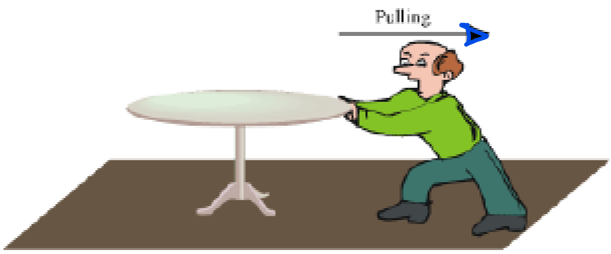
Force and Pressure

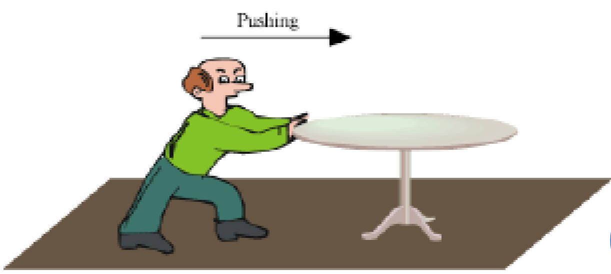
Force: Push or Pull

A table can be moved from one place to another by either pushing it or pulling it. Similarly, you can open a door by either pushing or pulling it. When a ball is thrown with more force, it travels a longer distance. The shape of a bottle can change when it is squeezed. Also, the direction of a moving ball can change by striking it.



Have you wondered how the shape of a bottle changes when squeezed? Or how can the direction of a moving ball change by kicking it in different ways?

All the above activities can be associated with **pushing** or **pulling**. Therefore, whenever an object is moved, we can say that it has either been pushed or pulled.



This push or pull is known as force. In other words, a body moves whenever a force is applied to it. Therefore, a body cannot move unless a force is applied.

Apart from push or pull, force is any action that has the tendency to change the position, shape, or size of an object. Everyday actions such as pushing, pulling, stretching, lifting, squeezing, and twisting are also examples of force.

Let us try to list some examples of everyday force and see if we can classify them as push or pull. A few examples have already been classified for you. Try to classify the rest.

Description	Push or Pull

Hitting a cricket ball with a bat	Push
Opening a door	Push and Pull
Plucking a flower	Pull
Flying a kite	Push
Moving a wheel barrow	Push or pull
Hitting a tennis ball with a racquet	Push
Taking a carrot out of the ground	Pull
Playing on a swing	Push or pull
Picking up a shopping bag	Pull
Squeezing a toothpaste tube	Push

Interaction of Forces

Unit of Force

Do you require equal amount of force to lift your physics book and a bucket full of water? Definitely not! You require greater force to lift the bucket. Can you tell how much more force is required to lift the bucket?

For that, we have to measure the forces. Thus, we require some unit to describe the amount of force.

N

The SI (International System of Units) unit of force is Newton, which is denoted by N.

You must have heard the term **kilogram force (kgf)**. It is the commonly used unit of force and is defined as the **force that is required to lift a mass of 1 kg vertically upward**.

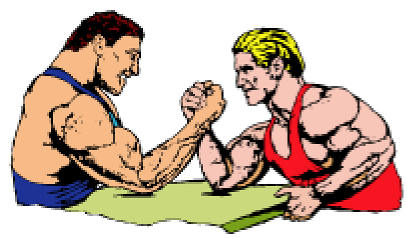
Do you know what the relation between the two units of force is?

1 kgf = 10 N

Therefore, you can easily define 1 N. Just try it.

Interactions of Forces

Have you ever seen an arm wrestling match? In an arm wrestling match, both the players try to push each other's hand towards the table. Hands move along the direction of the player who applies a greater force. The player who is able to apply more force wins the match.

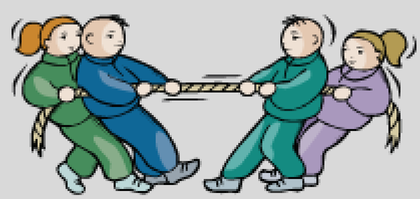


A table in your room or a vehicle parked outside your house cannot move unless it is either pushed or pulled. To move a table, you have to either push or pull it. In cricket, a bat exerts force on the ball. Thus, the ball is able to gain speed and can reach the boundary line.

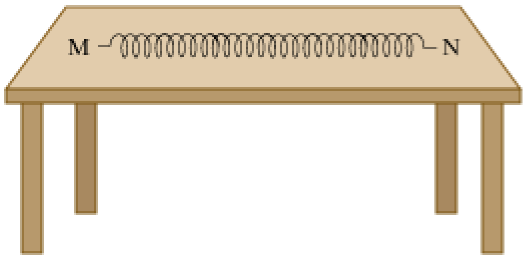
Thus, we can observe that force comes into play when at least two bodies interact with each other. **Can you list the two interacting bodies in the cases that we have discussed?**

Scenario	Interacting bodies
Arm wrestling	Arms of the players
Pushing or pulling a table	You and the table
A moving vehicle	Vehicle and the road (or the ground)
Bat hitting a ball	Bat and ball

In a game of tug of war, two teams try to pull each other towards themselves. This game is won by the team, which applies more force in their direction. Thus, the net resultant force is in their direction.



Balanced and unbalanced forces in a body



A metal spring having two ends M and N are placed on a table.

When you pull the end M of the spring, it will move towards the left and when you pull the end N of the spring, it will move towards the right. **What will happen if you simultaneously pull both ends of the spring with the same force?**

The spring will stretch and its shape and size will change, but it will not move because the net force acting on it is zero.

What will happen if two unequal forces are applied at the two ends of the spring?

When unbalanced forces are applied at the ends of the spring, it will start moving in the direction of the greater force. Hence, the net force is not zero in this case.

A toy car is pushed on a rough floor and is allowed to move. It moves some distance and comes to rest. **Why does the toy car come to rest?**

The toy car comes to rest after some time because of the frictional force between the moving wheels of the car and the rough floor. This force acts in the direction opposite to the direction of motion of the car. This means that an unbalanced force acts on the car in the direction opposite to the direction of motion of the car.

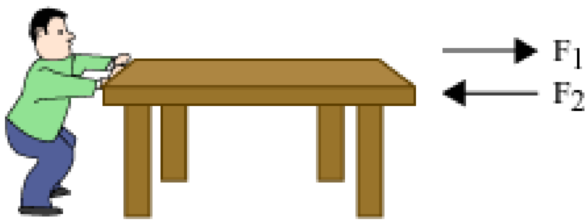
As a result, it will come to rest after some time. Hence, in order to keep the toy car moving, one should push it again before it comes to rest.

An unbalanced force can stop a moving object.

An object moves with a uniform velocity when no net external force is acting on it i.e., the forces acting on it are balanced.

What will happen if you try to push a table on a rough floor?

The result of the applied force will depend on the magnitude of the force applied on the table.



The figure given above shows the various forces acting on the table.

Where,

F_1 → Magnitude of the applied force

F_2 → Frictional force caused by the rough surfaces in contact

It is clear from the figure that the frictional force F_2 opposes the applied force whereas force F_1 tends to overcome the frictional force. The table will not move, if you apply a small force. However, if you apply a force that is greater than the frictional force, then the table will move in the direction of the applied force.

Thus, from the above observations, we can conclude as follows

- If many forces act on a body in the same direction, the net force on the body is equal to the sum of all the forces.
- If two forces are acting on a body on opposite direction, the net force on the body is equal to the difference of the two forces. For the above example of table being pushed on a rough floor, the net force on the table = $F_1 - F_2$, when table is moving. If the table is not moving, the net force on the table = $F_2 - F_1$.

Effects of Force

Force cannot be seen, heard, or tasted. Only its effects can be felt or seen. It is correctly defined as a push or pull upon an object resulting from the object's interaction with another object. The various effects of force are:

- It can move a body initially at rest.
- It can bring a moving body to rest.
- It can change the direction of a moving body.
- It can change the speed of a moving body.
- It can change the shape of a body.

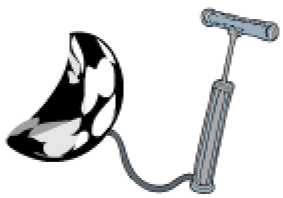
⑥ It can change the size of a body.

Let us take an example of a football lying in a field. When a player hits the ball, it starts moving, i.e., it starts moving only when we apply force. Thus, force can move a body initially at rest.

Now, if the goalkeeper catches the moving ball, then it comes to rest. The goalkeeper applies a force to stop the moving ball. Hence, we can say that force can bring a moving body to rest.

If another player kicks the moving ball in the opposite direction, then it starts moving in the direction towards which it is kicked i.e. the direction of the football changes. The player applies force on the football to change its direction. Hence, force can change the direction of a moving body. Also, if the player hits the ball hard, then the net speed of the ball will also change. Hence, the speed of a moving body can be changed by applying force.

The shape of a deflated football can be changed by inflating it. When you inflate a football, you apply force on the pump. Hence, force can change the shape of an object. Also, if you keep inflating the football, then its size will keep on increasing. Hence, force can change the size of an object.



A deflated football

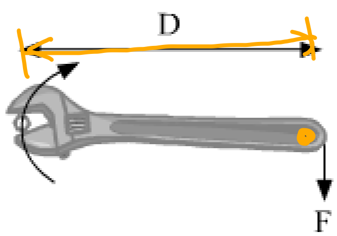
Force can change the shape of an object

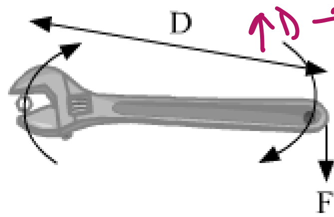
Force can change the size of an object

Moment of Force and Couple

To move a body from a state of rest, a force is needed. Similarly, a couple of forces are needed to rotate a body about an axis. Have you ever imagined why a door has its handle at one end and not in the middle? The concept of moment of a force.

Moment of force (Torque)





The given figure shows a wrench and a nut. When a force, *F*, is applied to the handle of the wrench, the nut turns in a direction as shown in the given diagram.

It is interesting to note that the greater the distance between the nut and the point of application of force (denoted by *D* in the figures), the easier it will be to turn the nut.

Therefore, the turning of the nut depends on two factors:

i. The greater the applied force *F*, the more easily the nut can be turned.

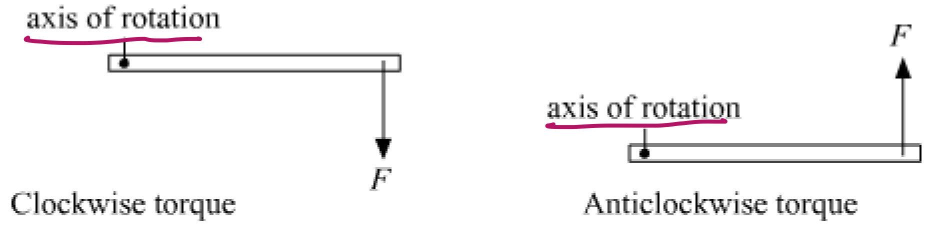
ii. The greater the distance *D*, the more easily the nut can be turned.

It is clear from these points that the turning effect can be increased either by increasing *F* or by increasing *D* (distance between the nut and the point of application of force *F*)

On account of these points, we define a quantity called **torque.**

Torque (τ) = Force (*F*) × Perpendicular distance (*D*)

Torque represents the turning force acting on an object. It can be either clockwise or anticlockwise, depending upon how the force is applied. The given figures show clockwise as well as anticlockwise torque.



A clockwise torque tends to turn an object in the clockwise direction. Similarly, an anticlockwise torque tends to turn an object in the anticlockwise direction.

Torque is also known as moment of force.

Unit of torque

Torque (τ) = Force (F) × Perpendicular distance (D)

Since the unit of force is newton (N) and the unit of distance is metre (m), the unit of torque is Nm (newton-metre).

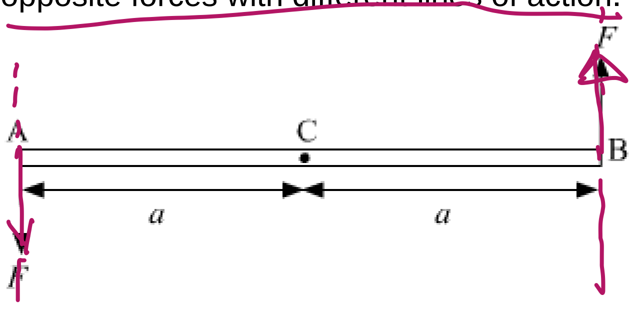
Now, you have understood that a door has the handle at the extreme end but not in the middle because, to produce the same torque on the door, less force is to be applied at the point of application of force that is farthest from the hinge.

Couple

When two equal and opposite forces act on a body and their lines of action do not coincide, then the body will not move but rotate about the given axis, e.g., a tap that is being opened or closed.

Definition of couple

A couple is said to be acting on a system or body when it is under two equal and opposite forces with different lines of action.

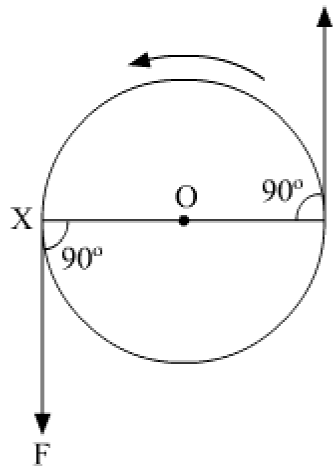


A couple of forces are acting on the rod.

You must have seen several examples. Some of them are as follows.

(i) When you have to open the lid of a bottle, you have to apply a couple of forces tangentially on it in order to rotate the lid and open the bottle.

(ii) When two strings are tied to a wheel, and two equal and opposite forces are exerted tangentially on the wheel, the wheel tends to rotate.



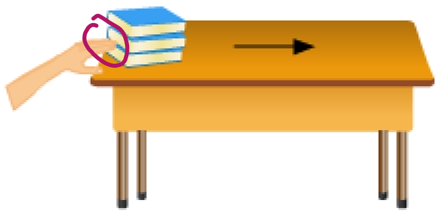
Here, we can also see that the two equal and opposite forces act in such a way that their lines of action do not coincide.

Thrust and Pressure

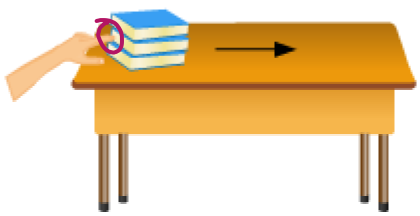
Thrust and Pressure: An Overview

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.

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.

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

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 m², produces a pressure of 500 Pa. Find the value of the force.

Solution:

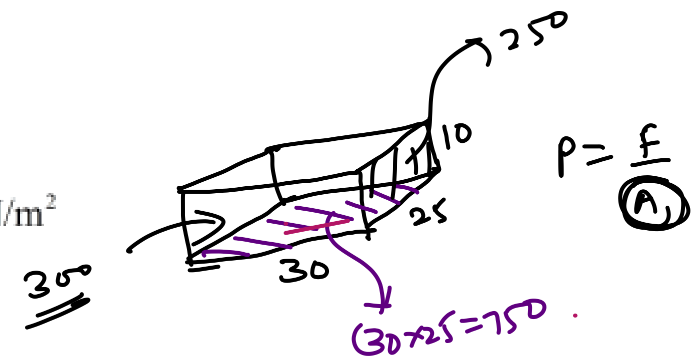
$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$
$$\Rightarrow \text{Force} = \text{Pressure} \times \text{Area}$$
$$= 0.5\ \text{N/m}^2 \times 500\ \text{m}^2 = 250\ \text{N}$$

Example 2:

A force of 100 N is applied on an area of 2 m². 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/s²)

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:

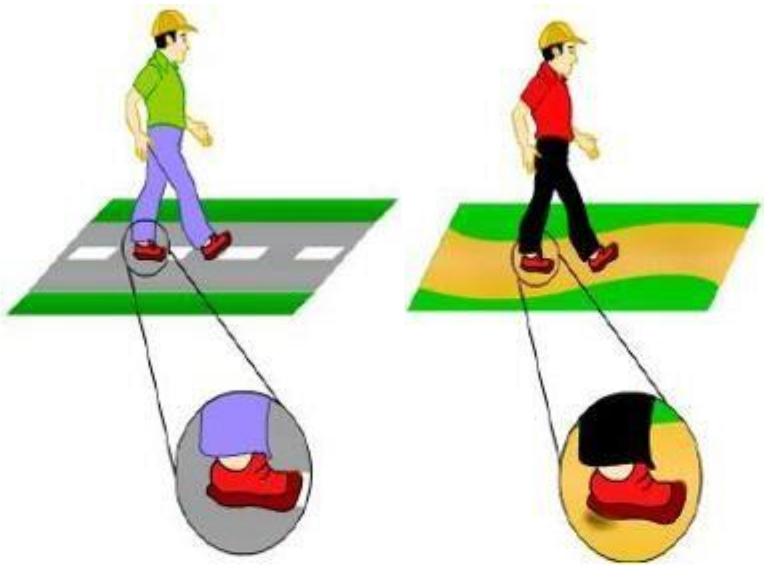
The steel belt covering the wheels of an army tank has a large surface area. This reduces the pressure exerted by the tank on the ground. As a result, the tank can move easily without damaging the ground or sinking in it.

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.

P = F/A

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

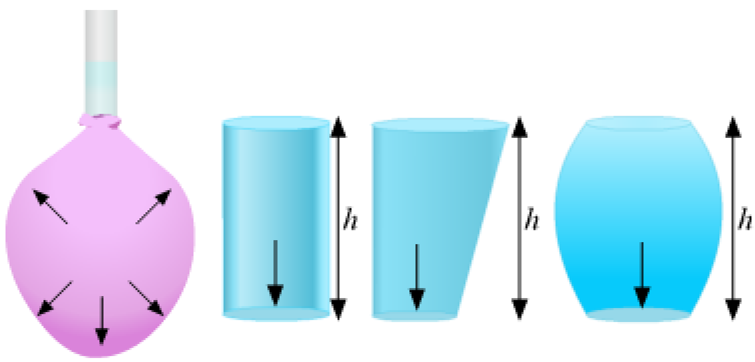
snow without sinking into it.

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.



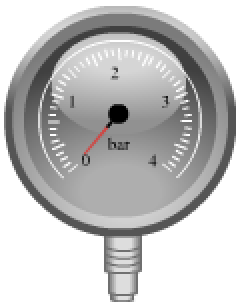
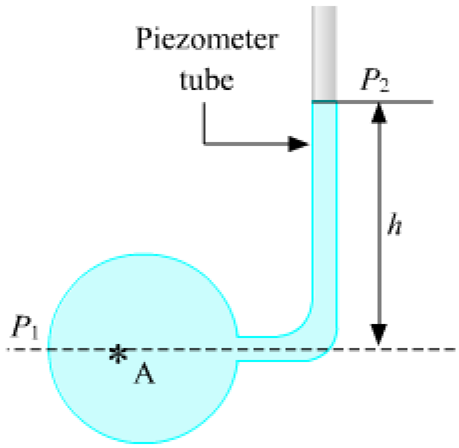
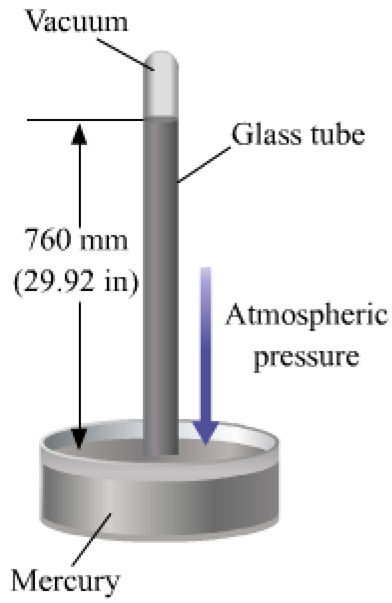
The shape and area of a fluid surface do not affect the pressure exerted by the fluid. It is the height of the fluid column which determines this pressure.

Did You Know?

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

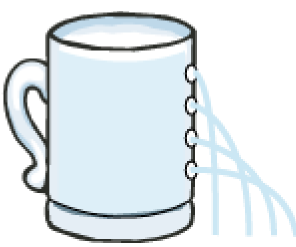
Instruments that Measure Pressure

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?**

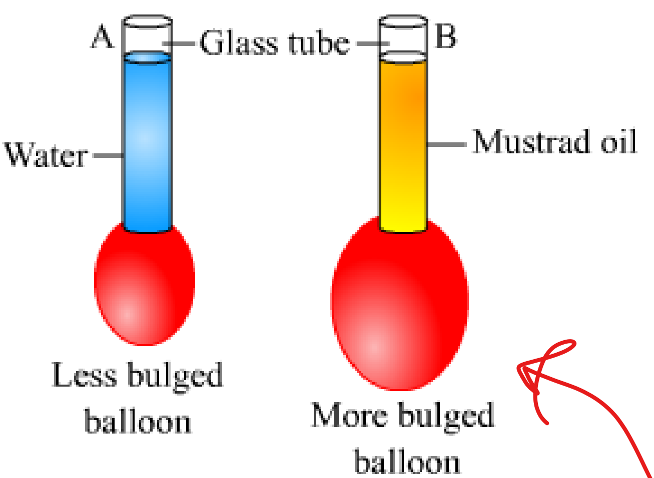
You will observe that water coming out of the holes fall at different distances. The pressure at which water comes out of the holes is directly proportional to its depth.

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.

Atmospheric Pressure

You know that solids as well as liquids exert pressure. **Do you know that gases also exert pressure?** Let us see how gases exert pressure.

Air in an inflated tyre exerts pressure on the tyre from inside.

Air in an inflated balloon exerts pressure on its skin.

Atmosphere exerts pressure on the surface of the Earth.

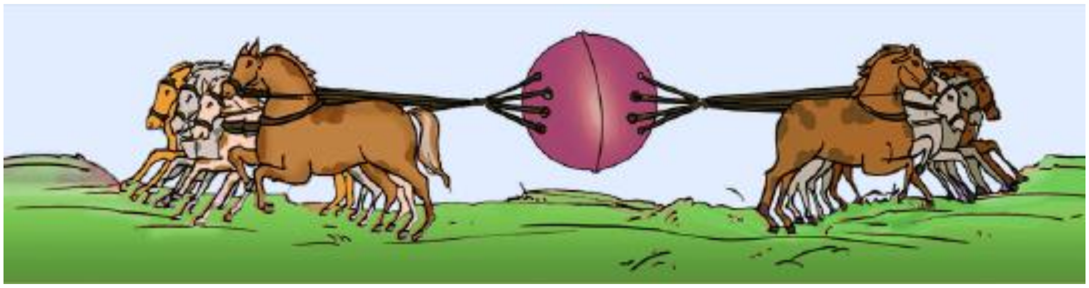
The Earth is surrounded by an envelope of different gases. This envelope of different gases is known as the **atmosphere**. It extends up to a few thousand kilometres. These gases exert pressure known as ***atmospheric pressure***. This pressure results from the weight of the gas molecules present in air.

The weight of air in a column of height of the atmosphere and area 10 cm × 10 cm is as large as 1000 kg.

Take an empty soft drink can. Pump all the air out of it, till practically there is no air left inside the can. This can be done using a vacuum pump. Due to the absence of air inside the can, it can be squeezed and crumbled under the effect of atmospheric pressure acting on the outer surface of the can.

Interesting Fact:

Otto von Guericke, a German scientist, in 1654 at Magdeburg took two hollow metallic hemispheres of 51 cm each. He joined the two hemispheres together. When there was air inside them, they could be easily separated from each other. However, when all the air was pumped out, the force due to the atmospheric pressure on the outer surface of the two hemispheres became so large, that even horses on each side could not separate the two hemispheres.



The 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 the Earth. As gases have mass, they exert pressure on their surroundings. Atmosphere is made up of gases; hence, it also exerts pressure on the Earth' surface as well as on all its life forms. This pressure exerted by the atmosphere is called atmospheric pressure.

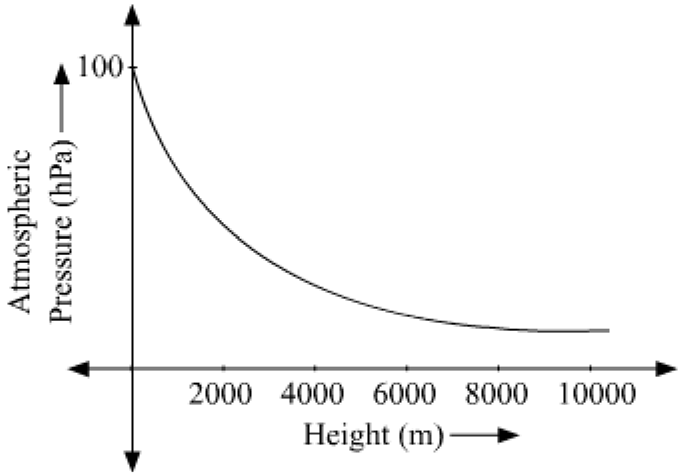
We can now define atmospheric pressure as follows:

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.

Measurement of Atmospheric Pressure

The value of atmospheric pressure is not the same at all places. It is higher at sea level than on mountains. At sea level, the atmospheric pressure is about 100000 Pa or 102102 hPa. The below graph shows the variation of Earth's atmospheric pressure with height from the sea level.



To measure atmospheric pressure, we use an instrument called Barometer.

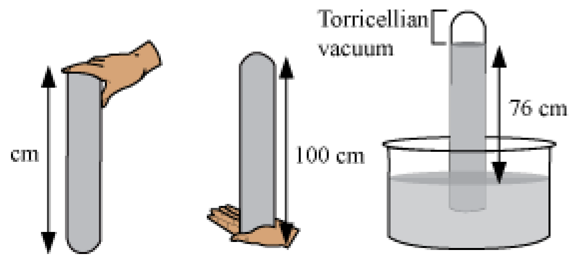
Barometer

Construction—

- A hard glass tube is taken and filled with mercury.
- The open end of the tube is closed with a finger.
- The tube is inverted over a trough filled with mercury.
- The 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; the mercury column shows the height of 76 cm.

*__Mercury is used in a barometer because—__

- It is the heaviest liquid. Hence, only 76 cm of mercury column is needed.
- 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.



Drawbacks of a Barometer—

- Trough is open; hence, there is always a chance of impurities getting mixed with pure mercury.
- It is not portable.
- It is not compact.

Effects of Atmospheric Pressure

If such a big force is acting all around us, then how is it that it is not felt by us? It is not felt by us because the oxygen in our blood also has pressure, which acts in the direction opposite to atmospheric pressure. This pressure of oxygen balances the pressure of the atmosphere. Hence, atmospheric pressure is not felt by us.

If we travel in an airplane and it is not pressurised properly, then our nose would start bleeding at high altitudes. This would happen because pressure at high altitudes is lesser than the pressure of the oxygen in our blood. This difference of pressure would burst the capillaries within our nose, thereby making our nose bleed.

So, a passenger aircraft is pressurised properly so that the pressure in the aircraft is the same as at the ground level. Even astronauts wear space suits to counter the low pressure that exists in outer space. Fishes in deep sea water experience more pressure than we do on land; hence, their internal body pressure is more than ours.

If these fishes are brought out of water, their body bursts because of the excess outward pressure that exists in the blood.

Similarly, if you take a fountain pen to a higher altitude, you will see that it leaks. This happens because the pressure outside gets reduced in comparison to the pressure inside. The pressure inside the pen squeezes the ink out.

When you use a straw to suck in a soft drink, the same principle is at work. When you suck air out of a straw, the pressure inside it falls. This fall in pressure is compensated by the liquid that is forced up by atmospheric pressure.