End of Unit Questions

Section (A) Multiple Choice Questions (MCQs)

1. The springs in brakes and clutches are used
   a) To restore original position
   b) To measure forces
   c) To absorb shocks
   d) To absorb strain energy
2. If the material recovers the original dimensions, when an external force is removed, this deformation is known as ______ deformation.
   a) Inelastic b) Permanent
   c) Elastic d) Irreversible
3. Which of the following material is more elastic?
   a) Rubber b) Glass
   c) Steel d) Wood
4. If a spring stretches easily then its spring constant has ______.
   a) Large value b) Small value
   c) Constant Value d) Both (a) and (b)
5. What is the unit for the spring constant?
   a) Nm b) Nm^{-2}
   c) Nm^{-1} d) Nm^{2}
6. The spring obeys Hooke's law for the earlier extensions and when the spring becomes damaged it does not appear to do so; Fig 5.12. Estimate, from graph, after addition of which weight the spring damaged.
   a) 1.5 N b) 8 N
   c) 1.6 N d) 2.0 N
7. Which of the following is not a unit of pressure?
   a) Pascal b) Bar
   c) Atmosphere d) Newton

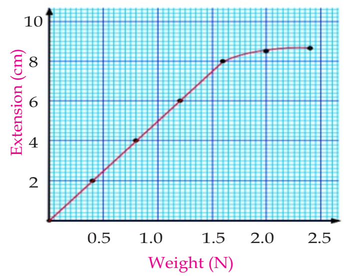


Fig 5.12
Graph between weight and extension for spring

8. If a metal block applies a force of 20 N on an area of 5 cm^2. Find the pressure being applied by the block on the area of ____.
   a) 100 Ncm^{-2} b) 0.8 Ncm^{-2}
   c) 0.25 Ncm^{-2} d) 4 Ncm^{-2}

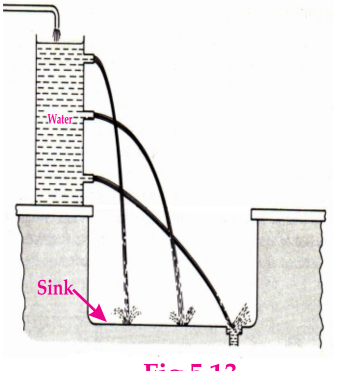


Fig 5.13

9. The Fig 5.13 shows a container with three spouts. The container is filled with water. Jets of water pour out of the spouts. Why does the jet of water from the bottom spout goes farthest out from the container?
   a) Pressure decreases with depth.
   b) Pressure increases with depth.
   c) More water available to flow out from the bottom.
   d) Density of water different at different places.

Section (B) Structured Questions

Stretching of Spring

1. Some students experimented to find out how a spring stretched when loads were added to it

Table 5.3 For load and extension

Load (N)	0	2	4	6	8	10	12	14
Extension (mm)	0	15	30	45	60	75	90	100

a) Use these results to plot a graph. (Plot x = load, y = extension in spring).
b) Use your graph to find
   i) The extension when the load is 3 N;
   ii) The load which produces an extension of 40mm.

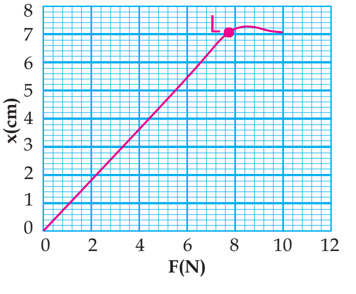


Fig 5.14
Graph between force loadand extension

2. The variation in extension x of the force F for a spring is shown in Fig 5.14. The point L on the graph is the elastic limit of the spring.
   a) Describe the meaning of elastic limit.

b) Calculate the force in extending the spring to its elastic limit 'L'.

Hooke's Law

3. State Hooke's law.
4. Calculate the spring constant for a spring which extends by a distance of 3.5cm when a load of 14N is hung from its end.
5. Table 5.4 shows the results of an experiment to stretch a spring.

Table 5.4 For load and extension in spring

Load (N)	Extension (cm)
0.0	0.0
2.0	80.0
4.0	83.0
6.0	86.0
8.0	89.0
10.0	92.0
12.0	93.0

a) Use the result to plot an extension against load graph.
b) On the graph mark the limit of proportionality and state the value of the load at this point.
c) Calculate the spring constant k.
d) Show maximum force at which hooke's law is applicable.

Pressure

6. a) Define the term pressure.
b) Write down the S.I unit of pressure.

7. Why does pressure increases as you dig deeper; Explain in detail.
8. A boy is pressing a thumbtack into a piece of wood with a force of 20 N. The surface area of head of thumbtack is $1cm^2$ and the cross-section area of the tip of the thumbtack is $0.01cm^2$. Calculate

   a) The pressure exerted by boy's thumb on the head of thumbtack.
   b) The pressure of the tip of the thumbtack on the wood.
   c) What conclusion can be drawn from answers of part (a) and (b)?
9. The Fig 5.15 shows a basic hydraulic system that has small and large pistons of cross section area of 0.005 m^2 and 0.1 m^2 respectively. A force of 20N is applied to small piston. Calculate
   a) The pressure transmitted into hydraulic fluid.
   b) The force at large piston.
   c) Discuss the distance travelled by small and large pistons.

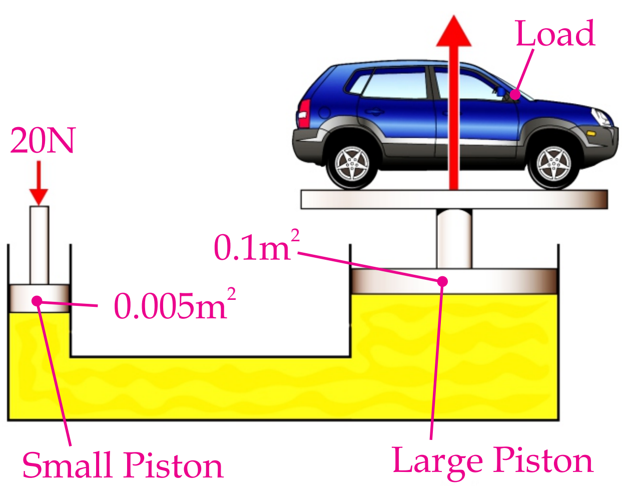


Fig 5.15
A hydraulic system

Unit - 6

GRAVITATION

The natural force which pulls every two objects in the universe towards each other is known as "Gravity". This force acts on all objects which have mass. This force depends upon the masses of the objects. Big masses have high gravitational pull while small masses have low gravitational pull. Gravity of earth hold all objects like buildings, animals, trees, human beings etc on Earth. Moon, stars and planets all have gravity. The gravity causes weight. The weight of an object is smaller at moon than Earth. Gravity causes the satellites and planets to move in their orbits.

Students Learning Outcomes (SLOs)

After learning this unit students should be able to:

- State Newton's law of gravitation
- Explain that the gravitational forces are consistent with Newton's third law.
- Explain gravitational field as an example of field of force.
- Solve problems using Newton's law of gravitation.
- Define weight (as the force on an object due to a gravitational field.)
- Calculate the mass of earth by using law of gravitation.
- Discuss the importance of Newton's law of gravitation in understanding the motion of satellites.
- Describe how artificial satellites keep on moving around the earth due to gravitational force.

Do You Know!

Sir Isaac Newton, was one of the greatest scientist of the world. He made fundamental contributions not only to several branches of Physics (like optics and mechanics) but also to Astronomy and Mathematics. He formulated the laws of motion and law of Universal gravitation.

Why a leaf which drops from a tree always falls on the Earth? Why a ball which is thrown upward comes back to Earth? Which force keeps object around us at their places? Why a body has weight? Which force is responsible for the motion of an artificial satellite around the Earth?

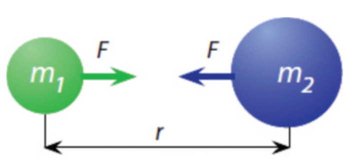
After studying this unit you will be able to find the answers of such questions and other similar questions.

Among famous stories in the history of science one comes from 1666. One day Isaac Newton was sitting in his mother's, garden where he witnessed an apple falling from a tree. The scenario helped him to explore the idea of gravity. Newton successfully discovered the cause of falling bodies. He further revealed that gravity makes the planets to revolve around the sun and it also causes the moon and satellite orbiting around the earth in a specific fashion.

6.1 Newton's Law Of Gravitation

Newton's law of universal gravitation states that:

Everybody in the universe attracts every other body with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres.



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

Fig 6.1
Newton's Law of Universal Gravitation

To understand this law, let us consider two bodies of masses m_1 and m_2. The distance between their centers is r (Fig 6.1).

According to the statement force of attraction between two bodies is directly proportional to the product of their masses. Therefore,

$$F \propto m_1 m_2 \text{ ----------(i)}$$

The gravitational force of attraction is inversely proportional to the square of the distance between the centers of the masses of the bodies. Therefore

$$F \propto \frac{1}{r^2} \quad \text{----------(ii)}$$

Combining equation (i) and equation (ii)

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

$$\mathbf{F = G\frac{m_1 m_2}{r^2}} \quad \text{......................(6.1)}$$

Where 'G' is constant of proportionality known as "Universal gravitational constant". The value of 'G' in SI unit is 6.673×10^{-11} Nm^2kg^{-2}. This is very small value. 'G' remains constant everywhere.

We do not feel the gravitational force of attraction between objects around us due to the very small value of 'G'. But it exists everywhere in the universe.

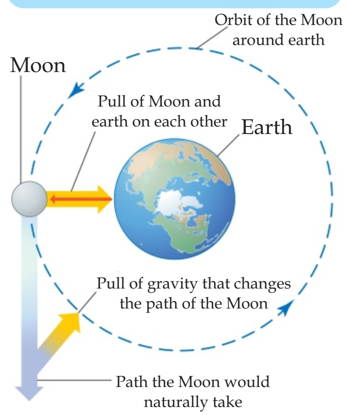
Difference between "G" and "g".

"G"	**"g"**
It is universal gravitational constant.	It is acceleration due to gravity which determines the gravitational force acting per unit mass.
It has same value everywhere in the universe.	It has different values at different places.
It has value 6.673×10^{-11} Nm^2kg^{-2}	It near earth's surface has value $10 ms^{-2}$ or $10 Nkg^{-1}$.

Do You Know!

Demonstration of Newton's law of universal gravitation

The pull of the gravity changes the path of the Moon around the Earth.



Weblinks

- https://www.youtube.com/watch?v=Ym6nlwvQZnE
- https://www.youtube.com/watch?v=2PSjARmmL7M

Do You Know!

"G" is also known as Newtonian constant of gravitation or the Cavendish gravitational constant.

Key points

Gravitational force has following characteristics:

i) It is always present between every two objects because of their masses.
ii) It exists everywhere in the universe.
iii) It forms an action-reaction pair.
iv) It is independent of the medium between the objects.
v) It is directly proportional to the product of the masses of objects.
vi) It is inversely proportional to the square of the distance between the centres of the objects.
vii) Hence it follows the "Inverse Square Law".

Worked Example 1

Determine the gravitational force of attraction between two spherical bodies of masses 500kg and 800kg. Distance between their centers is 2 meters.

Solution

Step:1 Write down known quantities and quantities to be found.

$m_1 = 500\text{kg}$

$m_2 = 800\text{kg}$

$r = 2\text{m}$

$G = 6.67 \times 10^{-11}\text{Nm}^2\text{kg}^{-2}$

$F = ??$

Step:2 Write down formula and rearrange if necessary

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

Step:3 Put the values in formula and calculate

$$F = \frac{6.67 \times 10^{-11}\text{Nm}^2\text{kg}^{-2} \times 500\text{kg} \times 800\text{kg}}{(2\text{m})^2}$$

$$F = 6.67 \times 10^{-6}\text{N}$$

Hence, the gravitational force of attraction between the bodies is 6.67×10^{-6}N.

Law of Gravitation and Newton's Third law of Motion

According to Newton's law of gravitation, every two objects attract each other with equal force but in opposite direction. As shown in fig 6.2.

From the figure:

$m_1 \rightarrow$ Mass of body A

$m_2 \rightarrow$ Mass of body B

$F_{12} \rightarrow$ Force with which body A attracts body B

$F_{21} \rightarrow$ Force with which body B attracts body A

Then according to this law

$$F_{12} = -F_{21}$$

This shows that, the two forces are equal in magnitude but opposite in direction. Now, if F_{12} is considered as "Action Force" and F_{21} as "Reaction Force". Then by using above equation, it is concluded that "Action equals to reaction but in opposite direction".

Recall that, above statement is in accordance with the Newton's third law of motion which states that "To every action there is always an equal and opposite reaction".

Hence, Newton's law of gravitation is consistent with Newton's third law of motion.

For example, according to Newton's law of Universal gravitation the Earth pulls the Moon with its gravity and the Moon pulls the Earth with its gravity. Therefore they form an action-reaction pair, which is in accordance with Newton's third law of motion.

Do You Know!

Henry Cavendish in 1798 completed the 1st experiment that demonstrated the Newton's Law of universal gravitation. This happens more than a century after Newton had announced law of universal gravitation.

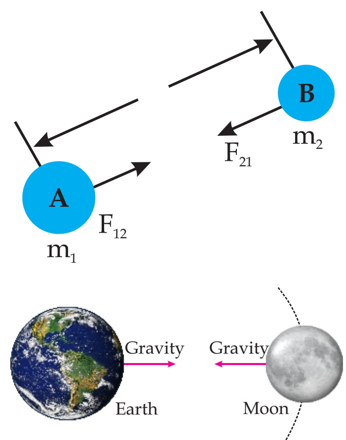


Fig 6.2

Demonstration of Newton's law of universal gravitation in accordance with Newton's third law of motion.

Gravitational Field

Gravitational field can be described as:

"A gravitational field is a region in which a mass experiences a force due to gravitational attraction".

The earth has an attractive gravitational field around it. Any object near the Earth experience this

Activity

Measure the masses of your copy and pen and then calculate the gravitational force of attraction between them.

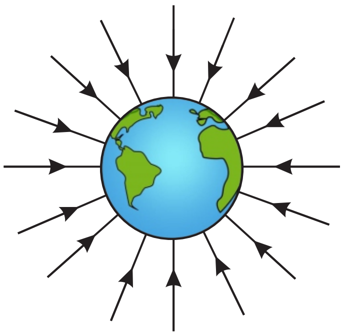


Fig 6.3
Gravitational field around the Earth is directed toward center of earth from all direction

Point to Ponder

- Does the whole solar system works in a push and pull network?

Planet	Value of g ms^{-2}
Earth	10
Moon	1.62
Venus	8.87
Mars	3.77
Jupiter	25.95
Sun	274
Mercury	3.59
Saturn	11.08
Uranus	10.67
Neptune	14.07

Table 6.1
Acceleration due to gravity "g" at different planets.

force which is due to Earth's gravity. This field is directed towards the centre of the Earth as shown in fig 6.3.

This field is strongest near the surface of the Earth and gets weaker as we move farther & farther away from the Earth. This force is called the "Field Force" because it acts on all objects whether they are in contact with Earth's surface or not. So, it is a non-contact force. For example, it acts on an aeroplane either it is standing on Earth's surface or flying in the sky.

A body of mass one kilogram (1kg) on Earth experiences a force of about ten newton (10N) due to Earth's gravitational field. This force determines the gravitational field strength which is defined as:

Gravitational field strength 'g' is the gravitational force acting per unit mass.

The gravitational field strength "g" is approximately 10 Newton per kilogram $10Nkg^{-1}$.

The gravitational field strength "g" is different at different planets. For example, the gravitational field strength "g" on the surface of Moon is approximately 1.6 Newton per Kilogram $1.6Nkg^{-1}$. Acceleration due to gravity "g" at different planets is shown in the table 6.1.

Self Assessment Questions:

Q1: What will be the effect on gravitational pull between two objects if medium between them is changed?

Q2: Which force causes the moon to move in orbit around earth?

6.2 WEIGHT

We know that all the objects which are thrown upward in the air, fall back to the ground. Have you noticed why this is so?

The force applied by the Earth's gravitational field, pulls the objects downward. Weight is another name for the Earth's gravitational force on the objects. Therefore weight can be defined as:

The weight of an object is the measurement of gravitational force acting on the object.

Weight 'W' of an object of mass 'm', in a gravitational field of strength 'g' is given by the relation:

$$W = mg \quad \text{.......................} (6.2)$$

Like other forces weight is also measured in Newton's (N). Spring balance is used to measure weight of an object; Fig 6.4.

An object of mass 1kg has a weight of 9.8N near the surface of Earth. Though 10N is accurate enough for many calculations. Therefore we use 10N in this book. The objects with larger masses may have larger weights. Your weight vary slightly from place to place, because Earth's gravitational field strength varies at different places. The weight of the object changes as it moves away from the Earth. The weight of the object is different at different planets. For example: you will have less weight at Moon because Moon's gravitational field is weaker than Earth.

Fig 6.4
Spring balance

Do You Know!

'Gravity' is taken from Latin word 'gravitas' means 'weight'.

Activity

The teacher should encourage and facilitate the students in the class to measure their masses and then calculate their weights on Earth, Moon and Mars.

Worked Example 2

Calculate the weight of Rumaisa, who has a mass of 65kg standing at the ground. The strength of gravitational field on Rumaisa is 10 Newton per kilogram?

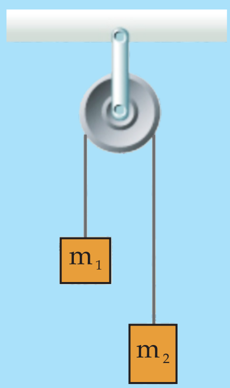
Solution

Step:1 Write down known quantities and quantities to be found.

$m = 65kg$
$g = 10Nkg^{-1}$
$W = ??$

Do You Know!

British scientist George Atwood (1746-1807) used two masses suspended from a fixed pulley, to study the motion and measure the value of 'g'. This is named as "Atwood Machine".



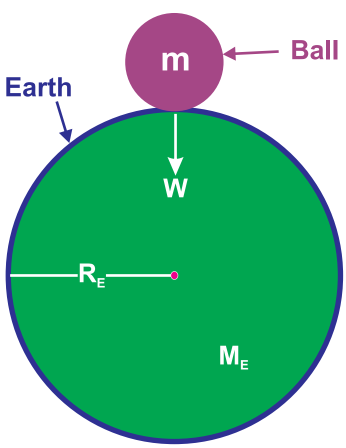


Fig 6.5
Weight of a ball is equal to the gravitational force between the ball and the Earth.

Step:2 Write down formula and rearrange if necessary

$$W = mg$$

Step:3 Put the values in formula and calculate

$$W = 65kg \times 10Nkg^{-1}$$

Hence, the weight of Rumaisa is 650 Newton.

Self Assessment Questions:

Q3: Why weight of an object is different at different planets?

Q4: What is the actual value of 'g' near the surface of Earth?

Q5: The strength of gravity on the Moon is 1.6 Nkg^{-1}. If an astronaut's mass is 80kg on Earth, what would it be on the Moon?

Q6: If you go on a diet and lose weight, will you also lose mas? Explain.

6.3 Mass of Earth

Mass of Earth can not be measured directly by placing it on any weighing scale. But it can be measured by an indirect method. This method utilizes the Newton's law of universal gravitation. Let us consider; Fig 6.5, in which a small ball is placed on the surface of Earth.

$m \rightarrow$ Mass of the ball.
$M_E \rightarrow$ Mass of Earth.
$G \rightarrow$ Universal gravitational constant.
$R_E \rightarrow$ Radius of earth; which is also the distance between the ball and centre of earth.

Then according to Newton's law of universal gravitation, the gravitational force F of the Earth acts on the ball is:

$$F = G\frac{mM_E}{R_E^2} \qquad \text{.....................(6.3)}$$

Whereas the force with which Earth attracts the ball towards its centre is equal to the weight of the ball. Therefore

$$\mathbf{F = W = mg} \quad \text{....................(6.4)}$$

Comparing equation (6.3) and (6.4); we get:

$$\mathbf{mg = G\frac{mM_E}{R_E^2}}$$

Re-arrangment of above equation gives

$$\mathbf{M_E = \frac{gR_E^2}{G}} \quad \text{....................(6.5)}$$

Numerical values of the constants at right hand side of equation (6.5) are:

$g = 10Nkg^{-1}$

$R_E = 6.38 \times 10^6 m$

$G = 6.673 \times 10^{-11} Nm^2kg^{-2}$

Substituting these values in equation (6.5), we get:

$$M_E = \frac{10Nkg^{-1} \times (6.38 \times 10^6 m)^2}{6.673 \times 10^{-11} Nm^2kg^{-2}}$$

$$M_E = 6.0 \times 10^{24} kg.$$

Thus, mass of Earth is 6.0×10^{24}kg.

Worked Example 3

Calculate the acceleration due to gravity on a planet that has mass two times to the mass of Earth and radius 1.5 times to the radius of Earth. If the acceleration due to gravity on the surface of Earth is $10ms^{-2}$. Calculate acceleration due to gravity on the planet?

Solution

Step 1: Write down known quantities and quantities to be found.

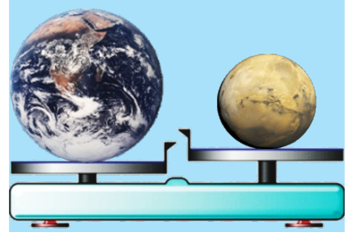
Mass of the planet = $M_p = 2M_E$

Mass of the Earth = $M_E = 6.0 \times 10^{24}$kg

Do You Know!

Ocean tides are caused by the gravity of Moon.

Do You Know!



The Earth has 9.3 times more mass than Mars

Activity

Calculate the mass of the Earth if acceleration due to gravity; g = $9.8ms^{-2}$.

Mass and Radius of different planets.

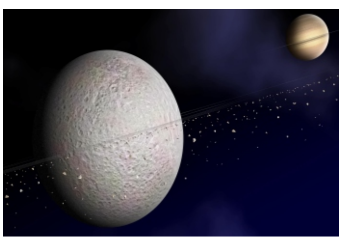


Fig 6.6 (a)
A natural satellite Moon revolving around the Earth

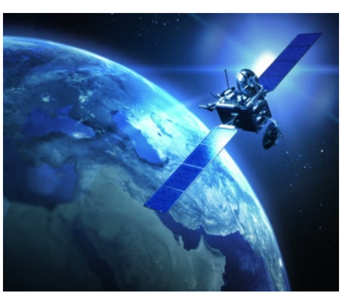


Fig 6.6 (b)
An artificial satellite revolving around the Earth

Radius of the planet = $R_p = 1.5\ R_E$
Radius of the Earth = $R_E = 6.38 \times 10^6$m
Universal gravitational constant
$= G = 6.673 \times 10^{-11} Nm^2kg^{-2}$
Acceleration due to gravity on the Earth = $g_E = 10ms^{-2}$
Acceleration due to gravity on the planet = g_p = ??

Step 2: Write down formula and rearrange if necessary

$$g_E = \frac{GM_E}{R_E^2}$$

For the planet:

$$g_p = \frac{GM_p}{R_p}$$

Step 3: Put the values in formula and calculate:

$$g_p = \frac{6.673 \times 10^{-11} Nm^2kg^{-2} \times 2 \times 6.0 \times 10^{24} kg}{(1.5 \times 6.38 \times 10m^6)^2}$$

$$g_p = 8.74ms^{-2}$$

Hence, acceleration due to gravity on the planet is $8.74ms^{-2}$.

Self Assessment Questions:

Q7: What will be the value of acceleration due to gravity on the surface of earth if its radius reduces to half?

Q8: What will be acceleration due to gravity on the surface of earth f its mass reduces by 25%?

Q9: What will be the mass of a planet whose radius is 20% of the radius of earth?

6.4 Artificial Satellites

A satellite is an object that revolves around a planet. Satellites are of two types:

1. Natural satellites Fig 6.6 (a).
2. Artificial satellites Fig 6.6 (b).

Natural Satellites	Artificial Satellites
The planet which revolves around another planet naturally is called "Natural Satellite".	The object which are sent into space by scientists to revolve around the Earth or other planets are called "Artificial Satellite".
E.g Moon is a natural satellite because it revolves around the Earth naturally.	E.g. Sputnik-1, Explorer-1 are amongst the artificial satellites.

Artificial satellites are used for different purposes like

- For communication.
- For making star maps.
- For making maps of planetary surfaces.
- For collecting information about weather.
- For taking pictures of planets, etc.

Artificial satellites carry instruments, passengers or both to perform different experiments in space.

Artificial satellites have been launched into different orbits around the Earth. There are different types of orbits like:

- For communication.
- Low- Earth orbit.
- Medium- Earth orbit.
- Geostationary orbit.
- Elliptic orbit.

These orbits are characterized on the basis of different parameters like, their distance from the Earth, their time period around the Earth etc.

An artificial satellite which completes its one revolution around the Earth in 24 hours is used for communication purpose. As Earth also completes its one rotation about its axis in 24 hours, therefore the above satellite appears to be stationary with respect to

Interesting Information

Mass and radius of different objects		
Planet / Star	Mass (Kg)	Radius (m)
Sun	1.99×10^{30}	6.96×10^{8}
Moon	7.35×10^{22}	1.74×10^{6}
Mercury	3.30×10^{23}	2.44×10^{6}
Venus	4.87×10^{24}	6.05×10^{6}
Earth	5.97×10^{24}	6.38×10^{6}
Mars	6.42×10^{23}	3.40×10^{6}
Jupiter	1.90×10^{27}	6.91×10^{7}
Saturn	5.68×10^{26}	6.03×10^{7}
Uranus	8.68×10^{25}	2.56×10^{7}
Neptune	1.02×10^{26}	2.48×10^{7}

Do You Know!

First artificial satellite was Sputnik-1 which was sent into space by Soviet Union (Russia) on 4th October 1957.

Earth. Its orbit is therefore called "Geostationary orbit". As it is used for communication purpose, therefore it is known as "Communication Satellite".

Newton's Law of Gravitation in the motion of satellite

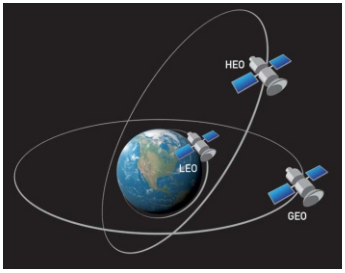


Fig 6.7
Motion of satellites in different orbits

The curved path along which a natural or artificial satellite revolves around a planet is called an "orbit"; (Fig 6.7). Rockets are used to put satellites into orbits in space. The Newton's law of gravitation has an important role in the motion of satellite in its orbit, because the gravitational pull of Earth on the satellite provides the centripetal force needed to keep a satellite in orbit around some planet.

Let us consider the motion of a satellite which is revolving around the Earth; Fig 6.8. In the figure:

$m \rightarrow$ Mass of the satellite.
$M \rightarrow$ Mass of Earth.
$R \rightarrow$ Radius of Earth
$h \rightarrow$ Height(altitude) of satellite from the surface of Earth.
$r = R + h \rightarrow$ Radius of orbit.

Then, as we already discussed:

Centripetal force = Gravitational force

$$\text{or} \qquad F_C = F_G \longrightarrow \text{(i)}$$

$$\because \quad F_C = \frac{mv^2}{r} \qquad \text{and}$$

$$F_G = \frac{GmM}{r^2}$$

Substituting the values of F_C and F_G in equation (i):

$$\frac{mv^2}{r} = \frac{GmM}{r^2}$$

$$v^2 = \frac{GM}{r} \qquad [\because r = R + h]$$

$$\therefore \qquad v^2 = \frac{GM}{R+h}$$

Do You Know!

The height of a geostationary satellite is about 42,300 km from the surface of the Earth. Its velocity with respect to Earth is zero.

$$\mathbf{v} = \sqrt{\frac{\mathbf{GM}}{\mathbf{R+h}}} \quad ....(6.6)$$

This gives the velocity that a satellite must possess when orbiting around Earth in an orbit of radius ($r = R+h$).

This shows that, the speed of the satellite is independent of its mass. Hence every satellite whether it is very massive (large) or very light (small) has the same speed in the same orbit.

The time required for a satellite to complete one revolution around the Earth in its orbit is called its time period "T". The time period of a satellite can be calculated as:

$$\because \qquad T = \frac{2\pi r}{v} -----------(i)$$

The velocity of satellite is given by equation (6.6) as:

$$v = \sqrt{\frac{GM}{R+h}}$$

Substituting it in equation (i)

$$\therefore \qquad T = \frac{2\pi r}{\sqrt{\frac{GM}{R+h}}} \qquad \because \quad r = R+h$$

$$\therefore \qquad T = 2\pi r\sqrt{\frac{r}{GM}}$$

$$\therefore \qquad \mathbf{T = 2\pi\sqrt{\frac{r^3}{GM}}} \quad ....(6.7)$$

Equations (6.7) gives the expression for the time period of a satellite orbiting around the Earth. Thus, Newton's law of gravitation helps to describe the motion of a satellite in an orbit around the Earth.

Motion of Artificial Satellite around the Earth

The satellites are put into their orbits around the Earth by rockets. When a satellite is put into orbit, its speed is selected carefully and correctly. If speed is not

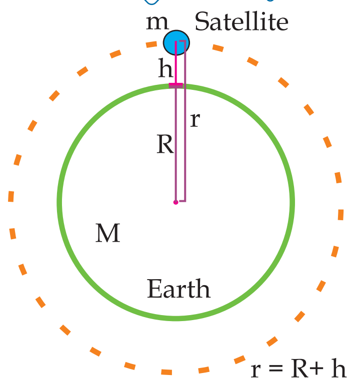


Fig 6.8
A Satellite is orbiting around the Earth

Weblinks

How satellite is launched into an orbit:
https://www.youtube.com/watch?v=8t2eyEDy7p4

chosen correctly then the satellite may fall back to Earth or its path may take it further into orbit. During the motion of a satellite in the orbit the gravitation pull of Earth on it is always directed towards the centre of Earth.

Newton used the following example to explain how gravity makes the orbiting possible.

Imagine a cannonball launched from a high mountain; Figure 6.8; shows three paths the ball can follow.

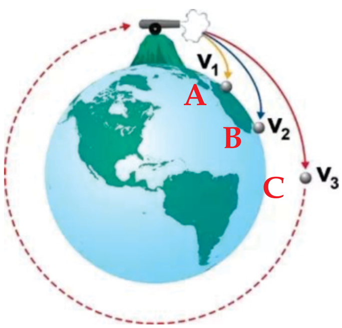


Fig 6.8
A cannon ball launched from high mountain

Path A	Path B	Path C
The canon ball is launched at a slow speed.	The canon ball is launched at a medium speed.	The canon ball is launched at a high speed.
The canon ball will fall back to Earth.	The canon ball will fall back to Earth.	The canon ball will not fall back to Earth instead it orbits around the Earth.

Above example shows that, for an artificial satellite to orbit the Earth and to retrace its path it requires certain orbital velocity. The orbital velocity is defined as:

The velocity required to keep the satellite into its orbit is called "Orbital Velocity"

The gravitational pull of Earth on a satellite provides the necessary centripetal force for orbital motion. Since this force is equal to the weight of satellite, '$W_S = mg$', therefore

$$F_C = W_S \text{ ----------- (i)}$$

and, $$W_S = mg_h$$

where,

m → Mass of the satellite.

g_h → Acceleration due to gravity at height 'h' from the surface of Earth.

Do You Know!

Tides in ocean result from the gravitational attraction of sun and moon. Sun's gravitational attraction to the Earth is 177 times greater that of the moon to the Earth

The centripetal force 'F_C' on the satellite is:

$$F_C = \frac{mv^2}{r}$$

Substituting the values of 'F_C' and 'W_S' in equation (i):

$$\frac{mv^2}{r} = mg_h$$

$$\therefore \quad v^2 = g_h r$$

$$\therefore \quad v = \sqrt{g_h r}$$

$$\because \quad r = R + h$$

$$\therefore \quad \mathbf{v = \sqrt{g_h (R+h)}} \quad \text{....................(6.8)}$$

If satellite is orbiting very close to the surface of Earth then: $h << R$

In this case orbital radius may be considered equal to radius of Earth.

Therefore, $R + h = R$

Also $g_h = g$

and $v = v_C$

Where,

$v_C \rightarrow$ Critical velocity

$g \rightarrow$ Acceleration due to gravity on the surface of Earth.

In terms of above factors equation (6.8) becomes:

$$\mathbf{v_C = \sqrt{gR}} \quad \text{....................(6.9)}$$

This is known as "Critical velocity". It is defined as:

The constant horizontal velocity required to put the satellite into a stable circular orbit around the Earth.

It is also known as orbital speed or proper speed.

If

$$g = 10 ms^{-2}$$

$$R = 6.38 \times 10^6 m$$

Then equation (6.9) becomes.

$$v_c = \sqrt{gR} = \sqrt{10ms^{-2} \times 6.38 \times 10^6 m}$$

$$v_c = 7.99 \times 10^3 ms^{-1}$$

or $$v_c = 8.0kms^{-1}$$

It should be noted that as the satellite get closer to the Earth, the gravitational pull of the Earth on it gets stronger.

So, the satellites in order to stay in an orbit closer to Earth needs to travel faster as compare to those satellites in the farther orbits.

Worked Example 4

Calculate the speed of a satellite which orbits the Earth at an altitude of 1000 kilometres above Earth's surface?

Solution

Step: 1 Write down known quantities and quantities to be found:

$$M_{Earth} = M = 6.0 \times 10^{24} kg$$

$$R_{Earth} = R = 6.38 \times 10^6 m$$

$$h = 1000km = 1000 \times 10^3 m = 1 \times 10^6 m$$

$$G = 6.673 \times 10^{-11} Nm^2kg^{-2}$$

$$v = ??$$

Step:2 Write down formula and rearrange if necessary:

$$v = \sqrt{\frac{GM}{R+h}}$$

Step:3 Put the values in formula and calculate:

$$v = \sqrt{\frac{6.673 \times 10^{-11} Nm^2kg^{-2} \times 6.0 \times 10^{24} kg}{6.38 \times 10^6 m + 1 \times 10^6 m}}$$

$$v = 7.36 \times 10^3 ms^{-1}$$

Hence, the orbital speed of satellite is $7.36 \times 10^3 ms^{-1}$.

Self Assessment Questions:

Q10: Write down any four uses of artificial satellites.

Q11: What is Geostationary orbit?

Q12: Why the two satellites of different masses have same speed in the same orbit?

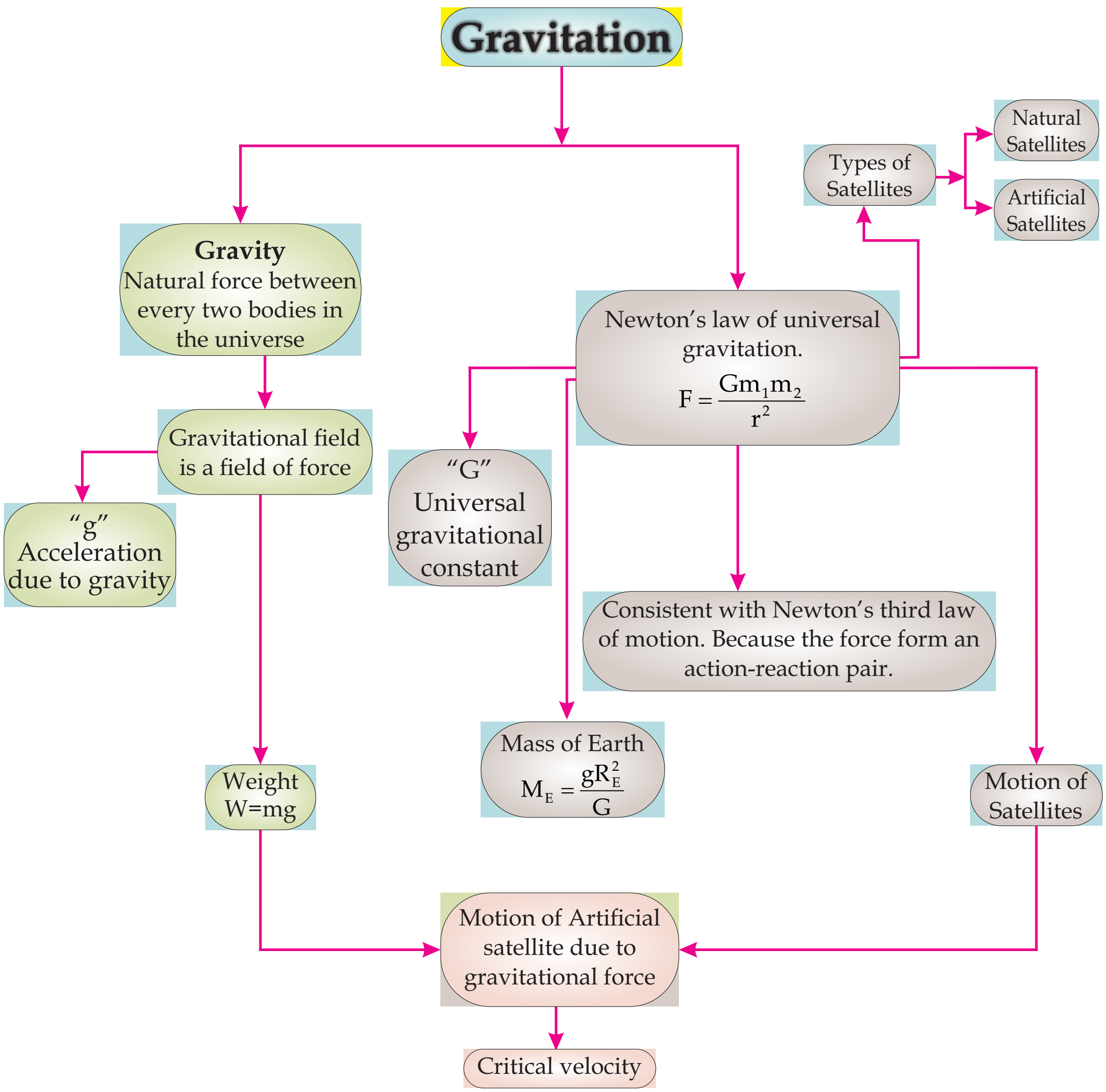
SUMMARY

- The gravitational force (pull) of Earth is known as gravity.
- Everybody in the universe attracts every other body with a gravitational force of magnitude

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

- Gravitational force forms an action-reaction pair. Newton's law of gravitation is consistent with Newton's third law of motion.
- "G" has constant value through out the universe.
- "g" has different values at different places.
- A gravitational field is a region in which a mass is attracted due to gravitational attraction.
- Weight of an object is the gravitational pull of Earth acting on it. Mathematically, W = mg.
- Mass of Earth is 6.0×10^{24} kg.
- A satellite is an object that revolves around a planet.
- Natural satellite is a planet that revolves around another planet naturally, like Moon is natural satellite of Earth.
- An artificial satellite is an object which is sent to space to revolve around a planet, like Sputnik-1, Meteosat are artificial satellites of Earth.
- Critical velocity is the constant horizontal velocity needed to put a satellite into an stable circular orbit around the Earth.

CONCEPT MAP


Gravitation
Gravity
Natural force between every two bodies in the universe
Gravitational field is a field of force
"g" Acceleration due to gravity
Weight W=mg
Newton's law of universal gravitation.
$F = \frac{Gm_1m_2}{r^2}$
"G" Universal gravitational constant
Types of Satellites
Natural Satellites
Artificial Satellites
Consistent with Newton's third law of motion. Because the force form an action-reaction pair.
Mass of Earth
$M_E = \frac{gR_E^2}{G}$
Motion of Satellites
Motion of Artificial satellite due to gravitational force
Critical velocity

End of Unit Questions

Section (A) Multiple Choice Questions (MCQs)

1. The motion of a falling ball towards Earth is due to the -----------.
   a) Weightlessness
   b) Gravitational force
   c) Acceleration due to gravity
   d) Both 'a' and 'b'
2. Newton's law of gravitation holds between every two objects on the -----------.
   a) on Earth b) on Jupiter
   c) on Moon d) on Universe
3. Numerical value of G is -------------.
   a) $G = 6.673 \times 10^{-11} Nm^2\ kg^{-2}$
   b) $G = 6.673 \times 10^{11} Nm^2\ kg^{-2}$
   c) $G = 6.763 \times 10^{-11} Nm^2\ kg^{-2}$
   d) $G = 6.763 \times 10^{11} Nm^2\ kg^{-2}$
4. Gravitational field of Earth is directed --------------.
   a) towards the Earth b) towards the Sun
   c) towards the Moon d) away from Earth
5. -------------------- was the first scientist who gave the concept of gravitation.
   a) Einstein b) Newton
   c) Faraday d) Maxwell
6. According to Newton's law of universal gravitation force $\propto$ _______.
   a) m_1m_2 b) $\frac{1}{r^2}$
   c) r^2 d) Both (a) and (b)
7. Gravitational force is always -------------.
   a) Repulsive b) Attractive
   c) Both d) None of these