Revision Notes

Class – 11 Physics

Chapter 8 – Gravitation

1. Introduction

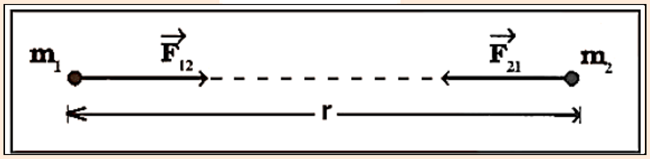
The constituents of the universe are galaxy, stars, planets, comets, asteroids, meteoroids. The force which keeps them bound together is called gravitational force. Gravitation is a nature phenomenon by which material objects attract towards one another.

In 1687 A.D. English Physicist, Sir Isaac Newton published principia Mathematica, which explains the inverse-square law of gravitation.

2. Newtons Law of Gravitation

2.1 Definition

Every particle of matter attracts every other particle of matter with a force that is proportional to the product of their masses and inversely proportional to the square of their separation.



2.2 Mathematical Form

If m_1 and m_2 are the masses of the particles and r is the distance between them, the force of attraction F between the particles is given by: $F \propto \frac{m_1 m_2}{r^2}$

$\therefore \quad F = G\frac{m_1 m_2}{r}$. (**G** is the universal constant of gravitation.)

2.3 Vector Form

In vector form, Newton's law of gravitation is represented in the following manner. The force $\left(\vec{F}_{21}\right)$ exerted on the particle m_2 by the particle m_1 is given by:

$$\vec{F}_{21} = -G\frac{m_1 m_2}{r^2}(\hat{r}_{12}) \qquad \ldots(1)$$

Where $(\hat{r}_{12})$ is a unit vector drawn from particle m_1 to particle m_2.

Similarly, the force $\left(\vec{F}_{21}\right)$ exerted on particle m_1 by particle m_2 is given by $\frac{x}{B}$ …(2)

Where $(\hat{r}_{12})$ is a unit vector drawn from particle m_1 to particle m_2.

From (1) and (2):

$$\vec{F}_{12} = -\vec{F}_{21}$$

3. Universal Constant for Gravitation

Universal gravitation constant is given as, $G = \frac{Fr^2}{m_1 m_2}$

Suppose that, $m_1 = m_2 = 1$, and $r = 1$ *then* $G = F$.

The force of attraction between two unit masses put at a unit distance apart is numerically equal to the universal gravitation constant.

3.1 Unit

SI unit: $\frac{\text{newton}(\text{metre})^2}{(\text{kilogram})^2} = \frac{\text{Nm}^2}{\text{kg}^2}$

CGS Unit: $\text{dyne cm}^2/\text{gm}^2$.

3.2 Value of **G**

The value of **G**; $G = 6.67 \times 10^{-11} \, Nm^2 / kg^2$

Dimensions of G:

$$[G] = \frac{[F]\left[r^2\right]}{\left[m_1 m_2\right]} = \frac{\left[M^1 L^1 T^2\right]\left[M^0 L^2 T^0\right]}{\left[M^2 L^0 T^0\right]} = = \left[M^{-1} L^3 T^{-2}\right]$$

Notes:

1. The gravitational force is independent of the intervening medium.
2. The gravitational force is a conservative force.
3. The first particle exerts a force on the second that is exactly equal to and opposite to the second particle's force on the first.
4. The gravitational force between two particles acts along the line that connects them, and they are part of an action-reaction pair.

4. VARIATION IN ‘g’

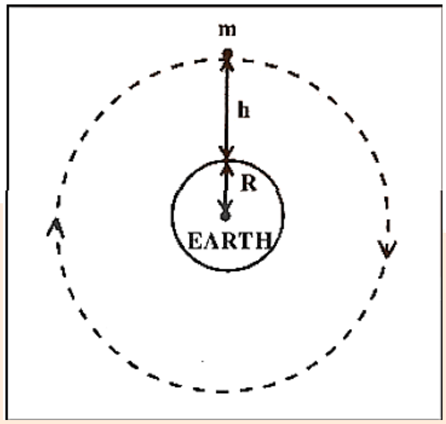
4.1 The Acceleration due to Gravity at a height h above the Earth’s surface

Let M and R be the earth's mass and radius, respectively, and g denote the acceleration due to gravity at the surface. Assume that a mass of m is placed on the earth's surface.

The weight ‘mg’ of the body is equal to the gravitational force acting on it.

$$mg = \frac{GMm}{R^2} \quad => \quad g = \frac{GM}{R^2} \qquad \ldots(1)$$

Now suppose that the body is raised to a height h, above the earth’s surface, the weight of the body is now mg and the gravitational force acting on it is $\frac{GMm}{(R+h)^2}$.



$$\therefore \quad mg_h = \frac{GMm}{(R+h)^2}$$

$$g_h = \frac{GM}{(R+h)^2} \qquad \ldots(2)$$

Dividing eq (2) by eq (1), we get, $\frac{g_h}{g} = \frac{R^2}{(R+h)^2}$

$$\Rightarrow \quad g_h = \left[\frac{R^2}{(R+h)^2}\right] g \;.$$

4.2 Acceleration due to gravity at a very small height

$$g_h = g\left(\frac{R+h}{R}\right)^2 \Rightarrow g_h = g\left(1-\frac{h}{R}\right)^{-2} \Rightarrow g_h = g\left(1-\frac{2h}{R}+\frac{h^2}{R^2}\ldots\ldots\right)$$

If h << R, then neglecting high power's of 'h' we get; $g_h = g\left(1-\frac{2h}{R}\right)$.

4.3 Effect of depth on a acceleration due to Gravity

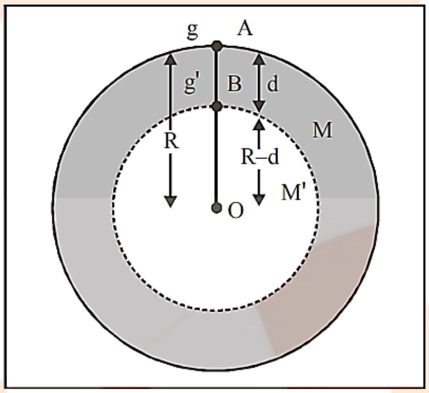
Also **g** in terms of ρ: $g = \frac{GM}{R^2}$

If ρ is density of the material of earth, then: $M = \frac{4}{3}\pi R^3 \rho$

$$g = \frac{G \times \frac{4}{3}\pi R^3 \rho}{R^2}$$

$$g = \frac{4}{3}\pi G R \rho \qquad \ldots(1)$$

Let g_d be the gravitational acceleration at point B at a depth x below the earth's surface. At point B, there is a body will only be subjected to force as a result of the earth's part OB (R – d) radius. The outer spherical shell, whose thickness is d, will not exert any force on body at point B. Because it will acts as a shell and point is inside.



Now, $M' = \frac{4}{3}\pi (R - x)^3 \rho$

Or $\quad g_d = \frac{4}{3}\pi G (R - d)\rho \qquad \ldots(2)$

Dividing the equation (2) by (1), we have:

$$\frac{g_d}{g} = \frac{\frac{4}{3}\pi G (R-d)\rho}{\frac{4}{3}\pi G R \rho} = \frac{R-d}{R} \text{ or } g_d = g\left(1 - \frac{d}{R}\right) \qquad \ldots(3)$$

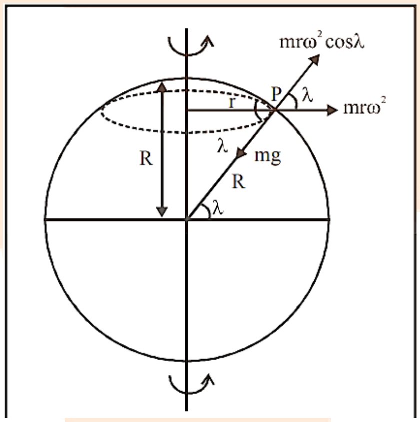
Therefore, the value of acceleration due to gravity decreases with depth.

4.4 Variation of ‘g’ with latitude due to Rotational motion of Earth

The force $mr\omega^2 \cos\lambda$ acts radially outwards due to the earth's rotation. As a result, the net force of attraction exerted by the particle's earth and directed towards the earth's centre is provided by:

$$mg' = mg - mr\omega^2 \cos\lambda \ .$$

where g' is the value of the acceleration due to gravity at the point P.



$$g' = g - r\omega^2 \cos\lambda$$

Now, $r = R\cos\lambda$ (where R is the radius of the earth)

Then $g' = g - (R\cos\lambda)\omega^2 \cos\lambda$

$$\therefore \quad g' = g - R\omega^2 \cos^2\lambda$$

The effective acceleration due to gravity at a point 'P' is given by $g' = g - R\omega^2 \cos^2\lambda$

Thus value of 'g' changes with 'λ' and 'ω'.

1. At poles,

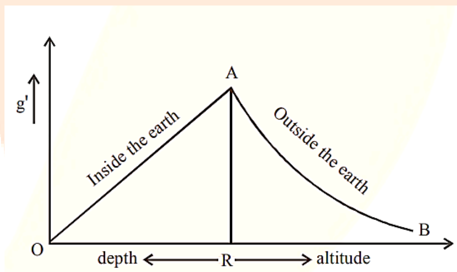
$$\lambda = 90$$
$$g' = g - R\omega^2 \cos^2 90$$
$$g' = g$$

2. At Equator

$$\lambda = 0$$
$$g' = g - R\omega^2 \cos^2 0$$
$$g' = g - R\omega^2$$

NOTE:

The variation of acceleration due to gravity according to the depth and the height from the earth's surface can be expressed with help of following graph.



5. SATELLITE

Any smaller body which revolves around another larger body under the influence of its gravitation is called a **satellite**. It may be natural or artificial.

1. The moon is a satellite of the earth since it rotates around it. Jupiter has sixteen satellites that circling around it. Natural satellites are the name given to these satellites.
2. An artificial satellite is one that has been built and launched into circular orbit by humans. The USSR launched the first satellite, SPUTNIK–I, while India launched the first satellite, ARYABHATTA.

5.2 Minimum two stage rocket is used to project a satellite in a circular orbit round a planet

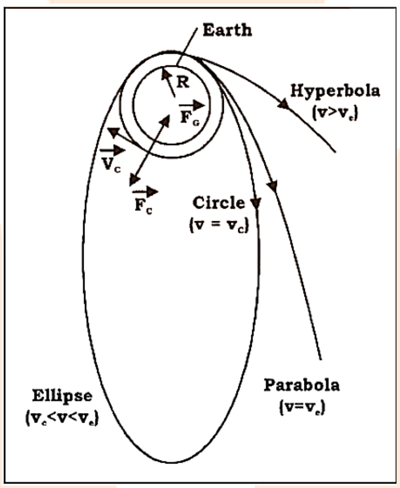
Assume that a single-stage launching system (i.e., a rocket) is utilised to launch a satellite from the earth's surface. The rocket begins to go upwards once the fuel in the rocket is ignited. When all of the fule has been used up, the rocket reaches its maximum velocity.

1. If the rocket's maximum velocity is equal to or greater than the escape velocity, the rocket escapes into space with the satellite, overcoming the earth's gravitational effect.
2. If the rocket's maximum velocity is less than escape velocity, it will be unable to resist the earth's gravitational pull, and both the rocket and the satellite will eventually descend to the earth's surface owing to gravity.

As a result, a single-stage rocket cannot put a satellite into a circular orbit around the globe. As a result, to launch a satellite into a circular orbit around the earth, a launching device (i.e., a rocket) with two or more stages must be used.

5.3 Different cases of Projection:

Depending on the amount of the horizontal velocity, the following four instances may occur when a satellite is lifted to a certain height above the earth and then projected horizontally.



1. If the velocity of the projection is less than the critical velocity then the satellite moves in elliptical orbit, but the point of projection is apogee and int he orbit, the satellite comes closer to the earth with its perigee point lying at 180°. If it enters the atmosphere while coming towards perigee it will loose energy and spirally comes down. If it does not enters the atmosphere it will contiune to move in elliptical orbit.
2. If the projection velocity equals the critical velocity, the satellite will move in a circular orbit around the planet.

3. If the projection velocity is more than the critical velocity but less than the escape velocity, the satellite will be in an elliptical orbit with an apogee, or farthest distance from the earth, larger than the projection height.
4. If the velocity of the projection is equals to the escape velocity, then the satellite moves in parabolic path.
5. It the velocity of the projection is greater than the escape velocity, then orbit will hyperbolic and will escape the gravitational pull of the earth and continue to travel infinitely.

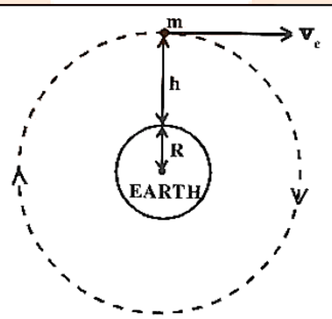
6. ORBITAL VELOCITY

6.1 Definition

The horizontal velocity with which a satellite must be projected from a point above the earth's surface, so that it revolves in a circular orbit round the earth, is called the **orbital velocity** of the satellite.

6.2 An Expression for the Critical Velocity of a Satellite revolving round the Earth

Suppose that a satellite of mass m is raised to a height h above the earth's surface and then projected in a horizontal direction with the orbital velocity v_c. The satellite begins to move round the earth in a circular orbit of radius, $R + h$, where R is the radius of the earth.



CIRCULAR ORBIT OF A SATELLITE

The gravitational force acting on the satellite is $\frac{GMm}{(R+h)^2}$, where M is the mass of the earth and G is the constant of gravitation.

For circular motion,

Centrifugal force = Centripetal force

$$\frac{mv_c^2}{(R+h)} = \frac{GMm}{(R+h)^2}$$

$$\therefore \quad v_c = \sqrt{\frac{GM}{(R+h)}}$$

This expression gives the critical velocity of the satellite. From the expression, it is clear that the critical velocity depends upon.

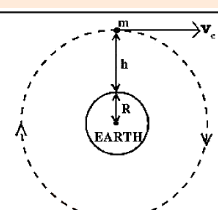
1. Mass of the earth
2. Radius of the earth
3. Height of the satellite above the surface of the earth.

7. Height of the satellite above the surface of the earth

The time taken by a satellite to complete one revolution round the earth is called its **period** or **periodic time (T)**. Consider a satellite of mass m revolving in a circular orbit with a orbital velocity v_c at a height h above the surface of the earth. Let M and R be the mass and the radius of the earth respectively.

The radius (r) of the circular orbit of the satellite is r = R + h.

For the circular motion,



CIRCULAR ORBIT OF A SATELLITE

$$v_c = \sqrt{\frac{GM}{r}} \qquad \ldots(1)$$

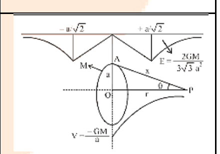
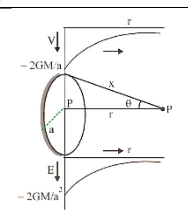
If T is the period of revolution of the satellite, $Period\ (T) = \frac{circumference\ of\ orbit}{critical\ velocity} = \frac{2\pi r}{v_c}$

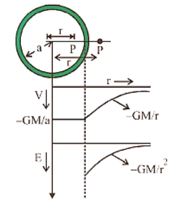
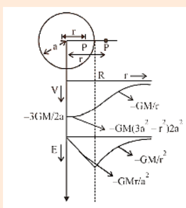
$$T = \frac{2\pi r}{\sqrt{GM/r}} \quad \Rightarrow \quad T = 2\pi\sqrt{\frac{r^3}{GM}}$$

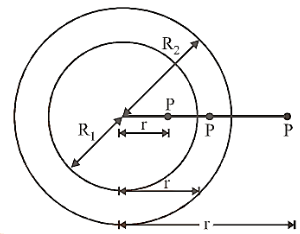
This expression gives the periodic time of the satellite. Squaring the expression, we get, $T^2 = \frac{4\pi^2 r^3}{GM}$

$T^2 \alpha r^3$ ...(since G and M are constants)

Thus, the square of the period of revolution of a satellite is directly proportional to the cube of the radius of its orbit.

Object	**Potential** (V)	**Electric Field** (E) $v_e = \sqrt{\frac{2GM}{R}}$ R G m	**Figure**
Ring	$V = \frac{-GM}{(a^2 + r^2)^{1/2}}$	$\vec{F} = \frac{-GMr}{(a^2 + r^2)^{3/2}}\hat{\mathbf{r}}$	
Thin Circular Ring	$V = \frac{-2GM}{a^2}\left[\sqrt{a^2 + r^2} - r\right]$	$\vec{E} = -\frac{2GM}{a^2}\left[1 - \frac{r}{\sqrt{r^2 + a^2}}\right]\hat{\mathbf{r}}$	

Uniform thin spherical shell **(a)** Point P inside the shell $(r \le a)$ **(b)** Point P outside the shell $(r \ge a)$	$V = \frac{-GM}{a}$ $V = \frac{-GM}{r}$	$E = 0$ $\vec{E} = \frac{-GM}{r^2}\hat{r}$	
Uniform solid sphere **(a).** Point P inside the sphere $(r \le a)$ **(b)** Point P outside the shell $(r \ge a)$	$V = -\frac{Gm}{2a^3}\left(3a^2 - r^2\right)$ $V = -\frac{GM}{r}$	$\vec{E} = \frac{-GM}{a^3}\hat{r}$ $\vec{E} = \frac{-GM}{r^2}\hat{r}$	

Uniform thick sphere **a.** Point outside the shell **b.** Point inside the shell **c.** Point between the two surfaces	$V=-G\frac{M}{r}$ $V=\frac{-3}{2}GM\left(\frac{R_2+R_1}{R_2^2+R_1R_2+R_1^2}\right)$ $V=\frac{-GM}{2r}\left(\frac{3rR_2^2-r^3-2R_1^3}{R_2^3-R_1^3}\right)$	$\vec{E}=-G\frac{M}{r^2}\hat{r}$ $\vec{E}=0$ $\vec{E}=\frac{-GM}{r^2}\left(\frac{r^3-R_1^3}{R_2^3-R_1^3}\right)\hat{r}$	

8. GRAVITATIONAL FIELD

A gravitational field is the space that surrounds any mass. A gravitational pull acts on any additional mass introduced into this space. In a nutshell, the area in which a gravitational pull is experienced by any mass field of gravity.

9. GRAVITATIONAL INTENSITY

The gravitational intensity at any point in a gravitational field is defined as the force acting on a unit mass placed at that point.

1. The gravitational intensity (E) at a point at distance r from a point mass M is given by: $E=\frac{GM}{r^2}$ (where G is the constant of **gravitation**)
2. If a point mass m is placed in a gravitational field of intensity E, the force (F) acting on the mass m is given by: $F=mE$.

10. GRAVITATIONAL POTENTIAL

The work required to transport a unit mass from infinity to any location in a gravitational field is defined as the gravitational potential at that point.

1. The gravitational potential (V) at a point at distance r from a point mass M is given by: $V = {-GM}/{r}$
2. The work done on a unit mass is converted into its potential energy. Thus, the gravitational potential at any point is equal to the potential energy of a unit mass placed at that point.
3. If a small point mass m is placed in a gravitational field at a point where the gravitational potential is V, the gravitational potential energy (P.E.) of the mass m is given by: $\text{P.E.} = \text{mass} \times \text{gravitational potential} = mV$

$$\text{P.E.} = -\frac{GMm}{r}$$

10.1Gravitational Potential Energy

The work done in taking a body from infinity to a specific point is defined as **gravitational potential energy**.

Let a body of mass m is displaced through a distance 'dr' towards the mass M, then work done given by: $dW = Fdr = \frac{GMm}{r^2}dr \Rightarrow \int dW = \int_{\infty}^{r} \frac{GMm}{r^2}dr$

Gravitational potential energy, $U = -\frac{GMm}{r}$.

1. From above equation, it is clear that gravitational potential energy increases with increase in distance (r) (i.e. it becomes less negative).
2. Gravitational P.E. becomes maximum (or zero) at $r = \infty$.

10.2 Expressions for different Energies of Satellite

1. Potential Energy

2. Kinetic Energy

3. Total Energy

4. Binding energy

Let M = mass of the earth

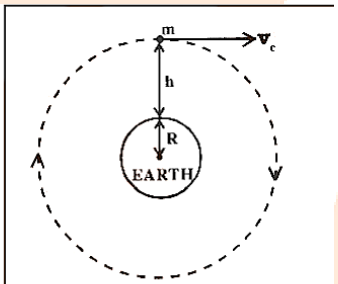
R = radius of the earth

m = mass of the satellite

G = constant of gravitation

h = height of satellite

1. **Potential energy (P.E.)** : The satellite is at a distance (R + h) from the centre of the earth.



CIRCULAR ORBIT OF A SATELLITE

$$U = -\frac{Gm_1m_2}{r} \Rightarrow -\frac{GMm}{R+h} = U$$

2. **Kinetic energy (K.E.)** : The satellite is revolving in a circular orbit with the critical velocity (vc). Hence its kinetic energy is given by: $K.E. = \frac{1}{2}mv_c^2$

$$v_c = \sqrt{\frac{GM}{R+h}} \Rightarrow K.E. = \frac{1}{2}m\left(\frac{GM}{R+h}\right) = \frac{GMm}{2(R+h)}$$

3. Total energy (T.E.): T.E = P.E. + K.E

$$T.E = -\frac{GMm}{R+h} + \frac{GMm}{2(R+h)} = -\frac{GMm}{2(R+h)}$$

The $-ve$ sign indicates that the satellite is bound to the earth.

4. Binding energy (B.E.) : From the expression for the total energy, it is clear that if the satellite is given energy equal to $+\frac{GMm}{2(R+h)}$ the satellite will escape to infinity where its total energy is zero.

$$B.E. = -(\ T.E.) = -\left[-\frac{GMm}{2(R+h)}\right] = +\frac{GMm}{2(R+h)}$$

5. **Binding Energy of a satellite**: The minimum energy which must be supplied to a satellite, so that it can escape from the earth's gravitation field, is called the binding energy of a satellite. When the body of mass m is at rest on the earth's surface, its gravitational potential energy is given by:

$$U = -\frac{GMm}{R}$$

If the body is give an energy equal to: $+\frac{GMm}{R}$ it will escape to infinity.

Binding energy of the body $+\frac{GMm}{R}$

11. ESCAPE VELOCITY OF A BODY

11.1 Expression for the escape velocity of a body at rest on the earth's surface

The escape velocity is the lowest velocity at which a body should be ejected from the earth's surface in order to escape the gravitational field of the planet velocity.

Thus, if a body or a satellite is given the escape velocity, its kinetic energy of projection will be equal to its binding energy.

Kinetic Energy of projection = Binding Energy

$$\frac{1}{2}mv_e^2 = \frac{GMm}{r} \quad => \quad v_e = \sqrt{\frac{2GM}{R}}$$

11.2 Expression for 'V_e' in term's of 'g'

The escape velocity for any object on the earth's surface is given by: $v_e = \sqrt{\frac{2GM}{R}}$

If m is the mass of the object, its weight mg is equal to the gravitational force acting on it.

$$mg = \frac{GMm}{R^2} \Rightarrow G.M = gR^2$$

Substituting this value in the expression for V_e we get, $v_e = \sqrt{2gR}$

11.3 Expression for the escape velocity of a body from Earth in terms of mean density of the planet

1. Derive expression for $v_e = \sqrt{\frac{2GM}{R}}$

2. Let ρ be the mean density of the planet. Then, $M = \frac{4}{3}\pi R^3 \rho$

$$v_e = \sqrt{\frac{2G}{R} \times \frac{4}{3}\pi R^3 \rho} \Rightarrow v_e = 2R\sqrt{\frac{2\pi G\rho}{3}}$$

11.4 The escape velocity of a body from the surface of the earth is 2 times its critical velocity when it revolves close to the earth's surface

Let M and R be the earth's mass and radius, respectively, and m be the body's mass. The radius of the orbit is nearly equal to R while orbiting close to the earth's surface. If v_c is the body's critical velocity, then the orbit is circular.

Centripetal force = Gravitational force

$$mv_c^2 = \frac{GMm}{R^2} \Rightarrow v_c = \sqrt{\frac{GM}{R}} \qquad \ldots(1)$$

If v_e is the escape velocity from the earth's surface,

K.E. of projection = Binding energy m_G

$$\frac{1}{2}mv_e^2 = \frac{GMm}{R^2}$$

$$\therefore \quad v_e = \sqrt{\frac{2GM}{R}} \qquad \mathbf{\ldots(2)}$$

From Eq (1) and Eq. (2), we get, $v_e = \sqrt{2}v_c$

12. COMMUNICATION SATELLITE

An artificial satellite that revolves in a circular orbit around the earth in the same sense as the earth's rotation and has the same period of revolution as the earth's rotation($\text{i.e.1 day} = 24 \text{ hours} = 86400 \text{ seconds}$) is called as geo-stationary or communication satellite.

As relative velocity of the satellite with respective to the earth is zero it appears stationary from the earth's surface. Therefore it is know as geo-stationary satellite or geosynchronous satellite.

1. The height of the communication satellite above the earth's surface is about $36000\ km$ and its period of revolution is $24\ hours\ or\ 24 \times 60 \times 60\ seconds$.
2. The satellite appears to be at rest, because its speed relative to the earth is zero, hence it is called as geostationary or geosynchronous satellite.

12.1 Uses of the communication satellite

1. For sending TV signals over large distances on the earth's surface

2. Telecommunication.

3. Weather forecasting.

4. For taking photographs of astronomical objects.

5. For studying of solar and cosmic radations.

13. WEIGHTLESSNESS

1. The weight of a body refers to the gravitational force that pulls it towards the earth's centre a feeling of weightlessness is like a moving satellite. It isn't because the weight is zero.

2. When an astronaut is on the surface of earth, gravitational force acts on him. This gravitational force is the weight of astronaut and astronaut exerts this force on the surface of earth. The surface of earth exerts an equal and opposite reaction and due to this reaction he feels his weight on the earth.

3. for an astronaut in an orbiting satellite, the satellite and astronaut both have same acceleration towards the centre of earth and this acceleration is equal to the acceleration due to gravity of earth.

4. As a result, astronaunt does not have any effect on the satellite's floor. Naturally, the astronaut is unaffected by the floor's reaction force. The astronaut experiences a sense of weightlessness since there is no reaction. (i.e. he has no idea how heavy he is).

NOTE:

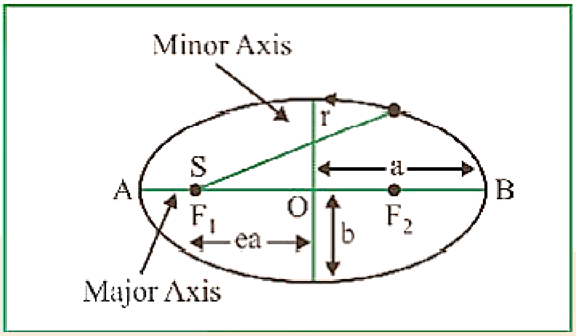
1. The sensation of weightlessness experienced by an astronaut is not the result of there being zero gravitational acceleration, but of there being zero difference between the acceleration of the spacecraft and the acceleration of the astronaut.
2. The most common problem experienced by astronauts in the initial hours of weightlessness is known as space adaptation syndrome (space sickness).

14. KEPLER'S LAWS

14.1 Law of Orbit

Each Planet move surround the sun in an elliptical orbit with the sun at one of the foci as shown in figure. The eccentricity of an ellipse is defined as the ratio of the distance SO and AO i.e. $e = \frac{SO}{AO}$

$e = \frac{SO}{a}$ => $SO = ea$



The distance of closest approach with sun at F1 is AS. This distance is called perigee. The greatest distance (BS) of the planet from the sun is called apogee.

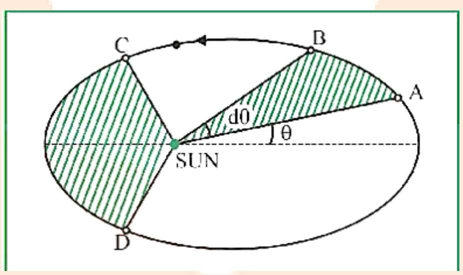
Perigee (AS) = AO – OS = $a - ea = a(1 - e)$

apogee (BS) = OB + OS = $a + ea = a(1 + e)$

14.2 Law of Area

The line joining the sun and a planet sweeps out equal areas in equal intervals of time. A planet takes the same time to travel from A to B as from C to D as shown in figure.

(The shaded areas are equal). Naturally the planet has to move faster from C to D.

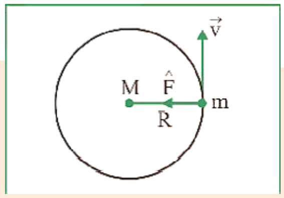


$$Area\,velocity = \frac{Area\,swept}{time} = \frac{\frac{1}{2}r(rd\theta)}{dt} = \frac{1}{2}r^2\frac{d\theta}{dt} = \text{constant}$$

Hence, $\frac{1}{2}r^2\omega = \text{constant}$

14.3 Law of Periods

The square of the time for the planet to complete a revolution about the sun is proportional to the cube of semimajor axis of the elliptical orbit.



i.e. Centripetal force = Gravitational force

$$\frac{mv^2}{R} = \frac{GMm}{R^2} \Rightarrow \frac{GM}{R} = v^2$$

Now, velocity of the planet is, $v = \frac{circumference\ of\ the\ circular\ orbit}{Time\ Period} = \frac{2\pi R}{T}$

Substituting Value in above equation $\frac{GM}{R} = \frac{4\pi^2 R^2}{T^2}$ or $T^2 = \frac{4\pi^2 R^3}{GM}$

Since, $\left(\frac{4\pi^2}{GM}\right)$ is constant.

$\therefore T^2 \propto R^3$ or $\frac{T^2}{R^3} = \text{constant}$

14.4 Gravity

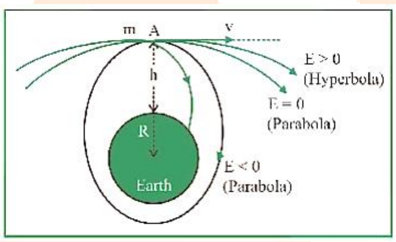
The force of attraction exerted by the earth towards its centre on a body lying on or near the surface of the earth is known as gravity. Gravity is a type of gravity that is also known as the earth's gravitational pull.

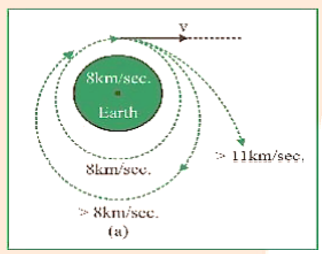
Weight of a body is defined as the force of attraction exerted by the earth on the body towards its centre. The units and dimensions of gravity pull or weight are the same as those of force.

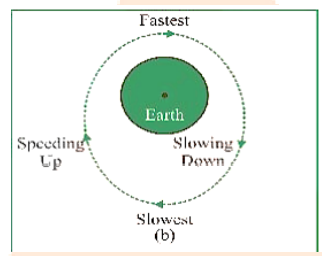
Body	Sun	Earth	Moon
Mean radius, (m)	6.95×10^8	6.37×10^6	1.74×10^6

Mass, (kg)	1.97×10^{30}	5.96×10^{24}	7.30×10^{22}
Mean density ($10^3 kg/m^3$)	1.41	5.52	3.30
Period of rotation about axis, (days)	25.4	1.00	27.3

LAUNCHING OF AN ARTIFICIAL SATELLITE AROUND THE EARTH







The satellite is placed upon the rocket which is launched from the earth. After the rocket reaches its maximum vertical height h, a spherical mechanism gives a thrust to the satellite at point A (figure) producing a horizontal velocity v. The total energy of the satellite at A is thus,

$$E=\frac{1}{2}mv^2-\frac{GMm}{R+h}$$

The orbit will be an ellipse (closed path), a parabola, or an hyperbola depending on whether E is negative, zero, or positive. In all cases the centre of the earth is at one focus of the path. If the energy is too low, the elliptical orbit will intersect the earth and the satellite will fall back. Otherwise it will keep moving in a closed orbit, or will escape from the earth, depending on the values of v and R. Hence a satellite carried to a height $h\ (<< R)$ and given a horizontal velocity of $8\ km/sec$ will be placed almost in a circular orbit around the earth (figure). If launched at less than $8\ km/sec$, it would get closer and closer to earth until it hits the ground. Thus $8\ km/sec$ is the critical (minimum) velocity.

14.5 Inertial mass

Newton's second law of motion defines a body's inertial mass, which is related to its inertia in linear motion.

Let a body of mass mi move with acceleration a under the action of an external force F. According to Newton's second law of motion, $F = m_i\ a \text{ or } m_i = F/a$

As a result, a body's inertial mass is equal to the magnitude of external force necessary to produce unit acceleration.

14.6 Gravitational mass

Gravitational mass of a body is related to gravitational pull on the body, and is defined by Newton's law of gravitational.

$$F = \frac{GMm_G}{R^2} \quad \text{or} \quad m_G = \frac{F}{\left(GM/R^2\right)} = \frac{F}{I}.$$

The mass m_G of the body in this sence is the gravitational mass of the body. The intertia of the body has no effect on the gravitational mass of the body. $m_G = F$

Thus, Gravitational mass of a body is defined as the magnitude of gravitational pull experienced by the body in a gravitational field of unit intensity .

14.7 Centre of Gravity

Centre of gravity of a body placed in the gravitational field is that point where the net gravitational force of the field acts.