Gravitation

(gravitational PE, escape velocity, orbital velocity and geostationary satellite)

Note : This PPT will NOT help you learn physics concepts. It is intended only as a quick revision of formulas, definitions, theorems and concepts before examinations. No physics can be learnt just by watching a few videos or going through a few slides of PPT.

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Gravitational potential energy

Gravitational potential of a system of two masses is the work done to assemble these mass from infinity.

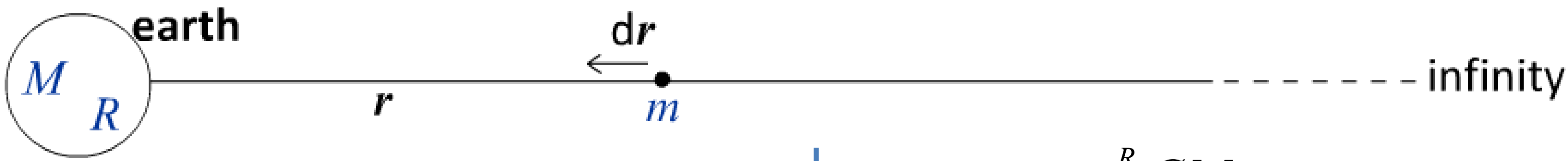
$$U = -\frac{Gm_1 m_2}{r}$$

Gravitational potential energy of earth-body system

Gravitational potential of a body and the earth when their centre of masses are at a distance of R is

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

Gravitational potential energy of earth-body system



Gravitational force acting on the body at this point is

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

Work done (dW) is causing a small displacement is

$$\mathrm{d}W = \overline{F} \bullet \mathrm{d}\overline{r}$$

$$\mathrm{d}W = F\,\mathrm{d}r$$

$$\mathrm{d}W = \frac{GMm}{r^2}\,\mathrm{d}r$$

Total work done from infinity to a distance R from centre of the earth is

$$W = \int_{\infty}^{R} \frac{GMm}{r^2}\,\mathrm{d}r$$

$$W = GMm\int_{\infty}^{R} \frac{1}{r^2}\,\mathrm{d}r$$

$$W = -GMm\left[\frac{1}{R} - \frac{1}{\infty}\right]$$

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

This work is stored as potential energy, therefore

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

Escape speed (v_e)

The minimum speed with which a body should be projected from the earth so that it eventually escapes the earth's gravitational pull.

Total initial energy of the system when projected from the surface of the earth is

$$TE = KE + PE$$

$$TE = \frac{1}{2}mv^2 - \frac{GMm}{R}$$

Total final energy of the system when the body escapes the earth's pull is

$$TE = KE + PE$$

$$TE = 0 + 0$$

Using law of conservation of energy

$$TE_{\text{initial}} = TE_{\text{final}}$$

$$\frac{1}{2}mv^2 - \frac{GMm}{R} = 0$$

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

$$v^2 = \frac{2GM}{R}$$

$$v_e = \sqrt{\frac{2GM}{R}} = \sqrt{2gR}$$

Escape velocity from the surface of the earth is 11.2 km s^{-1}

Initial velocity greater than escape velocity

An object projected with a velocity greater than or equal to 11.2 km.s^{-1} will not return to earth.

Escape velocity of 11.2 km s^{-1} is the minimum velocity required for a body to escape the earth's gravitational pull. If the initial velocity of the body is more than the escape velocity then its velocity as it escapes the earth's gravitational pull may be determined using the law of conservation of energy

$$\frac{1}{2}mu^2 + \left(-\frac{GMm}{R}\right) = \frac{1}{2}mv^2 + 0$$

$$\frac{1}{2}v^2 = \frac{1}{2}u^2 - \frac{GM}{R}$$

$$v = \sqrt{u^2 - \frac{2GM}{R}}$$

Application of escape speed

Hydrogen is in abundance around the sun but not around earth.

Due to the large mass of the sun, escape velocity from the surface of the sun is large. Due to the high escape velocity, hydrogen is not able to escape from the sun even though it is available in large amount.

Due to the relative less mass of the earth, escape velocity from the surface of the earth is also relatively less. Free hydrogen attains this velocity at sufficiently high temperature and escapes the earth.

Orbital speed (v_e)

Speed required for a body to revolve around the earth in a stationary orbit.

Gravitational force acting on a body of mass m orbiting the earth at a height h from its surface is

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

Force required to maintain a circular path (centripetal force) is

$$F = \frac{mv^2}{(R+h)}$$

Gravitational force provides the required centripetal force, therefore

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

$$v^2 = \frac{GM}{(R+h)}$$

$$v_o = \sqrt{\frac{GM}{(R+h)}}$$

For low altitudes of orbits ($h << R$) we get

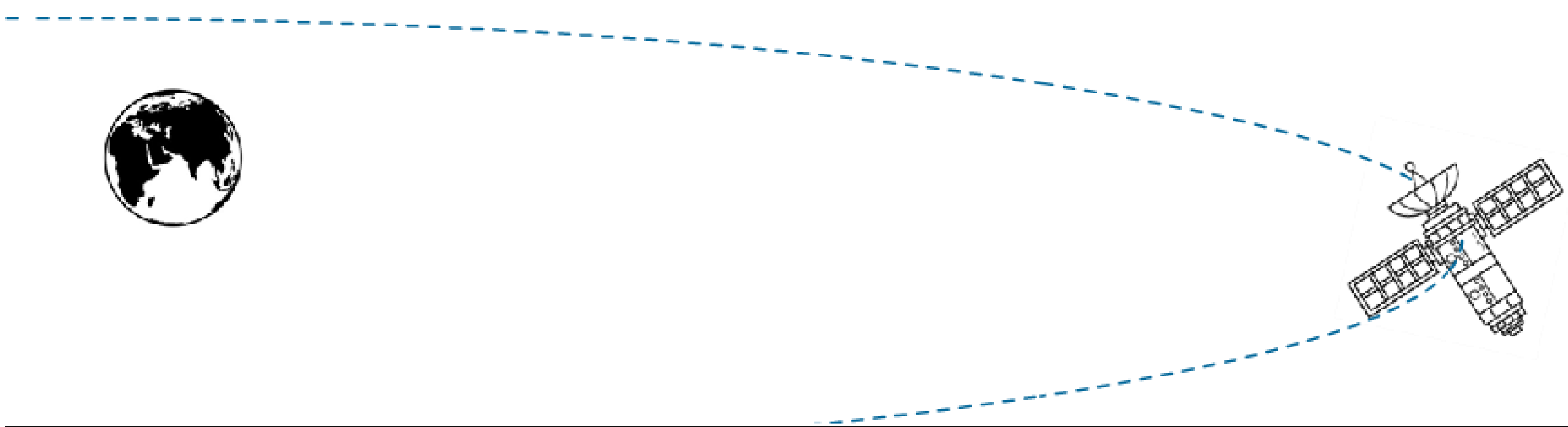
$$v_o \approx \sqrt{gR}$$

Application of orbital speed

If a nut becomes loose and gets detached from a satellite revolving around the earth, will it fall down to earth or will it revolve around earth?

If a nut becomes loose and detaches from a satellite orbiting the Earth, it will keep moving around the Earth in the same orbit as that of the satellite. It will not to the Earth.

This is because the nut , before being detached, the nut was revolving with the satellite in a stationary orbit. Even after being detached it maintains the same orbital speed due to the conservation of momentum. Due to this orbital velocity, it continues its circular path around the Earth in the absence of any external force to change its state.



Geostationary satellite

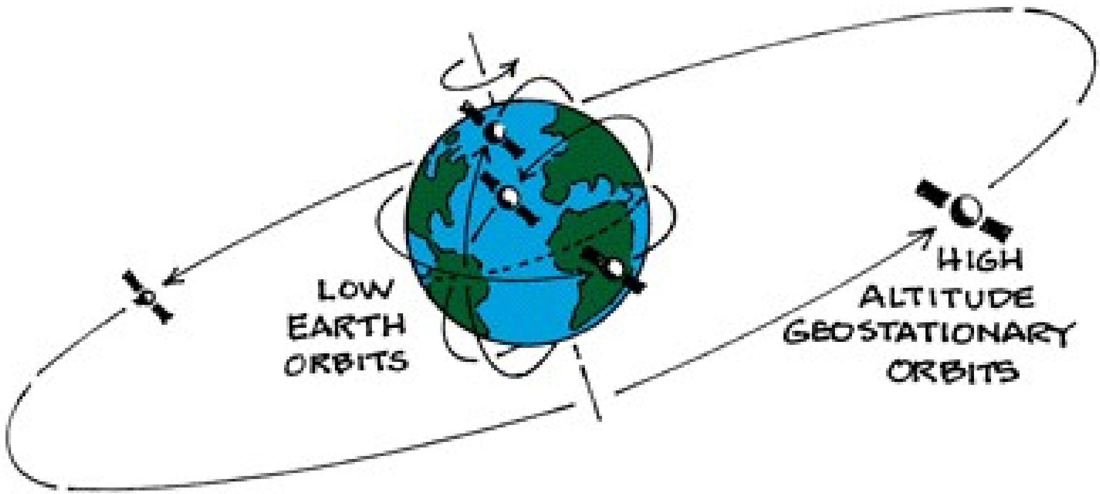
A satellite that appears to be stationary for an observer located on the earth.

Conditions for a satellite to be geostationary

- Its direction of revolution should be same as that of the earth i.e. west to east
- Its time period of revolution should be same as that of the earth i.e. 24 hours.

Uses of a geostationary satellite

1. Weather forecasting
2. Communication



Polar satellites

A satellite that orbits the earth passing over the geographic north and south poles is capped a polar satellite.

<u>Uses of a polar satellite</u>

1. Remote sensing
2. Environmental monitoring and mapping
3. Meteorology (study of Earth's atmosphere that influence weather and climate)