GRAVITATIONAL FIELD

Gravitational field is a region or space around a mass in which the gravitational force of the mass can be felt. In other words, gravitational field is space around a body where in gravitational force acts upon the object. For example, the earth exerts a force on the moon which is about 385,000km away. The sun also exerts a gravitational force on the earth even though the earth is about 1.5×10^8 km away.

In order to explain the observation of forces acting at a distance especially between planetary bodies, it has been postulated that a gravitational field surrounds everybody that has mass, and this field fills up all of space.

It was Sir Isaac Newton who first proposed the relationship between the gravitational force, F between two masses, m_1, m_2, and the distance, r, between the masses. The relationship can be stated as the Law of Universal Gravitation. It states that "Every particle in the universe attracts every

other particle with a force that is proportional to the product of their mass and inversely proportional to the square of the distance between them. Mathematically, it states that:

$$F \propto \frac{m_1\, m_2}{r^2} \;\Rightarrow\; F = \frac{G\, m_1\, m_2}{r^2}$$

where m_1 and m_2 are the masses of the two particles, r is the distance between them and G is a universal constant of gravitation or simply gravitational constant, and is equal to $6.67 \times 10^{-11} Nm^2 kg^{-2}$.

Gravitational attraction keeps the moon in its orbit around the earth and the earth in its orbit around the sun. Also, it keeps humans on the earth surface.

Acceleration of Gravity

The earth is supposed to be a sphere of radius, r_e, with its mass m_e concentrated at the earth's centre. The distance of any object on the earth surface to the centre of the earth is r_e the earth's radius. The

gravitational force of attraction of the earth on any mass, m on the earth's surface is given by

$$F = \frac{G\, m_e m}{r^2}$$

This is the force of gravity on the mass due to the earth, that is, the weight of the object, mg, where g is the acceleration due to gravity. Thus,

$$F = \frac{G\, m_e m}{r_e^2} = mg$$

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$$g = \frac{G\, m_e}{r_e^2}$$

Gravitational Potential

The work done in raising a mass, m from the ground surface to a height, h above the ground is given by

$$W = mgh$$

The work been done against the gravitational pull of the earth. This work appears as the gravitational potential energy (PE) of the body. This pull depends on the height, h, or the relative position of the body from the ground or zero level where the P.E. is considered to be zero.

Gravitational Potential (V) at a point is defined as the work done in taking a unit mass from infinity to that point. Unit is Jkg^{-1}. It is given as:

$$V = \frac{-Gm}{r}$$

where m is the mass producing the gravitational field and r is the distance of the point to the mass. The gravitational potential decreases as r increases and becomes zero where r is infinitely large. The negative sign indicates that potential at infinity (zero) is higher than the potential close to the mass.

Escape Velocity

There are many man-made satellites that circle around the earth at the present time. One common feature of these bodies is that they are held in approximately circular path by the earth's gravitational pull. It is this force that provides the needed centripetal force to keep the satellites in their orbits. The velocity (V_s) of the satellite as it orbits around the earth is given by:

$$mv_2^2 = F = \frac{G\, m\, m_e}{r_e^2}$$

$$v_s = \sqrt{\frac{G\, m_e}{r_e}}$$

v_s is the velocity with which the satellite moves round the earth. Notice that the mass of the satellite is not in the equation, thus all satellites in orbit with radius r_e must have the speed. For a satellite to escape from the earth and never return, it must be launched with a velocity greater than v_s, which is the one required to make it orbit.

Escape velocity (v_e) is the minimum velocity required for an object (e.g. satellite or rocket) to just escape or leave the gravitational influence or field of an astronomical body (e.g. the earth) permanently.

To obtain the formula for escape velocity we can use the following formula:

$$F = \frac{G\, m_e m}{r^2};\; E = W = F \times r_e \quad and$$

$$KE = \frac{1}{2} m v_e^2$$

$$E = W = \frac{G\, m_e m}{r_e^2} \times r_e = \frac{G\, m_e m}{r_e}$$

$$E = KE = \frac{1}{2}\, m\, v_e^2 = \frac{G\, m_e\, m}{r_e}$$

$$v_e^2 = \frac{2\, G\, m_e m}{m\, .\, r_e} = \frac{2\, G\, m_e}{r_e}$$

$$v_e = \sqrt{\frac{2G\, m_e}{r_e}} = \sqrt{2gr}$$

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