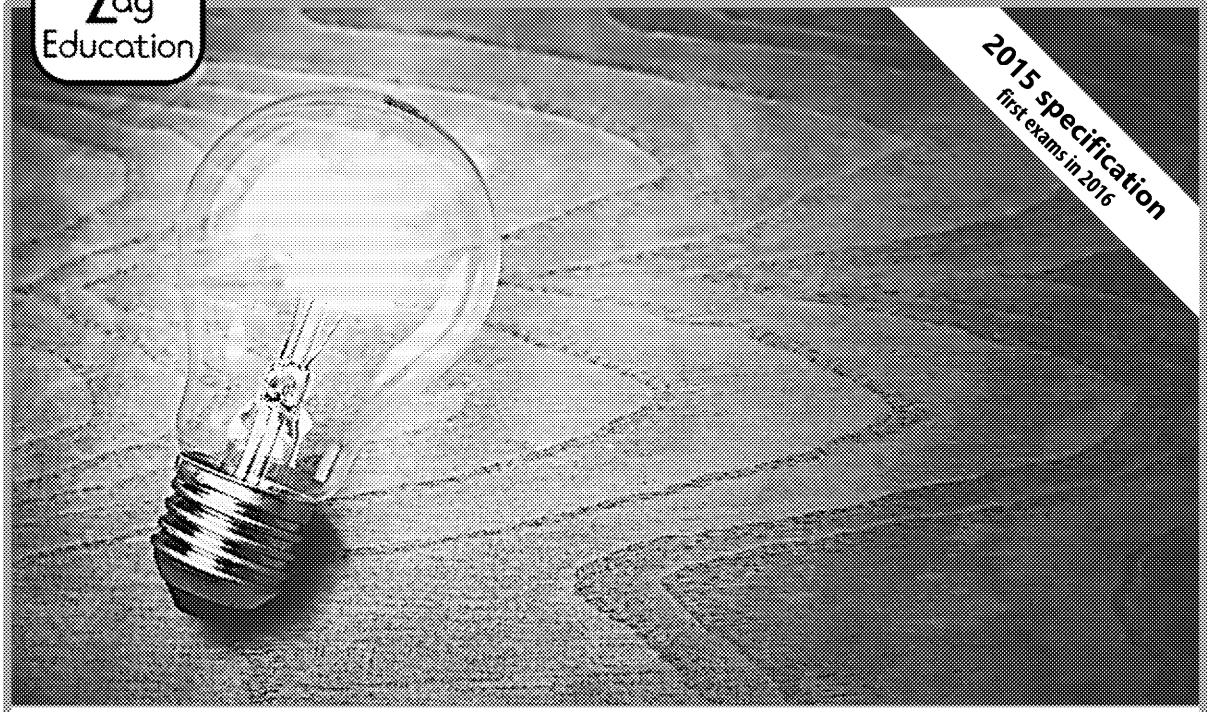
Physics

AS | AQA | 7407/7408



Topic Review for AS AQA Physics

Section 5: Electricity

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POD
7592

Contents

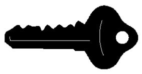
Teacher's Introduction

This Topic Review covers the first half of the AQA Physics A Level and the AQ
is for this review to go over the topics in the specification in a focused but com
students to consolidate their learning and to prepare for their exams. The reso
each small topic to allow students to test their understanding and ability to ap
Worked answers are included with the questions so students can check their a
gone wrong.

Each section of the review starts with a checklist of all the topics in the section, a
to know about the topic before moving on. This can be used as a self-assessmen
students know where to focus their time, or at the end to ensure they have no g

Worked examples are provided for calculations throughout (including deriva
giving students not only knowledge of the appropriate facts and equations, b

Exam style questions are provided for each topic, so that students can test th
their upcoming exams. These exam style questions have worked mark sche
used by the exam board, so that students can check their own answers and s



Key equations and definitions are highlighted with a key sy

Equations in the data booklet are marked with a star so stud
memorise and what they can refer to the data book for in th

Required practicals are covered in the appropriate topic, en
understanding of how to perform the practical, and underst
practical itself.

Exam tips are included regularly throughout to help studen
common mistakes and to give students a steer on things the
in revision.

Students should be able to work through this review in their own time, aft
topic in lessons, or during revision. I would be a great accompaniment for
revision notes or an easy reference text as they do practice papers.

I hope that this review will be of real benefit.

Chapter 5: Electricity

Chapter 5 checklist

By the end of this chapter you should be able to:

5.1

- Understand current as flow of charge...
- Understand potential difference as work done per unit charge ....
- Calculate current, potential difference and resistance ....

5.2

- Understand current-voltage characteristics of ohmic conductors, diod
- Understand Ohm's law ....
- Understand that ideal ammeters have zero resistance ....
- Understand that ideal voltmeters have infinite resistance.........................

5.3

- Understand and calculate resistivity...
- Understand the effect of temperature on the resistance of metals and t
- Remember some applications of thermistors...
- Understand superconductivity ....
- Remember some applications of superconductors ....

5.4

- Calculate the total resistance of resistors in series and parallel circuits .
- Understand the relationships between current, potential differences a and parallel circuits ....
- Calculate the energy and power of circuits..
- Understand the conservation of charge and energy in DC circuits...........

5.5

- Understand how a potential divider works and what they are used for .
- Calculate output voltages of a potential divider..
- Design circuits using potential dividers ....

5.6

- Understand what is meant by emf, terminal potential difference and i
- Perform calculations involving cells with non-negligible internal resis

5.1 Basics of electricity

The modern world uses electricity all the time for communication, transport, i
electrical appliances work using the same basic electrical quantities – **current**,
resistance.

Current is the rate of flow of charge, or how quickly charge (carried by electro
component.

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

Potential difference (sometimes called **voltage**) is the work done per unit cha
energy that can be transferred by a component.

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

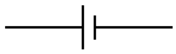
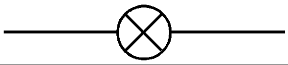
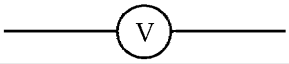
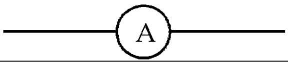
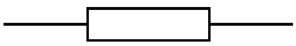
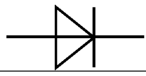
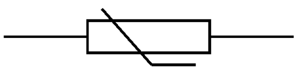
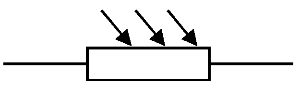
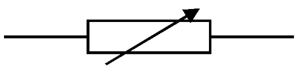
Resistance is a characteristic of a component that describes how much the com
through it.

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

Electrical components

The table below shows some common components and the symbols we use to

This list isn't comprehensive, but covers a lot of the components you'll need i

Component	Symbol	
Cell		Pr
Lamp		
Voltmeter		M
Ammeter		
Resistor		
Switch		Cl C
Diode		Al
Thermistor		
LDR (light dependent resistor)		C
Variable resistor		Re

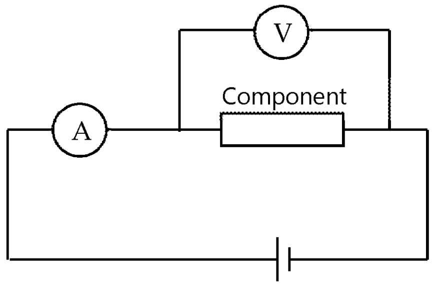
A **battery** is multiple cells connected together.

Measuring resistance

To determine the resistance of a component we need to measure the poten
component and current through the component.

To measure **potential difference** across the component we place a **voltme**
component.

To measure **current** through the component we place an **ammeter** in **serie**



Exam tip

An **ideal voltmeter** has **infinite resistance** so that no current is drawn

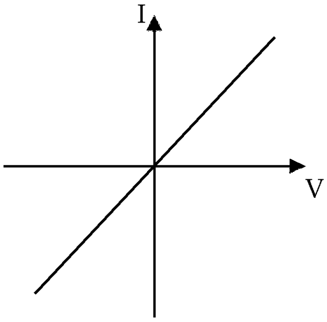
An **ideal ammeter** has **zero resistance** so that there is no potential diff

5.2 Current-voltage characteristics

Key term: Ohmic conductor
An ohmic conductor, such as a wire, is a component for which the potential diffe
relationship, and the resistance is constant.

I–V graphs

Ohmic conductor



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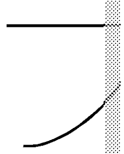
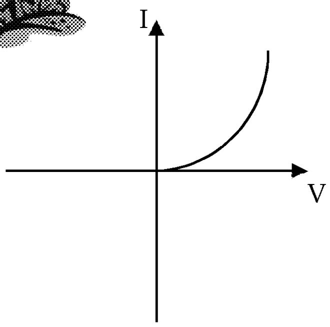
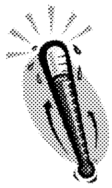


Ohmic conductors follow **Ohm's law**, a special case where $I \propto V$.

For a **filamen**
up as the curr
the resistance i

Semiconductor diode





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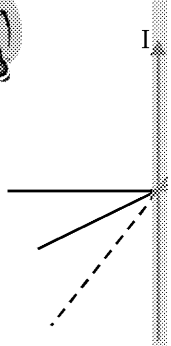


For a **semiconductor diode**, current is zero at negative potential differences.

This is because the semiconductor material is polarised so that current can only flow in one direction.

A **thermistor** is a c
in resistance at hig

A **light dependent resis**
to a thermistor, changin
intensity instead of tem

At higher light intensiti
resistance.

Exam tips

The straight line *I–V* graph for an ohmic conductor is of the form $y =$

So the gradient of the graph is $\frac{1}{R}$, or $\frac{1}{\text{Resistance}}$.

An experiment which measures the current through, and potential difference acro
find the resistance of that component.

Pay close attention to axes!

All the graphs here have current on the y-axis and potential difference on the x-

Questions

1. Draw I–V graphs for an ohmic conductor and a filament lamp. Explain the shapes of both.
2. a) 2.88×10^{20} electrons pass through a resistor every minute. Calculate the current passing through the resistor. The charge on an electron is 1.60×10^{-19} C

   b) 750 kJ are used to transfer the electrons in the question abo Calculate the potential difference across the resistor.

   c) Calculate the resistance of the resistor.
3. Lightning strikes a tree, passing through the tree to the ground in The resistance of wet wood is 8.09×10^{5} Ω and the lightning strik difference across the tree of 3.26×10^{9} V.

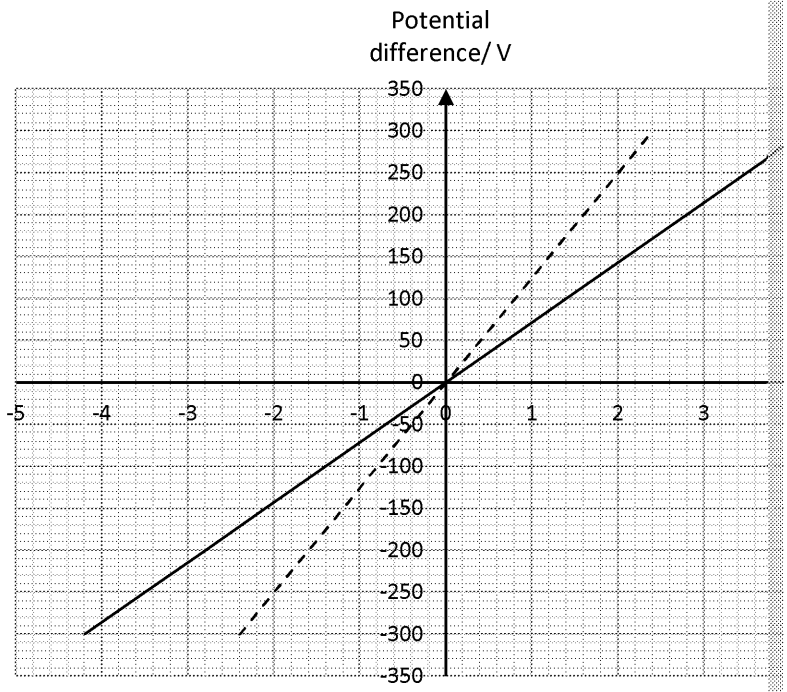
   a) What is the current passing through the tree?

   b) How much charge travels through the tree?

   c) How much energy does the lightning transfer to the tree?
4. The graph below shows an I–V graph of an LDR at two light inten

   a) Find the resistance of the LDR at each light intensity.

   b) Which line represents a higher light intensity?



5.3 Resistivity

Key term: Resistivity

Resistivity, ρ, is the property of a material that determines how much it restricts

Resistivity is different from resistance because resistance is a property of an en volume, while resistivity takes into account the material only.

Resistivity is given by:

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

ρ = resisti
R = resista
A = cross-
L = length

Resistivity and temperature

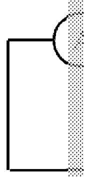
In **metal conductors**, resistivity increases with higher temperatures. The v higher temperatures cause the conduction electrons to collide with the ato the conduction electrons lose energy.

Thermistors are components that decrease in resistivity with higher temperatures. This is because the greater energies at higher temperatures liberate electrons from the atoms they are bound to, so the number of char carriers increases.

Thermistors can be used in a variety of circuits that require temperature de temperature sensors or thermostats.

Determining resistivity of a wire

- Set up a circuit, as seen to the right, with a wire between the terminals of the voltmeter.
- Take readings of current and potential difference from the ammeter and voltmeter, respectively.
- Measure the length of the wire.
- Use a **micrometer** to take a measurement of the radius of the wire.
- Repeat the measurements for other lengths and thicknesses of wire and average the results.



Analysis

- Calculate resistance from $R = \frac{V}{I}$
- Calculate area of the wire from $A = \pi r^2$
- Calculate resistivity from $\rho = \frac{RA}{L}$

Example

A copper rod has a resistance of 9.45 μΩ. The rod is 4.5 cm long and has an are
What is the resistivity of copper?

To find resistivity, use $\rho = \frac{RA}{L}$.

First, all units need to be converted to SI units so that they are consistent
$R = 9.45\ \mu\Omega = 9.45 \times 10^{-6}\ \Omega$
$L = 4.5\ \text{cm} = 4.5 \times 10^{-2}\ \text{m}$
$A = 80\ \text{mm}^2 = 80 \times (10^{-3})^2 = 80 \times 10^{-6}\ \text{m}^2$

$$\rho = \frac{9.45\times10^{-6}\times80\times10^{-6}}{4.5\times10^{-2}}$$

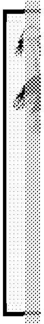
$$\boldsymbol{\rho = 1.68 \times 10^{-8}\ \Omega\ \text{m}}$$

Superconductors

A **superconductor** is a material with **zero resistance**.
A material will only become superconductive **at or below a certain tempe** **temperature**, which is different for different materials.

Producing superconductors is incredibly difficult, requiring temperatures materials maintain their superconductivity is even harder; as soon as the m critical temperature it will stop acting as a superconductor.

Material	Critical temperature/ K
$HgBa_2Ca_2Cu_3O_8$	134
Yttrium barium copper oxide ($YBa_2Cu_3O_{7-x}$)	92
Magnesium diboride (MgB_2)	39
Niobium (Nb)	9.26
Tin (Sn)	3.72
Titanium (Ti)	0.39



Uses of superconductors

Superconductors have some incredible properties – because they have no resistance, there is no power loss when they carry a current.
Superconductors could revolutionise how we transmit energy from pow plants to homes and businesses, as well as allow us to make generators and motors more efficient.

Superconductors can be used to generate incredibly strong magnetic fiel These magnetic fields can be used in MRI scanners and to contain and direct the incredibly high energy particle beams used in particle accelerators.

Magnetic fields can't penetrate superconductors. Instead, the magnetic field lines wrap around the superconductor and produce a repulsive magnetic force.

This effect is used in the "MagLev" train – a train that rests above the tracks so that it can travel with no friction.

Questions

1. a) A metal wire is in a circuit, with its resistance measured.
The wire is placed into a beaker of water which is heated.
Describe how the resistance of the wire changes as the tempe
why this is.

   b) The metal wire is replaced with a thermistor, and again plac
which is then heated.
Describe how the resistance of the thermistor changes as th
Explain why this is.

   c) Draw a circuit that could be used to measure the resistivity o
explain how it would be used.

2. A wire has a resistance of 78.4 kΩ, and is 22.9 cm long with a cro
mm^2.
What is the resistivity of the wire?

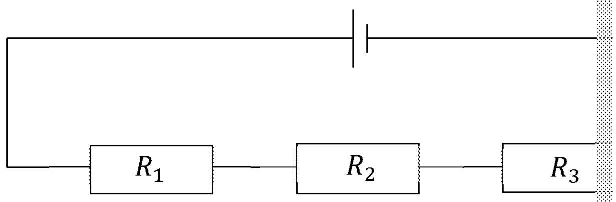
3. a) Define what is meant by superconductor and describe the p
superconductor.

   b) List some of the applications of superconductors.

5.4 Circuits

Components in a circuit can either be set up in **series** or in **parallel**.

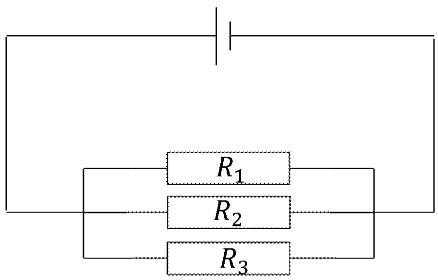
Series



The combined resistance of resistors in series is given by:

$$\boldsymbol{R_{total} = R_1 + R_2 + R_3 + \cdots}$$

Parallel



The combined resistance of resistors in parallel is given by:

$$\boldsymbol{\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots}$$

	Series	
Current	The current is the **same** at all points of a series circuit $I_1 = I_2 = I_3 = \cdots$	The current is ... I_{tot}
Potential difference	The potential difference is **split** across all components in a series circuit $V_{total} = V_1 + V_2 + V_3 + \cdots$	The potentia branch

Exam tip

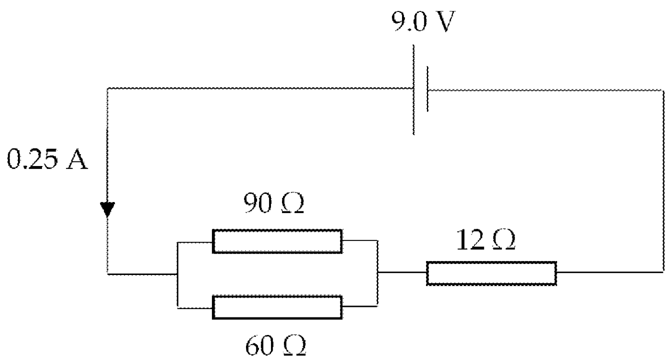
Think of current in terms of flow and potential difference in terms of e

In a series circuit, the flow is the same throughout, it can't go through i takes a little bit of energy.

In a parallel circuit, the flow has to split up across different branches, but the tw same difference in energy.

Example

Three resistors are placed in a circuit, as seen below:



a) What is the potential difference across the 12 Ω resistor?
b) What is the current through the 60 Ω resistor?
c) What is the total resistance of the circuit?

a) The two parallel resistors act as a single resistor, in series with the 1
In a series circuit, the current is the same at all points, so the current th
The potential difference across the resistor is $V = IR = 0.25 \times 12 = 3$

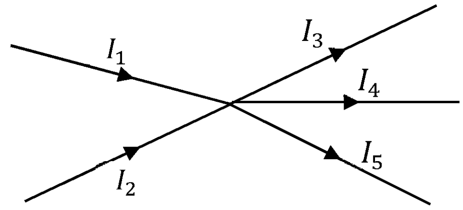
b) The potential difference across the two resistors in parallel is 6 V (9
across **both** resistors.
$I = \frac{V}{R} = \mathbf{0.1\ A}$

c) For the resistors in parallel:
$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{60} + \frac{1}{90} = \frac{1}{36}$
$R_{total} = 36\,\Omega$

We can treat the resistors in parallel as a single resistor in series wit
$R_{total} = R_1 + R_2 = 36 + 12 = \mathbf{48\,\Omega}$

Conservation in circuits

At a junction in a circuit, the current into the junction must equal the curre
due to **conservation of charge**.



For a complete loop of a circuit, the potential difference gained by the sou
difference drops around the circuit. This is due to **conservation of energy**

Energy in a circuit

The energy transferred to a component is given by:

$$\boldsymbol{E = IVt}$$

As power is the rate of transfer of energy, the power of a component is giv

$$\boldsymbol{P = IV}$$

which, using $V = IR$, can be made into different forms.

$$\boldsymbol{P = I^2R}$$

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

E = energy t
P = rate of e
t = time
I = current
V = potenti
R = resistan

Example

1. *A battery provides 12 V and has 0.080 A through it. How much energy is di hour?*

   In this question, current, potential difference and resistance have been is needed.
   Use $E = IVt = 0.080 \times 12 \times 30 \times 60 = \mathbf{1.72\ kJ}$

2. *What is the power dissipated by a 28 kΩ resistor with 4.0 A flowing throug*

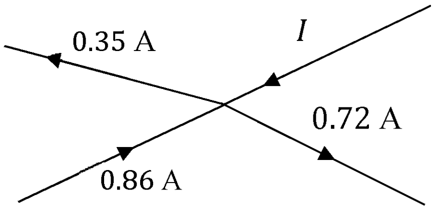
   In this question, resistance and current have been given and power is
   Use $P = I^2R = 4.0^2 \times 28 \times 10^3 = \mathbf{450\ kW}$

3. *A bulb has a power rating of 40 W, and has 230 V across it.*
   What is the resistance of the bulb?

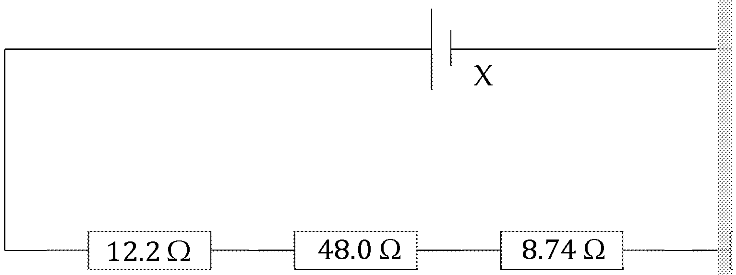
   In this question, power and potential difference have been given, and
   Use $P = \frac{V^2}{R}$ and rearrange for R to give $R = \frac{V^2}{P} = \frac{230^2}{40} = \mathbf{1300\ \Omega}$

Questions

1. The diagram below shows a node in a circuit.



Calculate the value of I.

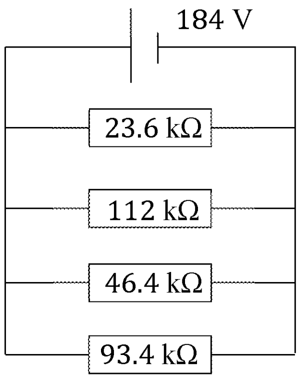


2. a) What is the total resistance in this circuit?

   b) The current at the point marked X is 0.38 A.

   What is the potential difference supplied by the cell?

3.



   a) What is the total resistance of this circuit?

   b) The potential difference supplied by the cell is 184 V.

   What is the total current supplied by the cell?

4. a) A phone charger draws a current of 866 mA and has a pote
   20.6 V.

   Calculate the power in the circuit

   b) How much energy is transferred to the charger in 1 hour?

5. a) A kettle has a potential difference across it of 230 V.
   It has a power rating of 1730 W.
   Calculate the resistance of the kettle.

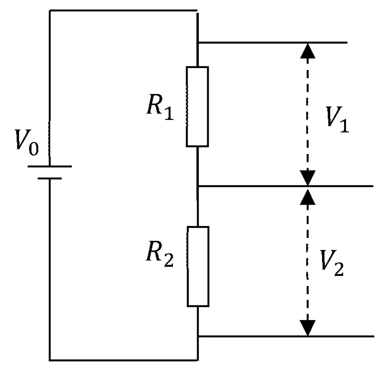
   b) The bulb in a handheld torch has a resistance of 3.46 Ω and
   What is the current drawn by the bulb?

5.5 Potential dividers

Key term: Potential divider

A **potential divider** uses two resistors to provide a specific voltage. The potenti
two resistors depending on their resistances. The voltage across one resistor can b
with a resistor with a different value of resistance.

The set-up below shows a potential divider that gives a fixed potential diff



The total resistance of the two resistors is given by $R_{total} = R_1 + R_2$.

As the resistors are in series, the current in both resistors is the same and is

$$I = \frac{V}{R} = \frac{V_0}{R_1 + R_2}$$

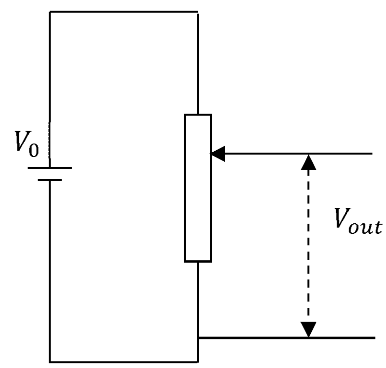
Using $V = IR$, we can find the potential differences across each resistor.

$$\boldsymbol{V_1 = IR_1 = \frac{V_0 R_1}{R_1 + R_2}}$$

$$\boldsymbol{V_2 = IR_2 = \frac{V_0 R_2}{R_1 + R_2}}$$

By choosing resistors of specific values, we can select the output potential d

A **variable potential divider** uses a variable resistor, so that the circuit can
potential differences.

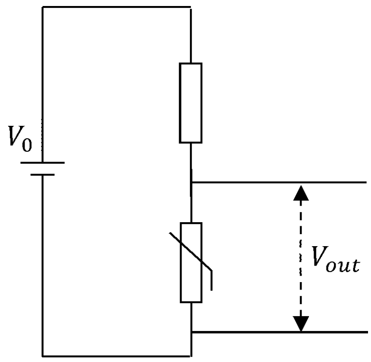


Applications of potential dividers

Potential dividers can be used as follows:
- Many digital electronics require specific potential differences to run
  ensure a fixed voltage of a specific value.
- Scaling down a high voltage for easier measurement with a voltmete
- Sensing temperature or light by using a thermistor or LDR.

Sensors

A **thermistor** in a potential divider can be used to create a temperature sen



At a given temperature, the potential diff resistor and thermistor.

When the temperature increases, the resi decreases and the potential difference ac

The potential difference can be measured temperature sensor.

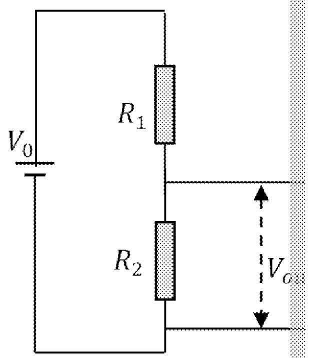
If the sensor only had the thermistor and would always have the same potential di

A light dependent resistor (LDR) can be used in place of a thermistor to cr (The resistance of the LDR decreases as light intensity increases.)

Example

Design a circuit which provides a fixed voltage of 8.0 V, using a battery which p and one other resistor.

The best option for a circuit like this is a potential divider.



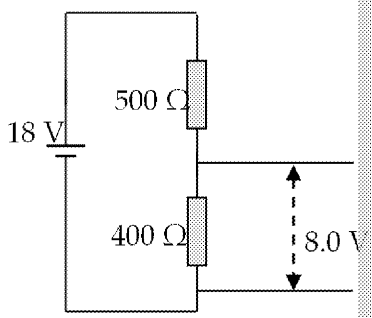
Call the 500 Ω resistor R_1 and the other resistor R_2. 8.0 V can be produce this case it is being produced across R_2.

Start with $V_{out} = \frac{V_0 R_2}{R_1+R_2}$ and rearrange for R_2 to give $R_2 = \frac{V_{out}R_1}{V_0 - V_{out}}$

Make sure that you can do this rearrangement!

$R_2 = \frac{8.0\times500}{18-8.0} = \mathbf{400\ \Omega}$

So the circuit we've designed is:



5.6 Electromotive force and internal resistance

The **electromotive force (emf)** of a cell is the potential difference supplied

The emf is defined as the energy supplied per unit charge.

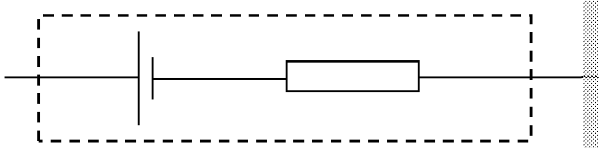
$$\boldsymbol{\varepsilon = \frac{E}{Q}}$$

The **internal resistance** of the cell is the resistance supplied by the cell its
there is a loss of potential difference in the cell as the current passes throu

$$\boldsymbol{\varepsilon = I(R + r)}$$

The terminal potential difference, given by Ir, is the potential difference th

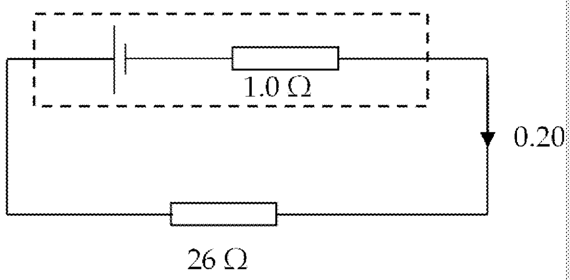
Internal resistance is shown in a circuit diagram by a cell with a resistor in s
both, as shown below.



The power delivered by a cell is given by:

$$\boldsymbol{P = I\varepsilon}$$
$$\boldsymbol{P = I^2R + I^2r}$$

Example



a) What is the emf of the cell seen above?
b) What is the power delivered by the cell in the above circuit?

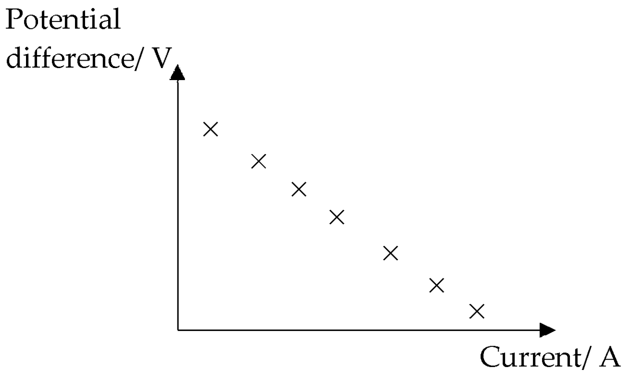
a) Use $\varepsilon = I(R + r)$
$\varepsilon = 0.2 \times (26 + 1.0)$
$\varepsilon = \mathbf{5.4\ V}$

b) Use $P = I^2R + I^2r$
$P = 0.2^2 \times 26 + 0.2^2 \times 1.0 = \mathbf{1.08\ W}$

Note: $P = I\varepsilon$ could also have been used for the same result.

Investigation of emf and internal resistance of a battery

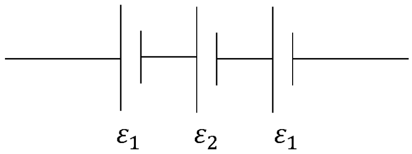
- Set up a circuit, as seen to the right.
- Take readings of current and potential difference from the ammet and voltmeter, respectively.
- Change the resistance of the variable resistor.
- Plot potential difference against current for different resistances, giving a graph like the one below.



- We can substitute $V = IR$ into the equation for the emf of a cell, $\varepsilon =$ and rearrange to give $V = \varepsilon - Ir$, which is in the form $y = mx + c$.
- The y-intercept, where the graph crosses the y-axis, is ε, the termina cell.
- The gradient of the graph is $-r$, where r is the internal resistance of t

Cells in series and parallel (from section 5.4)

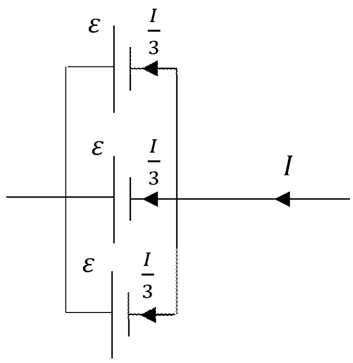
Series



For cells in series, the total emf provided by the cells to the circuit is the su
emf.

$$\boldsymbol{\varepsilon_{total} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \cdots}$$

Parallel



For n identical cells in parallel, each with an emf of ε and an internal resist
each cell is given by $\frac{I}{n}$ where n is the number of cells.

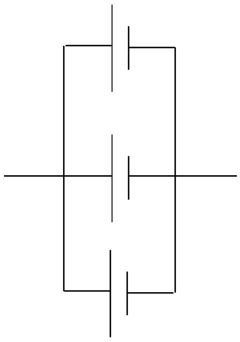
The internal resistance of each cell causes a potential difference drop acros
potential difference supplied by each cell is:

$$\text{Potential difference across the circuit} = \text{emf of cell} - \frac{\text{potential differe}}{\text{nu}}$$

$$\boldsymbol{IR = \varepsilon - \frac{Ir}{n}}$$

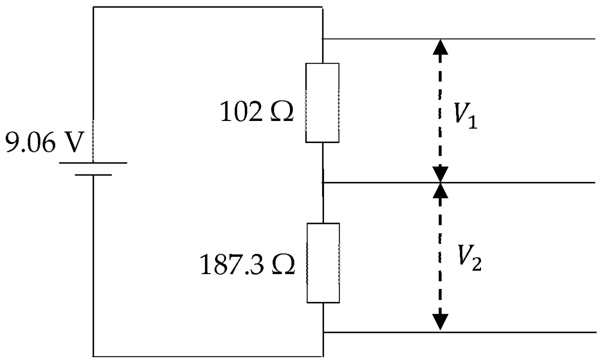
Questions

1. A cell supplies 38.6 J of energy to 2.46×10^{22} electrons.
   What is the emf produced by the cell?
   The charge on an electron is 1.60×10^{-19} C.

2. 

   Each cell in the battery above produces an emf of 4.73 V and h
   18.7 Ω.
   The battery is connected up to a circuit with a resistance of 58.5
   What is the current flowing through the circuit?

3. A circuit has a resistance of 12.2 Ω.
   The potential difference in the circuit is supplied by a cell which
   and the current in the circuit is 3.11 A.
   What is the internal resistance of the cell?

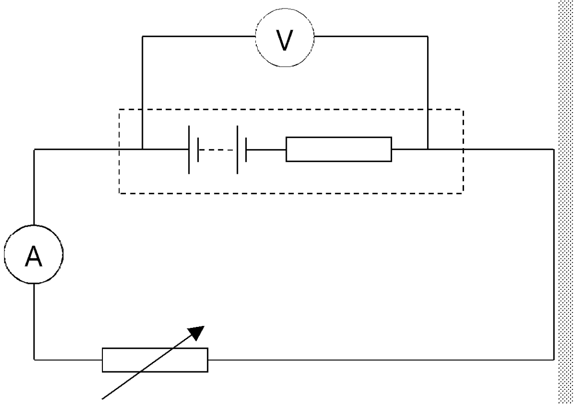
4. 

   Calculate the values of V_1 and V_2 in the circuit above

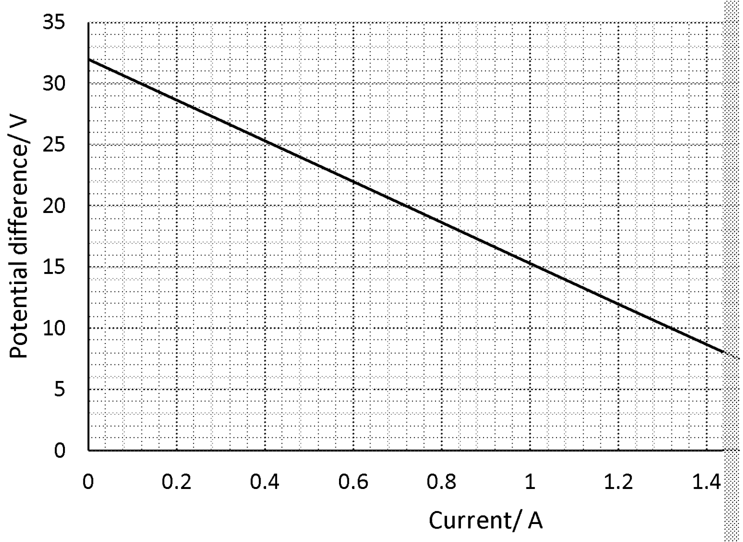
5. Design a circuit which will turn off a heater when the temperatu
   The heater should be designed such that it will turn off when it is su
   below 20 V.
   In the circuit, use a power source which supplies a potential diffe
   thermistor which has resistance of 30 Ω at 20 °C.

Exam style questions

1. **A circuit is setup to determine the properties of a battery, as seen be**



The resistance of the variable resistor is changed and the data shown collected.



1.1 Describe what is meant by the term "internal resistance".

1.2 What is the terminal potential difference of the battery in the circu

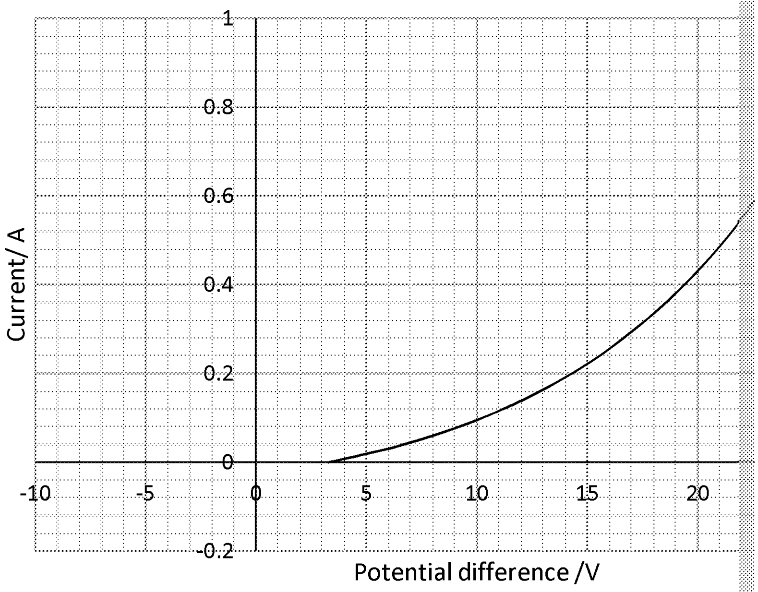
1.3 Calculate the internal resistance of the battery.

1.4 Why is the voltage provided by the battery always less than the te difference of the cell?

1.5 The resistance is set so that the current through the battery is 0.8 A How much energy is dissipated by the battery during this 5 minu

1.6 Calculate the amount of charge that passes through the cell durin of time detailed in 1.5.

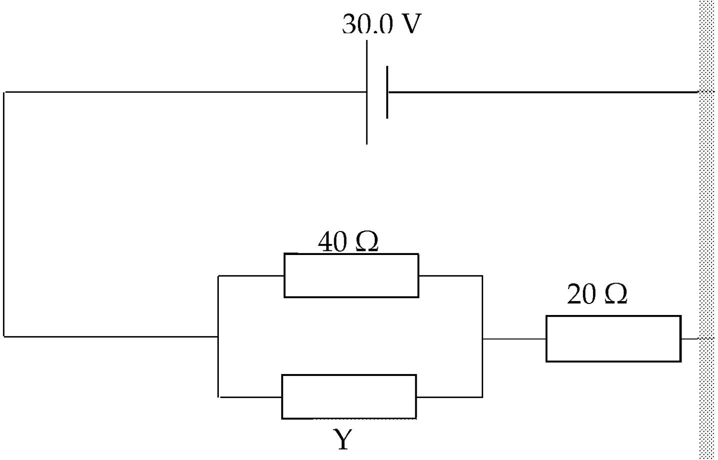
2. The graph of current against potential difference for Component W i



2.1 Calculate the resistance of Component W when a current of 0.6 A i through it.

2.2 What type of component has generated this graph? Explain.

Component Y is placed in the circuit below as shown.



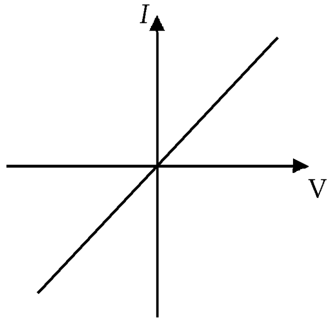
2.3 Calculate the value of resistor Y.

2.4 Resistor Y breaks, such that no current flows through it. Describe the current through each of the other resistors in the circuit.

Answers

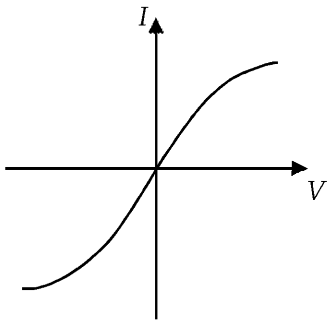
5.2 Current-voltage characteristics

1. Ohmic conductor



An ohmic conductor is a component with constant resistance i.e. current is prop

Filament lamp



At higher currents, a filament lamp heats up, increasing its resistance.

2. a) $Q = \text{number of electrons} \times e$
$Q = 2.88 \times 10^{20} \times 1.60 \times 10^{-19} = 46.08\ \text{C}$
$I = \frac{\Delta Q}{\Delta t} = \frac{46.08}{60}$
$I = 0.768\ \text{A}$

b) $V = \frac{W}{Q} = \frac{750 \times 10^3}{46.08} = 16.28\ \text{kV}$
$V = 16.3\ \text{kV}$

c) $R = \frac{V}{I} = \frac{16.28 \times 10^3}{0.768}$

$R = 21.2\ \text{k}\Omega$

3. a) $I = \frac{V}{R} = \frac{3.26 \times 10^9}{8.09 \times 10^5} = 4029\ \text{A}$
$I = 4.03\ \text{kA}$

b) $\Delta Q = I\Delta t = 4.029 \times 10^3 \times 0.239 = 963.1\ \text{C}$
$\Delta Q = 963\ \text{C}$

c) $W = QV = 963.1 \times 3.26 \times 10^9$
$W = 3.14 \times 10^{12}\ \text{J}$

4. a) Resistance = gradient of line = $\frac{\Delta y}{\Delta x}$

Dashed line
Resistance = $\frac{\Delta y}{\Delta x} = \frac{250-0}{2.00-0}$
Resistance = $125\ \Omega$

Solid line
Resistance = $\frac{\Delta y}{\Delta x} = \frac{285-0}{4.00-0}$
Resistance = $71.2\ \Omega$

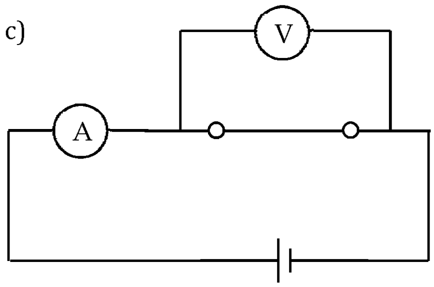
b) The solid line represents the higher light intensity – the resistance of LDRs d

5.3 Resistivity

1. a) The resistance of the wire increases as the temperature increases. Conduc… frequently with atoms at higher temperatures due to the vibrations of the a… electrons to lose energy.

   b) The resistance of the thermistor decreases as the temperature increases. A… more energy, bound electrons gain enough energy to leave the atom, so the… to conduct electricity.

   c)



   Potential difference measured with voltmeter. Current measured with ammete…
   Measure length and radius of component. Calculate area from radius.
   Calculate resistivity from $\rho = \frac{RA}{L}$.

2. $\rho = \frac{RA}{L} = \frac{78.4\times10^{3}\times3.7\times10^{-6}}{22.9\times10^{-2}}$
   $\rho = 1.27\ \Omega\ \text{m}$

3. a) A superconductor is a material with zero resistance.
   Superconductors become superconductive below a certain temperature.
   Superconductors can conduct energy with no power loss and magnetic fiel…

   b) "MagLev" trains; power transmission; particle accelerators; MRI scanners; e…

5.4 Circuits

1. Total current into junction = total current out of junction
   $I + 0.86 = 0.35 + 0.72$
   $I = 0.35 + 0.72 - 0.86 = 0.21\ \text{A}$

2. a) $R_{total} = R_1 + R_2 + R_3 + R_4 = 12.2 + 48.0 + 8.74 + 64.1$
   $R_{total} = 133\ \Omega$

   b) $V_{total} = V_1 + V_2 + V_3 + V_4$
   $V_{total} = IR_1 + IR_2 + IR_3 + IR_4 = IR_{total} = 0.38 \times 133$
   $V_{total} = 50.6\ \text{V}$

3. a) $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{23.6\times10^3} + \frac{1}{112\times10^3} + \frac{1}{46.4\times10^3} + \frac{1}{93.4\times10^3} = 8.356 \times$
   $R_{total} = 12.0\ \text{k}\Omega$

   b) $I_{total} = I_1 + I_2 + I_3 + I_4 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} + \frac{V}{R_4} = \frac{V}{R_{total}} = \frac{184}{12.0\times10^3}$
   $I_{total} = 15.4\ \text{mA}$

4. a) $P = IV = 866 \times 10^{-3} \times 20.6$
   $P = 17.8\ \text{W}$

   b) $E = IVt = Pt = 17.8 \times 60 \times 60$
   $E = 64.2\ \text{kJ}$

5. a) $P = \frac{V^2}{R}$
   $R = \frac{V^2}{P} = \frac{230^2}{1730}$
   $R = 30.6\ \Omega$

   b) $P = I^2R$
   $I = \sqrt{\frac{P}{R}} = \sqrt{\frac{5.85}{3.46}}$
   $I = 1.30\ \text{A}$

5.6 Electromotive force and internal resistance

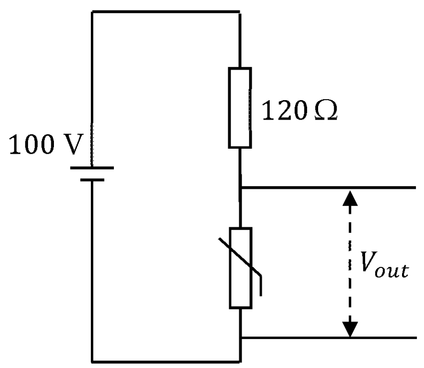
1. $\varepsilon = \frac{E}{Q} = \frac{38.6}{2.46\times10^{22}\times1.60\times10^{-19}}$
   $\varepsilon = 9.81 \times 10^{-3}$ V

2. $IR = \varepsilon - \frac{Ir}{n}$
   $I = \frac{\varepsilon}{R+\frac{r}{n}} = \frac{4.73}{58.5+\frac{18.7}{3}}$
   $I = 73$ mA

3. $\varepsilon = I(R + r)$
   $r = \frac{\varepsilon - IR}{I} = \frac{52.6-3.11\times12.2}{3.11}$
   $r = 4.71\ \Omega$

4. $V_1 = \frac{V_0R_1}{R_1+R_2} = \frac{9.06\times102}{102+187.3}$
   $V_1 = 3.19$ V
   $V_2 = \frac{V_0R_2}{R_1+R_2} = \frac{9.06\times187.3}{102+187.3}$
   $V_2 = 5.87$ V

5. $V_{out} = \frac{V_0R_2}{R_1+R_2}$
   We want $V_{out} = 20$ V, $V_0 = 100$ V, $R_2 = 30\ \Omega$
   $\frac{V_{out}}{V_0} = \frac{R_2}{R_1+R_2}$
   $\frac{20}{100} = \frac{1}{5} = \frac{30}{30+R_1}$
   $R_1 = 120\ \Omega$



Exam style questions

Q1.1	The resistance of the power source in the circuit ✓
Q1.2	32 V ✓
Q1.3	Internal resistance = − gradient of graph ✓ $r = \frac{32-4}{1.68-0}$ $r = 16.7\ \Omega$ ✓
Q1.4	There is always a potential drop across the internal resistance of the battery ✓
Q1.5	(emf = 32 V) $E = \varepsilon \times I \times t$ $E = 32 \times 0.8 \times 5 \times 60$ ✓ $E = 7680\ \text{J}$ ✓
Q1.6	$\varepsilon = \frac{E}{Q}$ $Q = \frac{E}{\varepsilon}$ $Q = \frac{7680}{32}$ ✓ $Q = 240\ \text{C}$ ✓

Q2.1	At $I = 0.6$ A, $V = 22.5$ V $R = \frac{V}{I}$ $R = \frac{22.5}{0.6}$ ✓ $R = 37.5\ \Omega$ ✓
Q2.2	(Semiconductor) diode ✓ No current flows through component below threshold voltage ✓
Q2.3	Potential difference across 20 Ω resistor = $0.6 \times 20 = 12$ V Voltage across resistors in parallel is 18 V ✓ Total resistance of resistors in parallel is: $R_{total} = \frac{V}{I} = \frac{18}{0.6} = 30\ \Omega$ ✓ $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2}$ $\frac{1}{R_2} = \frac{1}{R_{total}} - \frac{1}{R_1}$ $\frac{1}{R_2} = \frac{1}{30} - \frac{1}{40}$ ✓ $\frac{1}{R_2} = \frac{1}{120}$ $R_2 = 120\ \Omega$ ✓
Q2.4	Current through 20 Ω resistor stays the same ✓ Current through 40 Ω resistor increases ✓