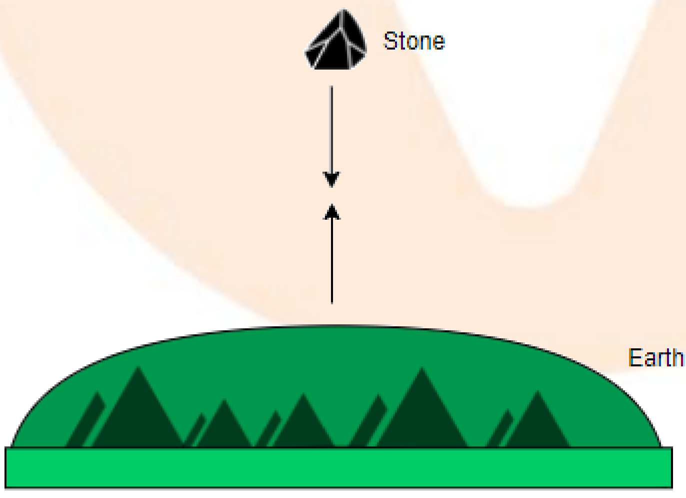
Revision Notes

Class 9 Science Chapter 9 - Gravitation

- Toss a stone from a great height. What are your observations?
- The stone, which was at first at rest, begins to move towards the ground and reaches its maximum speed right before it meets it.
- The stone is not travelling at a constant rate. Its speed fluctuates at all times, indicating that the stone is accelerating.
- A **force** is necessary to cause an acceleration in a body, according to **Newton's second law of motion**.
- The stone was not pushed or pulled in any way. What was the source of the force?
- Sir **Isaac Newton** came up with the solution to this dilemma after seeing an apple fall from a tree.
- His thesis was that the apple is attracted to the Earth, and the Earth is attracted to the apple The Earth's force on the apple is enormous, and as a result, the apple arrives on Earth.
- The apple, on the other hand, is unable to draw the Earth since the force it exerts on it is insignificant.
- As a result, we can deduce that the acceleration caused by Earth's immense force of attraction is the cause of the stone's acceleration.



A stone falling towards Earth

- It is evident from the preceding example that this force of attraction ties our complicated universe together, keeps the moon revolving around the Earth, keeps all of the planets in their orbits around the Sun, and helps us walk correctly on the Earth's surface.

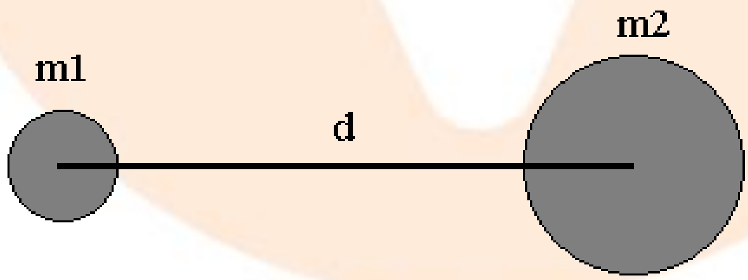
- **The force of gravitation**, or **gravitation**, is a **form of attraction that exists between any two objects in the universe.**
- **The force of gravity** or **gravity** is the **attraction or gravitational force between Earth** (or any planet) **and any other material objects in the cosmos.**

The Universal Law of Gravitation or Newton's Law of Gravitation:

- The **universal law of gravitation** is a mathematical relationship that **Sir Isaac Newton** proposed **to measure the gravitational force**.
- According to this law "**Every particle in the universe attracts every other particle with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them, the direction of the force being along the line joining the masses**".
- Consider two mass m_1 and m_2 objects separated by a distance d. The **gravitational force** F is **proportional** to the product of the **masses**, according to **Newton's law**.

  $F \propto m_1 m_2 \quad ...... (1)$

  and **inversely proportional to the square of the distance between the masses** $F \propto \frac{1}{d^2} \quad ...... (2)$



Two Objects of Masses m_1 and m_2 separated by a distance d.

Inversely proportional is always represented as directly proportional to the reciprocal of that quantity.

Combining equation (1) and equation (2), we get

$$F \propto \frac{m_1 m_2}{d^2}$$

$$F \propto \frac{G m_1 m_2}{d^2} \quad \ldots\ldots (3)$$

Where G is a **proportionality constant** known as the **universal gravitational constant**.

G is known as the universal constant because its **value remains constant throughout the cosmos and is unaffected by object masses.**

Universal Gravitational Constant:

- The **mathematical form** of **Newton's Law of Gravitation** is

  $$F = \frac{G m_1 m_2}{d^2}$$

  If $m_1 = m_2 = 1$, and $d = 1$, then

  $$F = \frac{G \times 1 \times 1}{1^2}$$

  $$F = G$$

- As a result, the **universal gravitational constant** can be defined as the **gravitational force** that exists between two unit masses separated by a unit distance.

- SI **unit of gravitational constant:**

  $$G = \frac{Fd^2}{m_1 m_2}$$

  SI Unit of force F is N, SI unit of distance is metres and that of mass is kg.

  $$\text{SI Unit of } G = \frac{Nm^2}{kg \times kg}$$

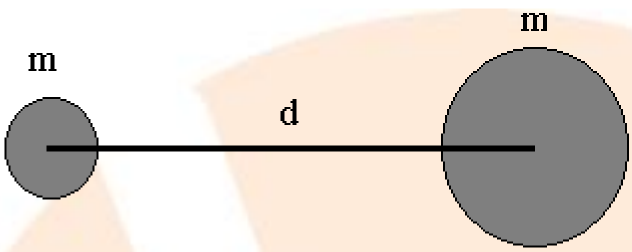
  $$\text{SI Unit of } G = N\frac{m^2}{kg^2} \text{ or } Nm^2kg^{-2}$$

  The **experimental value** of G equal to $6.6734 \times 10^{11} \frac{Nm^2}{kg^2}$ was measured by **Sir Henry Cavendish** in 1798.

Dependence of Gravitational Force on Mass:

The **force of attraction** is directly proportional to the mass of the body, according to **Newton's law of gravitation**.

1. Two objects of mass m separated by a distance d:

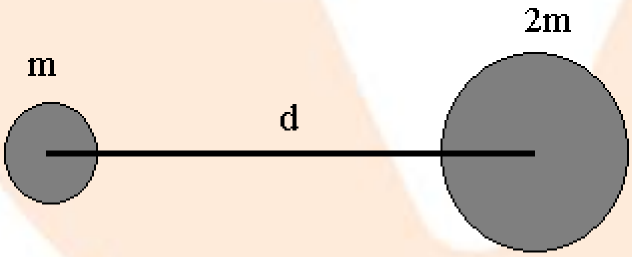


If two objects of mass m are separated by a distance d, the force between them is given by the relation are as follows;

$$F_1 = \frac{Gmm}{d^2}$$

$$= \frac{Gm^2}{d^2}$$

2. Two objects of mass m and $2m$ separated by a distance d :



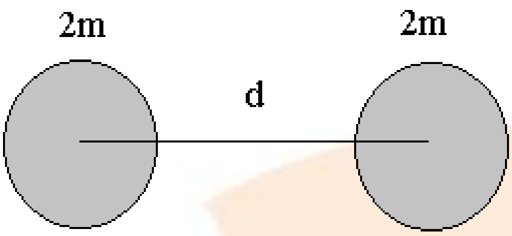
When the **mass of one of the two objects is doubled**, force of attraction is given by the relation are as follows;

$$F_2 = \frac{Gm_2m}{d^2}$$

$$= \frac{2Gm^2}{d^2}$$

$$= 2F_1$$

3. **Two objects of mass $2m$ separated by a distance d:**



When the **masses of both bodies are doubled**, the force of attraction is given as;

$$F_3 = \frac{G_2 m_2 m}{d^2}$$

$$= \frac{4Gm^2}{d^2}$$

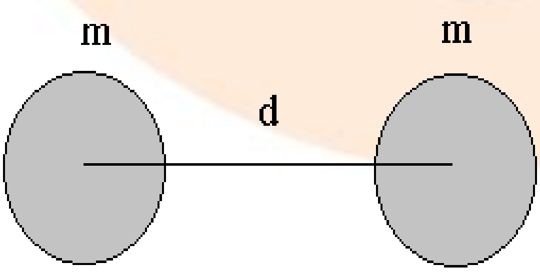
$$= 4F_1$$

That is **whenever the mass increases the force of attraction also increases**.

Dependence of Gravitational Force on Distance:

The force of attraction between two bodies is **inversely proportional to the square of their distance**, according to the universal law of gravitation.

1. **Force of attraction between two bodies of mass m separated by a distance d :**

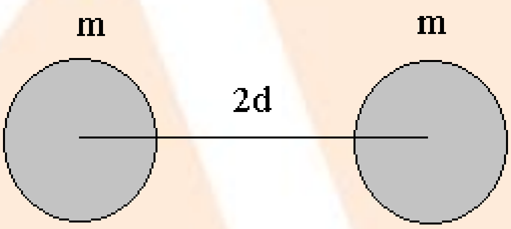


$$F_1 = \frac{Gm_1m_2}{d^2}$$
$$= \frac{Gm^2}{d^2}$$

Here, two bodies of mass m are separated by a distance d and hence,

$$F_1 = \frac{Gm^2}{d^2}$$

2. The force of attraction when the distance is doubled:

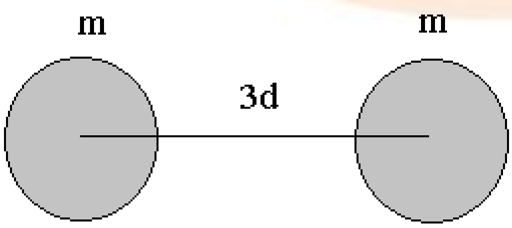


$$F_2 = \frac{Gmm}{(2d)^2}$$
$$= \frac{Gm^2}{4d^2}$$

Here, two bodies of mass m are separated by a distance $2d$ and therefore,

$$F_2 = \frac{1}{4}\frac{Gm^2}{d^2}$$
$$F_2 = \frac{1}{4}F_1$$

3. Force of attraction when the distance between the bodies is increased three times:



$$F_3 = \frac{Gmm}{(3d)^2}$$

$$= \frac{Gm^2}{9d^2}$$

Here, two bodies of mass m are separated by a distance $3d$ and therefore,

$$F_3 = \frac{1}{9}\frac{Gm^2}{d^2}$$

$$F_3 = \frac{1}{9}F_1$$

It results that

a) When the **distance** is **doubled**, the **force** is **decreased to** $\frac{1}{4}$ **th of its original value**.

b) If the **distance** is **extended three times**, the **force** is **reduced to** $\frac{1}{9}$ **th of its original value.**

c) We can conclude from the preceding example that **the force of attraction between the bodies varies inversely with the square of distance between them.**

Gravitational Force between two Light Objects:

Let us now calculate the force of gravitation existing between two unit masses separated by a unit distance.

$m_1 = 1\ kg$

$m_2 = 1\ kg$

$d = 1\ m$

$$G = 6.6734 \times 10^{-11} \frac{Nm^2}{kg_2}$$

Therefore, force can be calculated as;

$$F = \frac{Gm_1m_2}{d^2}$$

$$F = \frac{6.6734 \times 10^{-11} \times 1 \times 1}{1^2}$$

$$F = 6.6734 \times 10^{-11}\ N$$

This is a very weak force.

To find Force existing between two objects of masses $60\ \text{kg}$ and $100\ \text{kg}$ separated by a distance of $1\ \text{m}$:

$$F = \frac{Gm_1m_2}{d^2}$$

$$F = \frac{6.6734\times10^{-11}\times60\times100}{1^2}$$

$$F = 6.6734\times10^{-8}\times6$$

$$F = 40.04\times10^{-8}\ \text{N}$$

This is also a very weak force.

It is clear from the preceding two examples **why we do not feel the force produced by one object (on the Earth's surface) on the other**.

Gravitational Force between Massive Objects:

Let's calculate the force of attraction between a $50\ \text{kg}$ object and the Earth. The Earth's mass is approximately $6\times10^{24}\ \text{kg}$. The Earth's distance from the object is roughly $64\times10^5\ \text{m}$.

The force of attraction between the object and the Earth is,

$$F = \frac{Gm_1m_2}{d^2}$$

$$= \frac{6.6734\times10^{-11}\times6\times10^{24}\times50}{\left(64\times10^5\right)^2}$$

$$= \frac{6.6734\times6\times5\times10^{-11}\times10^{25}}{(64)^2\times10^{10}}$$

$$= \frac{6.6734\times6\times5\times10^{-11}\times10^{25}\times10^{-10}}{64\times64}$$

Therefore,

$$F = \frac{6.6734\times6\times5\times10^{4}}{64\times64}$$

$$= \frac{6.6734\times3\times10^{5}}{64\times64}$$

$$F = 488.7\ \text{N}$$

This force is strong, we cannot ignore it.

Now let us calculate the force of attraction between Earth and the Sun. The mass of the Earth $= 6\times10^{24}$ kg

The mass of the Sun $= 1.99\times10^{30}$ kg

The distance between the Earth and the Sun $= 15\times10^{10}$ m

Therefore,

$$F = \frac{Gm_1m_2}{d^2}$$

$$= \frac{6.6734\times10^{-11}\times6\times10^{24}\times1.99\times10^{30}}{\left(15\times10^{10}\right)^2}$$

$$= \frac{6.6734\times6\times1.99\times10^{-11}\times10^{24}\times10^{30}\times10^{-20}}{225}$$

Hence,

$$F = \frac{6.6734\times6\times1.99\times10^{23}}{225}$$

$$F = 3.541\times10^{22}\ \text{N}$$

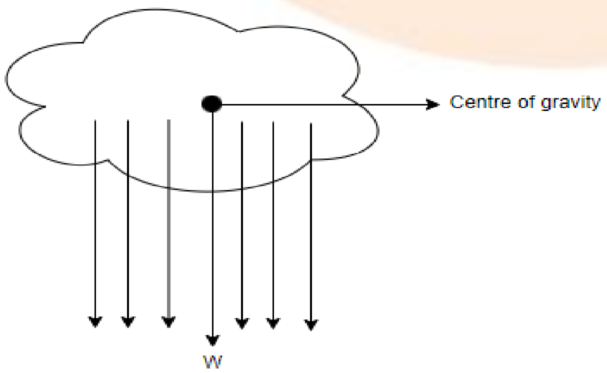
This force is very large and it is this force which keeps the planets in their respective orbits.

Conclusion:

When two objects of ordinary size are considered, the gravitational force is quite tiny, but when at least one of the items is huge, the force is very large.

Centre of Gravity:

- Every particle is drawn to the centre of the earth, as we all know. A body is made up of number of particles. Because the body is small in comparison to the earth, the gravitational attraction acting on these particles can be considered parallel to one another, as illustrated in the diagram.



- **A single force acting vertically in the downward direction can be replaced by a single force acting through a fixed location called the body's centre of gravity**.
- The resulting force is equivalent to the body's weight.
- As a result**, the centre of gravity is the point through which the body's weight acts regardless of its position.**
- For bodies which are of **regular shape and which have uniform density**, **the centre of gravity lies at the geometrical centre of the body.**
- **The geometrical centre of gravity of bodies of regular shape and uniform density is located at the geometrical centre of the body.**

Application of Newton's Law of Gravitation:

- One of the important applications of Newton's law is to **estimate masses of binary stars**. A binary star is a system of two stars orbiting round their common centre of mass.
- Any **irregularity in the motion** of a star indicates that it might be another star or a planet going round the stars. This regularity in the motion of a star is called a wobble.

Mass and Weight:

- Mass and weight are sometimes confused, yet they are two distinct numbers. Let's try to figure out what makes them different.
- **Mass of a body is defined as the amount of matter contained in it.**
- The **kilogramme** is the SI **unit of mass** (kg).
- Mass is a **scalar quantity**.
- The amount of matter contained in a body does not vary with time or location, i.e., the mass of a body remains constant throughout the cosmos. However, the masses of two bodies might differ significantly.
- A **pan balance** is used to determine a person's mass.
- **Weight is defined as the force with which an object is pulled towards the centre of the Earth.**
- Weight of a body = force exerted by the Earth = mg (according to
- Newton's second law of motion)
- W = mg

  SI **unit of weight is Newton**.

  For example, the weight of a body having a mass of 1kg is

$W = mg$

$W = 1 \times 9.8$

$W = 9.8\ N$

- We know that $kg\ wt$ is commonly used as the **unit of weight**.
- $1kg$ weight **is the force with which an object of mass** $1kg$ **is pulled towards the Earth.**

$W = mg$

$1\ kg\ wt = 1 \times 9.8$

$1\ kg\ wt = 9.8\ N$

- **Spring balance** is used to determine weight.
- Weight fluctuates from location to place because it is affected by gravity's acceleration.
- **At the poles, a body weighs more than in the equator**, and **at the centre of the Earth, a body's weight becomes zero** because **gravity's acceleration is zero**

Difference between Mass and Weight:

Mass	Weight
It is the amount of matter contained in an object	It is the force with which an object is pulled towards the Earth
The mass of a body is constant throughout the universe	Weight varies from place to place as g varies
Mass can never be equal to zero	Weight can be equal to zero
Mass is a scalar quantity	Weight is a vector quantity
SI unit of mass is kg	SI unit of weight is Newton

To show that weight of a body on moon is $\frac{1}{6}^{th}$ its weight on Earth:

- Let m be the mass of a body on Earth. Its weight on Earth is given by the equation is as follows;

$W_e = mg_e$

$$W_e = \frac{mGM_e}{R_e^{\ 2}} \quad ----(1)$$

Since,

$$\left[g_e = \frac{GM_e}{R_e^{\,2}}\right]$$

The weight of the same body on moon (Wm) is given by,

$$W_m = mg_m$$

$$W_m = \frac{mGM_m}{R_m^{\,2}} \qquad ----(2)$$

Since,

$$\left[g_m = \frac{GM_m}{R_m^{\,2}}\right]$$

By dividing equation (2) by equation (1) we get,

$$\frac{W_m}{W_e} = \frac{mGM_m}{R_m^{\,2}} \times \frac{R_e^{\,2}}{mGM_e}$$

$$\frac{W_m}{W_e} = \frac{M_m R_e^{\,2}}{R_m^{\,2} M_e}$$

$$\frac{W_m}{W_e} = \left(\frac{M_m}{M_e}\right)\left(\frac{R_e}{R_m}\right)^2 \qquad ----(3)$$

But we know that , $M_e = 100M_m$ and $R_e = 4R_m$, therefore

$$\frac{M_m}{M_e} = \frac{1}{100}$$

$$\frac{R_e}{R_m} = 4$$

By substituting above values in equation (3), we get

$$\frac{W_m}{W_e} = \left(\frac{1}{100}\right)(4)^2$$

$$\frac{W_m}{W_e} = \frac{16}{100}$$

$$\frac{W_m}{W_e} = \frac{1}{6.25}$$

$$\frac{W_m}{W_e} = \frac{1}{6}$$

$$W_m = \frac{1}{6} W_e$$

That is the weight of a body on moon is $\frac{1}{6}$ th its weight on Earth.

Weightlessness:

- We frequently hear that astronauts in space experience weightlessness. What exactly does this imply?
- Let us show weightlessness with a simple experiment. Suspend a stone from a spring balance, and the weight of the stone is displayed on the spring balance's pointer.
- Allow the stone, as well as the spring balance, to fall freely.
- The spring balance registers 0 weight, showing that the stone is devoid of weight.
- Does this imply that the stone has no weight?
- The stone, on the other hand, is in a state of weightlessness because it is falling freely.
- When the weight of one object is balanced against the weight of another, the body becomes aware of its own weight.

The spring balance shows the weight of the stone

Freely falling spring balance with the stone shows a zero reading

- Let us now attempt to explain why an astronaut in a spaceship feels weightless.
- When an astronaut is orbiting the Earth in a spaceship, both the person and the spaceship are in free fall towards the Earth.
- During a free fall, both go downhill with the same acceleration, which is

equal to gravity's acceleration.

- As a result, the astronaut exerts no force on the spaceship's sides or floor, and the spaceship's sides and floor do not push the astronaut up.
- As a result, the astronaut feels weightless while orbiting the Earth in a spaceship.

A Satellite / Spaceship Orbiting the Earth

Density:

- Cotton takes up more room than iron, hence $0.5\ \text{kg}$ of cotton takes up more space than $0.5\ \text{kg}$ of iron.
- Iron particles are tightly packed, whereas cotton particles are loosely packed. There is more iron packed into a given volume.
- This explains why iron is heavier than cotton of the same volume.
- **A substance's density is defined as the mass per unit volume of the substance.**
- $\text{Density} = \dfrac{\text{Mass of the substance}}{\text{Volume of the substance}}$

  $D = \dfrac{M}{v}$

  Where, D represents the density, M mass and v volume.

  SI unit of density is $\dfrac{\text{kg}}{\text{m}^3}$
- When specific criteria are met, a substance's density remains constant.
- As a result, one of a material's distinguishing characteristics is its density, which may be used to determine the purity of any substance.

Relative Density of a Substance:

- We utilise the relation $D = \frac{M}{v}$ to determine the **density** of a substance or an item by determining the mass and volume of the substance.
- Only if the thing has a regular shape is this possible.
- Measuring the size of an object with an irregular shape is difficult.
- In such instances, we express the object's density in terms of water density.
- The relative density of a substance is the ratio of its density to the density of water at 4 degrees Celsius. The relative density of water is assumed to be one.
- What does it mean when someone says gold's relative density is 19.3 ?
- It means that gold has 19.3 times the density of water of the same volume.
- **Objects with a relative density less than one float in water, while those with a density larger than one sink.**

$$\text{Relative density of a substance} = \frac{\text{Density of the substance}}{\text{Density of water at } 4^0\text{C}}$$

$$= \frac{\left(\frac{\text{Mass of the substance}}{\text{Volume of the substance}}\right)}{\left(\frac{\text{Mass of water}}{\text{Volume of water}}\right)}$$

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

- Now, if we take equal amounts of the material and water, we get the Following:

$$\text{Relative density of a substance} = \frac{\text{Mass of the substance}}{\text{Volume of an equal volume of water}}$$

- **The relative density has no unit because it is a ratio of two identical quantities.**

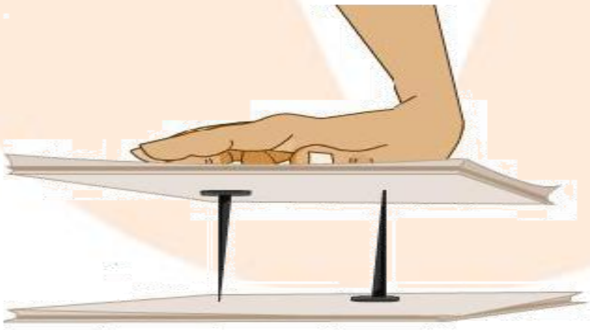
Thrust and Pressure:

- We defined force as an external agent that modifies the direction of motion, speed, or shape of the body at the start of this chapter.
- We were simply talking about the forces acting at a spot on a body the whole time.
- Consider the forces at work in a given location.
- If you want to hang a poster on your classroom bulletin board, you must apply force to the head of the drawing pin, which is perpendicular to the surface of the bulletin board.

- This force, which is acting perpendicular to the surface, is referred to as thrust.

Force Applied is Perpendicular to the Board

- **The force operating on a body perpendicular to its surface is known as thrust.**
- **The Newton is the** SI **unit of thrust** (N) **.**
- Let's see if there's a relationship between the **applied force (thrust) and the region on which it acts**.
- Hold a pin erect in the middle of a stack of papers. Another pin should be placed next to it, upside down, with its flat head resting on the pile.
- Place a flat object, such as a duster, on both of these pins to press them down. We notice that the erect pin pierces through the stack of papers.



Applying Force on Both the Pins, the Erect Pin Pierces Through the Pile of Papers

- This is because the force operating on the erect pin is applied over a limited area, but the force acting on the second pin is applied over a broad area.

- A thin yet durable string strap is used to hold your bag.
- Now, using a wide cloth band as a strap, raise the same bag. A school bag with a wide textile band is more comfortable to carry than one with a tiny strip.
- This is because the weight of the books is dispersed over a larger area of the shoulder in the second example, exerting less force.
- As can be seen from the examples above, the efficiency of the applied force is dependent on the region on which it acts.
- There is now a requirement to define a new physical quantity known as **pressure**.
- **The force operating on a unit area is known as pressure**

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

$$\text{Pressure} = \frac{\text{Thrust}}{\text{Area}}$$

The SI **unit of pressure is** $\frac{\text{N}}{\text{m}^2}$ **.**

$\frac{\text{N}}{\text{m}^2}$ is known as **Pascal** (Pa) in honor of the **French Scientist Blaise Pascal.**

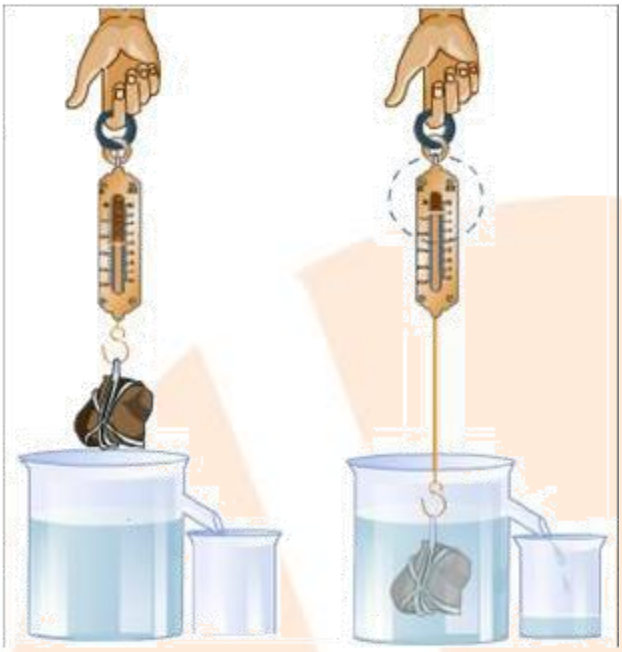
$$1\ \frac{\text{N}}{\text{m}^2} = 1\ \text{Pascal}$$

- Because a kilopascal is a very small unit, we frequently utilise it.
- **The force exerted and the area over which the force acts are the two factors that determine pressure.**

Buoyancy and Archimedes' Principle:

- It is general knowledge that when bodies are submerged in water or any other liquid, they appear lighter.
- While bathing, we notice that as soon as the mug of water rises over the water's surface, it becomes noticeably heavier.
- When a fish is taken out of the water, it looks to be heavier in the air than it was in the water.
- Let's have a look at why that is.
- Because the liquid or water exerts an upward force on the items immersed in it, they appear to be lighter in water or any other liquid.
- Let's see if there is an apparent loss of weight while immersed in water by conducting an experiment.
- Attach a stone to one of the spring balance's ends. Suspend the spring

balance in the manner depicted in the diagram.



Experimental set up to Prove Archimedes' Principle:

- Take note of the spring balance reading. Let's call it W1 .
- Now carefully immerse the stone into a jar of water and record the reading on the spring balance.
- The spring balance's reading continues to drop until it is entirely submerged in water.
- The weight of the stone is determined by the reading on the spring balance.
- We may deduce that the weight of the object is reducing as it is dropped in water because the reading continues to decrease.
- The apparent weight loss indicates that a force is working on the object in an upward direction, causing it to lose weight.
- **The buoyant force is the upward force exerted on an object immersed in a liquid that causes the object to appear to lose weight.**
- **Buoyancy is defined as a liquid's tendency to exert an upward force on an object placed in it, causing it to float or rise.**

Factors Affecting the Buoyant Force:

- We know that an iron nail sinks when placed on the surface of water, whereas an iron ship floats. This is due to the ship's larger size or volume.
- When an iron nail and a cork of equal mass are placed in water, the iron nail sinks because the density of the iron nail is greater than that of the water, whilst the density of the cork is lower.

- When the density of the liquid exceeds the density of the body's material, the body floats due to the **buoyant force** it exerts, and vice versa.
- **The buoyant force experienced by a body while submerged in a liquid is dependent on the volume of the body and the density of the liquid**, as shown in the examples above.

Archimedes' Principle:

- **Archimedes investigated the up thrust acting on a body when it is partially or entirely submerged in a fluid, conducting various tests, and finally stating the Archimedes' Principle.**
- **When a body is partially or completely immersed in a fluid, it feels an up thrust (buoyant force) equal to the weight of the liquid displaced, according to this principle.**

Experiment to Verify Archimedes' Principle:

- Using a physical balance, determine the mass (m) of a clean and dry beaker.
- Suspend a stone from a spring balance to determine its weight. Fill a Eureka can (a beaker with a spout towards the top) with water until it reaches the spout. Place the mass m beaker under the spout.
- Gently lower the solid into the Eureka can, suspended from spring balance, until the stone is entirely immersed in water.
- When submerged in water, the stone displaces a particular amount of water.
- The spring balance registers a lower value, indicating that the solid is **up thrust**. The water that has been displaced is collected in the beaker.
- The mass of the water and beaker is calculated using the physical balance. Let's call it m_1.
- Therefore, Amount of water displaced $= m_1 - m$
- When the apparent loss of weight of the solid in water is compared to the amount of water displaced, they are found to be equal. As a result, this experiment proves Archimedes' Principle.

Application of Archimedes' Principle:

- It's employed in the construction of **ships and submarines**.
- This principle underpins **lactometers and hydrometers**, which are used to determine the **density of liquids** and **measure the purity of a sample of milk.**