Edexcel International A Level (IAL) Physics

Your notes

Current, Potential Difference, Resistance & Power

Contents

Your notes

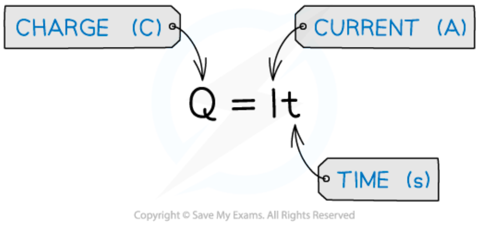
Electric Current

Electric Current

- Electric current is defined as:

  The rate of flow of charge

- It is measured in units of **amperes (*A*)** or **amps**
- The charge, current and time are related by the equation:



- There are several examples of electric currents, including in household wiring and electrical appliances

Electric Charge

- Electric charge is a property of some particles
  - For example, **protons** have a **positive** charge and **electrons** have a **negative** charge
- Charge has the unit Coulombs, C
- In electric circuits, **electrons** are usually the **charge carriers**
  - They have a charge of 1.6×10^{-19} C
- Charge, Q, can be calculated using the equation

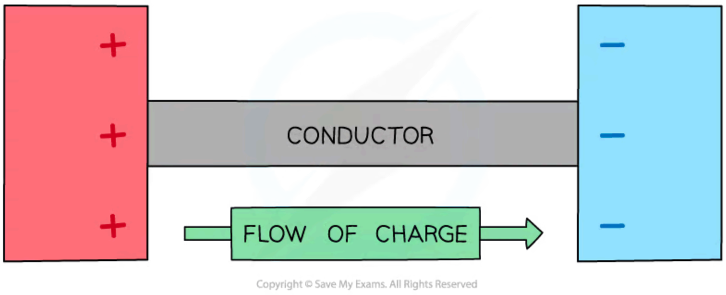
$$Q = ne$$

- Where:
  - Q = charge (C)
  - n = number of electrons
  - e = electron charge (C)
- If 1 electron has a charge of 1.6×10^{-19} C
  - Then, 1 C of charge contains 6.25×10^{18} electrons
- Charge is sometimes written as ΔQ which means 'change in charge'

- Similarly, time is written as Δt 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:

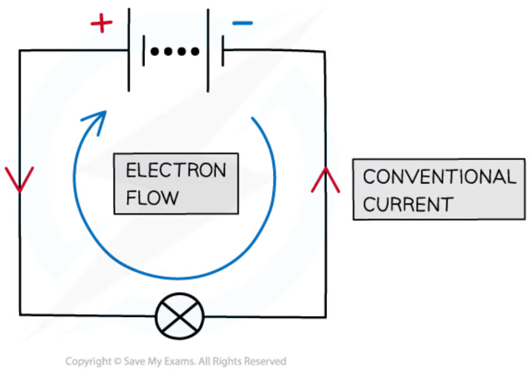
$$I = \frac{\Delta Q}{\Delta t}$$



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

Direction of Flow of Charge

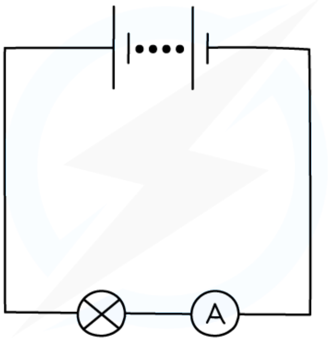
- In electrical wires, the current is a flow of **electrons**
- Electrons are negatively charged; they flow away from the negative terminal of a cell towards the positive terminal
- Conventional current is defined as the flow of **positive** charge from the **positive terminal of a cell to the negative 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)

Measuring Current

- Current is measured using an **ammeter**
- Ammeters should always be connected in **series** with the part of the circuit the current is to be measured through
    - This is because the current is the same in all components connected in series



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

Worked Example

The current in a filament lamp is 8 mA.

Which answer below explains how this current can be obtained?

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

B. A charge of 4 C passes in 500 s

C. A charge of 8 C passes in 100 s

D. 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

Your notes

- 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**

Your notes

Examiner Tips and Tricks

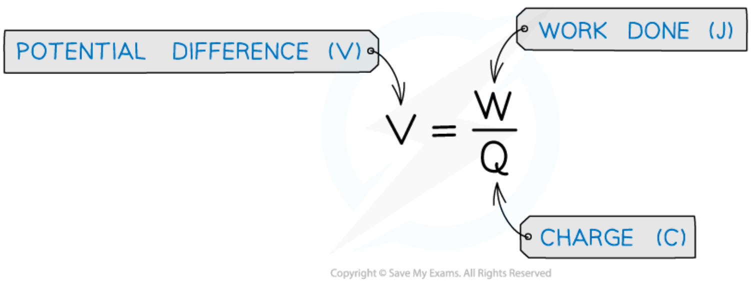
Although electric charge can be positive or negative, since the conventional direction of current is the flow of **positive** charge the current should always be a positive value for your exam answers.

An example of this is electrolysis where ions are used as charge carriers in the ionic solution and the ions travel through a liquid as an electric current

Potential Difference

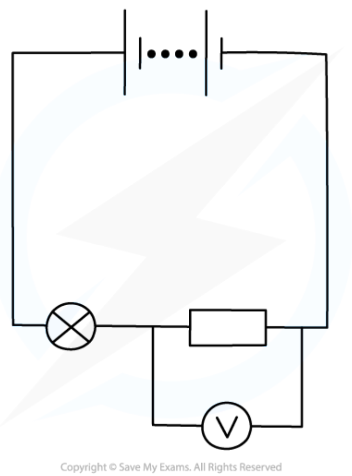
Potential Difference

- 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*)**



Measuring Voltage

- Potential difference (or voltage) is measured using a **voltmeter**
- A voltmeter is always set up **in parallel to** (also called 'across') the component being measured
  - Potential difference across components in parallel is always the same due to conservation of energy



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

Your notes

Worked Example

A resistor is connected to a battery which provides a potential difference of 10 V.

Calculate the work done when a charge of 2 C passes through the resistor.

Answer:

Step 1: Write down the known quantities

- Potential difference, V = 10 V
- Charge, Q = 2 C

Step 2: Write down the equation relating potential difference, work done and charge

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

Step 3: Rearrange the equation to make work done the subject

$$W = VQ$$

Step 4: Substitute in the values and calculate W

$$W = 10 \times 2 = 20 \, J$$

Examiner Tips and Tricks

Think of potential difference as being the **energy per coulomb** of charge transferred between two points in a circuit

Your notes

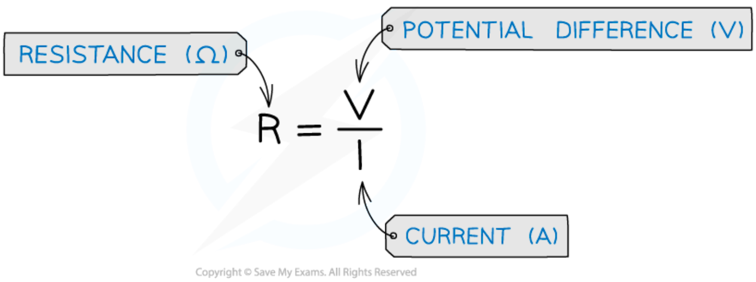
Defining Resistance

Resistance

- Resistance is defined as the **opposition** to current
- It is further defined by Ohm's Law, which says that the resistance of a conductor is given by the ratio of potential difference across it to the current flowing in it

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

- For a given potential difference, then, **the higher the resistance the lower the current**



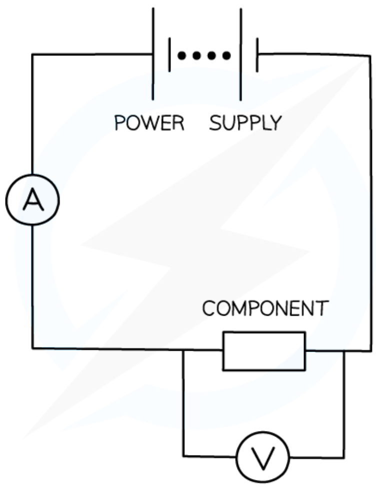
Resistance of a component is the ratio of the potential difference and current

- 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

Measuring Resistance

- To find the resistance of a component, a simple circuit can be used, containing:
  - A power supply
  - A component (such as a lamp or resistor)
  - An ammeter in series with the component
  - A voltmeter in parallel with the component

Your notes



A circuit to determine the resistance of a component

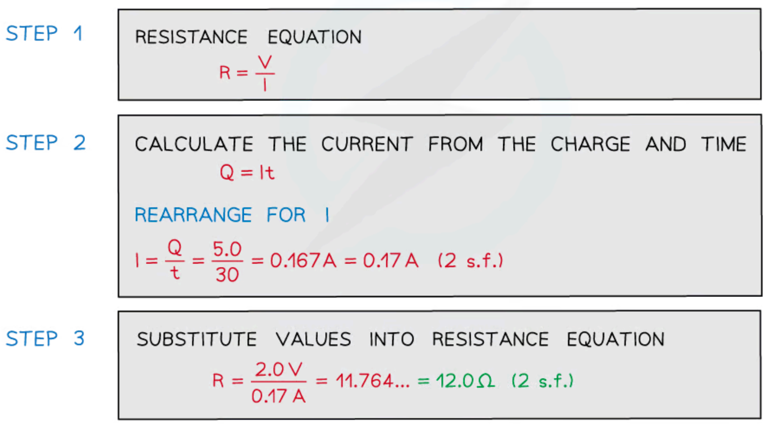
- The power supply should be set to a low voltage to avoid heating the component, typically 1–2 V
- Measurements of the potential difference and current should then be taken from the voltmeter and ammeter respectively
- Finally, these readings should be substituted into the resistance equation

Worked Example

A charge of 5.0 C passes through a resistor of resistance R Ω at a constant rate in 30 s.

If the potential difference across the resistor is 2.0 V, calculate the value of R.

Answer:

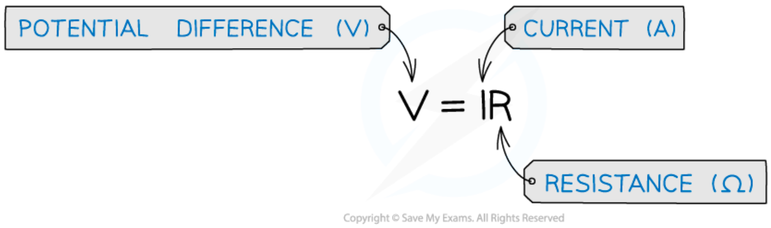


Ohm's Law

- Ohm's law is defined as:

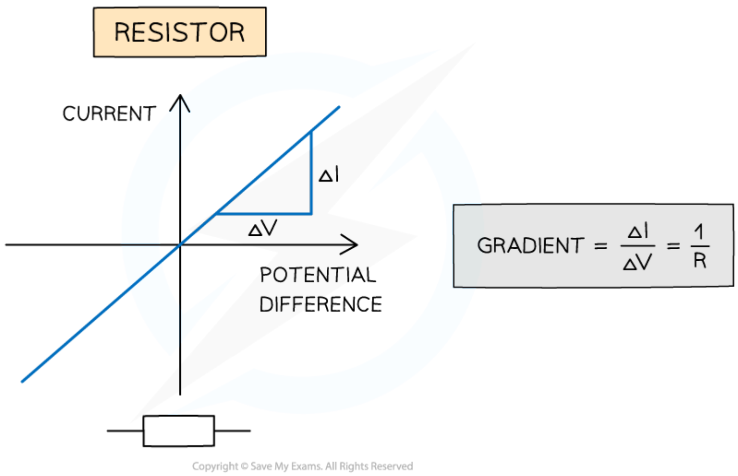
  The current through a component is directly proportional to the potential difference across it, providing the temperature is constant

- Constant temperature implies constant resistance
- This is shown the equation below:



Ohm's law

- By adjusting the resistance on the variable resistor, the current and potential difference will vary in the circuit.
- The variation of current with potential difference through the fixed resistor can be plotted on a pair of axes
  - This will produce a straight-line graph



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

Your notes

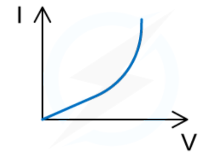
- A resistor **does** obey Ohm's law
- A filament lamp does **not** obey Ohm's law

- Any metal wires will follow Ohm's Law, provided that the current isn't large enough to increase their temperature

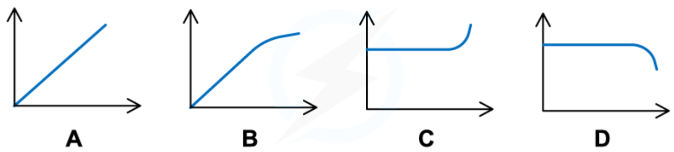
Your notes

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

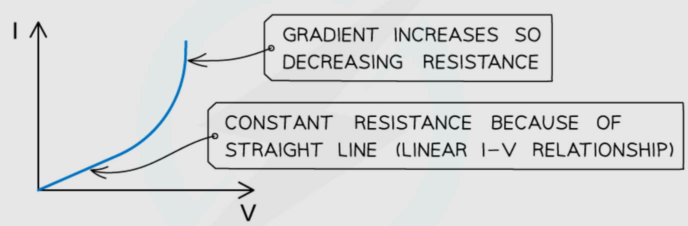
USE OHM'S LAW TO FIND R IN TERMS OF V AND I

$V = IR$ 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

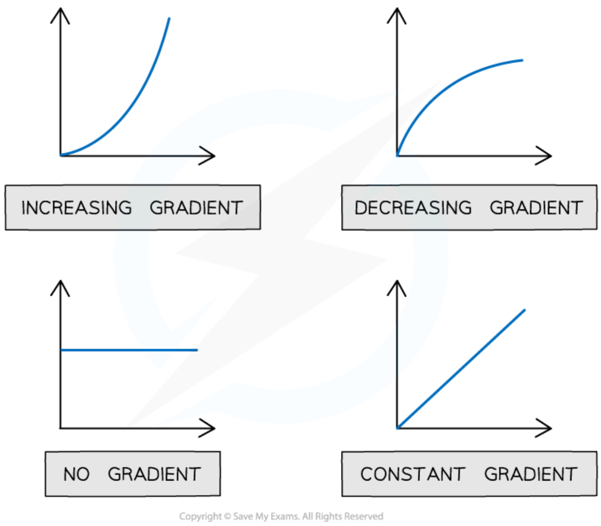
OPTION D IS THE BEST DESCRIPTION OF THIS

Examiner Tips and Tricks

Resistance is used to control current. Increasing the resistance in a circuit will reduce the current. Don't get the cause and effect mixed up here. Reducing current does not increase resistance - it's the other way round!

Using graphs;

- 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



Graphs showing varying gradients

Your notes

Charge Conservation in Circuits

The Electric Current Rule (Kirchhoff's First Law)

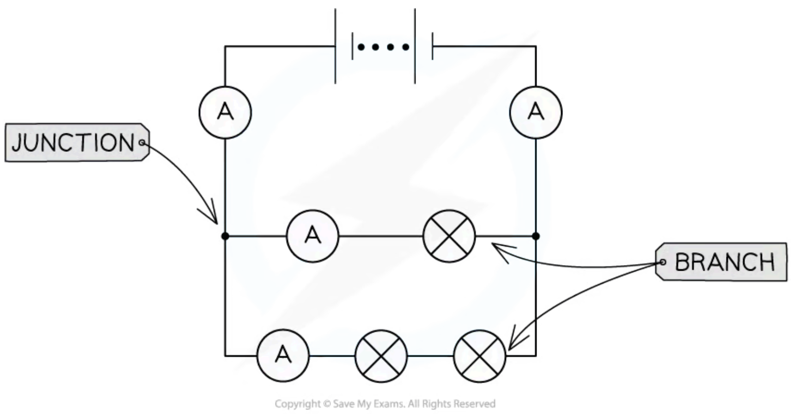
- The electric current rule is defined as:

  The algebraic sum of the currents entering and leaving a junction is equal to zero

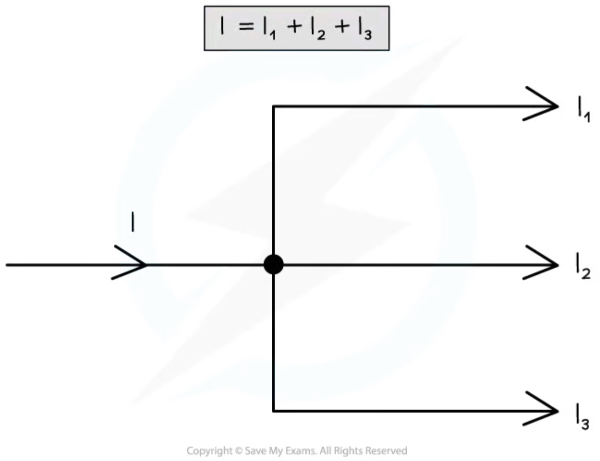
- This is a consequence of conservation of **charge –** current shouldn't decrease or increase in a circuit when it splits

Series and Parallel

- In a circuit:
  - A **junction** is a point where at least three circuit paths meet
  - A **branch** is a path connecting two junctions

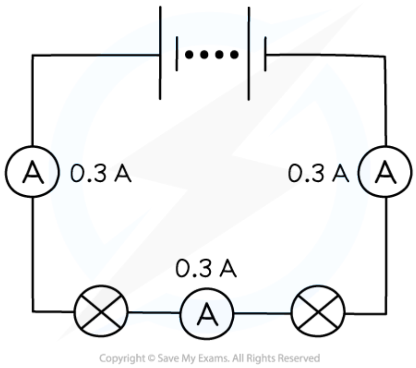


- If a circuit splits into two **branches**, then the current before the circuit splits should be equal to the current after it has split
- A typical circuit might have a setup where $I = I_1 + I_2 + I_3$ where:
  - I represent the current in the circuit before it branches
  - I_1, I_2 and I_3 represent the current in the respective three branches



The current I into the junction is equal to the sum of the currents out of the junction

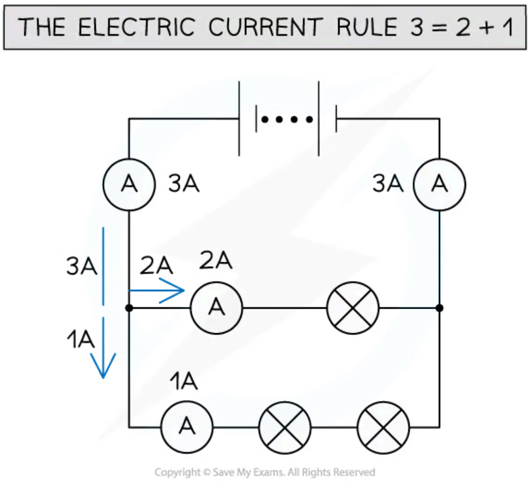
- The charge is conserved on both sides of the junction
- In a **series** circuit, the current is the same at any point



The current is the same at all points in a series circuit

- In a **parallel** circuit, the current divides at the junctions and each branch has a different value.
- The electric current rule applies at each junction
  - The sum of the currents before the junction will equal the sum of the currents after the junction

Your notes



The current divides at each junction in a parallel circuit

Examiner Tips and Tricks

Junctions only appear in parallel circuits as circuits become more complex. It can be confusing to work out which currents are going into the junction and which are coming out. Drawing arrows on the diagram for the current flow (making sure it's from positive to negative) at each junction, such as in the worked example, will help with this.

The electric current rule is also known as Kirchhoff's First Law, and you may come across this phrase.

Your notes

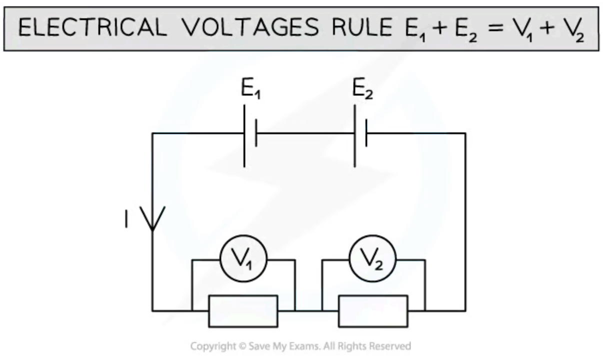
Energy Conservation in Circuits

The Electrical Voltages Rule (Kirchhoff's Second Law)

- Energy is never used up or lost in a circuit, since everything follows the Law of Conservation of Energy
- The electrical voltages rule is defined as:

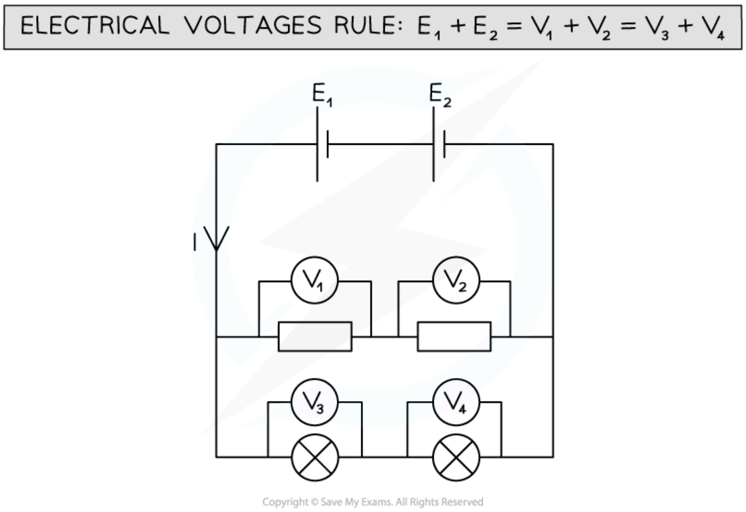
  The sum of the e.m.f.s in a closed circuit loop is equal to the sum of the potential differences around that loop

- Each closed circuit loop can be treated like a series circuit
- A typical circuit might have a setup where $E_1 + E_2 = V_1 + V_2$ where:
  - E_1 and E_2 represent the e.m.f.s in the closed loop
  - V_1 and V_2 represent the potential differences in the closed loop



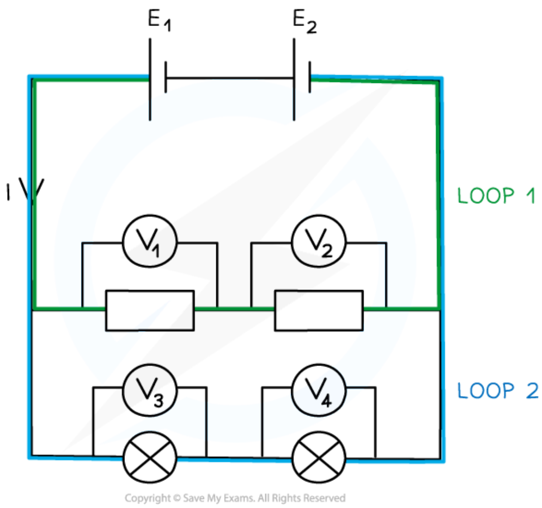
The sum of the voltages is equal to the total e.m.f from the batteries

- In a **series** circuit, the voltage is split across all components depending on their resistance
  - The sum of the voltages is equal to the total e.m.f of the power supply
- In a **parallel** circuit, the voltage is the same across each closed loop
  - The sum of the voltages **in each closed circuit loop** is equal to the total e.m.f of the power supply:



The sum of the p.ds in each closed loop is equal to the total e.m.f of the power supply

- A closed-circuit loop acts as its own independent series circuit
- Each loop separates at a junction
- A parallel circuit is made up of two or more of these loops



Each circuit loops acts as a separate, independent series circuit

- This makes parallel circuits incredibly useful for home wiring systems
  - A single power source supplies all lights and appliances with the same voltage
  - If one light breaks, voltage and current can still flow through for the rest of the lights and appliances

Examiner Tips and Tricks

The Electrical Voltages Rules is sometimes known as Kirchhoff's Second Law.

Drawing the loops in different colours, as in the example above, can be a helpful way of identifying the different loops.

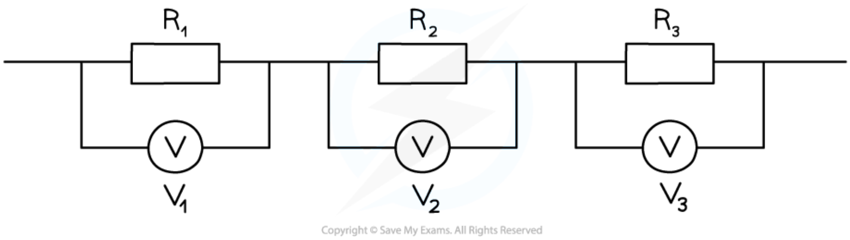
Your notes

Your notes

Deriving Equations for Resistance in Series & Parallel

Resistors In Series

- When two or more components are connected in series:
  - **The combined resistance of the components is equal to the sum of individual resistances**

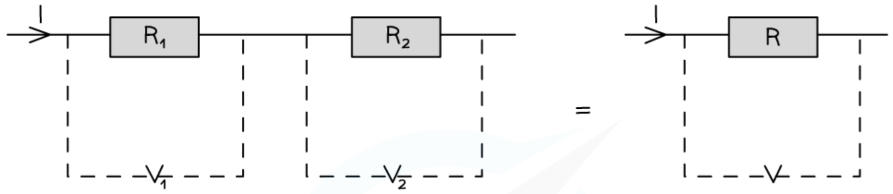


Resistors connected in series

- The equation for combined **resistors in series** is derived using the electric current rule and the electrical voltages rule
- These rules describe that for a series circuit:
  - The current is the same through all resistors
  - The potential difference is split between all the resistors

CONSIDER TWO RESISTORS R_1 AND R_2 CONNECTED IN SERIES
A SINGLE RESISTOR R IS EQUIVALENT TO THEM

FROM THE ELECTRIC CURRENT RULE: THE CURRENT I THROUGH EACH RESISTOR IS THE SAME SINCE THEY ARE CONNECTED IN SERIES (NO JUNCTIONS)



FROM THE ELECTRICAL VOLTAGES RULE: THE TOTAL p.d OF BOTH RESISTORS IN A CLOSED CIRCUIT LOOP MUST EQUAL THE SUM OF THE p.ds (THE p.d ACROSS THE SINGLE RESISTOR)

$$V = V_1 + V_2$$

FROM OHM'S LAW, POTENTIAL DIFFERENCE IS GIVEN BY THE PRODUCT OF CURRENT AND RESISTANCE

$$IR = IR_1 + IR_2$$

SINCE CURRENT I IS THE SAME FOR ALL RESISTORS, DIVIDING BY I

$$R = R_1 + R_2$$

THIS EQUATION CAN BE EXTENDED SO THE EQUIVALENT RESISTOR R OF SEVERAL RESISTORS CONNECTED IN SERIES IS GIVEN BY

$$R = R_1 + R_2 + R_3 + R_4 \ldots$$

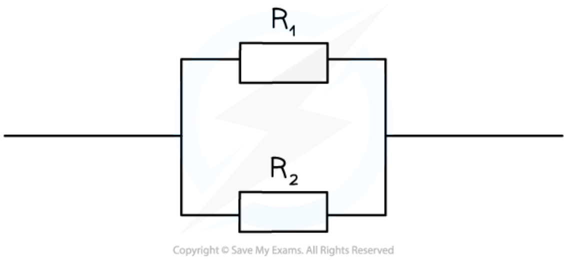
- The equation for the combined resistance of resistors in series is therefore:

COMBINED RESISTANCE IN SERIES	$R = R_1 + R_2 + R_3 \ldots$

Resistors In Parallel

- In a parallel circuit, the combined resistance of the components requires the use of **reciprocals**
  - **The reciprocal of the combined resistance of two or more resistors is the sum of the reciprocals of the individual resistances**

Your notes



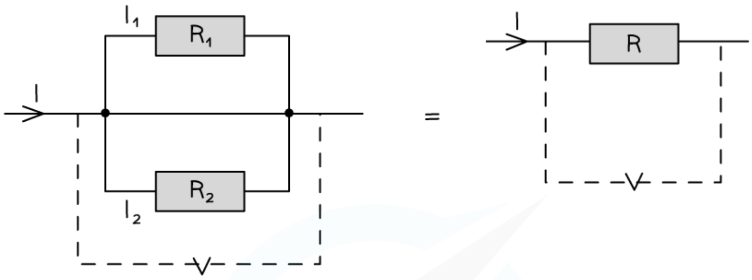
Resistors connected in parallel

- The equation for combined **resistors in parallel** is derived using the electric current rule and the electrical voltages rule
- These rules describe that for a parallel circuit:
  - The current is the split at the junction (and therefore between resistors)
  - The potential difference is the same across all resistors

Your notes

CONSIDER TWO RESISTORS R_1 AND R_2 CONNECTED IN PARALLEL
A SINGLE RESISTOR R IS EQUIVALENT TO THEM

FROM THE ELECTRICAL CURRENT RULE: THE CURRENT THROUGH EACH RESISTOR WILL BE DIFFERENT DUE TO THE CURRENT SPLITTING AT THE JUNCTION
THE CURRENT THROUGH THE EQUIVALENT RESISTOR R WILL BE THE TOTAL CURRENT I



$$I = I_1 + I_2$$

FROM THE ELECTRICAL VOLTAGES RULE: THE p.d ACROSS EACH RESISTOR IN DIFFERENT BRANCHES IS THE SAME
THE RESISTOR R WILL HAVE THAT SAME p.d ACROSS IT TOO

$$V = V_1 = V_2$$

REARRANGING OHM'S LAW $V = IR$ FOR CURRENT I

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

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2}$$

SINCE POTENTIAL DEFFERENCE V IS THE SAME FOR ALL RESISTORS, DIVIDING BY V

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

THIS EQUATION CAN BE EXTENDED SO THE EQUIVALENT RESISTOR R OF SEVERAL RESISTORS CONNECTED IN PARALLEL IS GIVEN BY

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots$$

- The equation for the combined resistance of resistors in parallel is therefore:

COMBINED RESISTANCE IN PARALLEL	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots$

- This means the combined resistance decreases

- The combined resistance is less than the resistance of any of the individual components
- For example, If two resistors of equal resistance are connected in parallel, then the combined resistance will halve

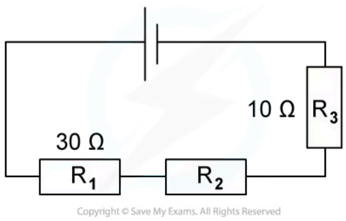
Your notes

Using Equations for Resistance in Series & Parallel

Series Circuits

Worked Example

The combined resistance *R* in the following series circuit is 60 Ω.



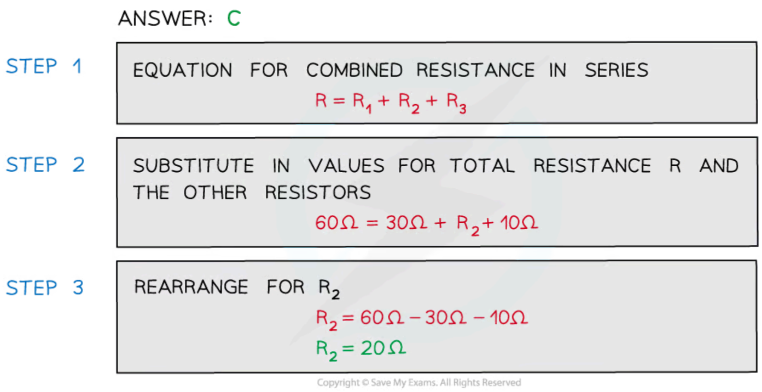
Wich of the following is the value of R_2?

A. 100 Ω

B. 30 Ω

C. 20 Ω

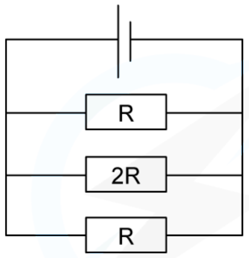
D. 40 Ω



Parallel Circuits

Worked Example

The circuit below shows 3 resistors connected in parallel.



Which value gives the combined resistance of all the resistors in this circuit?

A. $\frac{5R}{2}$ **B.** $\frac{2}{5R}$ **C.** $\frac{5}{2R}$ **D.** $\frac{2R}{5}$

ANSWER: D

STEP 1

RESISTORS IN PARALLEL EQUATION

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots$$

STEP 2

SUBSTITUTE VALUES OF R_1, R_2 AND R_3 INTO THE EQUATION

R_T = TOTAL COMBINED RESISTANCE

$$\frac{1}{R_T} = \frac{1}{R} + \frac{1}{2R} + \frac{1}{R}$$

$$\frac{1}{R_T} = \left(1 + \frac{1}{2} + 1\right)\frac{1}{R} = \frac{5}{2}\frac{1}{R}$$

STEP 3

CALCULATE R_T FROM THE RECIPROCAL OF THE SUM

R_T IS THE RECIPROCAL OF $\frac{1}{R_T}$

R_T = RECIPROCAL OF $\frac{5}{2}\frac{1}{R}$

"FLIP ROUND" THE FRACTION

$$R_T = \frac{2}{5}R$$

Examiner Tips and Tricks

The most common mistake is to forget to find the correct value for R_T in parallel.

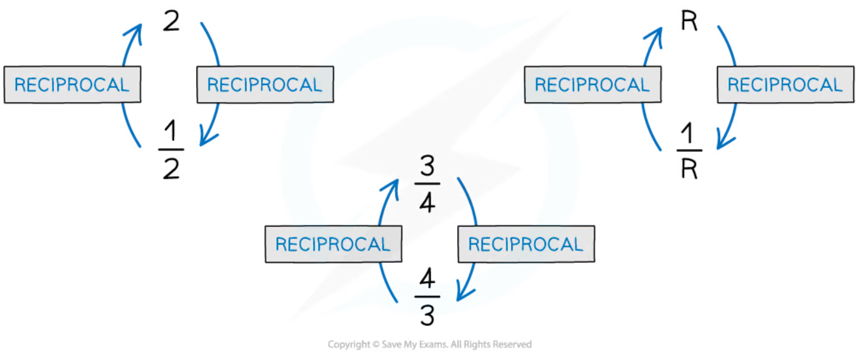
Remember to do $\frac{1}{\text{answer}}$ to get the correct value.

Reciprocals can be considered in the following way:

- The reciprocal of a value is $\frac{1}{\text{value}}$

Your notes

- For example, the reciprocal of a whole number such as 2 equals $\frac{1}{2}$
- The reciprocal of $\frac{1}{2}$ is 2
- If the number is already a fraction, the numerator and denominator are 'flipped' round



The reciprocal of a number is 1 ÷ number

- In the case of the resistance R, this becomes $\frac{1}{R}$
  - To get the value of R from $\frac{1}{R}$, you must do $\frac{1}{\text{answer}}$
- You can also use the reciprocal button on your calculator (labelled either x^{-1} or $\frac{1}{x}$, depending on your calculator)

Your notes

Your notes

Electrical Power

- Work is also defined as a transfer of energy
- When components transfer electrical energy to other stores, work must be done because energy is transferred
- Therefore, potential difference is the **work done per unit charge**

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

- Current is the **rate of flow of charge**

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

- These equations can be combined to give the work done by a component in an electric circuit

$$W = VIt$$

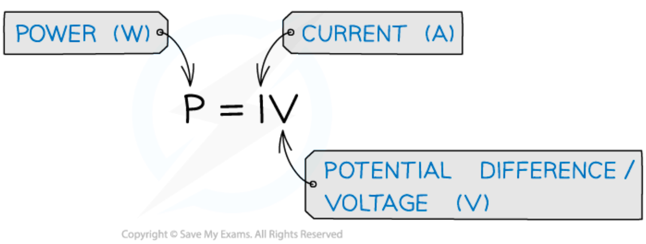
- Power is **the rate of doing work**

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

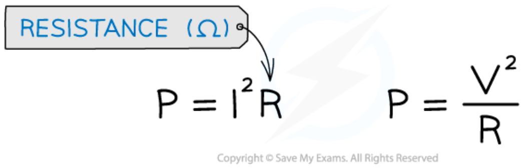
- This gives us

$$P = \frac{VIt}{t} = VI$$

- Therefore, the power dissipated (produced) by an electrical device is given by:



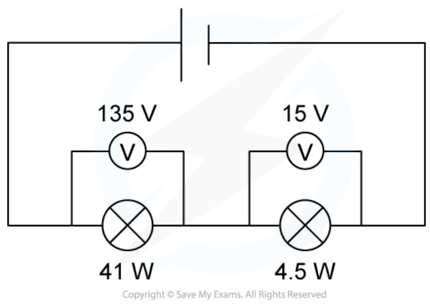
- Using ***V* = *IR*** to rearrange for either *V* or *I* and substituting into the power equation means we also write power in terms of resistance *R*



- Since current and voltage are both squared in these equations, this means that
  - for a given resistance, if the current or voltage **doubles**, the power will increase by a factor of **four**
  - for a given power, if the resistance **doubles**, the current will decrease by a factor of $\sqrt{2}$, and the voltage will increase by a factor of $\sqrt{2}$

Worked Example

Two lamps are connected in series to a 150 V power supply.



Which statement is correct?

A. Both lamps light normally

B. The 15 V lamp blows

C. Only the 41 W lamp lights

D. Both lamps light at less than their normal brightness

Answer: A

Your notes

STEP 1	CALCULATE CURRENT NEEDED FOR BOTH LAMPS TO OPERATE $P = IV$
STEP 2	REARRANGE FOR I $I = \frac{P}{V}$
STEP 3	FOR THE 41 W LAMP: $I = \frac{41\ W}{135\ V} = 0.3\ A$ FOR THE 4.5 W LAMP: $I = \frac{4.5\ W}{15\ V} = 0.3\ A$
STEP 4	FOR BOTH TO OPERATE AT THEIR NORMAL BRIGHTNESS, A CURRENT OF 0.3 A IS REQUIRED. SINCE THE LAMPS ARE CONNECTED IN SERIES, THE SAME CURRENT WOULD FLOW THROUGH BOTH.
STEP 5	THE LAMPS WILL LIGHT AT THEIR NORMAL BRIGHTNESS – OPTION A

Your notes

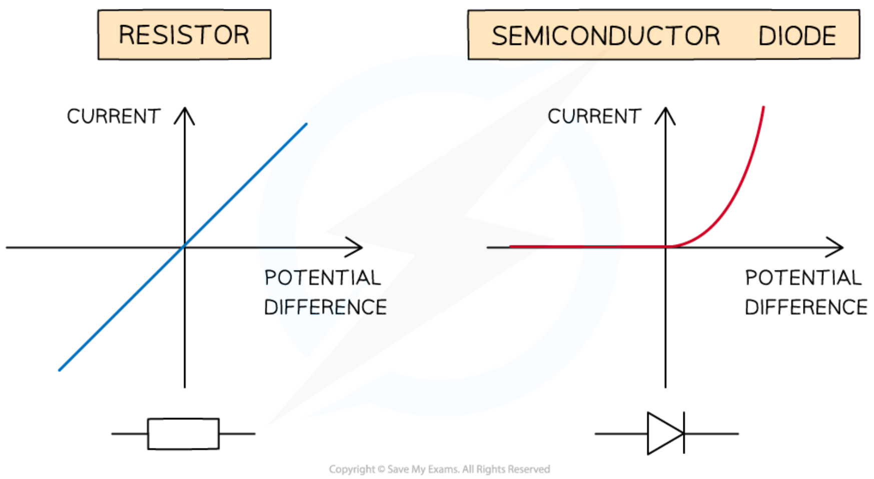
Examiner Tips and Tricks

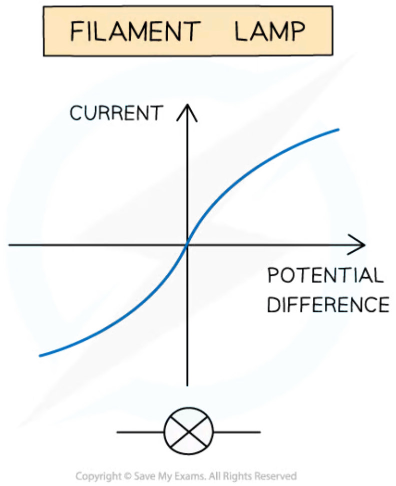
You can use the mnemonic "Twinkle Twinkle Little Star, Power equals I squared R" to remember whether to multiply or divide by resistance in the power equations.

Which equation to use will depend on whether the value of current or voltage has been given in the question.

Current-Potential Difference Graphs

- 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 a current-potential difference or *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

Your notes

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

Diode

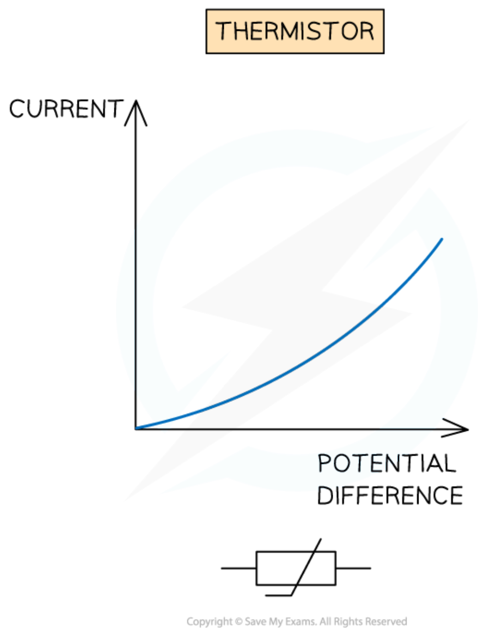
- The *I–V* graph for a diode is slightly different.
- A diode is used in a circuit to allow current to flow only in a specific direction:
  - When the current is in the direction of the arrowhead symbol, this is **forward bias.** This is shown by the sharp increase in potential difference and current 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
  - The threshold voltage at which a diode starts to conduct is typically around 0.6V

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

Thermistor

- The *I–V* graph for a thermistor is a shallow curve upwards

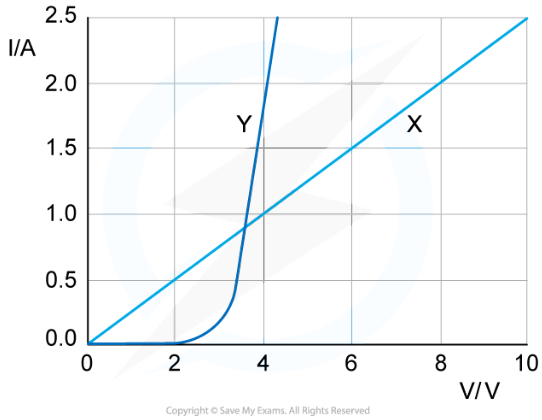


- The increase in the potential difference results in an increase in current which causes the **temperature** of the thermistor to rise
- As its temperature rises, its resistance **decreases**
  - This means even more current is able to flow through
- Since the current is not directly proportional to the potential difference (the graph is still curved), the thermistor does **not** obey Ohm's law
- The *I*–*V* graph for a thermistor shows the current increasing at a proportionally **faster** rate than the potential difference (the curve becomes steeper)
- This is because:
  - As the current increases, the **temperature** of the thermistor **increases**
  - A higher temperature causes **resistance** to **decrease**
  - The lower resistance allows **more current** to flow for each increase in p.d., so the graph is curved (non-ohmic)

Worked Example

The *I*–*V* graph of two electrical components **X** and **Y** are shown

Your notes



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

Step 1: Consider the characteristics of graph X

- The *I*–*V* graph **X** is **linear**
  - This means the graph has a constant gradient. *I*/*V* and the resistance is therefore also constant (since gradient = 1/*R*)
  - This is the *I*–*V* graph for a conductor at constant temperature e.g. a resistor

Step 2: Consider the characteristics of graph Y

- 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

Step 3: Compare this information with the statements A–D

- **A.** Resistance is constant
  - therefore this statement is **incorrect**
- **B.** At 2V the current of X is 0.5 A and the current of Y is 0 A.
  - therefore this statement is **incorrect**
- **D.** X is an ohmic component such as a resistor, however Y is the graph for a diode not a filament bulb.
  - therefore this statement is **incorrect**

Step 4: State the correct answer

- The correct answer is **C**

Your notes

Examiner Tips and Tricks

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

You may get a question asking you to explain why resistance in a metal increase with temperature. This is usually two marks given for:

- The vibrations of metal atoms are faster and of greater displacement from equilibrium
- Therefore there are more collisions between the conduction electrons and the atoms