AQA Physics A-level

Topic 7: Fields and their consequences

Key Points

Gravitational Fields

A force field is a region in which a body experiences a **non-contact** force.

Gravitational fields are regions where a mass experiences an **attractive force** due to gravity. This force is determined by **Newton's Law of Gravitation**, which states that:

- The force is **directly** proportional to product of the **masses** involved
- The force is **inversely** proportional to the square of the **separation** between the two masses

As an equation this is:

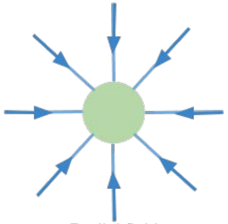
$$F = \frac{GMm}{r^2}$$

(G = Gravitational Constant)

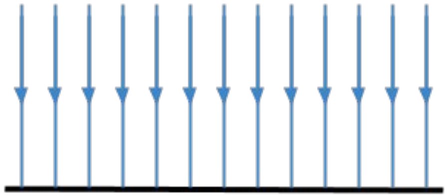
Field Lines

Field lines can be drawn to represent a gravitational field. The lines:

- Always point towards the **centre** of the mass producing the field
- Show the **direction** in which a mass would experience a force if placed at a point in that field
- Are **closer** together at points where the field is **stronger**
- Are **further** apart at points where the field is **weaker**
- **Never cross** over each other



Radial field



Uniform field

Gravitational Field Strength

A useful way to compare gravitational fields is by comparing gravitational field strengths. Gravitational field strength is defined as the **attractive gravitational force** that a **unit mass** would experience, at a **given point** in the field. As an equation this is:

$$g = \frac{F}{m}$$

Which for a radial field gives...

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

The gravitational field strength at the **surface of Earth** is roughly **9.81 N/kg**. This means that a mass of 1kg would experience of force of 9.81N.

Gravitational Potential

Gravitational potential is the amount of **work done** in moving a **unit mass** from **infinity** to a **given point** in a gravitational field. As an equation this is:

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

The key points to note are that:

- Gravitational potential is defined as being **zero at infinity**
- **Work is done** to move an object closer into the field, and so gravitational potential is always a **negative value**

Equipotentials are planes containing points with equal gravitational potential. This means that the amount of work done when an object is moved around these planes is **zero**.

Orbits

The orbits of planets and satellites are a result of the **gravitational force** produced by the body they are orbiting. This force acts as a **centripetal force**, which results in circular motion. There are many different types of orbit and you should know that:

- **Synchronous orbit** have a time period of one day, and so return to the same place in the sky each day.
- **Low orbits** orbit at heights of between 160 km and 2000 km.
- **Geostationary orbits** have a time period of one day and stay over the same point on the Earth's surface. They must be directly above the equator and travel in the same direction as the earth's rotation.

Electric Fields

All charged particles and surfaces produce an electric field around themselves. An electric field is a region where a **charged particle** experiences a **non-contact force**. Unlike gravitational fields, this force can be **attractive or repulsive**.

- Same charges **repel** each other
- Opposite charges **attract** each other

Electric **field lines** point in the **direction** that a **positive** charge would experience a force and so point from positive to negative.

Coulomb's Law

The force that acts between two charges is determined by Coulomb's Law. This states that:

- The force is **directly** proportional to product of the **charges** involved
- The force is **inversely** proportional to the square of the **separation** between the two charges

As an equation, this is:

$$F = \frac{KQq}{r^2} \qquad \textit{where....} \qquad K = \frac{1}{4\pi\varepsilon_0}$$

If the force has a **positive** value, it is a **repulsive** force.
If the force has a **negative** value, it is an **attractive** force.

Electric Field Strength

Electric field strength is defined as the **electrostatic force** that a **unit positive charge** would experience, at a **given point** in the field. As an equation this is:

$$E = \frac{KQ}{r^2} \quad \textit{where....} \quad K = \frac{1}{4\pi\varepsilon_0}$$

The electric field strength around a charge **decreases** as you move further away from it.

The **weaker** the electric field strength, the **less dense** the electric field lines are.

Electric Potential

Electric potential is the amount of **work done** moving a unit **positive point charge** from **infinity** to a point in the **field**. As an equation this is:

$$V = \frac{KQ}{r} \quad \text{where....} \quad K = \frac{1}{4\pi\varepsilon_0}$$

Electric potential difference is the work done moving a positive charge from one point to another. This means that when you move a charge through a **potential difference**, work is done, equal to:

$$\Delta W = Q\Delta V$$

As with gravitational fields, **equipotentials** are planes of points where the electric potential is the same, and consequently **no work is done** when moving along these lines.

Capacitance

The **capacitance** of a capacitor is the amount of **charge** it can store per unit of **potential difference**, measured in **Farads**.

$$C = \frac{Q}{V}$$

Capacitors consist of two metal plates separated by a **dielectric**. The capacitance of a given capacitor depends on the **surface area** of the plates, their **separation** and the **dielectric** being used.

$$C = \frac{A\varepsilon_0\varepsilon_r}{d}$$

Dielectrics

A polar dielectric consists of lots of **polarised molecules** each with a positive end and a negative end. When placed in a capacitor, the **molecules align** and all the positive ends are attracted to the negative plate, and all the negative ends are attracted to the positive plate. This results in the capacitance of the capacitor increasing since:

- The polarised molecules each have an **electric field** around them
- This electric field **opposes** the electric field of the capacitor plates
- Consequently the potential difference required to charge the plates decreases

$$C = \frac{Q}{V}$$

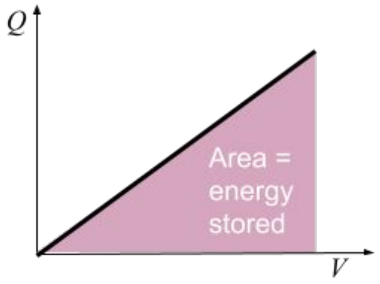
So, if the **potential difference** is **decreased**, the **capacitance** is **increased**.

Energy Stored by a Capacitor

A number of equations can be used to calculate the **energy stored** in a capacitor:

$$E = \tfrac{1}{2} QV \qquad E = \tfrac{1}{2} CV^2 \qquad E = \frac{Q^2}{C}$$

The energy stored can also be calculated by determining the **area** under a Charge-Voltage graph.

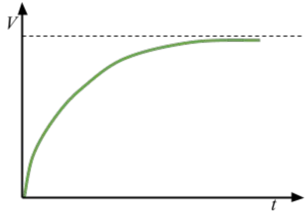


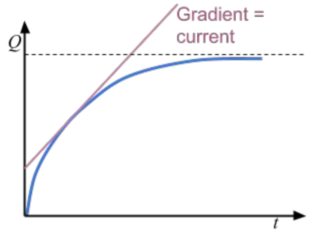
The gradient of the graph is equal to the capacitance.

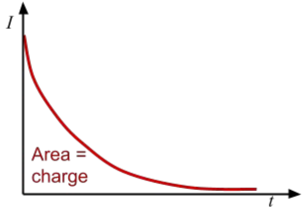
Charging and Discharging

You should know the shapes of the charging and discharging graphs for a capacitor, for potential difference, charge and current:

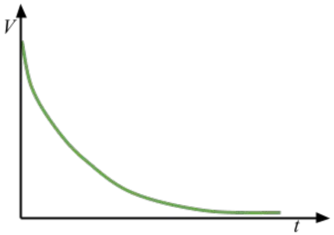
Charging

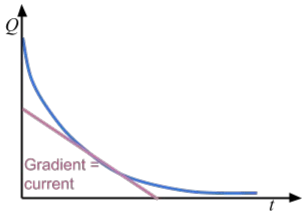


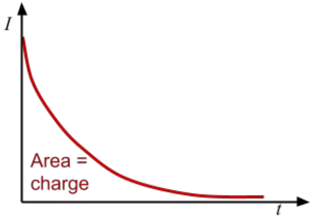




Discharging



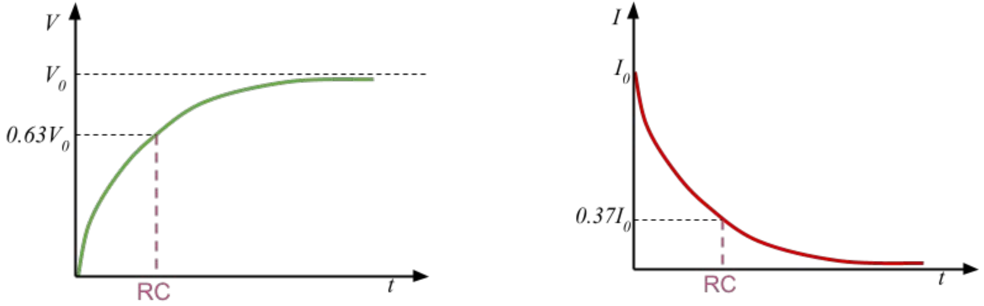




Time Constant

An important value when working with capacitors is the **time constant**. It is equal to:

- The product of the resistance in the circuit and the capacitance of the capacitor
- The time taken to **charge** the capacitor to (1 - 1/e) of its final value
- The time taken to **discharge** the capacitor to 1/e of its initial value



Magnetic Flux Density

When a **current** passes through a wire, a magnetic field is **induced** around it. This field consists of **concentric circles** around the wire. The strength depends on:

- The **distance** from the wire
- The strength of the current passing through the wire

If a current carrying wire is placed in a magnetic field, the **two fields interact** and a force acts on the wire. The magnitude of this force depends on:

- The **length** of the wire
- The **current** passing through the wire
- The **magnetic flux density** of the field

Magnetic flux density is a measure of the strength of a field. The unit is the **Tesla**.

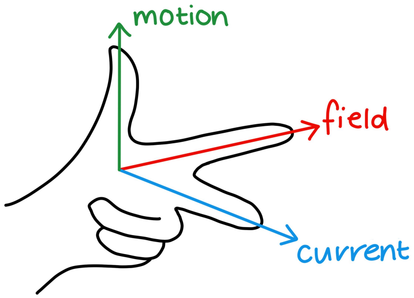
Motor Effect

When a current-carrying wire experiences a **force** in a field, it is referred to as the motor effect. The **magnitude** of the force can be calculated using:

Force (N) = Magnetic Flux Density (T) x Current (A) x Length of Wire (m)

$$F = B\ I\ L$$

The **direction** of the force (motion) can be determined using **Fleming's Left**



Moving Charges in a Field

When a charge moves in a magnetic field, it will experience a force. The magnitude of this force depends on:

- The **magnitude** of the charge
- The **magnetic flux density** of the field
- The **velocity** of the charge

The equation used to calculate the force is:

Force (N) = Magnetic Flux Density (T) x Charge (C) x Velocity (ms^{-1})

$$F = BQv$$

Use **Fleming's Left Hand Rule** to determine the **direction**, with the second finger being the direction of a **positive** charge (so if its a negative charge, point it in the opposite direction)!

Magnetic Flux and Flux Linkage

Magnetic flux is a measure of the **magnetic field** that passes through a given **area**. It can be thought of as a measure of the number of field lines passing through the surface, or the density of the field lines that are passing through it. It is calculated using:

Magnetic Flux (Wb) = Magnetic Flux Density (T) x Area (m^2)

$$\Phi = B\,A$$

This only applies when the magnetic field lines are **perpendicular** to the area.

If using a coil, a more useful quantity is **magnetic flux linkage**. This is the magnetic flux multiplied by the number of turns of the coil the field passes through.

$$N\Phi = B\,A\,N$$

Electromagnetic Induction

If a current-carrying conductor moves relative to a magnetic field, an **EMF** is **induced**. This is as a result of the charge carriers in the conductor experiencing a force. If the conductor forms a **complete loop**, a **current** flows as a result of the induced EMF.

The law that governs the magnitude of the induced EMF is **Faraday's Law** which states that:

The magnitude of the induced EMF is directly proportional to the rate of change of magnetic flux linkage.

As an equation, this is:

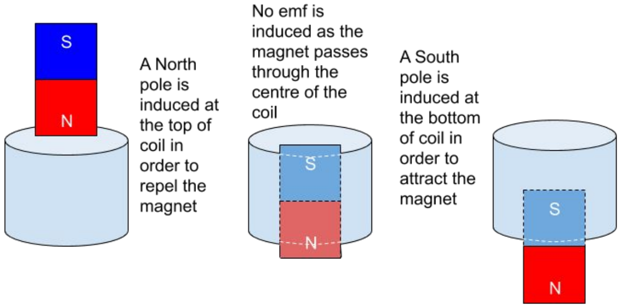
$$\varepsilon = N\frac{\Delta\Phi}{\Delta t}$$

Lenz's Law

The **direction** of the induced EMF is governed by a second law known as Lenz's Law. This states that:

The direction of an induced current is such that is opposes the change that created it.

An example of this is a magnetic falling through a non-magnetic metal tube.



Generators

An **A.C generator** consists of a metal coil in a magnetic field. As the coil turns, the changing magnetic flux linkage passing through it induces an EMF.

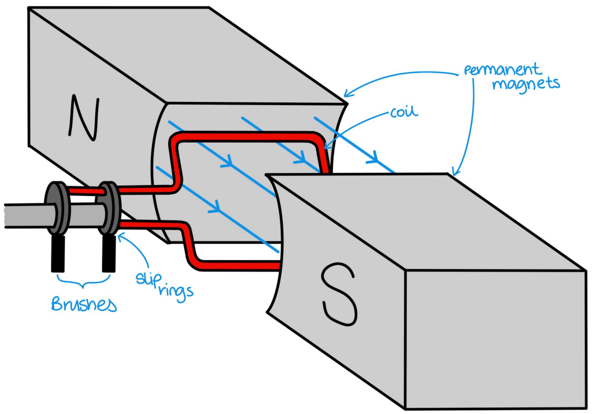
The **flux linkage** varies sinusoidally between +BAN and -BAN.

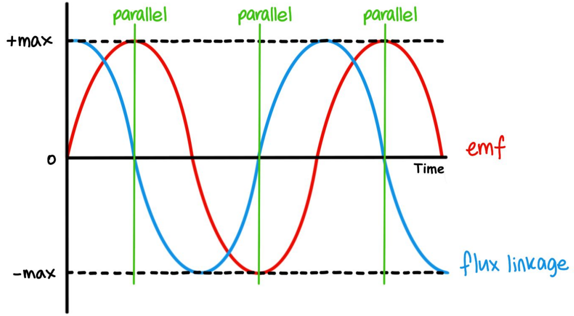
$$N\Phi = -BAN\cos\omega t$$

According to **Faraday's law**, the EMF is the rate of change of flux linkage.

$$\varepsilon = \omega BAN\sin\omega t$$

Increasing the **speed/frequency** of rotation or increasing the magnetic flux density will increase the maximum EMF.



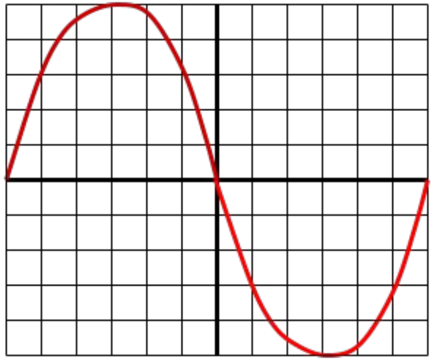


Alternating Current

An oscilloscope is used to show voltage against time.

The time base controls how fast the wave moves across the screen (e.g 2ms per division)

The Y-gain is the voltage per division (e.g. 2V per division.)



Alternating current
Time base turned on

$$V_{rms} = \frac{V_0}{\sqrt{2}}$$

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

V_0 is the **peak voltage**. However the 'average voltage' is not the peak voltage, and therefore we find the **root mean square**.

The rms is usually quoted when referring to a AC power supply.

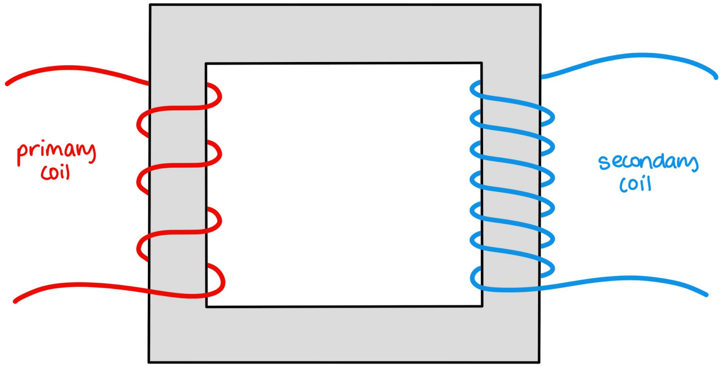
$$Power_{rms} = I_{rms} \times V_{rms}$$

Transformers

Transformers are used to **increase** or **decrease** the voltage of a power source. They come in two main types:

1. **Step-Up**: Number of coils on secondary coil > Number of coils on primary coil
2. **Step-Down**: Number of coils on primary coil > Number of coils on secondary coil

- A current pases through the **primary** coil which induces a magnetic field in the core
- The current is an **alternating-current** so that the magnetic field in the core is constantly changing
- This constant changing causes a change of **flux linkage** in the **secondary** coil, which induces an **EMF** and therefore current



Inefficiencies

If a transformer was **100% efficient** the power in would equal the power out - however power is lost due to:

- Eddy currents (looping currents which generate heat in the core)
- Heat loss in the wires
- Work done magnetising and demagnetising the core

To **reduce** these factors:

- The core can be **laminated** to prevent eddy currents flowing
- The wires can be **low resistance** wires to reduce heating
- The core can be made from **soft** iron, which is easily magnetised