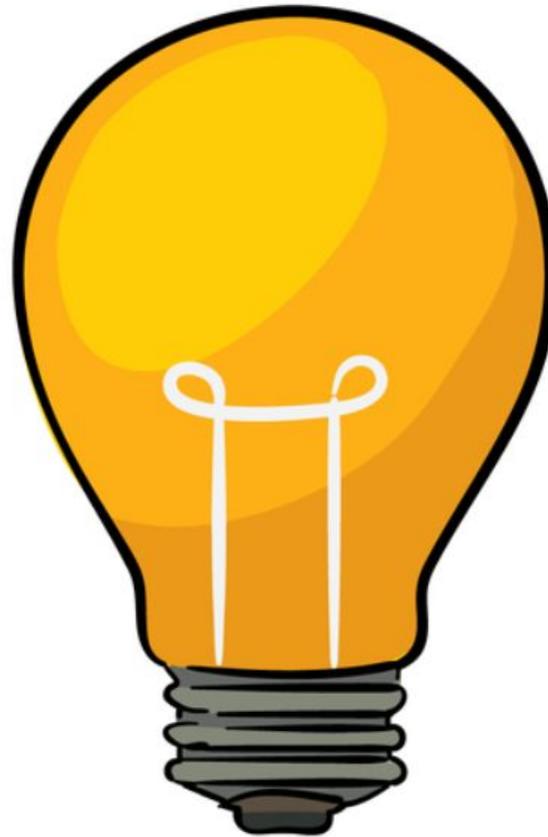


Electricity and Circuits



Material Covered

Electricity

1. Charge and Current.
2. Voltage, Energy and Power.

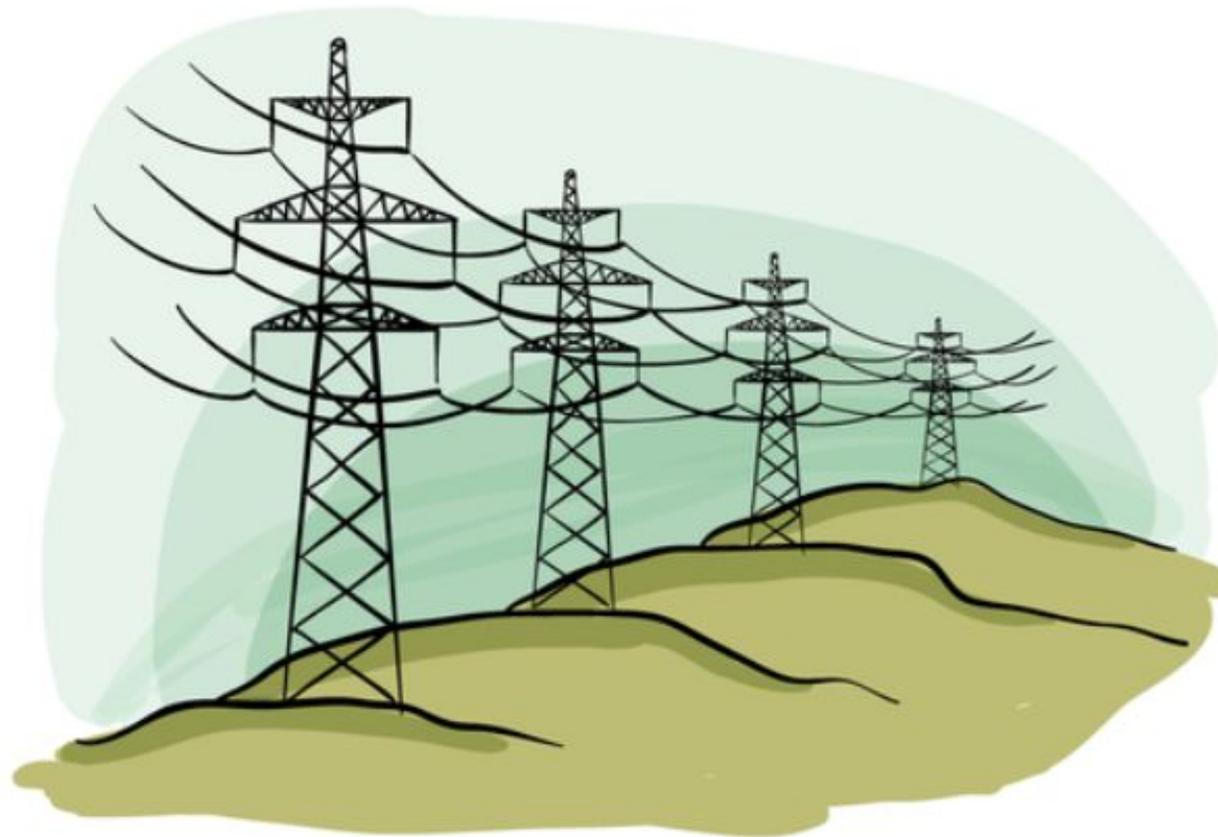
Ohm's Law and Resistivity

1. Resistance and Ohm's Law.
2. Thermistors, LDRs and Diodes.
3. Resistivity.

Circuits

1. Electromotive Force and Internal Resistance.
2. Kirchhoff's Laws.
3. Potential Dividers.

Electricity



Specification Points - AQA

3.5.1.1 Basics of electricity

Content	Opportunities for skills development
<p>Electric current as the rate of flow of charge; potential difference as work done per unit charge.</p> $I = \frac{\Delta Q}{\Delta t}, V = \frac{W}{Q}$ <p>Resistance defined as $R = \frac{V}{I}$</p>	<p>AT b, f</p> <p>Students can construct circuits from the range of components.</p>

3.5.1.4 Circuits

Content

Energy and power equations: $E = IVt$;

$$P = IV = I^2R = \frac{V^2}{R}$$

Specification Points – OCR A

4.1.1 Charge

Learning outcomes	Additional guidance
<i>Learners should be able to demonstrate and apply their knowledge and understanding of:</i>	
(a) electric current as rate of flow of charge; $I = \frac{\Delta Q}{\Delta t}$	
(b) the coulomb as the unit of charge	
(c) the elementary charge e equals 1.6×10^{-19} C	Learners will be expected to know that an electron has charge $-e$ and a proton a charge $+e$. HSW7
(d) net charge on a particle or an object is quantised and a multiple of e	
(e) current as the movement of electrons in metals and movement of ions in electrolytes	HSW7
(f) conventional current and electron flow	HSW7

4.1.2 Mean drift velocity

Learning outcomes
<i>Learners should be able to demonstrate and apply their knowledge and understanding of:</i>
(a) mean drift velocity of charge carriers
(b) $I = Anev$, where n is the number density of charge carriers

4.2.5 Power

Learning outcomes
<i>Learners should be able to demonstrate and apply their knowledge and understanding of:</i>
(a) the equations $P = VI$, $P = I^2R$ and $P = \frac{V^2}{R}$
(b) energy transfer; $W = VIt$
(c) the kilowatt-hour (kW h) as a unit of energy; calculating the cost of energy.

Specification Points – OCR B

3.1.2 Sensing

Learning outcomes

(a) *Describe and explain:*

- (i) current as the flow of charged particles
- (ii) potential difference as energy per unit charge
- (iii) resistance and conductance, including series and parallel combinations

(c) *Make calculations and estimates involving:*

$$(i) \quad R = \frac{V}{I}, \quad G = \frac{I}{V},$$

$$V = \frac{W}{Q} = \frac{P}{I},$$

$$P = IV = I^2 R,$$

$$W = VIt,$$

$$(ii) \quad I = \frac{\Delta Q}{\Delta t},$$

(b) *Make appropriate use of:*

- (i) the terms: e.m.f, potential difference, current, charge, resistance, conductance, series, parallel, internal resistance, load, resistivity, conductivity, charge carrier number density
- (ii) and recognise standard circuit symbols

Specification Points - Edexcel

31. understand that electric current is the rate of flow of charged particles and be able to use the equation $I = \frac{\Delta Q}{\Delta t}$

32. understand how to use the equation $V = \frac{W}{Q}$

36. be able to derive the equations for combining resistances in series and parallel using the principles of charge and energy conservation, and be able to use these equations

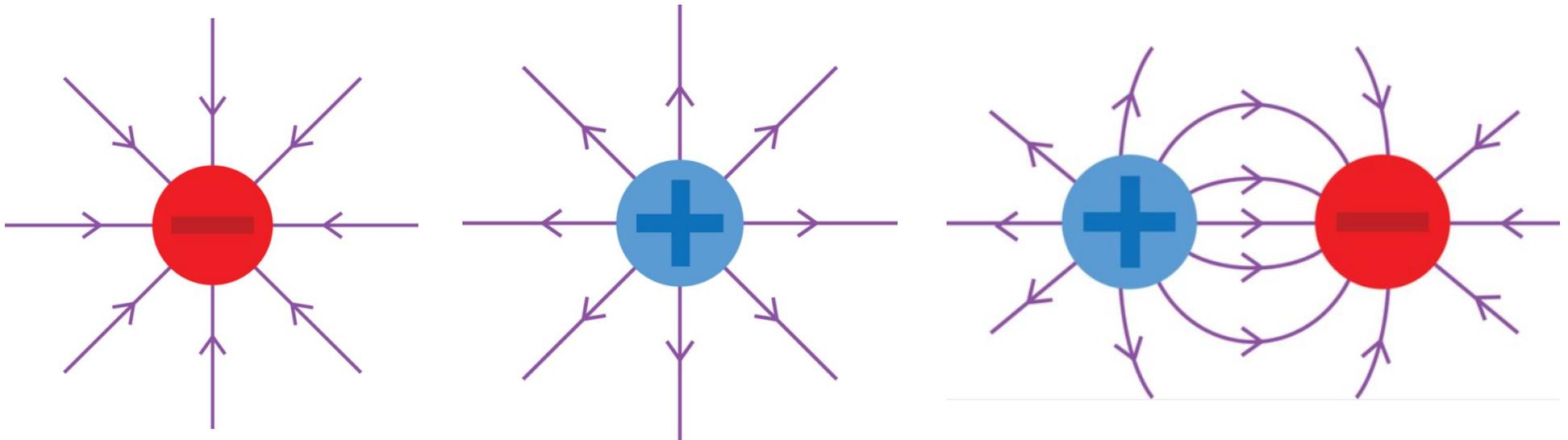
37. be able to use the equations $P = VI$, $W = VIt$ and be able to derive and use related equations, e.g. $P = I^2R$ and $P = \frac{V^2}{R}$

41. be able to use $I = nqvA$ to explain the large range of resistivities of different materials

Charge

Charge carriers are particles which possess a positive or negative electric charge.

- The **SI unit of charge** is the **Coulomb (C)**.
- **Electric fields around charges cause attraction/repulsion.**



Charge

The smallest possible **charge** is the **magnitude** of the **charge** of one **electron** (or one **proton**), known as the **elementary charge** (e).

$$e = 1.6 \times 10^{-19} \text{ C}$$

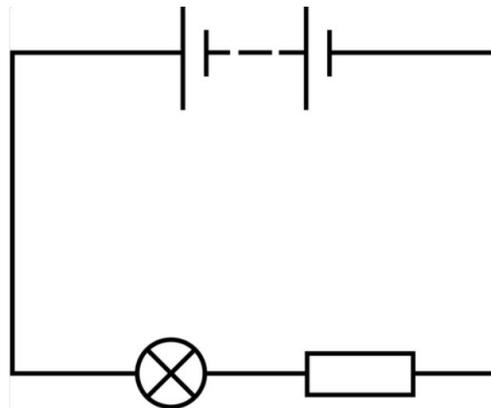
We can use the **elementary charge** to determine the **number of electrons flowing** through a **conductor**.

When **charge carriers**, such as **electrons** or **ions**, have a **net flow** in one **direction** a **current** is produced.

Current is defined as the rate of flow of electric charge.

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

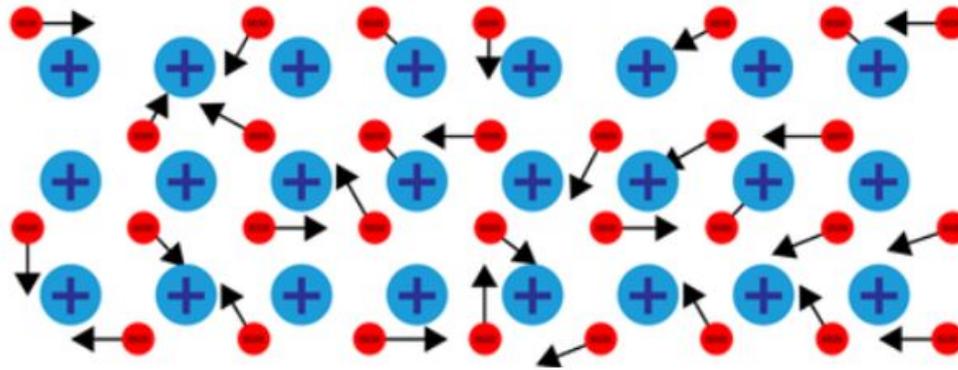
Conventional current is defined as the flow of positive charge. This is **opposite** to the **direction of flow of electrons**.



In a **circuit**, **current** flows from the **positive terminal** to the **negative terminal**.

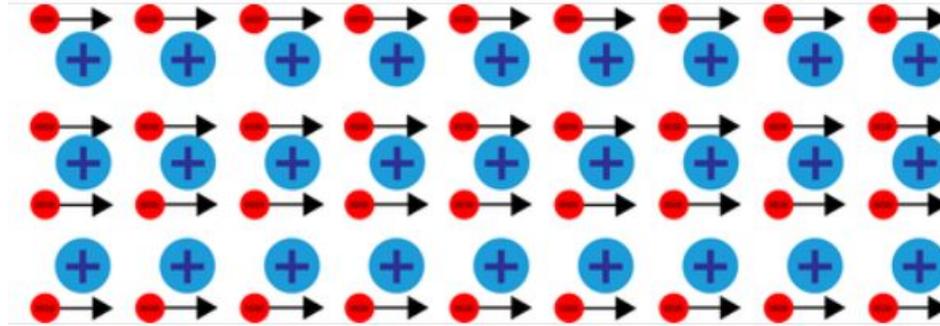
Current

In a **conductor**, the **charge** carrying **electrons** are **constantly moving** in **different directions**.



- When a **potential difference** is applied, there is a **net flow** of **electrons** towards the **positive terminal** at the **mean drift velocity** (v).

The **mean drift** of **charge carriers** creates a **current** which can be **calculated** with the **transport equation**:



$$I = nAve$$

Exemplar Explanation Exam Question

What would the **charge** of the drop **depend on**?

Context: Charge carriers.

- 1) In 1909, Robert Millikan devised an experiment to measure the negative charge gained by oil droplets which had gained electrons. He found that all the oil droplets had charges that were integer multiples of an elementary charge e . Explain this result.

[3 marks]

Explanation Question:
Bullet-point format.

Indicates that we will need to mention about **3 points**.

-
- Charge of the droplet is equal to the total charge of the gained electrons
-

[1 Mark]

-
- All electrons carry the negative elementary charge e .
-

[1 Mark]

-
- So the charge of the droplet is dependent on the number of gained electrons, n , and is equal to ne .
-

[1 Mark]

Voltage, Energy and Power

Charge carriers acquire **energy** at the **cell** or **power supply** and **do work** passing through **components**, depositing their **energy** around the **circuit**.

The **potential difference** of a **circuit** is defined as the **work done** (or **energy transferred**) per **unit charge**.

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

1 Volt is the **potential difference** across a **component** when **1 Joule** of **energy** is **transferred** to **other forms of energy** per **Coulomb** of **charge** passing through the **component**.

Voltage, Energy and Power

We can also express **energy transferred** in a **component** in terms of **current** (I) and **voltage** (V).

$$E = IV\Delta t$$

The **power rating** of a **component** (P) is equal to the **rate of work done**:

$$P = \frac{E}{\Delta t}$$

$$P = IV$$

- Using **Ohm's Law** for resistance R ($V = IR$) we can **write** this in other **forms**:

Exemplar Plot/Sketch Exam Question

Labels for axes.

Sketch/Plot Question: Asking for **graph** which demonstrates **quantitative relationship**.

- 1) Sketch the graph for the dependence of power on current for a resistor. State any assumptions you make about the nature of the resistor.

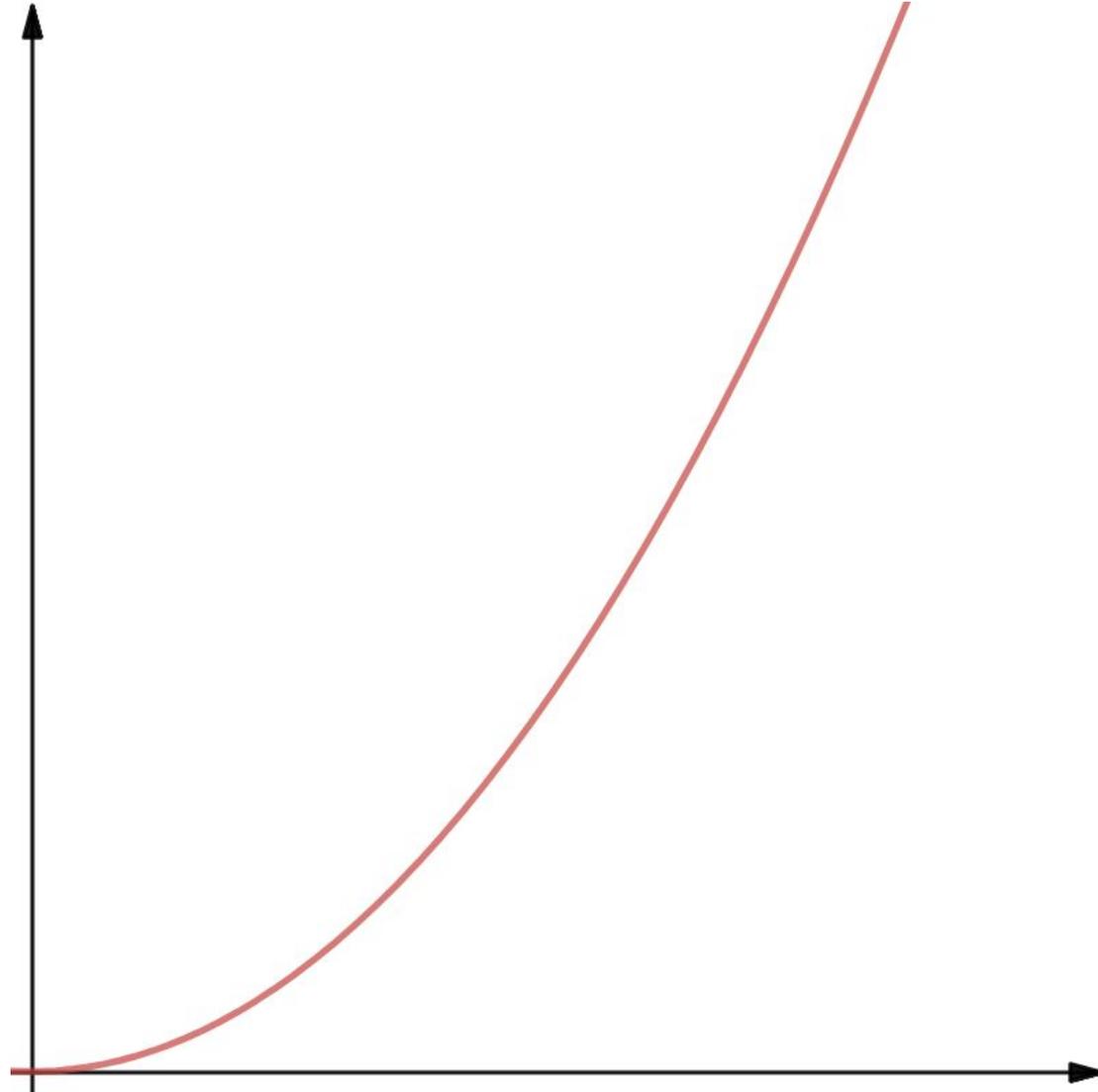
[2 marks]

Context: Power in resistors.

Recall **equation** for **power**.

1 mark for correct **sketch** and **1 mark** for **assumption**.

P



$$P = I^2 R$$

↓

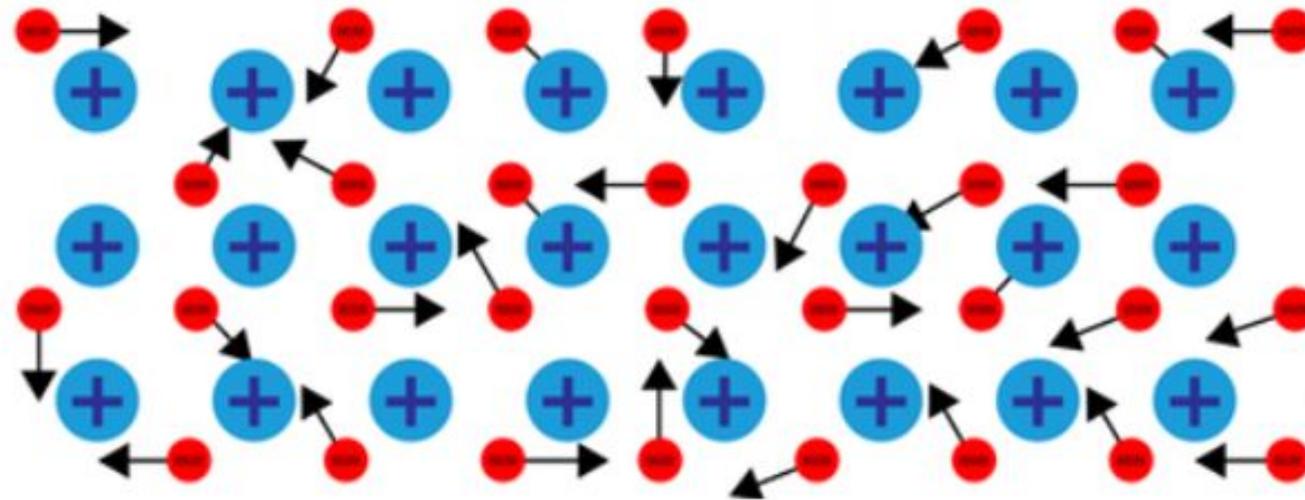
$$P \propto I^2$$

[1 Mark]

Assume resistance of resistor is constant (resistor does not heat up as current increases).

[1 Mark]

Ohm's Law and Resistivity



Specification Points - AQA

3.5.1.2 Current–voltage characteristics

Content

For an ohmic conductor, semiconductor diode, and filament lamp.

Ohm’s law as a special case where $I \propto V$ under constant physical conditions.

Unless specifically stated in questions, ammeters and voltmeters should be treated as ideal (having zero and infinite resistance respectively).

Questions can be set where either I or V is on the horizontal axis of the characteristic graph.

3.5.1.3 Resistivity

Content

Resistivity, $\rho = \frac{RA}{L}$

Description of the qualitative effect of temperature on the resistance of metal conductors and thermistors.

Only negative temperature coefficient (ntc) thermistors will be considered.

Applications of thermistors to include temperature sensors and resistance–temperature graphs.

Superconductivity as a property of certain materials which have zero resistivity at and below a critical temperature which depends on the material.

Applications of superconductors to include the production of strong magnetic fields and the reduction of energy loss in transmission of electric power.

Critical field will not be assessed.

Required practical 5: Determination of resistivity of a wire using a micrometer, ammeter and voltmeter.

Opportunities for skills development

MS 3.2, 4.3 / PS 1.2 / AT a, b, f, g

Investigation of the variation of resistance of a thermistor with temperature.

Specification Points – OCR A

4.2.3 Resistance

Learning outcomes	Additional guidance
<i>Learners should be able to demonstrate and apply their knowledge and understanding of:</i>	
(a) resistance; $R = \frac{V}{I}$; the unit ohm	Learners will also be expected to recall this equation.
(b) Ohm's law	
(c) (i) I - V characteristics of resistor, filament lamp, thermistor, diode and light-emitting diode (LED)	M3.12 HSW5, 8, 9
(ii) techniques and procedures used to investigate the electrical characteristics for a range of ohmic and non-ohmic components.	PAG3 HSW3, 4, 5 Investigating components and analysing data using spreadsheet.
(d) light-dependent resistor (LDR); variation of resistance with light intensity.	

4.2.4 Resistivity

Learning outcomes
<i>Learners should be able to demonstrate and apply their knowledge and understanding of:</i>
(a) (i) resistivity of a material; the equation $R = \frac{\rho L}{A}$
(ii) techniques and procedures used to determine the resistivity of a metal.
(b) the variation of resistivity of metals and semiconductors with temperature
(c) negative temperature coefficient (NTC) thermistor; variation of resistance with temperature.

Specification Points – OCR B

3.1.2 Sensing

Learning outcomes

(a) *Describe and explain:*

- (v) dissipation of power in electric circuits
- (vi) the relationship between potential difference and current in ohmic resistors (Ohm's law)
- (viii) simple electrical behaviour of metals, semiconductors and insulators in terms of the number density of mobile charge

(c) *Make calculations and estimates involving:*

(i) $R = \frac{V}{I}, G = \frac{I}{V},$ (iii) $R = \frac{\rho L}{A}; G = \frac{\sigma A}{L}$

(d) *Demonstrate and apply knowledge and understanding of the following practical activities (HSW4):*

- (i) investigating electrical characteristics for a range of ohmic and non-ohmic components using voltmeters and ammeters
- (ii) determining the resistivity or conductivity of a metal

(b) *Make appropriate use of:*

- (i) the terms: e.m.f, potential difference, current, charge, resistance, conductance, series, parallel, internal resistance, load, resistivity, conductivity, charge carrier number density

(ii) and recognise standard circuit symbols

by sketching and interpreting:

- (iii) graphs of current against potential difference and graphs of resistance or conductance against temperature for ohmic and non-ohmic devices or components.

Specification Points - Edexcel

33. understand that resistance is defined by $R = \frac{V}{I}$ and that Ohm's law is a special case when $I \propto V$ for constant temperature

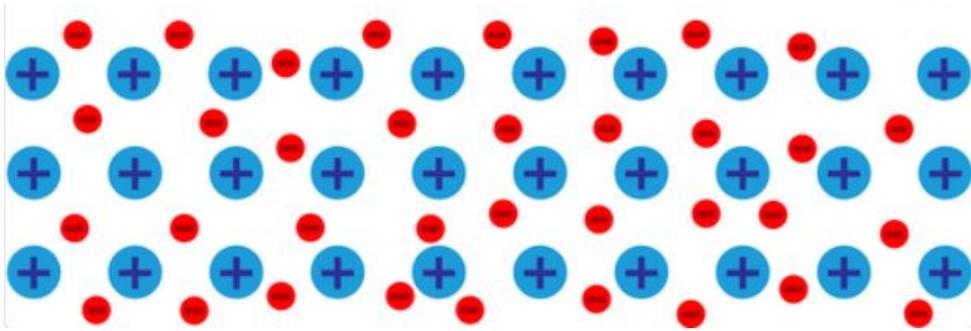
38. understand how to sketch, recognise and interpret current-potential difference graphs for components, including ohmic conductors, filament bulbs, thermistors and diodes

39. be able to use the equation $R = \frac{\rho l}{A}$

40. **CORE PRACTICAL 2: Determine the electrical resistivity of a material.**

Resistance

As **electrons** carrying **current** move through a **component**, they **collide** with the **positive ion metal lattice**. This converts **electrical work** to **heat**.



As **heat** is produced, **positive ions vibrate** more and **resistance** increases.

- **Resistance** is a **circuit component's** opposition to **electric current**.
- **Resistance** (R) is equal to the **ratio** of the **potential difference** (V) across a **component** to the **current** (I) flowing through it:
- **Resistance** is measured in **Ohms** (Ω).

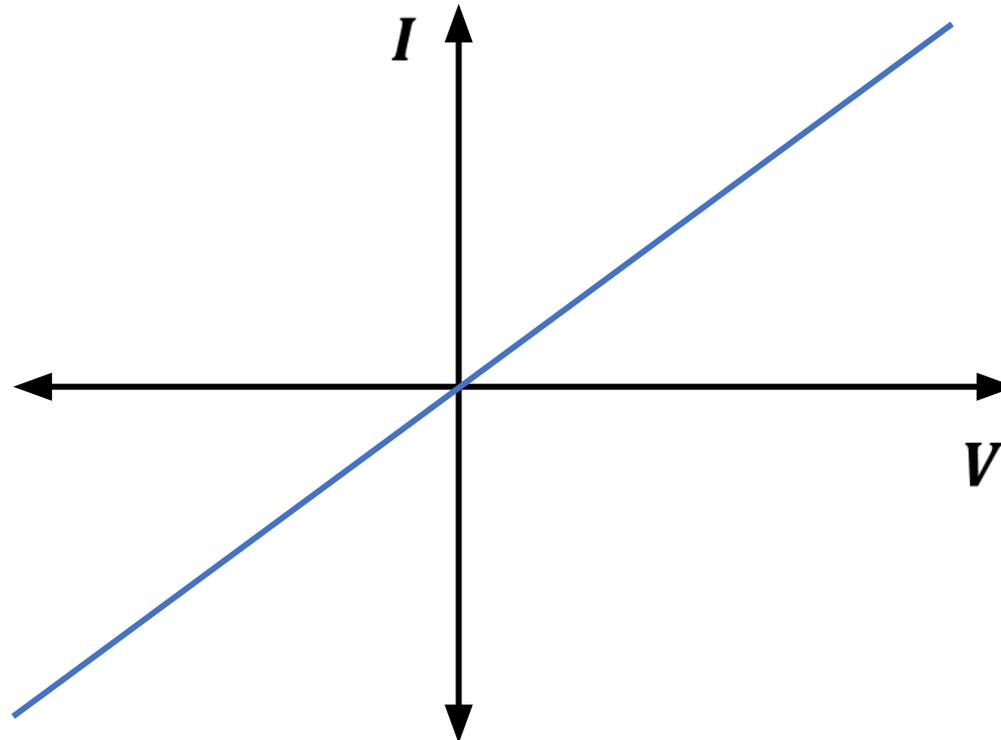
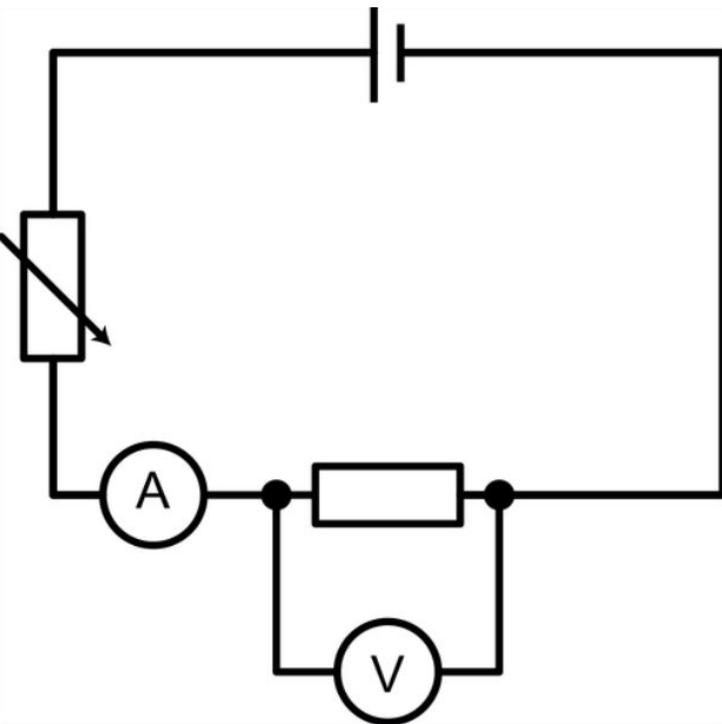
$$R = \frac{V}{I}$$

Ohm's Law

Ohm's Law states that the **potential difference** across an **Ohmic conductor** at **constant temperature** is **directly proportional** to the **current** through it.

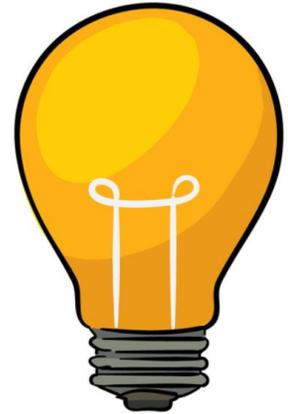
$$V = IR$$

Resistance can therefore be determined from the **gradient** of an **I - V graph** for a **component**.

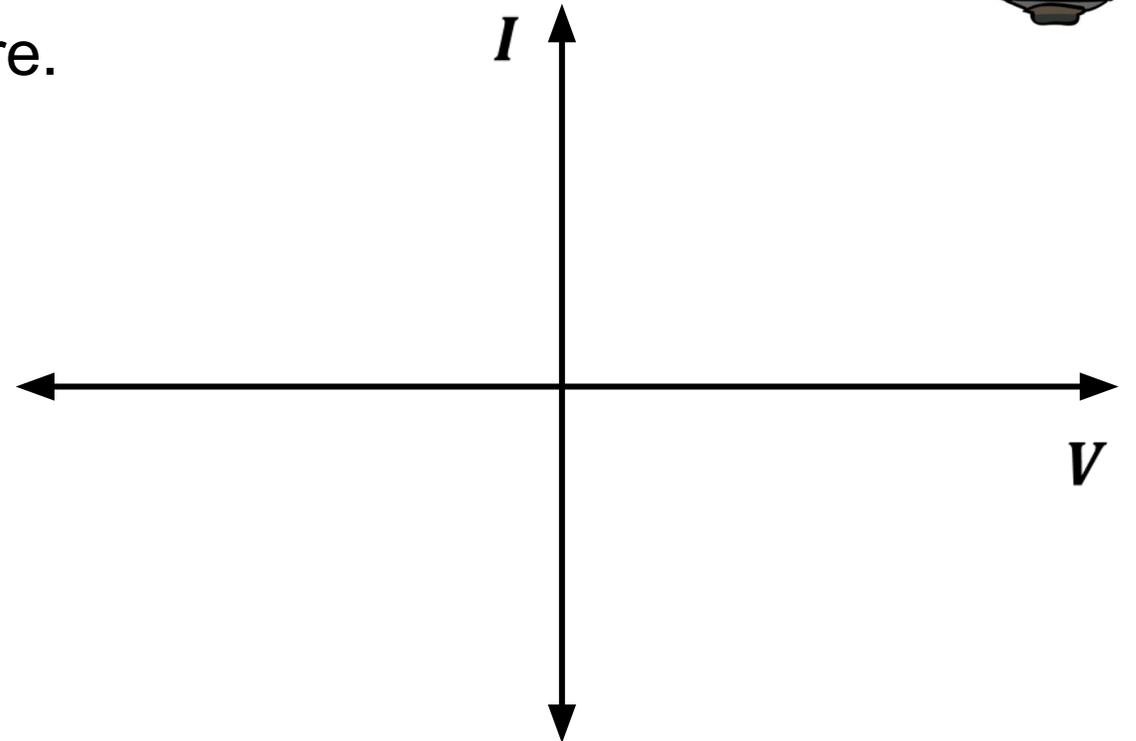


Ohm's Law

We have so far **assumed** that **temperature** and **resistance** are **constant**.



- A **bulb filament** heats up as **current** flows through it.
- This causes the **metal ions** to **vibrate** more.
- As they **vibrate** more, these **ions** obstruct the flow of **current** more.
- The **result** is that **resistance increases** as **current increases**.



Exemplar Experimental Analysis Exam Question

Experimental Analysis Question: Draw a **circuit diagram** with correct **layout** and **symbols**.

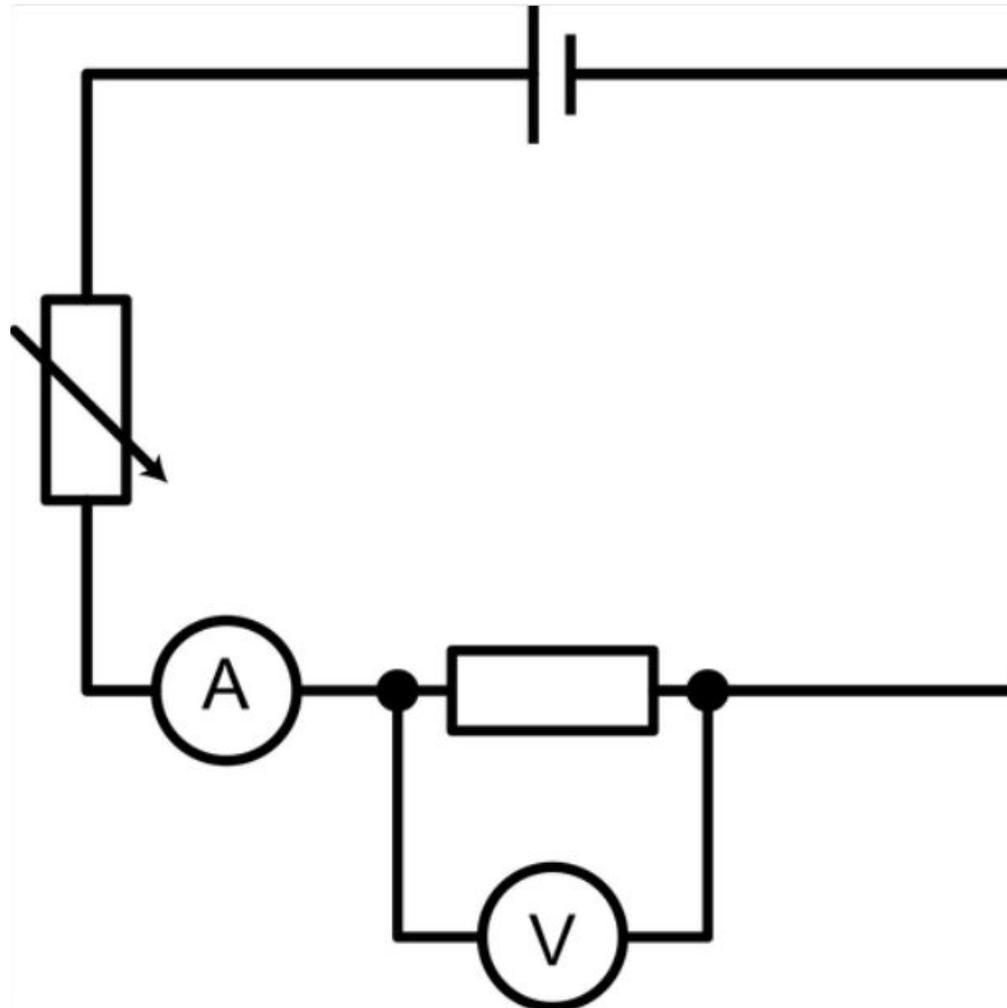
- 1) Describe a method to accurately determine the resistance of fixed resistor.

[5 marks]

Context: Determining **resistance**. Recall **Ohm's Law**.

Require mention of **accuracy**.

Marks for diagram, setup and analysis.



[2 Marks]

(For correct components and for correct layout.)

-
- Use variable resistor to adjust current and potential difference in steps and record values at each step.
-

[1 Mark]

-
- Plot an I - V graph with data and determine resistance from reciprocal of gradient.
-

[1 Mark]

-
- Voltmeter should have very high resistance to prevent current passing through it so that the ammeter will record the exact value of current. Ammeter should have very low resistance.
-

OR

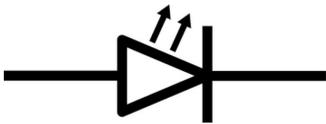
[1 Mark]

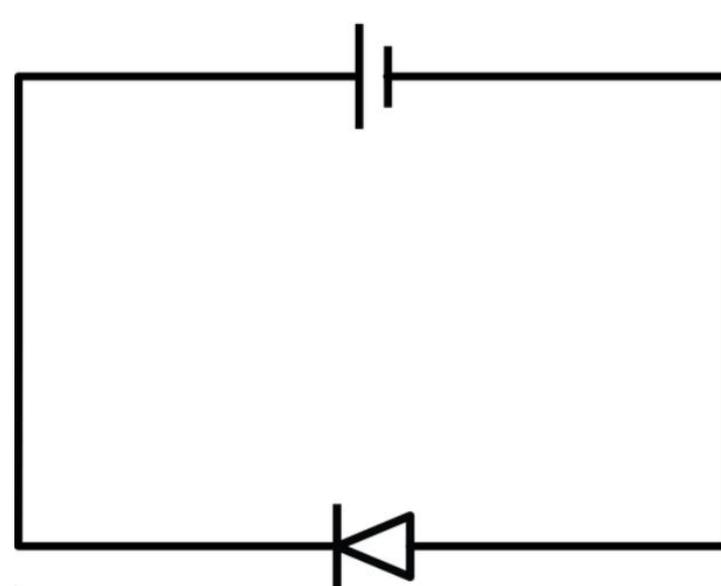
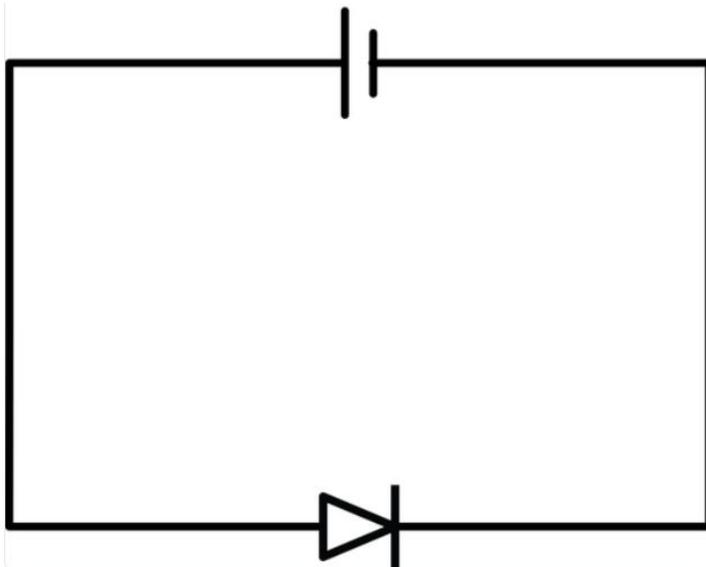
-
- Use current in range such that conductor remains Ohmic.
-

[1 Mark]

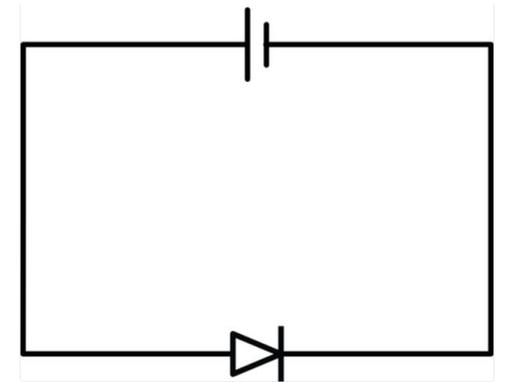
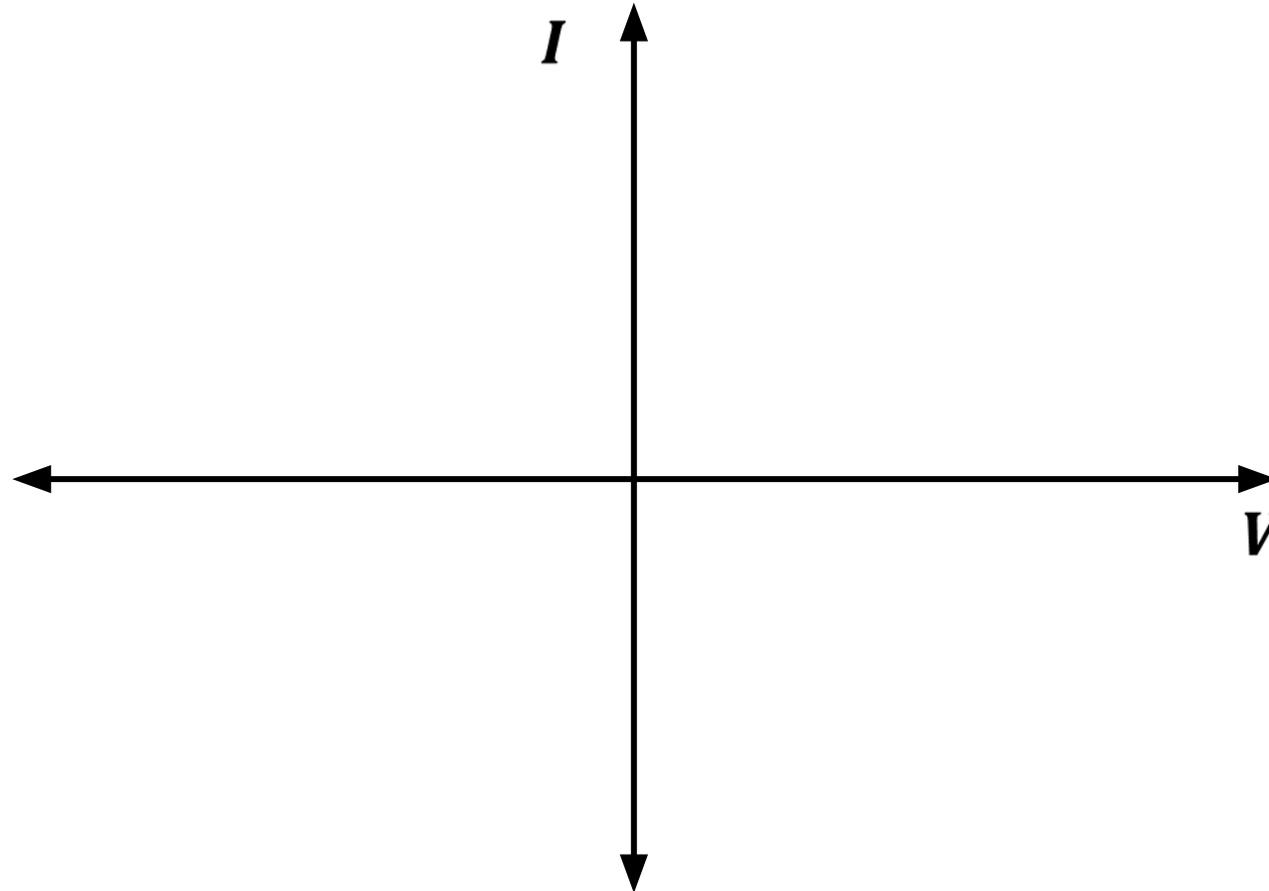
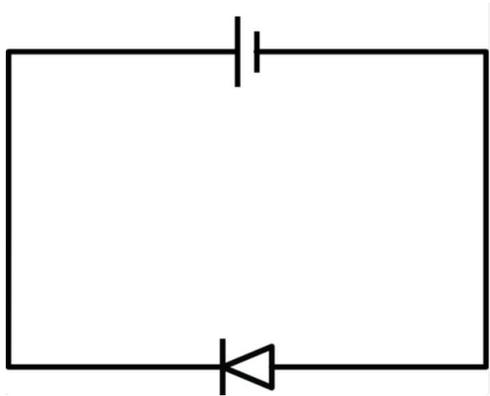
Diodes

Diodes are circuit components which have a very **high resistance** in one **direction** and a very **low resistance** in the **opposite direction**.

- **LEDs are diodes** that emit **light** with **high efficiency**: 

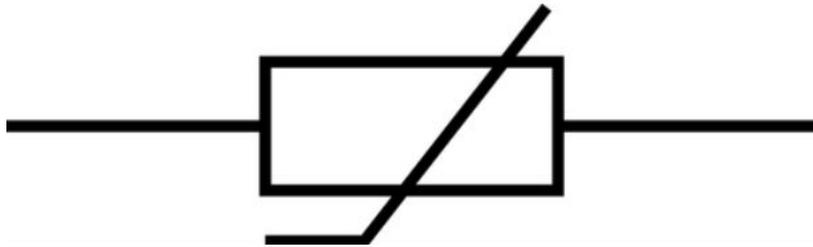


Diodes

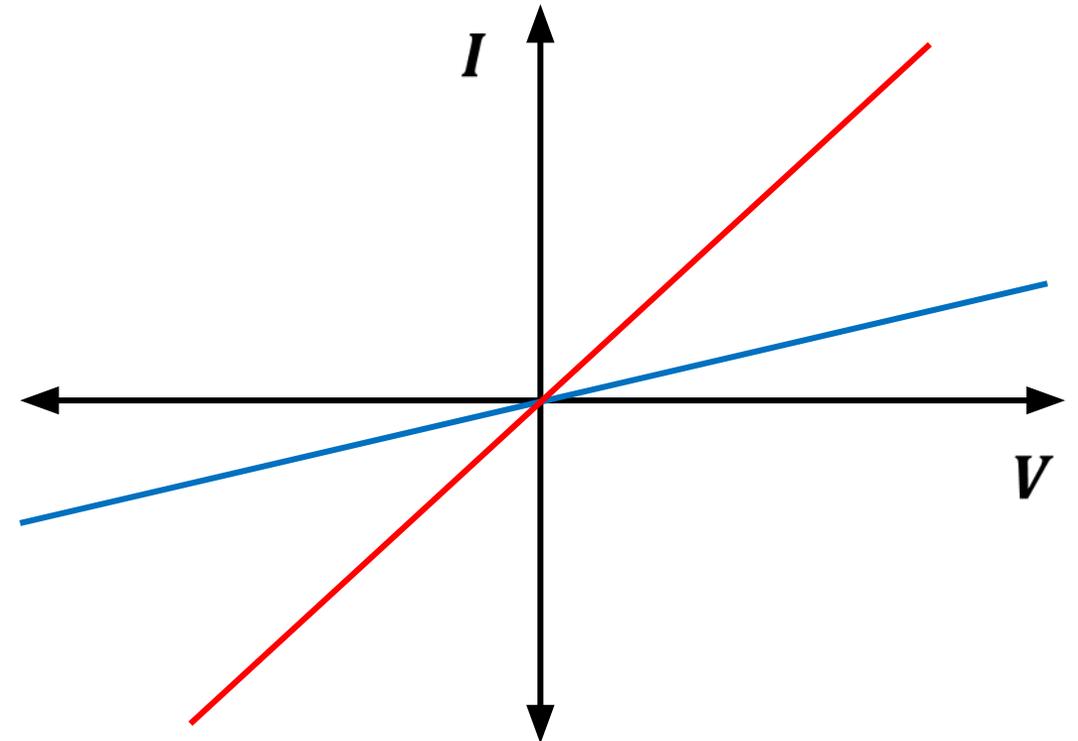


Thermistors

Thermistors are circuit components which have a resistance which decreases as their temperature increases.

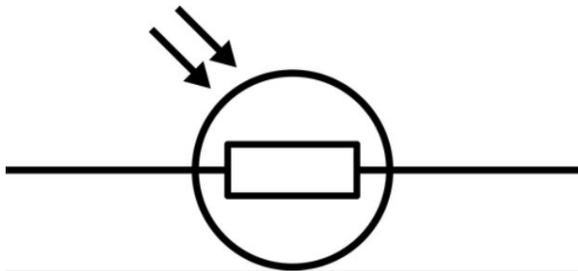


- This is due to **charge carriers** becoming **thermally activated** and **free to carry charge** across the **thermistor**.

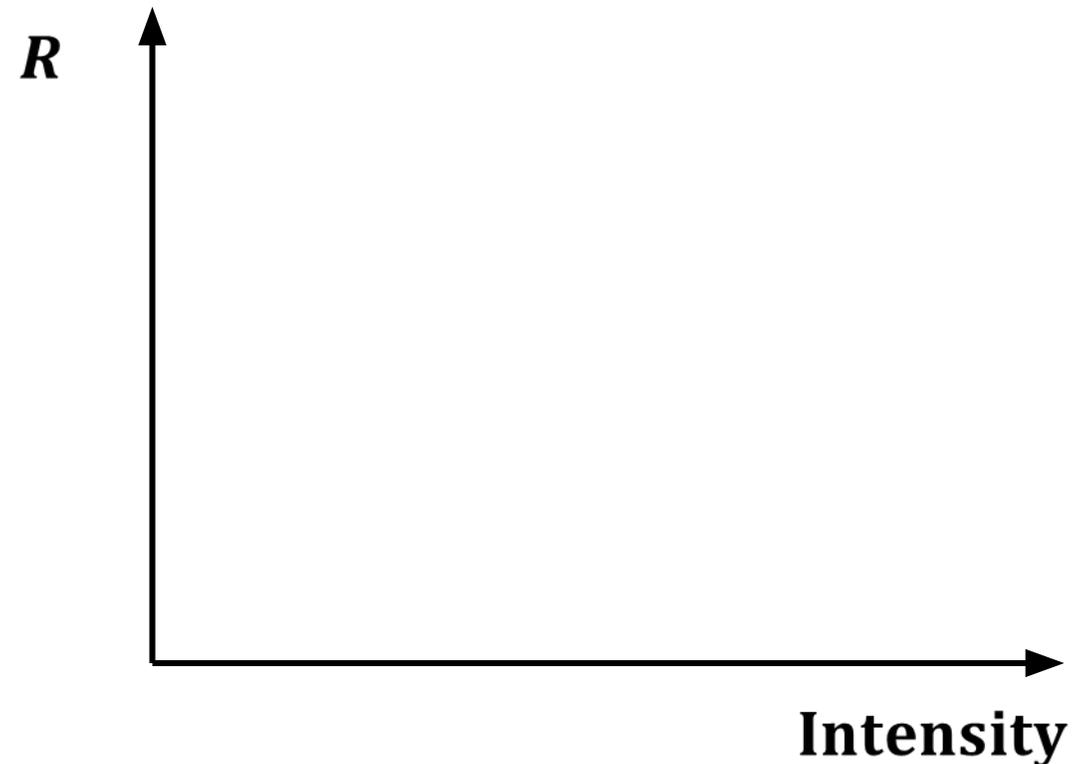


L.D.Rs

Light Dependent Resistors (LDRs) have a resistance which decreases as the light intensity upon them increases.



- This is due to **light** liberating **charge carriers** within the **LDR** allowing for a greater **flow of current** across it.
- As **potential difference** remains **constant** an increase in **current** reduces **resistance**.



Exemplar Explanation Exam Question

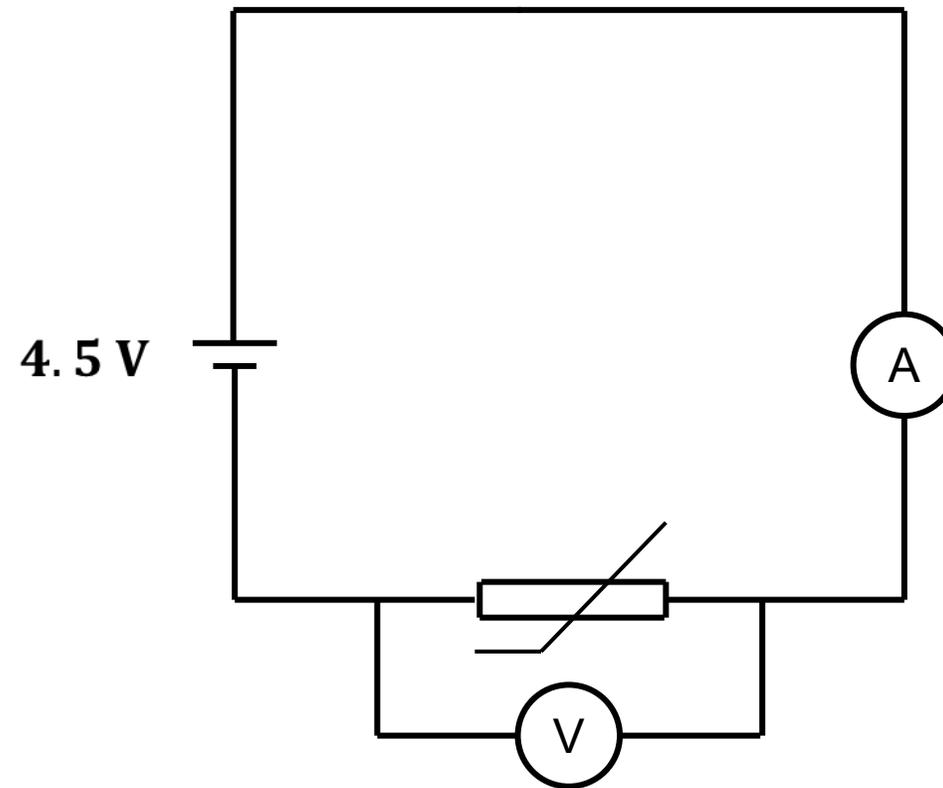
Context: Thermistors. Recall their temperature-resistance relation.

Explanation Question: Bullet-point format.

Use given diagram.

- 1) The following diagram shows a temperature-sensing circuit which is safely submerged in a waterbath so a change in temperature only affects the thermistor. It can be assumed that the voltmeter connected perpendicular to the thermistor has infinite resistance, and the ammeter connected in series with it has zero resistance. Discuss how these meters will respond to a change in temperature in the bath
[4 marks]

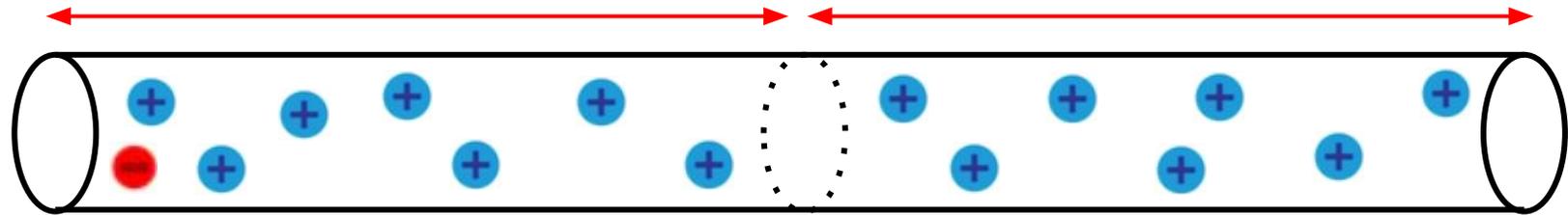
Indicates that we will need to mention about **4 points.**



- As the temperature increases, the resistance of the thermistor decreases. **[1 Mark]**
- As thermistor is the only component with resistance in the circuit, it will always have a potential difference equal to the e.m.f. **[1 Mark]**
- Therefore, the current through the thermistor increases **[1 Mark]**
- As an equal current flows through the ammeter, the reading of the ammeter increases as the temperature increases. **[1 Mark]**

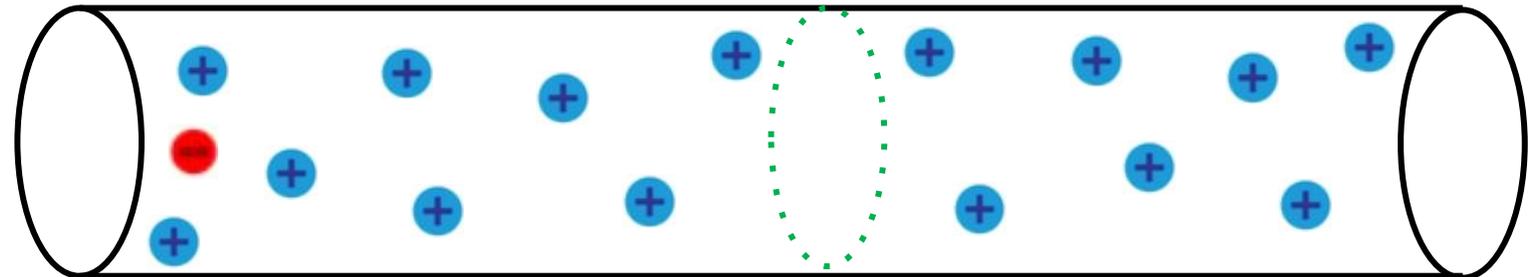
Resistivity

- The **resistance** of a **conductor** increases as the **length** (L) of the **conductor** increases.



This is due to the **charge carriers** encountering more **ions** as **obstacles** on their **path**.

- The **resistance** of a **conductor** decreases as the **cross-sectional area** (A) of the **conductor** increases.



This is due to the **charge carriers** having more possible **paths** around **ion obstacles**.

Resistivity

We can **form an equation** involving R , L and A and a **constant** of the **conducting material** - its **resistivity** ρ .

$$R = \rho \times \frac{L}{A}$$

Resistivity is the **degree** to which a **material resists** the **flow of charge carriers** through it.

- **Materials with high resistivity** are typically **insulators**.
- **Materials with low resistivity** are typically **conductors**.

Exemplar Calculation Exam Question

Key numerical values.

Calculation Question: Mathematical question – we need to show our working.

- 1) The potential difference across a cylindrical bulb filament is **15 V** and the charge flowing through it every minute is **138 C**. Determine the resistivity of the bulb filament if it has a diameter of **0.5 mm** and a length of **1.4 cm**.

[3 marks]

Context: Resistivity. Recall definition of **resistivity** from **equation**.

Exemplar Calculation Question Answer

Determine resistance of bulb

$$R = \frac{V}{I} \qquad I = \frac{Q}{\Delta t}$$

$$R = \frac{V\Delta t}{Q}$$

$$R = \frac{15 \times 60}{138}$$

$$R = 6.521 \dots \Omega$$

[1 Mark]

Exemplar Calculation Question Answer

Determine resistivity of bulb

$$R = \rho \frac{L}{A} \quad A = \pi \left(\frac{d}{2}\right)^2$$

[1 Mark]

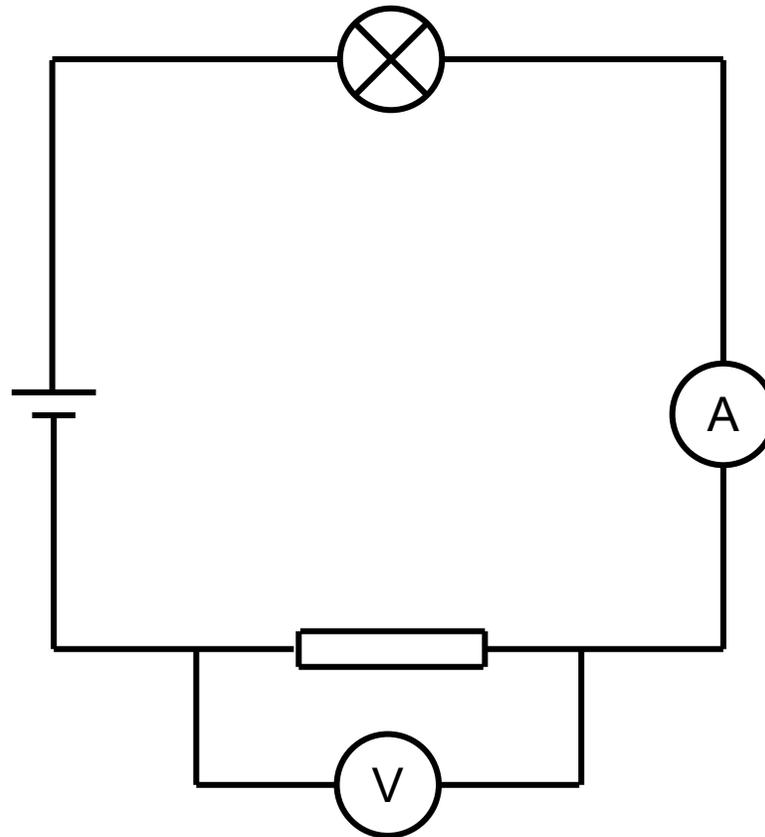
$$\rho = \frac{R\pi\left(\frac{d}{2}\right)^2}{L}$$

$$\rho = \frac{6.521\dots\pi\left(\frac{0.5\times 10^{-3}}{2}\right)^2}{0.014}$$

$$\rho = 9.15 \times 10^{-5} \Omega\text{m}$$

[1 Mark]

Circuits



Specification Points - AQA

3.5.1.5 Potential divider

Content	Opportunities for skills development
<p>The potential divider used to supply constant or variable potential difference from a power supply.</p> <p>The use of the potentiometer as a measuring instrument is not required.</p> <p>Examples should include the use of variable resistors, thermistors, and light dependent resistors (LDR) in the potential divider.</p>	<p>MS 3.2 / PS 4.1 / AT f</p> <p>Students can investigate the behaviour of a potential divider circuit.</p> <p>MS 3.2 / AT g</p> <p>Students should design and construct potential divider circuits to achieve various outcomes.</p>
<p>Conservation of charge and conservation of energy in dc circuits.</p>	

3.5.1.6 Electromotive force and internal resistance

Content
<p>$\varepsilon = \frac{E}{Q}$, $\varepsilon = I(R + r)$</p> <p>Terminal pd; emf</p> <p>Students will be expected to understand and perform calculations for circuits in which the internal resistance of the supply is not negligible.</p>
<p>Required practical 6: Investigation of the emf and internal resistance of electric cells and batteries by measuring the variation of the terminal pd of the cell with current in it.</p>

Specification Points – OCR A

4.3.1 Series and parallel circuits

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

- (a) Kirchhoff's second law; the conservation of energy
- (b) Kirchhoff's first and second laws applied to electrical circuits

4.3.3 Potential dividers

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

- (a) potential divider circuit with components
- (b) potential divider circuits with variable components e.g. LDR and thermistor
- (c)
 - (i) potential divider equations e.g. $V_{\text{out}} = \frac{R_2}{R_1 + R_2} \times V_{\text{in}}$ and $\frac{V_1}{V_2} = \frac{R_1}{R_2}$
 - (ii) techniques and procedures used to investigate potential divider circuits which may include a sensor such as a thermistor or an LDR.

Additional guidance

Learners will also be expected to know about a potentiometer as a potential divider.

M2.3

PAG4

HSW4 Designing temperature and light sensing circuits.

4.3.2 Internal resistance

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

- (a) source of e.m.f.; internal resistance
- (b) terminal p.d.; 'lost volts'
- (c)
 - (i) the equations $\mathcal{E} = I(R + r)$ and $\mathcal{E} = V + Ir$
 - (ii) techniques and procedures used to determine the internal resistance of a chemical cell or other source of e.m.f.

Additional guidance

HSW9, 12

HSW5, 6

PAG4

HSW4, HSW8 Investigating the internal resistance of a power supply.

Specification Points – OCR B

3.1.2 Sensing

Learning outcomes

(a) Describe and explain:

- (iv) the effect of internal resistance and the meaning of e.m.f.
- (vii) the action of a potential divider
- (ix) conservation of charge and energy.

(c) Make calculations and estimates involving:

$$(i) \quad R = \frac{V}{I}, G = \frac{I}{V},$$

$$V = \frac{W}{Q} = \frac{P}{I},$$

$$P = IV = I^2 R,$$

$$W = VIt,$$

$$V = \mathcal{E} - Ir_{\text{internal}}$$

$$(ii) \quad I = \frac{\Delta Q}{\Delta t},$$

$$\frac{1}{G} = \frac{1}{G_1} + \frac{1}{G_2} + \dots \quad G = G_1 + G_2 + \dots$$

$$R = R_1 + R_2 + \dots \quad \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$$

$$(iii) \quad R = \frac{\rho L}{A}; G = \frac{\sigma A}{L}$$

(iv) simple cases of a potential divider in a circuit using:

$$V_{\text{out}} = \frac{R_2}{R_1 + R_2} \times V_{\text{in}} \quad \text{and} \quad \frac{V_1}{V_2} = \frac{R_1}{R_2}.$$

(b) Make appropriate use of:

(i) the terms: e.m.f, potential difference, current, charge, resistance, conductance, series, parallel, internal resistance, load, resistivity, conductivity, charge carrier number density

(ii) and recognise standard circuit symbols

(d) Demonstrate and apply knowledge and understanding of the following practical activities (HSW4):

(iii) use of potential divider circuits, which may include sensors such as thermistor, LDR

(v) determining the internal resistance of a chemical cell or other source of e.m.f.

Specification Points - Edexcel

34. understand how the distribution of current in a circuit is a consequence of charge conservation

35. understand how the distribution of potential differences in a circuit is a consequence of energy conservation

43. understand the principles of a potential divider circuit and understand how to calculate potential differences and resistances in such a circuit

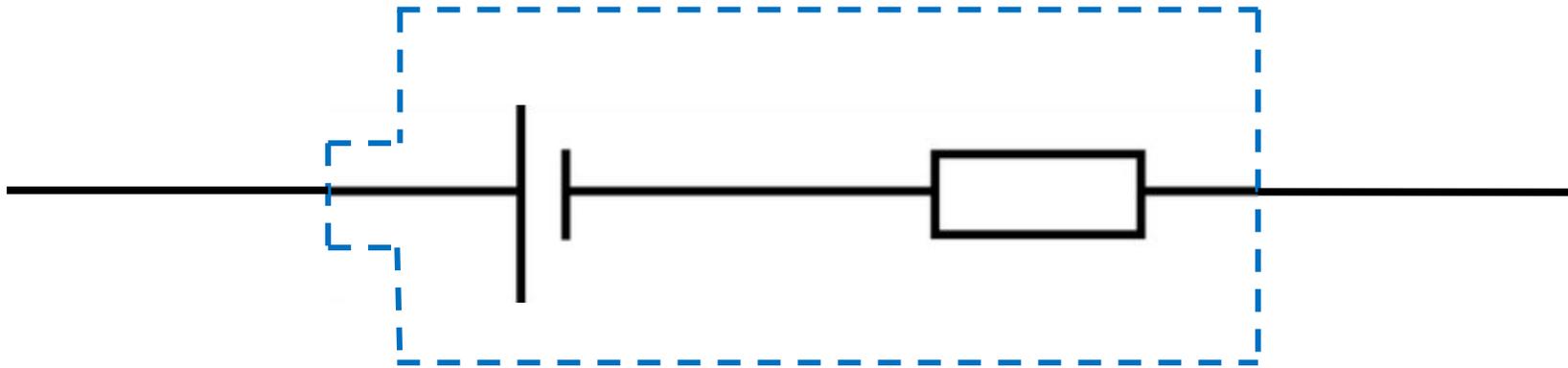
44. be able to analyse potential divider circuits where one resistance is variable including thermistors and light dependent resistors (LDRs)

45. know the definition of *electromotive force (e.m.f.)* and understand what is meant by *internal resistance* and know how to distinguish between e.m.f. and *terminal potential difference*

46. **CORE PRACTICAL 3: Determine the e.m.f. and internal resistance of an electrical cell.**

Electromotive Force and Internal Resistance

Cells and power supplies cannot always be assumed to have **zero resistance**. The **resistance** of these **sources** is known as **internal resistance**.



- The **internal resistance** (r) of a **source** is the loss of **potential difference** per **unit current** in the **source** when **current** passes through the **source**.

Electromotive Force and Internal Resistance

Sources provide the **charge carriers** with **electrical energy** (E) which is **expended** in **components** around the **circuit**.

- The **electromotive force** (emf, ε) of a **source** is the **electrical energy** per **unit charge** provided by the **source**.

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

$$\varepsilon = V + Ir$$

- **Increasing** the **current** through a **source** **increases** the **volts lost** in the internal resistance ($= Ir$) and **decreases** the **terminal p.d** (V).

Exemplar Experimental Analysis Exam Question

Require **details** of measurements.

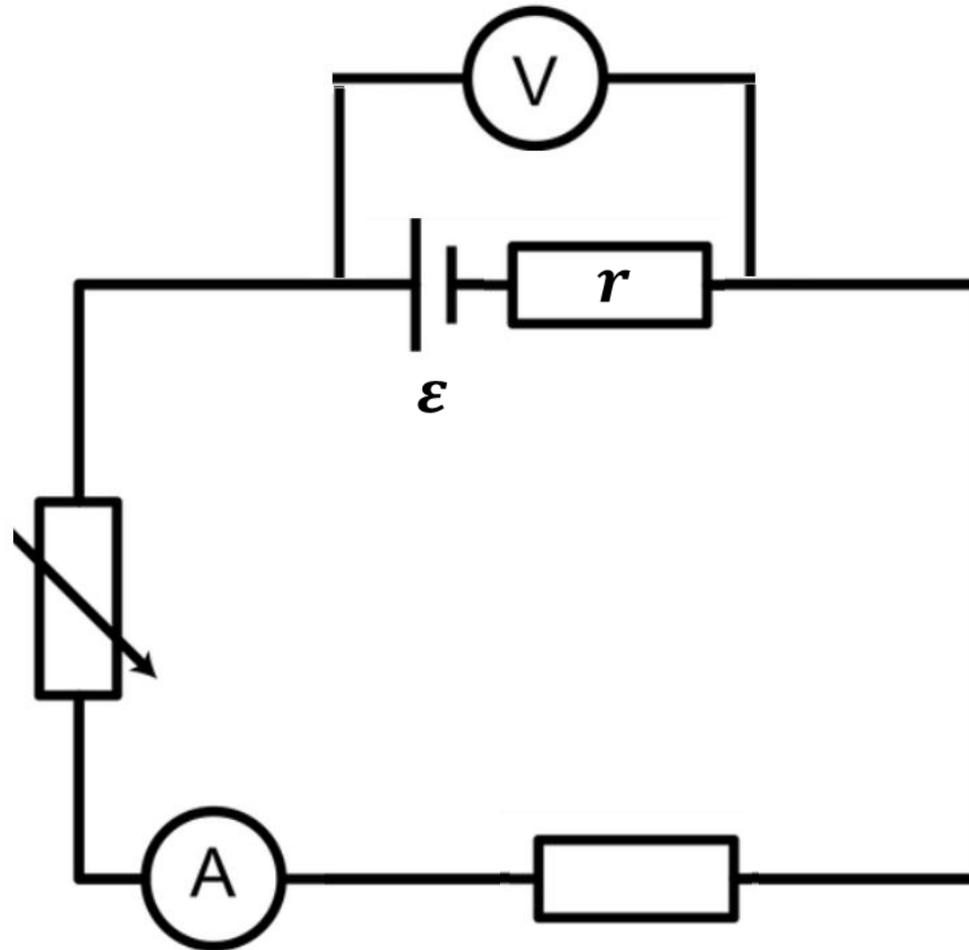
Context: Emf and internal resistance.
Recall **definitions** and **equations**.

- 1) Determine a method to measure the emf and internal resistance of a circuit by taking measurements with a voltmeter and ammeter. Construct a circuit diagram to show the setup used.
marks]

[4

Experimental Analysis Question: Draw a **circuit diagram** with correct **layout** and **symbols**.

Marks for diagram, setup and analysis.



[2 Marks]

(For correct components and for correct layout.)

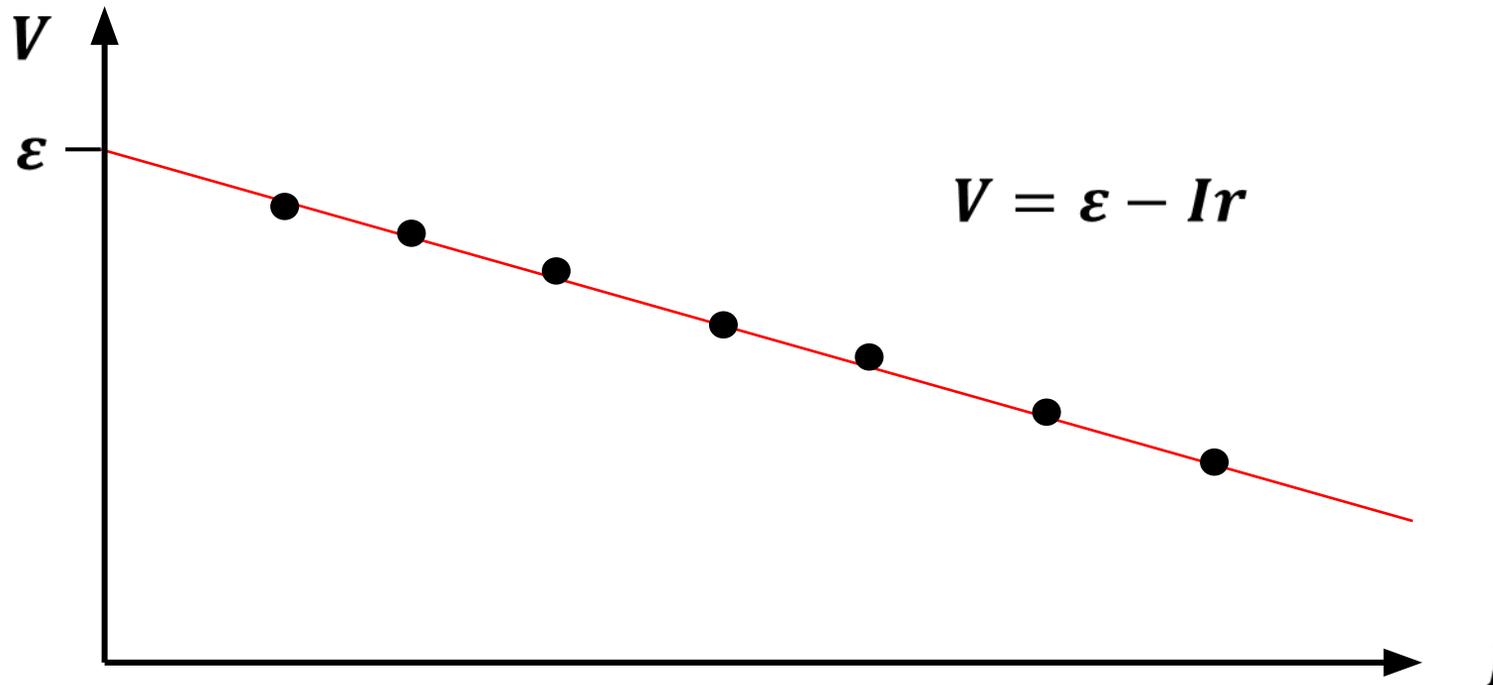
- Adjust current by varying the variable resistance. Fixed resistor limits maximum current passing through cell.

- Ammeter measures cell current and voltmeter measures terminal p.d.

[1 Mark]

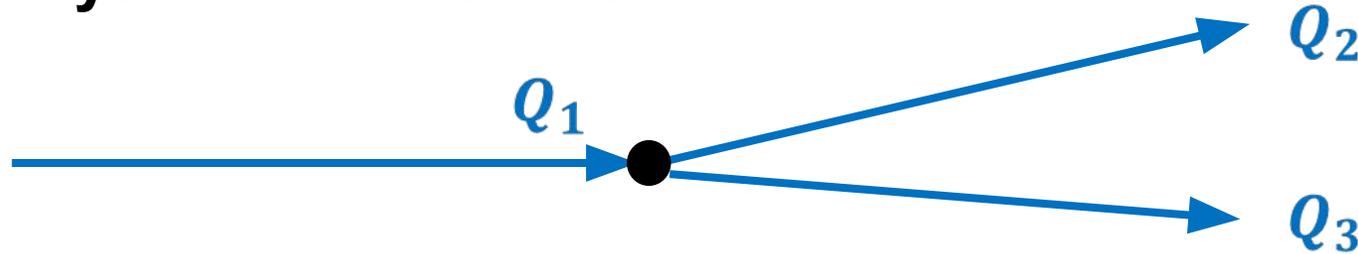
- Plot I - V graph and draw straight line of best fit with negative gradient. (Compare $y = mx + c$ to equation $V = \varepsilon - Ir$.)

-
- Gradient of graph is equal to $-r$. Intercept with V -axis gives ε (terminal p.d is equal to emf at zero current). **[1 Mark]**
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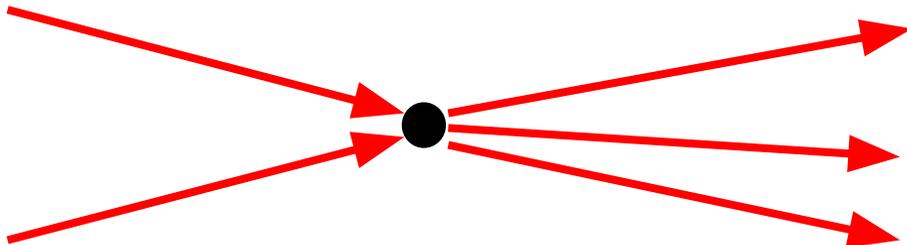


Kirchhoff's Laws

The **principle of conservation of charge** states that the **total charge** in an **isolated system** is **constant**.

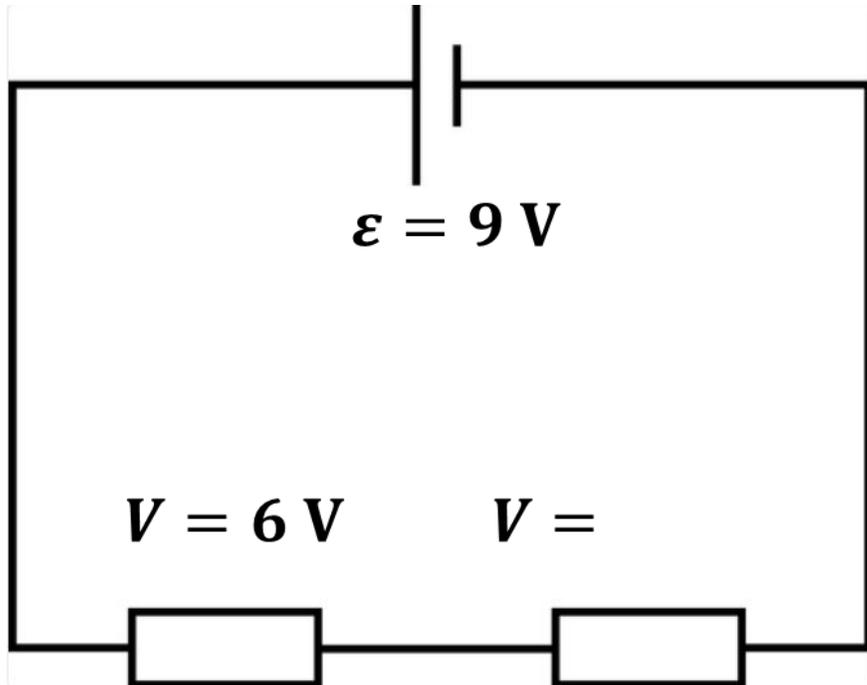


Kirchhoff's First Law states that for any **point** in an **electrical circuit** the **sum** of the **current flowing in** is **equal** to the **sum of current flowing out**.

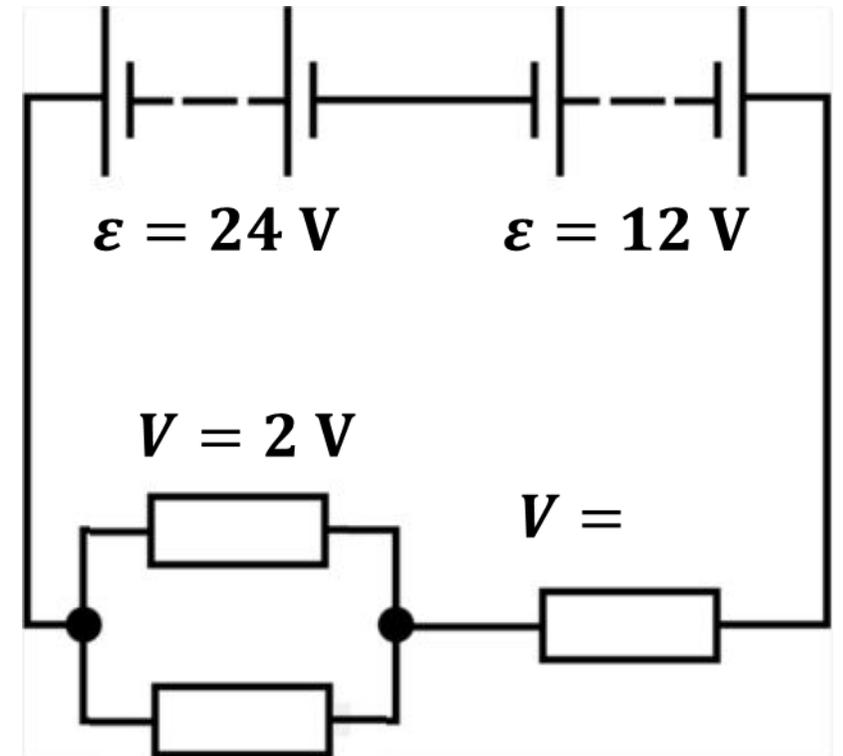


$$\sum I_{\text{IN}} = \sum I_{\text{OUT}}$$

Kirchhoff's Second Law states that for any **complete loop** around a **circuit**, the **sum** of the **e.m.fs** around the **loop** is **equal** to the **sum** of **potential drops** around the **loop**.



$$\sum \varepsilon = \sum V$$



Exemplar Calculation Exam Question

Context: Recall and apply Kirchhoff's Laws.

Use **information** given in the **diagram**.

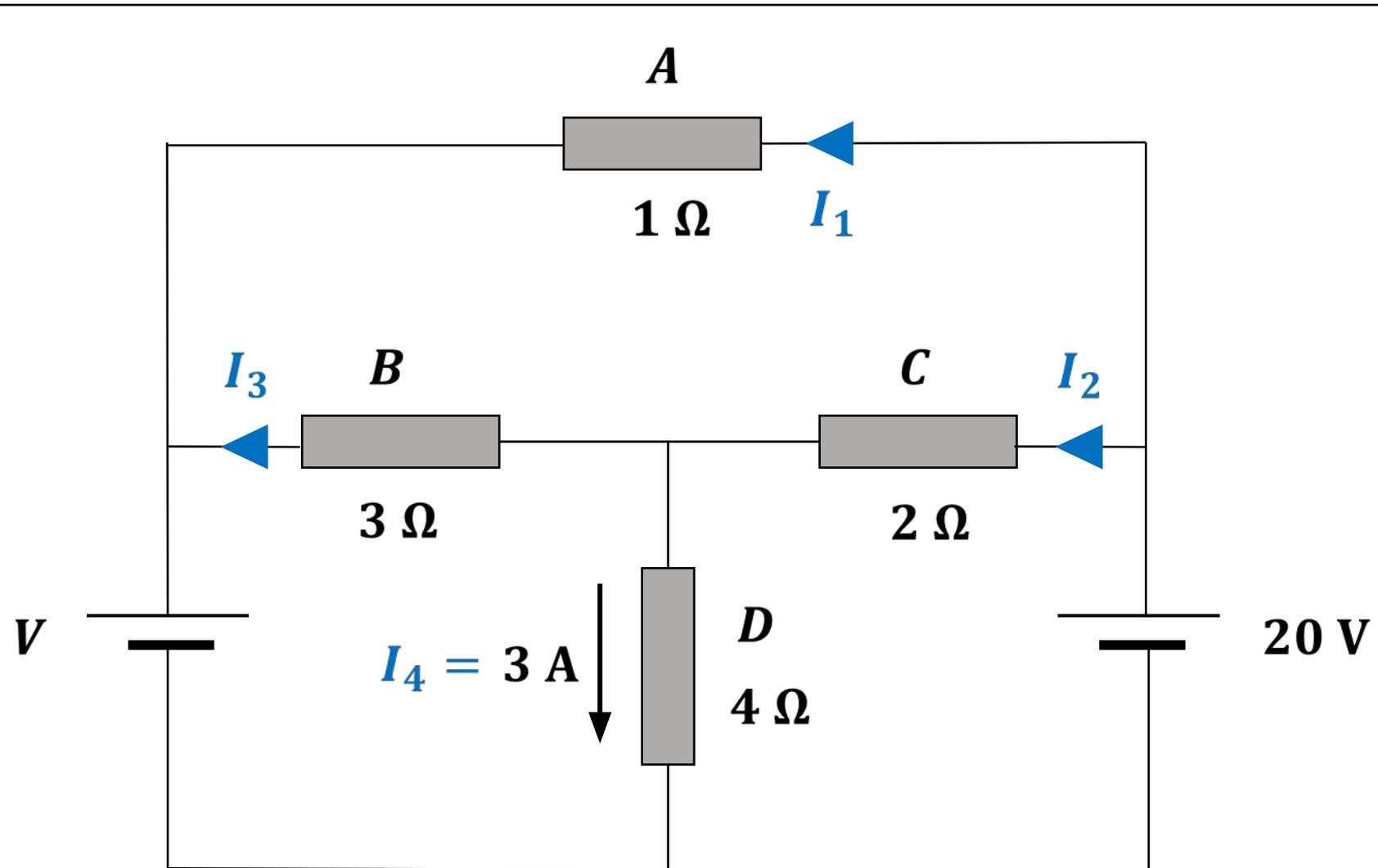
- 1) Consider the following circuit diagram. The current flowing through resistor ***D*** is **3 A**. By using Kirchhoff's Laws, determine the current flowing through resistors ***A***, ***B*** and ***C*** and the voltage of the cell ***V***.

[4 marks]

Calculation Question:

Mathematical question – we need to show our working.

Indicates that there will be about **4 steps** to our **calculation**. We also need to provide **4 answers**.



Exemplar Calculation Question Answer

Write out Kirchhoff's Laws:

$$\sum I_{\text{IN}} = \sum I_{\text{OUT}} \quad \sum \varepsilon = \sum V$$

Consider bottom-right closed loop:

$$20 \text{ V} = I_2(2 \Omega) + (3 \text{ A})(4 \Omega)$$

$$I_2 = 4 \text{ A}$$

[1 Mark]

Exemplar Calculation Question Answer

Apply Kirchhoff's 1st Law to centre wire:

$$I_2 = I_3 + I_4 \quad 4 \text{ A} = I_3 + 3 \text{ A} \quad I_3 = 1 \text{ A} \quad [1 \text{ Mark}]$$

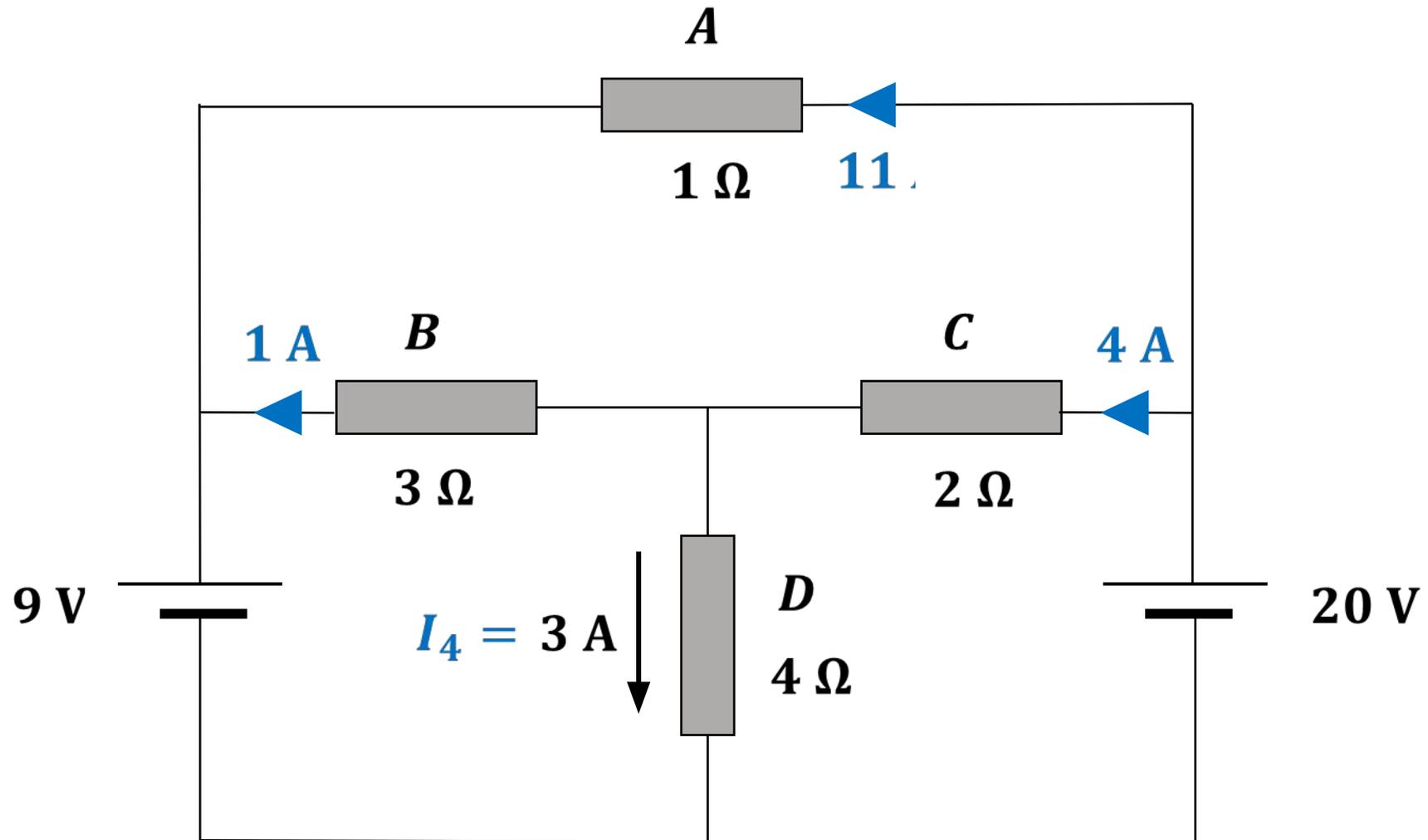
Consider top closed loop:

$$I_1(1 \Omega) = (4 \text{ A})(2 \Omega) + (1 \text{ A})(3 \Omega) \quad I_1 = 11 \text{ A} \quad [1 \text{ Mark}]$$

Consider outer closed loop:

$$20 \text{ V} = (11 \text{ A})(1 \Omega) + V \quad V = 9 \text{ V} \quad [1 \text{ Mark}]$$



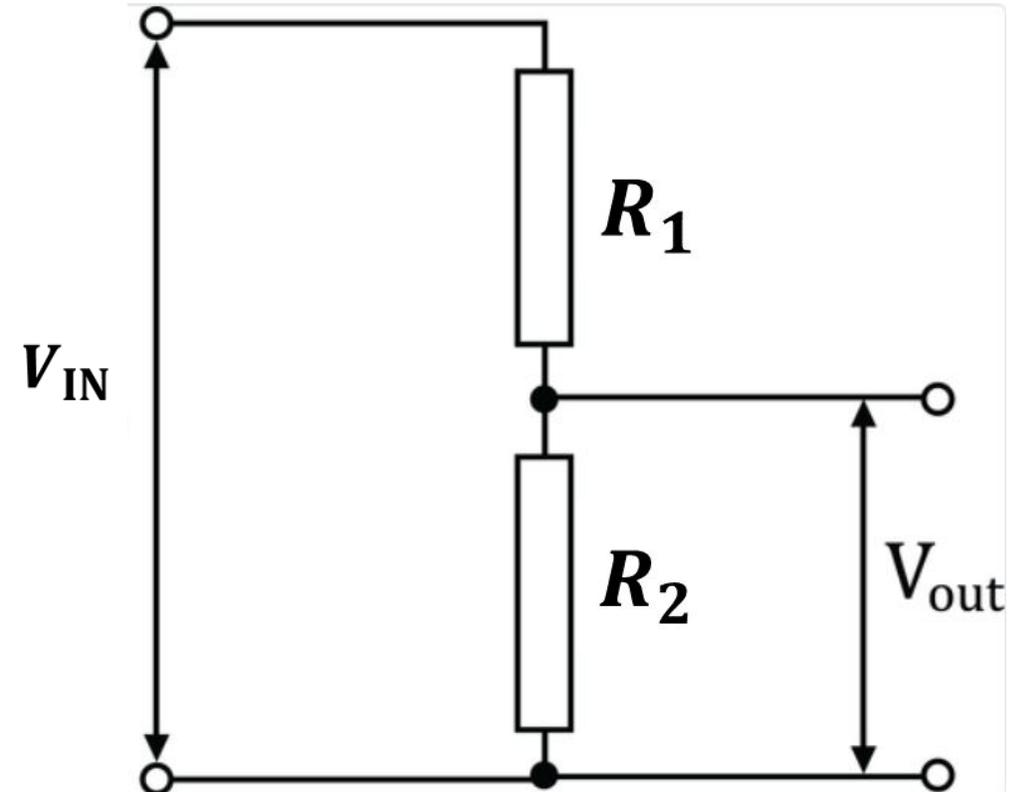


Potential Dividers

A **potential divider** consists of at least 2 **resistors** in **series** with a **fixed source** of potential difference (V_{IN}).

- **Potential dividers** are used to **extract** any **voltage** required from a **circuit** (V_{OUT}) up to the maximum **source p.d** by **varying** the **ratio** $\frac{R_1}{R_2}$.

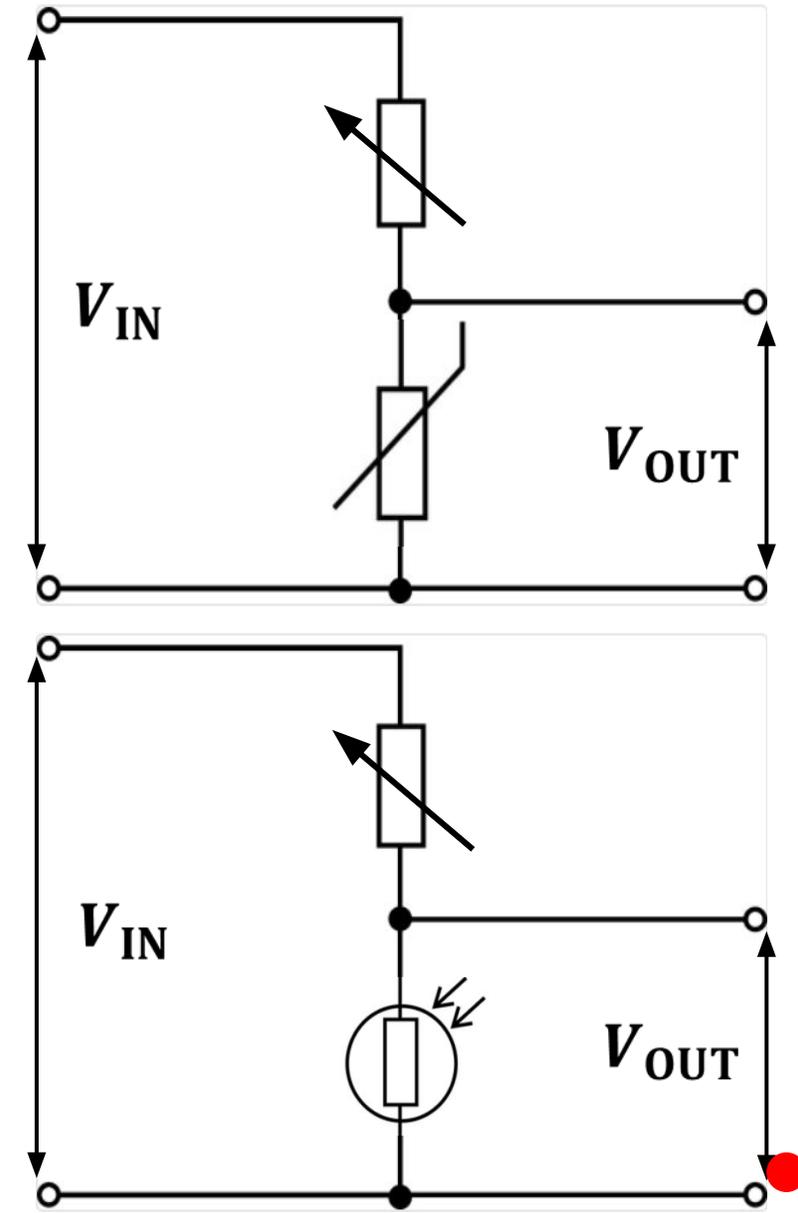
$$V_{OUT} = \left(\frac{R_2}{R_1 + R_2} \right) \times V_{IN}$$



Potential Dividers

Potential dividers can be used in combination with a **thermistor** or **LDR** to create a **sensor**.

- In these **circuits**, varying the **resistance** of the **variable resistor** sets the initial value of V across the thermistor or LDR.
- A **thermistor** is used to create a **temperature sensor**. As the **temperature** increases, its **resistance** decreases, so V_{OUT} decreases.
- An **L.D.R** is used to create a **light sensor**. As the **light intensity** increases, its **resistance** decreases, so V_{OUT} decreases.



Exemplar Calculation Exam Question

Context:
Potential Divider.
Recall
potential divider equation.

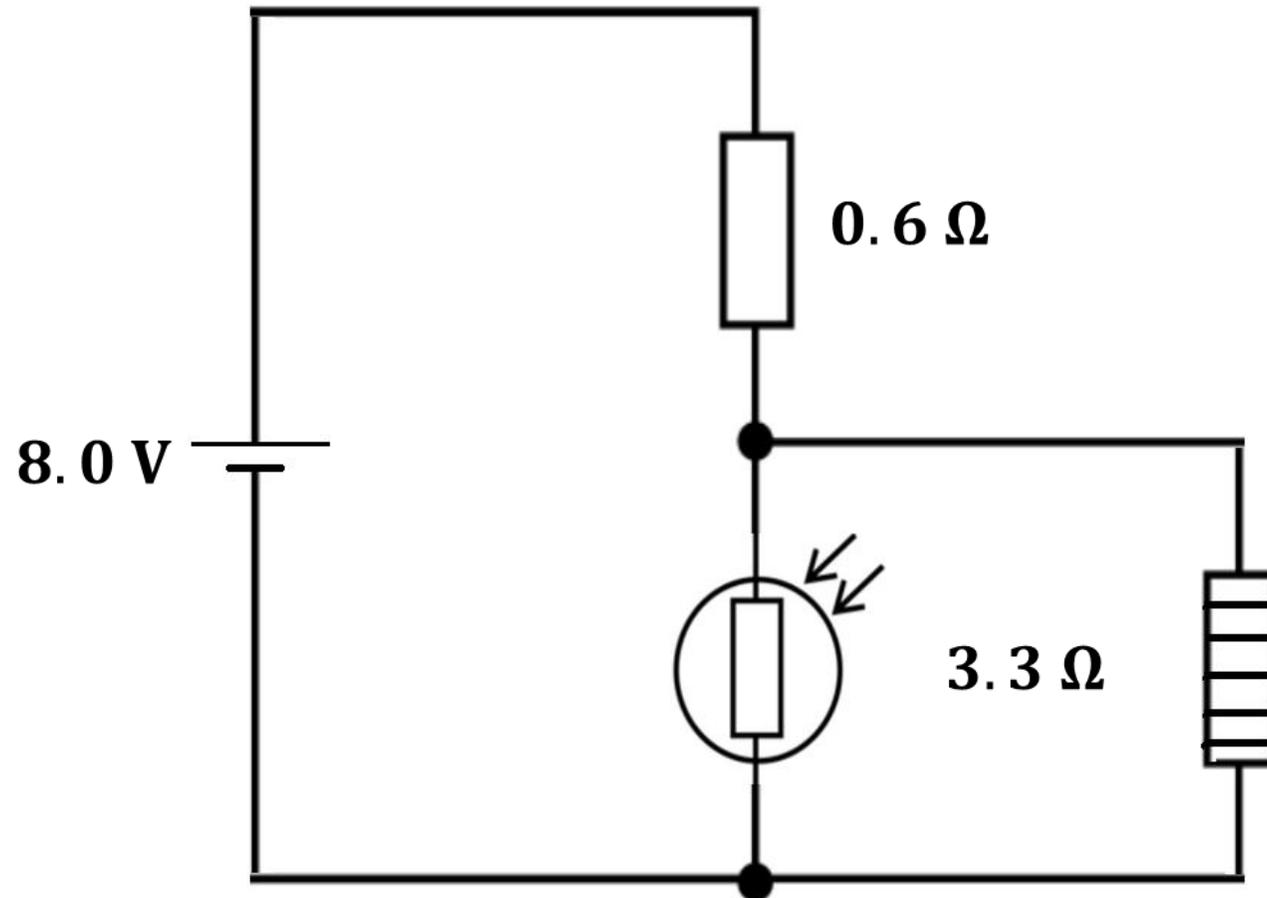
Key values we will require.

- 1) A light sensor circuit is connected to a heater such that the heater switches on during the daytime, according to the following circuit diagram. The heater has a resistance of 480Ω and it and the LDR have a combined resistance of 3.3Ω and the fixed resistor has a resistance of 0.6Ω . The cell provides a potential difference of 8 V . Calculate the power produced by the heater.

Calculation Question: Mathematical question – we need to show our working.

[3 marks]

Indicates that there will be about 3 **steps** to our **calculation**.



Exemplar Calculation Question Answer

Use potential divider equation

$$V_{OUT} = \frac{R_2}{R_1 + R_2} V_{IN}$$

[1 Mark]

$$V_H = \frac{3.3}{0.6 + 3.3} \times 8.0$$

$$V_H = 6.7692..V$$

[1 Mark]

Exemplar Calculation Question Answer

Use p.d/power equation

$$P = \frac{V^2}{R}$$

$$P = \frac{6.7692..^2}{480}$$

$$P = 0.095 \text{ W}$$

[1 Mark]

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- 1) Suggest a reason for connecting a variable resistor, rather than a fixed resistor, with a thermistor in a temperature sensor circuit.
[2 marks]

- Altering resistance of the variable resistor allows the value of V_{OUT} to be adjusted.

[1 Mark]

- Value of V_{OUT} can be set for specific temperature.

[1 Mark]

- 2) Describe and explain why it is preferable to transmit electricity to a town through electric power lines at a very high voltage.

[3 marks]

-
- Power loss during transmission is given by: $P_{\text{Loss}} = IV = I^2R$.
-

[1 Mark]

-
- Current required by city is given by $I = \frac{P}{V}$ where P is power required by city.
-

[1 Mark]

$$\Rightarrow P_{\text{Loss}} = \left(\frac{P}{V}\right)^2 R$$

-
- Therefore increasing V of transmission decreases power loss.
-

[1 Mark]

- 3) A power cable is used to transmit electricity from a power station to a nearby transformer **2.4 km** away. The cable is formed of a bunch of **10** copper wires each of radius **3.0 cm**. The voltage in the cable is **220 kV**. Determine the number of charge carriers which flow past a point in the cable in 1 minute. The resistivity of copper is **$1.68 \times 10^{-8} \Omega\text{m}$** .

[4 marks]

Exam Question Answer

Determine resistance of each cable

$$R = \frac{\rho L}{A} = \frac{1.68 \times 10^{-8} \times 2.4 \times 10^3}{\pi \times (3.0 \times 10^{-2})^2} = 1.426 \dots \times 10^{-2} \Omega$$

[1 Mark]

Determine current through each cable

$$I = \frac{V}{R} = \frac{220 \times 10^3}{1.426 \dots \times 10^{-2}} = 1.5427 \dots \times 10^7 \text{ A}$$

[1 Mark]

Exam Question Answer

Determine charge transferred past a point in one cable in 1 minute

$$Q = I\Delta t = 1.5427 \dots \times 10^7 \times 60 = 9.2564 \dots \times 10^8 \text{ C}$$

[1 Mark]

Determine number of charge carriers transferred by all 10 cables

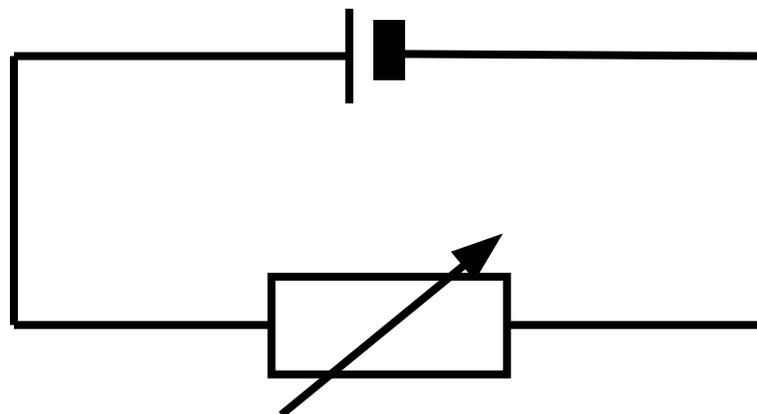
$$n = 10 \times \frac{Q}{e} = 10 \times \frac{9.2564 \dots \times 10^8}{1.60 \times 10^{-19}} = 5.785 \dots \times 10^{28}$$

$$n = 5.7 \times 10^{28} \text{ (to 2 s.f.)}$$

[1 Mark]

- 4) The cell in the circuit below has an emf of 2.0 V. When the variable resistor has a resistance of 4.0Ω , the potential difference (p.d.) across the terminals of the cell is 1.0 V. What is the p.d. across the terminals of the cell when the resistance of the variable resistor is 12Ω ?

[4 Mark]



Exam Question Answer

Determine current when the resistance is 4Ω

$$I = \frac{V}{R} = \frac{1}{4} = 0.25 \text{ A}$$

[1 Mark]

Use the equation for emf to calculate internal resistance

$$\epsilon = V + Ir \Rightarrow r = \frac{\epsilon - V}{I} = \frac{2 - 1}{0.25} = 4 \Omega$$

[1 Mark]

Exam Question Answer

Determine current when the resistance is 12Ω

$$\epsilon = IR + Ir \Rightarrow \epsilon = I(R + r) \Rightarrow 2 = I(12 + 4)$$

$$I = 0.125 \text{ A}$$

[1 Mark]

Determine the potential difference across the terminals of the cell using Ohm's law

$$V = IR = 0.125 \times 12 = 1.5 \text{ V}$$

[1 Mark]

5) State Kirchhoff's first law.

[1 Mark]

Exam Question Answer

Kirchhoff's First Law states that for any point in an electrical circuit the sum of the current flowing in is equal to the sum of current flowing out.

[1 Mark]