Chapter 4 Electricity and Magnetism

4.1 Simple phenomena of magnetism

Core

1 Describe the forces between magnetic poles and between magnets and magnetic materials, including the use of the terms north pole (N pole), south pole (S pole), attraction and repulsion, magnetised and unmagnetised

2 Describe induced magnetism

3 State the differences between the properties of temporary magnets (made of soft iron) and the properties of permanent magnets (made of steel)

4 State the difference between magnetic and non-magnetic materials

5 Describe a magnetic field as a region in which a magnetic pole experiences a force

6 Draw the pattern and direction of magnetic field lines around a bar magnet

7 State that the direction of a magnetic field at a point is the direction of the force on the N pole of a magnet at that point

8 Describe the plotting of magnetic field lines with a compass or iron filings and the use of a compass to determine the direction of the magnetic field

9 Describe the uses of permanent magnets and electromagnets

Supplement

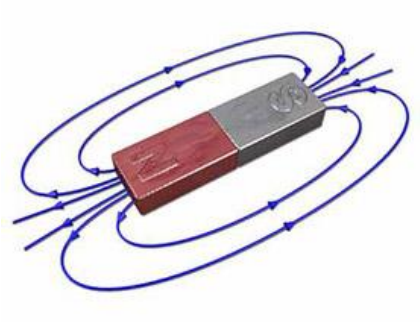
10 Explain that magnetic forces are due to interactions between magnetic fields

11 Know that the relative strength of a magnetic field is represented by the spacing of the magnetic field lines

- Magnets have a magnetic field around them and two opposite poles (north and south). Like poles repel and unlike poles attract.
- Magnets can attract magnetic materials and induce magnetism in them. Non-magnetic materials are not affected.
- Induced magnetism is weak and can be strengthened by stroking with a magnet. The most effective method is using a solenoid with a DC current.
- Ferromagnetic materials (e.g., iron, nickel, cobalt) can be magnetized, but not all magnetic materials are ferromagnetic (e.g. aluminum, copper, gold).
- Soft ferromagnetic materials are used for temporary magnets, while hard ferromagnetic materials are used for permanent magnets.
- Permanent magnets are used in a variety of applications, such as refrigerator magnets, motors, generators, and speakers. Electromagnets are temporary magnets that are created by running an electric current through a coil of wire. They are used in applications where the magnetism is needed only temporarily, such as cranes and doorbells.
- Magnetic forces are due to the interactions between magnetic fields. The strength of a magnetic field depends on the strength of the magnet and the

distance from the magnet. The spacing between magnetic field lines indicates the strength of the field - the closer the lines, the stronger the field.

- Magnetic field lines go from north to south. The south pole of a magnet is attracted to the north end of a compass needle.
- Materials can be demagnetized by a demagnetizing field (using a solenoid with AC), high temperature, or physical impact.



4.2 Electrical quantities

4.2.1 Electric charge

Core

1 State that there are positive and negative charges

2 State that positive charges repel other positive charges, negative charges repel other negative charges, but positive charges attract negative charges

3 Describe simple experiments to show the production of electrostatic charges by friction and to show the detection of electrostatic charges

4 Explain that charging of solids by friction involves only a transfer of negative charge (electrons)

5 Describe an experiment to distinguish between electrical conductors and insulators

6 Recall and use a simple electron model to explain the difference between electrical conductors and insulators and give typical examples

Supplement

7 State that charge is measured in coulombs

8 Describe an electric field as a region in which an electric charge experiences a force

9 State that the direction of an electric field at a point is the direction of the force on a positive charge at that point

10 Describe simple electric field patterns, including the direction of the field:

(a) around a point charge

(b) around a charged conducting sphere

(c) between two oppositely charged parallel conducting plates (end effects will **not** be examined)

4.2.2 Electric current

Core

1 Know that electric current is related to the flow of charge

2 Describe the use of ammeters (analogue and digital) with different ranges

3 Describe electrical conduction in metals in terms of the movement of free electrons

4 Know the difference between direct current (d.c.) and alternating current (a.c.)

Supplement

5 Define electric current as the charge passing a point per unit time; recall and use the equation

$$I = \frac{Q}{t}$$

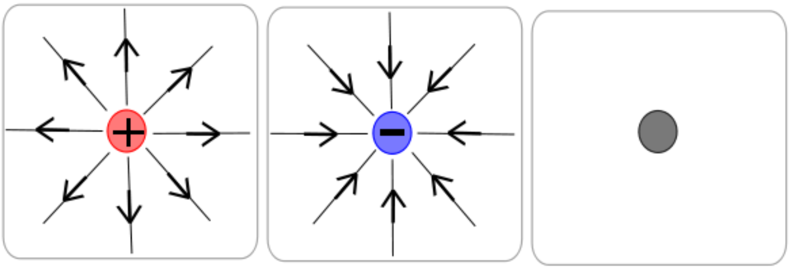
6 State that conventional current is from positive to negative and that the flow of free electrons is from negative to positive

- Electrical charge can be either positive or negative. The unit of charge is the coulomb (C). Like charges repel and opposite charges attract. Electrons are the cause of charge and are negatively charged (1.6x10-19 C).
- When electrons flow into a neutral object, it becomes negatively charged. When electrons are removed, it becomes positively charged.
- Electric current is the rate of charge flow in a circuit. It is measured in amperes (A) and can be calculated using the formula

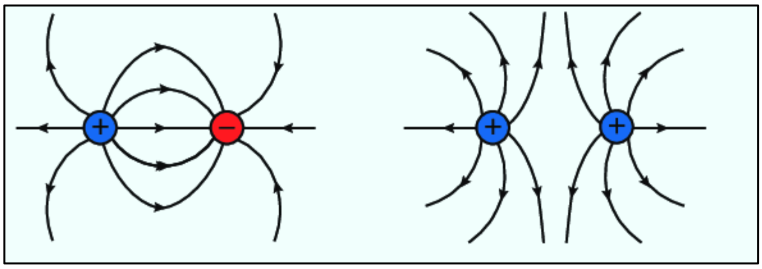
$$I = \frac{Q}{t}$$

where Q is the charge in coulombs and t is the time in seconds.

- The current flows in the opposite direction of the electrons.
- An electric field is a region where charges experience electric force. It is represented by arrow lines and is stronger at the source and weaker further away. A stronger field is indicated by more lines. Positive charges have arrow lines pointing outwards, while negative charges have arrow lines pointing inwards.



You can combine '+' and '-' fields to get more exotic shapes (see below).



4.2.3 Electromotive force and potential difference

Core

1 Define electromotive force (e.m.f.) as the electrical work done by a source in moving a unit charge around a complete circuit

2 Know that e.m.f. is measured in volts (V)

3 Define potential difference (p.d.) as the work done by a unit charge passing through a component

4 Know that the p.d. between two points is measured in volts (V)

5 Describe the use of voltmeters (analogue and digital) with different ranges

Supplement

6 Recall and use the equation for e.m.f.

$$E = \frac{W}{Q}$$

7 Recall and use the equation for p.d.

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

4.2.4 Resistance

Core

1 Recall and use the equation for resistance

$$R = \frac{V}{I}$$

2 Describe an experiment to determine resistance using a voltmeter and an ammeter and do the appropriate calculations

3 State, qualitatively, the relationship of the resistance of a metallic wire to its length and to its cross-sectional area

Supplement

4 Sketch and explain the current–voltage graphs for a resistor of constant resistance, a filament lamp and a diode

5 Recall and use the following relationship for a metallic electrical conductor:

(a) resistance is directly proportional to length

(b) resistance is inversely proportional to cross-sectional area

4.2.5 Electrical energy and electrical power

Core

1 Understand that electric circuits transfer energy from a source of electrical energy, such as an electrical cell or mains supply, to the circuit components and then into the surroundings

2 Recall and use the equation for electrical power

$$P = IV$$

3 Recall and use the equation for electrical energy

$$E = IVt$$

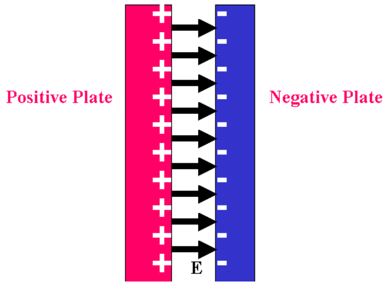
4 Define the kilowatt-hour (kW h) and calculate the cost of using electrical appliances where the energy unit is the kW h

Supplement

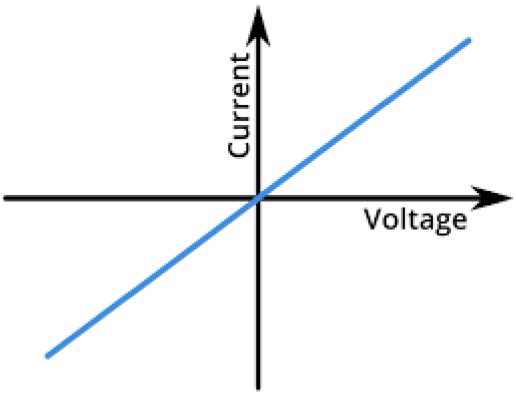
- Electromotive force (e.m.f.) and potential difference (voltage) are often confused because they are similar concepts.
- Electromotive force is the work done by a cell to drive a unit of charge around a complete circuit. It is measured in volts.
- Potential difference (voltage) is the work done to transfer a unit of charge across two points of different potential. It is calculated using the formula

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

where V is the potential difference in volts, W is the work done in joules, and Q is the charge in coulombs.



- Resistance is the opposition to electrical current. It is measured in ohms (Ω) and is determined by the material and shape of a conductor. The higher the resistance, the more work is required to push the same amount of current through the conductor.



- Ohm's Law states that the potential difference (voltage) across a conductor is directly proportional to the current flowing through it, provided that the conductor is ohmic and the temperature and other physical properties remain constant. The equation for Ohm's Law is:

$$V = IR$$

where V is the potential difference (voltage) in volts, I is the current in amperes, and R is the resistance in ohms. This equation can also be rearranged to solve for any of the three variables: I = V/R, R = V/I.

- The resistance of a conductor is affected by several factors:
  1) Length: The longer the length of the conductor, the greater its resistance.
  2) Diameter or area: The larger the area of the conductor, the lower its resistance.
  3) Temperature: The higher the temperature of the conductor, the greater its resistance.
  4) Material: The type of material of a conductor can affect its resistance, with some materials being more conductive and others being more insulative.

- Resistance is the opposition to electrical current. It is measured in ohms (Ω) and is determined by the material and shape of a conductor. The higher the resistance, the more work is required to push the same amount of current through the conductor.
- Power is the rate of work done or energy transferred. Recall the equation for power is

$$P = \frac{W}{t}$$

where P is power, w is work, and t is time. Depending on the information given, the equation for power can be written in different forms.

- Electrical power is the rate at which electrical energy is transferred. It is measured in watts (W) and can be calculated using the following equation:

$$P = V*I$$

where P is power, V is voltage (potential difference), and I is current.

4.3 Electric circuits

4.3.1 Circuit diagrams and circuit components

Core

1 Draw and interpret circuit diagrams containing cells, batteries, power supplies, generators, potential dividers, switches, resistors (fixed and variable), heaters, thermistors (NTC only), light-dependent resistors (LDRs), lamps, motors, ammeters, voltmeters, magnetising coils, transformers, fuses and relays, and know how these components behave in the circuit

Supplement

2 Draw and interpret circuit diagrams containing diodes and light-emitting diodes (LEDs), and know how these components behave in the circuit

4.3.2 Series and parallel circuits

Core

1 Know that the current at every point in a series circuit is the same

2 Know how to construct and use series and parallel circuits

3 Calculate the combined e.m.f. of several sources in series

4 Calculate the combined resistance of two or more resistors in series

5 State that, for a parallel circuit, the current from the source is larger than the current in each branch

6 State that the combined resistance of two resistors in parallel is less than that of either resistor by itself

7 State the advantages of connecting lamps in parallel in a lighting circuit

Supplement

8 Recall and use in calculations, the fact that:

(a) the sum of the currents entering a junction in a parallel circuit is equal to the sum of the currents that leave the junction

(b) the total p.d. across the components in a series circuit is equal to the sum of the individual p.d.s across each component

(c) the p.d. across an arrangement of parallel resistances is the same as the p.d. across one branch in the arrangement of the parallel resistances

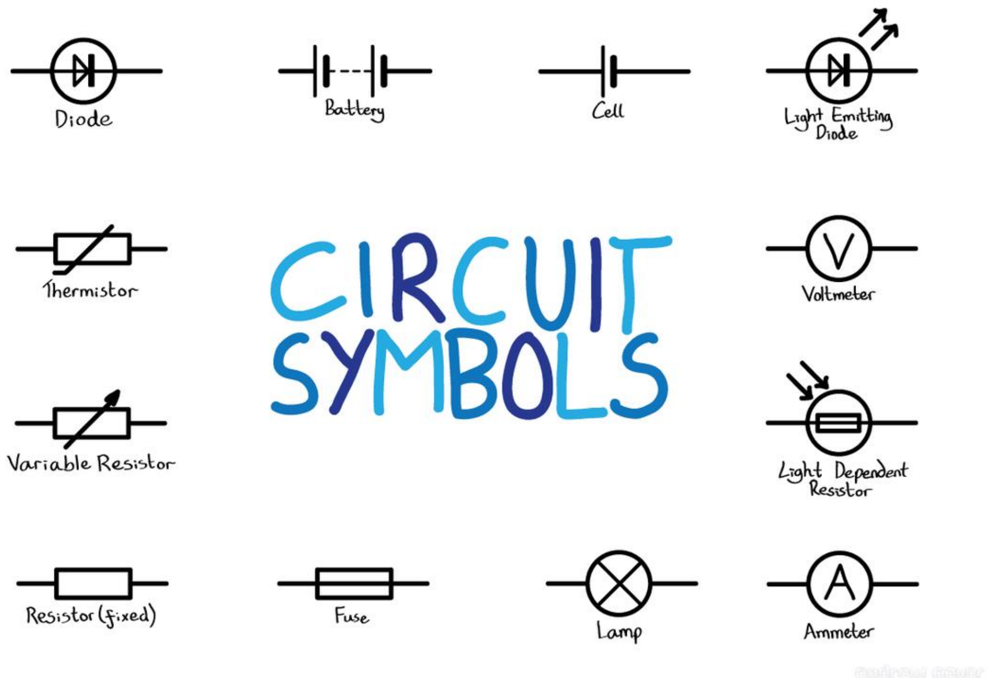
9 Explain that the sum of the currents into a junction is the same as the sum of the currents out of the junction

10 Calculate the combined resistance of two resistors in parallel

4.3.3 Action and use of circuit components

Core	Supplement
1 Know that the p.d. across an electrical conductor increases as its resistance increases for a constant current	2 Describe the action of a variable potential divider
	3 Recall and use the equation for two resistors used as a potential divider $\frac{R_1}{R_2} = \frac{V_1}{V_2}$

- Thermistors are resistors whose resistance decreases with increasing temperature. They are used in temperature sensing and control applications.
- Light-dependent resistors (LDRs) are resistors whose resistance decreases with increasing light intensity. They are used in light sensing applications.
- Fuses and relays are electrical components that are used to protect circuits and devices from excessive current. Fuses are one-time use components that break the circuit when the current exceeds a certain level, while relays are switch-like components that can open or close a circuit under certain conditions.
- Diodes are two-terminal electronic components that allow current to flow in only one direction. They are used to protect circuits and devices from reverse current and voltage.
- Light-emitting diodes (LEDs) are diodes that emit light when current flows through them. They are used as indicators and in lighting applications.



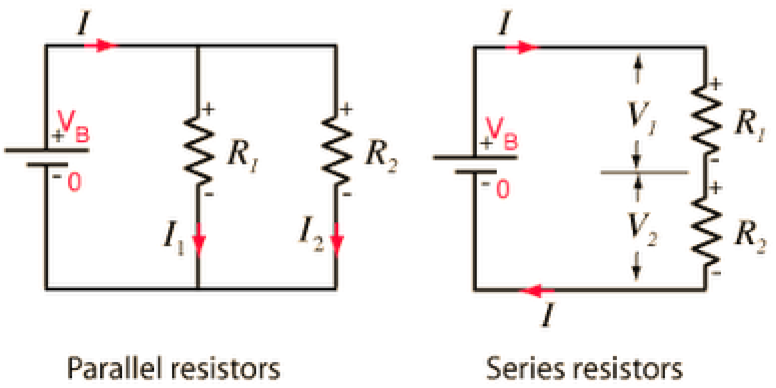
- A parallel circuit is a type of electrical circuit in which the components are connected in parallel, meaning that they are connected to the same voltage source and have their own individual current paths.
- In a parallel circuit, the total current is equal to the sum of the individual branch currents.
- The total resistance in a parallel circuit is calculated using the formula:

  $$1/R_t = 1/R_1 + 1/R_2 + 1/R_3 + ...$$

  where Rt is the total resistance, and R1, R2, R3, etc. are the resistances of the individual branches.
- The voltage across each component in a parallel circuit is the same.
- A series circuit is a type of electrical circuit in which the components are connected in series, meaning that they are connected in a chain and only have one current path.
- In a series circuit, the total current is equal to the current through any one of the components.
- The total resistance in a series circuit is calculated by adding the resistances of the individual components using the formula:

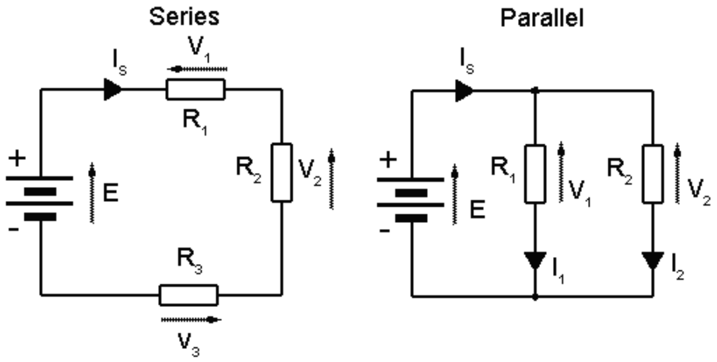
  $$R_t = R_1 + R_2 + R_3 + ...$$

  where Rt is the total resistance, and R1, R2, R3, etc. are the resistances of the individual components.
- The voltage across each component in a series circuit is different. The voltage drop (difference in potential) across a component is proportional to the resistance of the component.



$$\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$R_{equivalent} = R_1 + R_2$$



$E = V_1 + V_2 + V_3$

$I_s = I_1 + I_2$

The supply current I_s flows through all resistors

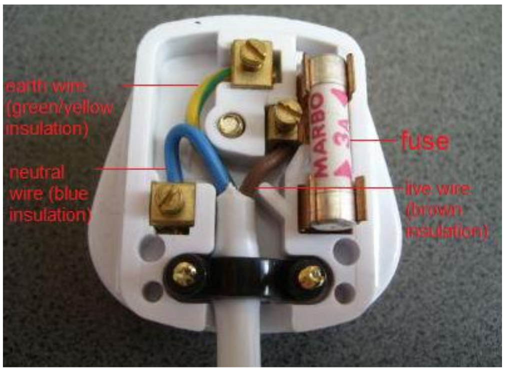
The supply voltage E appears across both resistors so $E = V_1 = V_2$

Characteristic	Series Circuit	Parallel Circuit
Total current	Equal to any one branch current	Sum of branch currents
Total resistance	Rt = R1 + R2 + R3 + ...	Calculated using 1/Rt = 1/R1 + 1/R2 + 1/R3 + ...
Voltage across components	Different, proportional to resistance	Same

4.4 Electrical safety

Core	Supplement
1 State the hazards of: (a) damaged insulation (b) overheating cables (c) damp conditions (d) excess current from overloading of plugs, extension leads, single and multiple sockets when using a mains supply 2 Know that a mains circuit consists of a live wire (line wire), a neutral wire and an earth wire and explain why a switch must be connected to the live wire for the circuit to be switched off safely 3 Explain the use and operation of trip switches and fuses and choose appropriate fuse ratings and trip switch settings 4 Explain why the outer casing of an electrical appliance must be either non-conducting (double-insulated) or earthed 5 State that a fuse without an earth wire protects the circuit and the cabling for a double-insulated appliance	

- Damaged insulation on electrical wires can cause electric shock, which can result in serious injury. For example, if a frayed wire is touched, the person may receive an electric shock.
- Overheating of electrical cables can be caused by coiling them up tightly, which can lead to a fire hazard. For example, if an extension lead is coiled up tightly and then plugged in, it may overheat and potentially cause a fire.
- Wet conditions can increase the risk of electrocution due to water's ability to conduct electricity. For example, if an electrical appliance is used near a wet floor, there is an increased risk of electrocution.
- Excess current can be caused by overloading of plugs, extension leads, and sockets when using a mains supply. This can result in overheating and potentially cause a fire. For example, if a single socket is used to power multiple appliances that exceed the socket's current rating, it can cause excess current and potentially start a fire.
- Fuses are used to protect electrical circuits from excessive current by melting (blowing) if the current becomes too high. They should be chosen based on the current rating of the appliance they are protecting. For example, if a 15-amp fuse is used to protect a 20-amp appliance, it may not trip in the event of an excess current and could potentially cause a fire.



- Circuit breakers are automatic switches that open the circuit when the current exceeds a certain value. They can be reset after tripping and offer better protection than fuses because they can be used multiple times. For example, if a circuit breaker trips due to excess current, it can be reset once the cause of the excess current has been addressed, whereas a fuse must be replaced after it has blown.

4.5 Electromagnetic effects

4.5.1 Electromagnetic induction

Core

1 Know that a conductor moving across a magnetic field or a changing magnetic field linking with a conductor can induce an e.m.f. in the conductor

2 Describe an experiment to demonstrate electromagnetic induction

3 State the factors affecting the magnitude of an induced e.m.f.

Supplement

4 Know that the direction of an induced e.m.f. opposes the change causing it

5 State and use the relative directions of force, field and induced current

4.5.2 The a.c. generator

Core

Supplement

1 Describe a simple form of a.c. generator (rotating coil or rotating magnet) and the use of slip rings and brushes where needed

2 Sketch and interpret graphs of e.m.f. against time for simple a.c. generators and relate the position of the generator coil to the peaks, troughs and zeros of the e.m.f.

4.5.3 Magnetic effect of a current

Core

1 Describe the pattern and direction of the magnetic field due to currents in straight wires and in solenoids

2 Describe an experiment to identify the pattern of the magnetic field (including direction) due to currents in straight wires and in solenoids

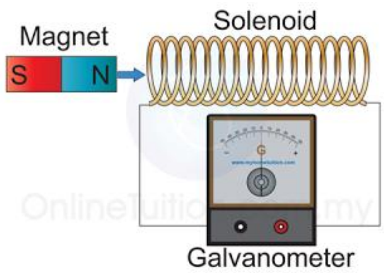
3 Describe how the magnetic effect of a current is used in relays and loudspeakers and give examples of their application

Supplement

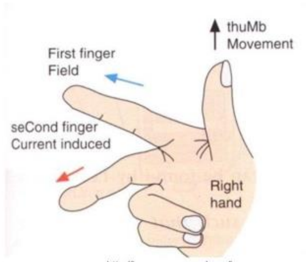
4 State the qualitative variation of the strength of the magnetic field around straight wires and solenoids

5 Describe the effect on the magnetic field around straight wires and solenoids of changing the magnitude and direction of the current

- Electromagnetic induction occurs when a magnet is moved in and out of a solenoid, causing the magnetic field flux of the magnet to be cut by the coil, which in turn induces an electromotive force (e.m.f.) in the wire.
- If the solenoid is connected to a closed circuit, an induced current will flow through the circuit.
- The production of electric current through electromagnetic induction only occurs when the magnet or solenoid is moving relative to one another.

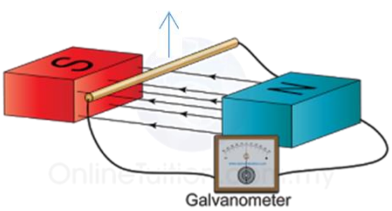


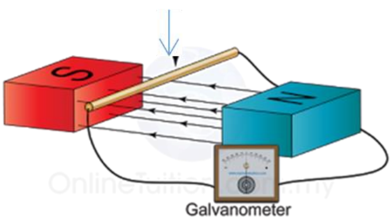
- Faraday's Law states that the magnitude of the induced e.m.f. is directly proportional to the rate of change of magnetic flux through a solenoid or the rate of the magnetic flux being cut. **Increasing the speed** of the magnet, using a **stronger magnet**, or **increasing the number of coils** in the solenoid will all **increase the induced e.m.f**.
- Lenz's Law states that the induced current always flows in the direction that opposes the change in magnetic flux. This law obeys the conservation of energy principle, as work is done to move the magnet against the repulsive force, which is then converted to electric energy (current).
- Electromagnetic induction occurs when a straight conductor (e.g. wire) moves and cuts through a magnetic field, causing an e.m.f. to be induced across the conductor. If the conductor is a complete circuit, current will flow in the conductor. The direction of the current can be determined using Flemming's RHR.



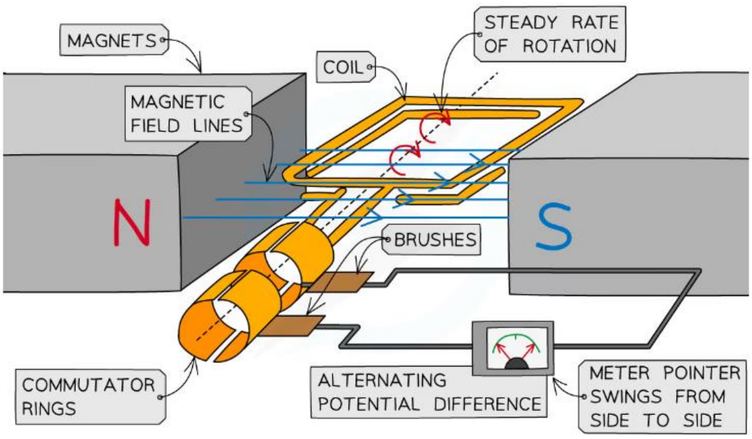
Example problems

Find the direction of the induced current.



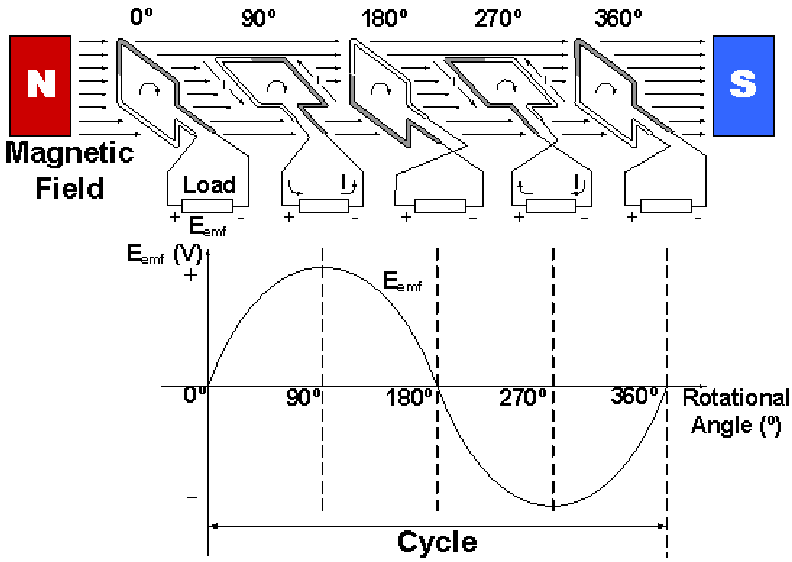


- When a bar magnet is moved into a solenoid, the solenoid will cut the magnetic flux of the bar magnet, inducing a current and e.m.f. in the solenoid. The induced current will produce another magnetic field around it, the pole and direction of which can be determined using Lenz's Law.
- Applications of electromagnetic induction include DC generators and AC generators.
- An AC generator is a device that converts mechanical energy (e.g. from a turbine or engine) into electrical energy. It is based on the principle of electromagnetic induction, which states that a changing magnetic field can induce an e.m.f. in a conductor.
- AC generators consist of a rotating magnet (the rotor) or a rotating coil of wire (the armature) and a stationary coil of wire (the stator). As the magnet or armature rotates, it cuts through the magnetic field of the stator, inducing an e.m.f. in the wire. This e.m.f. causes a current to flow in the wire, producing an AC voltage.
- The frequency of the AC voltage produced by an AC generator is directly proportional to the speed of the rotor or armature.
- In some AC generators, the rotor or armature is connected to the external circuit via slip rings and brushes. These components allow the current to flow from the rotating part of the generator to the stationary part, while minimizing electrical loss due to friction.
- AC generators are used in many applications, including power plants and portable generators. Understanding how they work is important for studying electricity and electrical devices.

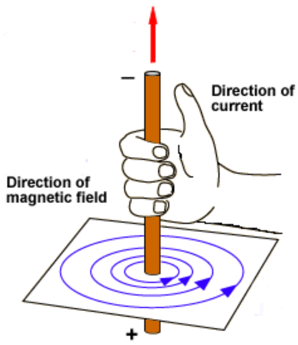


- An AC generator produces voltage that periodically changes direction
- Plotting the e.m.f. of an AC generator against time produces a sine wave
- The peaks of the sine wave represent the maximum positive and negative values of the voltage
- The troughs of the sine wave represent the minimum positive and negative values of the voltage

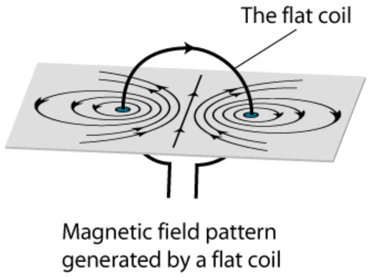
- The zero points of the sine wave represent points where the voltage is zero
- The position of the generator coil determines the position of the peaks, troughs, and zeros on the sine wave
- As the magnet or armature of the AC generator rotates, the position of the generator coil changes, causing the e.m.f. to follow a sine wave pattern



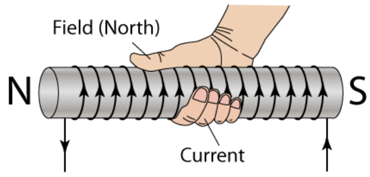
- An electromagnet is a temporary magnet made by winding an insulated wire around a soft iron core, forming a solenoid
- When current passes through the solenoid, it produces a magnetic field
- The solenoid becomes magnetized and functions as an electromagnet
- The strength of the electromagnet depends on the number of turns in the solenoid, the type of material used for the core, and the amount of current flowing through the solenoid
- Electromagnets are used in a wide range of applications, including motors, generators, relays, and speakers
- The right-hand thumb rule is a way to find the direction of the magnetic field around a conductor carrying current.
- The right-hand thumb rule can be used for straight wires, single coils, and solenoids.
- Straight wire



- Coil



- Solenoid



4.5.4 Force on a current-carrying conductor

Core

1 Describe an experiment to show that a force acts on a current-carrying conductor in a magnetic field, including the effect of reversing:
(a) the current
(b) the direction of the field

Supplement

2 Recall and use the relative directions of force, magnetic field and current

3 Determine the direction of the force on beams of charged particles in a magnetic field

4.5.5 The d.c. motor

Core

1 Know that a current-carrying coil in a magnetic field may experience a turning effect and that the turning effect is increased by increasing:
(a) the number of turns on the coil
(b) the current
(c) the strength of the magnetic field

Supplement

2 Describe the operation of an electric motor, including the action of a split-ring commutator and brushes

4.5.6 The transformer

Core

1 Describe the construction of a simple transformer with a soft iron core, as used for voltage transformations

2 Use the terms primary, secondary, step-up and step-down

3 Recall and use the equation

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

where p and s refer to primary and secondary

4 Describe the use of transformers in high-voltage transmission of electricity

5 State the advantages of high-voltage transmission

Supplement

6 Explain the principle of operation of a simple iron-cored transformer

7 Recall and use the equation for 100% efficiency in a transformer

$$I_p V_p = I_s V_s$$

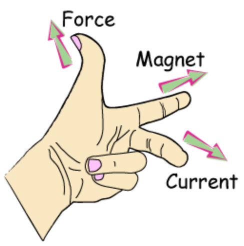
where p and s refer to primary and secondary

8 Recall and use the equation

$$P = I^2 R$$

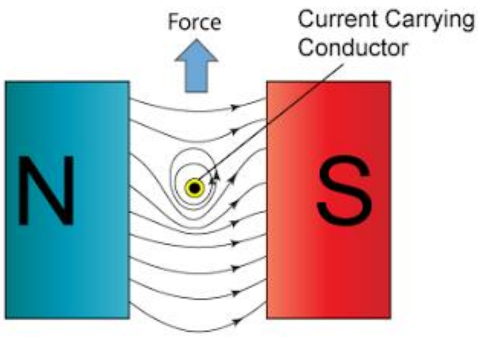
to explain why power losses in cables are smaller when the voltage is greater

- When a current-carrying conductor is placed in a magnetic field, the interaction between the two magnetic fields produces a force on the conductor.
- To determine the direction of this force, use Fleming's left-hand rule.



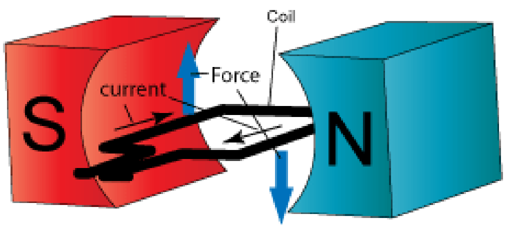
1) Place your thumb, forefinger, and middle finger perpendicular to each other.
2) Point your forefinger in the direction of the magnetic field, your middle finger in the direction of the current, and your thumb in the direction of the force.

- The strength of the force can be increased by:
  1) Increasing the current
  2) Using a stronger magnet
  3) Using a longer wire
  4) Arranging the wire perpendicular to the direction of the magnetic field
- A current-carrying conductor placed in a magnetic field generates a force
- The direction of this force can be determined using Fleming's left-hand rule

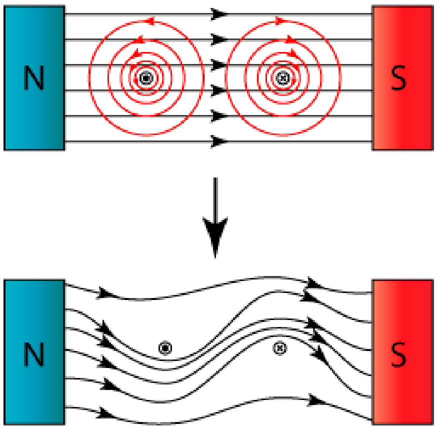


Catapult Field

- A current-carrying coil placed in a magnetic field generates a pair of opposing forces
- These forces constitute a couple, causing the coil to rotate

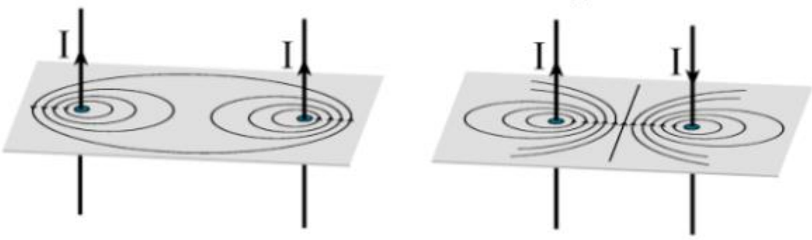


Turning Effect of a Coil in a Magnetic Field



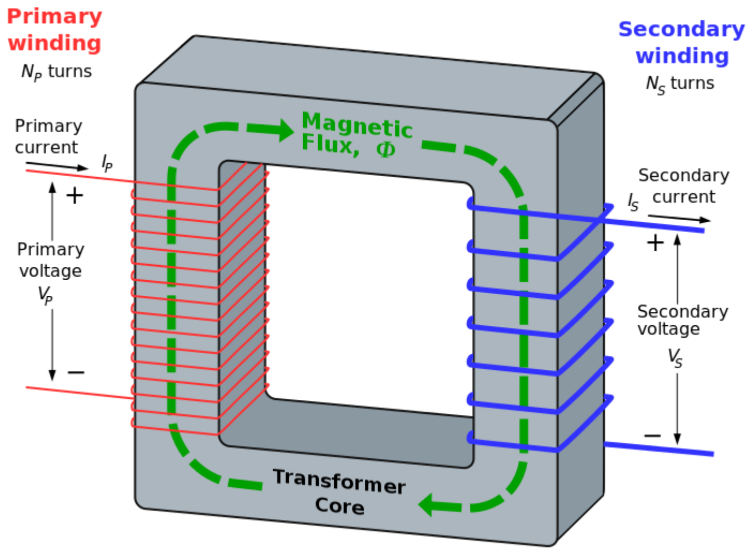
Interaction of the magnetic
fields produces a catapult field

- Examples of equipment that use this effect include DC motors and moving coil meters.
- Two current-carrying conductors placed close to each other will generate a force between them
- If the currents in both conductors flow in the same direction, the conductors will repel each other
- If the currents flow in opposite directions, the conductors will attract each other



Catapult field produced by 2 straight curretn carrying conductors

- A transformer is a device that changes the potential difference of an AC current



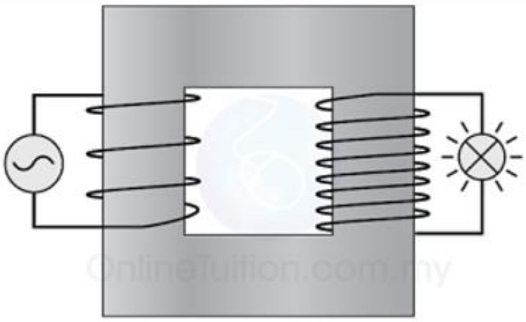
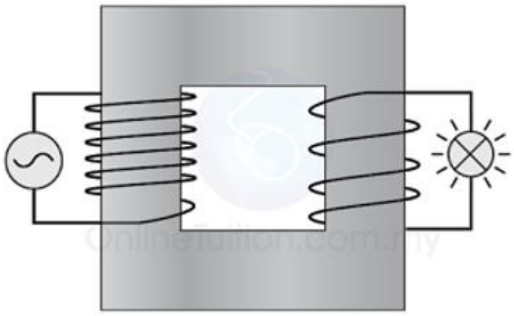
- It consists of a primary and secondary coil wound on a soft iron core
- When AC current flows in the primary coil, a changing magnetic flux is generated and transferred to the secondary coil through the iron core
- Induces an EMF in the secondary coil, magnitude determined by the ratio of primary to secondary turns
- Input current flows through primary winding, output exits through secondary winding
- Current in primary must be AC to generate changing flux
- In an ideal transformer, input power = output power and induced current in secondary is AC and has the same frequency as input

$$V_P I_p = V_S I_S$$

- Relationship between input and output voltage, current, and power:

$$\frac{V_P}{V_s} = \frac{N_P}{N_s}$$

- A step-up transformer increases voltage on secondary coil relative to primary coil and reduces current
- A step-down transformer decreases voltage on secondary coil relative to primary coil and increases current.
- The turns in primary and secondary coils are inversely proportional to voltage in primary and secondary coils.

Step-up transformer	Step-down transformer
	
$N_P < N_s$	$N_P > N_s$
$V_P < V_s$	$V_P > V_s$
$I_P > I_s$	$I_P < I_s$