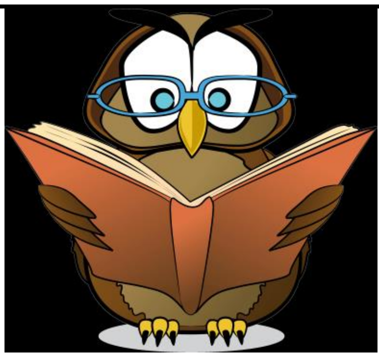


KNOWLEDGE

ST MARY'S SCIENCE DEPARTMENT:

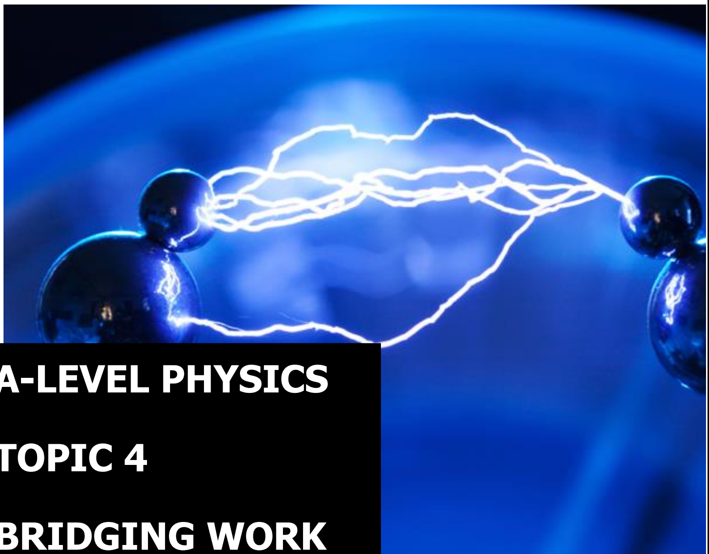
PHYSICS

A LEVEL PHYSICS **YEAR 1**
PREPARATORY READING BOOK
ELECTRICITY

VERSION 1.1

WEEK 3

NAME	
PHYSICS CLASS	



A-LEVEL PHYSICS

TOPIC 4

BRIDGING WORK

THIS MUST BE BROUGHT TO PHYSICS LESSONS AT THE START OF YEAR 12.

Contents

3.5.1.1 Basics of Electricity
3.5.1.2 Current-Potential Difference Characteristics
3.5.1.3 Resistivity

Overview

This bridging course will provide you with a mixture of information about A-level Physics, and what to expect from the course, as well as key work to complete. Students who are expecting to study Physics at A-level, and are likely to meet the entry requirements, must complete the bridging course fully and thoroughly, to the best of their ability.
You should complete all work on paper and keep it in a file, in an ordered way. You will submit it to your teacher in September.

All of the work will be reviewed, and selected work will be assessed, and you will be given feedback on it. This work will be signalled to you. If you do not have access to the internet, please contact the school and appropriate resources will be sent to you.

If you are thinking about studying Physics at A-level, you should attempt this work to see whether or not you think studying a subject like this is right for you. If you later decide to study Physics, you must ensure you complete this work in full.

This work should be completed after you have read and completed the Study Skills work that all of Year 12 should complete.

Course Overview

To successfully achieve a qualification in A-Level Physics students must carry out two years of studies (Year 12 and Year 13) and carry out 3 assessments at the end of the course based on the specification below.

In addition, students must carry out a list of 12 required practical activities that they must carry out. Exam questions will be based on these practicals. 6 practicals will be carried out in Year 12 and 6 practicals will be carried out in Year 13.

If successful, students will receive a practical endorsement along with their A-Level Physics qualification.

First year of A-level

1. Measurements and their errors, including use of SI units and their prefixes, limitations of physical measurement, estimation of physical quantities

2. Particles and radiation, including constituents of the atom, particle interactions, collisions of electrons with atoms.

3. Waves, including progressive waves, interference, diffraction.

4. Mechanics and energy, including projectile motion, Newton's laws of motion.

5. Electricity, including current/ voltage characteristics, circuits, electromotive force and internal resistance.

Second year of A-level

6. Further mechanics and thermal physics, including periodic motion, thermal energy transfer, and molecular kinetic theory model.

7. Fields, including Newton's law of gravitation, orbits of planets and satellites, magnetic flux density.

8. Nuclear physics, including evidence for the nucleus, radioactive decay, nuclear instability.

Plus one option from:

• Astrophysics, including classification of stars by luminosity, Doppler Effect, detection of exoplanets.

• Medical physics, including physics of vision, ECG machines, x-ray imaging.

• Engineering physics, including rotational dynamics, thermodynamics and engines.

• Turning points in physics, including discovery of the electron, Einstein's theory of special relativity.

• Electronics, including discrete semiconductor devices, data communication systems.

Assessment Schedule

To gain a qualification in A Level Physics – you must sit **three** examinations.

Paper 1	+	Paper 2	+	Paper 3
Content • Topics 1 – 5 • and periodic motion		**Content** • Topics 6 – 8		**Content** • Practical skills • Data analysis • Optional topic
Assessment • Written exam: 2 hours • 85 marks • 34% of A-level		**Assessment** • Written exam: 2 hours • 85 marks • 34% of A-level		**Assessment** • Written exam: 2 hours • 80 marks • 32% of A-level
Questions • 60 marks: a mixture of short and long answer questions • 25 marks: multiple choice questions		**Questions** • 60 marks: a mixture of short and long answer questions • 25 marks: multiple choice questions		**Questions** • 45 marks: questions on practical experiments and data analysis • 35 marks: questions on optional topic

The marks awarded on the papers will be scaled to meet the weighting of the components.

Students' final marks will be calculated by adding together the scaled marks for each component. Grade boundaries will be set using this total scaled mark. The scaling and total scaled marks are shown in the table below.

Component	Maximum raw mark	Scaling factor	Maximum scaled mark
Paper 1	85	x1	85
Paper 2	85	x1	85
Paper 3: Section A	45	x1	45
Paper 3: Section B (Astrophysics – option)	35	x1	35
Paper 3: Section B (Medical physics – option)	35	x1	35
Paper 3: Section B (Engineering physics – option)	35	x1	35
Paper 3: Section B (Turning points in physics – option)	35	x1	35
Paper 3: Section B (Electronics – option)	35	x1	35
		Total scaled mark:	250

Aim

In this bridging course, we will outline the basic principles of the four key topics covered in Year 12 Physics.

In each topic, we will start by reviewing the understanding which you gained in GCSE Physics and apply it to more advanced applications found in A-Level Physics.

This is not a comprehensive overview of the A-Level Physics specification, rather a taster on what is covered throughout the course.

This bridging course should give you an experience of the level you will be expected to study at, at the start of Year 12

Important

Please remember to look after your own wellbeing as you work through this bridging course.

Please take regular breaks as you go through this work.

This work should take approximately 5 hours, so should not be completed in one sitting.

Do not worry or panic if there is something challenging or which you do not understand at first. This is completely normal.

If you do not understand a concept after reviewing this work, please contact Mr. Turnbull on his school e-mail address.

WEEK 3: Electricity

RECAP TASK

In the previous week, we looked at key concepts in Waves.

This included looking at the progressive waves, longitudinal and transverse waves, and superposition to produce standing waves.

To recap and assess your understanding, answer the following questions on these topics.

Q1. Explain the differences between an undamped progressive transverse wave and a stationary transverse wave, in terms of (a) amplitude, (b) phase and (c) energy transfer.

Q1.1 Amplitude

[2 Marks]

Progressive Wave

....

....

Stationary Wave

....

....

Q1.2 Phase

[2 Marks]

Progressive Wave

....

....

Stationary Wave

....

....

Q1.3 Energy Transfer

[2 Marks]

Progressive Wave

....

....

Stationary Wave

....

....

Reference: AQA A-Level Physics Legacy Materials

Q2.1 For a sound wave travelling through air, explain what is meant by particle displacement, amplitude, and wavelength.

[4 Marks]

Particle Displacement

....

....

....

....

Amplitude

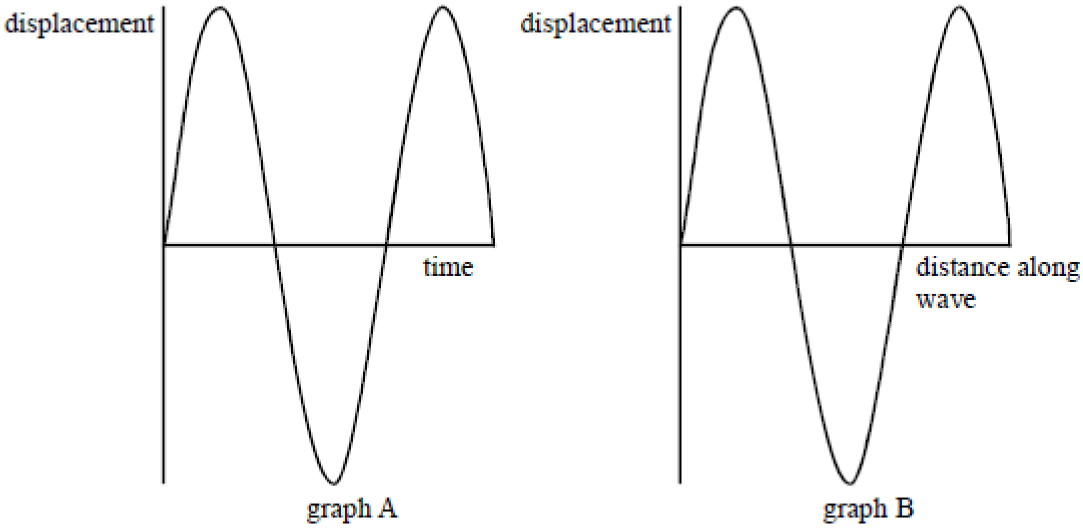
....

....

Wavelength

....

....



Graph **A** shows the variation of particle displacement with **time** at a point on the path of a progressive wave of constant amplitude.

Graph **B** shows the variation of particle displacement with **distance** along the same wave at a particular instant.

Q2.2 Show on graph **A**

[2 Marks]

(1) the wave amplitude, a,

(2) the period, T, of the vibrations providing the wave.

Q2.3 Show on graph **B**

[2 Marks]

(1) the wavelength of the wave, λ,

(2) two points, **P** and **Q**, which are always π/2 out of phase.

Reference: AQA A-Level Physics Legacy Materials

Q3. Figure 1 represents a stationary wave formed on a steel string fixed at **P** and **Q** when it is plucked at its centre.

Figure 1

Q3.1 Explain why a stationary wave is formed on the string.

[3 Marks]

....

....

....

....

Q3.2 The stationary wave in **Figure 1** has a frequency of 150 Hz. The string **PQ** has a length of 1.2 m. Calculate the wave speed of the waves forming the stationary wave.

[2 Marks]

....

....

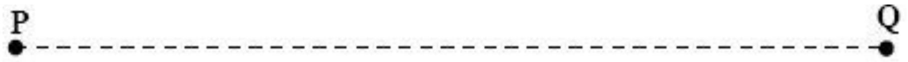
....

Answer ______________________ $m\ s^{-1}$

Q3.3 On **Figure 2**, draw the stationary wave that would be formed on the string at the same tension if it was made to vibrate at a frequency of 450 Hz.

[2 Marks]

Figure 2



Reference: AQA A-Level Physics Legacy Materials

ANSWERS

Q1.

Amplitude: each point along wave **(1)**
has <u>same</u> amplitude for progressive wave
but varies for stationary wave **(1)**

Phase: progressive wave, adjacent points vibrate with different phase **(1)**
stationary wave, between nodes all particles vibrate in phase
[or there are only two phases] **(1)**

Energy transfer: progressive wave, energy is transferred through space **(1)**
stationary wave, energy is not transferred through space **(1)**

Q2.1 displacement is distance of particle **(1)**

from mean [or equilibrium] position **(1)**

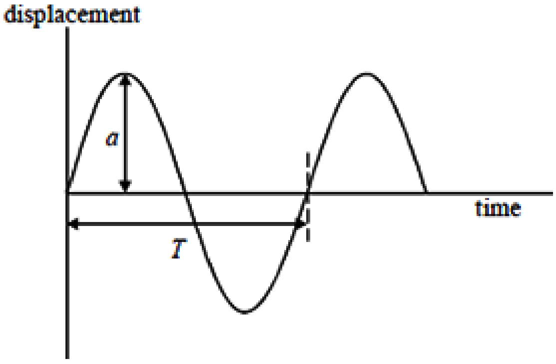
in direction of wave (energy) **(1)**

amplitude is maximum displacement **(1)**

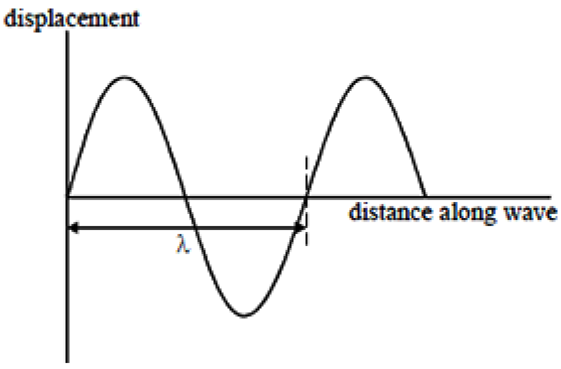
wavelength is shortest distance **(1)**

between two points in phase **(1)**

Q2.2



Q2.3



any two points $\frac{\lambda}{4}$ apart **(1)**

Q3.1 (progressive waves travel from centre) to ends and reflect **(1)**

two (progressive) waves travel in opposite directions along the string **(1)**

waves have the same frequency (or wavelength) **(1)**

waves have the same (or similar) **amplitude (1)**

superposition (accept 'interference') **(1)**

max 3

Q3.2 wavelength (= 2 × PQ = 2 × 1.20 m) = 2.4 m **(1)**

speed (= wavelength × frequency = 2.4 × 150) = 360 m s^{-1} **(1)**

(answer only gets both marks)

Q2.3 diagram to show three 'loops' **(1) and** of equal length and good shape **(1)** (or loop of one third length **(1)**)

4

Definition List

Definitions you must learn for this module.

Key Word	Symbol	Definition
Charge carriers		Charged particles that move through a substance when a pd is applied across it such as electrons.
Current	**I**	The rate of charge carriers moving in an electrical circuit.
Electromotive force (emf),	**ε**	The amount of electrical energy per unit charge produced inside a source of electrical energy.
Ohm's Law		The pd across a metallic conductor is proportional to the current, provided the physical conditions do not change.
Potential Difference	**PD**	Work done or energy transfer per unit charge between two points when charge moves from one point to another.
Power	**P**	The rate of transfer of energy.
Resistance	**R**	The impedance of charge carriers moving in an electrical circuit. = pd/current.
Resistivity	**ρ**	Resistance per unit length x area of cross-section. The impedance of current based on the properties of the material only.
Semi-conductor		A substance in which the number of charge carriers increases when the temperature is raised.
Thermistor		Resistor which is designed to have a resistance that changes with temperature.

Equations

The equations below are used in this module.

Quantity/Concept	Equation(s)
Current/Charge	$I = \frac{\Delta Q}{\Delta t}$ $\Delta Q = I\,\Delta t$
Potential Difference/EMF	$V = PD = \varepsilon = \frac{\Delta W}{\Delta Q}$
Resistance	$R = \frac{V}{I}$
Electrical Power	$P = VI = I^2R = \frac{V^2}{R}$
Electrical Energy Transferred	$E = Vit = \frac{V^2t}{R} = I^2Rt$
Resistivity	$\rho = \frac{RA}{l}$
Cross Sectional Area of Wire	$A = \Pi r^2$ This equation is not given in your examination book.

IMPORTANT

A video of Mr. Turnbull going through this book can be found here.

SCAN ME

VIDEO
COURSE OVERVIEW

To watch a video looking at all of the concepts in electricity, please scan one of the following codes with your smartphone.

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TOPIC: 3.5.1.1 Basics of Electricity
SPEC CHECK

Specification	Completed?
Electric current as the rate of flow of charge; potential difference as work done per unit charge.	
$I = \frac{\Delta Q}{\Delta t}$, $V = \frac{W}{Q}$	
Resistance defined as R = V/I	
Students can construct circuits from the range of components.	

Student Checklist
Complete the following before attempting any work on this section.

Have I…….	Yes or No?
Read through the notes of this section?	
Highlighted/underlined the key concepts of this section?	
Made my own notes based on the notes of this section?	

Complete the above checklist with the notes of each section before you attempt to answer any questions on this section of work.

Definitions

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Electricity.**

Current, I
Electrical current is the rate of flow of charge in a circuit.
Electrons are the most common charged particles that move around the circuit. The electrical current is the rate of the flow of charge carriers (most commonly electrons), not so much the speed but the number of charge carriers moving in the circuit.

Examination Hint: Whilst electrons are the most common type of charge carrier, any particle/molecule which has a charge can be a charge carrier. For example, sodium ions are charged carriers in your body.

If we imagine that electrons are Year 7 students and a wire of a circuit is a corridor, the current is how many students passing in a set time.

Current is measured in Amperes (or Amps), A

Examination Hint: Memorise this base unit of current.

Physics Tip

Remember that conventional current flows from + to -, the opposite way from electron flow.

Physics Tip

When you are doing calculation questions in the exam, do not forget to check your units are correct.

Charge, Q
The amount of electrical charge is a fundamental concept in the Universe, like mass and length and time. The charge is the ability for an object to interact with an (and produce an) electromagnetic field in the Universe.
At GCSE, you used relative charges to describe particle properties.
There are 1.60×10^{-19}C in one relative charge.
The charge on one electron is -1.60×10^{-19} C.

Examination Hint: Memorise the conversion between relative charge and Coulombs.

This means that it takes 6.25×10^{18} electrons to transfer 1C of charge.

Charge is measured in Coulombs, C

Examination Hint: Memorise this base unit of charge.

Physics Tip

When a charge flows through a component, it transfers energy to the component (it does work).

Voltage/Potential Difference/Electromotive Force, V

Voltage is the amount of energy transferred (or work done) per unit charge in a circuit.
There are two types of voltage – potential difference (commonly called pd) and electromotive force (commonly called emf).

Potential difference is the work done per unit charge, where work is being done to transfer **energy out** of a circuit (work out of the circuit). Electromotive force is the work done per unit charge, where work is being done to transfer **energy into** the circuit (work into the circuit).

> **Examination Hint:** Output devices like bulbs have a potential difference across them. This can be thought of as the energy (potential) drop from before the device compared to after the device.
>
> Power supplies like power packs and batteries have a electromotive force across them. This can be though as the energy (potential) increases from before the supply compared to after the device.

1 coulomb of charge is produced in 6.25 x 10^{18} electrons, so we can think of potential difference as the energy given to each of the electrons, or the pushing force on the electrons.

It is the potential difference that causes a current to flow and we can think of it like water flowing in a pipe. If we make one end higher than the other end, water will flow down in, if we increase the height (increase the potential difference) we get more flowing.

If we think of current as Year 7s walking down a corridor, the harder we push them down the corridor the more we get flowing.

> **Examination Hint:** A potential difference will only cause a current when the conductor the potential difference is over is part of a complete circuit.

> **Examination Hint:** Memorise this base unit of potential difference.

Potential Difference is measured in Volts, V

> **Prior Knowledge Link**
> This is a topic found in a previous GCSE module **– Electricity.**

Resistance, R

The resistance of a material tells us how easy or difficult it is to make a current flow through it.
If we think of current as Year 7s walking down a corridor, it would be harder to make the Year 7s flow if we added some Year 11 rugby players into the corridor.

Resistance is caused by the charge carriers colliding with objects as they travel down the conductor – this tends to be ions of the conductor itself.

The greater the amplitude of vibration of particles (temperature increase), the greater the amount of collisions between ions and charge carriers, the greater the resistance.

The more energy per charge the charge carriers have, the greater the amount of collisions between ions and charge carriers, the greater the resistance. Increasing resistance lowers the current.

Resistance is measured in Ohms, Ω

> **Examination Hint:** Memorise this base unit of resistance.

> **Physics Tip**
>
> You could be asked to give the definition of resistance in the exam – make sure you know it.

Time, t

You know, time! How long stuff takes and that.

Time is measured in seconds, s

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Electricity.**

Equations

There are three equations that we need to be able to explain and substitute numbers into.

1

Study Tip
Learn the base units for this equation and the context in which it can be used in.

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

Examination Hint: This equation is given in the data booklet, however memorising this gives you a better chance of exam success.

This says that the current is the rate of change of charge per second.

This shows current is the rate at which charge flows.

Study Tip

Learn what these equations represents.

The shows the current and charge in an electrical circuit.

This can be rearranged into

$$\Delta Q = I\Delta t$$

Which means that the charge is equal to how much current is flowing multiplied by how long it flows for.

2

Study Tip
Learn the base units for this equation and the context in which it can be used in.

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

Examination Hint: This equation is given in the data booklet, however memorising this gives you a better chance of exam success.

This says that the potential difference is equal to the energy per charge.

The 'push' of the electrons is equal to the energy given to each charge (electron).

3

Study Tip
Learn the base units for this equation and the context in which it can be used in.

$$V = IR$$

Examination Hint: This equation is given in the data booklet, however memorising this gives you a better chance of exam success.

This says that increasing the p.d. increases the current.
Increasing the 'push' of the electrons makes more flow.

It also shows us that for constant V, if R increases I gets smaller.
Pushing the same strength, if there is more blocking force less current will flow.

Study Tip

Learn what these equations represents.

The shows the different voltages in a circuit.

Power

Power is a measure of how much work is done (energy is transferred between different stores) in a particular time.

Power is linked to energy by the equation:

$$Power = \frac{Energy}{time}$$

Examination Hint: This equation is given in the data booklet, however memorising this gives you a better chance of exam success.

Study Tip

Learn how to derive the equations and how they link together.

Power is measured in Watts, W
Energy is measured in Joules, J
Time is measured in seconds, s

New Equations for A-Level

Energy

$V = \frac{E}{Q}$ can be placed into $E = VQ$ and we know that $Q = It$ so combining these equations we get a new one to calculate the energy in an electric circuit:

$E = VQ$ <--------------------- $Q = It$ so $$E = VIt$$ (1)

Study Tip
Learn the base units for these equations and the context in which they can be used in.

Examination Hint: This equation is given in the data booklet, however memorising this gives you a better chance of exam success.

Power

If we look at the top equation, to work out power we divide energy by time:

$\frac{E}{t} = \frac{VIt}{t}$ which cancels out to become $$P = VI$$ (2)

If we substitute $V = IR$ into the last equation, we get another equation for power:

$P = IV$ <--------------------- $V = IR$ so $$P = I^2R$$ (3)

We can also rearrange $V = IR$ into $I = \frac{V}{R}$ and substitute this into $P = VI$ to get our last equation for power:

$P = VI$ <--------------------- $I = \frac{V}{R}$ so $$P = \frac{V^2}{R}$$ (4)

Examination Hint: These equations are given in the data booklet, however memorising them gives you a better chance of exam success.

All equations can be used to answer an exam question; the choice is dependent on the quantities given in the examination question.

A

Energy

Two more equations for energy can be derived from equating the equation at the top with equations 3 and 4

Energy = Power x time

$Pt = I^2Rt$ Equation 3 becomes $$E = I^2Rt$$ (5)

Study Tip
Learn the base units for these equations and the context in which they can be used in.

$Pt = \frac{V^2}{R}t$ Equation 4 becomes $$E = \frac{V^2}{R}t$$ (6)

Examination Hint: These equations are given in the data booklet, however memorising them gives you a better chance of exam success.

All equations can be used to answer an exam question; the choice is dependent on the quantities given in the examination question.

Physics Tip

You won't be given P = E /t in the exam, but you will be given P = ΔW/Δt – so you do not need to remember this equation as long as you remember that work done is the same as energy transferred.

Study Tip

Learn what these equations represents.

The shows the work done and the power in an electrical circuit.

Study Tip

Learn how to derive the equations and how they link together.

VIDEO

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REVISION SHEET

Highlight or underline the key information on the revision sheet to consolidate your understanding.

Current is the **Rate** of **Flow** of **Charge**

1) The **current** in a **wire** is like **water** flowing in a **pipe**. The **amount** of water that flows depends on the **flow rate** and the **time**. It's the same with electricity — **current is the rate of flow of charge**.

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

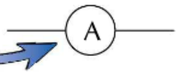
Where I is the current in amperes, ΔQ is the charge in coulombs, and Δt is the time taken in seconds.

Remember that conventional current flows from + to –, the opposite way from electron flow.

2) The **coulomb** is the **unit of charge**.

One coulomb (C) is defined as the **amount of charge** that passes in **1 second** when the **current** is **1 ampere**.

3) You can measure the current flowing through part of a circuit using an **ammeter**. This is the circuit symbol for an ammeter:



Attach an ammeter in series with the component you're investigating.

Potential Difference is the **Work Done** per **Unit Charge**

1) To make electric charge flow through a conductor, you need to do **work** on it.
2) **Potential difference** (p.d.), or **voltage**, is defined as the **work done per unit charge moved**:

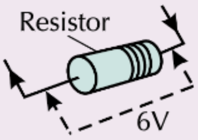
$$V = \frac{W}{Q}$$

W is the work done in joules (see p.34). It's the energy transferred in moving the charge.

The **potential difference** across a component is **1 volt** (V) when you do **1 joule** of work moving **1 coulomb** of charge through the component. This **defines** the volt.

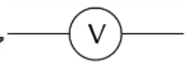
$$1\ \text{V} = 1\ \text{J}\,\text{C}^{-1}$$

Back to the 'water analogy' again. The p.d. is like the pressure that's forcing water along the pipe.



Here you do 6 J of work moving each coulomb of charge through the resistor, so the p.d. across it is 6 V. The energy gets converted to heat.

3) You can measure the potential difference across a component using a **voltmeter**. This is the circuit symbol for a voltmeter:



4) Remember, the potential difference across components in parallel is **the same**, so the **voltmeter** should be connected in **parallel** with the component you're investigating.

The maximum value that a voltmeter or ammeter can measure is called the full scale deflection.

Power** is the **Rate** of **Transfer** of **Energy

Power (P) is **defined** as the **rate** of **doing work**. It's measured in **watts** (**W**), where **1 watt** is equivalent to **1 joule of work done per second**.

in symbols: $P = \frac{W}{t}$

There's a really simple formula for **power** in **electrical circuits**:

$$P = VI$$

In an electrical circuit, W is the work done moving a charge.

This makes sense, since:

1) **Potential difference** (V) is defined as the **work done** per **coulomb**.
2) **Current** (I) is defined as the **number** of **coulombs** transferred per **second**.
3) So **p.d.** × **current** is **work done per second**, i.e. **power**.

Arnold had a pretty high resistance to doing work.

You also know (from the definition of **resistance**) that $V = IR$ (see p.44). **Combining** this with the equation above gives you loads of **different ways** to **calculate power**.

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

Obviously, which equation you should use depends on what **quantities** you're given in the **question**.

Example: A robotic mutant Santa from the future converts 750 J of electrical energy into heat every second.

a) What is the operating power of the robotic mutant Santa?

b) All of the robotic mutant Santa's components are connected in series, with a total resistance of 30 Ω. What current flows through his wire veins?

a) Power = $W \div t = 750 \div 1 =$ **750 W**

b) $P = I^2R$ so $I = \sqrt{\frac{P}{R}} = \sqrt{\frac{750}{30}} = \sqrt{25} =$ **5.0 A**

Energy** is Easy to **Calculate** if you Know the **Power

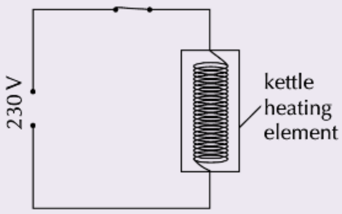
Sometimes it's the **total energy** transferred that you're interested in. In this case you simply need to **multiply** the **power** by the **time**. So:

$$W = VIt \quad \left(\text{or } W = \frac{V^2}{R}t \text{ or } W = I^2Rt\right)$$

Make sure that the time is in seconds before you use these equations.

Example: The circuit diagram on the right is part of an electric kettle. A current of 4.0 A flows through the kettle's heating element once it is connected to the mains (230 V).

The kettle takes 4.5 minutes to boil the water it contains. How much energy does the kettle's heating element transfer to the water in the time it takes to boil?



Time the kettle takes to boil in seconds = 4.5 × 60 = 270 seconds.

Use the equation $W = VIt = 230 \times 4.0 \times 270 = 248\,400$ J = **250 kJ (to 2 s.f.)**

Remember, this is the circuit symbol for an open switch:

Reference: CGP Revision Guides

REVIEW QUESTIONS

To assess your understanding, answer the following questions on this topic.

A1. Define the term 'electrical current'.

[1 Mark]

....

....

A2. Are ammeters connected to a compound in series or in parallel?

[1 Mark]

....

....

A3. Define the term 'potential difference'.

[1 Mark]

....

....

A4. What is meant by resistance?

[1 Mark]

....

....

A5. What is Ohm's Law?

[1 Mark]

....

....

A6. What happens to the resistance of an ohmic conductor if you double the potential difference across it? Give a reason for your answer.

[1 Mark]

....

....

The answers to the review questions are found on the next page.

REVIEW ANSWERS

A1. Electrical current is the rate of flow of charge in a circuit.

A2. Ammeters are connected in series.

A3. The potential difference between tow points is the work done in moving a unit charge between the points.

A4. The resistance of something is a measure of how difficult it is to get a current to flow through it. This is R = V / I.

A5. Provided the physical conditions, such as temperature, remain constant, the current through an ohmic conductor is directly proportional to the potential difference across it.

A6. Nothing – the resistance of an ohmic conductor is constant (if the physical conditions it is under are constant).

SELF ASSESSMENT

A1. In each of the following circuits the battery has negligible internal resistance and the bulbs are identical.

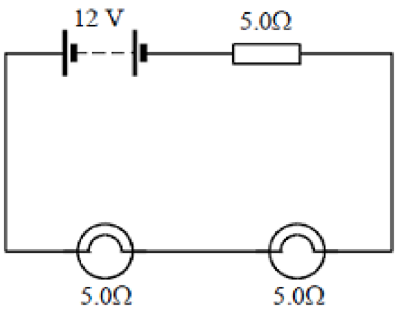


Figure 1

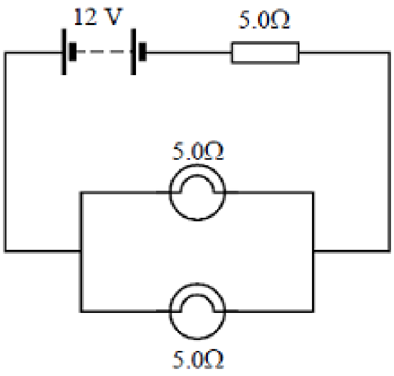


Figure 2

To practice your understanding, answer the following questions.

DO NOT WORRY IF YOU STRUGGLE AT FIRST.

The answers are found after the questions.

For the circuit shown in **Figure 1** calculate

A1.1 the current flowing through each bulb,

[1 Mark]

....

....

A1.2 the power dissipated in each bulb.

[1 Mark]

....

....

A1.3 In the circuit shown in **Figure 2** calculate the current flowing through each bulb.

[3 Marks]

....

....

....

....

A1.4 Explain how the brightness of the bulbs in **Figure 1** compares with the brightness of the bulbs in **Figure 2**.

[2 Marks]

....

....

Reference: AQA A-Level Examination Legacy Specimen A

Q2. A 2.0 kW heater is used to heat a room from 5 °C to 20 °C. The mass of air in the room is 30 kg.

Under these conditions the specific heat capacity of air = 1000 J kg^{-1} K^{-1}.

Calculate

Q2.1 The gain in thermal energy of the air,

[1 Mark]

....

....

Q2.2 The minimum time required to heat the room.

[3 Marks]

....

....

....

....

Q2.3 State and explain **one** reason why the actual time taken to heat the room is longer than the value calculated in part **Q2.2.**

[2 Marks]

....

....

....

....

Reference: AQA A-Level Examination Legacy Specimen A

ANSWERS

A1.1 I = $\frac{12}{15}$ = 0.80 A **(1)**

A1.2 $P = (0.80)^2 \times 5 = 3.2$ W **(1)** (allow e.c.f. from (a)(i))

(2)

A1.3 $I_{tot} = \frac{12}{7.5}$ **(1)** = 1.60 (A) **(1)**

$I = \frac{1.6}{2}$ = 0.80 (A) **(1)** (allow e.c.f. from I_{tot})

(3)

A1.4 same brightness **(1)**
because same current **(1)**
[or an answer consistent with their current values]

(2)
[7]

A2.1 (use of $\Delta Q = mc\Delta\theta$ gives) $Q = 30 \times 1000 \times 15$ **(1)**
$= 4.5 \times 10^5$ J **(1)**

A2.2 $P \times t = 4.5 \times 10^5$ **(1)**

$t = \frac{4.5 \times 10^5}{2000}$ = 225 s **(1)**

(allow C.E. for value of Q from (i)

4

A2.3 heat is lost to surroundings or other objects in room or to heater itself **(1)**
more (thermal) energy required from heater **(1)**

[or because convection currents cause uneven heating]
[or rate of heat transfer decreases as temperature increases]

2
[6]

ASSESSMENT QUESTION

Please answer this assessment question on this topic in Physics.

This work will be formally assessed with feedback given.

This work will be submitted at the start of the A-Level course in Year 12.

If we require any help or you wish to receive immediate feedback, please e-mail Mr. Turnbull.

Q3.1 A steady current of 0.25 A passes through a torch bulb for 6 minutes.
Calculate the charge which flows through the bulb in this time.

[2 Marks]

....

....

....

....

The torch bulb is now connected to a battery of negligible internal resistance. The battery supplies a steady current of 0.25 A for 20 hours. In this time the energy transferred in the bulb is 9.0×10^4 J.

Calculate

Q3.2 The potential difference across the bulb,

[1 Mark]

....

....

Q3.3 The power of the bulb.

[2 Marks]

....

....

....

....

Reference: AQA A-Level Examination Legacy Specimen A

TOPIC: 3.5.1.2 Current-Potential Difference

Characteristics
SPEC CHECK

Specification	Completed?
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.	

Student Checklist
Complete the following before attempting any work on this section.

Have I…….	**Yes or No?**
Read through the notes of this section?	
Highlighted/underlined the key concepts of this section?	
Made my own notes based on the notes of this section?	

Complete the above checklist with the notes of each section before you attempt to answer any questions on this section of work.

Ohm's Law

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Electricity.**

A potential difference causes a current to flow in a conductor when it is in a complete circuit, and that the size of the current depends on the size of the potential difference.
For something to obey Ohm's law the current flowing is directly proportional to the potential difference producing it. This only true if the physical conditions remain constant.

Examination Hint: Do not forget the physical conditions caveat of Ohm's Law.

As we said $V=IR$ so this means the resistance is constant.

The physical conditions of a conductor are the area of the conductor, the length of the conductor and the temperature of the conductor.

On a graph of current against potential difference, this appears as a straight line through the origin, as this shows directly proportional.

Physics Tip

Anything which is a metallic conductor are ohmic conductors e.g. iron, copper, silver, gold, titanium.

Examination Hint: It is a common examination question to define Ohm's law.

The current through a conductor between two points is directly proportional to the potential difference across the two points

(provided the temperature remains constant) (1 mark)

Examination Hint: It is a common examination question to state errors made when taking measurements to confirm Ohm's law.

voltmeter position is incorrect because it is across the cell (1 mark)

voltmeter should be connected across the putty (1 mark)

the resistor is not suitable to control the current (1 mark)

pd range is insufficient for experiment (1 mark)

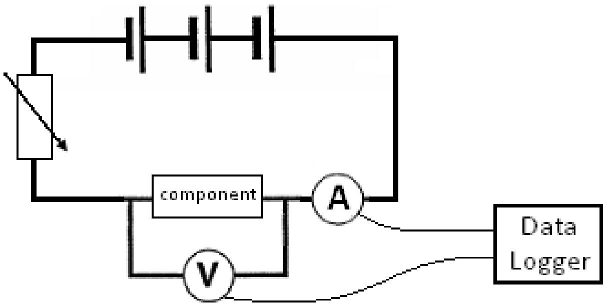
Taking Measurements

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Electricity.**

To find how the current through a component varies with the potential difference across it we must take a number of readings.
To measure the potential difference, we use a voltmeter connected in parallel and to measure the current we use an ammeter connected in series.

Physics Tip

In the exams, you can assume all voltmeters and ammeters are ideal unless the question tells you otherwise.



Physics Tip

You could use multimeters to measure current and/or voltage.

A multimeter is a measuring instrument that can measure current, voltage or resistance.

If we connect the component to a battery, we would now have one reading for the potential difference and one for the current. But what we require is a *range* of readings.
One way around this would be to use a range of batteries to give different potential differences. A better way is to add a variable resistor to the circuit, this allows us to use one battery and get a range of readings for current and potential difference.
An ideal ammeter has no resistance, as otherwise it would affect the measurements taken.
An ideal voltmeter has infinite resistance, as otherwise it would affect the measurements taken.
To obtain values for current in the negative direction we can reverse either the battery or the component.

Examination Hint: Do not forget to discuss how to achieve a range of results including the negative values.

The greater the range, the more values the relationship is true for.

Working Scientifically Link

Remember when to use a potentiometer and when to use a rheostat.

Potentiometers can vary the voltage to zero – rheostats can not do this.

Working Scientifically Link

Remember how to remove systematic and random error from measurements.

Working Scientifically Link

You must understand how various electrical circuits can be constructed correctly to measure the values wanted.

Working Scientifically Link

Remember the ammeter must be in series and the voltmeter in parallel with the component being measured.

Working Scientifically Link

The potentiometer must have three outputs if you wish it to alter values in an electrical circuit.

I-V Graphs

Prior Knowledge Link
This is a topic found in a previous GCSE module – **Electricity.**

Key Topic Warning
This topic is very common for questions on previous A-Level Papers.

I-V graphs place the current on the y-axis and the potential difference on the x-axis.

The gradient of the trend line produced is the conductance of the component – how easy it is for the component to allow charger carriers to flow through it.

$$\text{Conductance} = \frac{1}{\text{Resistance}}$$

Examination Hint: In examination, you should be able to describe and explain trends in terms of both conductance and resistance.

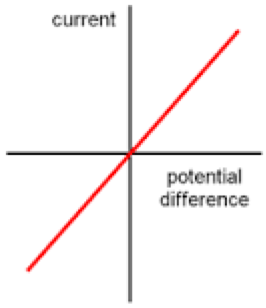
Physics Tip

I-V curves crop up a lot in exams, so make sure that you really know them.

You could be asked about V-I graphs too.

Resistor

Study Tip
Memorise a sketch graph of this trend and explain why this trend is followed.



This shows that when potential difference is zero so is the current.
When we increase the potential difference in one direction the current increases in that direction.
If we apply a potential difference in the reverse direction a current flows in the reverse direction.

The straight line through the origin shows that current is directly proportional to potential difference and it obeys Ohm's law.

The gradient of the line is constant indicating the conductance and resistance is constant.

Examination Hint: This graph is only true for a resistor when the physical conditions are kept constant. This is maintained in experiments by only allowing a current to flow when taking a reading.

Working Scientifically Link

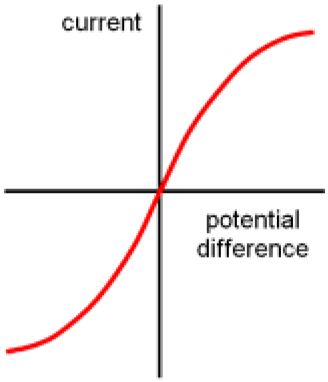
Remember how to numerically prove direct proportionality.

Working Scientifically Link

Remember how to determine resistance from this graph.

Filament Lamp

Study Tip
Memorise a sketch graph of this trend and explain why this trend is followed.



Physics Tip

The I-V graphs for ohmic conductors and filament lamps can be sketched on V-I graphs – the axes are just swapped over.

Make sure you can draw and recognise these too.

At low values the current is proportional to potential difference and so, obeys Ohm's law.

As the potential difference and current increase so does the temperature, this means it no longer obeys Ohm's law. The increased temperature increase ion vibration (the ions vibrate with a greater amplitude), this increases the collisions with the charge carriers.

This increases the resistance and the graph curves, since resistance changes it no longer obeys Ohm's law.

Examination Hint: Remember the gradient for the graph shows conductance. The decreasing gradient shows a decreasing conductance and increasing resistance.

Examination Hint: It is a common examination question to explain, in terms of electron motion, why the I–V characteristic for the filament lamp is a curve.

An increase in current/voltage leads to an increase in temperature (more heat generated) (1 mark)

This causes an increase in the movement of the lattice/ions/atoms (1 mark)

And therefore, an increase in the rate of collisions with electrons (1 mark)

So, the resistance increases as shown by V/I changing/V not proportional to I (on the graph) (1 mark)

Examination Hint: It is a common examination question to explain how the resistance of the lamp varies as the voltage across it is increased from zero to its working voltage.

Resistance increases (1 mark)

Temperature increases (1 mark)

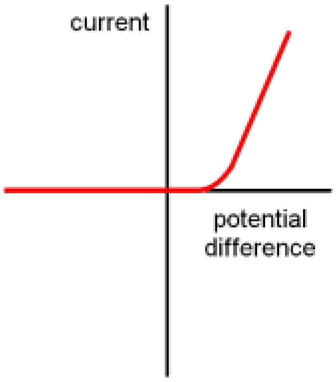
More collisions/interaction of electrons with lattice ions (1 mark)

Working Scientifically Link

Remember how to determine resistance from this graph.

Diode

Study Tip
Memorise a sketch graph of this trend and explain why this trend is followed.



Examination Tip
You can be asked to determines values using a V-I graph.

However, remember this only determines values for the component being graphed – not the whole circuit.

This shows us that in one direction increasing the potential difference increases the current but in the reverse direction the potential difference does not make a current flow.
We say that it is forward biased.
Since resistance changes it does not obey Ohm's law.
The value of potential difference in the positive direction where current rapidly increases is called the threshold voltage.

Examination Hint: Look at the circuit diagrams carefully in questions – is the diode in forward or reverse bias? If it is in reverse bias, no current will flow.

Examination Hint: It is a common examination question to explain the limitations of using a variable resistor to collect data for I-V graphs.

Can attain neither maximum nor minimum voltage (1 mark)

Explanation of either maximum OR minimum (1 mark)

Examination Hint: It is a common examination question to state how you can experimentally produce a I-V graph for a diode.

Mention of how to vary pd (seen in viable circuit) obtain several readings of I and V with at least 6 different values where the pd does not exceed 1.0V.

Mention of limiting current through diode using protective resistor.

Consider advantage of data logger.

Mention forward bias.

Must include potentiometer.

The following must be included…

means of controlling pd across diode indication of range and frequency of measurement mention of limiting current to avoid damage to diode a consideration of the advantages of a datalogger e.g. many readings, computer display of results use of potential divider instead of series resistor

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Electricity.**

Three Special Resistors

Variable Resistor
A variable resistor is a resistor whose value can be changed.

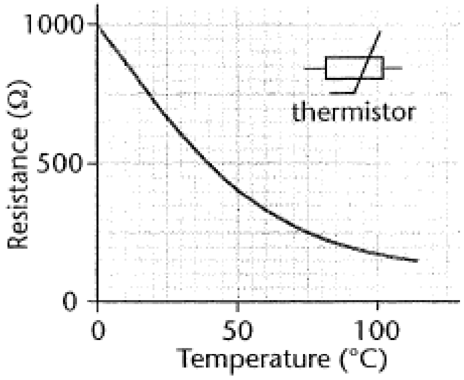
Examination Hint: A rheostat is a two-terminal variable resistor.

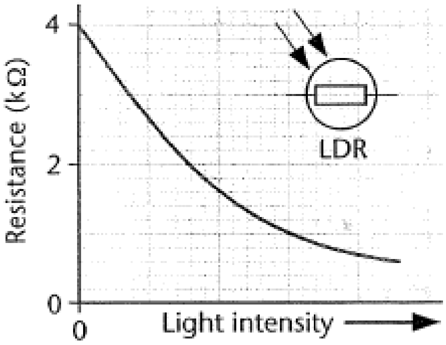
A potentiometer is a three-terminal variable resistor.

There are two types of variable resistor which changes the resistance they produce with external conditions. This allows these devices to act as a measure of these external conditions.

Both of these devices are called semi-conductor. Semi-conductors can change the number of free electrons (mobile charge carriers) that become released from their ion lattice structure depending on the conditions. The greater the free electrons in the component, the lower the resistance.

Examination Hint: Technically semi-conductor has a double effect since when an electron is released from the structure it leaves a 'positive' hole in the structure travelling in the opposite direction to the negative electron.





Study Tip
Memorise a sketch graph of this trend and explain why this trend is followed.

Study Tip
Memorise how semi-conductors work and how it changes with conditions.

Thermistor
The resistance of a thermistor varied with temperature.

At low temperatures the resistance is high (few electrons released), at high temperatures the resistance is low (a large number of free electrons released as they have enough energy to leave the lattice).

Examination Hint: It is a common examination question to state and explain what happens to the ammeter reading in a circuit when the temperature of the thermistor increases.

At higher temp, resistance of T is lower (1 mark)

So, circuit resistance is lower, so current/ammeter reading increases (1 mark)

Examination Hint: It is a common examination question to state how data have to be obtained so that a graph can be plotted to show how the reading on the voltmeter varies with temperature between 0 ºC and 100 ºC for a thermistor.

The candidate measures V and temperature.

They have a workable method of varying temperature from 0 °C to 100 °C. They explain why R is necessary and are able to use the thermistor to measure temperature using a graph and calibration curve.

The following should be discussed measurement of V from the voltmeter, use of a thermometer, use of water bath, use of ice, importance of stirring, explanation of the need for series resistor, plotting of a calibration curve, use of calibration curve to determine temperature of room.

The resistance of a thermistor varied with light intensity.
In dim light the resistance is high (few electrons released) and in bright light the resistance is low (a large number of free electrons released as the light has given them enough energy to break free and leave the lattice structure).

Physics Tip

A commonly used semiconductor is silicon – many types of electrical components are made from it e.g. diodes.

Physics Tip

LDRs have a similar resistance curve to thermistors – only it is an increase in light intensity not temperature, which causes the resistance to drop.

VIDEO

To watch a video looking at this concept, please scan one of the following codes with your smartphone.

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REVISION SHEET

Highlight or underline the key information on the revision sheet to consolidate your understanding.

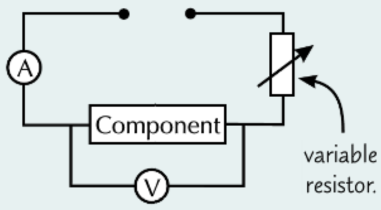
I-V Graphs Show How *Resistance Varies*

Make sure you learn all the circuit symbols that come up in this section, and know how to design and use circuits using them.

The term '***I-V* characteristic**' refers to a **graph** which shows how the **current** (*I*) flowing through a **component changes** as the **potential difference** (*V*) across it is increased.

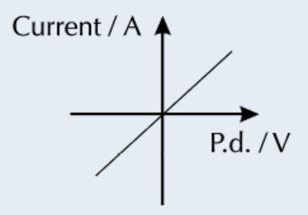
You can investigate the *I-V* characteristic of a component using a **test circuit** like this one:

1) Use the **variable resistor** to alter the **potential difference** across the component and the **current** flowing through it, and record *V* and *I*.
2) **Repeat** your measurements and take **averages** to reduce the effect of random errors on your results.
3) **Plot a graph** of current against potential difference from your results. This graph is the ***I-V* characteristic** of the component.



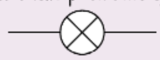
The *I-V Characteristic* for a *Metallic Conductor* is a *Straight Line*

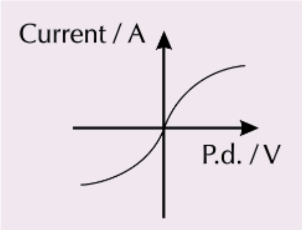
1) At **constant temperature**, the **current** through a **metallic conductor**, e.g. a **wire** or a **resistor**, is **directly proportional** to the **potential difference**.
2) The fact that the characteristic graph is a **straight line through the origin** tells you that the **resistance doesn't change** — it's equal to 1 / gradient.
3) The **shallower** the **gradient** of the characteristic ***I-V*** graph, the **greater** the **resistance** of the conductor.
4) **Metallic conductors** are **ohmic** — they have **constant resistance provided** their temperature doesn't change (see below).



The *I-V Characteristic* for a *Filament Lamp* is *Curved*

Filament lamp circuit symbol:

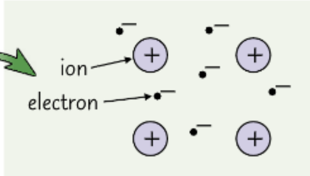




1) The characteristic graph for a **filament lamp** is a **curve**, which starts **steep** but gets **shallower** as the **potential difference rises**.
2) The **filament** in a lamp is just a **coiled up** length of **metal wire**, so you might think it should have the **same characteristic graph** as a **metallic conductor**.
3) However, **current** flowing through the lamp **increases** its **temperature**, so its **resistance increases** (see below).

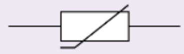
The *Resistivity* of a Metal *Increases* with *Temperature*

1) **Charge** is carried through **metals** by **free electrons** in a **lattice** of **positive ions**.
2) Heating up a metal makes it **harder** for electrons to **move about**. The **lattice of ions vibrates more** when heated, meaning the electrons **collide** with them more frequently, **transferring** some of their **kinetic energy** into other forms.
3) When kinetic energy is **lost** by the individual electrons, their speed and therefore the **mean drift velocity** (see page 43) decreases. As current is proportional to drift velocity, ($I = nqvA$) this means the **current** in the wire **decreases** so its **resistance** (and its resistivity, as it's dimensions haven't changed) **increases**.

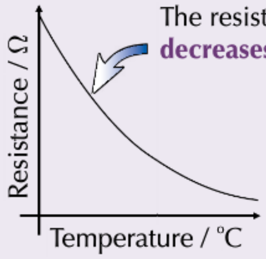


The **Resistance** of a **Thermistor** Depends on **Temperature**

Thermistor circuit symbol:

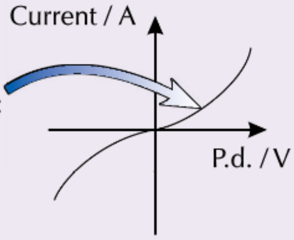


A **thermistor** is a **resistor** with a **resistance** that depends on its **temperature**. You only need to know about **NTC** thermistors — NTC stands for 'Negative Temperature Coefficient'. This means that the **resistance decreases** as the **temperature goes up**.



The resistance of an NTC thermistor **decreases** with **temperature**.

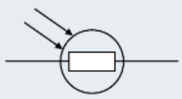
The characteristic ***I-V* graph** for an NTC thermistor looks like this: As the voltage **increases**, the current **increases**. More current leads to an **increase in temperature** and so a **decrease in resistance**. This in turn means more current can flow, so the graph **curves upwards**.



Warming the thermistor gives more **electrons** enough **energy** to **escape** from their atoms. This means that there are **more charge carriers** available, so the **current increases** and the **resistance decreases** ($R = V/I$).

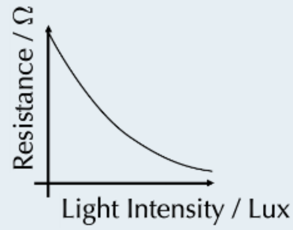
The **Resistance** of an **LDR** Depends on **Light Intensity**

LDR circuit symbol:

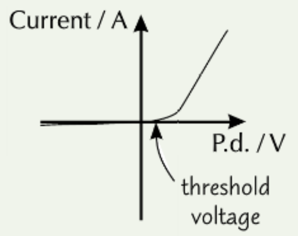


LDR stands for **Light-Dependent Resistor**. The **greater** the intensity of **light** shining on an LDR, the **lower** its **resistance**.

The explanation for this is similar to that for the thermistor. In this case, **light** provides the **energy** that releases more electrons. This means more charge carriers, which means a higher current and a lower resistance.



Diodes Only Let **Current Flow** in **One Direction**

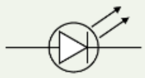


Diodes (including light-emitting diodes (LEDs)) are designed to let **current flow** in **one direction** only. You don't need to be able to explain how they work, just what they do.

1) **Forward bias** is the **direction** in which the **current** is **allowed to flow**.
2) **Most** diodes require a **threshold voltage** of about **0.6 V** in the **forward direction** before they will conduct.
3) In **reverse bias**, the **resistance** of the diode is **very high** and the current that flows is **very tiny**.

Diode circuit symbol:

LED circuit symbol:



Reference: CGP Revision Guides

REVIEW QUESTIONS

To assess your understanding, answer the following questions on this topic.

A1. What resistances do you normally assume a voltmeter and an ammeter to have?

[1 Mark]

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....

A2. Sketch the characteristic I-V graph of an ohmic conductor under constant physical conditions.

[1 Mark]

A3. Sketch the characteristic I-V graph of a filament lamp.

[1 Mark]

A4. Sketch the characteristic I-V graph of a diode.

[1 Mark]

A5. Is a filament lamp an ohmic conductor? How can you tell from its characteristic I-V graph?

[1 Mark]

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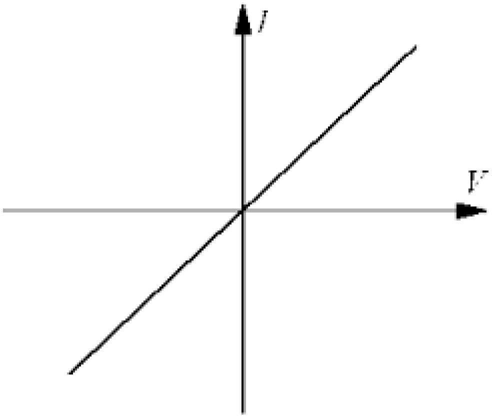
The answers to the review questions are found on the next page.

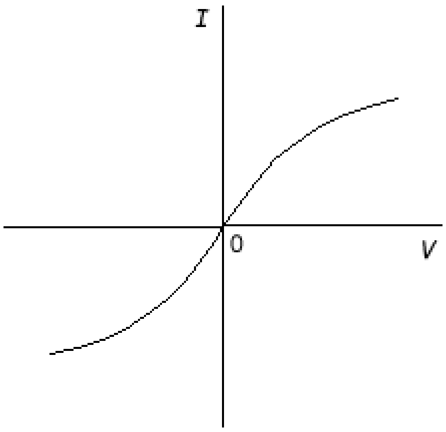
REVIEW ANSWERS

A1. An ideal ammeter has zero resistance and an ideal voltmeter has infinite resistance.

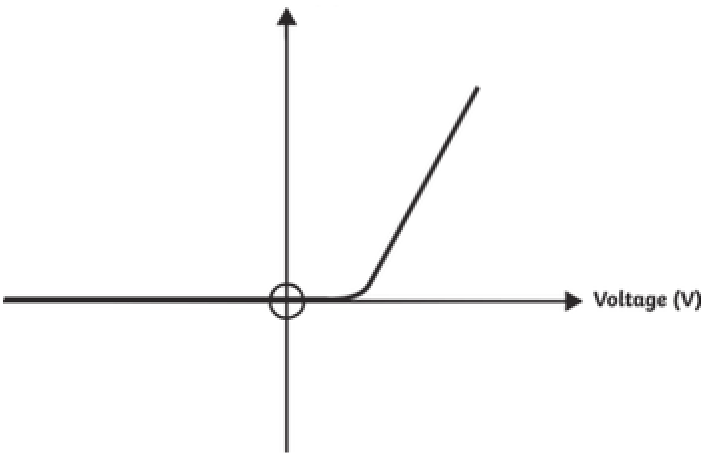
A2.



A3.



A4.



A5. A filament lamp is not an ohmic conductor. It has a characteristic I-V graph which is not a straight line, so the voltage is not proportional to the current.

SELF ASSESSMENT

Q1.1 On the axes in **Figure 1** draw $I-V$ characteristics for **two** components, **A** and **B**, both of which obey Ohm's law. Component **B** has a lower resistance than component **A**.

Label your characteristics clearly as **A** and **B**.

To practice your understanding, answer the following questions.

DO NOT WORRY IF YOU STRUGGLE AT FIRST.

The answers are found after the questions.

[2 Marks]

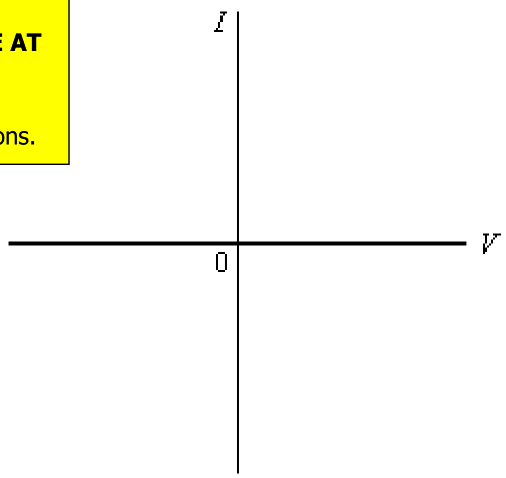


Figure 1

Q1.2 On the axes in **Figure 2** draw the $I-$ V characteristic for a silicon semiconductor diode, giving any relevant voltage values.

[3 Marks]

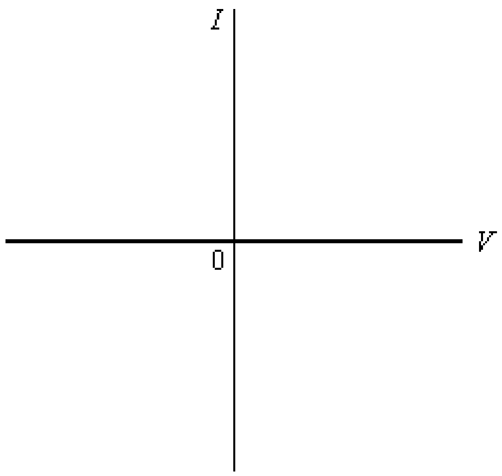


Figure 2

Q1.3 Figure 3 shows the $I - V$ characteristic of a filament lamp. Explain the shape of this characteristic.

[4 Marks]

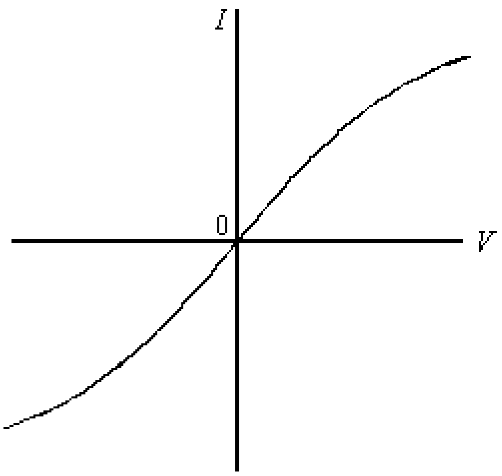


Figure 3

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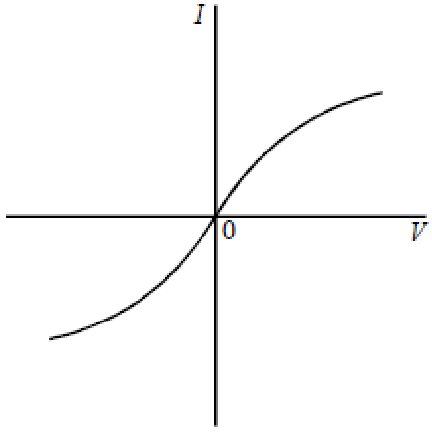
Reference: AQA A-Level Examination Legacy Specimen A

Q2.1 The characteristic shown below is that of a filament lamp.



Explain why, as the voltage is increased either positively or negatively from zero, the characteristic has the form shown in the figure.

[5 Marks]

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Q2.2 At a certain point on the characteristic, the power developed in the lamp is 20 W and the current is 90 mA. Calculate the resistance of the filament at this point on the characteristic.

[2 Marks]

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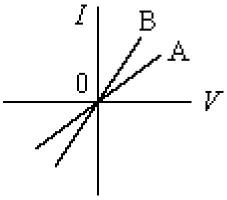
Reference: AQA A-Level Examination Legacy Specimen A

ANSWERS

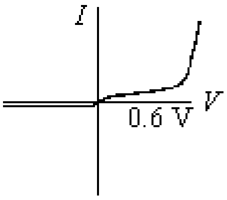
Q1.1



straight line in both quadrants,
through origin for A and B **(1)**
greater gradient for B **(1)**

2

Q1.2



characteristic to show:
positive current increasing slowly and then rapidly **(1)**
at ≈ 0.6V **(1)**
negative current either zero or just < zero **(1)**

3

Q1.3 as voltage increases, current increases **(1)**
current heats filament **(1)**
therefore resistance increases **(1)**
correct argument to explain curvature **(1)**
mirror image in negative quadrant **(1)**

max 4
[9]

Q2.1 Ohm’s law obeyed (or straight line graph) initially **(1)**
at a given voltage) current heats filament (to certain temperature) **(1)**
resistance constant at that temperature **(1)**
increase in voltage gives increase in current **(1)**
temperature of filament increases and resistance increases **(1)**
rate of increase of current less than if resistance was constant **(1)**
negative voltage and current produces same effect **(1)**

5

Q2.1 $P = I^2R$ **(1)**
$20 = (90 \times 10^{-3})^2 R$ and $R = 2.5 \times 10^3 \Omega$ **(1)** (2470 Ω)

2
[7]

ASSESSMENT QUESTION

Please answer this assessment question on this topic in Physics.

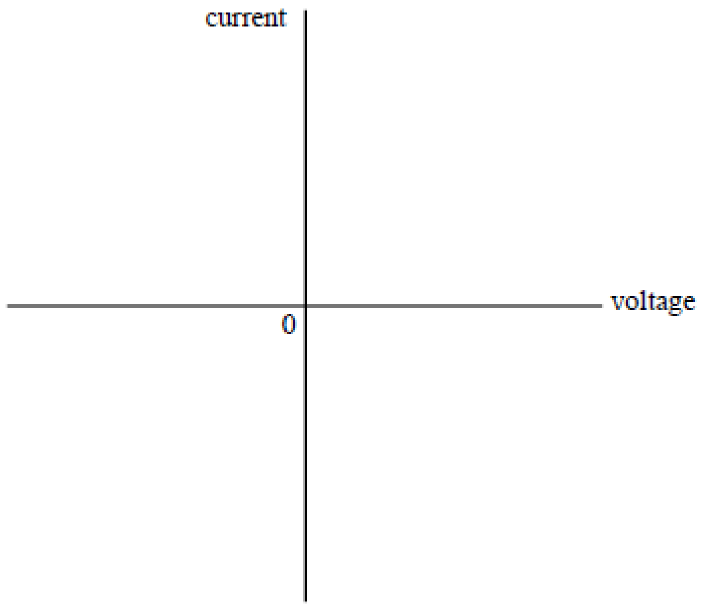
This work will be formally assessed with feedback given.

This work will be submitted at the start of the A-Level course in Year 12.

If we require any help or you wish to receive immediate feedback, please e-mail Mr. Turnbull.

Q3.1 Draw, on the axes below, the current/voltage characteristic for a filament lamp.
Do **not** insert any values for current or voltage.

[3 Marks]



Q3.2 Explain why the characteristic has the shape you have drawn.

[3 Marks]

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Q3.3 The current/voltage characteristic of a filament lamp is to be determined using a datalogger, the data then being fed into a computer to give a visual display of the characteristic.

Draw the circuit diagram required for such an experiment and state what is varied so as to produce a range of values.

[5 Marks]

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Reference: AQA A-Level Examination Legacy Specimen A

TOPIC: 3.5.1.3 Resistivity
SPEC CHECK

Specification	Completed?
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.	
Investigation of the variation of resistance of a thermistor with temperature.	

Student Checklist
Complete the following before attempting any work on this section.

Have I.......	**Yes or No?**
Read through the notes of this section?	
Highlighted/underlined the key concepts of this section?	
Made my own notes based on the notes of this section?	

Complete the above checklist with the notes of each section before you attempt to answer any questions on this section of work.

Resistivity

Key Topic Warning
This topic is very common for questions on previous A-Level Papers.

The resistance of a wire is caused by free electrons colliding with the positive ions that make up the structure of the metal.

The resistance depends upon several factors:

Length, l **Length increases – resistance increases**
The longer the piece of wire, the more collisions the charge carriers will have.

Area, A **Area increases – resistance decreases**
The wider the piece of wire, the more gaps there are between the ions, the fewer charge carrier collisions.

Temperature **Temperature increases – resistance increases**
As temperature increases the ions are given more energy and vibrate more, the charge carriers are more likely to collide with the ions.

Material
The structure of any two metals is similar but not the same, some metal ions are closer together, others have bigger ions. The closer the ions are, the greater the charge carrier collisions.

These are called the physical conditions of the material.

Examination Tip: This makes resistance dependent on the dimensions of the material.

This means there is no absolute value of resistance for a material.

Physics Tip

Do not confuse resistivity and resistance. Resistance is a property of an object and it depends on the material and dimensions of the object.

Resistivity is a property of a material.

Study Tip
Learn the base units for this equation and the context in which it can be used in.

$$R = \rho \frac{l}{A}$$

Study Tip

Learn what this equation represents.

The shows the resistivity of a material.

The resistance of a material can be calculate using

where ρ is the resistivity of the material.

Examination Tip: Questions commonly give the diameter of a material. You must use this to find the area of the material.

Examination Tip This equation is given in the data booklet, however memorising this gives you a better chance of exam success.

Physics Tip

For resistivity calculations, do not forget that you need to have the length in m and the cross-sectional area in m^2 – you will lose marks if you do not use the correct units.

Resistivity is a factor that accounts for the structure of the metal and the temperature.
It is a quantity which does not depend on dimensions – a material will have a constant value for resistivity.

Each metal has its own value of resistivity for each temperature.
Temperature is the only factor that can the resistivity of a material as it affects resistance.

For example, the resistivity of copper is 1.7×10^{-8} Ωm and carbon is 3×10^{-5} Ωm at room temperature.

When both are heated to 100°C their resistivities increase.

Resistivity is measured in Ohm metres, Ωm

Physics Tip

Remember the definition of resistivity.

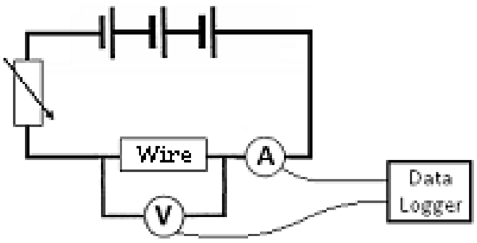
Resistivity = RA /l

Examination Hint: Do not confuse the unit of resistance with the unit of resistivity.

It is a common question to derive the resistivity units.

Measuring Resistivity

To measure resistivity of a wire we need to measure the length, cross-sectional area (using Area = πr^2) and resistance.



Remember, to measure the resistance we need to measure values of current and potential difference using the set up shown on the right

We then rearrange the equation to $\rho = \frac{RA}{l}$ and substitute values in

Physics Tip

It is assumed that the material measured is a wire, therefore the area is equal to Πr^2.

Examination Hint: Remember that 'l' in the equation is total length – this means that if there are turns on the wire then…

l = number of turns x circumference.

Working Scientifically Link

Remember when to use a potentiometer and when to use a rheostat.

Potentiometers can vary the voltage to zero – rheostats cannot do this.

Working Scientifically Link

Remember how to remove systematic and random error from measurements.

PRACTICAL:

Study Tip

Learn the key skills associated with this practical.

How to Measure Resistivity

1. Calculating Cross-Sectional Area

1. Measure the diameter of the wire in at least three different places along the wire using a micrometer.

2. Find the mean diameter and halve it to find the mean radius of the wire. You can assume that the cross-section of the wire is a circle, so you can calculate the cross-sectional area using the area of a circle.

2. Measuring Resistivity

1. Attach a flying lead to the end of a test wire and measure the length of the test wire connected in the circuit.

2. Close the switch and measure the current through the circuit and the potential difference across the test wire. Open the switch again once you have taken your measurements and use these values to calculate the resistance of the wire.

3. Repeat this process at least one more time and calculate the mean resistance for this length of wire.

4. Reposition the flying lead and repeat steps 2 and 3 to get an average resistance for a range of different lengths of test wire.

5. Plot a graph of average resistance against length using your results. This should be a straight line through the origin.

6. To find the resistivity you multiply the gradient of the straight line by the cross-sectional area of the wire.

Examination Hint: You can assume voltmeters and ammeters are ideal.

Examination Hint: A flying lead is a wire with a crocodile clip at the end to allow connection to any point along the test wire.

Examination Hint: If the wire heats up, its resistance and resistivity will increase. You can minimise how much it heats up by using a small current and using a switch to make sure current only flows through the wire for short amounts of time, while you are taking measurements.

Examination Hint: If you get an anomalous result when you calculate a resistance, you should discount it from calculations for the average resistance. You should also discount any anomalous values when drawing a line of best fit.

Examination Hint: The main sources of random errors in this experiment are likely to be the temperature of the wire changing and measuring the length of the wire.

Study Tip

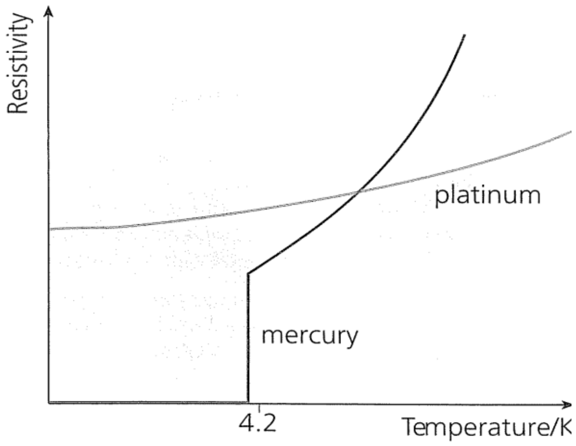
Learn the required practical process, how to gain accurate results and how the observations can be analysed.

Superconductivity

The resistivity (and so resistance) of metals increases with the temperature. The reverse is also true that, lowering the temperature lowers the resistivity.

When certain metals are cooled below a **critical temperature** their resistivity drops to zero. The metal now has zero resistance and allows massive currents to flow without losing any energy as heat. These metals are called superconductors. When a superconductor is heated above the critical temperature it loses its superconductivity and behaves like other metals.

The highest recorded temperature to date is –196°C, large amounts of energy are required to cool the metal to below this temperature.



Study Tip
Memorise a sketch graph of this trend and explain why this trend is followed.

Physics Tip

A superconductor is a material which has no resistivity.

Uses of Superconductors

High-power electromagnets
Power cables
Magnetic Resonance Imaging (MRI) scanners
Fast electronic circuits
Supercomputers
Particle accelerators

Examination Hint: Remember to memorise the definition of critical temperature and why this leads to few superconductors at room temperature.

Examination Hint: It is a common examination question to state the significance of the critical temperature of a material.

below the critical temperature/maximum temperature which resistivity/resistance (1 mark)

is zero/becomes superconductor (1 mark).

Working Scientifically Link

Remember the conditions needed for a superconductor.

VIDEO

To watch a video looking at this concept, please scan one of the following codes with your smartphone.

Scan me

Note

All rights to this video belong to the creator of the video.

This external third-party content – please check the contents are appropriate.

Scan me

Note

All rights to this video belong to the creator of the video.

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Highlight or underline the key information on the revision sheet to consolidate your understanding.

Everything has Resistance

1) If you put a **potential difference** (p.d.) across an **electrical component**, a **current** will flow.
2) **How much** current you get for a particular **p.d.** depends on the **resistance** of the component.
3) You can think of a component's **resistance** as a **measure** of how **difficult** it is to get a **current** to **flow** through it.

Mathematically, **resistance** is: $R = \frac{V}{I}$
This equation really **defines** what is meant by resistance.

This is the **circuit symbol** for a resistor: 

4) **Resistance** is measured in **ohms** (Ω).

A component has a resistance of **1 Ω** if a **potential difference** of **1 V** makes a **current** of **1 A** flow through it.

Three Things Determine Resistance

If you think about a nice, **simple electrical component**, like a **length of wire**, its **resistance** depends on:

1) **Length** (*l*). The **longer** the wire the **more difficult** it is to make a **current flow**.
2) **Area** (*A*). The **wider** the wire the **easier** it is to make a current flow.
3) **Resistivity** (ρ). This **depends** on the **material** the wire's made from, as the **structure** of the material may make it easy or difficult for charge to flow. In general, resistivity depends on **environmental factors** as well, like **temperature**.

ρ is the Greek letter rho, the symbol for resistivity.

The **resistivity** of a material is defined as the **resistance** of a **1 m length** with a **1 m² cross-sectional area**, so $\rho = \frac{RA}{l}$. Resistivity is measured in **ohm metres** (Ωm).

In your exams, you'll be given this equation in the **form**: $R = \frac{\rho l}{A}$ where A = cross-sectional area in m², and l = length in m

Typical values for the **resistivity** of **conductors** are **really small**.

However, if you **calculate** a **resistance** for a **conductor** and end up with something **really small** (e.g. 1×10^{-7} Ω), go back and **check** that you've **converted** your **area** into **m²**.

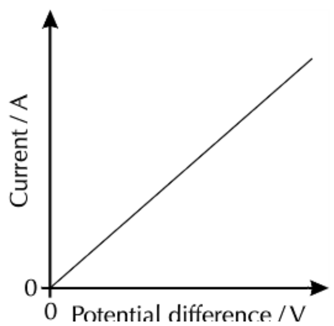
For an Ohmic Conductor, R *is a* Constant

A chap called **Ohm** did most of the early work on resistance. He developed a rule to **predict** how the **current** would **change** as the applied **potential difference increased**, for **certain types** of conductor.

The rule is now called **Ohm's law** and the conductors that **obey** it (mostly metals) ... **ohmic conductors**.

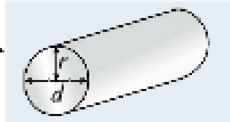
Provided the **temperature** is **constant**, the **current** through an ohmic conductor is **directly proportional** to the **potential difference** across it (that's $I \propto V$).

1) As you can see from the graph, **doubling** the **p.d. doubles** the **current**.
2) What this means is that the **resistance** is **constant**.
3) Often **external factors**, such as **temperature** will have a **significant effect** on resistance, so you need to remember that Ohm's law is **only** true for **ohmic conductors** at **constant temperature**.



*To Find the **Resistivity** of a **Wire** You Need to Find its **Resistance***

Before you start, you need to know the **cross-sectional area** of your test wire. Assume that the wire is **cylindrical**, and so the cross-section is **circular**.

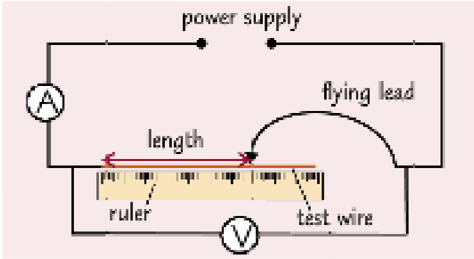


Then you can find its **cross-sectional area** using: **area of a circle = πr^2**

Use a **micrometer** to measure the **diameter** of the test wire for at least **three** different points along the wire. Take an **average** value of the diameter and divide by **2** to get the **radius** (make sure this is in m). Plug it into the equation for cross-sectional area and... **ta da**. Now you can get your teeth into the electricity bit...

A micrometer, sometimes called a micrometer caliper, is used to precisely measure very small distances.

1) The **test wire** should be **clamped** to a ruler and connected to the rest of the circuit at the point where the ruler reads zero.
2) Attach the **flying lead** to the test wire — the lead is just a wire with a crocodile clip at the end to allow connection to any point along the test wire.
3) Record the **length** of the test wire **connected** in the circuit, the **voltmeter reading** and the **ammeter reading**.
4) Use your readings to calculate the **resistance** of the length of wire, using: $R = \frac{V}{I}$
5) Repeat for several **different** lengths within a sensible range, e.g. at 0.10 m intervals from 0.10 m to 1.00 m.
6) Plot your results on a graph of **resistance** against **length**, and draw a **line of best fit** (see page 8).



You could also use a digital multimeter to measure the resistance of the wire directly — you'd connect it in parallel with the length of wire you're investigating and set it to measure resistance.

The **gradient** of the line of best fit is equal to $\frac{R}{l} = \frac{\rho}{A}$. So **multiply** the **gradient** of the line of best fit by the **cross-sectional area** of the wire to find the resistivity of the wire material.

7) The **resistivity** of a material depends on its **temperature**, so you can only find the resistivity of a material **at a certain temperature**. Current flowing in the test wire can cause its temperature to increase, so failing to keep the wire at a **constant temperature** could invalidate your results (see p.12). Try to keep the temperature of the test wire constant by e.g. only having small currents flow through the wire.

Reference: CGP Revision Guides

REVIEW QUESTIONS

To assess your understanding, answer the following questions on this topic.

A1. State the three things that the resistance of a material depends on.

[1 Mark]

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A2. What is resistivity?

[1 Mark]

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A3. Describe an experiment which could be used to investigate how the resistance of a thermistor changes with temperature.

[1 Mark]

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A4. Describe the effect of temperature on the resistance of a metal.

[1 Mark]

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....

A5. What is a superconductor?

[1 Mark]

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....

A6. Give two uses of superconducting wires.

[1 Mark]

....

....

The answers to the review questions are found on the next page.

REVIEW ANSWERS

A1. Length, area and resistivity.

A2. The resistivity of a material is the resistance of a 1m length with a 1m2 cross-sectional area. It is measured in ohm-metres (Ω m).

A3. The thermistor is connected to a power supply, which provides a constant potential difference, and an ammeter. The temperature of the thermistor is controlled by immersing it in a water bath. Hot water is poured into the water bath, so it covers the thermistor. The temperature of the thermistor and the current are recorded at regular intervals as the temperature of the water in the water bath drops. The potential difference and current data can be used to calculate the resistance of the thermistor at each temperature recorded.

A4. As the temperature of a metal increase, its resistance will also increase.

A5. A material that has zero resistivity when cooled below a critical temperature.

A6. Power cables/strong electromagnetic/fast electronic circuits.

SELF ASSESSMENT

To practice your understanding, answer the following questions.

DO NOT WORRY IF YOU STRUGGLE AT FIRST.

The answers are found after the questions.

Q1. The resistivity of a material in the form of a uniform resistance wire is to be measured. The area of cross-section of the wire is known.

The apparatus available includes a battery, a switch, a variable resistor, an ammeter and a voltmeter.

Q1.1 Draw a circuit diagram using some or all of this apparatus, which would enable you to determine the resistivity of the material.

[3 Marks]

Q1.2 Describe how you would make the necessary measurements, ensuring that you have a range of values.

[4 Marks]

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Q1.3 Show how a value of the resistivity is determined from your measurements.

[2 Marks]

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Q1.4 A sheet of carbon-reinforced plastic measuring 80 mm × 80 mm × 1.5 mm has its two large surfaces coated with highly conducting metal film. When a potential difference of 240 V is applied between the metal films, there is a current of 2.0 mA in the plastic. Calculate the resistivity of the plastic.

[3 Marks]

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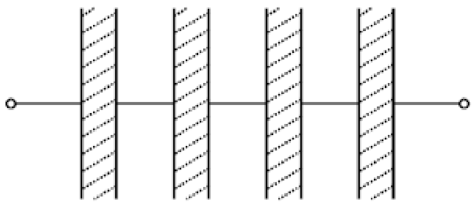
Q1.5 If four of the units described in **Q1.4** are connected as shown in the diagram, calculate the total resistance of the combination.

[2 Marks]



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Reference: AQA A-Level Examination Legacy Specimen A

Q2.1 Show that the unit of resistivity is Ω m.

[1 Mark]

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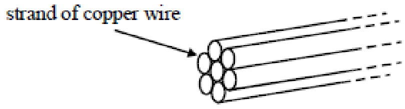
A cable consists of seven straight strands of copper wire each of diameter 1.35 mm as shown in the diagram.



Calculate

Q2.2 the cross-sectional area of **one strand** of copper wire,

[1 Mark]

....

....

Q2.3 the resistance of a 100 m length of the **cable**, given that the resistivity of copper is 1.6×10^{-8} Ωm.

[2 Marks]

....

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....

Q2.4 If the cable in part **Q2.3** carries a current of 20 A, what is the potential difference between the ends of the cable?

[2 Marks]

....

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....

Q2.5 If a single strand of the copper wire in part **Q3.2** carried a current of 20 A, what would be the potential difference between its ends?

[2 Marks]

....

....

Q2.6 State **one** advantage of using a stranded rather than a solid core cable with copper of the same total cross-sectional area.

[1 Mark]

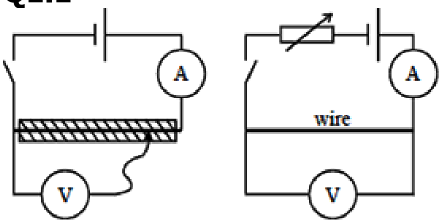
....

....

Reference: AQA A-Level Examination Legacy Specimen A

ANSWERS

Q1.1



(1) battery, wire, (variable resistor) and ammeter in series
(1) voltmeter connected across wire

Q1.2 (*α*) (with switch closed) measure I and V **(1)**
move contact along the wire **(1)** (or length of wire changed)
measure new (I and) V **(1)**
measure l each time **(1)**

or (*β*) measure I and V **(1)**
change variable resistor **(1)**
measure new I and V **(1)**
l known **(1)**

Q1.3 $R = \frac{\rho l}{A}$ or $\rho = \frac{RA}{l}$ or $\rho = \frac{A}{l} \times \frac{V}{I}$ (1)

(*α*) obtain gradient of graph of V or R vs l **(1)**
A (and I) known, hence ρ **(1)**

or (*β*) gradient of graph of V vs I **(1)**
A and l known, hence ρ **(1)**

[or, for both methods, measure $R = \frac{V}{I}$ for each length **(1)**

take mean and hence ρ **(1)**

9

Q1.4 (use of $V = IR$ gives) $R = \frac{240}{2 \times 10^{-3}}$ **(1)** (= 120 × 10^3 (Ω))

$$\rho = \left(\frac{RA}{l}\right) = \frac{120 \times 10^3 \times 80 \times 80 \times 10^{-6}}{1.5 \times 10^{-3}}$$ (1)

(allow C.E. for value of R)
= 5.1 × 10^5 Ω m **(1)**

3

Q1.5 four resistors in series **(1)**
R = 4 × (120 × 10^3) = 4.8 × 10^{5}Ω **(1)**
(allow C.E. for value of R)

2
[14]

Q2.1 $\rho = \frac{RA}{l} \Rightarrow \frac{\Omega m^2}{m} \Rightarrow \Omega m$

1

Q2.2 $A = 1.43 \times 10^{-6}\ m^2$ **(1)**

Q2.3 $R_{strand} = \frac{1.6 \times 10^{-8} \times 10^{2}}{1.4 \times 10^{-6}} = 1.1\Omega$ **(1)**

$R_{cable} = \frac{1.12}{7}$ **(1)** $= 0.16\Omega$ **(1)**

alternative (ii):
A = 7 **(1)** × 1.4×10^{-6}
substitution **(1)**
leading to $R_{cable} = 0.16\ \Omega$ **(1)**

4

Q2.4 V = 3.2 V **(1)**

Q2.5 $V = 7 \times 3.2$ V = 22V **(1)**

2

Q2.6 cable is flexible (*)
one strand fails, cable continues to conduct (*)
larger surface area so better heat dissipation etc (*)
(*) any one **(1)**

1
[8]

ASSESSMENT QUESTION

Please answer this assessment question on this topic in Physics.

This work will be formally assessed with feedback given.

This work will be submitted at the start of the A-Level course in Year 12.

If we require any help or you wish to receive immediate feedback, please e-mail Mr. Turnbull.

Q3.1 A sample of conducting putty is rolled into a cylinder which is 6.0×10^{-2} m long and has a radius of 1.2×10^{-2} m.

Resistivity of the putty = 4.0×10^{-3} Ωm.

Calculate the resistance between the ends of the cylinder of conducting putty.
Your answer should be given to an appropriate number of significant figures.

[4 Marks]

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Answer = ____________________ Ω

Q3.2 Given the original cylinder of the conducting putty described in **Q3.1**, describe how you would use a voltmeter, ammeter, and other standard laboratory equipment to determine a value for the resistivity of the putty.

Your description should include

A labelled circuit diagram,
Details of the measurements you would make,
An account of how you would use your measurements to determine the result,
Details of how to improve the precision of your measurements.

The quality of your written communication will be assessed in this question.

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Reference: AQA A-Level Examination Legacy Materials

FURTHER READING

You may wish to read around the following topics to further extend your understanding ahead of the start of the course in Year 12.

Potential Dividers

Scan me

Scan me

To watch a video looking at this concept, please scan one of the following codes with your smartphone.

Internal Resistance

Scan me

Scan me

To watch a video looking at this concept, please scan one of the following codes with your smartphone.

REVISION CHECKLIST

Specification reference	Checklist questions	
3.5.1.1	Can you explain electric current as the rate of flow of charge?	☐
3.5.1.1	Can you explain potential difference as work done per unit charge?	☐
3.5.1.1	Can you use the formulae $I = \frac{\Delta Q}{\Delta t}$ and $V = \frac{W}{Q}$?	☐
3.5.1.1	Can you define resistance as $R = \frac{V}{I}$?	☐
3.5.1.2	Can you recognise and use ohmic conductors, semiconductor diodes, and filament lamps?	☐
3.5.1.2	Can you explain Ohm's law as a special case where $I \propto V$ under constant physical conditions?	☐
3.5.1.2	Can you interpret characteristic graphs where I or V is on the horizontal axis?	☐
3.5.1.3	Can you explain resistivity and use the equation $\rho = \frac{RA}{L}$?	☐
3.5.1.3	Can you describe the effect of temperature on the resistance of metal conductors and thermistors?	☐
3.5.1.3	Can you describe application of thermistors as temperature sensors?	☐
3.5.1.3	Can you describe and sketch how resistance varies with temperature for a metal wire and for a thermistor?	☐
3.5.1.3	Can you describe superconductivity as a property of certain materials that have zero resistivity at/below a critical temperature which depends on the material?	☐
3.5.1.3	Can you describe some applications of superconductors, including their use in the production of strong magnetic fields and the reduction of energy loss in transmission of electric power?	☐
3.5.1.3	Have you carried out a practical to determine resistivity of a wire using a micrometer, ammeter, and voltmeter?	☐

DATASHEET

DATA – FUNDAMENTAL CONSTANTS AND VALUES

Quantity	Symbol	Value	Units
speed of light in vacuo	c	3.00×10^{8}	$\mathrm{m\ s^{-1}}$
permeability of free space	μ_0	$4\pi \times 10^{-7}$	$\mathrm{H\ m^{-1}}$
permittivity of free space	ε_0	8.85×10^{-12}	$\mathrm{F\ m^{-1}}$
magnitude of the charge of electron	e	1.60×10^{-19}	C
the Planck constant	h	6.63×10^{-34}	J s
gravitational constant	G	6.67×10^{-11}	$\mathrm{N\ m^{2}\ kg^{-2}}$
the Avogadro constant	N_A	6.02×10^{23}	$\mathrm{mol^{-1}}$
molar gas constant	R	8.31	$\mathrm{J\ K^{-1}\ mol^{-1}}$
the Boltzmann constant	k	1.38×10^{-23}	$\mathrm{J\ K^{-1}}$
the Stefan constant	σ	5.67×10^{-8}	$\mathrm{W\ m^{-2}\ K^{-4}}$
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass (equivalent to 5.5×10^{-4} u)	m_e	9.11×10^{-31}	kg
electron charge/mass ratio	$\frac{e}{m_e}$	1.76×10^{11}	$\mathrm{C\ kg^{-1}}$
proton rest mass (equivalent to 1.00728 u)	m_p	$1.67(3) \times 10^{-27}$	kg
proton charge/mass ratio	$\frac{e}{m_p}$	9.58×10^{7}	$\mathrm{C\ kg^{-1}}$
neutron rest mass (equivalent to 1.00867 u)	m_n	$1.67(5) \times 10^{-27}$	kg
gravitational field strength	g	9.81	$\mathrm{N\ kg^{-1}}$
acceleration due to gravity	g	9.81	$\mathrm{m\ s^{-2}}$
atomic mass unit (1u is equivalent to 931.5 MeV)	u	1.661×10^{-27}	kg

ALGEBRAIC EQUATION

quadratic equation $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

ASTRONOMICAL DATA

Body	Mass/kg	Mean radius/m
Sun	1.99×10^{30}	6.96×10^{8}
Earth	5.97×10^{24}	6.37×10^{6}

GEOMETRICAL EQUATIONS

arc length	$= r\theta$
circumference of circle	$= 2\pi r$
area of circle	$= \pi r^2$
curved surface area of cylinder	$= 2\pi rh$
area of sphere	$= 4\pi r^2$
volume of sphere	$= \frac{4}{3}\pi r^3$

Electricity

current and pd $I = \frac{\Delta Q}{\Delta t}$ $V = \frac{W}{Q}$ $R = \frac{V}{I}$

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

resistors in series $R_T = R_1 + R_2 + R_3 + \ldots$

resistors in parallel $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$

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

emf $\varepsilon = \frac{E}{Q}$ $\varepsilon = I(R + r)$

Circular motion

magnitude of angular speed $\omega = \frac{v}{r}$

$\omega = 2\pi f$

centripetal acceleration $a = \frac{v^2}{r} = \omega^2 r$

centripetal force $F = \frac{mv^2}{r} = m\omega^2 r$

Simple harmonic motion

acceleration $a = -\omega^2 x$

displacement $x = A \cos(\omega t)$

speed $v = \pm \omega \sqrt{(A^2 - x^2)}$

maximum speed $v_{max} = \omega A$

maximum acceleration $a_{max} = \omega^2 A$

for a mass-spring system $T = 2\pi \sqrt{\frac{m}{k}}$

for a simple pendulum $T = 2\pi \sqrt{\frac{l}{g}}$

Thermal physics

energy to change temperature $Q = mc\Delta\theta$

energy to change state $Q = m\,l$

gas law $pV = nRT$

$pV = NkT$

kinetic theory model $pV = \frac{1}{3} N m (c_{rms})^2$

kinetic energy of gas molecule $\frac{1}{2} m (c_{rms})^2 = \frac{3}{2} kT = \frac{3RT}{2N_A}$

Gravitational fields

force between two masses $F = \frac{Gm_1m_2}{r^2}$

gravitational field strength $g = \frac{F}{m}$

magnitude of gravitational field strength in a radial field $g = \frac{GM}{r^2}$

work done $\Delta W = m\Delta V$

gravitational potential $V = -\frac{GM}{r}$

$g = -\frac{\Delta V}{\Delta r}$

Electric fields and capacitors

force between two point charges $F = \frac{1}{4\pi\varepsilon_0} \frac{Q_1Q_2}{r^2}$

force on a charge $F = EQ$

field strength for a uniform field $E = \frac{V}{d}$

work done $\Delta W = Q\Delta V$

field strength for a radial field $E = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r^2}$

electric potential $V = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r}$

$E = \frac{\Delta V}{\Delta r}$

capacitance $C = \frac{Q}{V}$

$C = \frac{A\varepsilon_0\varepsilon_r}{d}$

capacitor energy stored $E = \frac{1}{2} QV = \frac{1}{2} CV^2 = \frac{1}{2} \frac{Q^2}{C}$

capacitor charging $Q = Q_0(1 - e^{-t/RC})$

decay of charge $Q = Q_0 e^{-t/RC}$

time constant RC

Acknowledgements

This document has been produced by Mr J Turnbull.

All relevant information has been credited in the document.

This document has been produced for educational purposes only.

This document has been produced for the AQA A Level Physics Specification.

Student Voice

If you when using this document, you believe there is an improvement to made, please state this in the space below.

Only constructive and reasoned feedback will be considered.