gas, the pressure is transmitted undiminished through the volume of the fluid in all directions.



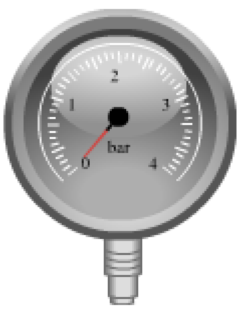
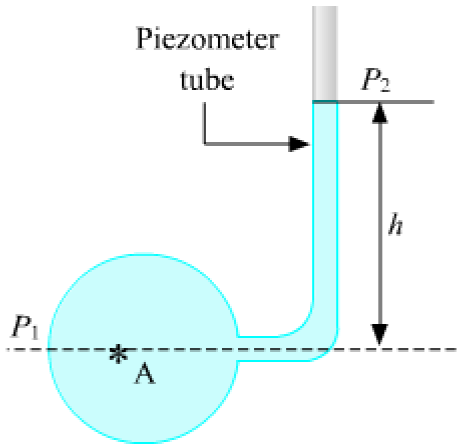
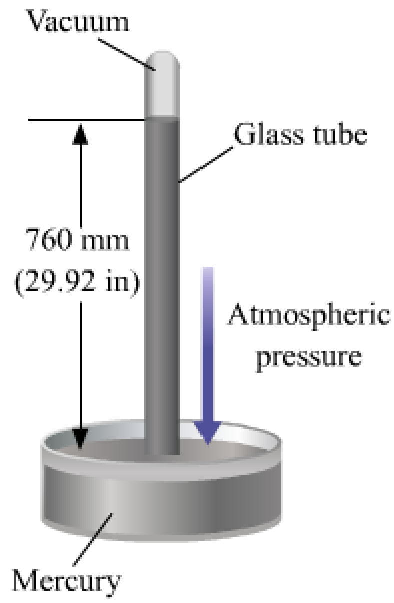
The shape and area of a fluid surface do not affect the pressure exerted by the fluid. It is the height of the fluid column which determines this pressure.

Did You Know?

Air in the atmosphere also exerts pressure. This is known as atmospheric pressure.

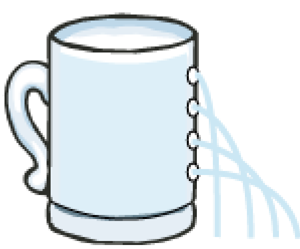
Instruments that Measure Pressure

Here are some instruments used for measuring pressure.

		
Bourdon pressure gauge	**Manometer**	**Barometer**

Liquids Exert Pressure

Therefore, it can be concluded that ***liquids also exert pressure***.



Take an empty plastic mug. Make four holes in the mug at different heights (as shown in the given figure). Now, fill the mug with water. **Does the water coming out of the holes fall at the same distance from the mug?**

You will observe that water coming out of the holes fall at different distances. The pressure at which water comes out of the holes is directly proportional to its depth.

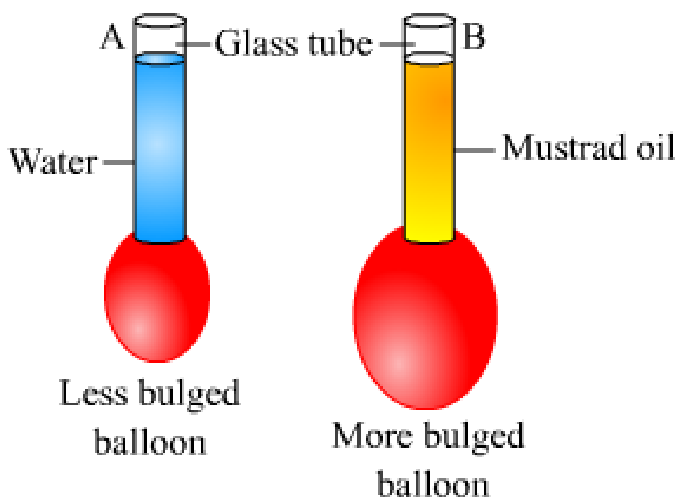
What happens when you make holes at the same height?

Water falls at the same distance. Thus, this proves that liquids exert equal pressure at the same depth.

Fluids exert pressure on the walls of the container.
Pressure exerted by fluids increases with depth.
Fluids exert equal pressure at the same depth.

- The liquid pressure at a point is independent of the quantity of liquid, but depends upon the depth of the point below the liquid surface. This is known as hydrostatic paradox.

- The liquid pressure increases with the increase in density of the liquid: As the density of mustard oil is more than water, so the balloon tied to tube bulges more than that tied to tube A. This proves that the liquid pressure increases with the increase in density of the liquid.



Liquid pressure increases with increase in density of liquid

- The atmospheric pressure at any point is equal to the weight of a column of air of unit cross-sectional area, extending from that point to the top of the earth's atmosphere.

- Atmospheric pressure at sea level is 1.013×10^5 Pa (1 atm).

- Two pressure-measuring devices are mercury barometer and open-tube manometer.

Consequences of liquid pressure

- The pressure at a certain depth in river water is less than that at the same depth in sea water. This is because the density of river water is less than that of the sea water.

- The wall of a dam is made thicker at the bottom as compared to its top. This is because the pressure exerted by the water (liquid) increases with depth. So to withstand such great pressure, thicker walls are required. Thus, the wall of a dam is made such that its thickness increases towards the base.

- The sea divers need to wear special protective suit while diving in deep sea. This is because in deep sea, the total pressure exerted on the diver's body is more than his/her blood pressure. To withstand such high pressure, the diver has to wear a special protective suit, made from glass reinforced plastic or cast aluminium. The pressure inside the suit is maintained at one atmosphere.

Pascal's Law of Transmission of Fluid Pressure

Fluids have a very interesting property. They can transmit pressure applied on them throughout the fluid in every direction. French mathematician Blaise Pascal conducted several experiments on transmission of pressure through liquids and reached the conclusion that:

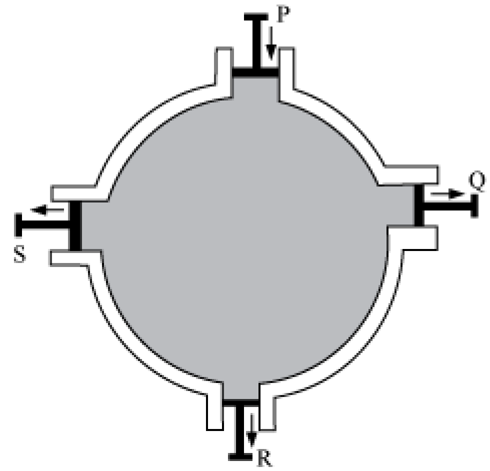
If a pressure is applied to a confined incompressible fluid at any point, then the pressure gets transmitted equally to all parts of the fluid in all directions and it always acts at right angles to the surface of the containing vessel.

This is known as **Pascal’s law** or the principle of transmission of fluid pressure.

If you apply pressure from top on water kept in a pot, then the pot will not break from its bottom, but from the sides. **Can you explain why this happens?**

Let us perform an experiment to find out the reason.

For the experiment, you require a vessel with four openings of equal cross-section. The openings are fitted with four water-tight movable pistons P, Q, R, S. Now, fill the vessel completely with water through one opening, keeping the other openings closed. If you push piston P with a force of 1 kgf, then you will find that the three other pistons also move and you have to apply 1 kgf force to each piston to stop their motions.



This shows that the applied force on P is equally distributed to all the pistons. Now, if you increase the area of one of the pistons (say S) three times, then what will happen?

You will observe that on increasing the cross-sectional area, the force required to check the motion of the piston motion also increases. In this case, you will be required to apply three times more force to check the motion of piston S. This shows that if pressure is applied to a fluid at one point, then the fluid distributes the pressure in all directions equally.

Now we are in a position to answer why a pot breaks from the sides when pressure in applied on the liquid kept in it. The area of cross-section of the side wall is more than that of the bottom. Therefore, when the applied pressure gets equally distributed, the side walls experience much greater force than the bottom.

Hydraulic Machines

Therefore, it can be concluded that fluids also exert pressure.

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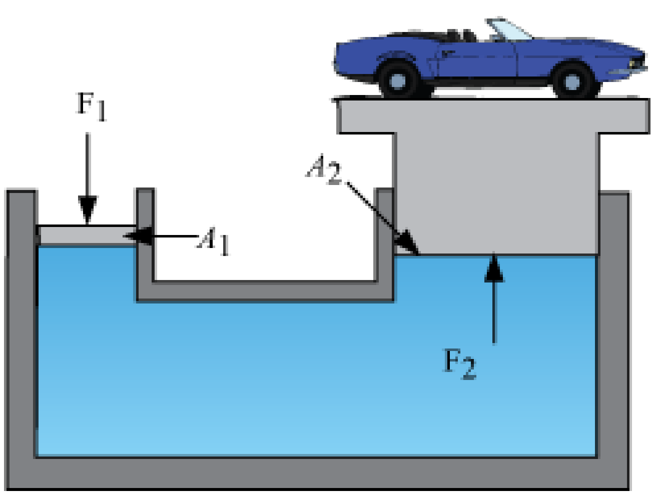
Fluids exert pressure on the walls of the container.
Pressure exerted by fluids increases with depth.
Fluids exert equal pressure at the same depth.

Let us take some more examples:

Hydraulic Machines

- These are based on Pascal's law for transmission of fluid pressure. This law states that the external pressure applied on any part of a fluid contained in a vessel is transmitted undiminished and equally in all directions.
- Hydraulic lift, hydraulic brakes, hydraulic press are some examples of hydraulic machines.

Hydraulic Lift



3Area of small cross-section = A_1

Force exerted on it = F_1

Pressure transmitted, $P = \frac{F_1}{A_1}$

Area of larger piston = A_2

Upward force on the piston = $P \times A_2$

Force supported by the large piston, $F_2 = PA_2$

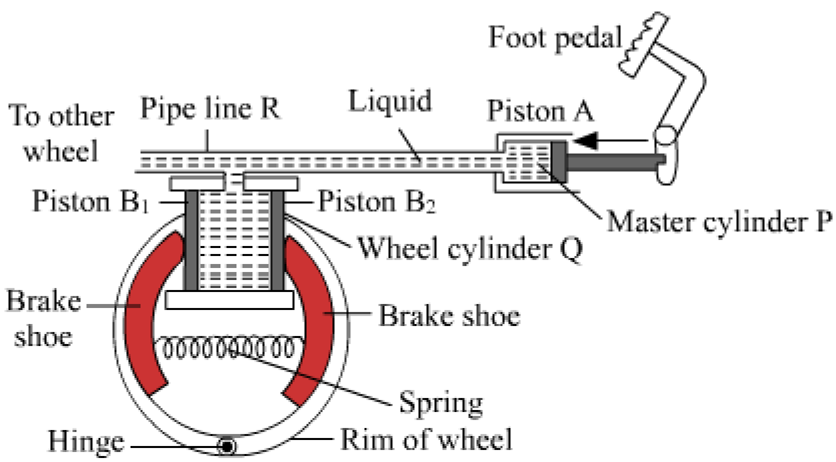
$F_2 = F_1 \frac{A_2}{A_1}$

Since A_2 is greater than A_1, force F_2 on the larger piston will also be much larger than the force F_1 applied on the smaller piston.

Mechanical advantage of the device is $\frac{A_2}{A_1}$.

Hydraulic Brakes

This is a hydraulic machine which runs on Pascal's law and is used in cars, bikes, etc.



Constructions

A hydraulic brake arrangement is shown above and it consists the following parts:

- A pipeline R containing oil is connected to the master cylinder P from one end and to the brake arrangement of all the wheels from other end.
- The master cylinder P is fitted with a piston A which is attached to a brake pedal or lever.
- A wheel cylinder Q having two pistons B_1 and B_2 is attached to the brake shoes which press against the rim of the wheel.

The area of cross-section of wheel cylinder Q is greater than the area of cross section of the master cylinder P.

Working

In order to apply brakes, the driver applies a small force on the break pedal which transmits the pressure on the oil present in the master cylinder P. This causes the oil to run out from the cylinder P to the wheel cylinder Q. Hence, an equal pressure is transmitted through the oil to the pistons B_1 and B_2 of the wheel cylinder Q.

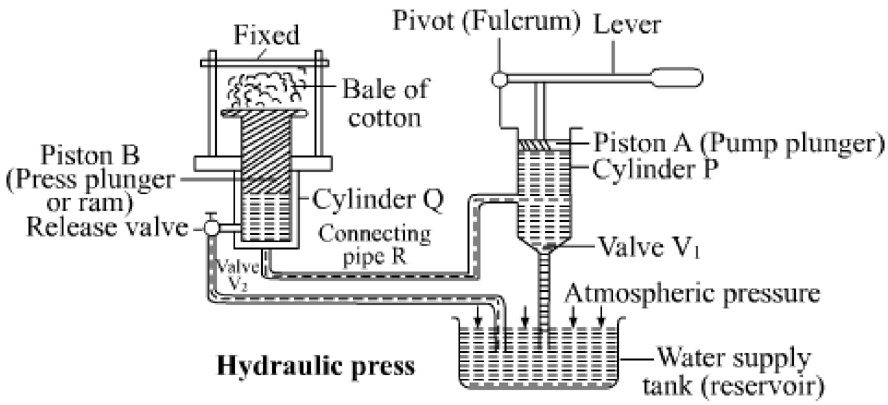
Now, B_1 and B_2 are pushed outwards and brake shoe get pressed against the rim of the wheel due to which the motion of the vehicle retards. It should be noted that a small force applied to piston A in the master cylinder P produces a large force on the piston B_1 and B_2 of the wheel cylinder Q because of smaller area of cross section of master cylinder P than wheel cylinder Q.

Hydraulic Press (or Bramah Press)

This is an another hydraulic machine which works on the principle of Pascal's law.

Construction

A graphical representation of hydraulic press is shown below. Its construction is as follows:



Hydraulic press

- Two hollow cylinder P and Q are fitted with valves V_1 and V_2, respectively.
- Cylinder P has a tank at the bottom connected through the valve V_1.
- Area of cross-section of cylinder Q is larger than the cylinder P and water-tight pistons A and B are fitted in these cylinders, respectively.
- These two cylinder are connected by a pipe R.
- Piston A is called pump plunger and piston B is called ram (or press plunger).
- To press down or raise up the piston A, a lever arrangement provided with handle H is used.
- A release valve is provided in the cylinder Q to connect the cylinder to the tank.

Principle

Its working is based on Pascal's law. When a force is applied on the piston A, a pressure is exerted on the liquid contained in the cylinder P. Now by using Pascal's law, this pressure gets transmitted through the liquid in tube R to the piston B of the cylinder Q because of which the piston B tends to move upwards. As the area of cross section of cylinder P is less than that of the cylinder Q, so by applying a small force on the piston A, we can lift a large weight kept on the piston B.

Working

When we apply an effort on handle H to raise the plunger A, the pressure in the cylinder P decreases and the valve V_1 opens upwards. This causes the water from the reservoir tank to get pushed up into the cylinder P by the atmospheric pressure acting on the free surface of water in the supply tank.

Now, if we apply an effort on the handle H to push the plunger A in downward direction, then this action would close the valve V_1 due to increase in the pressure in the cylinder P. And as per the Pascal's law, this pressure will be transmitted from cylinder P to the connecting pipe R. Now, the pressure in the connecting pipe R becomes greater than in the cylinder Q which causes the valve V_2 to open.

Thus the water from cylinder P is forced into the cylinder Q, due to which the press plunger B is raised against the fixed roof and the bale of cotton placed on the press plunger B gets compressed. Now when the job of machine is over, the release valve is opened so that the plunger B gets lowered and water of the cylinder Q runs out into the reservoir.

Uses of Hydraulic Press

This machine is used for

- pressing cotton bales and goods like quilts, books etc.
- extracting juice from sugarcane, sugar beet, etc.
- squeezing oil out of linseed and cotton seeds.

Atmospheric Pressure, Its Variation and Its Effect

Earth is surrounded by a lot of gases. This envelope of gases around our planet is called atmosphere. Atmosphere is vital for the survival of all life forms on our planet. As gases have mass, hence, they exert pressure on their surroundings. Atmosphere consists of gases. Hence, it also exerts pressure on the earth’s surface along with all the life forms living on it. This pressure exerted by the atmosphere is called atmospheric pressure.

We can now define atmospheric pressure as:

The force exerted on a unit area by a column of air above the earth’s surface is called atmospheric pressure.

The value of atmospheric pressure in the SI system is 100000 N/m^2 or 100000 Pa.

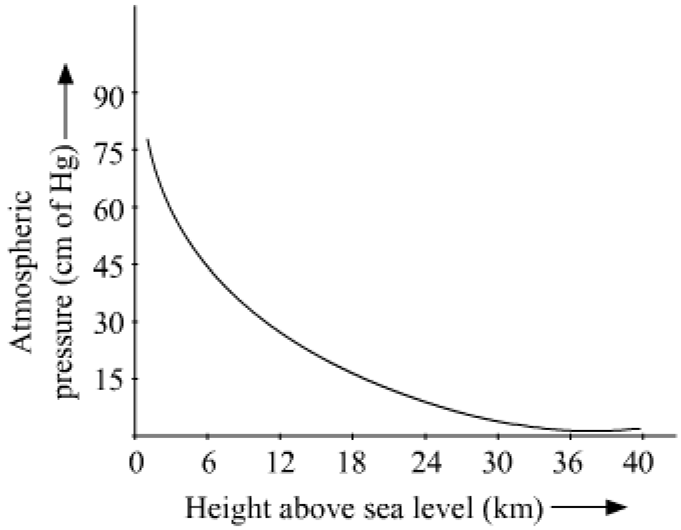
Variation in Atmospheric Pressure

Atmospheric pressure varies with:

- Height — With increase in height from the sea level, atmospheric pressure decreases. Following two factors are mainly responsible for this decrease in atmospheric pressure with height:

(1) decrease in height of air column results in a linear decrease in the atmospheric pressure and

(2) decrease in density of air with height results in a non-linear decrease in atmospheric pressure



- Season— With change in season on earth, the water vapour content in the atmosphere also changes. Therefore, the variation of pressure occurs with season change.

- Temperature— With increasing temperature, the atmospheric density decreases. Therefore, atmospheric pressure decreases with increasing temperature.

Effects of Atmospheric Pressure

- It is interesting to know that there is such big pressure acting all around us. Have you ever thought that how this pressure is not felt by us? It is not felt by us because our blood also exerts pressure on our body from inside. This pressure of blood balances the pressure of the atmosphere such that the atmospheric pressure is not felt by us.

- When we travel in an aeroplane, our nose may start bleeding, if the aeroplane is not pressurised properly. This happens because the atmospheric pressure at high altitude is lesser than the blood pressure inside our body. It is this difference of pressure that bursts our capillaries within our nose, making our nose bleed.

  It is for the same reasons an aircraft should be pressurised properly such that the pressure inside the aircraft remains the same as the normal atmospheric pressure at the ground level. Even astronauts wear space suits to counter the zero pressure that exists in the outer space.

  Fishes in deep sea water experience more pressure than we feel at land. Hence, their internal body pressure is more than ours. If these fishes are brought out of the water, then their body will burst because of the excess outward pressure of their internal body fluid.

- If you take a fountain pen to higher altitude, then you will see that the pen starts leaking. This happens because of low atmospheric pressure at high altitude. The ink pressure inside the pen becomes higher that the outside atmospheric pressure and as a result, the pen starts leaking.

- Sucking from a straw works on the same principle. When you suck the air out of the straw, pressure falls inside the straw. This fall in pressure is compensated by the liquid that is forced up by the atmospheric pressure.

Measurement of Atmospheric Pressure

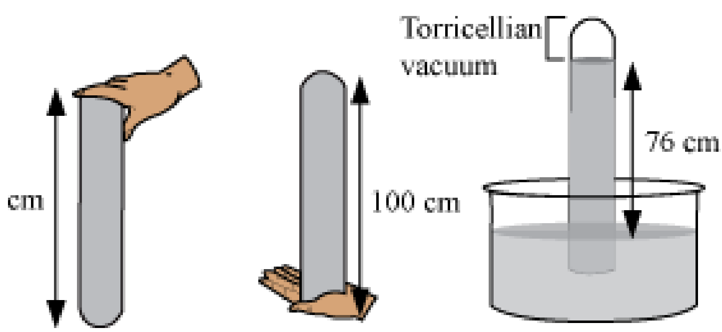
The value of atmospheric pressure is not the same everywhere. It is higher at sea level than at mountains. To measure the atmospheric pressure, we use an instrument called barometer.

Barometer

Construction

It consists of a hard glass tube, which is taken and filled with mercury. Open end of the tube is closed with a finger. This tube is inverted over a trough filled with mercury. Finger is removed only when the open end of the tube is completely immersed in the mercury of the trough.

On removing the finger, some mercury from the tube flows into the trough. Mercury column shows the height of 76 cm under normal conditions. This barometer is called Torricelli's barometer, named after its inventor Evangelista Torricelli, an Italian scientist.



Why is mercury used as the barometer material? • It is the heaviest liquid. Hence, only 76 cm of height of mercury column is required. • Mercury gives more accurate readings because it does not stick to the glass tube. • It can be easily seen while taking the reading because it is shiny and opaque.

- In normal temperature, the vapour pressure of mercury is negligible as compared to the atmospheric pressure. Therefore, mercury vapour that is present in the vacuum in a barometer does not affect the reading of the atmospheric pressure.

Drawbacks of Torricelli's Barometer

- In Torricelli's barometer, the trough remains open. Hence, a chance of mixing of impurities with the pure mercury is always there.
- It is not portable.
- It is not compact.

Fortin Barometer

It is a modified form of a simple barometer and has the same use as of simple barometer. It also uses mercury as the barometric liquid.

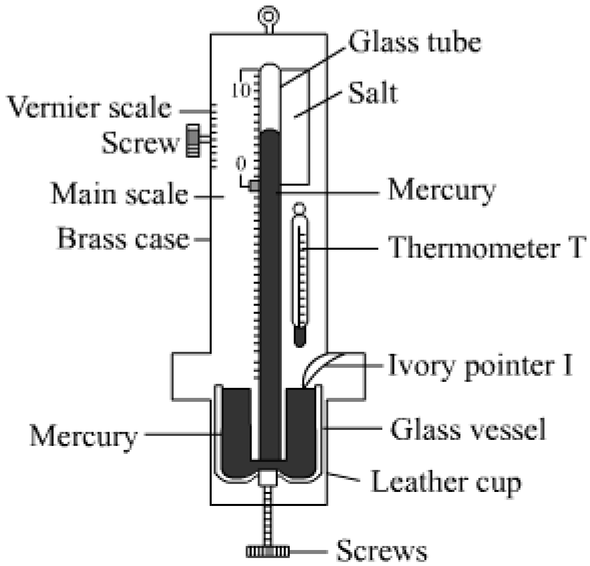
Construction

Fortin barometer has a narrow glass tube of length around 85 to 90 cm. One end of the tube is close and the other end has an opening in it. Pure mercury is completely filled in the tube and is kept inverted in a glass vessel having a leather cup at the bottom. This cup has mercury in it and acts like a trough. The end of tube, which is open, is dipped into the mercury present in the cup and this whole set-up is enclosed in a brass case.

A screw S, at the bottom of the brass case, supports the leather cup of the glass vessel. Screw S help in raising up and lowering down the leather cup so as to adjust the mercury level in the glass vessel.

The mercury level in the glass vessel is adjusted to coincide with zero mark of the main scale graduated in mm attached with brass tube. The zero mark of the fixed scale is at the tip of an ivory pointer I which is distinctly visible from outside.

The upper part of the brass tube has a slit in it so as to note the mercury level in the glass tube. A vernier scale, for accurate measurement, is provided which slides over the main scale by using screw R.



Fortin Barometer

Working

In this barometer, first the mercury level in the leather cup is raised up or lowered down using the screw S such the the level of mercury in the glass vessel just touches the ivory point *I*. The position of the mercury level in the barometer tube is noted with the help of the main scale and the vernier scale and the sum of both the readings (vernier and main scale reading) gives the barometric height.

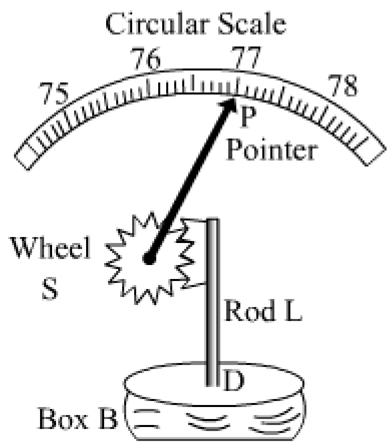
Aneroid Barometer

This barometer is an exception as it has no liquid. It is very light and can be transported from one place to another. It is calibrated to read directly the atmospheric pressure.

Construction

It has a partially evacuated metallic box B. The top of the box, shown by point D, is springy and is corrugated in form of a diaphragm. A thin rod L is placed in the middle of diaphragm and its upper end is toothed.

The teeth of the rod fit well into the wheel S attached with a pointer P which can slide over a circular scale. This scale is graduated and is initially calibrated with a standard barometer so as to read the atmospheric pressure directly in terms of the barometric height.



Working

The movement of rod L is affected by the change in atmospheric pressure. When the atmospheric pressure increases, it presses the diaphragm D and the rod L moves down. Hence, the adjoining wheel S rotates clockwise and pointer P moves to the right on the circular scale. Similarly, when the atmospheric pressure decreases, the diaphragm D bulges out due to which the rod L moves up and wheel S rotates anti-clockwise. As a result, the pointer moves to the left.

Uses of Barometer

- Measures atmospheric pressure of a place
- Forecasts weather
- Works as an altimeter to measure height

Weather Forecasting with the Help of Barometer

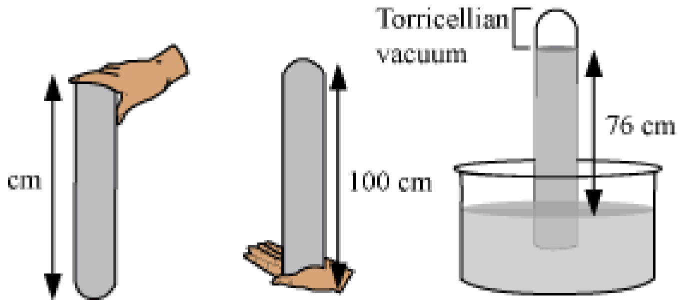
Barometer is used for measuring atmospheric pressure. But it can as well be used for weather forecasting.

How is pressure related to weather conditions?

Atmospheric pressure decreases mainly because of two reasons:

Increase in temperature of the atmosphere

Increase in moisture content of the atmosphere



A slow decrease in the height of the mercury column in a barometer indicates the lowering of atmospheric pressure. This happens because of an increase in temperature. Observing this decrease in height of the mercury column, a storm can be predicted because rise in temperature and fall in pressure results in creation of a low pressure region.

When barometer’s mercury height falls suddenly, a rain can be predicted because the sudden fall of mercury height occurs due to the increase of moisture content in the atmosphere. Rise in moisture and fall of pressure can be slow or can be sudden. A sudden change can result in a cyclone. Similarly, a sudden rise in moisture means an anti-cyclonic zone.

Altimeter

It is an aneroid barometer and is used only in aircraft to measure its altitude from the sea level. It is now well known that the atmospheric pressure decreases with height. Thus, in an altimeter, a barometer which is used to measure the atmospheric pressure is used to determine the altitude of a given place above sea level because the atmospheric pressure decreases with increase of height above the sea level. Its scale is calibrated in terms of height of ascent with height increasing towards left.

Archimedes' Principle

Archimedes’ Principle: An Overview

‘Eureka! Eureka!’ Screaming thus, Archimedes came out of his bathtub and ran straight to his king. A popular legend related to the discovery of the principle of buoyancy ends in this manner.

What is this principle of buoyancy? And why is it so important? If you have wondered about this phenomenon, then the following questions must have arisen in your mind.

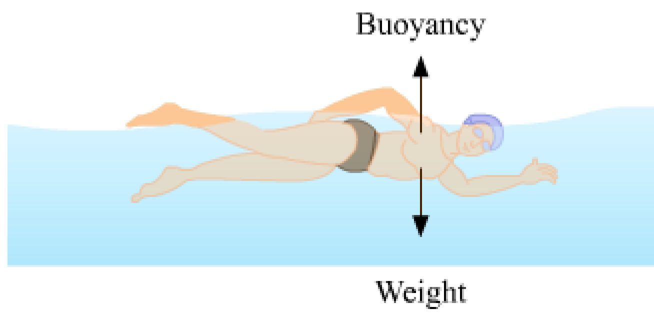
• What has buoyancy to do with the floatation of bodies in liquids?

• Why does a piece of cork rise back to the surface of water even after you force it harder into water?

• Why does a piece of nail made of steel sink but a ship made of the same material float in water?

• Why do you feel lighter while swimming in a pool?

•How can Archimedes' discovery be used in determining the purity of a substance?



Let us go through this lesson to get the answers to all the above questions.

Buoyancy

When an object is immersed partially or fully in a liquid, it experiences an upward force. This **upward force** is known as **buoyant force** and the phenomenon is called **buoyancy**.

When an object is immersed in a liquid, its weight seems to be less than its actual weight. The buoyant force exerted by the liquid is responsible for this phenomenon.

Cause of buoyant force

When a body is partially or fully immersed in a liquid, the displaced **fluid has the tendency to regain its original position due to gravity**. An upward force—called the buoyant force—is, thus, exerted on the body by the displaced fluid.

In equilibrium, the buoyant force is balanced by the weight of the immersed body or the force of gravity acting on it.

The magnitude of the buoyant force acting on the immersed body depends upon two factors.

- Volume of the immersed body
- Density of the liquid

The density of a substance, with respect to the density of a liquid, determines whether the substance will sink or float in the liquid. An iron nail sinks in water because the density of iron is greater than that of water. On the other hand, a cork floats in water as the density of cork is less than that of water. Density is expressed in terms of the volume of a substance. Hence, volume plays a major role in deciding whether a substance will sink or float. Such a relation was given by Archimedes.

Know Your Scientist

Archimedes (287−212 BC) was a Greek mathematician and physicist. According to a legend, he discovered the principle of buoyancy (Archimedes' principle) while taking a bath. It is said that he was so excited with his discovery that he ran naked in the street shouting '*Eureka*'.

Apart from this principle, Archimedes made some very important contributions to the fields of mechanics and geometry. He is considered one of the three greatest mathematicians of all time.

Archimedes' Principle

Archimedes' principle states that **when a body is immersed wholly or partially in a liquid, it experiences an upward buoyant force of magnitude equal to the weight of the liquid displaced by it**.

Buoyant force on an immersed body = Weight of the displaced liquid

Weight of the displaced liquid = Mass of the displaced liquid × Acceleration due to gravity

= Density of the liquid × Volume of the displaced liquid × Acceleration due to gravity

Volume of the displaced liquid = Volume of the immersed body

So,

Weight of the displaced liquid = Volume of the immersed body × Density of the liquid × Acceleration due to gravity

Hence, we can write the magnitude of the upthrust on a body immersed in a liquid as follows:

Buoyant force on an immersed body = Volume of the immersed body × Density of the liquid

× Acceleration due to gravity

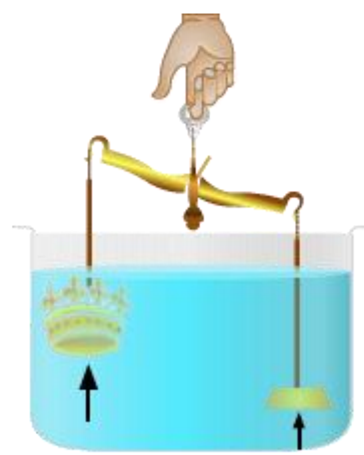
The buoyant force on an immersed body depends on the density of the liquid in which the body is immersed. So, this force is different in different liquids for the same body.

Application of Archimedes' Principle

Archimedes' principle can be used for determining the purity of substances such as gold.

Suppose we have a gold crown and need to determine if it is pure gold or not. We also have a block of pure gold as reference. The block and the crown have the same mass (as shown in the figure). Using Archimedes' principle, we can compare the densities of the crown and the block. If the crown is less dense than the block, then it will displace more water —owing to its greater volume. Consequently, the crown will experience a greater buoyant force than the block (as shown in the figure). This will indicate that the gold used in making the crown is not pure, but has some other metal or alloy mixed in it.

In air weight of the crown is equal to the weight of the piece of pure gold.



In water apparent weight of the crown is less than the apparent weight of pure gold.

Solved Examples

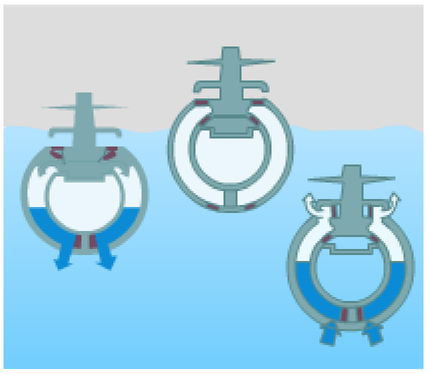
Easy

Example 1:

Do you know how submarines are made to float or sink as desired?

Solution:

A submarine has large tanks onboard which control how deep it sinks or how high it rises. These tanks are called ballast tanks. To sink the submarine, the tanks are filled with water. The greater the amount of water in the tanks, the deeper does the submarine sink.



To raise the submarine, water is released from the tanks and compressed air (kept onboard in flasks) is let into them. The greater the amount of compressed air in the tanks, the higher does the submarine rise.

Example 2:

When an iron block is dipped in water, it displaces 10 kg of water. Calculate the amount of buoyant force (in Newton) acting on the iron block. (Take *g* = 9.8 m/s^2)

Solution:

According to Archimedes' principle, the buoyant force on the iron block is equal to the weight of the water displaced by it.

It is given that:

Mass of the water displaced = 10 kg

Acceleration due to gravity = 9.8 m/s^2

∴ Weight of the water displaced = Mass of the water displaced × Acceleration due to gravity

= 10 × 9.8 = 98 N

Hence, the buoyant force acting on the iron block is 98 N.

Medium

Example 3:

How do the densities of an object and a liquid affect the sinking or floating of the object in the liquid?

Solution:

Suppose an object of density ρ and volume V is immersed completely in a liquid of density σ.

Then,

Apparent weight of the object = $W - w = V\rho g - V\sigma g$

Where, W = Weight of the object

w = Weight of the water displaced by the immersed part of the object

Case I: If $W > w$ ($\rho > \sigma$), then $W - w$ is positive.

In this case, the object will sink.

Case II: If $W < w$ ($\rho < \sigma$), then $W - w$ is negative.

In this case, the object will float.

Case III: If $W = w$ ($\rho = \sigma$), then $W - w = 0$.

In this case, the object will rest anywhere within the liquid.

Hard

Example 4:

An object weighs 300 N in air and 150 N in water. Find its relative density.

Solution:

Let us take:

Volume of the object = *V*

Density of the object = ρ

Density of water = σ_{w}

Acceleration due to gravity = *g*

It is given that the weight of the object in air is 300 N.

We know that:

Weight of the object = $V\rho g$

$$\rho = \frac{300}{Vg} \quad \ldots \text{(i)}$$

It is also given that the apparent weight of the object in water is 150 N.

We know that:

Apparent weight of the object = Weight of the object − Weight of the water displaced by it

So,

$$V\rho g - v\sigma_{\mathrm{w}} g = 150$$
$$\Rightarrow 300 - v\sigma_{\mathrm{w}} g = 150$$
$$\Rightarrow \sigma_{\mathrm{w}} = \frac{300-150}{Vg} \quad \ldots . \text{(ii)}$$

Now, the relative density of the object can be calculated as follows:

$$\text{Relative density of the object} = \frac{\text{density of the object}}{\text{density of water}} = \frac{\rho}{\sigma \mathrm{w}}$$

$$= \frac{\frac{300}{Vg}}{\frac{300-150}{Vg}}$$

Example 5:

An object of density ρ floats in kerosene of density 0.7×10^3 kg/m^3 up to a certain mark. If the same object is placed in water of density 1×10^3 kg/m^3, will it sink more or less in water?

Solution:

Let us take:

Volume of the object = V

Height of the cross-section of the object = h

Area of the cross-section of the object = A

Height of the object when immersed in kerosene = h'

Height of the object when immersed in water = h''

Acceleration due to gravity = g

It is given that:

Density of the object = ρ

Density of kerosene, $\rho_k = 0.7 \times 10^3$ kg/m^3

Density of water, $\rho_w = 1 \times 10^3$ kg/m^3

According to Archimedes' principle:

Weight of the object = Weight of the kerosene displaced by the object

= Weight of the water displaced by the object

$$\Rightarrow V\rho g = V'\rho_k g = V''\rho_w g$$

$$\Rightarrow (hA)\rho g = (h'A)\rho_k g = (h''A)\rho_w g$$

$$\Rightarrow (h'A)\rho_k g = (h''A)\rho_w g$$

$$\Rightarrow (h'A)\rho_k = (h''A)\rho_w$$

$$\Rightarrow \frac{h'}{h''} = \frac{\rho_w}{\rho_k} = \frac{1\times10^3}{0.7\times10^3} = 1.43$$

$$\text{So, } h' = 1.43h''$$

Therefore, the object will sink less in water.

Sinking or Floating

Two forces act on an object placed in a liquid:

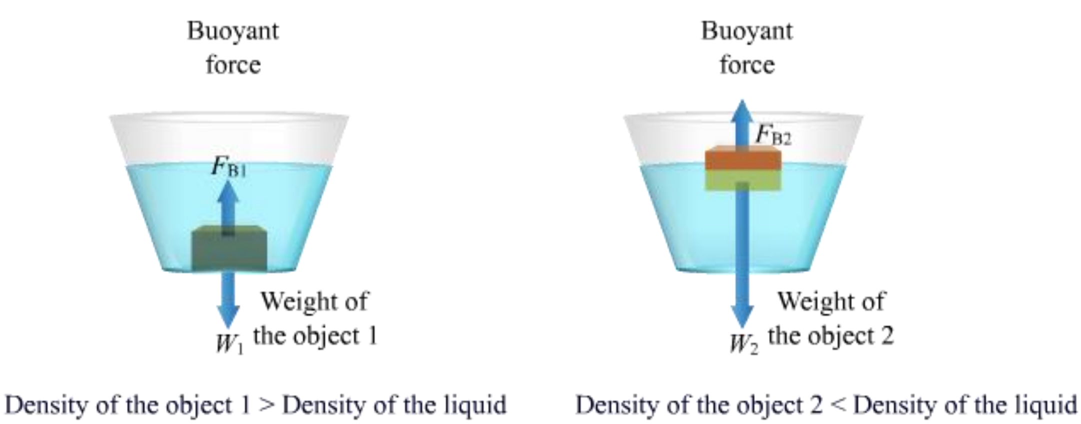
- Weight (*W*) of the object, which acts downwards
- Buoyant force or upthrust (*W'*) exerted by the liquid, which acts upwards

For any object immersed in a liquid:

- If the density of the object is less than the density of the liquid then it will float. The object will be immersed to an extent until the weight of the volume of liquid displaced is equal to the weight of the object

- If the density of the object is more than the density of the liquid then the object will sink as its weight is more than the weight of the liquid displaced.

- If the density of the object is equal to the density of the liquid then it will neither float nor sink in the liquid. It will remain in equilibrium within the liquid wherever it is placed.



Law of Flotation

According to the law of flotation, an object will float in a liquid if its weight is equal to or less than the weight of the liquid displaced by it.

The floating object may be partially or fully submerged in the liquid. Liquid is displaced by the submerged portion of the object.

We can tell whether an object will float or sink in a liquid by comparing its density (or average density) to that of the liquid.

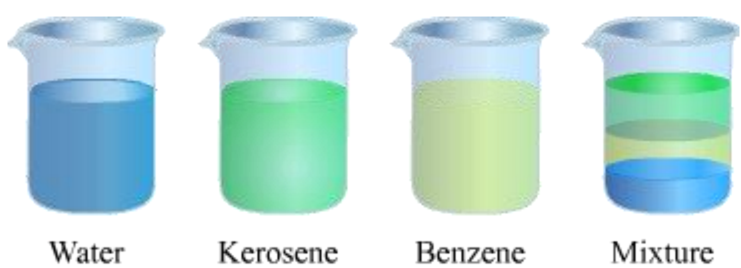
For any object immersed in a liquid:

- If the average density of the object is less than that of the liquid, then the object will float in the liquid.
- If the density of the object is equal to that of the liquid, then the object will float in the liquid but no part of it will be above the surface of the liquid.
- If the density of the object is greater than that of the liquid, then the object will sink in the liquid.

Relative Density

Relative Densities − An Overview

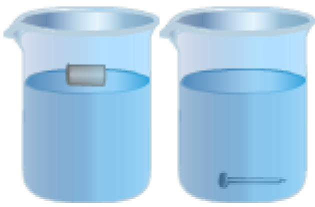
Whenever we use the term ‘relative’ to describe something, a sense of comparison comes to our mind. ‘Relative’ when used with ‘density’ also implies a comparison. It means the comparison of the density of matter.



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.

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

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).

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

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

$$\text{Relative density of a substance (R.D.)} = \frac{\text{Mass of substance}}{\text{Mass of an equal volume of water at } 4\,^{o}\text{C}}$$

Relative Density of a Solid Substance by Archimedes' Principle

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

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?

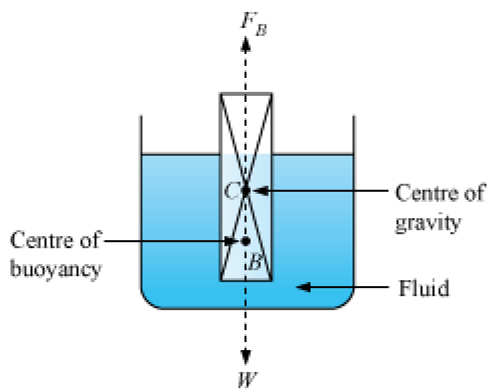
Solution:

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.

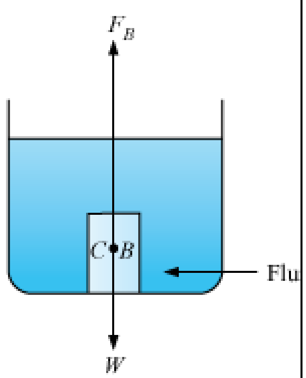
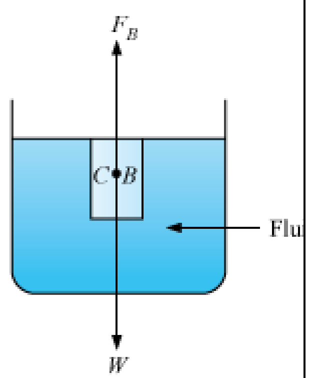
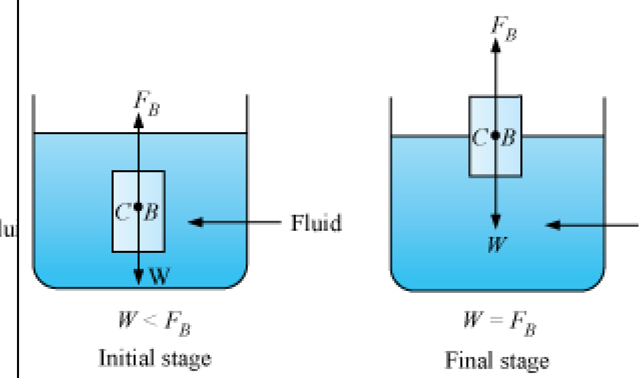
Law of Floatation

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 **When $W > F_B$**	**CASE − II** **When $W = F_B$**	**CASE − III** **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.*