OCR A Level Physics

Your notes

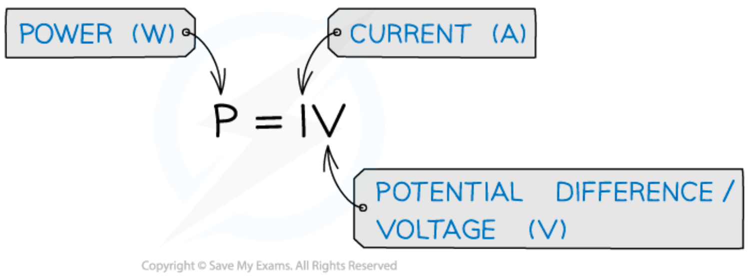
Series & Parallel Circuits

Contents

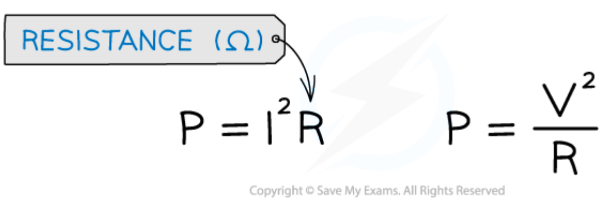
Power

Electrical Power

- In mechanics, power *P* is defined as the **rate of doing work**
  - Potential difference is the **work done per unit charge**
  - Current is the **rate of flow of charge**
- The electrical power dissipated (produced) by an electrical device is defined by the equation:



- The unit of power is **Watt (W)**
- Using Ohm's Law ***V* = *IR*** to rearrange for either *V* or *I* and substituting into the power equation, means power can be written in terms of resistance *R*

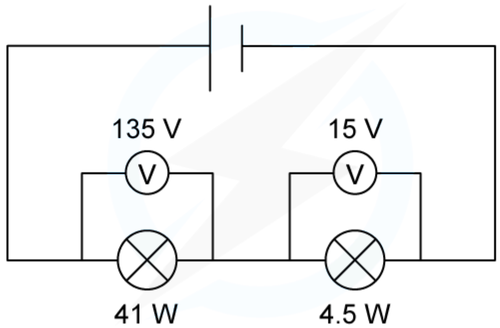


- This means for a given resistor if the current or voltage **doubles** the power will be **four** times as great

Worked Example

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

Your notes



Which statement most accurately describes what happens?

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

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

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. When doing calculations involving electrical power, remember the unit is Watts W, therefore, you should **always** make sure that the time is in **seconds**

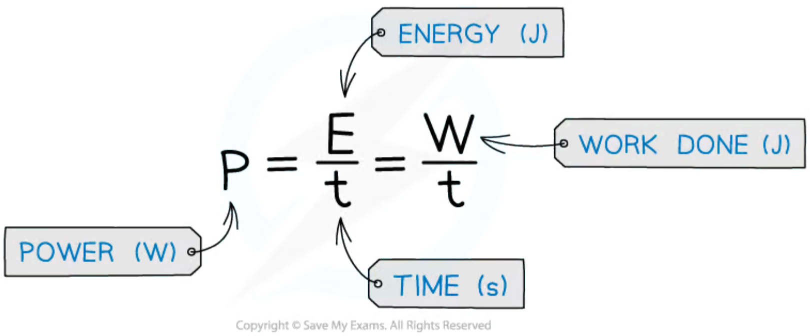
Your notes

Your notes

Electrical Energy

Electrical Energy Transfer

- The electrical power is also defined as the **rate of change of work done**:



- The work done is the **energy transferred**
  - The power is, therefore, the **energy transferred per second** in an electrical component
- Rearranging the energy and power equation, the energy can be written as:

$$W = Pt = IVt$$

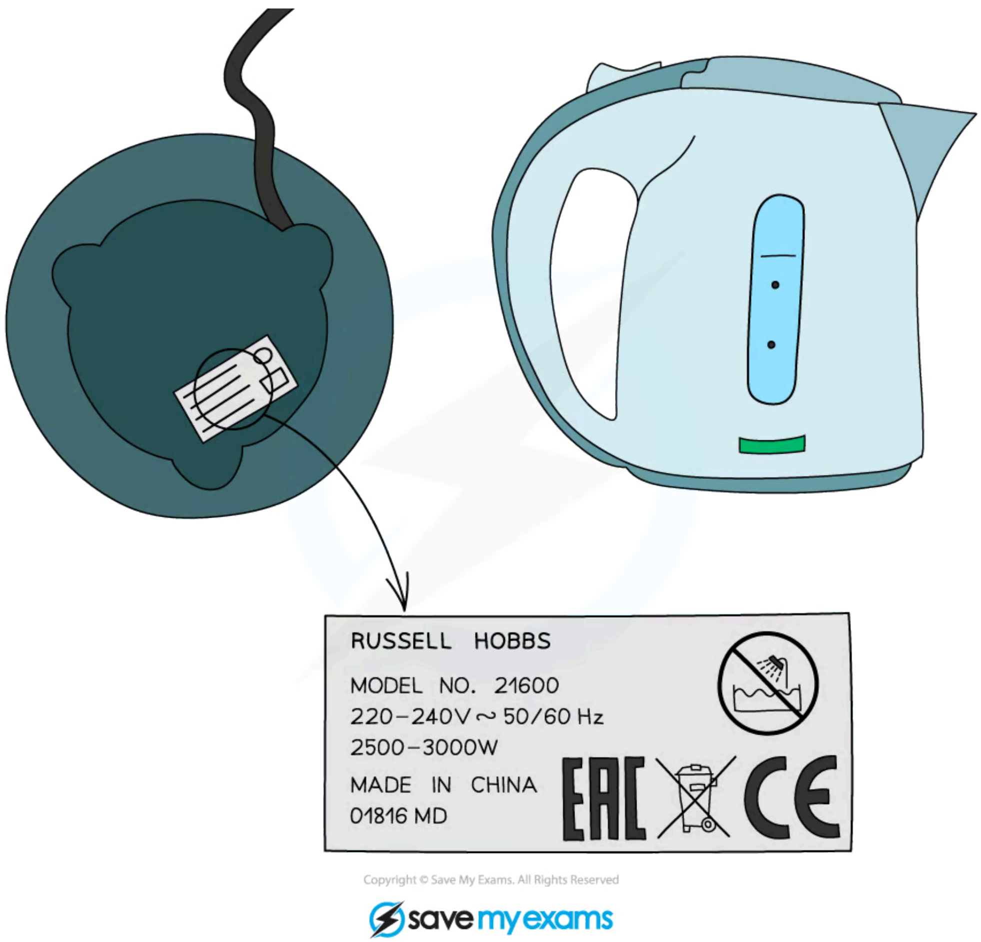
- Where:
  - W = Work done / energy transferred (J)
  - P = power (W)
  - V = voltage (V)
  - I = current (A)
  - t = time (s)

Calculating the Cost of Energy & The Kilowatt-hour (kWh)

- The power of an appliance is:

The amount of energy transferred (by electrical work) to the device every second

Your notes



The power consumption of an electrical appliance can be found on a label that looks like this. This kettle uses between 2500 and 3000 W of electrical energy

- This energy is commonly measured in **kilowatt-hour (kW h)**, which is then used to calculate the **cost** of energy
  - This is used to calculate electricity bills
- A kilowatt-hour is defined as:

  A unit of energy equal to 1 kW of power sustained for 1 hour

- Or as an equation:

$$\textbf{Energy (kW h)} = \textbf{Power (kW)} \times \textbf{Time (h)}$$

- Since the usual unit of energy is joules (J), this is the **1 W in 1 s**

- Therefore:

$$\mathbf{1\ kW\ h = 1000\ W \times 3600\ s = 3.6 \times 10^6\ J}$$

- Since 1 kW = 1000 W and 1 h = 3600 s
- To convert between Joules and kW h:

$$\mathbf{kW\ h \times (3.6 \times 10^6) = J}$$

$$\mathbf{J \div (3.6 \times 10^6) = kW\ h}$$

- The kW h is a large unit of energy, and mostly used for energy in homes

Worked Example

A cooker transfers 1.2×10^9 J of electrical energy to heat. How much will this cost if 1 kW h costs 14.2p?

Answer:

Step 1: Convert from J to kW h

$$(1.2 \times 10^9) \div (3.6 \times 10^6) = 333.333\ \text{kW h}$$

Step 2: Calculate the price

$$1\ \text{kW h} = 14.2\ \text{p}$$

$$333.333 \times 14.2 = 4733\ \text{p} = \mathbf{£47.33}$$

Your notes

Kirchhoff's Second Law

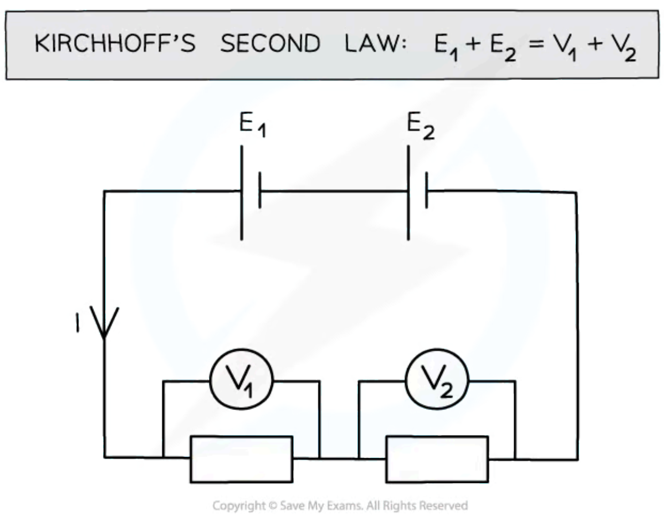
Your notes

Kirchhoff's Second Law

- Kirchhoff's second law states that:

  The sum of the e.m.f's in a closed circuit equals the sum of the potential differences

- This is a consequence of the conservation of **energy**



The sum of the voltages are equal to the sum of the 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:

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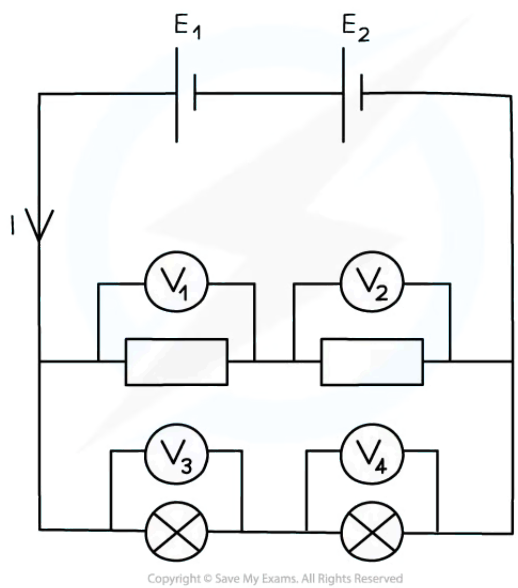
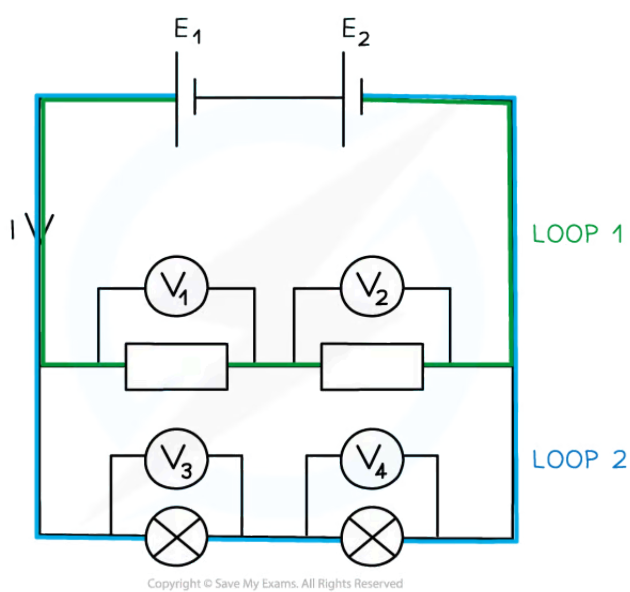
KIRCHHOFF'S SECOND LAW: $E_1 + E_2 = V_1 + V_2 = V_3 + V_4$



- A closed circuit loop acts as its own independent series circuit and each one 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 is why parallel circuits are 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

Your notes

Your notes

Kirchhoff's Laws in Circuits

Kirchhoff's First & Second Law in Circuits

- Kirchhoff's laws can be used to solve simple circuit problems

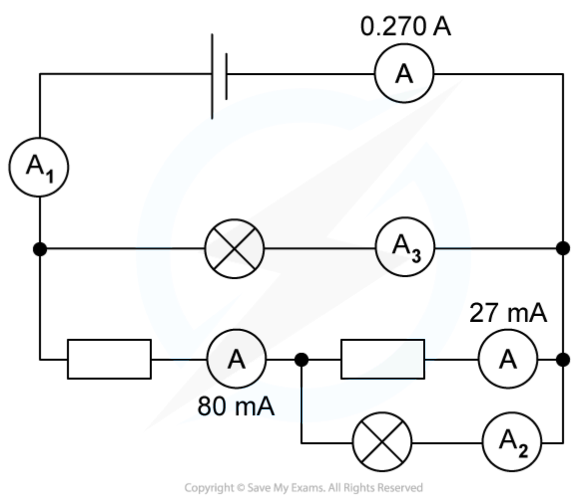
Using Kirchhoff's First Law

- Remember:

The sum of the currents entering a junction always equal the sum of the currents out of the junction

Worked Example

For the circuit below, state the readings of ammeters A_1, A_2 and A_3.



Answer:

Your notes

STEP 1

AMMETER A_1

0.270 A AND A_1 ARE CONNECTED IN SERIES. THE CURRENT ENTERING THE CELL EQUALS THE CURRENT LEAVING IT

A_1 IS ALSO 0.270 A

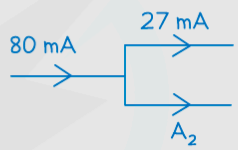
STEP 2

AMMETER A_2

FROM KIRCHHOFF'S FIRST LAW, THE TOTAL CURRENT INTO THE JUNCTION MUST EQUAL THE TOTAL CURRENT OUT OF IT.

$80 \text{ mA} = 27 \text{ mA} + A_2$

$A_2 = 80 - 27 = 53 \text{ mA}$



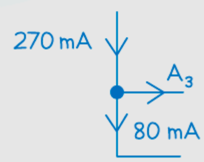
STEP 3

AMMETER A_3

KIRCHHOFF'S FIRST LAW AT A DIFFERENT JUNCTION

$270 \text{ mA} = A_3 + 80 \text{ mA}$

$A_3 = 270 - 80 = 190 \text{ mA}$



Using Kirchhoff's Second Law

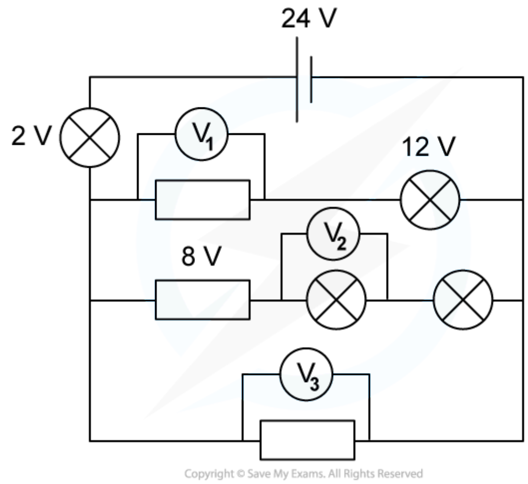
- Remember:

The sum of the e.m.f's in a closed circuit equals the sum of the potential differences

Worked Example

For the circuit below, state the readings of the voltmeters V_1, V_2 and V_3. All the lamps and resistors have the same resistance.

Your notes



Answer:

Your notes

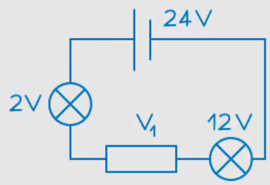
STEP 1

VOLTMETER V_1

KIRCHHOFF'S SECOND LAW STATES THAT THE SUM OF THE THREE COMPONENTS IS EQUAL TO THE e.m.f OF THE SUPPLY

$2V + V_1 + 12V = 24V$

$V_1 = 24 - 12 - 2 = 10V$



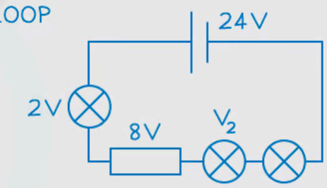
STEP 2

VOLTMETER V_2

KIRCHHOFF'S SECOND LAW IN THIS LOOP

$2V + 8V + V$ OF BOTH LAMPS $= 24V$

V BOTH LAMPS $= 24 - 8 - 2 = 14V$



SINCE BOTH LAMPS HAVE THE SAME RESISTANCE R AND THE CURRENT I THROUGH THEM BOTH IS THE SAME, THEY SHARE THE VOLTAGE LEFT EQUALLY

$V_2 = \frac{14}{2} = 7V$

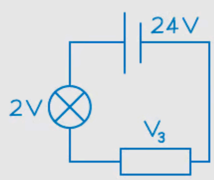
STEP 3

VOLTMETER V_3

KIRCHHOFF'S SECOND LAW IN THIS LOOP

$2V + V_3 = 24V$

$V_3 = 24 - 2 = 22V$



Examiner Tips and Tricks

The best way to practice these calculations is to understand **why** you have made a mistake Common mistakes are:

- Thinking the current is the same through every branch in a parallel circuit
- Thinking the voltage is the same through all components in a series circuit
- Not taking into account multiple resistors
- Not calculating the total resistance using the appropriate parallel or series resistance equation

- The sum of the voltages of all the components in a series circuit not adding up to the e.m.f of the supply
- The current into a junction not being equal to the current out of a junction (Kirchhoff's First Law)

Don't be afraid to annotate circuit diagrams to help with this. The more information you have about all the components, the easier it is to calculate values that are missing

Your notes

Resistors in Series & Parallel Circuits

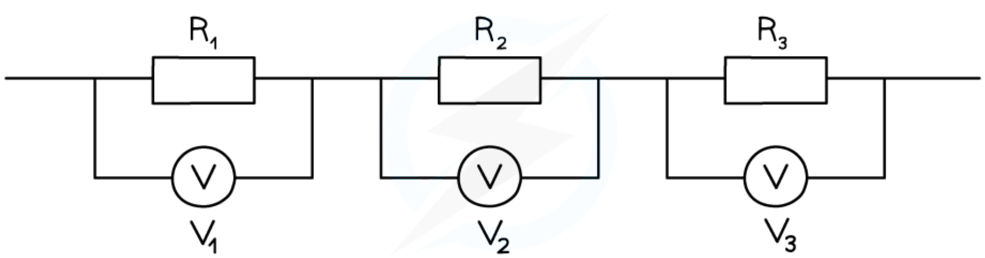
Your notes

Combining 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

- For example, for three resistors connected in series:

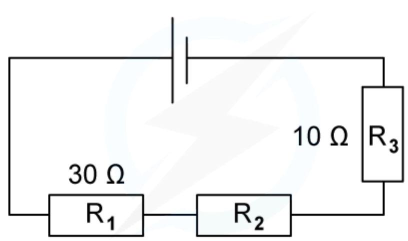


COMBINED RESISTANCE IN SERIES $R = R_1 + R_2 + R_3 \ldots$

Combined resistance of two or more resistors in series equation

Worked Example

The combined resistance *R* in the following series circuit is 60 Ω. What is the resistance value of R_2?



A. 100 Ω

B. 30 Ω

C. 20 Ω

D. 40 Ω

ANSWER: C

STEP 1
EQUATION FOR COMBINED RESISTANCE IN SERIES
$R = R_1 + R_2 + R_3$

STEP 2
SUBSTITUTE IN VALUES FOR TOTAL RESISTANCE R AND THE OTHER RESISTORS
$60\Omega = 30\Omega + R_2 + 10\Omega$

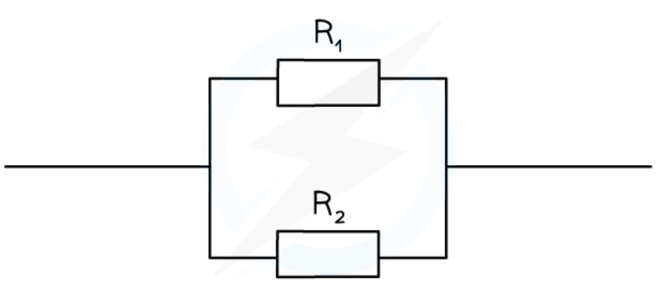
STEP 3
REARRANGE FOR R_2
$R_2 = 60\Omega - 30\Omega - 10\Omega$
$R_2 = 20\Omega$

Combining Resistors in Parallel

- When two or more component are connected in parallel:

  The reciprocal of the combined resistance is the sum of the reciprocals of the individual resistances

- For example, for two resistors connected in parallel:



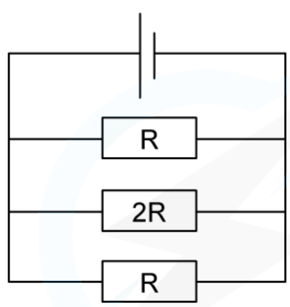
COMBINED RESISTANCE IN PARALLEL $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots$

Combined resistance of two or more resistors in parallel equation

- This means the combined resistance decreases and 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

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.** $\frac{2R}{5}$

Your notes

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

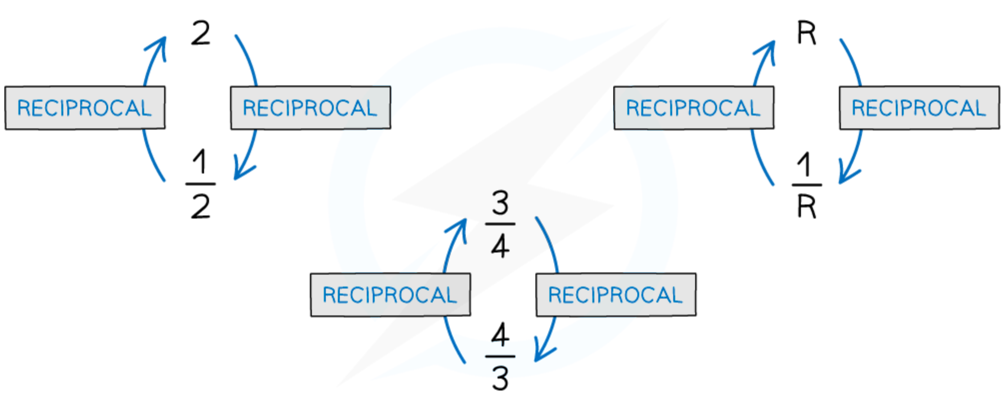
R_T IS THE RECIPROCAL OF $\frac{1}{R_T}$

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 reciprocal of R_T
- The reciprocal of a value is 1 / value
- For example, the reciprocal of a whole number such as 2 equals ½
    - The reciprocal of ½ is 2
- If the number is already a fraction, the numerator and denominator are 'flipped' round



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

Your notes

Your notes

Series & Parallel Circuits

Analysing Series & Parallel Circuits

Current

- In a **series** circuit, the current is the **same** for all components
- In a **parallel** circuit, the current is split across the different branches (or junction). The total current into a junction must equal the total current out of a junction
  - The amount of current in each branch depends on the total resistance of the components within that branch

Potential Difference

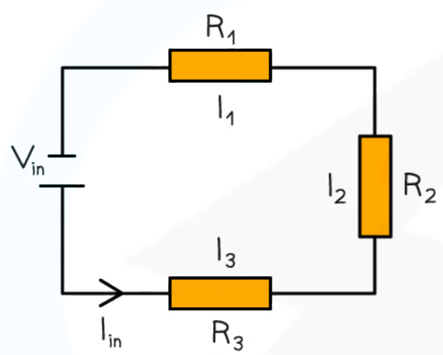
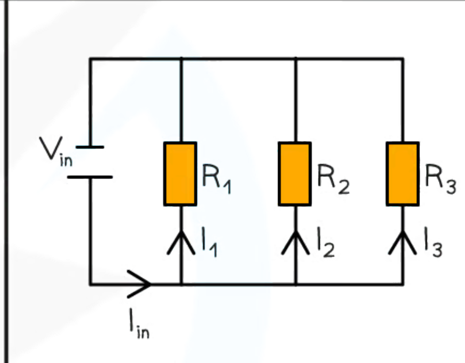
- In a **series** circuit, the e.m.f of the power supply is shared amongst all the components in different amounts, depending on their resistance
- In a **parallel** circuit, the voltage of all the components in each branch is equal to the e.m.f of the power supply

Summary

- A summary of the current, voltage and resistance within a series and parallel circuit are summarised below:

Table of Voltage, Current & Resistance in Series & Parallel Circuits

Your notes

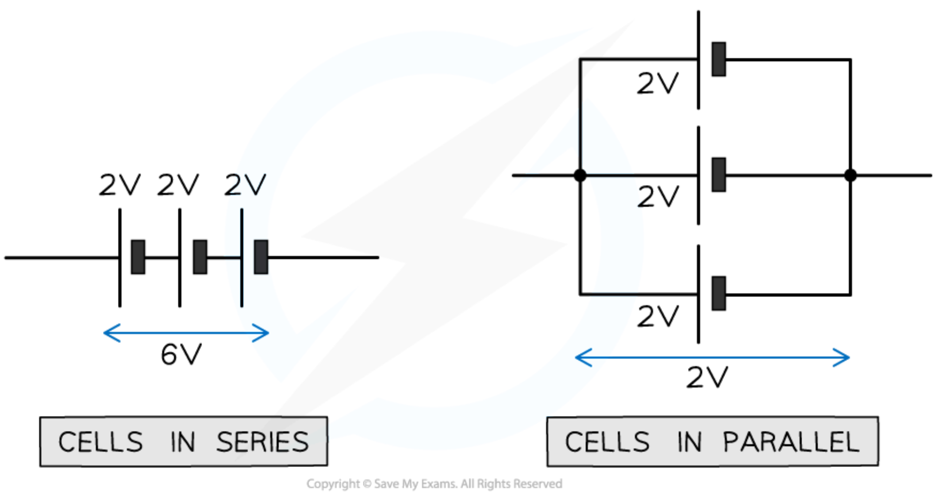
	Series	Parallel
Circuit		
Voltage	$V_{in} = V_1 + V_2 + V_3$	$V_{in} = V_1 = V_2 = V_3$
Current	$I_{in} = I_1 = I_2 = I_3$	$I_{in} = I_1 + I_2 + I_3$
Resistance	$R_{total} = R_1 + R_2 + R_3$	$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

Circuits with Multiple Sources of e.m.f

Your notes

Circuits with Multiple Sources of e.m.f

- More complex circuit problems may include circuits with two or more sources of e.m.f
  - This is often from multiple cells
- Cells can also be connected in **series** or **parallel**
- The total voltage of the combined cells can be calculated in the same way as voltage
  - If the cells are connected in **series**, the total voltage between the ends of the chain of cells is the sum of the potential difference across each cell
  - If the cells are connected in **parallel**, the total voltage across the arrangement is the same as for one cell



- The important part is making sure current flowing in one direction (from positive to negative) is taken as positive and the current flowing in the opposite direction as negative

Aims of the Experiment

- The aim of the experiment is to investigate circuits with more than one source of e.m.f (batteries)
- The total potential difference measured in a series and parallel circuit should be similar to the calculated total potential difference of the circuit

Variables:

Your notes

- Independent variable = Potential difference of the cells, V_{total}
- Dependent variable = Potential difference of the resistor, *V*

Equipment List

- Cells
- Leads
- Voltmeter
- Resistor
- Resolution of measuring equipment:
  - Voltmeter = 0.1 V

Method

1. Set up a circuit with two cells in series. They can be of any voltage but preferably low (eg. 5 V) with a fixed resistor. Connect a voltmeter around the resistor
2. Record the voltage across the resistor, as the resistor is the only

   component this will be the potential difference supplied by the cells
3. Swap at least one of the cells to one with a higher voltage
4. Record the reading on the voltmeter again
5. Repeat this for 3–5 voltage readings for the resistor
6. Set up a circuit now with the two cells in parallel. Still, connect a voltmeter around the resistor
7. Record the voltage across the resistor
8. Replace the batteries with two batteries with a different voltage, still in parallel. They both must have the same voltage
9. Repeat the experiment for 3–5 voltage readings for the resistor

Analysis of Results

- The expected combined potential difference (p.d) for each battery combination is calculated by the following:
  - In **series**: Combined p.d is the sum of their individual voltages

$$V_{total} = V_1 + V_2 + \dots V_n \text{ for n sources of e.m.f}$$

  - In **parallel**: Combined p.d is the same as the p.d of each battery

- Compare the results of the p.d across the resistor to its expected combined p.d

- In parallel, the resistor will have the same p.d as the batteries because their terminals are at the same point. Therefore, the potential between those two points are still the same
- The 2 batteries connected in parallel should **not** be different voltages
  - The one with the higher voltage will discharge into the one of lower until they are equal which can cause wires to be burnt, creating sparks when connecting the cells
  - This can cause overheating and failure of both batteries

Evaluating the Experiment

Systematic Errors:

- Make sure the voltmeter starts from 0, to avoid a zero error

Random Errors:

- The internal resistance of the cells will affect the reading on the voltmeter, so the p.d calculated may not be exactly as predicted
- If the circuit is not disconnected between each reading, the resistance of the components could be affected by the temperature rise in the components
- Repeat readings over a wide range of voltages will produce a more reliable result

Safety Considerations

- When there is a high current, and a thin wire, the wire will become very hot. Make sure never to touch the wire directly when the circuit is switched on
- Switch off the power supply right away if you smell burning
- Make sure there are no liquids close to the equipment, as this could damage the electrical equipment
- The components will get hot especially at higher voltages. Be careful when handling them
- Disconnect the power supply in between readings to avoid the components heating up too much