PENANG SANGAM HIGH SCHOOL

WEEK 8 **LESSON NOTES**

PYHSICS – Y13

STRAND: GRAVITATION

SUB-STRAND: Gravitational Potential Energy and Escape Velocity

CONTENT LEARNING OUTCOME: to be able to determine the gravitational potential energy and escape velocity of a satellite.

Gravitational Potential Energy (U)

The potential energy of an object can be found by using the equation $\boxed{E_P = m\,g\,h}$

Where – h is the height above or below a reference level

This equation is only valid when the object is near the earth's surface.

For objects high above the earth's surface, such as satellites, an alternative equation is used. The reference level is redefined. The reference or **zero level is placed at an infinite distance from the centre of the earth**. When a particle of mass m, is at distance r, from the centre of mass, the **potential energy(U)** of the system is same as the **work done** in the direction of the field to move the particle from Infinity (∞) to r.

Note : "U" at ∞ is equal to 0 J , because "g" is equal to 0 J at ∞, g = $\frac{GM}{r^2}$

Weight = gravitational force

$$m\,g = \frac{GMm}{r^2}$$

$$m\,g\,r = \frac{GMm}{r} \quad (\times r)$$

$$\boxed{U = \frac{-GMm}{r}}$$, **Gravitational Potential Energy**.

U is taken negative because position of "r" is before ∞ or because the object is not able to escape the earths gravity.

Escape Velocity

Is the velocity required by a projectile to **escape the earth's gravitational field**. For a body to escape earths gravitational field it must have enough energy to over come the total gravitational potential energy **"U"**, that is holding it. To derive an expression for the **escape velocity**, equate the **kinetic energy with its gravitational potential energy**.

$$E_K = U$$

$$\frac{1}{2} m v^2 = \frac{GM_e m}{r}$$

$$\boxed{V = \sqrt{\frac{2GM_e}{r}}}$$ **Where: r = radius of earth** .

Example 1

1) A satellite of mass 55 kg is placed in a circular orbit 500 km from the Earth's surface. The mass of the Earth is 5.98×10^{24} kg and the radius of Earth is 6.4×10^{6} m. Determine the:

   a) gravitational potential energy

$$U = -\frac{GMm}{r} = -\frac{(6.67\times10^{-11}\ \mathrm{Nm^2kg^{-2}})(5.98\times10^{24}\ \mathrm{kg})(50\ \mathrm{kg})}{(6.4+0.5)\times10^{6}\ \mathrm{m}} = -2.89\times10^{9}\ \mathrm{J}$$

Example 2

Find the escape velocity of a rocket of mass 5 tons from the surface of the earth.

(Mass of earth $= 5.98 \times 10^{24}$ kg, Radius of earth $= 6.4 \times 10^{6}$ m)

$$v = \sqrt{\frac{2GM_e}{r}}$$

$$= \sqrt{\frac{2(6.67\times10^{-11}\,Nm^2kg^{-2})(5.98\times10^{24}\,kg)}{(6.4\times10^{6}\,m)}}$$

$$= \underline{11\ 090\ \mathrm{m/s}}$$

Note: The escape velocity is independent of mass of rocket.

Exercise

A satellite of mass 700 kg is launched from a site on the earth's equator ir an orbit of 250 km above the surface of the earth. Assume the satellite orbit is circular.

Calculate the

(i) escape velocity of the satellite using $V = \sqrt{\frac{2GM_E}{r}}$.

(ii) Determine the gravitational potential energy of the satellite.