9.3.2 Electromagnetic Induction

The relative motion between a conductor and magnetic field is used to generate an electrical voltage

2.1 Outline **Michael Faraday's discovery** of the generation of an electric current by a moving magnet

- 1820, **Hans Christian Oersted** and **Andre Ampere** discovered electric current produced magnetic field
- **1831, Faraday** demonstrated electromagnetic induction
    - Wound two wires around a **stick**, and later **iron ring**
        - Turning on and off voltage (and current) induced a current on other wire
    - Attached two wires to a **rotating** copper disc between the poles of a horseshoe magnet
- Faraday proposed **magnetic field should be able to produce an electric current**
    - Necessity of a **moving/changing** magnetic field

2.2 Define **magnetic field strength B** as **magnetic flux density**

- **Magnetic field strength (B)**: determined by distance between magnetic field lines (i.e. density of lines)
- **Magnetic flux**: number of magnetic field lines passing through an (imaginary) area
- **Magnetic field strength equal to magnetic flux per unit of area** (i.e. **magnetic flux density**)

2.3 Describe the concept of **magnetic flux** in terms of magnetic flux density and surface area

- Magnetic flux equal to product of **magnetic field strength and size of area**
    - Depends on angle the magnetic field lines are heading towards the area

$$\varphi = B \times A \times \cos\theta$$

Where φ = magnetic flux density (Wb), B = magnetic field strength (T/Wb m^{-2}), A = area (m^2), θ = angle against normal

- When field lines perpendicular to area, **maximum flux density**, when parallel, **no effect**

2.4 Describe generated **potential difference** as the **rate of change of magnetic flux** through a circuit

- When changing magnetic flux, the **induced current changes, and therefore voltage (potential difference)**
- Thus the **generated potential difference** increases as the **rate of change of flux** in the circuit increases.

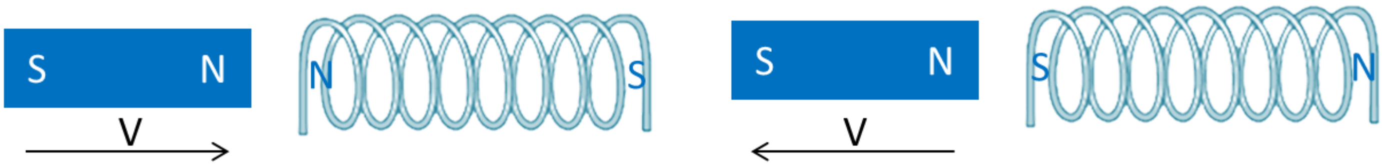
$$\varepsilon = \frac{\Delta\varphi}{\Delta t}$$

Where ε = potential difference/EMF, $\Delta\varphi$ = change in flux, Δt = change in time

- This is **Faradays' Law**: The size of an induced EMF is directly proportional to the rate of change in magnetic flux

2.5 Account for **Lenz's Law** in terms of **conservation of energy** and relate it to the production of **back emf** in motors

- **<u>Lenz's Law</u>** (Heinrich Lenz) – if an induced current flows, its direction is always such as to **oppose the change in flux** that produced it



  - In left, induced current flows left to oppose magnet, while right, induced current flows right
- As **work (energy) is used** to move through a magnetic field (or moving a magnetic field)
  - Converted to **electrical energy** that always **opposes this work** to ensure energy is not created or destroyed
  - The moving wire/field therefore **slows down**
- External continuous circuits are required to fill electron deficiencies in a wire

2.6 Explain that, in electric motors, **back emf opposes the supply emf**

- In electric motors, there is a **supply EMF**, which causes the **motor effect** and allows the motor to spin and create mechanical energy.
- However, **induced current** from the moving coil across magnetic field causes **Lenz's Law** to apply
  - As wire moves faster, **back EMF increases** (going opposite the supply EMF)
  - Without back EMF, it would **increase speed indefinitely**
  - When back EMF = supply EMF, maximum torque and rotational velocity reached
- **Starting resistance** can be employed to prevent burnout as back EMF is negligible when starting a motor. Resistor is switched off at higher speeds as back EMF replaces this role

2.7 Explain the production of **eddy currents** in terms of Lenz's Law

- **<u>Eddy Currents</u>**: circular closed **loops of current** in a solid conductor, follows Lenz's Law
  - Just like inducing a current, changing flux creates currents in solid conductors in **circles**
- Example is a **magnet** (or two in this case) **travelling across a sheet of copper**

AWAITING COOL IMAGE THAT SHOWS EDDY CURRENTS CLEARLY

- As the magnet (a North pole) moves to the right two things happen to oppose movement:
  - At the front, a **North pole** will be generated under the copper to counter the movement
  - At the back, a **South pole** will be generated under the copper to attempt to move it back
  - To generate these poles, the current induced are circles based on the **right hand grip rule**
- Better explanations http://webs.mn.catholic.edu.au/physics/emery/hsc_motors.htm#eddy
  - This does not need to be understood in depth

2.P1 Perform an investigation to **model** the **generation of an electric current by moving a magnet** in a coil or a coil near a magnet

AIM: To model the generation of electric current by moving a magnet in a coil

PROCEDURE: Draw diagrams and refer to Lenz's law to draw different cases and different current directions when moving a magnet in a coil.

2.P2 Plan, choose equipment or resources for, and perform a first-hand investigation to predict and verify the **effect on a generated electric current** when the **distance between** the coil and magnet is varied, the **strength** of the magnet is varied and the **relative motion between** the coil and the magnet is varied

AIM: To observe changes to generated electric current when changing magnetic flux

PROCEDURE: Wrap a coil of wire joined to a galvanometer and complete the circuit.
a) Move a magnet towards the coil. Move the magnet away from the coil. Observe changes in the galvanometer.
b) Use different magnet strengths (by changing to a neodymium magnet or by stacking magnets). Observe changes in the galvanometer when moving the magnets.
c) Identify changes in the galvanometer when the coil and magnet both moving away from each other, both moving towards each other, or going in the same direction at different velocities.

RESULTS should complement what was explained earlier in 9.3.2.

2.P3 Gather, analyse and present information to explain how **induction is used in cooktops in electric ranges**

- Electric ranges use an **AC power supply** to change current and therefore change magnetic field
- Magnetic field passes through ceramic cooktop
- **Eddy currents generate in the metal base** of a saucepan or container
    - Due to resistance, saucepan **generates heat**

2.P4 Gather secondary information to identify how **eddy currents** have been utilised in **electromagnetic braking**

- As eddy currents **oppose motion**, placing a magnetic field near a moving conductor (such as the wheels of a train) will slow it down
    - In the **wheels of a train**:
        - Smooth, as the opposing force reduces as train slows down
        - No wear and tear as there is no physical contact
        - Only works with metal wheels and at high speeds