CIE Physics IGCSE

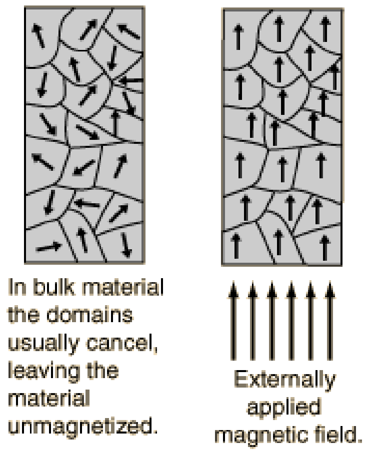
Topic 4: Electricity and Magnetism

Summary Notes

Simple phenomena of magnetism

Magnetic forces are due to interactions between magnetic fields. In a magnet, like poles repel and opposite poles attract.

- Magnetic materials are materials that are attracted to magnets and can be magnetised (e.g. iron, steel, cobalt, nickel)
- Non-magnetic materials are materials that are not attracted to magnets and cannot be magnetised (e.g. glass, plastic)



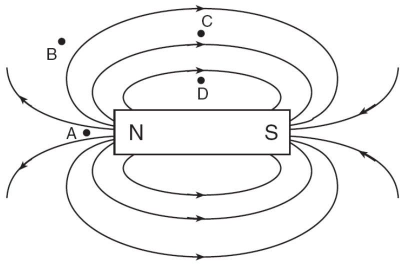
Induced magnetism:

- Magnetic materials can be magnetised by induced magnetism:
  - They can be magnetised by stroking them with a magnet, hammering them in a magnetic field, or putting them inside a coil with a direct current through it.
  - **They can be demagnetised by hammering them, heating them or putting them inside a coil with an alternating current through it.**
- Magnetic materials that can be permanently magnetised are described as magnetically hard (e.g. steel). Magnetic materials that are only temporarily magnetised are described as magnetically soft (e.g. soft iron).

Permanent magnets vs electromagnets:

- Permanent magnets are a hard-magnetic material that has been permanently magnetised whereas electromagnets consist of a coil of wire wrapped around a magnetically soft core and can be turned on and off.
- Permanent magnets are more useful when they do not need to be turned off such as a fridge magnet, whereas electromagnets have the ability to be turned on and off so they can be used for situations such as moving scrap metal.

Magnetic fields:



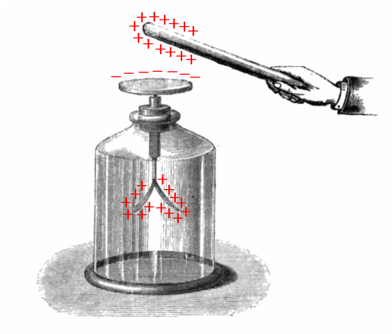
- Field lines around a bar magnet point from north to south
- **The direction of a magnetic field line shows the direction of the force on a north pole at that point.**
- Field strength decreases with distance from the magnet
- Plotting compasses are small compasses which show the direction and shape of a magnetic field.

Electrical quantities

Electric charge

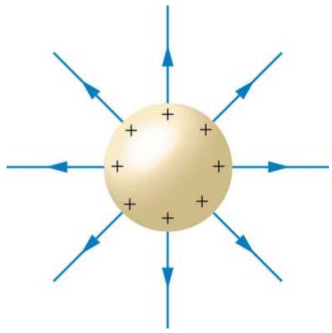
Charge is **measured in coulombs.** There are positive and negative charges; unlike charges attract and like charges repel.

- Charging a body involves the addition or removal of electrons.
- Conductors allow electrons to flow through them whereas insulators impede the flow of electrons.
    - Conductors such as metals are used as wires in circuits.
    - When two insulators are rubbed together, electrons move from one to the other and they become charged. For example, when a rod is rubbed with a cloth, electrons are transferred from the rod onto the cloth and the rod becomes positively charged.
- Charge can be detected using a gold leaf electroscope.
    - If a positively charged rod is brought close to the disc on top of the electroscope, electrons are attracted to the top of the disc, away from the bottom of the metal stem and the gold leaf. The gold leaf will then be repelled from the metal stem because they both become positively charged.
    - **If someone then touches the disc, electrons flow from the ground into the disc as they are attracted to the rod, and the electroscope now contains a net negative charge. This is called charging by induction.**



Charges create electric fields (regions in which an electric charge experiences a force); the direction of an electric field at a point is the direction of the force on a positive charge at that point.

- **Electric field lines point away from positive charges and towards negative charges.**
    - **The field lines around a charged conducting sphere are as if the charge was concentrated at the centre of the sphere.**
    - **The field lines between two charged plates go in straight lines from the positive plate to the negative plate and are equally spaced apart.**



Current

Current I is measured in amps and is the rate of flow of charge at a point in the circuit.

- **The current is given by I=Q/t.**
- It is measured with an ammeter placed in series.
- In metals, current is due to a flow of electrons. **Because electrons are negatively charged, conventional current (which is the rate of flow of positive charge) is in the opposite direction to the flow of electrons.**

Electromotive force

The electromotive force (e.m.f) of an electrical source of energy is measured in volts and is the **energy supplied by the source per unit charge in driving the charge round a complete circuit.**

Potential difference

Potential difference V is measured in volts **($1\ V = 1\ JC^{-1}$) and is the work done per unit charge in moving between two points in a circuit.**

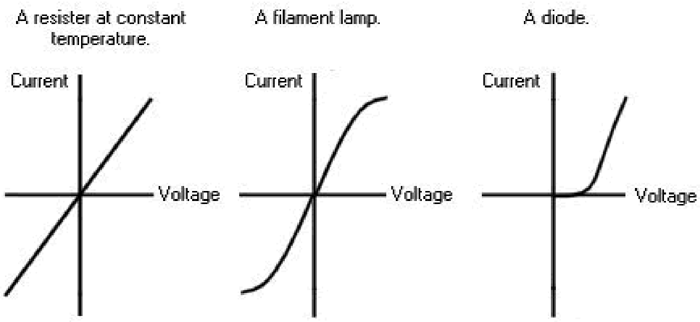
- It is measured with a voltmeter placed in parallel across the component.
- The higher the potential difference, the greater the current.

Resistance

The resistance of a component is given by the potential difference across it divided by the current through it. The greater the resistance, the harder it is for current to flow through the component.

- As the length of a resistor increases, the resistance increases.
    - **The resistance is directly proportional to the length.**
- As the diameter of a resistor increases, the resistance decreases.
    - **The resistance is inversely proportional to the cross-sectional area.**

In an ohmic conductor, the current is directly proportional to the voltage (i.e. it has constant resistance). In a non-ohmic conductor (such as a filament lamp), the resistance changes as the voltage and current change.



As the current increases through a filament lamp, so does the temperature. This means electrons and ions vibrate more and collide more, increasing resistance.

Electrical working

- Energy is transferred from chemical energy in the battery to electrical energy used by circuit components and then to the surroundings.
- **The power of a component is given by $P=IV$.**
- **By using $V=IR$, this can be shown to be equivalent to $P=I^2R$ and $P=V^2/R$.**

Electric circuits

Series:

- Components are connected end to end in one loop
- The same current flows through every component
- The potential difference is shared across each component (i.e. the sum of the p.d.s across the components is equal to the total p.d. across the supply).
- The total resistance is the sum of the resistances of each component $R_T = R_1 + R_2 + \ldots$
- **The combined e.m.f. of several sources in series is the sum of the individual e.m.f.s**

Parallel

- Components are connected to the power supply in separate branches
- The current is shared between each branch (i.e. the sum of the currents in the separate branches is equal to the current through the source)
- The potential difference is the same across every branch
- The total resistance of two resistors in parallel is less than the resistance of either resistor by itself, **and is given by** $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$
- Connecting lamps in parallel is advantageous because if one breaks, current can still pass through the rest.

A potential divider circuit divides the source voltage into smaller parts.

- The voltage across a certain component is given by $V_{out} = V_{in} \times \frac{R}{R_T}$ where V_{in} is the source voltage, R is the resistance of the component and R_T is the total resistance.

A thermistor is a resistor whose resistance decreases as the temperature increases.

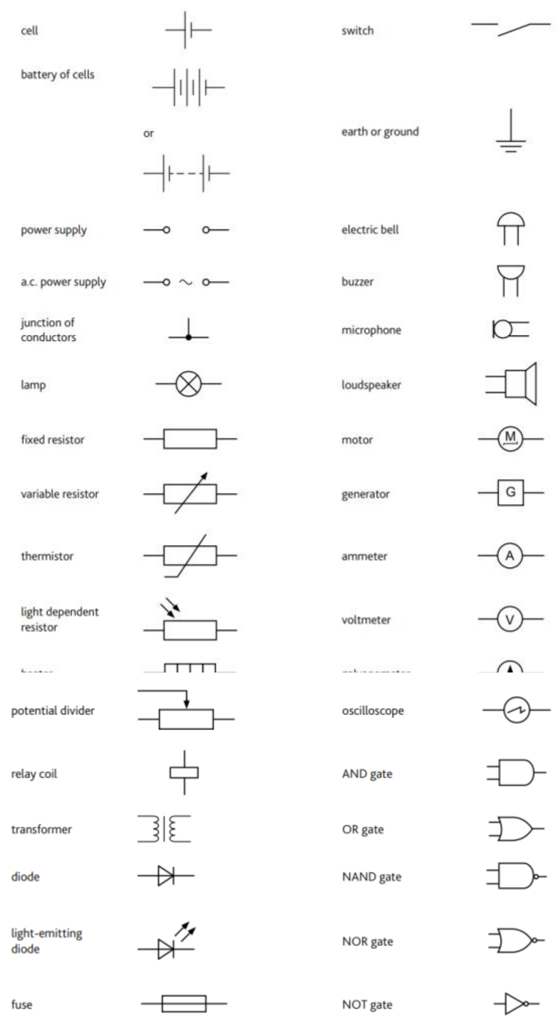
A light dependent resistor is a resistor whose resistance decreases as light intensity increases.

A relay is an electromagnetically operated switch. When a small current passes through the electromagnet, it switches on and attracts an iron arm. This arm rotates about a pivot and pushes the contacts in another circuit together.

- They are used to switch on a circuit with a high current using a circuit with a small current.

The above three components can be used in conjunction to operate light-sensitive switches and temperature-operated alarms.

Diodes only allow current to flow in one direction, because they have a very high resistance in the other direction. They can be used as a rectifier (i.e. convert AC into DC).



Digital electronics

- **Analogue signals vary continuously in amplitude, frequency or both.**
- **Digital signals are a series of pulses with two states, a high state and a low state. Digital signals carry more information per second and maintain their quality better over longer distances compared to analogue signals.**
  - **All signals get weaker as they travel longer distances and need to be amplified so they can be returned to the original. Noise in analogue signals is amplified too when the signal is amplified, so the quality is reduced. However, in digital signals, the noise is normally a lower amplitude than the high/low states used, so it can be ignored.**

Logic gates:

NOT gate	AND gate	OR gate	NAND gate	NOR gate
If the input is one state, the output will be the other state.	If both of the inputs are high, the output will be high; otherwise the output will be low.	If either of the inputs is high, the output will be high; otherwise the output will be low.	If both of the outputs are high, the output will be low; otherwise the output will be high.	If either of the inputs is high, the output will be low; otherwise the output will be high.

The symbols for the logic gates are shown in the diagram on the page above. Truth tables show the corresponding output of one or more gates given all possible inputs.

Dangers of electricity

Hazards:

- Damaged insulation – contact with the wire due to gaps in the insulation can cause an electric shock or pose a fire hazard by creating a short circuit.
- Overheating of cables – high currents passing through thin wire conductors cause the wires to heat up to very high temperatures which could melt the insulation and cause a fire.
- Damp conditions – water can conduct a current so wet electrical equipment can cause an electric shock.

Fuses:

- A fuse is a thin piece of wire which overheats and melts if the current is too high, protecting the circuit.
- Fuses have a current rating which should be slightly higher than the current used by the device in the circuit. The most common are 3A, 5A and 13A.

Circuit breakers:

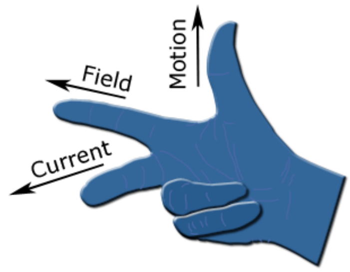
- Circuit breakers consist of an automatic electromagnet switch which which breaks the circuit if the current rises over a certain value.
- This is better than a fuse as it can be reset and used again, and they operate faster.

Earthing metal cases:

- Earth wires creates a safe route for current to flow through in the case of a short circuit, preventing electric shocks.
- Earth wires have a very low resistance so a strong current surges through them which breaks the fuse and disconnects the appliance.

Electromagnetic effects

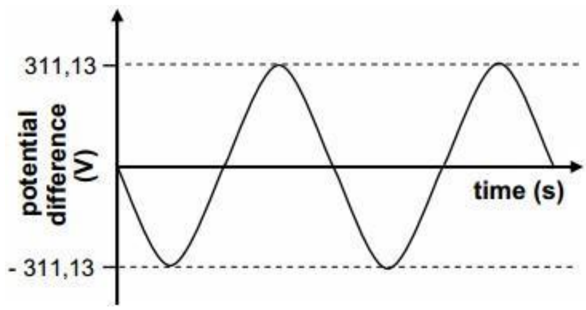
Electromagnetic induction



- When a wire moves across a magnetic field, an e.m.f. is induced in it. If it is part of a complete circuit, this causes a current to flow.
- **The induced current flows in such a direction that it opposes the change that produced it.**
- The induced e.m.f. can be increased by moving the wire more quickly, using a stronger magnetic field, or increasing the length of the wire.
- **The direction of the e.m.f. is determined by Fleming's right hand rule as shown in the diagram.**
- An e.m.f. is also induced if a changing magnetic field links with a conductor. For example, when a magnet is moved into a coil, the magnetic field through the coil changes and an e.m.f. is induced in it. The more quickly the magnetic field changes, the greater the e.m.f.

AC generator

- In a direct current, the current only flows in one direction whereas in an alternating current, the current continuously changes direction.
- **An AC generator consists of a coil of wire between two permanent magnets. They generate AC current because a slip ring commutator is used.**
- **As the coil rotates, the magnetic field through the coil changes, which induces an e.m.f. in the coil.**
- **The magnitude of the e.m.f. is maximum when the coil is horizontal as the field lines are cut the fastest, and zero when vertical as no field lines are being cut.**
- **The e.m.f. can be increased by increasing the number of turns on the coil, increasing the area of the coil, using a stronger magnet or increasing the speed of rotation.**



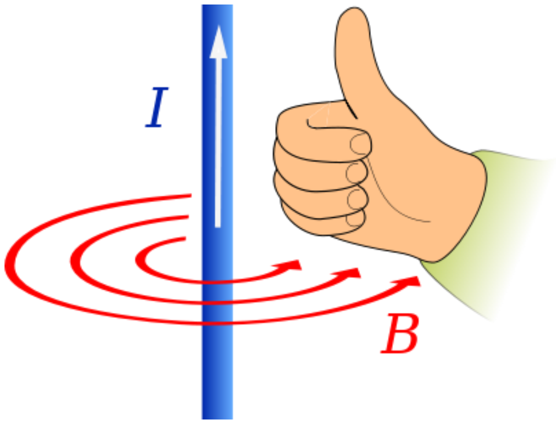
Transformer

- A transformer consists of two coils wrapped around a soft iron core and is used to transform voltages.
- **An alternating current in the primary coil creates a changing magnetic field; this changing magnetic field links with the secondary coil and induces an alternating e.m.f. in it.**

- A step up transformer has more turns on the secondary which means the voltage of the secondary is greater than that of the primary. A step down transformer has fewer turns on the secondary which means the voltage of the secondary is less than that of the primary.
- $\frac{number\ of\ coils\ on\ primary}{number\ of\ coils\ on\ secondary} = \frac{pd\ of\ primary}{pd\ of\ secondary}$ $\frac{N_{primary}}{N_{secondary}} = \frac{V_{primary}}{V_{secondary}}$
- **For a 100% efficient transformer, because the power used is constant,** $I_p V_p = I_s V_s$
- Transformers are used to step up the voltage in power lines which reduces power loss**. This is because a higher voltage means a smaller current and the loss of power due to P=I^{2}R will be lower.**

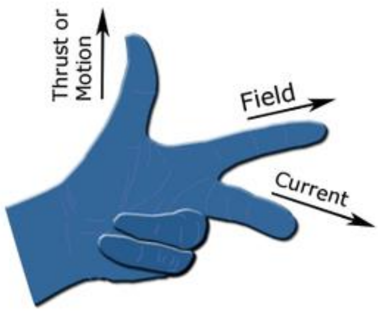
The magnetic effect of a current

- The right hand grip rule determines the direction of the magnetic field produced by a current carrying wire.
- The magnetic field created by a solenoid is like the field produced by a bar magnet.
- **Increasing the current through the wire increases the strength of the magnetic field, and reversing the direction of the current through the wire reverses the direction of the magnetic field.**
- The magnetic effect of current is used in relays.



Force on a current-carrying conductor

- A force acts on a current-carrying conductor in a magnetic field. **Fleming's left hand rule shows the relative directions of the force, field, and current.**
  - If a current-carrying wire is fixed in place between two magnets which rest on a balance, the wire will exert an equal and opposite force on the magnets and the reading will change, showing that a force is acting.
- If the current is reversed or the magnetic field is reversed, the force will be reversed.
- **A force is also exerted on charged particles moving in a magnetic field (because moving charged particles are current). If a beam of charged particles moves through a magnetic field, it will be deflected, showing that there is a force.**



DC motors

- DC motors consist of a coil of wire in between two permanent magnets.
- Current flows through the wire and it experiences a turning effect due to the forces exerted on it in the magnetic field. The turning effect can be increased by:
  - increasing the current
  - using a stronger magnetic field
  - increasing the number of turns on the coil.
- **A split ring commutator is used to ensure that the direction that the current flows in the coil reverses every half turn.**