BioMedical Admissions Test (BMAT)

Section 2: Physics

Topic P1 - Electricity

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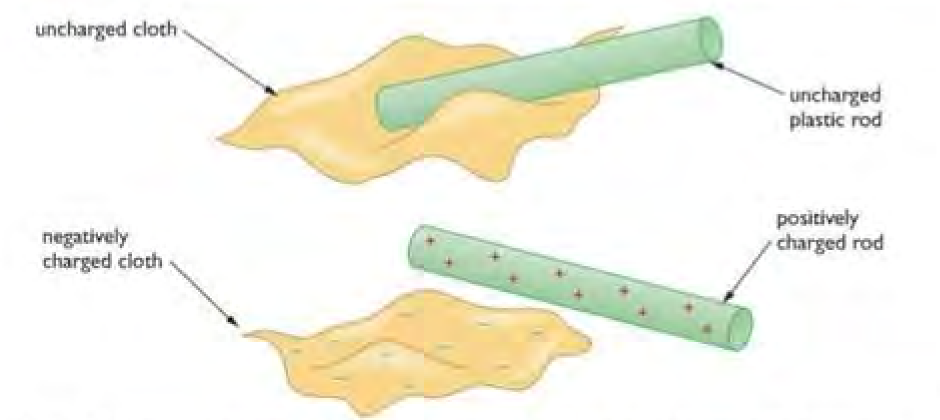
Electrostatics

An **electrostatic conductor** is a material that is able to disperse electrical current (electrons) easily.

Electrostatic insulators do not disperse electrical charge (electrons) easily.

- ➔ When insulators are rubbed together, there is a flow of charge (electrons) from one insulator to the other.
- ➔ The insulator that loses the electrons is said to have become positively charged. The insulator that gains the electrons is said to have become negatively charged.



- ➔ Objects with the **same** charge **repel** each other.
- ➔ Objects with **opposite** charge (i.e. positive and negative) **attract** each other.

Objects can also be charged by a process called **induction**:

- Placing a **neutral** object next to a **charged** object causes it to become charged.
- If one end of this newly charged object is momentarily **earthed**, the object becomes permanently charged.

Static electricity has uses in **industry**.

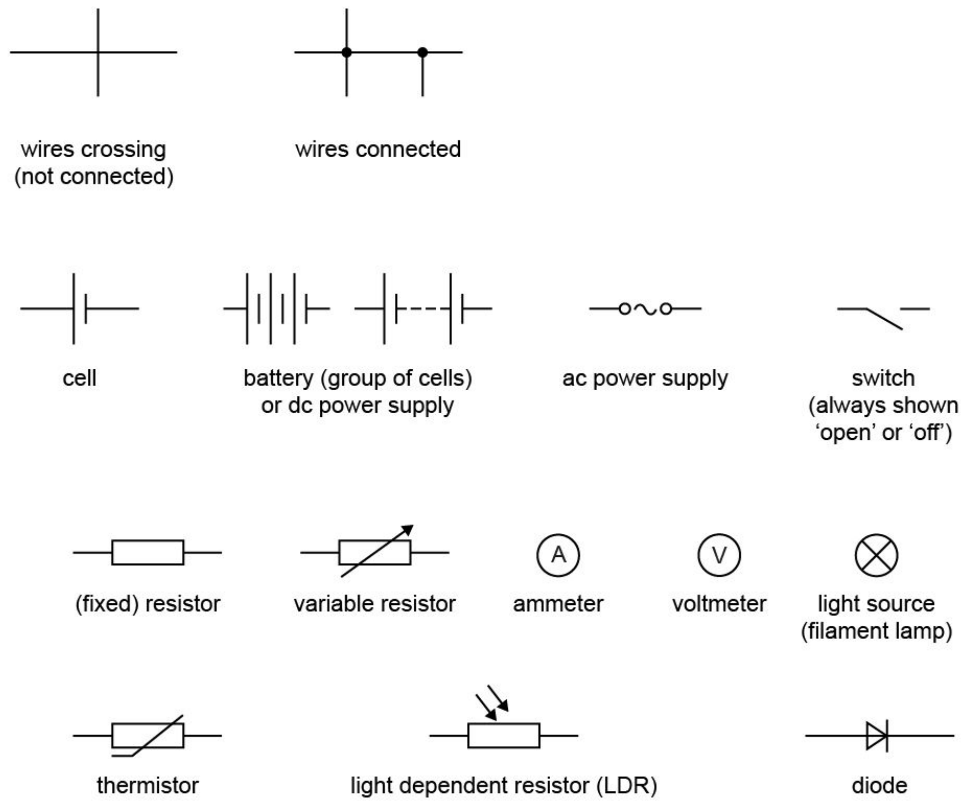
- ➔ One example is in spray paints; the object to be painted and the paint droplets are given opposite charges. This means the paint is attracted to the object, and therefore less paint is wasted.

Static electricity can be **dangerous**. Sparks can form upon spontaneous dissipation of electrical charge which can lead to fire.

Earthing of objects that can build up too much charge reduces the risk of a spark.

Circuit Theory

There are standard symbols used to represent **circuit components** in diagrams which are recognised **universally**:



Current can be supplied as **direct current** (DC) or **alternating current** (AC).

➔ **Direct current** is current that is always supplied in the same direction - this is how batteries or cells supply current.

➔ **Alternating current** is current that repeatedly changes directions - this is the output of power stations generators and the mains.

The current changes direction at a certain regular frequency which produces a **waveform**.

In the UK and Europe, the mains current is supplied at a frequency of 50Hz (50 oscillations or 100 changes in direction per second).

Electrical Current Potential Difference and Resistance

Current

Current is the flow of charged particles (electrons/ions etc.) through an electrical conductor.

- ➔ Current is represented by the symbol *I* and is measured in amperes (A).
- ➔ 1 ampere is the current when 1 coulomb of charge flows through a conductor per second.

Current = Charge / Time

Current is measured using an **ammeter** which is always placed in series with components of a circuit.

Potential Difference (Voltage)

Potential difference, also known as **voltage**, is the work done (energy required) to move charge between two points.

- ➔ Potential difference is represented by the symbol *V* and is measured in volts (V).
- ➔ 1 volt is work done moving 1 coulomb of charge between two points

Potential difference (V) = Work Done (J) / Charge(C)

Potential difference is measured using a **voltmeter** which is always placed in parallel with the component whose potential difference you are trying to measure.

Resistance

Resistance is the opposition to the flow of current (electrons) through a conductor. All conductors carry a certain resistance which is directly proportional to the length of the conductor and inversely proportional to the cross sectional area.

- ➔ Resistance is represented by the symbol R and is measured in ohms (Ω).
- ➔ 1 ohm is the resistance of a conductor when a potential difference of 1 volt produces a current of 1 ampere.

Resistance (Ω) = Potential Difference (V) / Current(A)

Voltage-Current Graphs

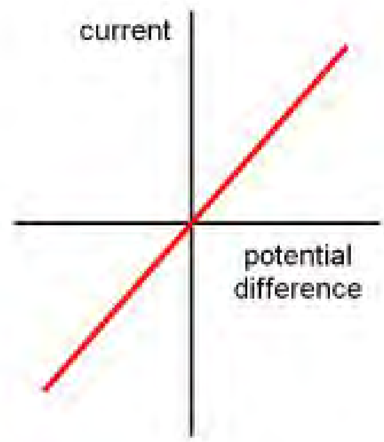
Voltage, current and resistance are all linked by the following equation:

Voltage (V) = Current (A) x Resistance (Ω)

This relationship between voltage and current can be expressed graphically through the use of **voltage current graphs**. Current is plotted along the y-axis and voltage is plotted along the x-axis.

Ohmic Conductors

A fixed resistor maintains **constant resistance** with different currents flowing through it.



The current flowing through the resistor is **directly proportional** to the potential difference across it.

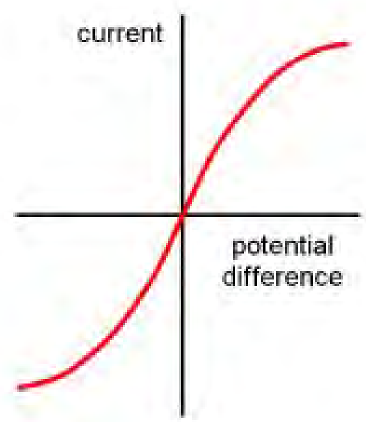
Resistance can be calculated by using the following logic:

1. The gradient of the line is:
   dy/dx = Current / Potential Difference
2. Rearranging **Voltage = Current x Resistance** gives the equation **Resistance = Potential Difference / Current**
3. You can therefore see that **Resistance = 1 / gradient of the line**

A fixed resistor such as this is an example of an **ohmic conductor**.

Non-ohmic Conductors

Not all components are ohmic conductors. **Non-ohmic conductors** resistance alters with varying current flowing through them and varying potential differences across them.



This means they do not produce a straight line on a voltage-current graph. Instead, the graph has a **sigmoidal curve**, as seen on the graph on the right.

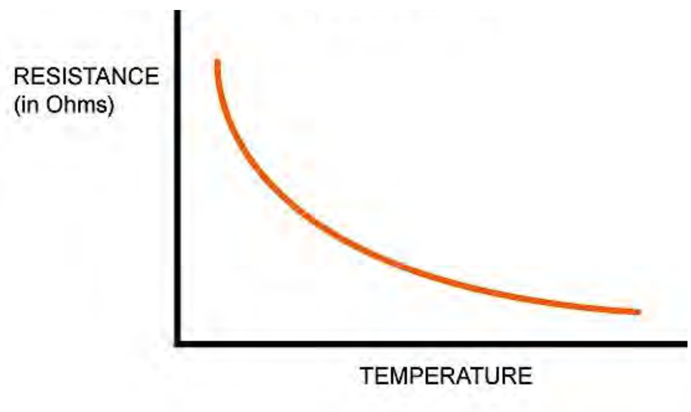
This graph would be produced by a component such as a filament lamp.

- ➔ As more current flows through the filament lamp, it begins to heat up due to increased electron collisions.
- ➔ The heat generated leads to an increased resistance through the filament lamp as particles vibrate with greater amplitude, making it harder for the free electrons to flow through the conductor.
- ➔ This leads to a decrease in current.

Thermistors

Thermistors are components whose **resistance is dependent on temperature**.

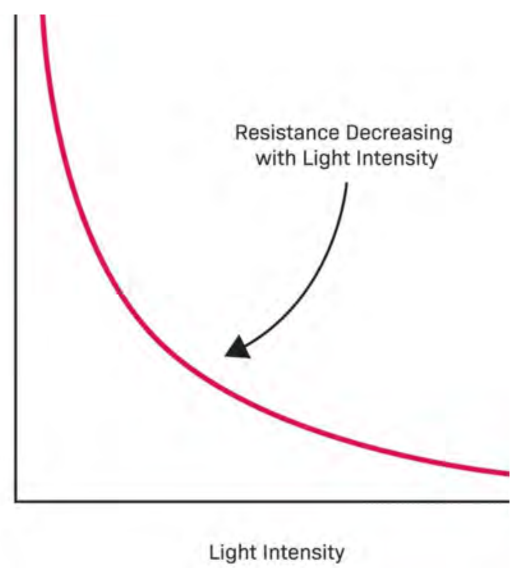
➔ For example, a negative temperature coefficient (NTC) thermistor's resistance decreases as its temperature increases.



Light dependent resistors

Light dependent resistors are components whose resistance is dependent on the light intensity incident on it.

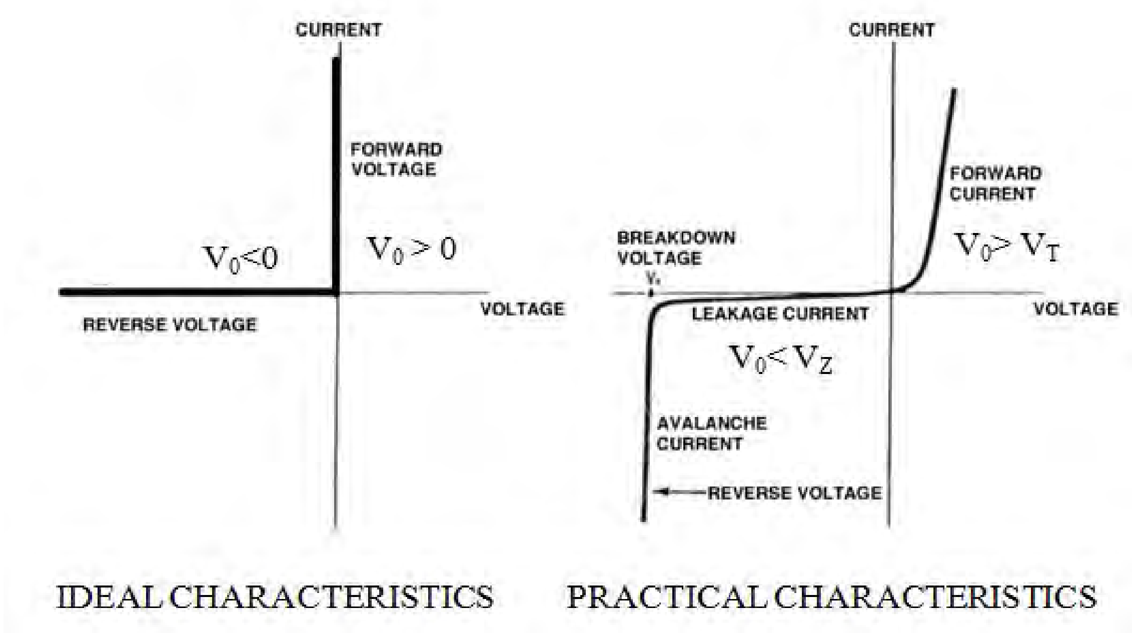
➔ The resistance of the LDR decreases as light intensity increases.



Ideal diodes

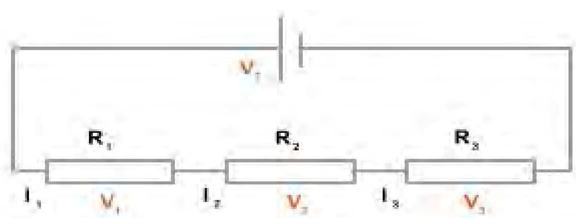
Ideal diodes are components that only allow current to flow in one direction which is shown by the arrowhead in the circuit symbol for the diode.

In reality, diodes are not perfect and usually require a **forward junction potential** before current will begin to flow through them. They also have a **breakdown voltage** in the reverse direction which will cause a negative current to flow through them.



Series and Parallel Circuits

A **series** circuit is one where each of the components are placed along one long continuous path and **current flows through every component**.



Therefore, the **current** measured at any point in the circuit or flowing through any of the components will be the same.

$$I_1 = I_2 = I_3$$

The **potential difference** that is supplied to a series circuit is equal to the sum of the potential difference across each of the components that the series circuit contains. This is because the energy carried by each coulomb of charge must be shared as it travels through each component.

$$V_T = V_1 + V_2 + V_3$$

The **resistance** of a series circuit is also equal to the resistance of all the components contained within the circuit.

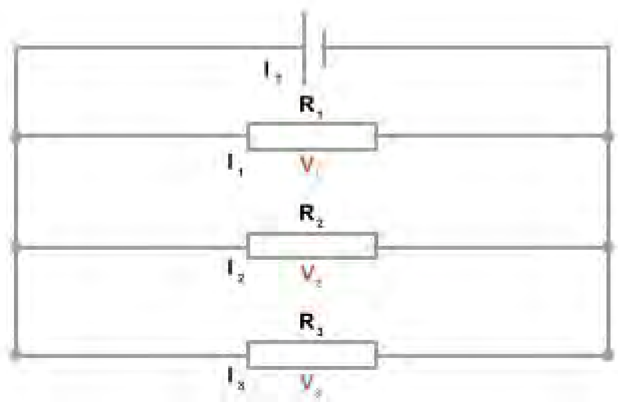
$$R_T = R_1 + R_2 + R_3$$

The voltage across the cell or battery (voltage drop) can be calculated by:

$$V_T = R_T \times I_T$$

Parallel Circuits

A **parallel** circuit is one in which the components are arranged in several 'parallel' branches. Note that components can be placed in a combination of series and parallel.



The **potential difference** across each loop in a parallel circuit. This is due to the fact that the electrons entering each loop have the same amount of energy. Therefore, the total voltage supplied by the cell is equal to the voltage across each of the loops in the parallel circuit.

$$V_T = V_1 = V_2 = V_3$$

The total **current** of the circuit is shared between branches in a ratio of the resistance of the components in each branch. Therefore, at a branch point the current will be equal to the sum of the currents going into each branch.

$$I_T = I_1 + I_2 + I_3.$$

However, current is not evenly split between the branches so I_1 is not necessarily equal to I_2.

The total resistance in a parallel is calculated by the **reciprocal law**:

$$1/R_T = 1/R_1 + 1/R_2 + 1/R_3$$

When dealing with circuits that consist of a combination of series and parallel resistors, use the reciprocal rule to calculate the total resistance of the parallel portion before adding the series resistances.

Series Circuits	Parallel Circuits
Current is constant throughout the circuit and its components	**Potential difference** is constant across each loop of the circuit
Potential difference varies across the components in the circuit	**Current** varies in each loop of the parallel circuit
Potential difference across the components can be calculated using **Ohm's law**	**Current** flowing through each loop can be calculated using **Ohm's law**

Electrical Power

Power is the rate of work done or energy transfer:

Power (W) = Energy (J) / Time (S)

The symbol for power is P and it is measured in watts (W).

The **transfer of electrical power** can be calculated by using the equation:

Power (W) = Voltage (V) x Current (I)

Substituting **V=IR** into this equation gives:

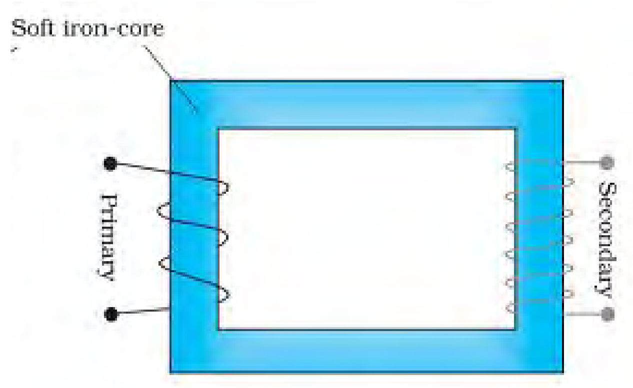
Power (W) = Current^2 x Resistance *or* **Power (W) = Voltage^2 / Resistance**

By combining two equations we then see that:

Energy (J) = Voltage (V) x Current (I) x Time (S).

Transformers

Transformers are devices that have the ability to alter voltage and current.



- **Step up transformers** are used to increase voltage and decrease current. This is useful when transferring electricity from power stations to the national grid in order to reduce energy losses.
- **Step down transformers** are then used to decrease voltage and increase current for more safe use in our homes as it reduces the risk of electric shocks.

A transformer consists of a primary coil wrapped around a core. When a current is allowed to flow through the primary coil, it creates a magnetic current which then induces a current in a secondary coil. The current and voltage can then be altered by varying the ratio of turns in the primary and secondary coils:

$$\frac{\text{Voltage in Secondary Coil}}{\text{Voltage in Primary Coil}} = \frac{\text{Turns on Secondary Coil}}{\text{Turns on Primary Coil}}$$

Whilst transformers are not 100% efficient, for the purpose of the BMAT you can assume they are unless stated otherwise. Therefore you can use the following equations:

Power(W) = Primary Voltage (V) x Primary Current (A)

Power (W) = Secondary Voltage (V) x Secondary Current (A)

Power Generation

The **generator effect** is the generation of a current by the movement of an electrical conductor relative to a magnetic field. This can also be accomplished by keeping a stationary conductor in a fluctuating magnetic field. This phenomenon is used in **generators**.

A generator consists of a **wire rotating in a magnetic field**.

- ➔ As it rotates, each side of the coil moves through the magnetic field in two different directions with each 360 degree rotation.
- ➔ As the wire is simultaneously moving in opposite directions through the magnetic field, it produces an alternating current

> **Exam Tip:** Any variable that is a rate can be found by taking the gradient of a quantity-time graph. For example, current can be calculated by taking the gradient of a charge-time graph and acceleration can be calculated by taking the gradient of a velocity-time graph etc. Take care when calculating your gradient to use a section of the graph where the line is straight (or use a tangent if the line is curved).