Gravitation

CLASS-9TH CHAPTER-10TH

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An object dropped from a height falls towards the earth.
all the planets go around the Sun.
The moon goes around the earth.
Some force acting on the objects, the planets andon the moon.

Isaac Newton could grasp that the same force is responsible for all these.
This force is called the **gravitational force**.
the moon goes around the earth. An object when thrown upwards, reaches a certain height and then falls downwards.

It is seen that a falling apple is attracted towards the earth. Does the apple attract the earth? If so, we do not see the earth moving towards an apple. Why?

According to the third law of motion, the apple does attract the earth. But according to the second law of motion, for a given force, acceleration is inversely proportional to the mass of an object.

The mass of an apple is negligibly small compared to that of the earth. So, we do not see the earth moving towards the apple.

Extend the same argument for why the earth does not move towards the moon. From the above facts Newton concluded that not only does the earth attract an apple and the moon, but all objects in the universe attract each other. This force of attraction between objects is called the gravitational force.

The Universal 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.

According to Newton's Universal Law of Gravitation, the force exerted between two objects, by each other is given by the following relation.

F= G m1.m2/r^2

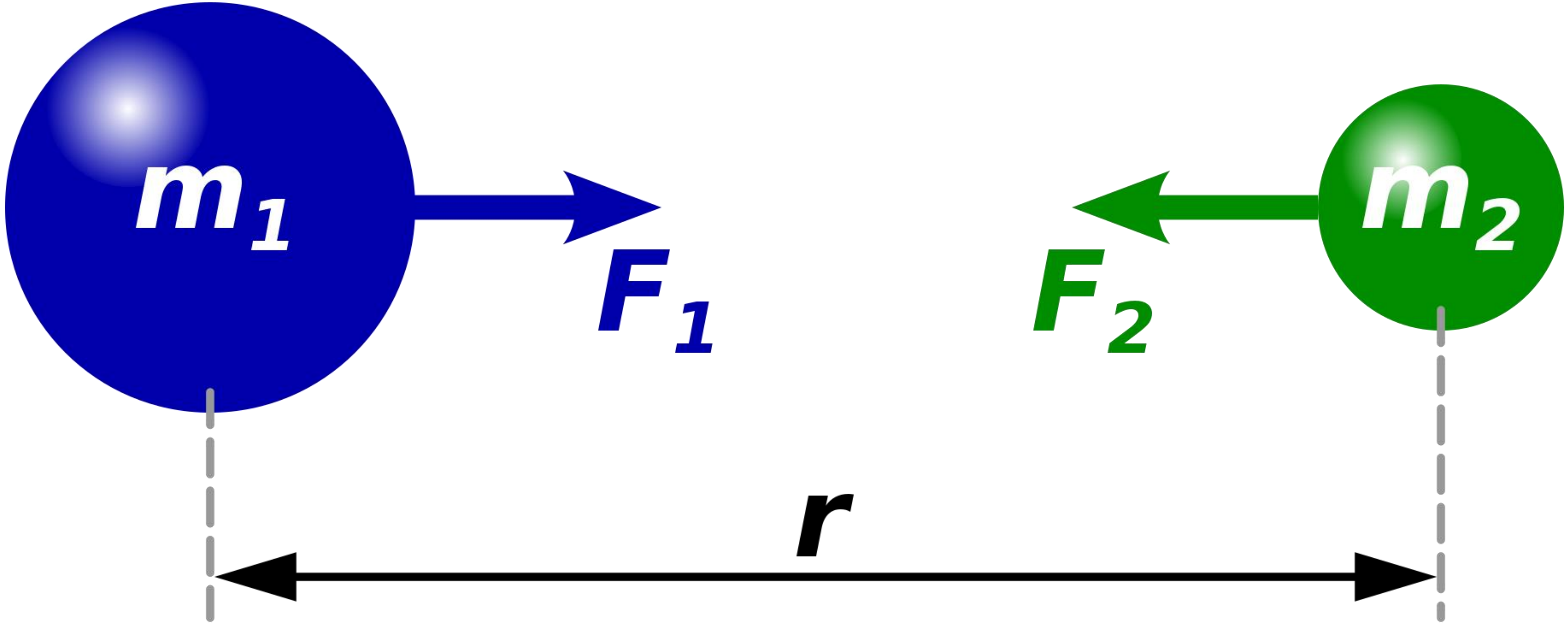
Where,

G: universal gravitational constant

m1: mass of one object

m2: mass of the second object

r: distance between the centers of two objects



$$F_1 = F_2 = G\,\frac{m_1 \times m_2}{r^2}$$

Gravitational Constant

The actual force exerted between two bodies can be given by the following equation-

$Fg = Gm1.m2/r2$

Where,

G is the universal gravitational constant with a value of;

$G=6.674\times10-11N\cdot(m/kg)2$

G here is an empirical constant of proportionality.

- This was calculated by Henry Cavendish in 1798 through a series of experiments and observations.

- It is hypothesized the influence of the earth's core on the experiments alters its rotational inertia because of which the value of G given is not always constant throughout the globe. acceleration due to gravity is smaller at the equator than at the poles.

- Another theory regarding the universal gravitational constant (fun fact: it is also referred to as Big G) is that, if it is true that the universe is expanding since the Big Bang, then the value of G will keep decreasing!

- The universal gravitational constant is used in Newton's Universal Law of Gravitation, Einstein's General Theory of Relativity and also Kepler's Third Law of Planetary Motion, to calculate the time period of a planet to complete one full revolution in its orbit.

IMPORTANCE OF THE UNIVERSAL LAW OF GRAVITATION

The universal law of gravitation successfully explained several phenomena which were believed to be unconnected:

(i) the force that binds us to the earth;
(ii) the motion of the moon around the earth
(iii) the motion of planets around the Sun; and
(iv) the tides due to the moon and the Sun.

Acceleration due to Gravity

⇒$F=mg$ and also $F=GMmR2$

⇒$g=GMmR2$

⇒Plug the values of $G = 6.673*10-11Nm2Kg-2$

⇒ M(mass of Earth) = 6 * 1024 kg and R= 6 * 106 m , to get the value of g as ≈ 9.8m/s–2.

This is the acceleration due to gravity and the acceleration felt by any freely falling body towards Earth.
Value of g keeps changing due to the variation of Earth’s radius.

Effective Acceleration Due to Gravity

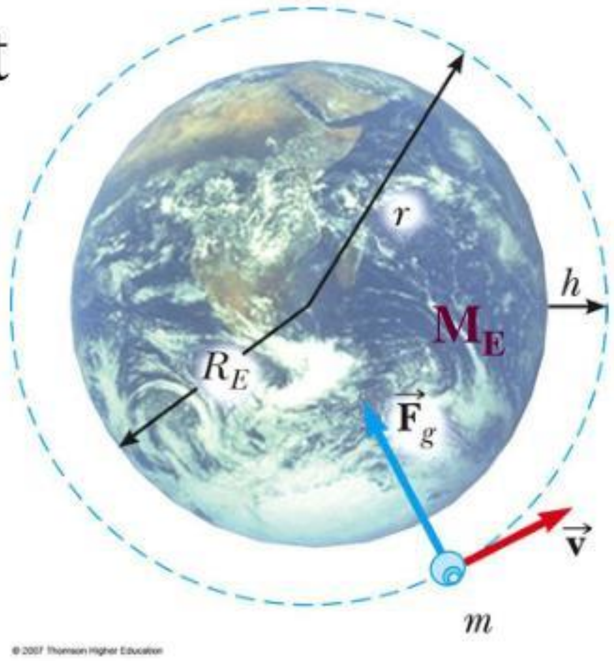
- The acceleration due to gravity at a distance **r** from Earth's center.
- Write gravitational force as:

$$F_G = G[(mM_E)/r^2] \equiv mg'$$

(effective weight)

$g' \equiv$ effective acceleration due to gravity.

SO : $g' = G\,(M_E)/r^2$



What is Acceleration due to Gravity?

Acceleration due to gravity is the acceleration gained by an object due to gravitational force. Its SI unit is m/s2.

It has both magnitude and direction, hence, it’s a vector quantity. Acceleration due to gravity is represented by g.

The standard value of g on the surface of the earth at sea level is 9.8 m/s2.

The Moon’s Falling – Moon’s revolution around Earth

The moon revolves around Earth due to centripetal force, which is the force of gravity of the Earth

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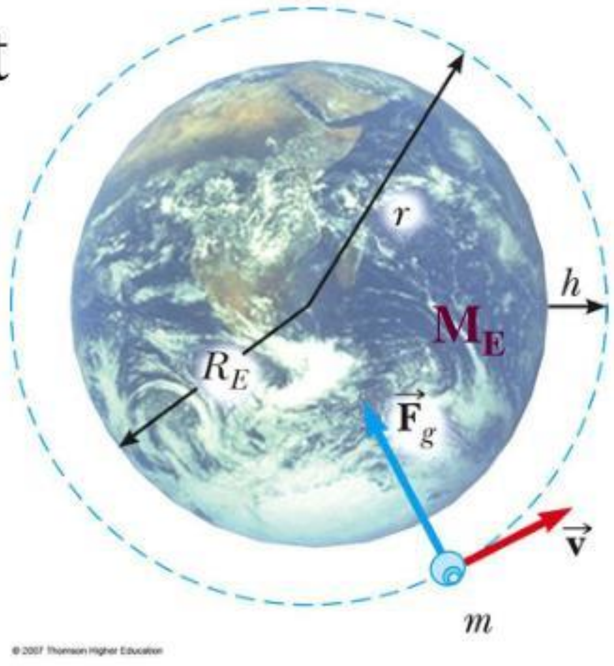


- If the force of attraction between Earth and moon ceases, then the moon will continue to travel in a straight line path tangential to its orbit around Earth.

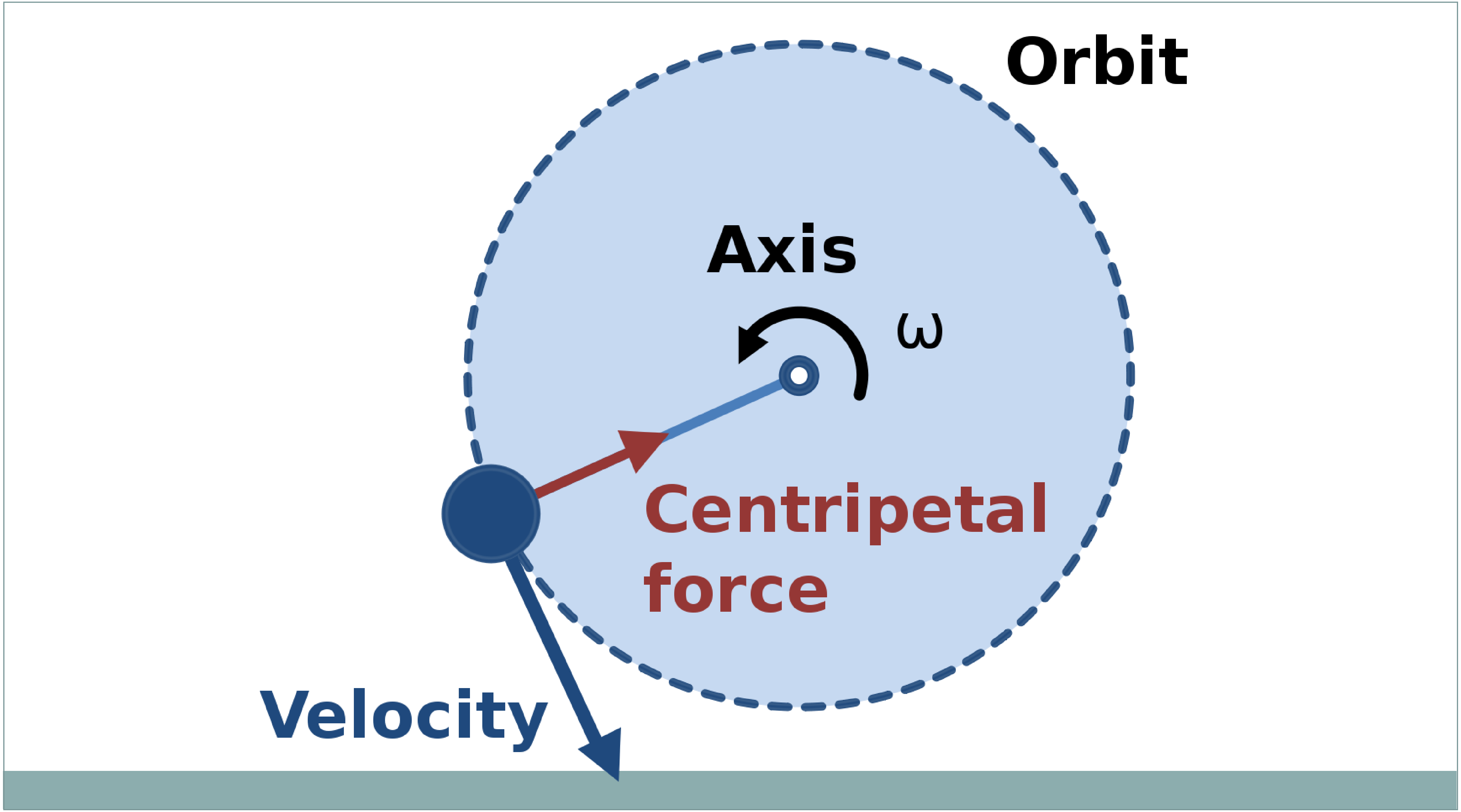
Centripetal force

- When a body undergoes circular motion, it experiences a force that acts towards the centre of the circle.

- This centre-seeking force is called a centripetal force.
- Centripetal Force Formula

- A force that acts on a body moving in a circular path and directed towards the centre around which the body is moving is called Centripetal force.

- When an object travels around a circular path with a constant speed, it experiences an accelerating centripetal force towards the centre.


Orbit
Axis
ω
Centripetal force
Velocity

Free Fall and Motion

- When an object is under free fall, acceleration due to gravity is constant at $g = 9.8ms^{-2}$.

- Value of g does not depend on mass i.e any object big or small experiences the same acceleration due to gravity under free fall.

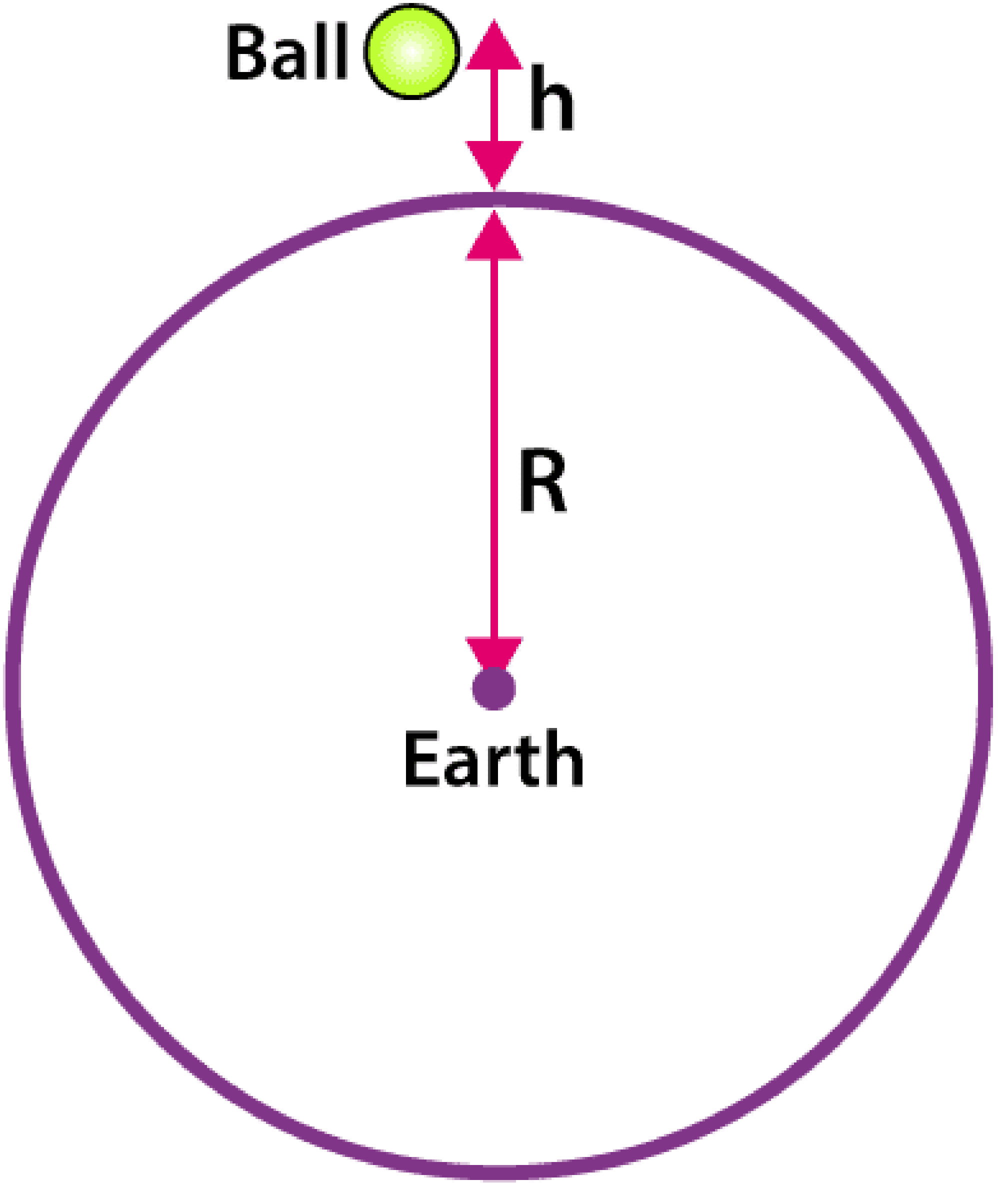
- All three equations of motion are valid for freely falling objects as it is under uniform motion.

- The sign of convention → towards earth g is +ve / away from earth g is -ve.

- Freefall is defined as a situation when a body is moving only under the influence of the earth's gravity.

- Since external force is acting on the ball, the motion will be accelerated.

- This free-fall acceleration is also known as acceleration due to gravity.


Ball
h
R
Earth

Weight and Mass

Mass of an object is the measure of its inertia and is constant throughout the universe.

Weight of an object keeps changing as the value of g changes. Weight is nothing but a force of attraction of the Earth on an object = mg.

Weight of an object on the Moon is 1/6 times the weight on Earth.

It is one of the fundamental quantities in Physics and the most basic property of matter.

We can define mass as the measure of the amount of matter in a body. The SI unit of mass is Kilogram (kg).

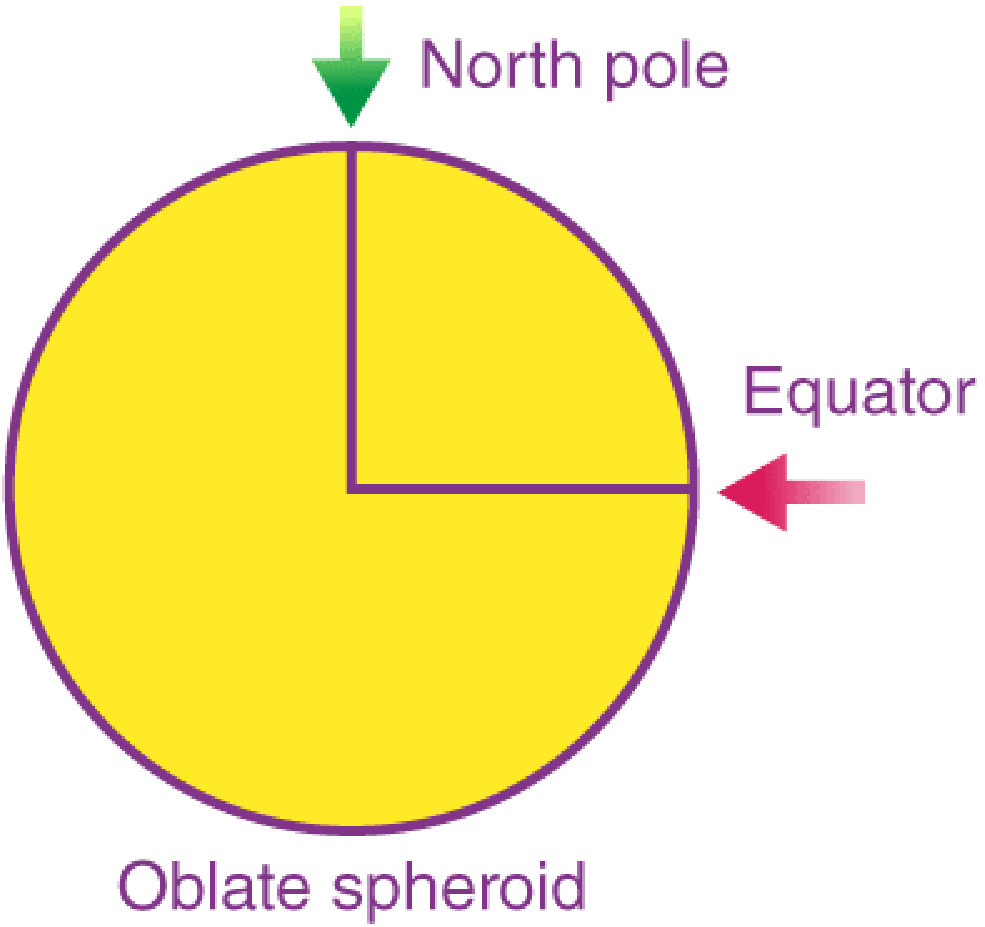
Note: The mass of a body does not change at any time. Only for certain extreme cases when a huge amount of energy is given or taken from a body. For example: in a nuclear reaction, tiny amount of matter is converted into a huge amount of energy, this reduces the mass of the substance.

What is Weight?

- It is the measure of the force of gravity acting on a body.
- The formula for weight is given by:
- $w = mg$
- As weight is a force its SI unit is also the same as that of force, SI unit of weight is Newton (N).
- The mass may not change but the acceleration due to gravity does change from place to place. To understand this concept let's take this example,

A body which has a mass m and weight of magnitude w:

$$w = mg$$



Shape of the earth is not completely spherical, but an oblate spheroid, therefore a person standing at the equator is far away from the centre of the earth than a person standing at the north pole, as acceleration due to gravity is proportional to the inverse of the square of the distance between two objects, a person standing at the north pole would experience more weight as he is closer to the centre of the earth than a person standing at the equator.

Thrust and Pressure
Force acting on an object perpendicular to the surface is called thrust. Effect of thrust depends on the area of contact. The pressure is thrust per unit area. SI unit is the pascal (Pa). Force acting on a smaller area applies more pressure than the same force acting on a larger area.

Pressure
Pressure is defined as the force per unit area. If a force F is applied on a surface of area A, then the pressure P is defined as:

P = FA

As you blow up a balloon, it becomes harder to blow the balloon as it becomes bigger and bigger. This is because the air pressure inside the balloon is increasing. Pressure is expressed in N/m2 which is also called a Pascal (Pa).

In fluids this pressure is always perpendicular to the surface of an object. It is this pressure that is applied on an object submerged in water that forms the thrust force.

The pressure applied by the fluid is:

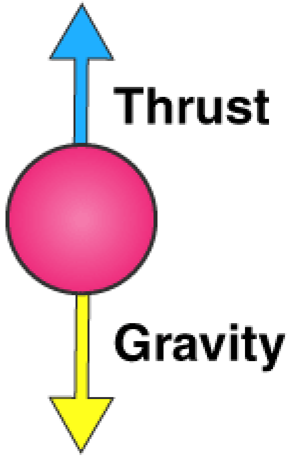
Pressure = ThrustArea

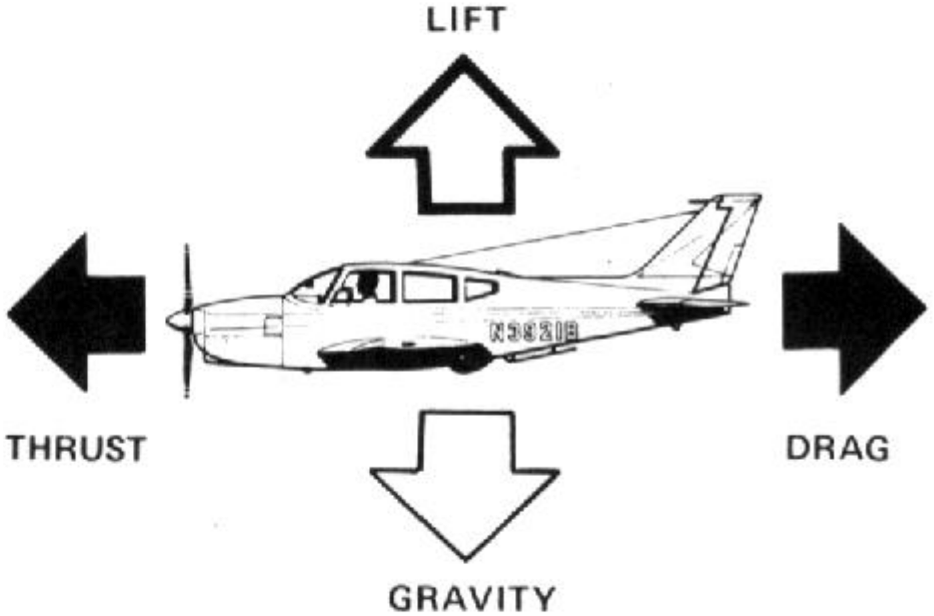
Also,

1 Pascal (Pa) = 1 Newton (N)/metre square (m2)

Or

Thrust = Pressure × Area


Thrust
Gravity


LIFT
THRUST
DRAG
GRAVITY

Pressure in fluids

- The pressure exerted by a fluid in a container is transmitted undiminished in all directions on the walls of the container.

- Archimedes' Principle – Why objects float or sink

- The upward force exerted by a fluid on an object is known as upthrust or buoyant force.

- The magnitude of buoyancy depends on the density of the fluid. If the density of an object is less than the fluid, it will float.

- If the density of the object greater than the fluid, it will sink.

- According to the Archimedes' principle, when a body is immersed fully or partially in a fluid, it experiences an upward force that is equal to the weight of the fluid displaced by it.

Pressure in a Fluid

Pressure in a fluid depends only on the depth *h* below the surface.

$$P = P_{at} + \rho g h \qquad \rho = density\ of\ fluid$$

Weight/Area of fluid

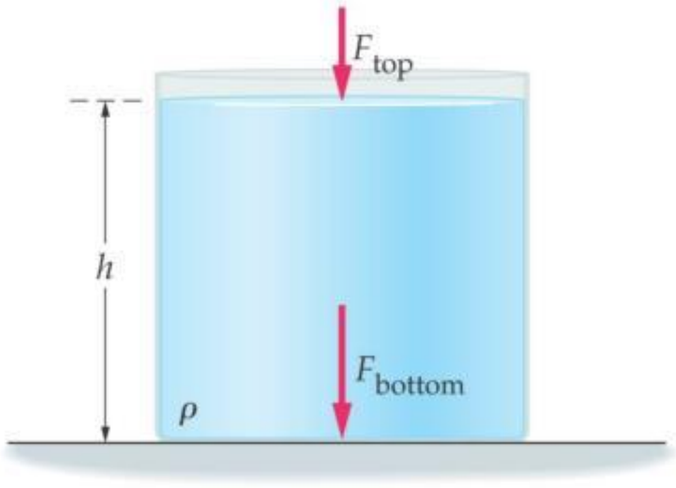
Weight/Area of atmosphere above fluid

IF the density of the fluid is constant and it has atmospheric pressure (P_{at}) at its surface.

Mass of fluid above depth h is

(density)(volume) = $\rho h A$

Force of gravity on fluid above depth h: W= $\rho g h A$



(a)

Relative Density

- Relative density = Density of a substance/ Density of water

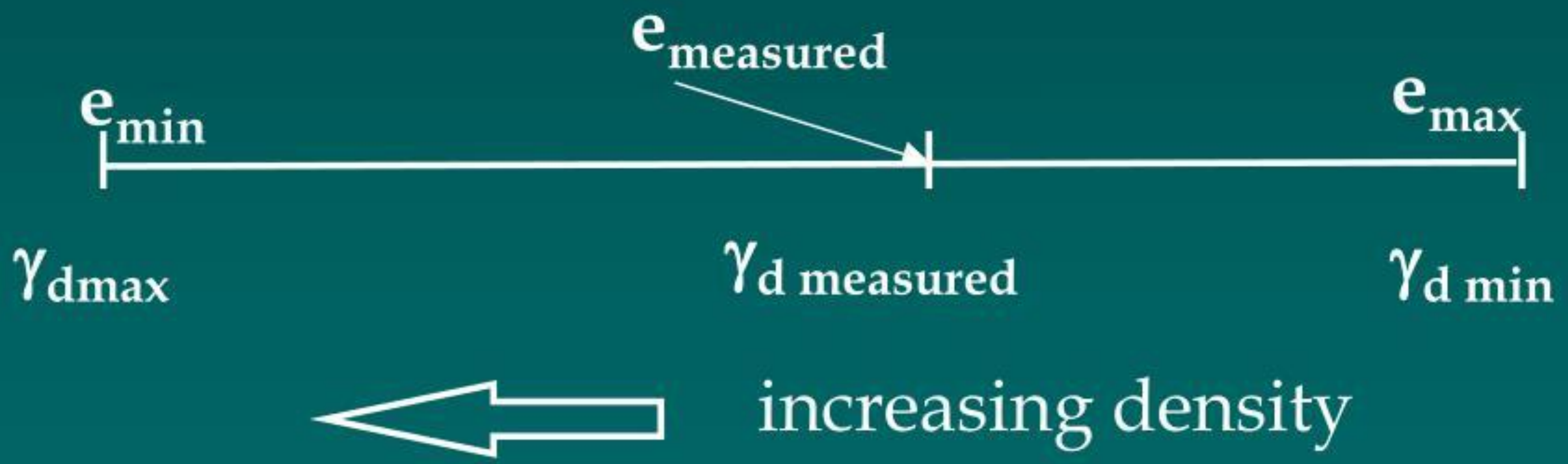
- Density is the amount of mass in a unit volume of matter, every substance has a different density,

- The difference between the specific gravity and density is that at room temperature and pressure is 1gram per 1 cubic cm is the density of water this density is treated as a standard and the density of any other material (usual liquids) is calculated relative to this is called relative density or specific gravity.

Relative Density Equation

$$R_d(\%) = \frac{e_{\max} - e_{measured}}{e_{\max} - e_{\min}} x100$$

Diagram below illustrates a relative density of about 40 %



Hence, specific gravity is the ratio of the mass of a substance to that of a reference substance, let's consider the density of honey is approx. 1.42 grams/cm3, so its specific gravity would be 1.42/1 = 1.42.

Specific gravity is a ratio, therefore specific gravity does not have a unit, and hence specific gravity is a dimensionless physical quantity.

The specific gravity of a substance if it will float or sink, it gives us the idea about relative mass or relative density.

If the specific gravity of a substance is below 1 then it will float and if it is greater than 1 it will sink.

THANKYOU

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