DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS

IB PHYSICS

LSN 10-2: MOTION IN A GRAVITATIONAL FIELD

Questions From Reading Activity?

Gravity Waves?

Essential Idea:

- Similar approaches can be taken in analyzing electrical and gravitational potential problems.

Nature Of Science:

- Communication of scientific explanations:
  - The ability to apply field theory to the unobservable (charges) and the massively scaled (motion of satellites) required scientists to develop new ways to investigate, analyze and report findings to a general public used to scientific discoveries based on tangible and discernible evidence.

Understandings:

- Potential and potential energy
- Potential gradient
- Potential difference
- Escape speed
- Orbital motion, orbital speed and orbital energy
- Forces and inverse-square law behavior

Applications And Skills:

- Determining the potential energy of a point mass and the potential energy of a point charge
- Solving problems involving potential energy
- Solving problems involving the speed required for an object to go into orbit around a planet and for an object to escape the gravitational field of a planet

Applications And Skills:

- Solving problems involving orbital energy of charged particles in circular orbital motion and masses in circular orbital motion
- Determining the potential inside a charged sphere
- Solving problems involving forces on charges and masses in radial and uniform fields

Guidance:

- Orbital motion of a satellite around a planet is restricted to a consideration of circular orbits (links to 6.1 and 6.2)
- Students should recognize that lines of force can be two-dimensional representations of three-dimensional fields

Guidance:

- Both uniform and radial fields need to be considered
- Students should assume that the electric field everywhere between parallel plates is uniform with edge effects occurring beyond the limits of the plates.

Data Booklet Reference:

$V_g = -\frac{GM}{r}$	$V_e = -\frac{kq}{r}$
$g = -\frac{V_g}{\Delta r}$	$E = -\frac{V_e}{\Delta r}$
$E_p = mV_g = -\frac{GMm}{r}$	$E_p = qV_e = -\frac{kq_1q_2}{r}$
$F_G = G\frac{m_1m_2}{r^2}$	$F_E = k\frac{q_1q_2}{r^2}$

- $V_{esc} = \sqrt{\frac{2GM}{r}}$
- $V_{orbit} = \sqrt{\frac{GM}{r}}$

Utilization:

- The global positioning system depends on complete understanding of satellite motion
- Geostationary/polar satellites
- The acceleration of charged particles in particle accelerators and in many medical imaging devices depends on the presence of electric fields (see Physics option sub-topic

Aims:

- Aim 2: Newton’s law of gravitation and Coulomb’s law form part of the structure known as “classical physics”. This body of knowledge has provided the methods and tools of analysis up to the advent of the theory of relativity and the quantum theory

Aims:

- Aim 4: the theories of gravitation and electrostatic interactions allows for a great synthesis in the description of a large number of phenomena

Newton's Law of Universal Gravitation

- Last year we learned,

$$F = -G\frac{M_1 M_2}{r^2}$$

- This year we look at it from an energy standpoint

$$E = W = Fd = -G\frac{M_1 M_2}{r}$$

Gravitational Potential Energy

- The gravitational force is an attractive force
- Work must be done to separate two bodies in space a certain distance R
- This work is converted to potential energy called the gravitational potential energy

$$E_p = -G\frac{M_1 M_2}{r}$$

Gravitational Potential Energy

- For a satellite orbiting a body, its total energy is the sum of its kinetic and potential energy

$$E_T = \frac{1}{2}mv^2 - G\frac{M_1 M_2}{r}$$

Gravitational Potential Energy

- If the satellite is in a stable, continuous orbit, the kinetic energy is equal to its potential energy

$$\frac{1}{2}mv^2 = G\frac{M_1 M_2}{r}$$

Gravitational Potential Energy

- Newton's Second Law tells us that the gravitational force will be balanced by the centripetal acceleration

$$\sum F = ma_c$$

$$G\frac{Mm}{r^2} = m\frac{v^2}{r}$$

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

Gravitational Potential Energy

- Substituting into the traditional value for kinetic energy gives us

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

$$E_k = \frac{1}{2}mv^2$$

$$E_k = \frac{1}{2}\frac{GMm}{r}$$

Gravitational Potential Energy

- And total energy for an orbiting body becomes

$$E_k = \frac{1}{2}\frac{GMm}{r}$$

$$E = E_k - E_p$$

$$E = \frac{1}{2}\frac{GMm}{r} - \frac{GMm}{r}$$

$$E = -\frac{GMm}{2r}$$

Gravitational Potential Energy

- Graph of kinetic, potential, and total energy as a function of distance for a circular orbit

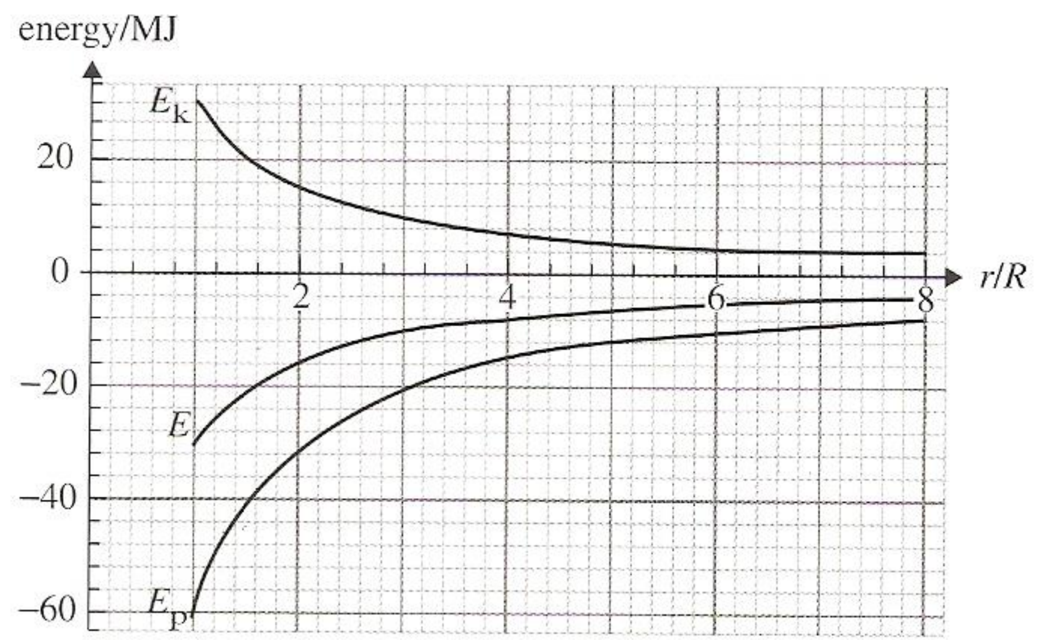


Figure 11.2 Graphs of the kinetic, potential and total energy of a mass of 1 kg in circular orbit around the earth.

Gravitational Potential Energy

- As you get further away from the earth's surface, the less potential energy there is, so less kinetic energy is required

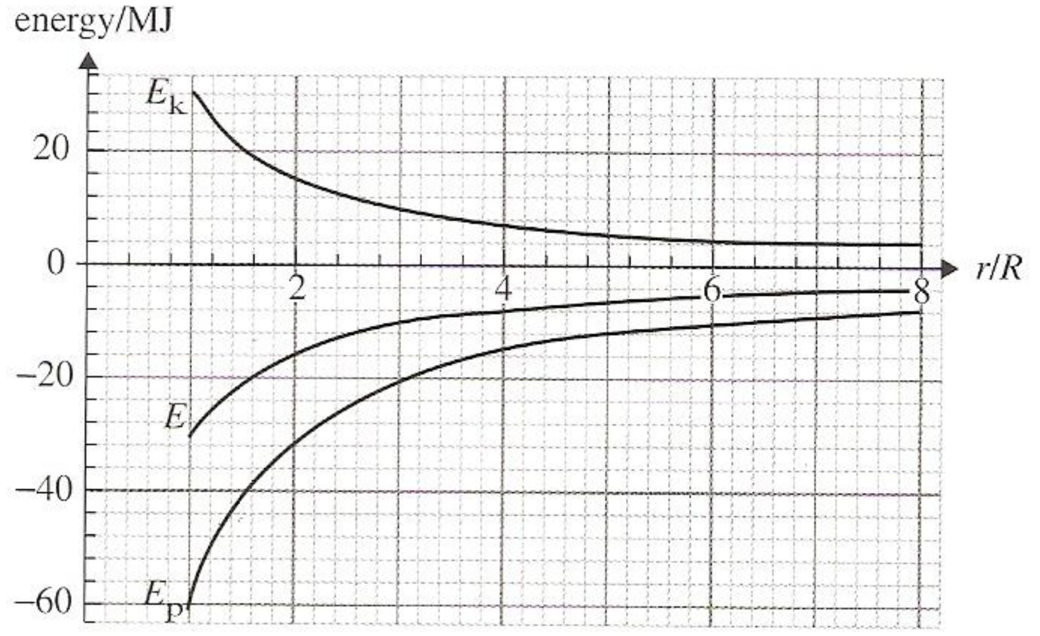


Figure 11.2 Graphs of the kinetic, potential and total energy of a mass of 1 kg in circular orbit around the earth.

Gravitational Potential Energy

- Because *r* is squared, it is an exponential and not a linear relationship

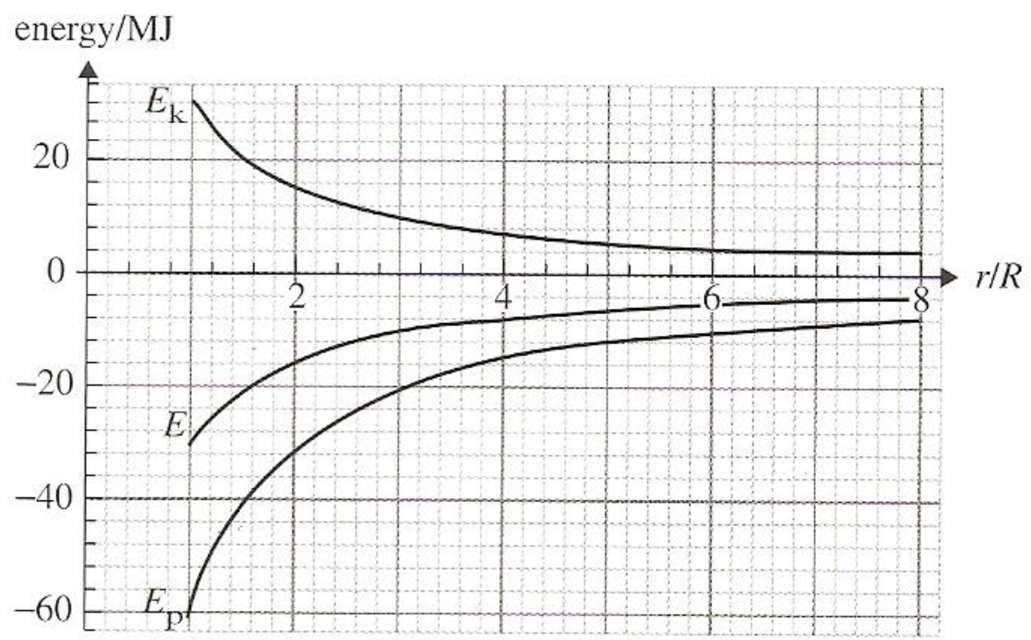
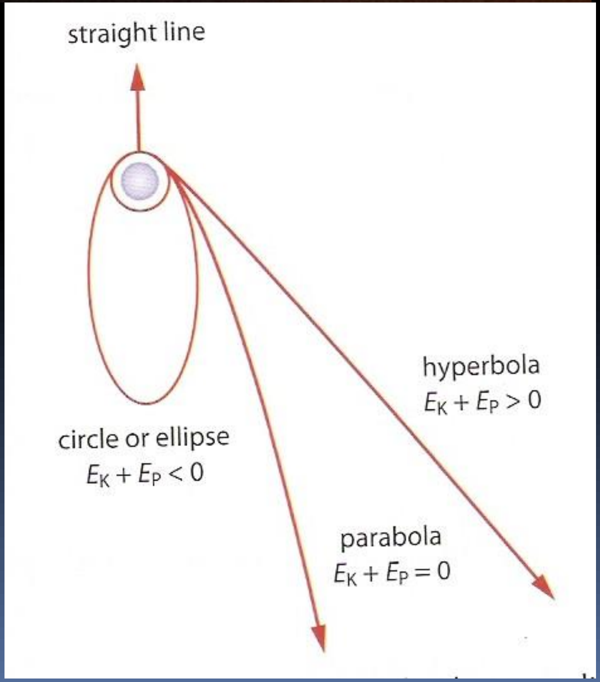


Figure 11.2 Graphs of the kinetic, potential and total energy of a mass of 1 kg in circular orbit around the earth.

What will happen?

- Suppose you launch a rocket with a given velocity. There are three options:
  - If total energy is positive ($E_K > E_P$), the rocket will follow a hyperbolic orbit and never return
  - If total energy is zero ($E_K = E_P$), the rocket will follow a parabolic orbit to infinity and never return
  - If total energy is negative ($E_K < E_P$), the rocket will enter a circular or elliptical orbit (or crash and burn)



Escape Velocity

- Total energy of a mass m moving near a large mass M is given by

$$E = \frac{1}{2}mv^2 - G\frac{M_1 M_2}{R}$$

- We assume the only force acting on m is the gravitational force created by M

Escape Velocity

- We want to know if a mass m is launched from the surface of M, will it escape M's gravitational field?

$$\frac{1}{2}mv_{esc}^2 - G\frac{Mm}{r} = \frac{1}{2}mv_{\infty}^2$$

Escape Velocity

$$E = \frac{1}{2}mv^2 - G\frac{M_1 M_2}{R}$$

- If total energy is greater than zero, m escapes
- If total energy is less than zero, m will eventually return to the surface of M

Escape Velocity

- The separation point is when V_∞ is equal to zero

$$\frac{1}{2}mv_{esc}^2 - G\frac{Mm}{R} = \frac{1}{2}mv_\infty^2 = 0$$

$$\frac{1}{2}mv_{esc}^2 = G\frac{Mm}{R}$$

$$v_{esc} = \sqrt{\frac{2GM}{R}}$$

Escape Velocity

- This is the minimum velocity needed to exceed the gravitational attraction of M and is called the escape velocity

$$v_{esc} = \sqrt{\frac{2GM}{R}}$$

- *What happens if we double the value of m?*

Escape Velocity

- This is the minimum velocity needed to exceed the gravitational attraction of M and is called the escape velocity

$$v_{esc} = \sqrt{\frac{2GM}{R}}$$

- *What happens if we double the value of m?*
  - *Nothing changes*

Escape from Planet Earth

- In reality there are other things to consider when launching a rocket from earth:
  - Atmospheric friction
  - Gravitational pull of the Sun, Moon, and other planets
  - Considers only ballistic motion and not that of a rocket with a continuous force applied

Orbital Motion

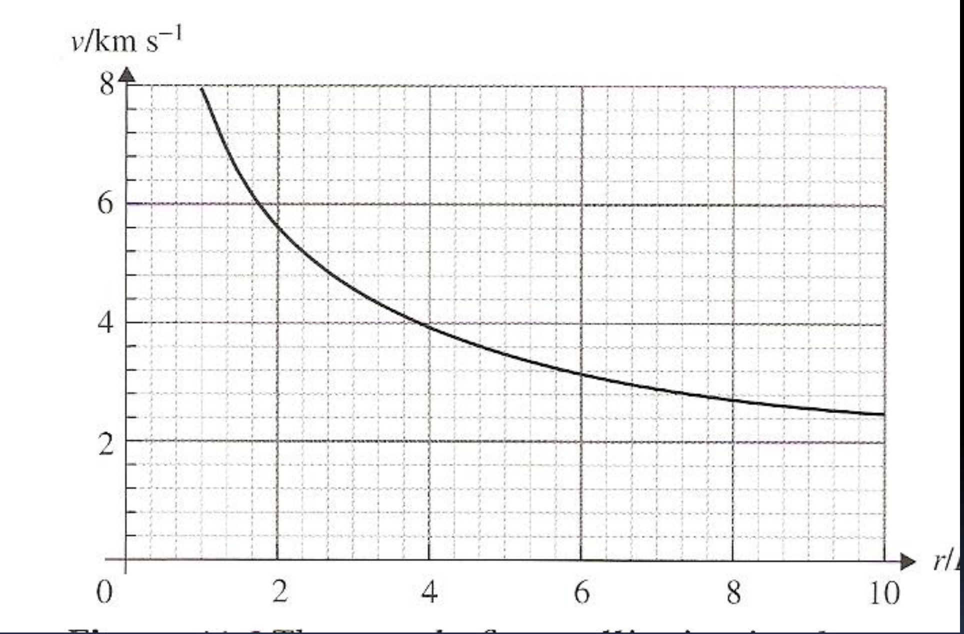
- The law of gravitational attraction combined with Newton's second law show that the orbit of any body due to gravitational attraction will follow the path of an ellipse or a circle (circles are ellipses with both foci at the same point).

Orbital Speed

$$\sum F = ma_c$$

$$G\frac{Mm}{r^2} = m\frac{v^2}{r}$$

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



Black Holes

- What if the required escape velocity exceeds the speed of light?
- This means that nothing, even light, can escape the star and it is a black hole
- The radius at which this occurs is called the Schwarzschild radius

$$c < v_{esc_{req}}$$

$$c < \sqrt{\frac{2GM}{R}}$$

$$R < \frac{2GM}{c^2}$$

Weightlessness

- "Relative weightlessness" occurs when the centripetal acceleration is equal to the acceleration due to gravity
  - Motorcycle jump
  - Ski jumper

$$mg = m\frac{v^2}{r}$$

$$g = \frac{v^2}{r}$$

Weightlessness

- Weightlessness in Space

$$\Sigma F = ma = W - N$$

$$N = W - \frac{mv^2}{r}$$

$$W = F_g = \frac{GMm}{r^2}$$

$$N = \frac{GMm}{r^2} - \frac{mv^2}{r}$$

Weightlessness

- Weightlessness in Space
- When the object is at orbit speed, the normal force is zero, i.e. “weightless”

$$N = \frac{GMm}{r^2} - \frac{mv^2}{r}$$

$$v_{orbit}{}^2 = \frac{GM}{r}$$

$$N = \frac{GMm}{r^2} - \left(\frac{m}{r}\right)\left(\frac{GM}{r}\right)$$

$$N = \frac{GMm}{r^2} - \left(\frac{GMm}{r^2}\right)$$

$$N = 0$$

Inverse Square Law Behavior

- The gravitational and electrical forces are inversely proportional to the square of the distance from the source

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

$$F_e = k\frac{q_1 q_2}{r^2}$$

$$F \propto r^{-2}$$

Inverse Square Law Behavior

- The gravitational and electrical forces are inversely proportional to the square of the distance from the source

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

$$F_e = k\frac{q_1 q_2}{r^2}$$

$$F \propto r^{-2}$$

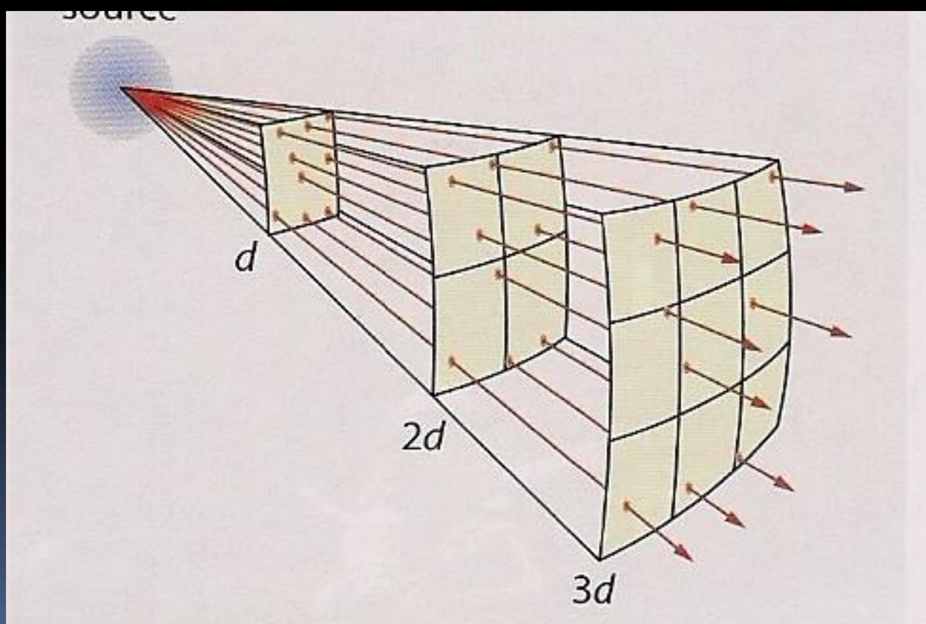
Inverse Square Law Behavior

- The gravitational and electrical forces are inversely proportional to the square of the distance from the source

$$F \propto r^{-2}$$

Inverse Square Law Behavior

- Since these forces radiate from the source, their spherical "area of influence" quadruples as distance doubles



$$F \propto r^{-2}$$

$$m : \frac{m}{4\pi d^2}$$

$$q : \frac{q}{4\pi d^2}$$

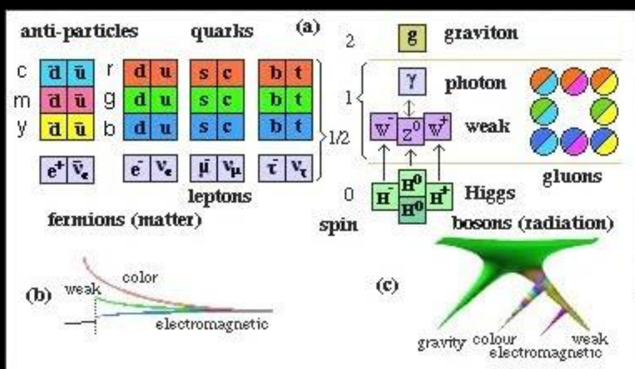
Inverse Square Law Behavior

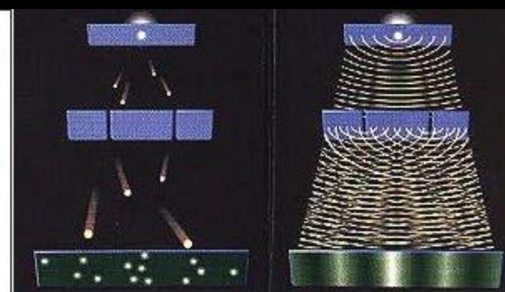
- It is also related to the fact that photons and gravitons have zero mass (Chapter 7)

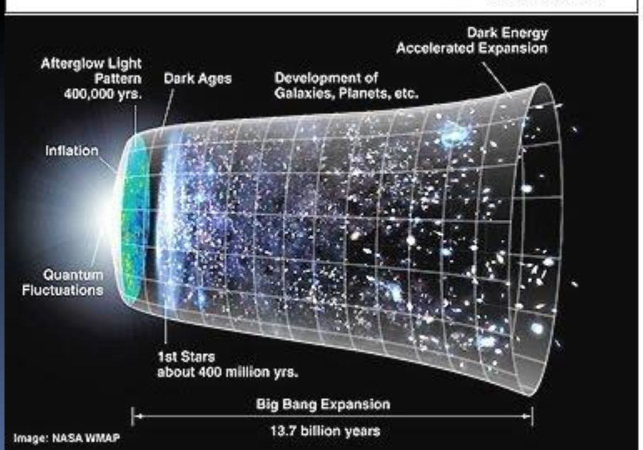
$$F \propto r^{-2}$$

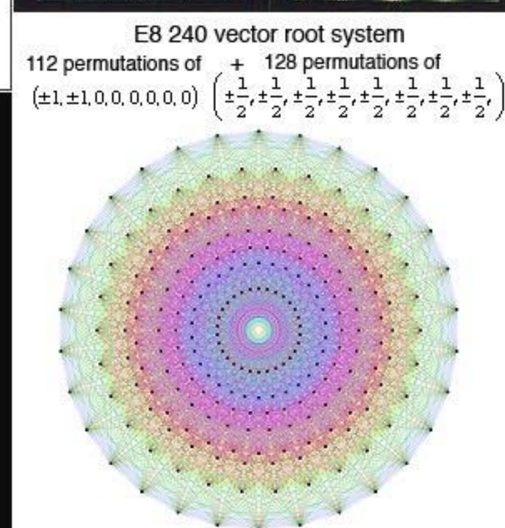
$$m : \frac{m}{4\pi d^2}$$

$$q : \frac{q}{4\pi d^2}$$









One Final Question

- What if we could fall through the center of the earth?

Understandings:

- Potential and potential energy
- Potential gradient
- Potential difference
- Escape speed
- Orbital motion, orbital speed and orbital energy
- Forces and inverse-square law behavior

Guidance:

- Orbital motion of a satellite around a planet is restricted to a consideration of circular orbits (links to 6.1 and 6.2)
- Students should recognize that lines of force can be two-dimensional representations of three-dimensional fields

Guidance:

- Both uniform and radial fields need to be considered
- Students should assume that the electric field everywhere between parallel plates is uniform with edge effects occurring beyond the limits of the plates.

Data Booklet Reference:

$V_g = -\frac{GM}{r}$	$V_e = -\frac{kq}{r}$
$g = -\frac{V_g}{\Delta r}$	$E = -\frac{V_e}{\Delta r}$
$E_p = mV_g = -\frac{GMm}{r}$	$E_p = qV_e = -\frac{kq_1q_2}{r}$
$F_G = G\frac{m_1m_2}{r^2}$	$F_E = k\frac{q_1q_2}{r^2}$

- $V_{esc} = \sqrt{\frac{2GM}{r}}$
- $V_{orbit} = \sqrt{\frac{GM}{r}}$

Utilization:

- The global positioning system depends on complete understanding of satellite motion
- Geostationary/polar satellites
- The acceleration of charged particles in particle accelerators and in many medical imaging devices depends on the presence of electric fields (see Physics option sub-topic

Aims:

- Aim 2: Newton's law of gravitation and Coulomb's law form part of the structure known as "classical physics". This body of knowledge has provided the methods and tools of analysis up to the advent of the theory of relativity and the quantum theory

Aims:

- Aim 4: the theories of gravitation and electrostatic interactions allows for a great synthesis in the description of a large number of phenomena

Essential Idea:

- Similar approaches can be taken in analyzing electrical and gravitational potential problems.

QUESTIONS?

Homework

#22-38