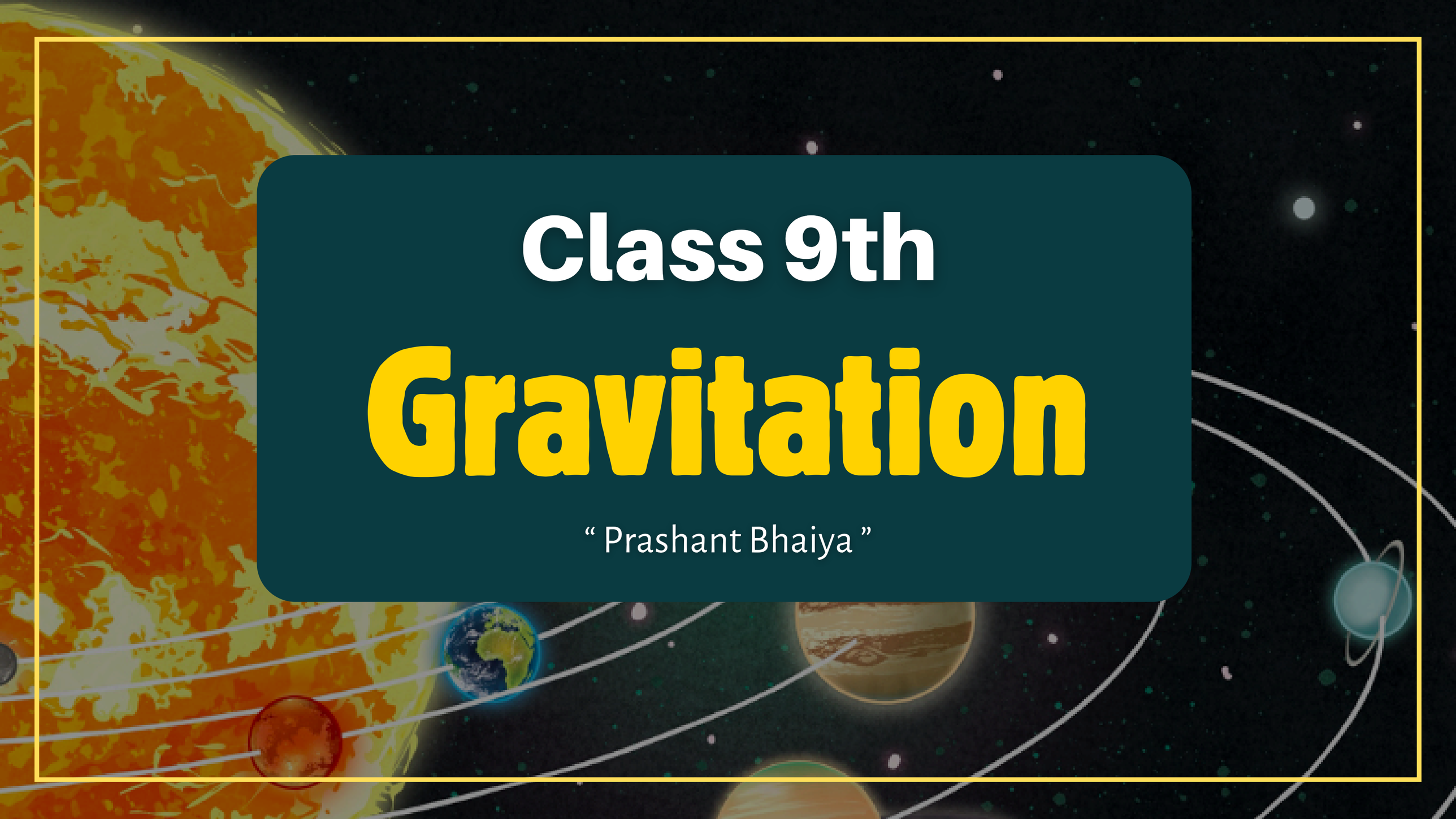


Class 9th

Gravitation

" Prashant Bhaiya "

Topics to be Covered

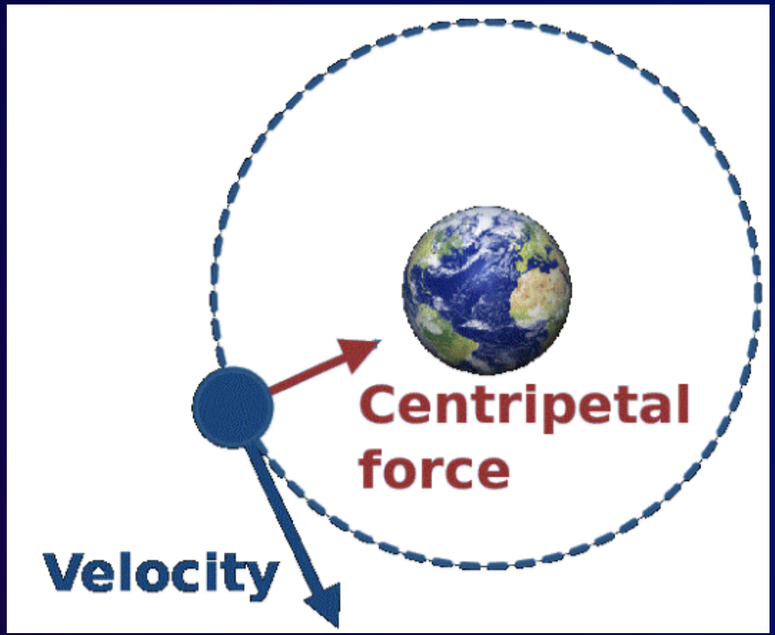
- Gravitation
- The Universal Law of Gravitation
- Free Fall
- The Value of g
- Mass and Weight
- Weight of an Object on the Moon
- Thrust and Pressure
- Buoyancy
- Archimedes’ Principle

Gravitation

In 1666, Newton saw an **apple** fall and wondered, "Why did it fall straight down?" He realized a force must pull objects toward Earth, the same force that keeps planets in orbit. He named this force **gravity**, leading to one of the greatest scientific discoveries.

Centripetal Force?

- A stone tied to a thread moves in a circle due to **centripetal force**, acting towards the center.
- Example: Earth's gravity provides the centripetal force for the Moon's orbit.
- Circular motion involves constant direction change, altering velocity.
- Centripetal force ensures circular motion, preventing the object from moving straight.
- The Moon's orbit is maintained by Earth's centripetal force.

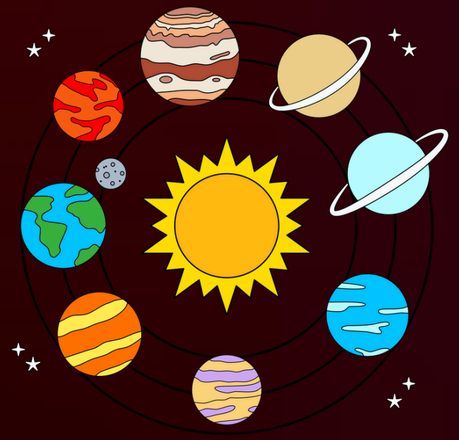


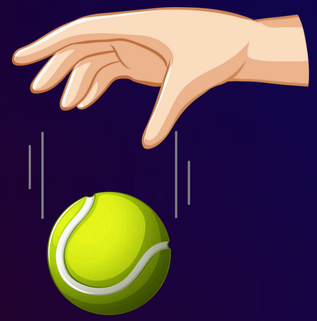
Gravitation

“Gravitation or just gravity is the force of attraction between any two bodies.”

Examples:

- The force that causes the ball to come down is known as gravity
- Gravity keeps the planets in orbit around the sun.
- Gravity is the force that causes a rock to roll downhill.





Newton’s Law of Gravitation

Newton’s Law of gravitation states that every object in the universe attracts every other object by a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

Let there are two objects of mass m_1 and m_2 and the distance between the objects is r, then according to law of universal attraction, the attraction between the objects

$F \propto m_1 . m_2$

And $F \propto \frac{1}{r^2}$

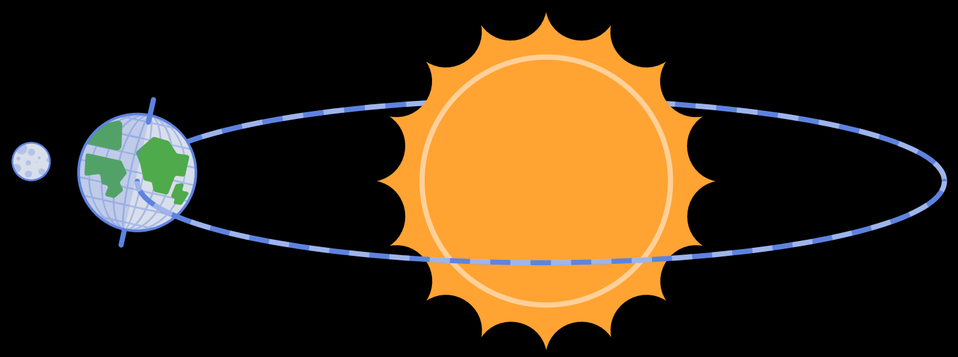
Therefore, $F \propto \frac{m_1 . m_2}{r^2}$

Or $F = G\frac{m_1 . m_2}{r^2}$, Where G is constant whose value is 6.67×10^{-11}.

Lets derive unit for gravitational constant (G):

Q. The Earth is acted upon by the gravitational force of the Sun, even though it does not fall into the Sun. Why?

[2013, 2017, 2020]



Q. A stone and the Earth attract each other with an equal and opposite force. Why then do we see only the stone falling towards the Earth but not the Earth rising towards the stone?

Q. How does the force of gravitation between two objects change when the distance between them is reduced to half?

Q. Determine the gravitational force if the mass of two bodies are 80 kg and 200 kg and they are separated by a distance of 6m.

Q. What is the magnitude of the gravitational force between the Earth and a 1 kg object on its surface? (Mass of the Earth is 6×10^{24} kg and radius of the Earth is 6.4×10^{6} m.)

Importance of the Universal Law of Gravitation:

- The force that binds us to the earth.
- The motion of moon around the earth.
- The motion of earth around the sun.
- The tides due to moon in the sea.

Acceleration due to Gravity

According to Newton's law of gravitation:

- G = gravitational constant.
- M = mass of the Earth.
- m = mass of the object.
- R = Earth's radius.

$$F = \frac{G \cdot M \cdot m}{R^2}$$

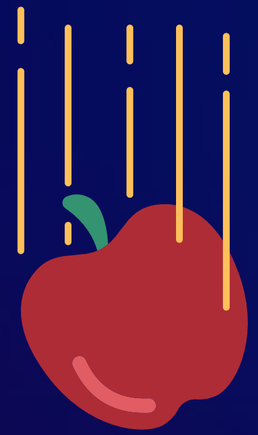
The force on an object due to gravity:

$$F = m \cdot g$$

{ g = acceleration due to gravity }

Equating Forces:

$$m \cdot g = \frac{G \cdot M \cdot m}{R^2} \longrightarrow g = \frac{G \cdot M}{R^2}$$



Value of g on the surface of Earth:

Where:

- $G = 6.673 \times 10^{-11}\,\mathrm{Nm^2/kg^2}$
- $M = 6 \times 10^{24}\,\mathrm{kg}$
- $R = 6.37 \times 10^{6}\,\mathrm{m}$

Now, substituting the values:

$$g = \frac{(6.673 \times 10^{-11}\,\mathrm{Nm^2/kg^2}) \times (6 \times 10^{24}\,\mathrm{kg})}{(6.37 \times 10^{6}\,\mathrm{m})^2}$$

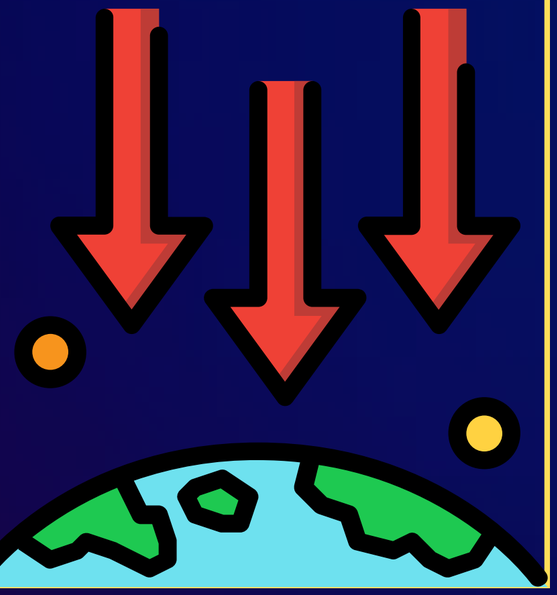
Calculating this:

$$g \approx \frac{4.0038 \times 10^{14}\,\mathrm{Nm/kg}}{4.059 \times 10^{13}\,\mathrm{m^2}}$$

$$g \approx 9.86\,\mathrm{m/s^2}$$

For simplicity, in most cases, g is rounded to:

$$g \approx 9.8\,\mathrm{m/s^2}$$



Variation in Value of (g)

Altitude

- g decreases as you move away from the Earth's surface because the Earth's radius increases.

Depth

- g decreases as you move deeper into the Earth because the Earth's mass decreases faster than its radius.

Latitude

- g is highest at the poles and lowest at the equator because the Earth is not a perfect sphere. The Earth bulges at the equator and flattens at the poles, so the radius is larger at the equator.

Q. Why does a body reach the ground quicker at the poles than at the equator when dropped from the same height?

Q. (i) What will be the effect on the value of g when we go up a hill?
(ii) Calculate the value of g at the surface of the Earth.

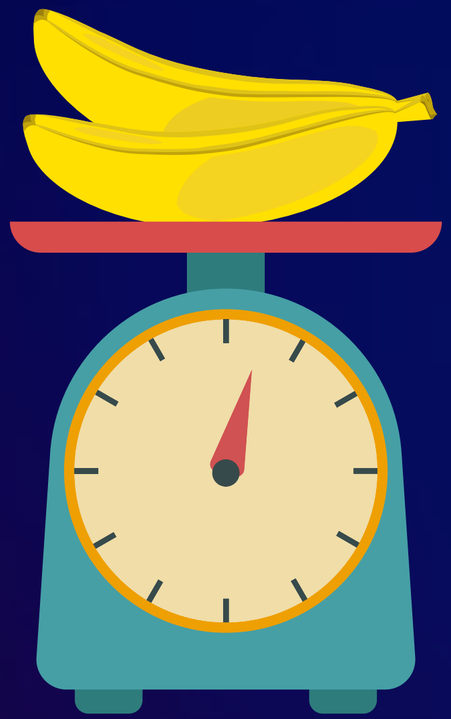
Q. A planet whose mass and radius are both half of that of earth. Acceleration due to gravity(g) at its surface should be:

Difference between ‘G’ and ‘g’

G	g
Universal Gravitational Constant	Acceleration due to gravity
It is constant everywhere in the universe.	It varies from planet to planet.
$G = 6.67 \times 10^{-11}$	$g = 9.8\ m/s^2$
Unit: Nm^2/Kg^2	SI Unit: m/s^2

Mass

- It can be defined as the measure of the amount of matter in a body.
- The SI unit of mass is Kilogram (kg).
- The mass of a body does not change at any time.



Weight

- It is the measure of the force of gravity acting on a body.
- The formula for weight is given by:

$$W = mg \qquad g = 9.8 \text{ N/kg}$$

- As weight is a force its SI unit is also the same as that of force, SI unit of weight is Newton (N).
- It depends on mass and the acceleration due to gravity, the mass may not change but the acceleration due to gravity does change from place to place.
- The weight of an object on the Moon is 1/6 times the weight on Earth.

SI No.	Mass	Weight
1	Mass is a scalar quantity.	Weight is a vector quantity.
2	Mass remains the same everywhere.	Weight changes from place to place and is zero at the center of the Earth.
3	Mass is measured using a traditional balance.	Weight is measured using a spring balance.
4	The unit of mass is kilogram (kg) or gram (g).	The unit of weight is Newton (N).
5	Mass can never be zero.	Weight can be zero depending on the gravitational force acting on it.
6	Mass does not change based on location.	Weight changes based on location, depending on gravity.

Q. How does the weight of an object vary with respect to the mass and radius of the Earth? In a hypothetical case, if the diameter of the Earth becomes half of its present value and its mass becomes four times its present value, how would the weight of any object on the surface of the Earth be affected?

Weight on the Moon

According to the universal law of gravitation, the weight of an object on the moon is given by:

$$W_m = \frac{G \cdot M_m \cdot m}{R_m^2}$$

- W_m = weight on the moon,
- G = gravitational constant,
- M_m = mass of the moon,
- m = mass of the object,
- R_m = radius of the moon.

Weight on the Earth

According to the universal law of gravitation, the weight of an object on the Earth is given by:

$$W_e = \frac{G \cdot M_e \cdot m}{R_e^2}$$

- W_e = weight on Earth,
- M_e = mass of the Earth,
- R_e = radius of the Earth.

Comparing Weights: Now, by dividing the weight on the moon by the weight on Earth, we get:

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

Substituting the values, we get

$$\frac{W_m}{W_e} = \frac{7.36 \times 10^{22} / (1.74 \times 10^6)^2}{5.98 \times 10^{24} / (6.37 \times 10^6)^2} \approx \frac{2.431 \times 10^{10}}{1.474 \times 10^{11}} \approx 0.165$$

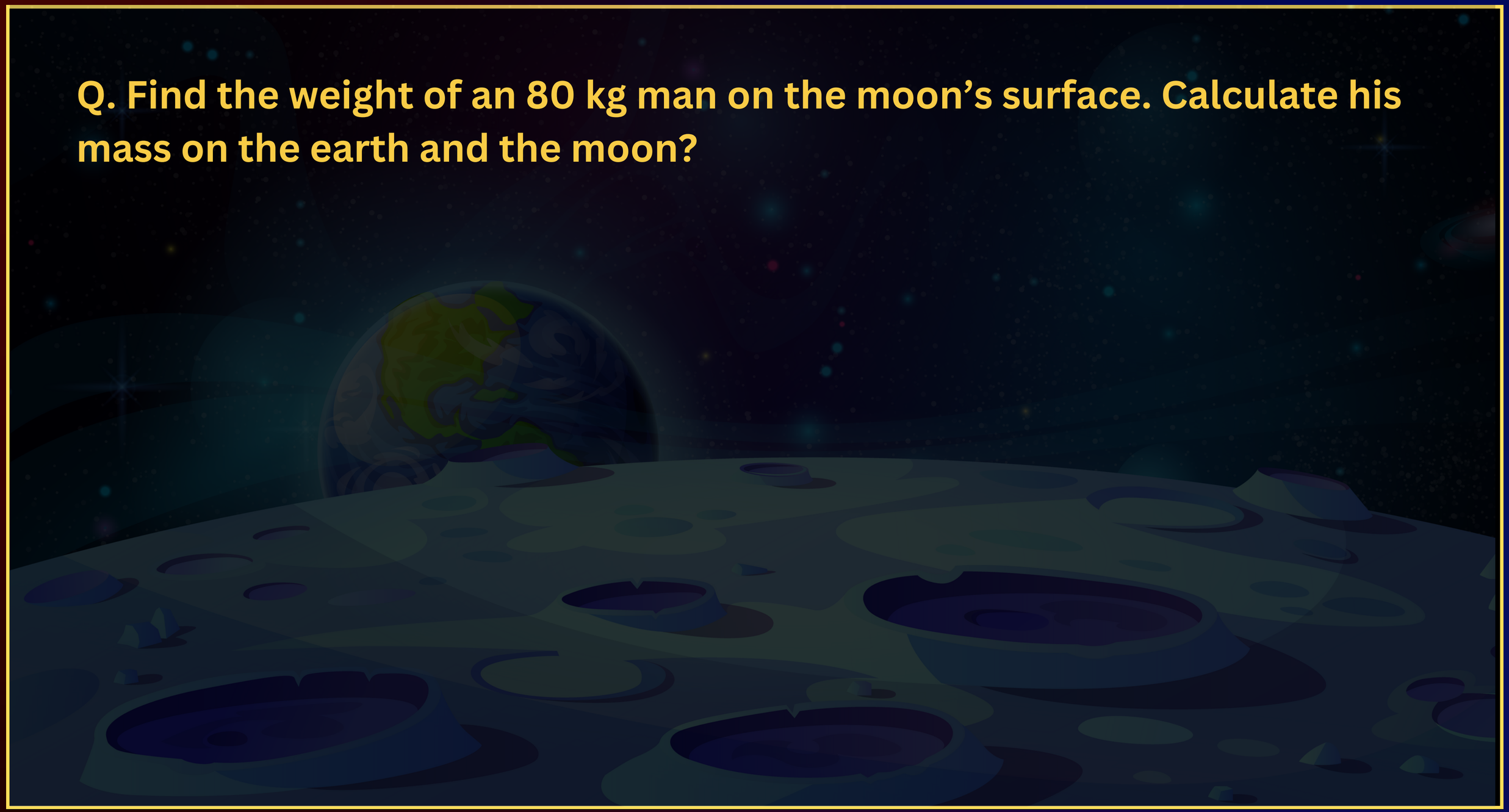
Therefore,

IMPORTANT

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

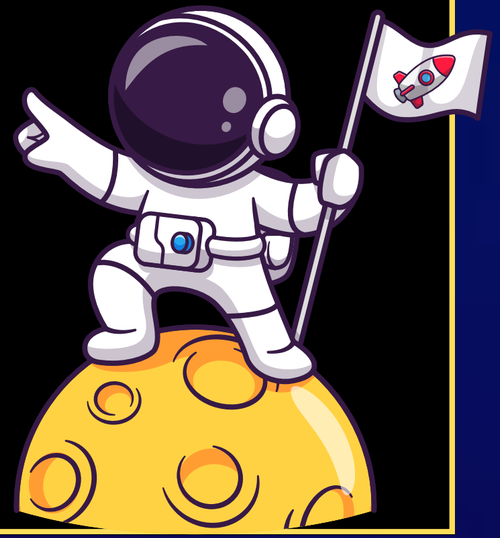
The weight of an object on the moon is approximately 1/6 of its weight on Earth.

Q. Find the weight of an 80 kg man on the moon’s surface. Calculate his mass on the earth and the moon?



Q. Suppose the gravity of Earth suddenly becomes zero. In which direction will the Moon begin to move if no other celestial body affects it?

Q. The weight of any person on the Moon is about 1\6 times that on the Earth. He can lift a mass of 15 kg on the Earth. What will be the maximum mass he can lift by applying the same force on the Moon?



Free Fall

- When an object is thrown upward, it reaches certain height, then it starts falling down towards earth. It is because the earth‘s gravitational force exerts on it.

- This fall under the influence of earth is called **‘free fall of an object’**.

(a) The first equation of motion, $v = u + at$

becomes $v = u + gt$

v = final velocity
u = initial velocity
g = acceleration due to gravity
t = time taken by the body
h = distance travelled by the body

(b) The second equation of motion,

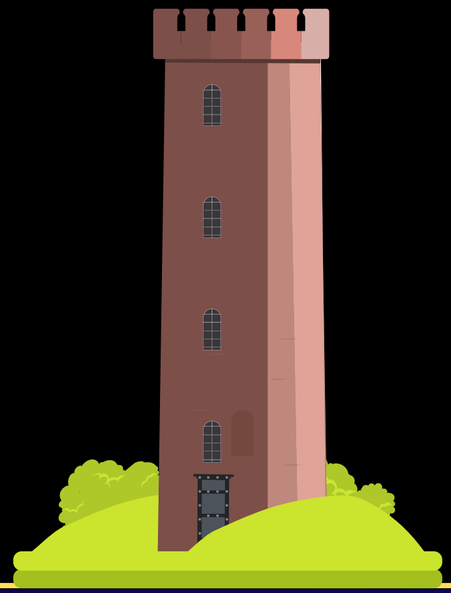
becomes $h = ut + \frac{1}{2}gt^2$

g = +9.8 m/s² (downward)
g = −9.8 m/s² (upward)

(c) The third equation of motion, $v^2 = u^2 + 2as$

becomes $v^2 = u^2 + 2gh$

Q. A stone is released from the top of a tower of 20 m. Calculate its velocity just before touching the ground.



Q. On the Earth, a stone is thrown from a height in a direction parallel to the Earth's surface while another stone is simultaneously dropped from the same height. Which stone would reach the ground first and why?

Q. A car falls off a ledge and drops to the ground in 0.5 s. Let $g=10\ m/s^2$ (for simplifying the calculations).

(i) What is its speed on striking the ground?

(ii) What is its average speed during the 0.5 s?

(iii) How high is the ledge from the ground?

[2015,2019]

Q. A stone is dropped from a height of 10 m on an unknown planet having g = 20 m/s^2. Calculate the speed of the stone when it hits the surface of the planet. Also, calculate the time it takes to fall through this height.

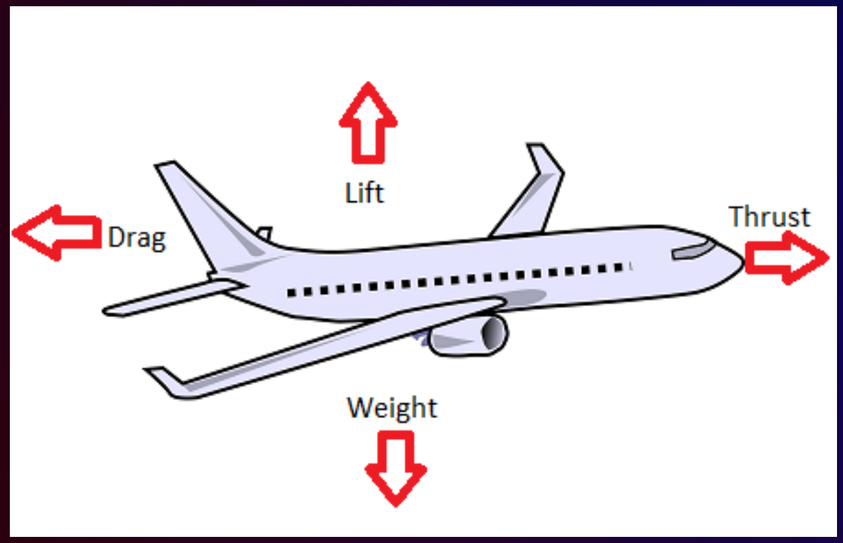
Kepler’s Laws :

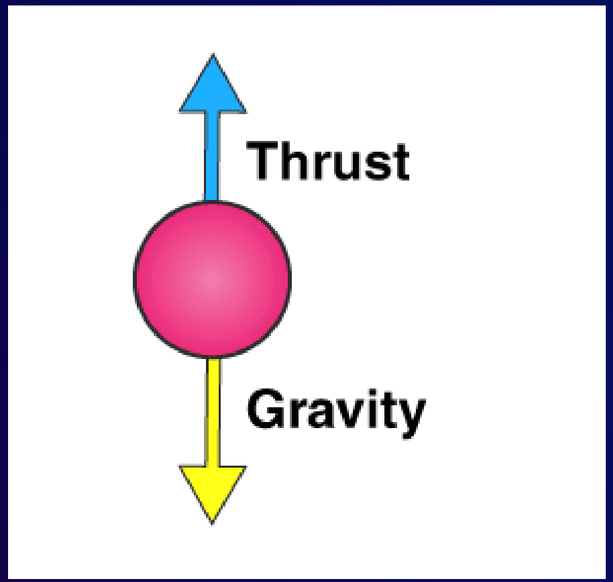
1. **Kepler’s Law of Orbits:** Planets move around the Sun in oval-shaped paths called elliptical orbits, with the Sun located at one of the two fixed points called foci.
2. **Kepler’s Law of Areas:** As a planet moves in its orbit, the imaginary line between the planet and the Sun sweeps out equal areas in equal time intervals. This means the planet moves faster when it is closer to the Sun and slower when it is farther away.
3. **Kepler’s Law of Periods:** The time a planet takes to complete one orbit around the Sun is related to its distance from the Sun. Specifically, the square of the time (the orbital period) is proportional to the cube of the average distance from the Sun.

Thrust

- Force acting on an object perpendicular to the surface is called thrust. The effect of thrust depends on the area of contact.

- SI unit : Newton.





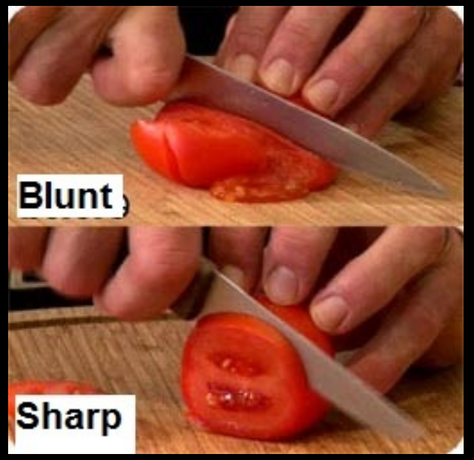
Pressure

- It is defined as Thrust acting on per unit **AREA**.
- SI unit : Pascal (Pa) or N/m^2.

Pressure =thrust/area

Q. The mass of a brick is 2.5 kg, and its dimensions are 20 cm x 10 cm x 5 cm. Find the pressure exerted on the ground when it is placed on the ground with different faces.

Q. Why does a sharp knife cuts better than a blunt knife?



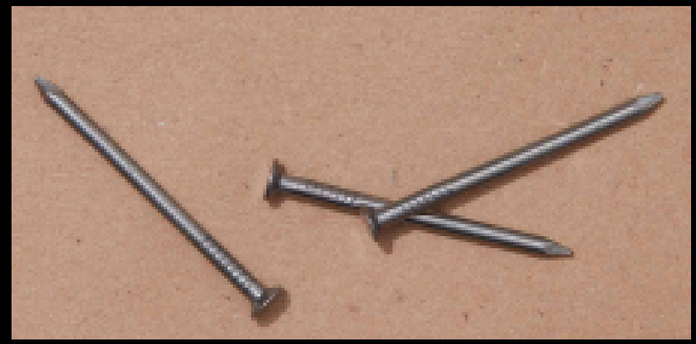
A sharp knife cuts better because it has a smaller edge area, creating higher pressure when force is applied. This higher pressure makes it easier to cut through materials. A blunt knife, with a larger edge area, produces lower pressure, making cutting less effective.

Q. Why is it difficult to hold a school bag having a strap made of a thin and strong string?

Holding a school bag with a thin string strap is difficult because the small surface area of the string concentrates the weight of the bag onto a tiny area of your shoulder, creating a high pressure point and making it uncomfortable to carry; essentially, the smaller the surface area, the greater the pressure exerted on that area.

Q. Why do nails have sharp ends?

A nail has a pointed end so that the surface area is less, when the surface area is less the pressure increases which makes it easy for the nail to be driven into the wall or where ever it may be inserted.



Q. Why does camel have broad feets?

Camels' broad feet spread out over the sand, giving them a larger surface area to distribute their weight. This reduces pressure and prevents them from sinking.

Q. Why do your feet sink deeper into loose sand when standing upright, but when lying down, you don't sink as much? (similarly with mattress)

The standing area of contact is lower so that the pressure exerted is greater and the contact area lying down is greater so that the pressure exerted is less.

Q. Give reason The rear wheels of a tractor are broad

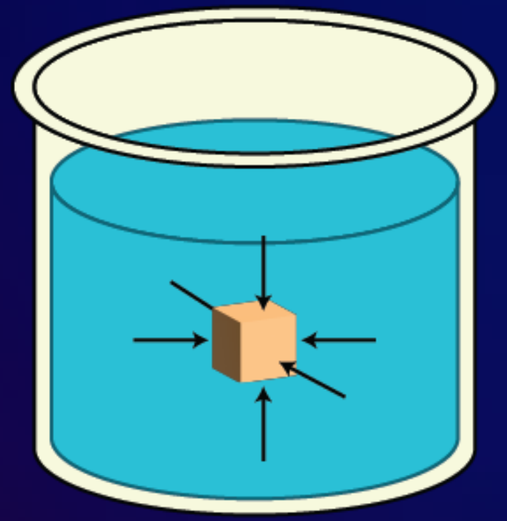
Pressure exerted by an object is inversely proportional to its surface area. So, tractors have broader tires so that the pressure exerted by them on soft soil (typical for farmlands) is comparatively less and they do not sink in as they are very heavy indeed. .

Pressure in Fluids

Pressure exerted by liquids is due to the weight of the liquid.

Characteristics of Pressure exerted by Liquids:

- At a given depth, pressure remains the same.
- It depends on the height or depth of the liquid.
- It is independent of size and shape of the container.

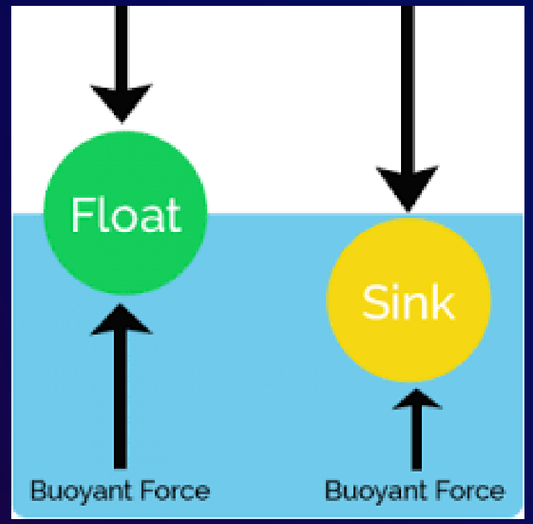


Buoyant Force

The buoyant force or Buoyancy is the upward force exerted on an object wholly or partly immersed in a fluid. This upward force is also called **Upthrust**. Due to the buoyant force, a body submerged partially or fully in a fluid appears to lose its weight, i.e. appears to be lighter.

The following factors affect buoyant force:

- **Density of the Fluid:** A denser fluid (like saltwater) exerts more buoyant force because it pushes harder against objects submerged in it.
- **Volume (Surface Area) of the Object:** Larger objects experience stronger buoyant force as they displace more fluid, which increases the upward force acting on them.



Law of Floatation

1. A body will float in a liquid if its density is less than the density of the liquid.
2. A body will be in equilibrium at any submerged depth if the density of the body is equal to the density of the liquid.
3. A body will sink in a liquid if it’s density is greater than the density of the liquid.

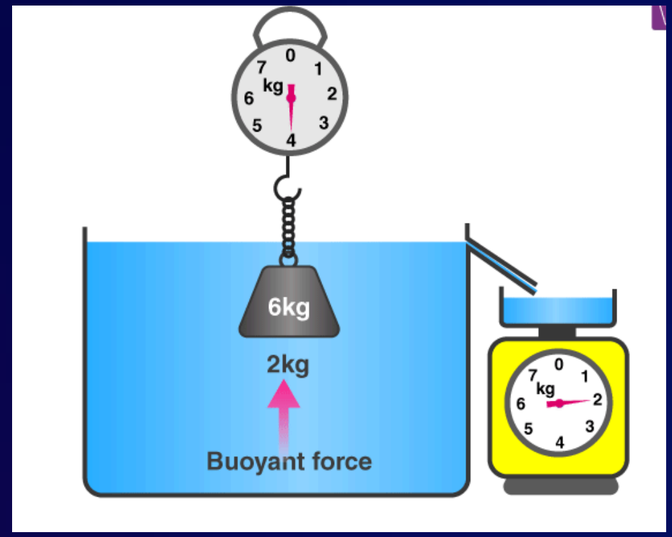
Floating: Object floats if buoyant force = weight of the object.
Sinking: Object sinks if buoyant force < weight of the object.
Suspended: Object remains suspended if buoyant force ≈ weight and **density

Q. Why it’s easier to swim in sea water then fresh water?

Sea water contains dissolved salts which makes its density more than river water. Hence, upthrust is more in sea water than river water So it is easier to swim in sea water than in river water.

Archimedes’ Principle

“Archimedes' principle states that when an object is partially or fully immersed in a fluid, it experiences an upward force called the buoyant force that is equal to the weight of the fluid displaced by the object”



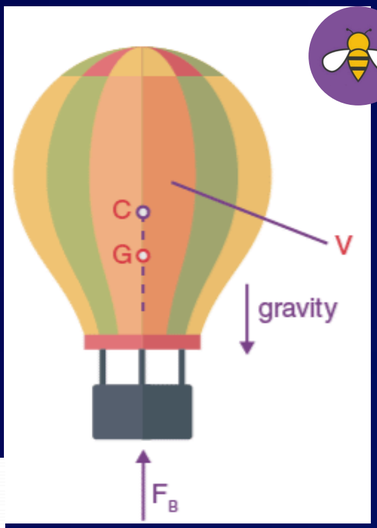
Applications of Archimedes’ principle:

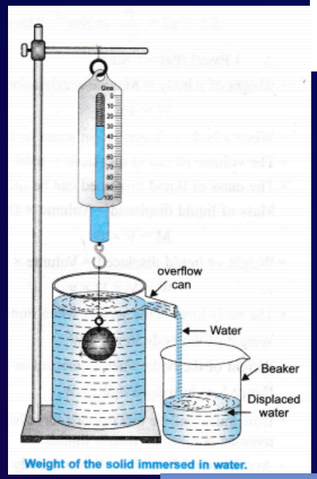
- ***Submarine:*** A submarine floats or sinks by changing the amount of water in its tanks. More water makes it heavier and it sinks because the buoyant force (weight of displaced water) is less than its weight. Less water makes it lighter, and it floats because the buoyant force is greater than its weight.

- ***Hot-Air Balloon:*** A hot-air balloon rises when the air inside is heated because it becomes lighter than the surrounding air. This means the buoyant force (weight of displaced air) is greater than the weight of the balloon. When the air cools, the balloon becomes heavier and the buoyant force decreases, causing it to sink.

- ***Hydrometer/Lactometer***: These tools float higher in denser liquids (like milk) because they displace more liquid, which means a greater buoyant force. In less dense liquids (like water), they float lower because they displace less liquid.

- ***Ships:*** Ships float because they are designed to displace a large volume of water. The buoyant force (weight of the displaced water) is greater than the weight of the ship, keeping it afloat.





TOP 5 Questions

1. An object weighs 10 N when measured on the surface of the Earth. What would be its weight when measured on the surface of the moon?

(a) 1.25 N

(b) 2.7 N

(c) 1.66 N

(d) 3.18 N

TOP 5 Questions

2. Which of the following is the unit of gravitational constant 'G'?

Options:

(a) N/kg

(b) $N.m^2/kg^2$

(c) m^2/s^2

(d) kg/m^2

[2016, 2020]

TOP 5 Questions

3.If the mass of one body is doubled and the distance between two bodies is halved, the gravitational force between them will become:

(a) 2 times

(b) 4 times

(c) 8 times

(d) 16 times

[2019, 2021]

TOP 5 Questions

4. A piece of cork floats on water due to buoyant force. What happens if you push it further into the water?
(a) The buoyant force will increase as the cork is immersed.
(b) The buoyant force will decrease.
(c) It will first increase and then decrease.
(d) The buoyant force will remain constant.

TOP 5 Questions

5. The force acting on an object perpendicular to the surface is called thrust. When you stand on loose sand, the force (which is your body weight) acts on an area equal to the area of your feet. When you lie down, the same force acts on a larger area—the contact area of your entire body. Thus, the effects of forces of the same magnitude on different areas are different. In the above cases, thrust remains the same, but the effects differ. Therefore, the effect of thrust depends on the area on which it acts. The effect of thrust on sand is larger while standing than while lying down. The thrust per unit area is called pressure.
Pressure = Thrust/Area.
The SI unit of pressure is N/m^2 or Pascal (Pa).
Questions:

1. SI unit of thrust is?
2. Given two different areas A and B where A > B, the relationship between pressure on A (PA) and pressure on B (PB) is?
3. SI unit of pressure is?
4. The effects of forces of the same magnitude on different areas are different. True or False

“ If life throws you down, blame gravity and bounce back! ”

- Gravitation