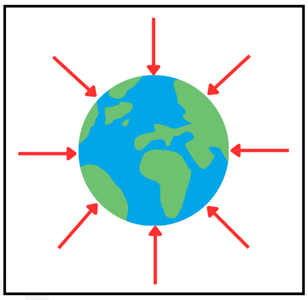
U3 AOS 2 Summary - Fields

Field Model

General rules for drawing field lines:

- Field lines never overlap
- Density of field lines indicate the strength of the field
  - Uniformly spaced field lines indicate a uniform field
- Field lines enter or emerge at 90° from the surface of the field source (e.g. a planet)



Gravitational field of Earth

Gravitational Field Lines	Electric Field Lines	Magnetic Field Lines
Point in the direction of a gravitational force exerted on a point mass	Point in the direction of an electric force exerted on a *positive* point charge	Point in the direction of a magnetic force exerted on a <u>hypothetical</u> magnetic *north* monopole at a particular point

Dipoles vs monopoles

Gravitational Fields	Electric Fields	Magnetic Fields
Always monopoles	Can be monopoles (e^-) or dipoles (p^+ and e^- together)	Always dipoles

Inverse square law:

The magnitude of the field strength (I) is inversely proportional to the square of the distance (r) from the source.

$$\boxed{I \propto \frac{1}{r^2}}$$

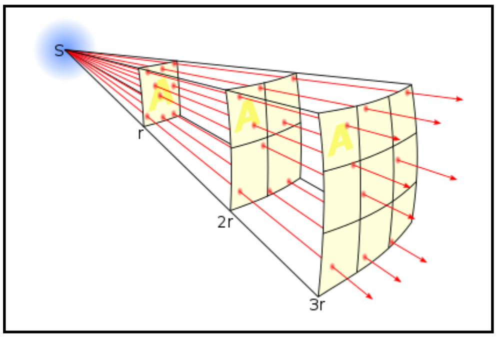


Diagram of the inverse square law. Notice when the distance is doubled, the area across which the field lines have to spread is quadrupled.

Using the inverse square law:

- The inverse square law is used in questions in which you have to compare the field strengths at two points, given their distances.
- Field strengths at two points can be related to their distances by:

$$\boxed{\frac{I_2}{I_1} = (\frac{r_1}{r_2})^2}$$

Potential energy changes (qualitative):

- A mass (in a gravitational field) or a positive charge (in an electric field) gains potential energy if it moves against the direction of the field lines.
- It loses potential energy, in exchange for kinetic energy, if it moves in the same direction as the field lines.

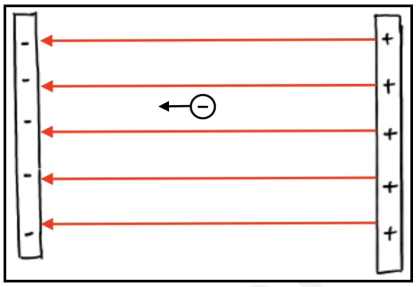


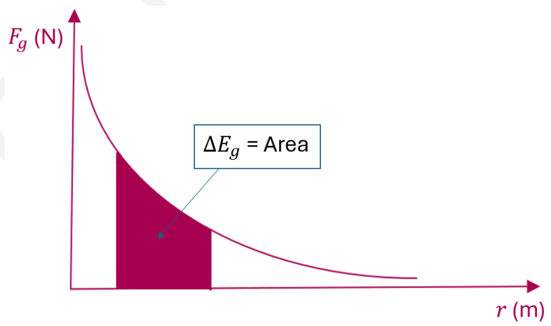
Diagram illustrating a negative charge gaining potential energy in exchange for kinetic energy despite moving in the same direction as the field lines.

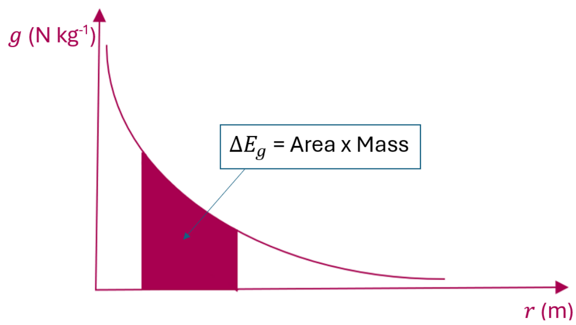
Describing Fields

	Static vs changing	Uniform vs non-uniform
Definition	Static fields are fields that remain constant over *time*. Changing fields are fields that vary over *time* due to change in magnitude or shape, or flip in direction.	Uniform fields are fields that are constant at different points in *space* as they have the same field strength at all points, represented by uniform parallel lines. Non-uniform fields have differing field strengths at different points in *space*.

Gravitational Fields:

	Gravitational Field Strength (N/kg)	Gravitational Force (N)	Change in Gravitational Potential Energy (J)
Formula - uniform field	$g = constant$	$F_g = mg$	$\Delta E_g = mg\Delta h$ (for objects near the surface)
Formula - non uniform field	$g = \frac{GM}{r^2}$	$F_g = G\frac{m_1 m_2}{r^2}$ OR $F_g = mg$ (if g is known)	Force distance graph: Area Field strength-distance graph: Area x Mass





Satellite Motion

- For orbiting satellites, the gravitational force they experience acts as the centripetal force driving the circular motion, so:

$$\boxed{F_g = F_c}$$

- All circular motion and gravitational field formulas apply in this topic, and can be related to each other to derive short cut formulas for the speed, period and radius. For example, the short cut formula for orbital speed is:

$$\boxed{v = \sqrt{\frac{GM}{r}}}$$

- Kepler's 3rd Law: states that the ratio of the radial distance^3 and the period^2 is constant, so

$$\boxed{\frac{r^3}{T^2} = \frac{GM}{4\pi^2}}$$

So, the radial distance and period of two satellites orbiting an identical planet can be related by:

$$\boxed{\frac{{r_1}^3}{{T_1}^2} = \frac{{r_2}^3}{{T_2}^2}}$$

Geostationary satellites:

- Must be directly above the equator. This is because:
  - The gravitational (centripetal) force must act towards the centre of the Earth
  - The satellite's orbit must be in the same plane as Earth's rotation.
- Period = 24 hours
- Revolve in the same direction as the direction of the Earth.
- The mechanics of the orbit can be described using satellite motion equations such as $F_g = F_c$

Electric Fields:

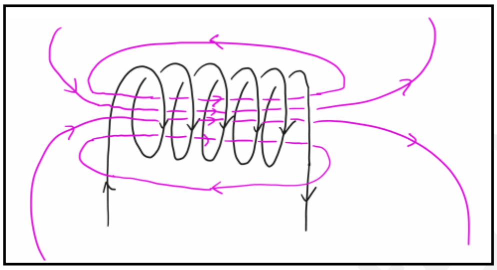
	Electric Field Strength (N/C)	Electric Force (N)	Change in Electrical Potential Energy (J)
Formula - uniform field	$E = \frac{V}{d} = constant$	$F_e = qE$	$W = qV$ $W = qEd = \Delta E_k$
Formula - non uniform field	$E = k\frac{Q}{r^2}$	$F_e = k\frac{q_1 q_2}{r^2}$. OR $F_e = qE$ (If E is known)	N/A

Magnetic Fields:

Magnetic fields produced by wires

	Purpose	Steps to Follow
Right hand grip rule	To find the shape of the magnetic field of a *straight wire*	1. Align your thumb with the direction of the current. 2. Wrap your fingers around the wire. Your fingers would represent the direction of the magnetic field that the current-carrying wire generates.
Right hand coil rule	To find the shape of the magnetic field of a *coil*	1. Trace the (conventional) current flowing in the coil. 2. Curl your fingers to follow this current. 3. Straighten out your thumb, which represents the direction of the magnetic field.

Magnetic field of a solenoid (using right hand coil rule):



Magnetic Force:

- A charged particle moving perpendicularly in a magnetic field will experience a force perpendicular to both the direction of the magnetic field and the velocity of the particle.

	Magnetic Force
Formula - single charged particles	$F_B = qvB$
Formula - current carrying wires	$F_B = nIlB$

- NOTE: if v is parallel to B or if I is parallel to B, then the magnetic force is ZERO. The above formulas can only be used if v is perpendicular to B or I is perpendicular to B.

Right-hand palm rule

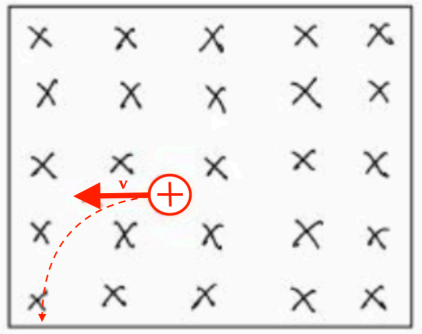
To find the direction of the magnetic force:
1. Hold right palm out so that your thumb is perpendicular to your fingers
2. Align your fingers in the direction of the magnetic field
3. Align your thumb in the direction of the movement of the positive charge or conventional current. (NOTE: if charge is negative, the thumb points opposite the direction of motion).

Path of a charged particle in a magnetic field:

- Charged particles in perpendicular uniform magnetic fields move in circular motion.

- There are two reasons why charged particles in perpendicular magnetic fields move in circular motion:

    1. The magnetic force is **constant** in magnitude (due to a uniform field) and always applied **perpendicular** to the velocity.
    2. The magnetic force always points towards centre of circle (another condition of circular motion).



Circular path of a positive charge in a uniform magnetic field.

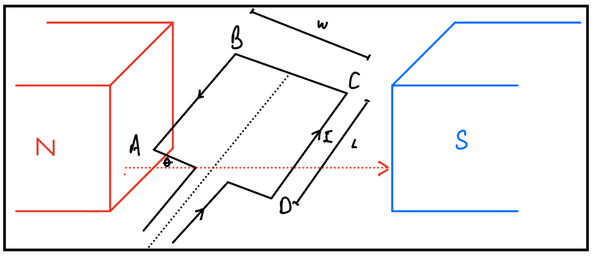
- The magnetic force acts as the centripetal force, so: $\boxed{F_B = F_c}$

- Short cut formula for the radius: $r = \dfrac{mv}{qB}$

Forces acting on parallel conductors:

- Currents in opposite directions->conductors repel
- Currents in same direction->conductors attract
- NOTE: explain in terms of right hand grip rule (magnetic field around a the wire), followed by right hand palm rule (magnetic force on a wire due to the magnetic field of the other wire), and finally Newton's Third Law.

DC Motors:



- DC motors are devices that utilise the magnetic force exerted on two perpendicular sides of a coil to convert *electrical potential energy into mechanical energy*

- **Split ring commutator**: Reverses the direction of the current between the internal coil and the external wires every half turn, when the plane of the coil becomes perpendicular to the magnetic field. This reverses the direction of magnetic force on each side, maintaining continuous rotation (torque) in the same direction.

Factors affecting torque of a DC motor:
- Current
- External magnetic field
- Number of loops of wire

If any of the above factors is increased, magnetic force on each side of the coil will increase, so torque will increase.