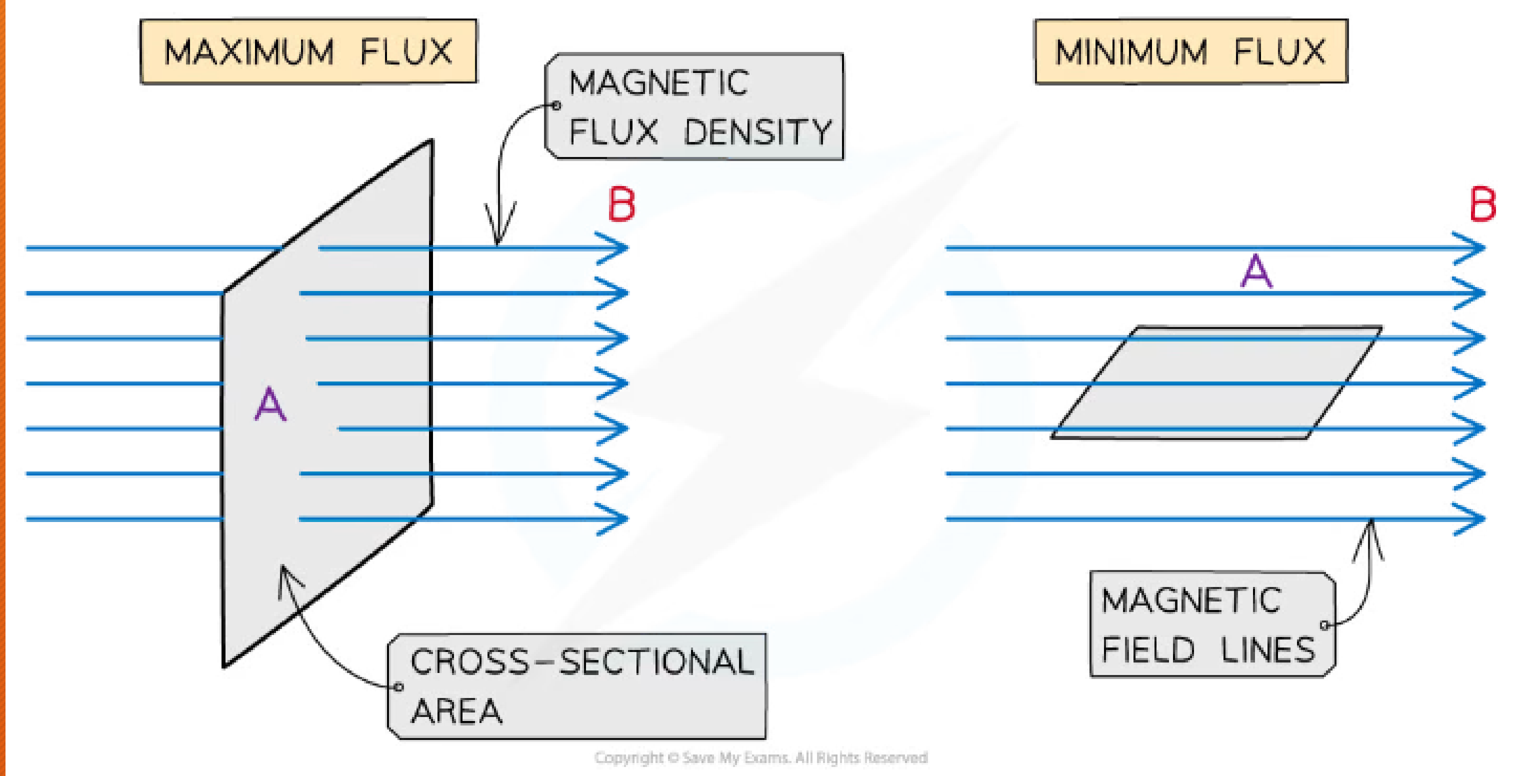
26. Electromagnetic induction

Magnetic Flux Definition

- Electromagnetic induction is when an **e.m.f** is induced in a closed circuit conductor due to it moving through a **magnetic field**
- This happens when a conductor **cuts** through magnetic field lines
- The amount of e.m.f induced is determined by the magnetic flux
- The amount of magnetic flux varies as the coil rotates within the field
    - The flux is the total magnetic field that passes through a given area
    - It is a maximum when the magnetic field lines are **perpendicular** to the area
    - It is at a minimum when the magnetic field lines are **parallel** to the area
- The **magnetic flux** is defined as:
- ***The product of the magnetic flux density and the cross-sectional area perpendicular to the direction of the magnetic flux density***
- It is calculated using the equation:

$\Phi = B \times A$, Φ = **magnetic flux, unit :(Weber=** Wb)

Magnetic Flux Definition



The magnetic flux is maximum when the magnetic field lines and the area they are travelling through are perpendicular

In other words, magnetic flux is the **number of magnetic field lines through a given area**

Magnetic Flux Linkage

- The **magnetic flux linkage** is a quantity commonly used for solenoids which are made of *N* turns of wire
- Magnetic flux linkage is defined as:

The product of the magnetic flux and the number of turns

- It is calculated using the equation:

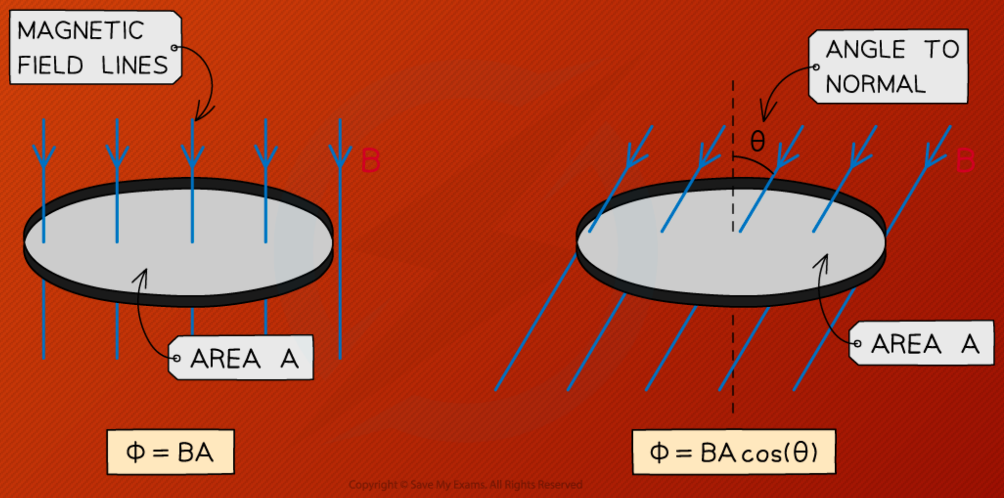
$$\Phi x N = B x A x N$$

- Where:
  - Φ = **magnetic flux** (Wb)
  - N = number of turns of the coil
  - B = magnetic flux density (T)
  - A = cross-sectional area (m^2)
- The flux linkage ΦN has the units of **Weber turns (Wb turns)**

Magnetic Flux Linkage

- As with magnetic flux, if the field lines are not completely perpendicular to the plane of the area they are passing through
- Therefore, the component of the flux density which is perpendicular is equal to:

$$\Phi \times N = B \times A \times N \times \cos(\theta)$$



Principles of Electromagnetic Induction

- Electromagnetic induction is a phenomenon which occurs when an **e.m.f** is induced when a conductor moves through a magnetic field
- When the conductor cuts through the magnetic field lines:
  - This causes a change in **magnetic flux**
  - Which causes **work to be done**
  - This work is then transformed into **electrical energy**
- Therefore, if attached to a complete circuit, a current will be induced
- This is known as **electromagnetic induction** and is defined as:

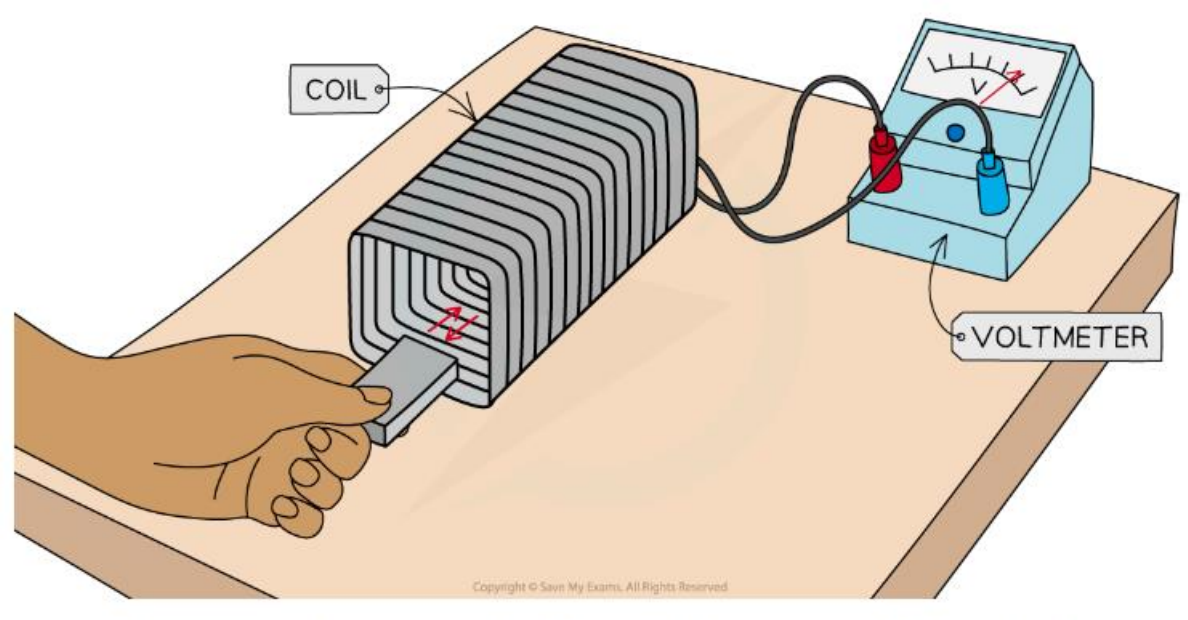
The process in which an e.m.f is induced in a closed circuit due to changes in magnetic flux.

Principles of Electromagnetic Induction

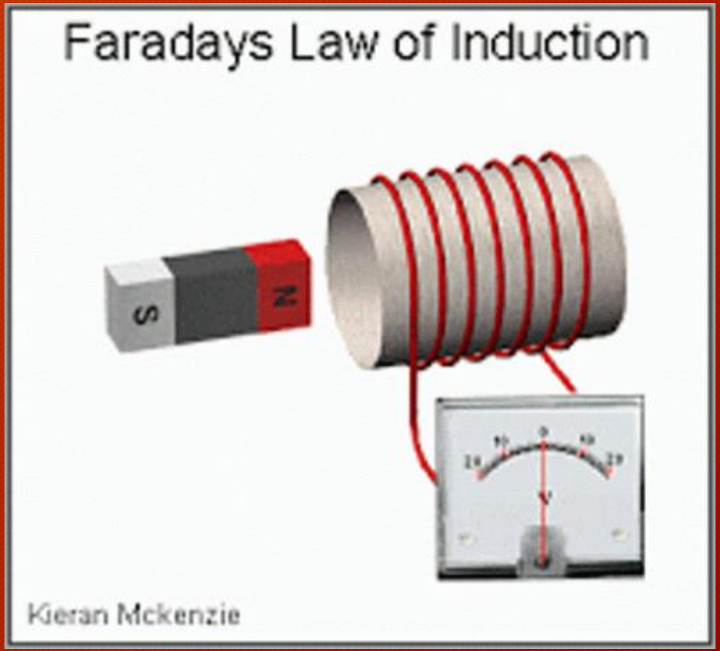
- This can occur either when:
  - A conductor cuts through a **magnetic field**
  - The direction of a magnetic field through a coil changes
- Electromagnetic induction is used in:
  - Electrical generators which convert mechanical energy to electrical energy
  - Transformers which are used in electrical power transmission
- This phenomenon can easily be demonstrated with a magnet and a coil, or a wire and two magnets

Experiment 1: Moving a magnet through a coil

- When a coil is connected to a sensitive voltmeter, a bar magnet can be moved in and out of the coil to induce an e.m.f



A bar magnet is moved through a coil connected to a voltmeter to induce an e.m.f



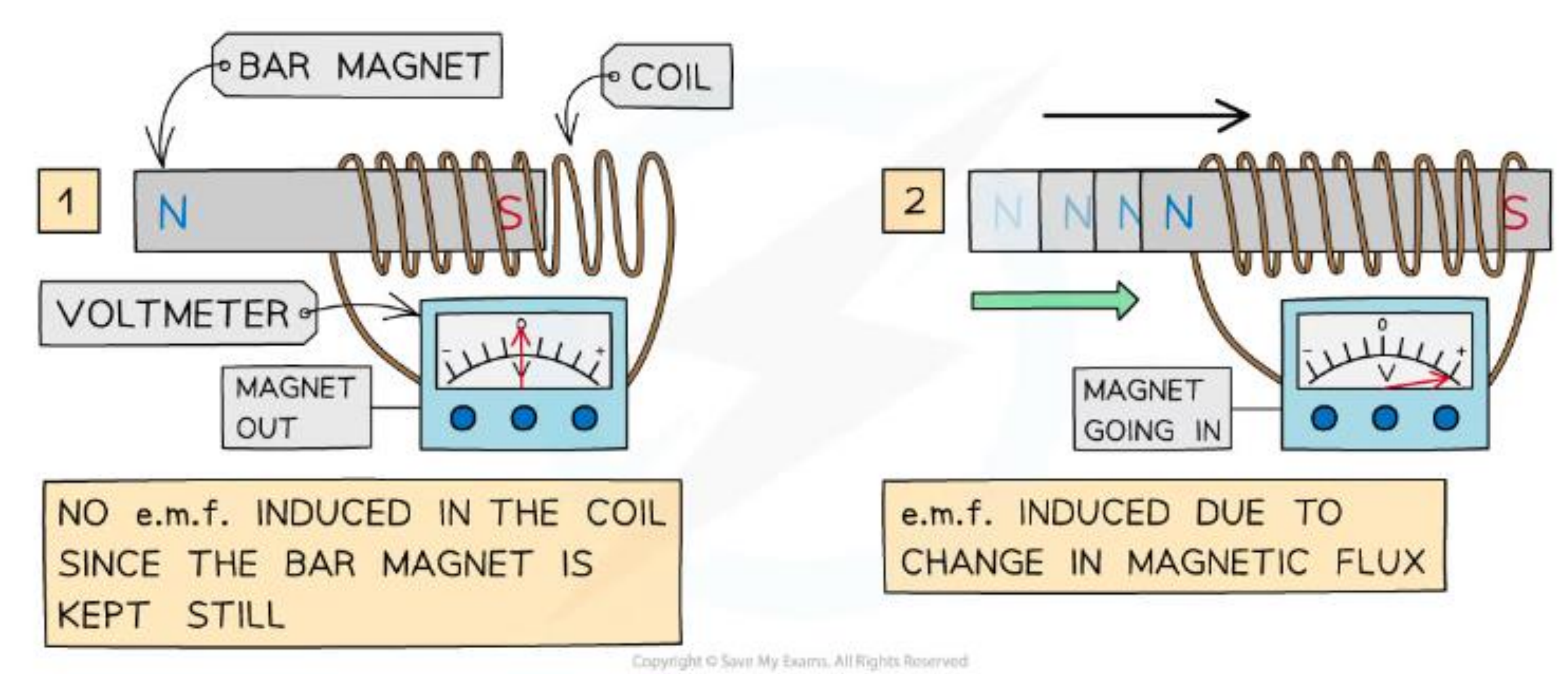
The expected results are:

- When the bar magnet is **not moving**, the voltmeter shows a **zero reading**
  - When the bar magnet is held still inside, or outside, the coil, the rate of change of flux is zero, so, there is **no e.m.f induced**
- When the bar magnet begins to move inside the coil, there is a reading on the voltmeter
  - As the bar magnet moves, its magnetic field lines 'cut through' the coil, generating a **change in magnetic flux**
  - This induces an **e.m.f** within the coil, shown momentarily by the reading on the voltmeter

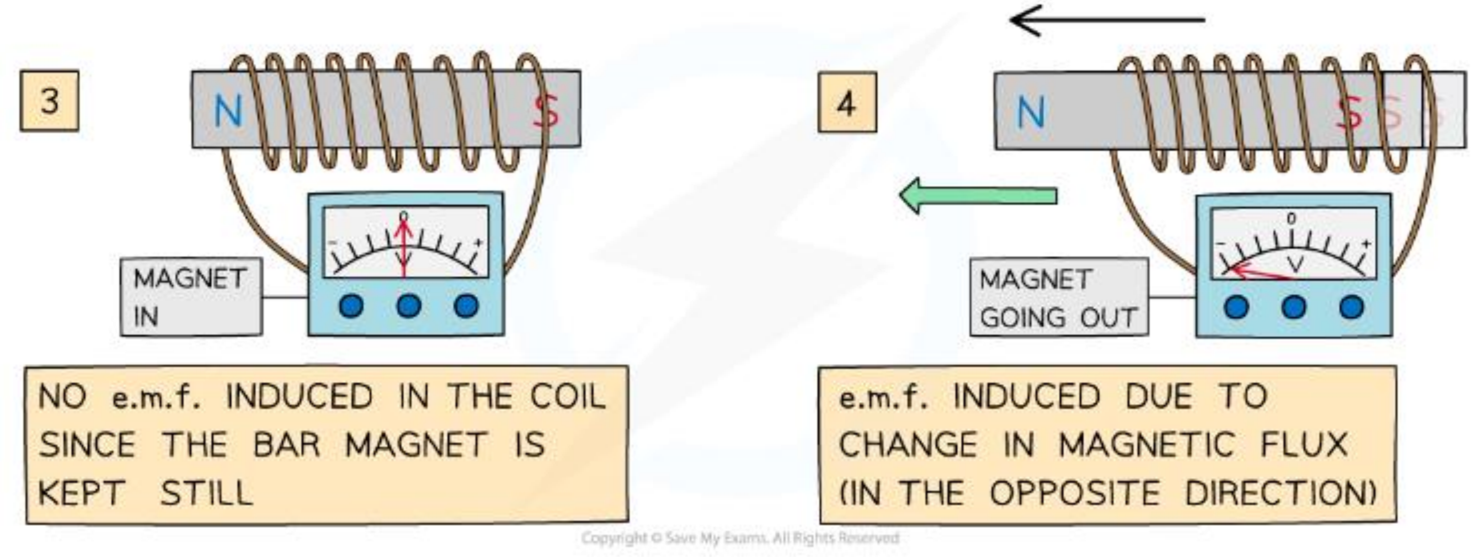
The expected results are:

- When the bar magnet is taken back out of the coil, an e.m.f is induced in the **opposite direction**
  - As the magnet changes direction, the direction of the current changes
  - The voltmeter will momentarily show a reading with the opposite sign
- Increasing the **speed** of the magnet induces an e.m.f with a **higher magnitude**
  - As the speed of the magnet increases, the rate of change of flux increases
- The direction of the electric current, and e.m.f, induced in the conductor is such that it **opposes** the change that produces it

The expected results are:



The expected results are:



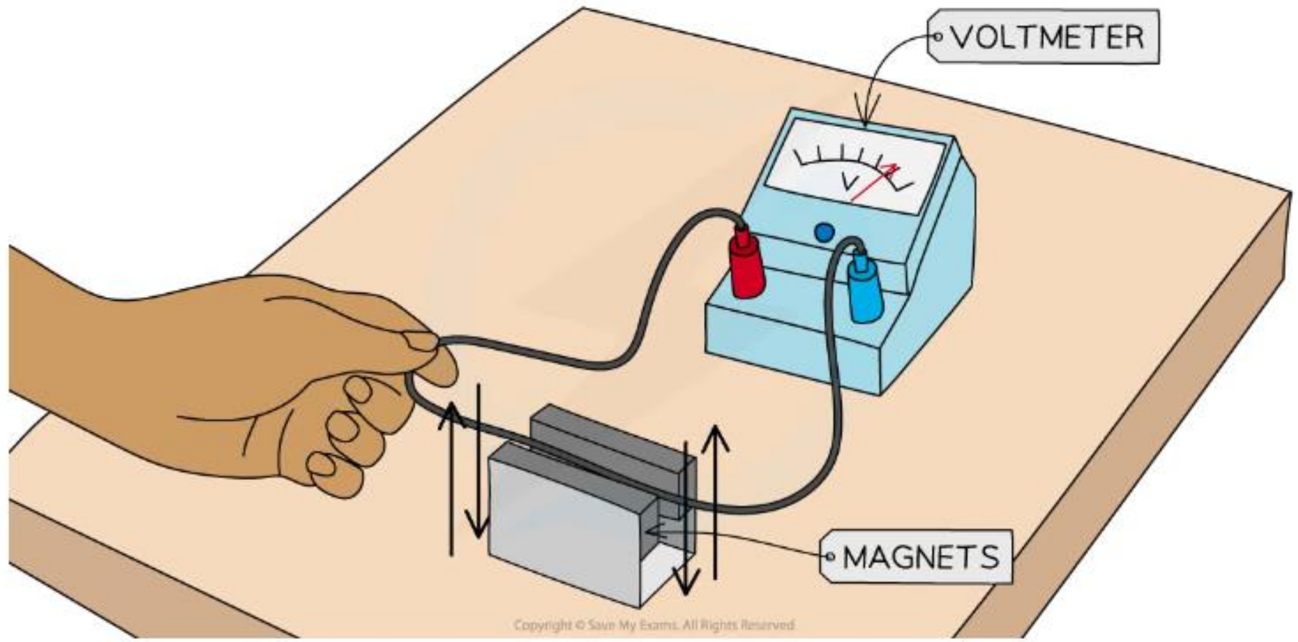
An e.m.f is induced only when the bar magnet is moving through the coil

Factors that will increase the induced e.m.f are:

- Moving the magnet faster through the coil
- Adding more turns to the coil
- Increasing the strength of the bar magnet

Experiment 2: Moving a wire through a magnetic field

- When a long wire is connected to a voltmeter and moved between two magnets, an e.m.f is induced
- **Note:** there is no current flowing through the wire to start with



A wire is moved between two magnets connected to a voltmeter to induce an e.m.f

The expected results are:

- When the wire is **not moving**, the voltmeter shows a **zero reading**
  - When the wire is held still inside, or outside, the magnets, the rate of change of flux is zero, so, there is **no e.m.f induced**
- As the wire is moved through between the magnets, an **e.m.f** is induced within the wire, shown momentarily by the reading on the voltmeter
  - As the wire moves, it ‘cuts through’ the magnetic field lines of the magnet, generating a **change in magnetic flux**

The expected results are:

- When the wire is taken back out of the magnet, an e.m.f is induced in the **opposite direction**
  - As the wire changes direction, the direction of the current changes
  - The voltmeter will momentarily show a reading with the opposite sign
- As before, the direction of the electric current, and e.m.f, induced in the conductor is such that it **opposes** the change that produces it
- Factors that will increase the induced e.m.f are:
  - Increasing the length of the wire
  - Moving the wire between the magnets faster
  - Increasing the strength of the magnets

Faraday's & Lenz's Laws

- Faraday's law tells us the magnitude of the induced e.m.f in **electromagnetic induction** and is defined as:
- ***The magnitude of the induced e.m.f is directly proportional to the rate of change in magnetic flux linkage***

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

- Where:
  - ε = induced **e.m.f** (V)
  - N = number of turns of coil
  - $\Delta\phi$ = change in **magnetic flux** (Wb)
  - Δt = time interval (s)

Faraday's & Lenz's Laws

- Lenz's Law gives the **direction** of the induced e.m.f as defined by Faraday's law:
- ***The induced e.m.f acts in such a direction to produce effects which oppose the change causing it***
- Lenz's law combined with Faraday's law is:

$$\varepsilon = -N \frac{\Delta\phi}{\Delta t}$$

Faraday's & Lenz's Laws

$$\varepsilon = -N \frac{\Delta \phi}{\Delta t}$$

- This equation shows:
  - When a bar magnet goes through a coil, an e.m.f is induced within the coil due to a change in magnetic flux
  - A current is also induced which means the coil now has its own magnetic field
  - The coil's magnetic field acts in the **opposite direction** to the magnetic field of the bar magnet
- If a **direct current** (d.c) power supply is replaced with an **alternating current** (a.c) supply, the e.m.f induced will also be alternating with the same frequency as the supply