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5.1 Current–Voltage Characteristics

PHYSICS

AQA A Level Revision Notes

A Level Physics AQA

5.1 Current-Voltage Characteristics

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5.1.1 Basics of Electricity

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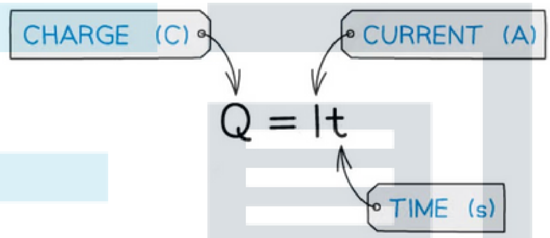
Electric Current & Potential Difference

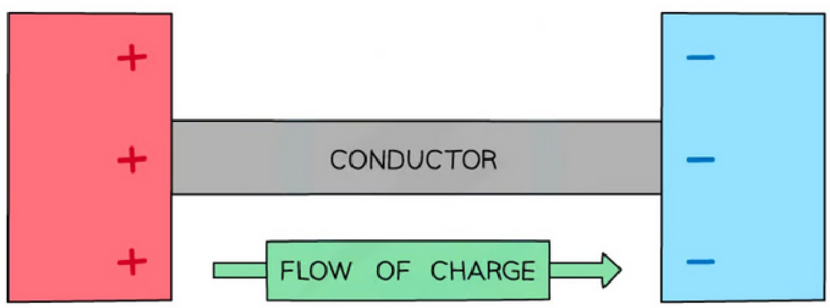
Electric Current

- Electric current is defined as **the rate of flow of positive charge** carriers
    - It is measured in units of **amperes (*A*)** or **amps**
- The charge, current and time are related by the equation:



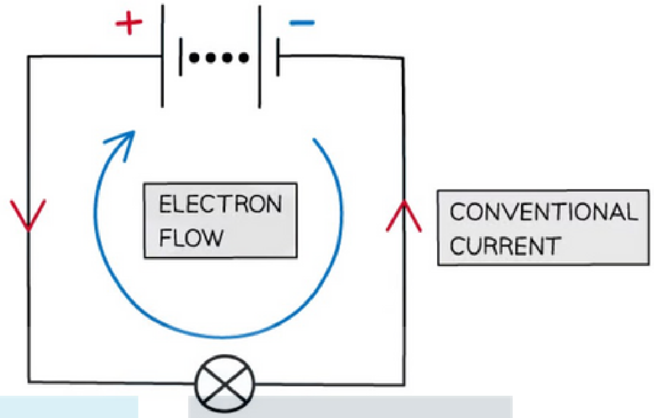
- Charge is sometimes written as ΔQ which means 'change in charge'
    - Similarly, time is written as Δ*t* means 'change in time'
- When two oppositely charged conductors are connected together (by a length of wire), charge will flow between the two conductors, causing a current
- Therefore, rearranging for current, *I* gives the equation:

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



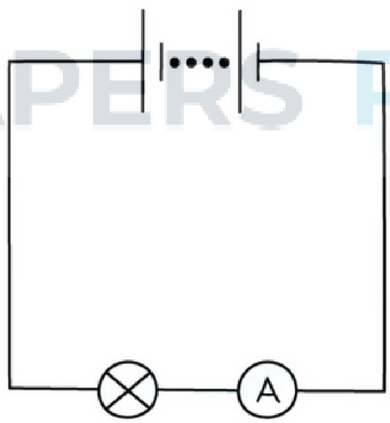
Charge can flow between two conductors. The direction of conventional current in a metal is from positive to negative

- In electrical wires, the current is a flow of **electrons**
- Electrons are negatively charged; they flow away from the negative terminal of a cell towards the positive terminal
- Conventional current is defined as the flow of **positive** charge from the **positive terminal of a cell to the negative terminal**
    - This is the opposite to the direction of electron flow, as the conventional current was described before electric current was really understood



By definition, conventional current always goes from positive to negative (even through electrons go the other way)

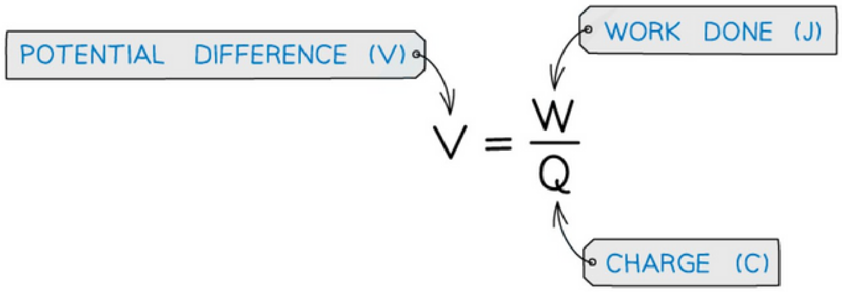
- There are several examples of electric currents, including in household wiring and electrical appliances
- Current is measured using an **ammeter**
- Ammeters should always be connected in **series** with the part of the circuit you wish to measure the current through



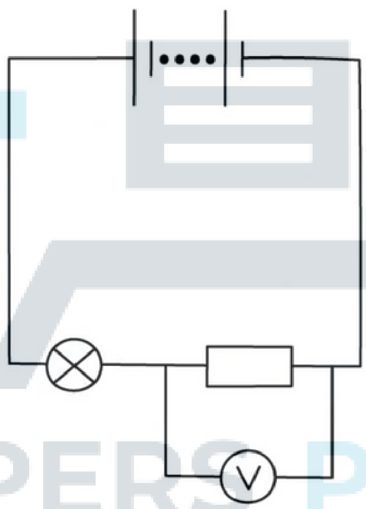
An ammeter can be used to measure the current around a circuit and is always connected in series

Potential Difference

- A cell makes one end of the circuit positive and the other negative
- This sets up a **potential difference** across the circuit
  - This is sometimes known as the **voltage**
- The potential difference is defined as **the work done per unit charge** and is measured in units of **volts (*V*)**



- Potential difference (or voltage) is measured using a **voltmeter**
- A voltmeter is always set up in parallel to the component you are measuring the voltage for



Potential difference can be measured by connecting a voltmeter in parallel between two points in a circuit

Worked Example

When will 8 mA of current pass through an electrical circuit?

A. When 1 J of energy is used by 1 C of charge

B. When a charge of 4 C passes in 500 s

C. When a charge of 8 C passes in 100 s

D. When a charge of 1 C passes in 8 s

ANSWER: B

Step 1: Write out the equation relating current, charge and time

$$Q = It$$

Step 2: Rule out any obviously incorrect options

- Option **A** does not contain charge or time, so can be ruled out

Step 3: Try the rest of the options to determine the correct answer

- Consider option **B**:

$$I = 4 / 500 = 8 \times 10^{-3} = 8 \text{ mA}$$

- Consider option **C**:

$$I = 8 / 100 = 80 \times 10^{-3} = 80 \text{ mA}$$

- Consider option **D**:

$$I = 1 / 8 = 125 \times 10^{-3} = 125 \text{ mA}$$

- Therefore, the correct answer is **B**

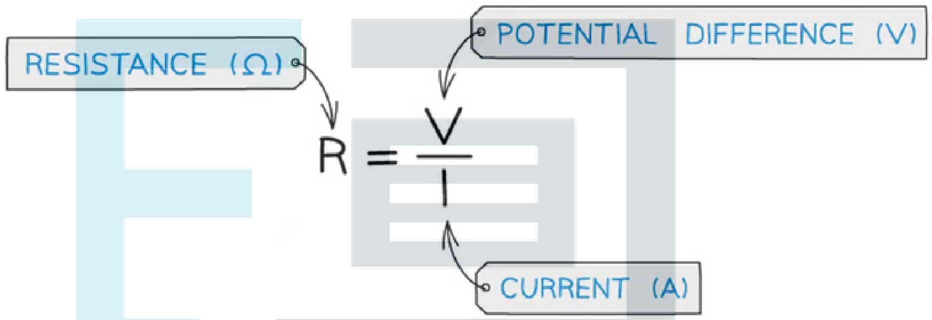
Exam Tip

Although electric charge can be positive or negative, since the conventional direction of current is the flow of **positive** charge the current should always be a positive value for your exam answers. Think of potential difference as being the **energy per coulomb** of charge transferred between two points in a circuit

Resistance

- Resistance is defined as the **opposition** to current
  - For a given potential difference: **The higher the resistance the lower the current**

- Wires are often made from copper because copper has a **low** electrical resistance. This is also known as a **good conductor**
- The resistance *R* of a conductor is defined as the ratio of the potential difference *V* across to the current *I* in it



Resistance of a component is the ratio of the potential difference and current

- Resistance is measured in **Ohms (Ω)**
- An Ohm is defined as **one volt per ampere**
- The resistance controls the size of the current in a circuit
  - A **higher** resistance means a **smaller** current
  - A **lower** resistance means a **larger** current

- All electrical components, including wires, have some value of resistance

Exam Tip

Although all electrical components have resistance, the resistance of wires is taken to be **zero** in exam questions.

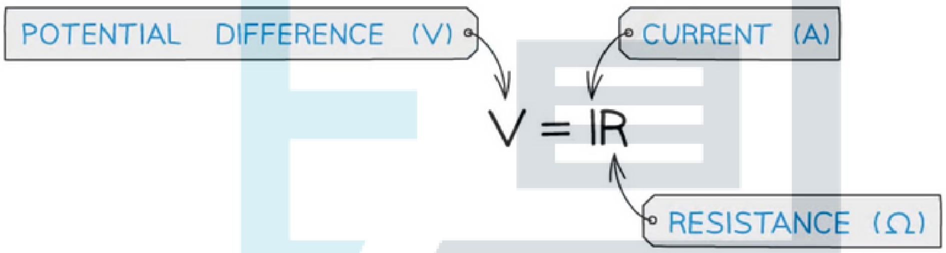
5.1.2 Current–Voltage Characteristics

Ohm's Law

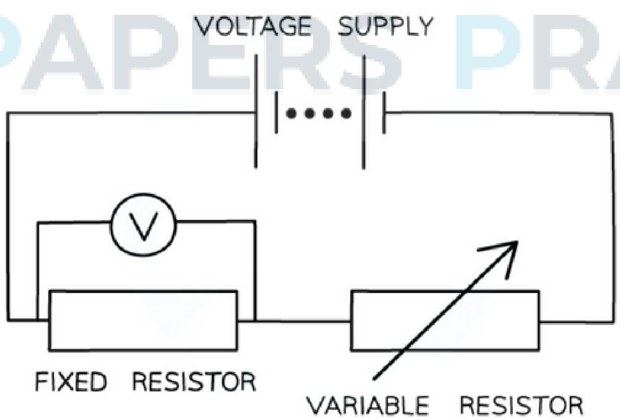
- Ohm's law states:

  For a conductor at a constant temperature, the current through it is proportional to the potential difference across it

- Constant temperature implies constant resistance
- Ohm's law is represented in the equation below:

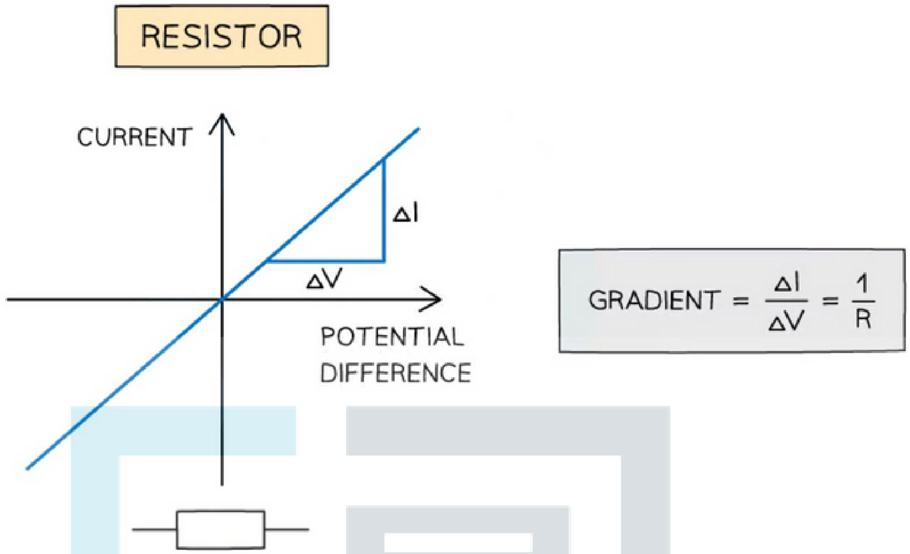


- The relation between potential difference across an electrical component (in this case, a fixed resistor) and the current can be investigated through a circuit such as the one below



Circuit for plotting graphs of current against voltage

- By adjusting the resistance on the variable resistor, the current and potential difference will vary in the circuit
- Measuring the variation of current with potential difference through the fixed resistor will produce a straight line graph, such as the one below

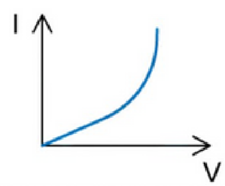


Circuit for plotting graphs of current against voltage

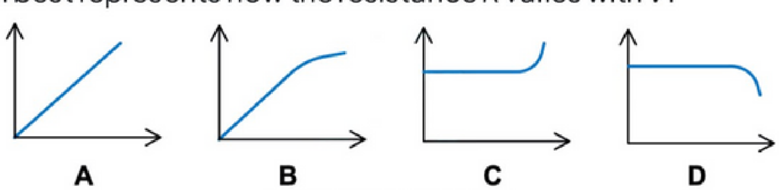
- Since the gradient is constant, the resistance *R* of the resistor can be calculated by using **1 ÷ gradient** of the graph
- An electrical component obeys Ohm's law if its graph of current against potential difference is a **straight line** through the origin
  - A resistor **does** obey Ohm's law
  - A filament lamp does **not** obey Ohm's law
- This applies to any metal wires, provided that the current isn't large enough to increase their temperature

Worked Example

The current flowing through a component varies with the potential difference *V* across it as shown.



Which graph best represents how the resistance *R* varies with *V*?



ANSWER: D

STEP 1

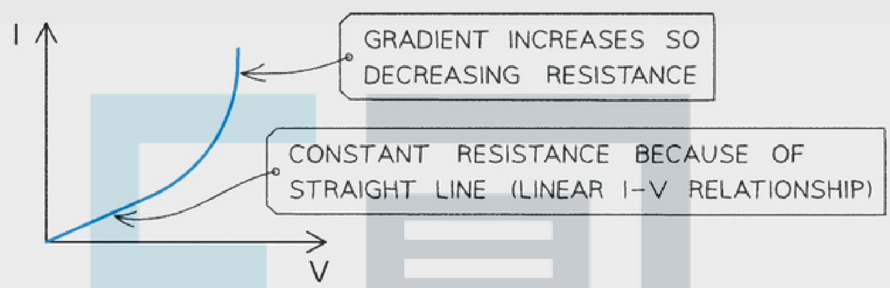
USE OHM'S LAW TO FIND R IN TERMS OF V AND I

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

STEP 2

THIS MEANS THE GRADIENT OF THE I–V GRAPH IS EQUAL TO $\frac{1}{R}$

STEP 3



STEP 4

HOW THIS RELATES TO R–V GRAPH

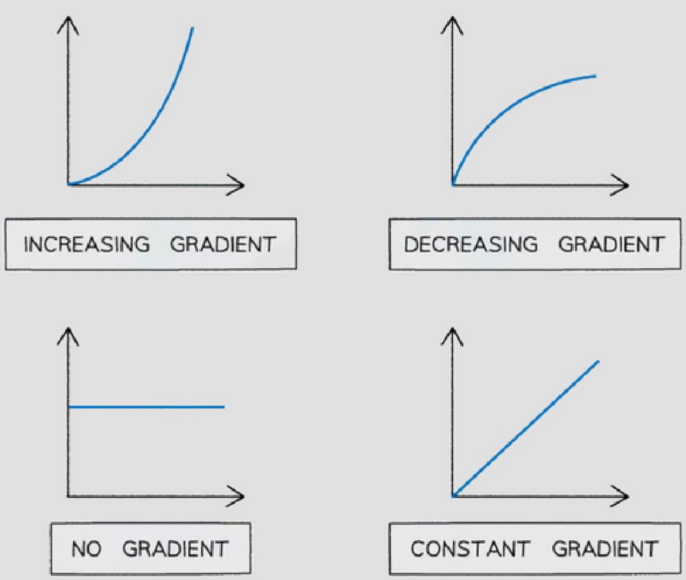
THE INITIAL LINE WILL BE HORIZONTAL SINCE RESISTANCE IS CONSTANT

THE LINE WILL THEN CURVE DOWNWARDS AS R DECREASES

OPTION D IS THE BEST DESCRIPTION OF THIS

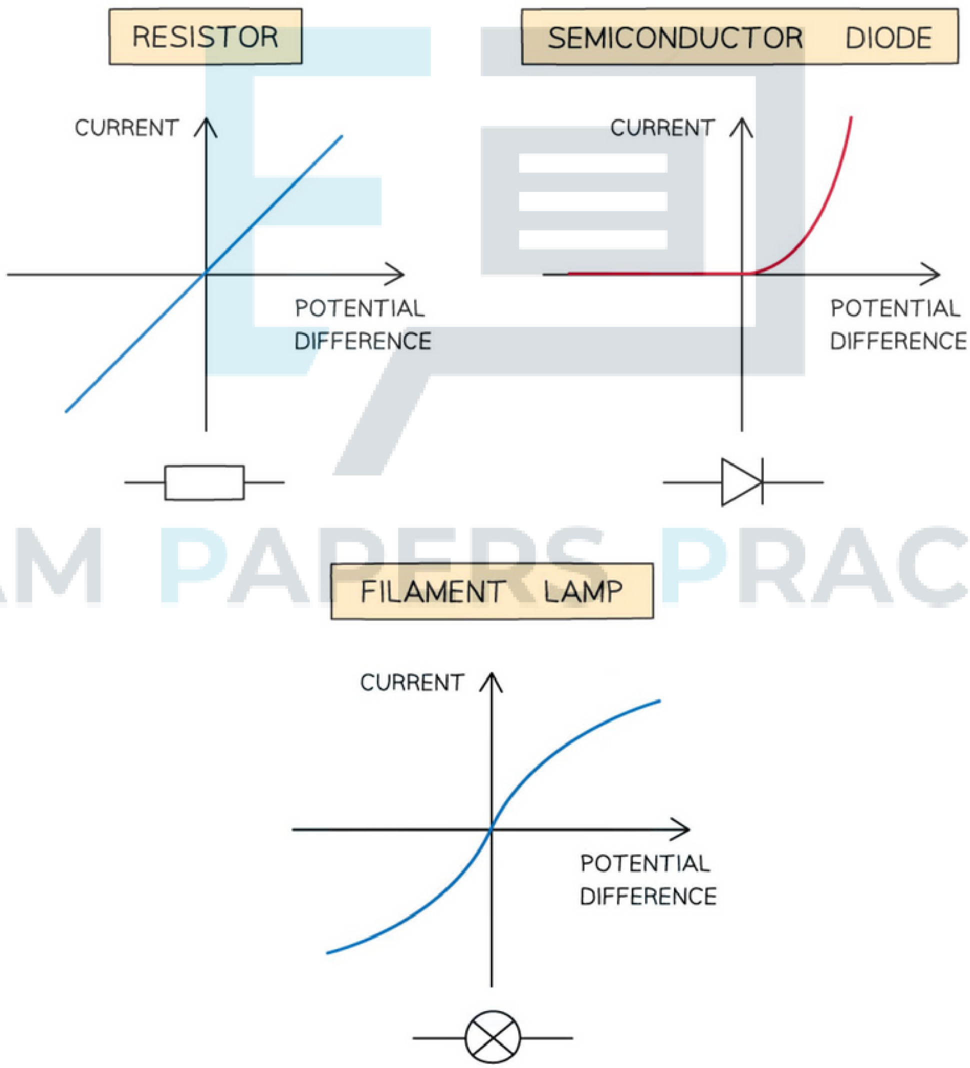
Exam Tip

- In maths, the gradient is the **slope** of the graph
- The graphs below show a summary of how the slope of the graph represents the gradient



I–V Characteristics

- As the potential difference (voltage) across a component is increased, the current also increases (by Ohm's law)
- The precise relationship between voltage and current is different for different components and can be shown on an *I*–*V* graph
  - For an ohmic conductor, the *I*–*V* graph is a straight line through the origin
  - For a semiconductor diode, the *I*–*V* graph is a horizontal line that goes sharply upwards
  - For a filament lamp, the *I*–*V* graph has an 'S' shaped curve



I–V characteristics for an ohmic conductor (e.g. resistor), semiconductor diode and filament lamp

Ohmic Conductor

- The *I*–*V* graph for an ohmic conductor at constant temperature e.g. a resistor is very simple:
  - The current is **directly proportional** to the potential difference
  - This is demonstrated by the **straight-line** graph through the origin

Semiconductor Diode

- The *I–V* graph for a semiconductor diode is slightly different. A diode is used in a circuit to allow current to flow only in a specific direction:
  - When the current is in the direction of the arrowhead symbol, this is **forward bias.** This is shown by the sharp increase in potential difference and current on the right side of the graph
  - When the diode is switched around, it does not conduct and is called **reverse bias.** This is shown by a zero reading of current or potential difference on the left side of the graph

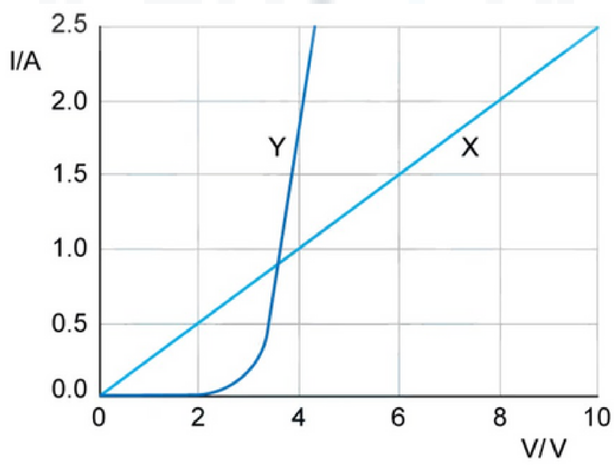
Filament Lamp

- The *I–V* graph for a filament lamp shows the current increasing at a proportionally slower rate than the potential difference
- This is because:
  - As the current increases, the **temperature** of the filament in the lamp **increases**
  - Since the filament is a metal, the higher temperature causes an **increase** in **resistance**
  - Resistance opposes the current, causing the **current** to **increase** at a **slower rate**

- Where the graph is a straight line, the resistance is constant
- The resistance increases as the graph curves
- The filament lamp obeys Ohm's Law for small voltages

Worked Example

The *I–V* characteristic of two electrical component **X** and **Y** are shown.



Which statement is correct?**A.** The resistance of **X** increases as the current increases

B. At 2 V, the resistance of **X** is half the resistance of **Y**

C. **Y** is a semiconductor diode and **X** is a resistor

D. **X** is a resistor and **Y** is a filament lamp

ANSWER: C

- The I–V graph **X** is **linear**
  - This means the graph has a constant gradient. I/V and the resistance is therefore als constant (since gradient = $1/R$)
  - This is the I–V graph for a conductor at constant temperature e.g. a resistor
- The I–V graph **Y** starts with zero gradient and then the gradient increases rapidly
  - This means it has infinite resistance at the start which then decreases rapidly
  - This is characteristic of a device that only has current in one direction e.g a semiconductor diode
- Therefore, the answer is **C**

Exam Tip

Make sure you're confident in drawing the I–V characteristics for different components, as you may be asked to sketch these from memory in exam questions