Generation Principles

- **calculate magnetic flux when the magnetic field is perpendicular to the area, and describe the qualitative effect of differing angles between the area and the field:**
- **$\Phi_B = B\perp A$.**
- **investigate and analyse theoretically and practically the generation of electromotive force (emf) including AC voltage and calculations using induced emf, $\varepsilon = -N\frac{\Delta\phi_B}{\Delta t}$, with reference to:**
  - **rate of change of magnetic flux**
  - **number of loops through which the flux passes**
  - **direction of the induced emf in a coil.**
- **explain the production of DC voltage in DC generators and AC voltage in alternators, including the use of split ring commutators and slip rings respectively.**

We know that electric currents produce magnetic fields.
Question: Do magnetic fields produce electric currents?

Answer: A <u>constant</u> magnetic flux does not, but a <u>changing</u> magnetic flux does!

What is Flux?

Magnetic flux (ϕ_B) is a measure of the amount of magnetic field passing through an area.

$$\Phi_B = B_\perp \times A$$

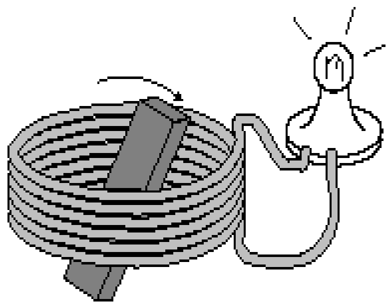
$$\therefore B = \frac{\Phi_B}{A}$$

ϕ_B is the magnetic flux (Wb - Weber)
$B_\perp$ is the magnetic field strength (T) perpendicular to the given area A
A is the area (m^2)

Hence, field strength can be defined as the flux density, or the number of field lines per square metre.

To change the magnetic flux we can

move a wire through a constant field	or	rotate a loop of wire in a constant field	or	change the strength of the magnetic field



The creation of an electric current in a conductor by changing the magnetic flux is called Electromagnetic Induction. The effect was discovered by the British physicist Michael Faraday and led directly to the development of the rotary electric generator, which converts mechanical motion into electric energy.

Devices that utilise Electromagnetic Induction are called Generators, for the simple reason that they "generate electricity". In fact, generators are opposite to D.C. motors in that they convert mechanical energy (moving a magnet, or a coil of wire) into electrical energy (the induced current.)

When a car is being driven, the engine recharges the battery continuously using a device called an alternator, which is really just a generator like the one shown to the left, except that the coil rotates while the permanent magnet is fixed in place.

EMF

EMF is the Electro-Motive Force. Despite its name, it is not strictly a force (It is not measured in Newtons.) EMF (ξ) is another name for potential difference. It is measured in Volts.
It can be convenient to think of EMF as electrical pressure. In other words, it is the force that makes electrons move in a certain direction within a conductor.

How do we create this "electrical pressure" to generate electron flow? There are many sources of EMF. Some of the more common ones are: batteries, generators, and photovoltaic cells, just to name a few. In Electromagnetic Induction, it is the EMF that is induced, not the current. The current is only flows if there is complete circuit.

Calculating the size of the EMF induced.

(Faraday's Law, the name is no longer on the course, but I think that it is vital)

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

For a single loop of wire, the induced emf can be calculated as

$$\xi = -\frac{\Delta\Phi_B}{\Delta t}$$

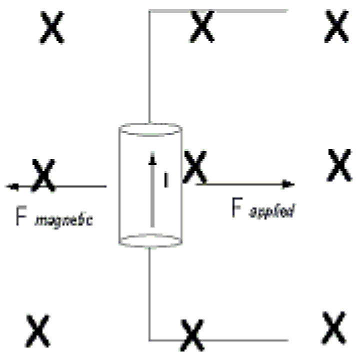
The minus sign is important, but is ignored in simple calculations

as $\Phi_B = \mathbf{B}_\perp \times \mathbf{A}$

$$\xi = -A\frac{\Delta B}{\Delta t}$$

$$\xi = -B\frac{\Delta A}{\Delta t}$$

Changing the flux by <u>moving a wire through area</u>



In the diagram, the wire is being moved to the right due to an applied force $\mathbf{F_{applied}}$.

The direction of the induced current is up. Why?

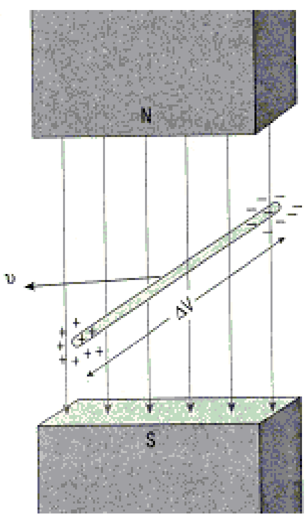
The induced current acts to create a magnetic field and associated force that will oppose the applied force.
Using the right hand rule, when

- the current flows **up**, and
- the field acts **into** the page

then the force due to the magnetic field around the wire is to the **left**.
This $\mathbf{F_{magnetic}}$ force acts to oppose the applied force, (and to attempt to oppose the motion.)

What is the size of the EMF induced? In this case, where the magnetic field is constant, the rate of change in magnetic flux is created by the rate of change of area.

$\xi = -\mathbf{B}\frac{\Delta A}{\Delta t}$ where $\frac{\Delta A}{\Delta t}$ represents the rate at which the conductor sweeps out area.



The diagram shows a metallic conductor and free electrons inside the conductor. When the conductor is moved to the left the electrons move, creating a potential difference ΔV between the two ends of the wire.
As the rod falls, the electrons and the positively charged nuclei in the rod are both moving down through the magnetic field. The magnetic field will therefore exert a magnetic force on the electrons and on the nuclei. In which direction will the magnetic force act on the electrons and the nuclei?

The force on the electrons will be towards the far end of the rod, while the force on the nuclei will be to the near end of the rod, as is shown in the diagram opposite.

Electrons tend to accumulate at one end of the conductor, setting up an electric field. Equilibrium is maintained when the electric forces balance the magnetic ones,

ie. $\mathbf{Eq} + \mathbf{Bqv} = \mathbf{0}$

$\mathbf{E} = \mathbf{-Bv}$

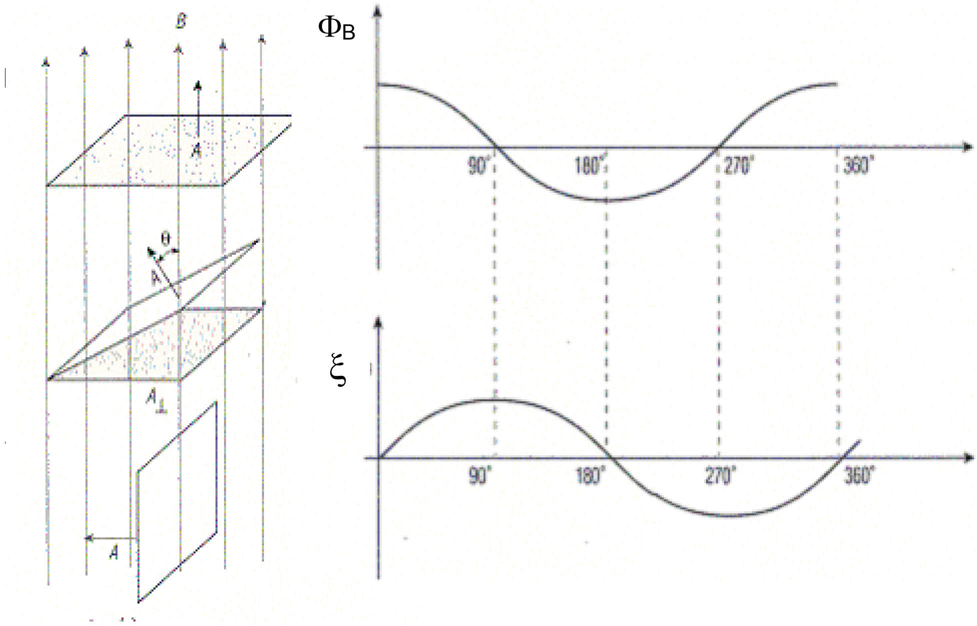
but the electric field is also the emf/length of the conductor.

$$\therefore \xi = -\mathbf{B}vl$$

The separation of charges, which is similar to a battery, ie the induced EMF (ξ), will only occur when the wire is moving.
The EMF, despite its name, is *not* a force, but voltage.

An EMF is induced in the wire only when it moves, cutting through the magnetic field i.e. perpendicular to the field. The EMF/current depends on the speed of the wire. **No EMF/current is produced when the wire moves parallel to the field.**

Changing the flux by <u>rotating a loop of wire</u>



From the graphs it is easy to see that the induced EMF

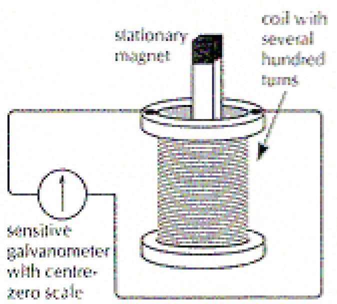
- is maximum/minimum when the flux is 0
- is 0 when the flux is a maximum/minimum

Notice that the instantaneous gradient of the flux/time graph allows the instantaneous EMF to be calculated. We can also, however, calculate the <u>average</u> EMF generated in any given amount of time as the average rate of change in flux in the given time.

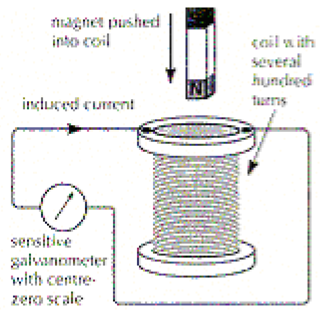
$$\xi = -\frac{\Delta\Phi_B}{\Delta t} \quad \text{hence} \quad \xi = -\frac{(\Phi_2 - \Phi_1)}{t}$$

Changing the flux by <u>changing the field strength</u>

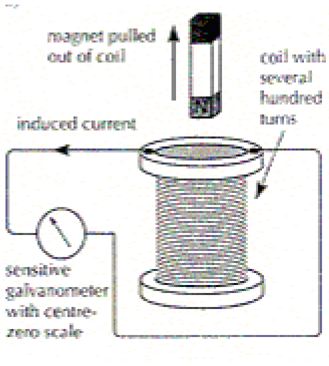
When the magnet is stationary, there is no current in the circuit.



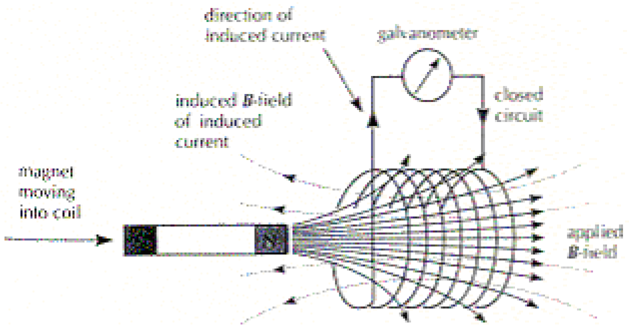
When the magnet is pushed down, the current is clockwise.



When the magnet is pulled up, the current is anti-clockwise.



Note: An emf (ξ) and hence a current, are induced in the solenoid when the magnet is moving into, or out of, the solenoid. The size of the emf (ξ) depends on the speed of movement and the number of turns on the solenoid, as well as the strength of the magnet.



As the north of the magnet is pushed toward the solenoid, an EMF is induced that will oppose this movement. The left end of the solenoid will act as a North Pole to repel the magnet.

After establishing this fact, we can use the right hand solenoid rule to determine the current direction that will create a north at the left end of the solenoid.

This means a conventional current direction flowing from the bottom to the top on the front side of the coil.

More loops means more EMF

If the coil has N turns then the EMF is given by

$$\xi = -N\frac{\Delta\Phi_B}{\Delta t}$$

Lenz's Law states that "the direction of the induced EMF is the same as that of a current whose magnetic action would oppose the flux change"

As shown in graphing the gradient above, the negative sign in the equation indicates the direction of the EMF.

The direction of the induced EMF.

The direction of the induced EMF is such that the field that is created (by the induced EMF) will oppose the change in **flux** that created it.

HOW TO SOLVE PROBLEMS INVOLVING LENZ'S LAW

1. Identify direction of the external magnetic field.

2. Identify what happens to the flux created by external field – does it increasing or decreasing.

3. If external flux decreasing – induced magnetic field will be in the same direction as external magnetic field.

4. If external flux increasing – induced magnetic field will be in the opposite direction to external magnetic field.

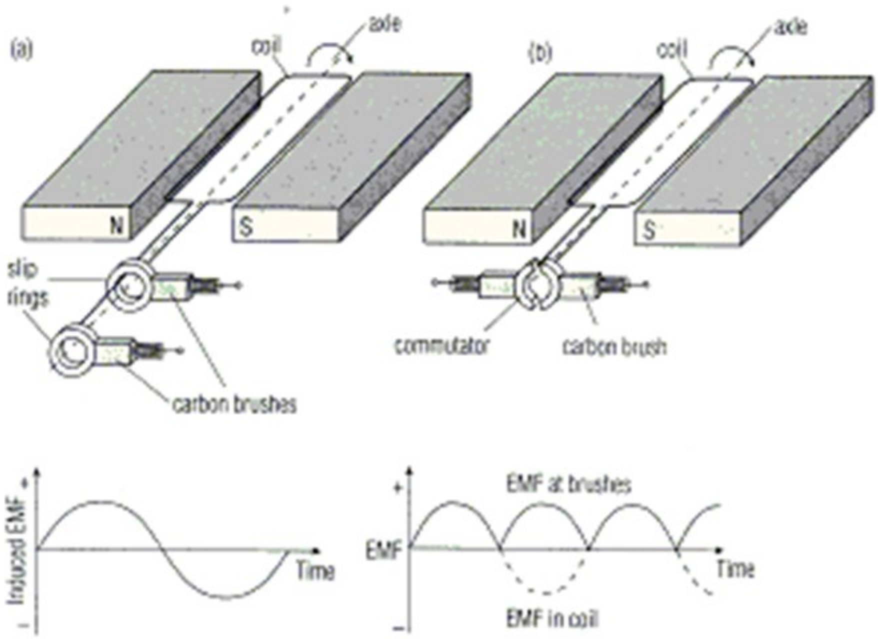
5. After identifying direction of induced magnetic field use right hand grip rule to identify direction of induced current.

Your explanation must talk about the **change in flux**, as it is the **change in flux** that induces the EMF. The current will only flow if the circuit is complete and if the circuit has a potential difference across it. So the EMF is induced, and the current only flows when the circuit is complete.

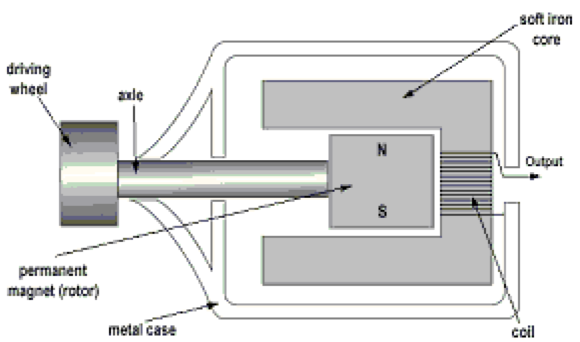
Examples of Generators: AC Generators (Alternators)

An AC generator has a rotating coil in a magnetic field, or a rotating magnetic field positioned inside a coil. Instead of a commutator, slip rings are used to keep contact with the brushes and the direction of the induced emf changes every half cycle and an AC output is produced.

Slip rings are used, where one end of the loop is always attached to the same ring, so that the output varies sinusoidally, i.e. AC output. If a split ring commutator is used the output is DC.



Examples of Generators: Dynamos



When a simple electric motor is set up so that the magnetic field is present, but the coil is not connected to a source of emf, a current can be generated in the coil by rotating it mechanically.

The direction of the current depends upon the direction of rotation of the coil. The current is direct if a split ring commutator is used for connecting the coil to the meter. The size of the current depends upon the rate of rotation of the coil. The rotation of the coil induces an emf (ξ) in the coil, giving rise to an induced current through the circuit.