Volume

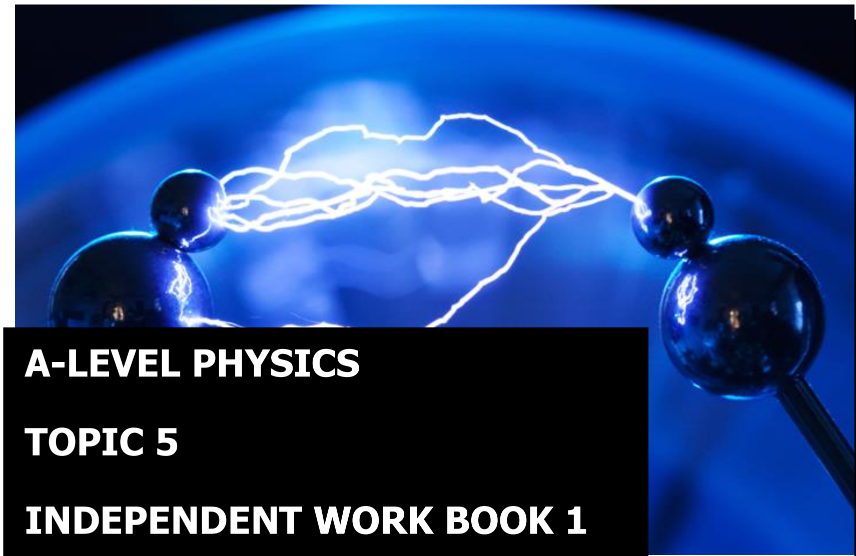
One

ST MARY’S SCIENCE DEPARTMENT:

PHYSICS

A LEVEL PHYSICS **YEAR 1**
STUDENT INDEPENDENT WORK BOOK
3.5.1: BASICS OF ELECTRICITY
VOLUME **ONE**

NAME	
PHYSICS CLASS	
MODULE TEACHER	
ALPS GRADE	



A-LEVEL PHYSICS

TOPIC 5

INDEPENDENT WORK BOOK 1

THIS MUST BE BROUGHT TO ALL PHYSICS LESSONS.

Contents

Overview

This section builds on and develops earlier study of these phenomena from GCSE.

It provides opportunities for the development of practical skills at an early stage in the course and lays the groundwork for later study of the many electrical applications that are important to society.

IMPORTANT NOTE
This book contains all of the activities you can carry out independently in your study periods to enhance your understanding in A-Level Physics.

You may work through the activities in this book and mark this work yourself. You work will then be reviewed by your teacher in KS5 file checks. This work is in addition to the class work and homework you carry out.

This book may also be used as a revision resource for intervention, internal assessments and external assessments.
Please keep this in your student file.

As part of this course you are expected to **read through this preparatory reading book** and **complete the independent study tasks**.

This work will not be assessed but will be monitored by your class teacher.

This must be completed by the deadline set by your class teacher.

SECTION 1

INDEPENDENT STUDY TASK

Instructions

Read through the information from the student preparatory book and then produce revision posters on the key points highlighted on the following pages.

These notes should be used as a revision resource for assessments.

INDEPENDENT STUDY TASK 1

Produce an **information sheet** on properties of electricity.

This is an independent study task to carried out outside of lesson.

INDEPENDENT STUDY TASK 2

Produce an **information sheet** on I-V Graphs and V-I Graphs

This is an independent study task to carried out outside of lesson.

INDEPENDENT STUDY TASK 3

Produce an **information sheet** on the resistivity required practical.

This is an independent study task to carried out outside of lesson.

INDEPENDENT STUDY TASK 4

Produce an **information sheet** on superconductivity.

This is an independent study task to carried out outside of lesson.

SECTION 2

KNOWLEDGE CHECKER

Instructions

Read through the information from the student preparatory book and then answer the following questions from the different parts of the topics.

These questions are designed to introduce the different parts of this module.

Use the mark schemes to review your knowledge and understanding.

QUESTIONS

Use the preparatory reading notes to answer these questions.

A1. Define the coulomb.

[1 Mark]

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A2. Define potential difference.

[1 Mark]

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A3. Give the values of resistance that we assume voltmeters and ammeters to have.

[1 Mark]

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A4. What is special about an ohmic conductor?

[1 Mark]

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A5. What are the units of resistivity?

[1 Mark]

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A6. What happens to mercury when it is cooled to its transition temperature?

[1 Mark]

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Use the preparatory reading notes to answer these questions.

A7. Power is measured in watts. What is 1 watt equivalent to?

[1 Mark]

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A8. What equation links power, potential difference and resistance?

[1 Mark]

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ADVANCED SECTION

A9. A battery delivers 4500C of electric charge to a circuit in 10.0 minutes. Calculate the average current.

[1 Mark]

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A10. A hair dryer is connected to the UK mains supply. The hair dryer has a power of 920W in normal operation. Calculate the current in the hair dryer.

[1 Mark]

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A24. A12V car battery supplies a current of 48A for 2.0 seconds to the car's starter motor. The total resistance of the connecting wires is 0.01Ω. Calculate the energy transferred from the battery.

[1 Mark]

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Use the preparatory reading notes to answer these questions.

Questions **A12-A13** refer to the following statement.

Aluminium has a resistivity of 2.8 x 10^{-8} Ωm at 20^{oC} and a transition temperature of 1.2K
A12. Calculate the resistance of a pure aluminium wire of length 4.00m and diameter 1.0mm, at 20^{oC}.

[1 Mark]

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A13. The wire is cooled to a temperature of 1K. What is the resistance now? Explain your answer.

[1 Mark]

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Use the preparatory reading notes to answer these questions.

ANSWERS

A1. Define the coulomb.

[1 Mark]

One coulomb is the amount of charge that passes in 1 second if the current is 1 ampere.

A2. Define potential difference.

[1 Mark]

Potential difference is the energy per unit charge transferred in an electrical circuit.

A3. Give the values of resistance that we assume voltmeters and ammeters to have.

[1 Mark]

Ammeters are assumed to have no resistance.
Voltmeters are assumed to have infinite resistance.

A4. What is special about an ohmic conductor?

[1 Mark]

An ohmic conductor has a directly proportional relationship between current and potential difference (when the temperature of the conductor is constant).

A5. What are the units of resistivity?

[1 Mark]

Ohm meters (Ωm)

A6. What happens to mercury when it is cooled to its transition temperature?

[1 Mark]

At temperatures lower than the transition temperature, the resistivity of mercury completely disappears, and the material becomes a superconductor.

A7. Power is measured in watts. What is 1 watt equivalent to?

[1 Mark]

1 watt is equivalent to one joule of energy transferring form every second.
1 watt is 1 joule of work being done per second.

A8. What equation links power, potential difference and resistance?

[1 Mark]

Power = Potential Difference^2/Resistance

ADVANCED SECTION

A9. A battery delivers 4500C of electric charge to a circuit in 10.0 minutes. Calculate the average current.

[1 Mark]

Time in Seconds = 10 x 60 = 600 seconds
$I = \Delta Q/t = 4500 / 600 = 7.5A$

A10. A hair dryer is connected to the UK mains supply. The hair dryer has a power of 920W in normal operation. Calculate the current in the hair dryer.

[1 Mark]

$I = P / V = 920 / 230 = 4.0A$

A11. A12V car battery supplies a current of 48A for 2.0 seconds to the car's starter motor. The total resistance of the connecting wires is 0.01Ω. Calculate the energy transferred from the battery.

[1 Mark]

$E = VIt = 12 \times 48 \times 2.0 = 1200J$

Questions **A12-A13** refer to the following statement.

Aluminium has a resistivity of 2.8×10^{-8} Ωm at 20^{oC} and a transition temperature of 1.2K

A12. Calculate the resistance of a pure aluminium wire of length 4.00m and diameter 1.0mm, at 20^{oC}.

[1 Mark]

Area = $\Pi (d/2)^2$
$d = 1.0 \times 10^{-3}$ m

Area = $\Pi \times (0.5 \times 10^{-3})^2$
Area = $7.853 \times 10^{-7} m^2$

$R = \rho l/A = (2.8 \times 10^{-8} \times 4.00) / 7.853 \times 10^{-7} = 0.14\Omega$

A13. The wire is cooled to a temperature of 1K. What is the resistance now? Explain your answer.

[1 Mark]

Resistance will now be zero.
Because aluminium is a superconductor below its transition temperature of 1.2K.

SECTION 3

QUESTIONS

Instructions

Read through the information from the student preparatory book and then answer the following questions from the different parts of the topics.

Use the mark schemes to review your knowledge and understanding.

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.	

PRACTICAL SKILLS

Complete the following practical skills-based task to improve your experimental understanding of this part of the course in preparation for **Physics Paper 3.**

A resistor of unknown resistance was connected to a variable power supply. The current through, I, and potential difference across, V, were measured. You will use this information to calculate the resistance, R, of the resistor.

Data

Potential Difference, V (V)			Current, I (A)		
9.12	9.05	9.07	1.18	1.26	1.24
6.98	7.03	7.06	0.98	0.92	1.01
5.03	4.93	5.02	0.71	0.69	0.65
-4.11	-4.02	-4.04	-0.53	-0.59	-0.53
-5.89	-6.02	-5.98	-0.84	-0.86	-0.78
-8.07	-8.10	-7.92	-1.11	-1.08	-1.14

Mean Potential Difference, V (V)	Mean Current, I (A)	Resistance, R (Ω)

Analysis

A1. Complete the table be calculating the mean values of V and I.

A2. What is the resolution of the voltmeter? What is the resolution of the ammeter?

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A3. What is the uncertainty in the largest positive potential difference?

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A4. Calculate this as a percentage of the mean potential difference.

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A5. What is the uncertainty in the smallest negative potential difference?

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A6. Calculate this as a percentage of the mean potential difference.

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A7. What is the uncertainty in the smallest positive current?

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A8. Calculate this as a percentage of the mean current.

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A9. What is the uncertainty in the largest negative current?

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A10. Calculate this as a percentage of the mean current.

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A11. Which type of error is responsible for the differences in the potential difference and current measurements?

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A12. Plot a graph of I (on the y axis) against V (on the x axis).

A13. Does your line of best fit pass through the origin? Should it? Explain your answer.

A14. What does the gradient of your graph represent?

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A15. Calculate the gradient of your line of best fit.

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A16. Use the gradient to calculate the resistance, *R*, of the resistor.

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A17. The given value of the resistor is 7.3Ω, what is the difference between your value and the given value?

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A18. What is this as a percentage of the accepted value?

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A19. Complete the table using the equation $V = IR$ to calculate *R*.

A20. Calculate the mean value of resistance from the table.

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A21. What is the uncertainty of the mean resistance?

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A22. What is the difference between the accepted value given above and the value you calculated from the table?

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A23. Calculate this as a percentage of the accepted value.

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EXTENDED WRITING

To enhance your skills in answering examination questions for the A-Level examinations, complete the following task.

Describe how you would use a voltmeter, ammeter and other standard laboratory equipment to obtain accurate and reliable measurement of the resistance of a wire at temperatures between 0°C and 100°C.

Your description should include:

- A labelled circuit diagram
- Details of measurements you would take
- An account of how you would use your measurements
- Details of how to improve the precision of your measurements
- A risk assessment.

ANSWERING SPACE

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MARKING

P	**Praise. What were the positive aspects of the work? What did they do well? What skills did they demonstrate?**

I	**Improvements. What were the literacy issues in the piece of work?**		*Write in ink.*		*Draw in Pencil.*		*Use a ruler.*
	Always use capital letters at the beginning of a sentence.		Learn the spellings identified in your work.				
	Always use capital letters for proper nouns.		Ensure sentences make sense.				
	Make sure you write on the line and not above or below it.		Use correct punctuation.				
	Use scientific vocabulary appropriate to the task.		Vary your sentences to demonstrate your understanding.				

D answer		B answer		A* answer	
There is a circuit diagram that contains a voltmeter, ammeter and cell or battery...		...the voltmeter is connected in parallel to the wire and the ammeter in series...		...there is some means of heating (water bath or beaker) and a thermometer.	
There is a description of how the temperature will be increased using a beaker of water and Bunsen burner or a water bath...		...and decreased by adding ice.		...the water must be stirred (so that the thermometer gives the actual temperature).	
The interval of temperature values is missing or described vaguely such as 'wide range of values'...		...the interval is present...		...between (and including) 0°C and 100°C.	
		The risk of burns at high temperatures is stated...		...and an appropriate control measure is given.	
For each temperature of the water the current and voltage is measured (at least) three times...		...anomalous results are removed and a mean is calculated...		...accuracy is improved further by reducing the interval so that R (or V and I) is measured at more temperatures so a more detailed line (of best fit) can be drawn.	
Resistance is calculated using the equation R=V/I...		...resistance is plotted against temperature and a line of best fit is drawn...		...temperature is plotted on the x axis and resistance on the y axis.	
The precision of the measurements could be improved by using instruments with smaller scale divisions (owtte)...		...such as a digital temperature probe set to 0.1°C (or smaller) ...		...connected to a data logger.	

N	**Next Steps. How can they move their work onto the next grade? What didn't they include?**	**Grade**	**Effort**

CHALLENGE QUESTION

To assess your understanding, answer the following higher-level question on this topic.

(a) A metal wire of constant resistance is used in an electric heater.
In order not to overload the circuit for the heater, the supply voltage to the heater is reduced from 230 V to 220 V.

Determine the percentage reduction in the power output of the heater.

reduction = ... % [2]

(b) A uniform wire AB of length 100 cm is connected between the terminals of a cell of e.m.f. 1.5 V and negligible internal resistance, as shown in Fig. 6.1.

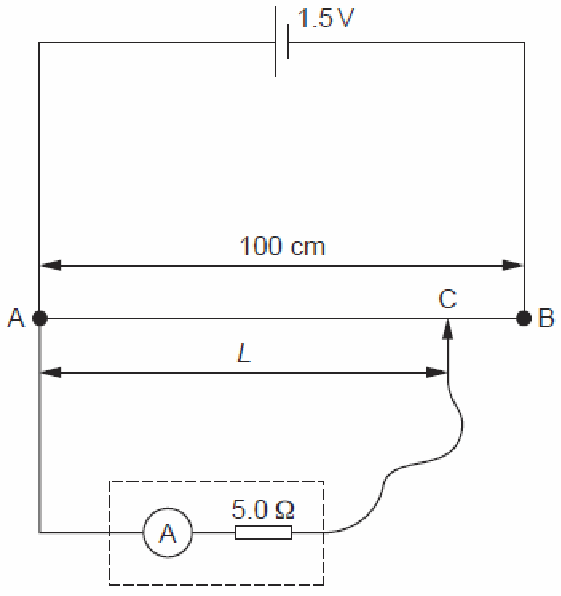

Fig. 6.1

An ammeter of internal resistance 5.0 Ω is connected to end A of the wire and to a contact C that can be moved along the wire.

Determine the reading on the ammeter for the contact C placed

(i) at A,

reading = ... A [1]

(ii) at B.

reading = ... A [1]

(c) Using the circuit in **(b)**, the ammeter reading I is recorded for different distances L of the contact C from end A of the wire. Some data points are shown on Fig. 6.2.

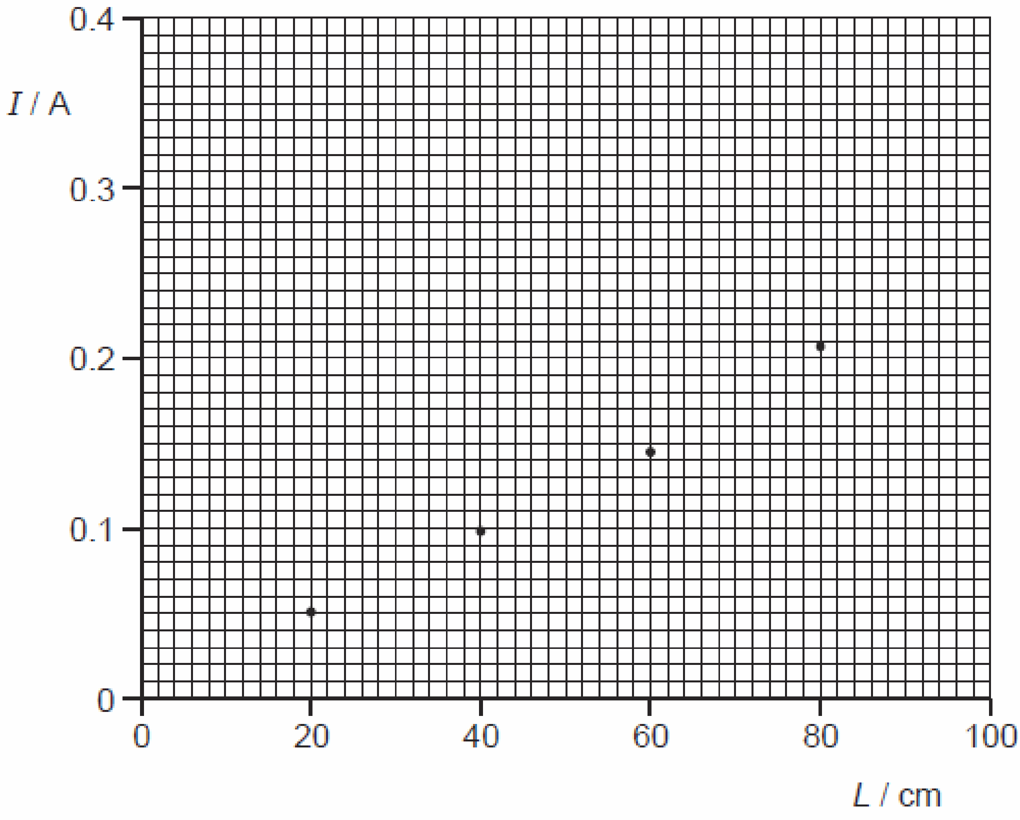

Fig. 6.2

(i) Use your answers in **(b)** to plot data points on Fig. 6.2 corresponding to the contact C placed at end A and at end B of the wire. [1]

(ii) Draw a line of best fit for all of the data points and hence determine the ammeter reading for contact C placed at the midpoint of the wire.

reading = ... A [1]

(iii) Use your answer in **(ii)** to calculate the potential difference between A and the contact C for the contact placed at the midpoint of AB.

potential difference = ... V [2]

(d) Explain why, although the contact C is at the midpoint of wire AB, the answer in **(c)(iii)** is **not** numerically equal to one half of the e.m.f. of the cell.

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....[2]

Reference: Cambridge International A Level Unit 2 June 2010 Examination

ANSWERS

(a)	*either* $P \propto V^2$ *or* $P = V^2/R$	C1	
	reduction = $(230^2 - 220^2)/230^2$		
	= 8.5 %	A1	[2]
(b)	**(i)** zero	A1	[1]
	(ii) 0.3(0) A	A1	[1]
(c)	**(i)** correct plots to within ± 1 mm	B1	[1]
	(ii) reasonable line/curve through points giving current as 0.12 A		
	allow ± 0.005A)	B1	[1]
	(iii) $V = IR$	C1	
	$V = 0.12 \times 5.0$		
	= 0.6(0) V	A1	[2]
(d)	circuit acts as a potential divider/current divides/current in AC not the same as current in BC	B1	
	resistance between A and C not equal to resistance between C and B	B1	
	or current in wire AC × R is not equal to current in wire BC × R	B1	[2]
	any 2 statements		

TOPIC: 3.5.1.2 Current-Voltage 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.	

SUPPORT

Electric current, I, is the rate of flow of **charge**, Q, in a wire or component. Charge is measured in coulombs (C), while current is measured in amperes (A) – usually shortened to 'amps'.

$$\text{current} = \frac{\text{flow of charge}}{\text{time}}$$

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

The current flowing through a component is measured by connecting an ammeter in series with the component.

The **potential difference**, V, is the work done (or energy transferred), W, per unit charge, Q. Potential difference is often referred to as pd and is measured in volts (V).

$$\text{potential difference} = \frac{\text{work done}}{\text{charge}}$$

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

Potential difference across a component can be measured by connecting a voltmeter in parallel with the component.

The **electromotive force (emf)** of a battery or cell is the energy provided per unit of charge passing through it, and so it is also measured in volts (V).

The energy transferred (or dissipated), ΔE, in a component is equal to the work done, W and is measured in joules (J).

energy transferred, ΔE = work done, W

= current × time × potential difference

$$W = ItV$$

Also, energy transferred = power × time

$$\Delta E = Pt$$

The **power**, P, in watts (W), supplied to a component, is the energy transferred (or dissipated) to that component per second.

$$\text{power} = \frac{\text{energy transferred}}{\text{time}}$$

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

Or, power = current × potential difference

$$P = IV$$

The **resistance**, R, of a component in a circuit is a measure of the difficulty of making current pass through the component. The unit of resistance is the ohm (Ω), which is equal to one volt per ampere.

Resistance is defined as $\dfrac{\text{potential difference}}{\text{current}}$

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

Resistance is caused by the repeated collisions between the charge carriers in the material with each other and with the fixed positive ions of the material.

If you measure the variation of current with pd for a component you can plot a **characteristic graph** of current (on the *y*-axis) against pd (on the *x*-axis). You should know what the characteristic graphs look like for a resistor, a filament lamp, and a diode – you need to make sure that you can remember these.

Task

Before looking at the worked examples, complete the table below.

Quantity	Symbol	Unit	Equation(s) which could be used to find this quantity
Charge			
Current			
Potential difference			
Resistance			
Energy			
Power			

Worked example 1

Resistance

Question

A pd of 15 V is needed to enable a current of 2.5 A to flow through a wire.
Calculate the resistance of the wire.

Answer

Step 1

Write down the values given in the question.

V = 15 V

I = 2.5 A

R = ? (*This is the quantity you need to calculate.*)

Step 2

Write down the appropriate equation and substitute the values.

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

$$= \frac{15}{2.5}$$

$$= 6.0\ \Omega$$

(*Remember to include units and use the appropriate number of significant figures.*)

Worked example 2

Energy

Question

Calculate the energy dissipated in 1.0 minute by an immersion heater of power 5.0 kW.

Answer

Step 1

Write down the values given in the question and convert them into SI units.

$P = 5.0\ \text{kW} = 5.0 \times 10^3\ \text{W}$

$t = 1.0\ \text{minute} = 60\ \text{s}$

Step 2

Write down the appropriate equation and substitute the values. Give your final answer to an appropriate number of significant figures.

$\Delta E = Pt$

$= (5 \times 10^3) \times 60$

$= 3.0 \times 10^5\ \text{J}$

Worked example 3

PD and Current

Question

A charge of 25 C flows in 10 s, delivering 200 J of energy to the outside circuit.

3.1 Calculate the pd across the battery.

3.2 Calculate the current flowing from the battery.

Answer

3.1 Step 1

Write down the values given in the question.

$\Delta Q = 25\ \text{C}$

$\Delta t = 10\ \text{s}$

$\Delta E = W = 200\ \text{J}$

$V = ?$ (*the pd across the battery*)

$I = ?$ (*the current flowing from the battery*)

Step 2

Write down the appropriate equation, rearrange for pd, and substitute values.

$W = QV$

so

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

$$= \frac{200}{25}$$

= 8.0 V

3.2 Step 3

Write down the appropriate equation for current and substitute values.

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

$$= \frac{25}{10}$$

= 2.5 A

Worked example 4

Power and Resistance

Question

A water heater connected to a 20 V supply, provides 200 J of electrical energy every second to heat the water.

4.1 Calculate the power of the heater.

4.2 Calculate the current passing through the heater.

4.3 Calculate the resistance of the heater element.

Answer

Step 1

Write down the values given in the question.

$V = 20$ V

$\Delta E = W = 200$ J

$t = 1$ s

P = ? (*the power of the heater*)

II = ? (*the current passing through the heater*)

R = ? (*the resistance of the heater element*)

4.1 Step 2

Write down the appropriate equation to find power, and substitute in the values.

$$P = \frac{\Delta E}{t} = \frac{200}{1} = 200\ \text{W}$$

4.2 Step 3

Write down the appropriate equation, rearrange to make current the subject, and substitute in the values (using your value of P from part **a**).

$P = IV$

so

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

$$= \frac{200}{20}$$

$= 10\ \text{A}$

4.3 Step 4

Write down the appropriate equation to find resistance, and substitute in the values (using your value for I from part **b**).

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

$$= \frac{20}{10}$$

$= 2.0\ \Omega$

Questions

S1. A pd of 15 V is needed to make a current of 2.5 A flow through a wire.

S1.1 Calculate the resistance of the wire.

[1 Mark]

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S1.2 Determine the pd needed to make a current of 2.0 A flow through the wire.

[2 Marks]

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S2. A current of 200 mA flows through a 4 kΩ resistor. Calculate the pd across the resistor.

[2 Marks]

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S3. A small water heater is rated at 12 V and 60 W.

S3.1 Calculate the current passing through the heater element.

[2 Marks]

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S3.2 Calculate the resistance of the heater element.

[1 Mark]

....

S4. A current of 4.0 A flows when a light bulb is connected across the terminals of a battery. The pd across the terminals is 12 V.

S4.1 State the amount of charge flowing past a set point in the circuit every second.

[1 Mark]

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S4.2 Calculate the electrical energy of each coulomb of charge flowing in the circuit.

[1 Mark]

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S4.3 Calculate the charge needed to transfer 60 J of energy.

[3 Marks]

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S4.4 Calculate how long the battery will take to transfer 60 J of energy.

[2 Marks]

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S5. Draw the I–V characteristic graphs for a resistor, a filament lamp, and a diode using the axes provided. Below each graph, give a description of the graph and explain the shape of the graph.

[6 Marks]

Resistor	**Filament lamp**	**Diode**

S6. Draw a labelled circuit diagram of a circuit that you could use to measure the variation of current with pd for a filament lamp. Describe your method.

[3 Marks]

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ANSWERS

Task

Quantity	Symbol	Unit	Equation(s) which could be used to find this quantity
Charge	Q	C	$Q = It$ $W = QV$
Current	I	A	$V = IR$ $Q = It$
Potential difference	V	V	$V = IR$ $W = QV$
Resistance	R	Ω	$R = \frac{V}{I}$
Energy	W	J	$W = QV$ $W = ItV$
Power	P	W	$P = IV$

Questions

S1.1 6.0 Ω (*1 mark*)
S1.2 12 V (*2 marks*)

S2. 800 V (or 8.0×10^2 V) (*2 marks*)

S3.1 5.0 A (*2 marks*)
S3.2 2.4 Ω (*1 mark*)

S4.1 4.0 C (*2 marks*)
S4.2 12 J (1 mark)
S4.3 5 C (3 marks)
S4.4 1.3 s to two significant figures (1.25 s) (*2 marks*)

PRACTICAL SKILLS

Complete the following practical skills-based task to improve your experimental understanding of this part of the course in preparation for **Physics Paper 3.**

This first set of questions checks your ability to apply your understanding of the heating effect of a current to a range of scenarios.

S1. Figure 1 shows the current–voltage (I–V) characteristics for a filament lamp.

S1.1 State the value of the current in the lamp when it stops obeying Ohm's law.

[1 Mark]

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S1.2 Explain why the lamp stops obeying Ohm's law as the current increases beyond this point.

[1 Mark]

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S1.3 Calculate the resistance of the lamp when the current is 0.2 A.

[2 Marks]

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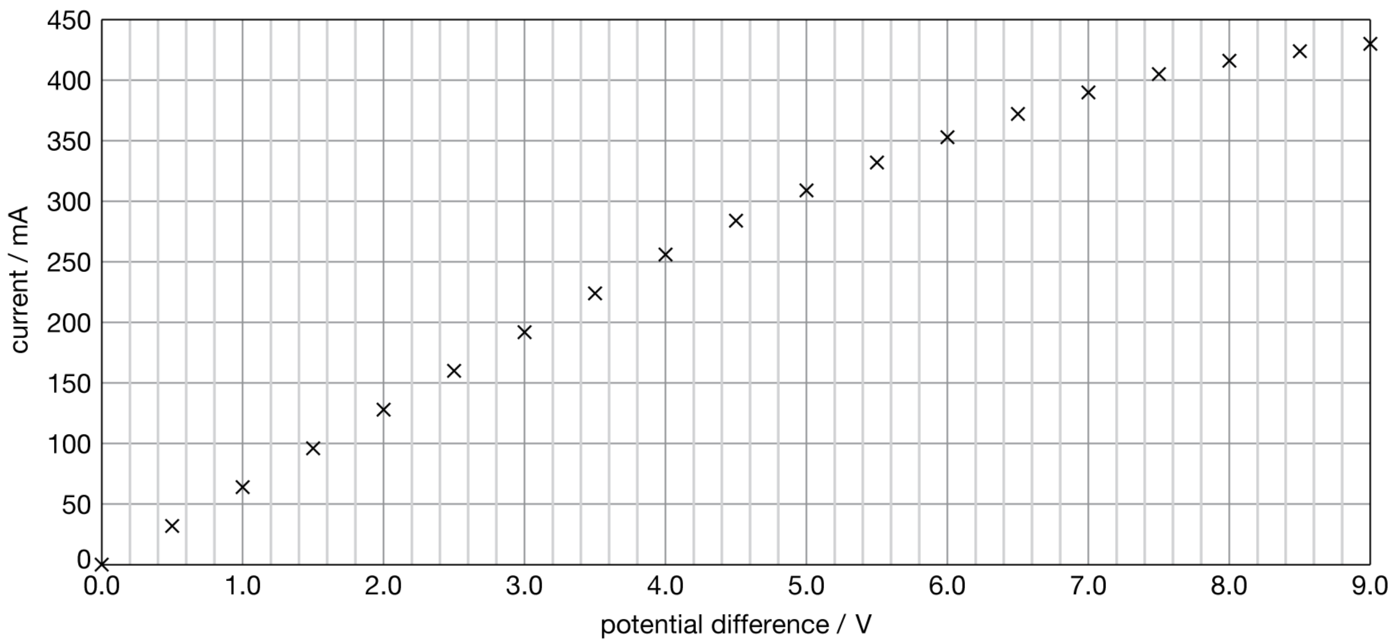

Figure 1 ***Current–voltage characteristics for a filament lamp***

S2. A car is fitted with an automatic window defrosting device, consisting of several very thin metal filaments running through the front windscreen in parallel. These elements are activated remotely by the owner several minutes before returning to the car to ensure that the windows are defrosted.

S2.1 When first activated, the system operates with a current of 1.20 A, and a potential difference of 12.0 V across it. Calculate the electrical power of the device.

[2 Marks]

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S2.2 After the frost on the windscreen melts, the current into the device reduces to 1.00 A. Explain this effect.

[3 Marks]

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S2.3 A chip in the windscreen breaks one of the filaments. Explain what effect, if any, this will have on the current into the device.

[2 Marks]

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S3. Polystyrene foam can be cut and shaped using a hot metal wire. As the wire is moved through the foam, the polystyrene melts. Figure 2 shows how the temperature of a cutting wire varies with the current in it. The melting point of polystyrene is 220 °C.

S3.1 What is the minimum current in the wire that will allow it to be used to cut polystyrene?

[1 Mark]

....

S3.2 The wire has a potential difference of 12 V and a current of 0.25 A in it during normal cutting. What is the temperature of the wire during normal operations?

[1 Mark]

………

What is the resistance of the cutting wire during normal operations?

[1 Mark]

………

What power is dissipated by the wire?

[1 Mark]

………

S3.3 Whilst being used, the wire snaps and is replaced by a wire made from the same material and of the same length but with twice the diameter of the original wire. The potential difference across the wire remains at 12 V. Discuss whether the wire will still be able to cut the polystyrene foam.

[3 Marks]

………

………

………

………

………

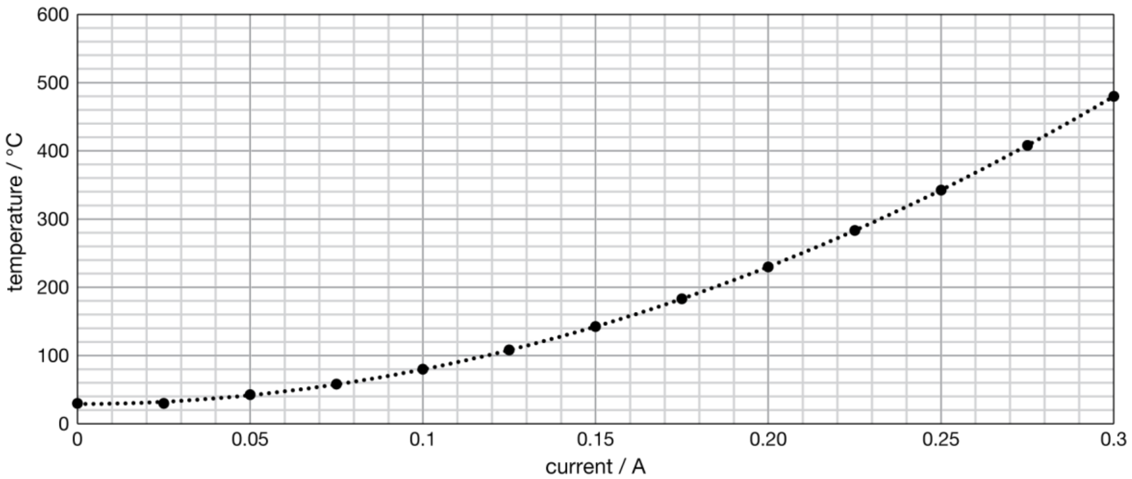


Figure 2 Effect of current on the temperature of a cutting wire

ANSWERS

S1.1 Accept answers in the range 4.0 to 5.0 V inclusive. (*1 mark*)

S1.2 The temperature of the lamp has increased. (*1 mark*)

S1.3 Correct reading of value from graph for V (3.1 V) (*1 mark*)

$R = \frac{V}{I} = \frac{3.1}{0.2} = 15.5\,\Omega$. (*1 mark*)

S2.1 $P = IV = 1.20 \times 12.0 = 14.4$ (*1 mark*) W (*1 mark*)

S2.2 Explanation should include:

- the temperature of the heating elements rises (*1 mark*)
- the resistance increases (*1 mark*)
- the current decreases as the pd remains the same (use of $V = IR$). (*1 mark*)

S2.3 The current of the circuit will decrease (*1 mark*) as the resistance has increased (*1 mark*). Do not accept answers implying there is no longer a complete circuit.

S3.1 0.2 A (*1 mark*)

S3.2 i 340 °C (*1 mark*)

ii $R = \frac{V}{I} = 48\,\Omega$ (*1 mark*)

iii $P = IV = 12 \times 0.25 = 3.0$ W. (*1 mark*)

S3.3 Yes, the wire will still be able to cut the polystyrene foam.

Any three of the following:

- cross-sectional area increased by factor of 4 (*1 mark*)
- resistance decreases as cross-sectional area increased (inversely proportional) (*1 mark*)
- $P = \frac{V^2}{R}$ shows that the power dissipated by the wire is now much greater (*1 mark*)
- the wire will become hotter (*1 mark*)
- surface area of wire increases in proportion to diameter (*1 mark*)
- increase in surface area would decrease energy radiated per square centimetre if power remained the same (*1 mark*)
- power has increased more than surface area so energy radiated per square centimetre increases. (*1 mark*)

PRACTICAL SKILLS

Complete the following practical skills-based task to improve your experimental understanding of this part of the course in preparation for **Physics Paper 3.**

A student collected the following data using a data logger to measure resistance and temperature simultaneously. Ignore the additional columns for now.

Temperature / °C	**Resistance (R) / Ω**	**Temperature (T) / K**	$\ln(R) - \ln(R_0)$	$\left(\frac{1}{T} - \frac{1}{T_0}\right) \times 10^{-4}$
70	37			
65	51			
60	71			
55	100			
50	143			
45	205			
40	299			
35	442			
30	660			
25	1000			

Understanding the graph to be plotted

The equation needs to be rearranged so that a straight-line graph can be produced, which will allow you to determine a value for β. This rearrangement is performed in the following stages.

Start with the original equation.	$R = R_0 e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)}$
Take natural logarithms of both sides.	$\ln(R) = \ln\left(R_0 e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)}\right)$
Logarithms allow us to separate factors that are multiplied into factors that are added, according to the logarithmic rule: ln(AB) = ln(A) + ln(B). Separate the factors in the equation.	$\ln(R) = \ln(R_0) + \ln\left(e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)}\right)$
Rearrange the equation to move ln (R_0) to the left-hand side.	$\ln(R) - \ln(R_0) = \ln\left(e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)}\right)$
As ln and e are inverse functions of each other, the following relations hold: $e^{\ln(x)} = x$, and $\ln(e)^x = x$. Using this relationship, remove ln and e from the right-hand side of the equation.	$\ln(R) - \ln(R_0) = \beta\left(\frac{1}{T} - \frac{1}{T_0}\right)$

The final function is of the form $y = mx + c$, the equation for a straight line.

The dependent variable, $y = \ln(R) - \ln(R_0)$

The independent variable, $x = \left(\frac{1}{T} - \frac{1}{T_0}\right)$

The gradient, $m = \beta$.

Selecting coefficients

The data from the results table can be used to determine some values for T, T_0, R, and R_0. We just have to pick any two temperatures and their corresponding resistances from the data table. It is best to choose values for T_0 and R_0 that are much bigger or much smaller than the values chosen for T and R.

We will select the following values from the results table.

T_0 = 298 K (25 °C)	R_0 = 1000 Ω	T = 343 K (70 °C)	R = 37 Ω

Processing the data

A1. Complete the column in the results table for temperature in kelvin.

[1 Mark]

A2. Carefully complete the end two columns in the results table.

[4 Marks]

A3. Plot a graph of $\ln(R) - \ln(R_0)$ against $\left(\frac{1}{T} - \frac{1}{T_0}\right)$ as described above.

[4 Marks]

A4. Does the shape of the graph confirm or disprove the form of the equation suggested?

[1 Mark]

....

A5. Calculate the gradient of this line of best fit and hence state a value for β.

[3 Marks]

....

....

....

....

....

ANSWERS

Temperature / °C	Resistance (R) / Ω	Temperature (T) / K	$\ln(R) - \ln(R_0)$	$\left(\frac{1}{T} - \frac{1}{T_0}\right)$
70	37	343	−3.302	−4.40E−04
65	51	338	−2.978	−3.97E−04
60	71	333	−2.645	−3.53E−04
55	100	328	−2.302	−3.07E−04
50	143	323	−1.948	−2.60E−04
45	205	318	−1.583	−2.11E−04
40	299	313	−1.206	−1.61E−04
35	442	308	−0.817	−1.09E−04
30	660	303	−0.415	−5.54E−05
25	1000	298	0.000	0.00E+00

A1. See answers in table above. Mark if all correct. (*1 mark*)

A2. See answers in table above.

Award *2 marks* if all figures in the third column are correct and *1 mark* if over half are correct.

Award *2 marks* if all figures in the fourth column are correct and *1 mark* if over half are correct.

A3. Suitable axis scales (*1 mark*)

Accurate plotting of all data (*1 mark*)

Data plotted to cover at least half of graph area (*1 mark*)

Line of best fit (*1 mark*)

A4. Graph should be linear, which suggests equation is correct. (*1 mark*)

A5. Large Δx and Δy triangle (*1 mark*)

Data read correctly from graph (*1 mark*)

Final value of $\beta = 7500$ (*1 mark*)

CHALLENGE QUESTION

To assess your understanding, answer the following higher-level question on this topic.

(a) **(i)** State what is meant by an *electric current*.

....

....[1]

(ii) Define *electric potential difference*.

....

....[1]

(b) The variation with potential difference V of the current I in a component Y and in a resistor R are shown in Fig. 6.1.

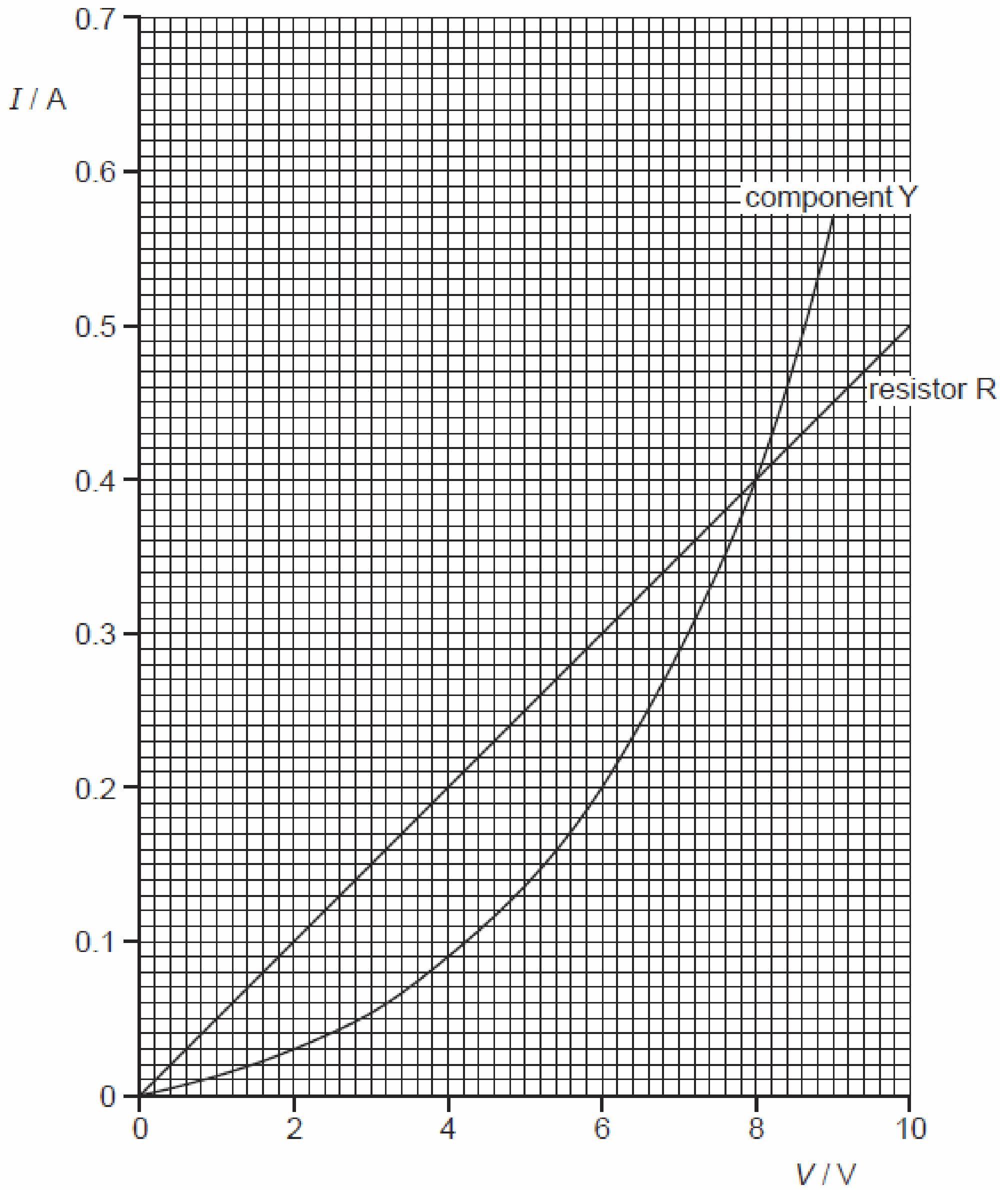


Fig. 6.1

Use Fig. 6.1 to explain how it can be deduced that resistor R has a constant resistance of 20 Ω.

....

....

....[2]

(c) The component Y and the resistor R in **(b)** are connected in parallel as shown in Fig. 6.2.

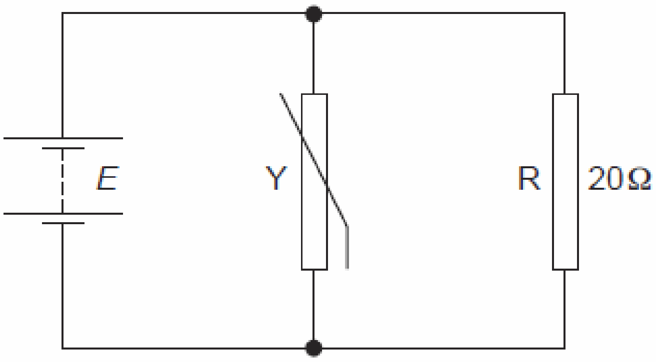


Fig. 6.2

A battery of e.m.f. *E* and negligible internal resistance is connected across the parallel combination.

Use data from Fig. 6.1 to determine

(i) the current in the battery for an e.m.f. *E* of 6.0 V,

current = ... A [1]

(ii) the total resistance of the circuit for an e.m.f. of 8.0 V.

resistance = ... Ω [2]

(d) The circuit of Fig. 6.2 is now re-arranged as shown in Fig. 6.3.

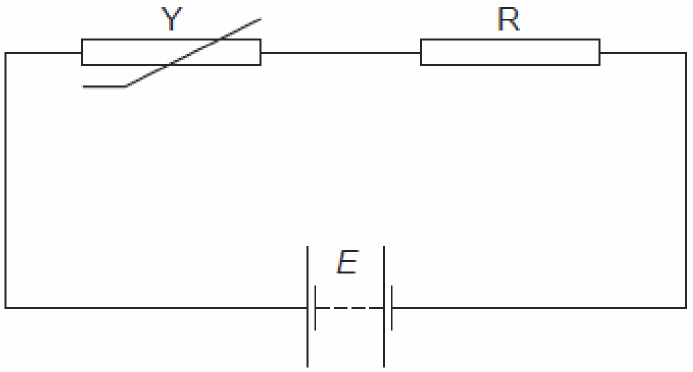


Fig. 6.3

The current in the circuit is 0.20 A.

(i) Use Fig. 6.1 to determine the e.m.f. *E* of the battery.

E = ... V [1]

(ii) Calculate the total power dissipated in component Y and resistor R.

power = ... W [2]

Reference: Cambridge International A Level Unit 2 June 2010 Examination

ANSWERS

(a)	(i) movement/flow of charged particles	B1	[1]
	(ii) work done per unit charge (transferred)	B1	[1]
(b)	straight line through origin	B1	
	resistance = V/I , with values for V and I shown	M1	
	= 20 Ω	A0	[2]
	(using the gradient loses the last mark)		
(c)	(i) 0.5A	A1	[1]
	(ii) *either* resistance of each resistor is 20 Ω *or* total current = 0.8 A	C1	
	either combined resistance = 10 Ω *or* $R = E/I$ = 10 Ω	A1	[2]
(d)	(i) 10 V	A1	[1]
	(ii) power = EI	C1	
	= 10 × 0.2 = 2.0 W	A1	[2]

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.	

SUPPORT

The resistance, R, of a component in a circuit is a measure of the difficulty of making current pass through the component. The unit of resistance is the ohm (Ω), which is equal to one volt per ampere.

$$\text{resistance} = \frac{\text{potential difference}}{\text{current}} \quad \left(R = \frac{V}{I}\right)$$

Resistance is caused by the repeated collisions between the charge carriers in the material. They collide with each other and with the fixed positive ions of the material.

Resistivity, ρ, is a measure of how strongly a material opposes, or resists, the flow of current. The unit of resistivity is Ω m. The resistivity of a material is a property of the material itself and does not depend on the quantity of the material.

The resistance of a conductor is related to the resistivity by the equation

$$\text{resistance} = \frac{\text{resistivity} \times \text{length of conductor}}{\text{cross-sectional area}} \quad \left(R = \frac{\rho L}{A}\right)$$

From the equation, we can see that the resistance of a conductor:

- is proportional to the resistivity of the material
- is proportional to the length of the conductor (i.e., doubling the length of a wire doubles its resistance)
- is inversely proportional to the cross-sectional area of the conductor (i.e., doubling the cross-sectional area of a wire halves its resistance).

Worked example

Question

A wire has a diameter of 1.0 mm and a resistivity of 5.0×10^{-6} Ω m.

Calculate the length of wire that would have a resistance of 5.0 Ω.

Answer

Step 1

Write down the values given in the question, and convert them into SI units.

$R = 5.0\ \Omega$

$\rho = 5.0 \times 10^{-6}\ \Omega\,\text{m}$

$d = 1.0\ \text{mm} = 1.0 \times 10^{-3}\ \text{m}$

L = ? (*This is the value you need to calculate.*)

Step 2

Write down the appropriate equation and rearrange for L.

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

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

Step 3

Calculate the cross-sectional area of the wire. The question gives the diameter of the wire – remember to divide this by two to find the radius, *r*.

$A = \pi r^2$ x $\pi \times (0.5 \times 10^{-3})^2 = 7.85 \times 10^{-7}\ \text{m}^2$

Step 4

Substitute the values into the equation to calculate *L*.

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

$$= \frac{5.0 \times (7.85 \times 10^{-7})}{5.0 \times 10^{-6}}$$

= 0.785 m = 0.79 m (to two significant figures)

Questions

S1. Calculate the resistivity of a wire of resistance 5.0 Ω, if the length of the wire is 2.0 m and the diameter of the wire 0.2 mm.

[2 Marks]

....

....

....

....

S2. Determine the length of a constantan wire, of resistivity $4.9 \times 10^{-7}\ \Omega\,\text{m}$ and diameter 0.1 mm, required to make a coil of resistance 20 Ω.

[2 Marks]

....

....

....

....

S3.1 Calculate the resistance of 10 m of wire of diameter 0.36 mm and resistivity $44 \times 10^{-8}\ \Omega\,m$.

[2 Marks]

....

....

....

....

S3.2 Deduce the resistance of another wire of the same material but of half the length and half the diameter

[1 Mark]

....

....

S4. The potential difference across 5.0 m of nichrome wire is 3.2 V and the current flowing through it is 0.20 A. The resistivity of nichrome is $1.0 \times 10^{-6}\ \Omega\,m$. Determine the diameter of the wire.

[3 Marks]

....

....

....

....

Exam-style question

S5. A generator produces 100 kW of power at 500 V. If the power lost in the 800 m long copper cables connected to the generator is 6% of the power produced, calculate the diameter of the cable.

Resistivity of copper = $1.6 \times 10^{-8}\,\Omega\,\text{m}$

[4 Marks]

....

....

....

....

....

....

....

....

ANSWERS

S1. $7.9 \times 10^{-8}\ \Omega\,m$ to two significant figures ($7.85 \times 10^{-8}\ \Omega\,m$) (*2 marks*)

S2. 0.32 m (*2 marks*)

S3.1 43 Ω to two significant figures (43.2 Ω) (*2 marks*)

S3.2 If L and D is halved, the resistance will double:

R = 86 Ω to two significant figures (86.4 Ω) (*1 mark*)

S4. 0.63 mm (3 *marks*)

S5. $I = \frac{P}{V} = \frac{100\,000}{500} = 200\ A$ (*1 mark*)

Power lost = 6000 = $200^2 R$ (*1 mark*)

R = 0.15 Ω (*1 mark*)

So, d = 1.0 cm (*1 mark*)

REQUIRED PRACTICAL FOLLOW UP

Complete the following practical skills-based task to improve your experimental understanding of the required practical 'resistivity of a wire'.

A student carries out an experiment to determine the resistivity of Nichrome wire, following the same method described in the Method sheet. The results of the experiment are shown in Table 1.

Length / m	pd / V	Current / A	Resistance / Ω	pd / V	Current / A	Resistance / Ω	pd / V	Current / A	Resistance / Ω	Mean resistance / Ω
0.90	0.48	0.21		0.50	0.22		0.53	0.24		
0.80	0.48	0.24		0.51	0.26		0.50	0.25		
0.70	0.52	0.30		0.52	0.30		0.59	0.30		
0.60	0.51	0.34		0.51	0.34		0.48	0.31		
0.50	0.49	0.39		0.50	0.40		0.49	0.40		
0.40	0.50	0.51		0.52	0.52		0.49	0.48		
0.30	0.49	0.66		0.52	0.67		0.49	0.64		

Table 1

Table 2 Diameter of Nichrome wire

Diameter / mm	0.78	0.79	0.78	0.78	0.79

S1. Identify the anomalous result that should be eliminated from the resistance table data.

[1 Mark]

....

....

S2. Calculate the values for resistance and add them to Table 1.

[3 Marks]

S3. Calculate the values for mean resistance and add them to Table 1.

[2 Marks]

S4. Use the data from Table 2 to calculate the cross-sectional area of the wire in m^2.

[3 Marks]

....

....

....

....

S5. Describe how the data from both tables can be used to determine the resistivity of Nichrome by comparing the equation for a straight-line graph ($y = mx + c$) with the equation for resistivity $\left(R = \frac{\rho L}{A}\right)$.

[3 Marks]

....

....

....

....

S6. Plot a suitable graph that will allow you to determine resistivity.

[4 Marks]

S7. Using your graph, determine the resistivity of the Nichrome sample.

[3 Marks]

....

....

....

....

S8. Determine the percentage difference between the experimental value for the resistivity of the wire and the manufacturer's stated resistivity of $1.10 \times 10^{-6}\,\Omega\,\text{m}$.

[1 Mark]

....

....

ANSWERS

Length / m	pd / V	Current / A	Resistance / Ω	pd / V	Current / A	Resistance / Ω	pd / V	Current / A	Resistance / Ω	Mean resistance / Ω
0.90	0.48	0.21	2.29	0.50	0.22	2.27	0.53	0.24	2.21	2.26
0.80	0.48	0.24	2.00	0.51	0.26	1.96	0.50	0.25	2.00	1.99
0.70	0.52	0.30	1.73	0.52	0.30	1.73	**0.59**	0.30	**1.97**	1.73
0.60	0.51	0.34	1.50	0.51	0.34	1.50	0.48	0.31	1.55	1.52
0.50	0.49	0.39	1.26	0.50	0.40	1.25	0.49	0.40	1.23	1.25
0.40	0.50	0.51	0.98	0.52	0.52	1.00	0.49	0.48	1.02	1.00
0.30	0.49	0.66	0.74	0.52	0.67	0.78	0.49	0.64	0.77	0.76

Diameter / mm	0.78	0.79	0.78	0.78	0.79

Mean diameter / mm	0.784
Area / m^2	4.83×10^{-7}
Gradient	2.477
Resistivity	1.20×10^{-6} Ω m

S1. The anomalous result is the third pd for 0.70 m length (in bold in table). (*1 mark*)

S2. Data should match Table 1. Award *2 marks* if all answers correct and *1 mark* for over half correct. Award *1 mark* for suitable use of significant figures (3 s.f.). Maximum *3 marks.*

S3. Data should match Table 1. *2 marks* if all answers correct and *1 mark* for over half correct.

S4. See Table 3.

Calculation of mean value for diameter. (*1 mark*)

Conversion of length to m. (*1 mark*)

Calculation of area. (*1 mark*)

S5. A graph of *R* against *L* needs to be plotted. (*1 mark*)

The gradient of such a graph will be resistivity over cross-sectional area. (*1 mark*)

Multiplying the gradient by cross-sectional area will give resistivity. (*1 mark*)

S6. Linear scales, labelled, and plotted points occupying over half the graph paper. (*1 mark*)

Award *2 marks* for accurate plotting of all data points, or *1 mark* for accurate plotting of over half the data points.

Line of best fit. (*1 mark*)

S7. Large triangle drawn to determine gradient. (*1 mark*)

Gradient calculated (2.48). (*1 mark*)

Resistivity calculated (gradient × cross-sectional area) (1.20×10^{-6} Ω m). (*1 mark*)

S8. Percentage difference = $\frac{0.1}{1.1}$ = 9.1%. (*1 mark*)

PRACTICAL SKILLS

Complete the following practical skills-based task to improve your experimental understanding of this part of the course in preparation for **Physics Paper 3.**

Different lengths of copper wire were used to find its resistivity. A potential difference was applied across the wires and the current through them was recorded. The wire had a diameter of 0.9 mm.

Data

Here is the experimental data collected from the different lengths of copper wire.

Length, *l* (m)	**p.d., *V* (mV)**	**Current, *I* (A)**			**Mean Current, *I* (A)**	**Resistance, *R* (Ω)**
1.00	54	2.103	1.978	1.995		
2.00	54	1.021	1.004	1.014		
3.00	54	0.651	0.662	0.712		
4.00	54	0.511	0.514	0.493		
5.00	54	0.395	0.411	0.409		
6.00	54	0.347	0.333	0.334		

Analysis

A1. Calculate the cross-sectional area of the wire using the equation $A = \pi . r^2$

....

....

A2. Calculate the mean value of current for each of the different lengths of wire.

A3. Use the equation $V = I.R$ to calculate the resistance of each of the different lengths of wire.

A4. What is the resolution of the length measurements?

....

....

A5. What is the smallest division on the ruler used to measure it?

....

A6. What is the resolution of the voltmeter used?

....

....

A7. Calculate the uncertainty in the current when the wire is 2.00 m long.

....

....

A8. What is this as a percentage of the mean current?

……

……

……

……

A9. What would be the percentage uncertainty in the corresponding value of *R*?

……

……

……

A10. Calculate the uncertainty in the current when the wire is 4.00 m long.

……

……

A11. What is this as a percentage of the mean current?

……

……

……

A12. What would be the percentage uncertainty in the corresponding value of *R*?

……

……

……

A13. Calculate the uncertainty in the current when the wire is 6.00 m long.

……

……

A14. What is this as a percentage of the mean current?

……

……

A15. What would be the percentage uncertainty in the corresponding value of *R*?

……

……

A16. Plot a graph of *R* (y axis) against *l* and draw a line of best fit.

A17. Does your line of best fit pass through the origin? Should it? Explain your answer.

....

....

A18. If the equation linking *R* and *l* is $R = \rho \frac{l}{A}$, what does the gradient of your line represent?

....

....

A19. Calculate the gradient of your line of best fit.

....

....

A20. Use the gradient to find the value of resistivity.

....

....

A21. The accepted value of the resistivity of copper at 20 °C is 1.68×10^{-8} Ωm.

....

....

A22. What is the difference between this value and the value you obtained from your graph?

....

....

A23. Calculate this as a percentage of the accepted value.

....

....

CHALLENGE QUESTION

To assess your understanding, answer the following higher-level question on this topic.

An electric heater is to be made from nichrome wire. Nichrome has a resistivity of $1.0 \times 10^{-6}\,\Omega\,m$ at the operating temperature of the heater.
The heater is to have a power dissipation of 60W when the potential difference across its terminals is 12V.

(a) For the heater operating at its designed power,

(i) calculate the current,

current = ... A [2]

(ii) show that the resistance of the nichrome wire is 2.4 Ω.

[2]

(b) Calculate the length of nichrome wire of diameter 0.80 mm required for the heater.

length = ... m [3]

(c) A second heater, also designed to operate from a 12 V supply, is constructed using the same nichrome wire but using half the length of that calculated in **(b)**.
Explain quantitatively the effect of this change in length of wire on the power of the heater.

....

....

....

.... [3]

Reference: Cambridge International A Level Unit 2 June 2010 Examination

ANSWERS

(a) (i) $P = VI$ C1
$60 = 12 \times I$
$I = 5.(0)$ A .... A1 [2]

(ii) *either* $V = IR$ *or* $P = I^2R$ or $P = V^2 / R$ C1
either $12 = 5 \times R$ *or* $60 = 5^2 \times R$ or $60 = 12^2/R$ M1
$R = 2.4\ \Omega$ .... A0 [2]

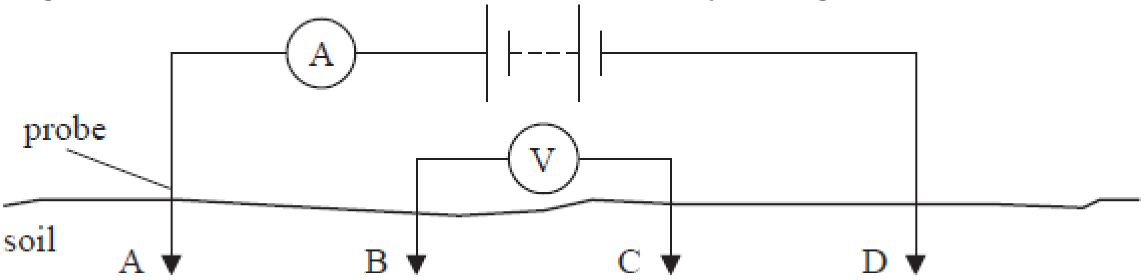
(b) $R = \rho L/A$ C1
$A = \pi \times (0.4 \times 10^{-3})^2$ $(= 5.03 \times 10^{-7})$ C1
$L = (2.4 \times 5.03 \times 10^{-7})/(1.0 \times 10^{-6})$
$= 1.2$ m .... A1 [3]

(c) resistance is halved M1
either current is doubled *or* power $\propto 1/R$ M1
power is doubled .... A1 [3]

CHALLENGE QUESTION

To assess your understanding, answer the following higher-level question on this topic.

1. Archaeologists use resistivity surveying of soil to search for the remains of buildings and settlements under the ground.
A basic arrangement that can be used to determine the resistivity of a region of soil is shown.



Probes are placed at positions **A** and **D** so that the length **AD** of soil forms part of the circuit.
The ammeter measures the current through the soil.
A second pair of probes connected to a voltmeter is placed at positions **B** and **C**.
This measures the potential difference between positions **B** and **C** in the soil.

1.1 Explain how the reading on the voltmeter will change if the length **BC** increases.

[2 Marks]

....

....

1.2 The table gives the resistivity of some different materials.

Material	Resistivity / Ω m
Undisturbed clay	4–20
Compacted clay	100–200
Limestone	500–1000
Sandstone	1500–10 000

The probes connected to the voltmeter are kept at a constant separation of 0.75 m and are moved along the soil between positions **A** and **D**.
The current is constant at 9.5 mA. The voltmeter reading varies between 1.8 V and 8.0 V.
It can be assumed that the sample of soil under investigation has a cross-sectional area of 0.65 m^2.
Deduce two possible materials that could be present in the soil between positions **A** and **D**.

[4 Marks]

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Reference: EdExcel AS Level Physics Paper 1 June 2018 Examination

ANSWERS

Question Number	Acceptable answers	Additional guidance	Mark
1.1	• The (voltmeter) reading will increase (1) • Resistance increases (with length) **Or** resistance ∝ length (1)	MP2: accept idea of a potential divider i.e. the ratio of the of BC to the total length AD will be greater, so the proportion of the total voltage will be greater ($\frac{BC}{AD}$ V) MP2: Do not award if there is also a reference to resistivity increasing	2
1.2	• Use of $V = IR$ (1) • Use of $R = \rho l/A$ (1) • (Min) resistivity = 160 (Ω m) **Or** (max) resistivity = 730 (Ω m) (1) • Compacted clay pathways **and** limestone are present in the soil (1)	Example of calculation $R_{min} = \frac{1.8\ V}{9.5 \times 10^{-3}\ A} = 189.5\ \Omega$ $R_{max} = \frac{8.0\ V}{9.5 \times 10^{-3}\ A} = 842.1\ \Omega$ $\rho_{min} = \frac{RA}{l} = \frac{189.5\ \Omega \times 0.650\ m^2}{0.75\ m} = 164.2\ \Omega\ m$ $\rho_{max} = \frac{RA}{l} = \frac{842.1\ \Omega \times 0.650\ m^2}{0.75\ m} = 729.8\ \Omega\ m$ conclusion to be consistent with calculated values	4

TOPIC: 3.5.1.4 Circuits
SPEC CHECK

Specification	Completed?
Resistors: in series, $R_T = R_1 + R_2 + R_3 + \ldots$ in parallel, $1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + \ldots$	
Energy and power equations: $E = IVt$; $P = IV = I^2R = \frac{V^2}{R}$	
The relationships between currents, voltages and resistances in series and parallel circuits, including cells in series and identical cells in parallel.	
Conservation of charge and conservation of energy in dc circuits.	
Students can construct circuits with various component configurations and measure currents and potential differences.	

STRETCH AND CHALLENGE

Metals

The resistance of a metal increases with an increase in temperature. This is because the positive ions in the metal vibrate more when its temperature is increased, so the conduction electrons cannot travel through as easily when a potential difference is applied.

The resistance, R_T, of a metal wire in ohms (Ω) at a given temperature, T, in degrees Celsius (°C) is:

$R_T = R_0 (1 + \alpha T)$ (Equation 1)

R_0 is the resistance of the wire at 0 °C in ohms (Ω)
α is the temperature coefficient of the metal in $°C^{-1}$.

A metal has a positive temperature coefficient because its resistance increases with increase of temperature.

If we rearrange Equation 1 and compare it to the equation of a straight-line graph ($y = mx + c$),

$R_T = R_0 + R_0 \alpha T$

$y = c - mx$

we can see that the gradient of the resistance–temperature graph is $R_0 \alpha$ and the intercept on the y-axis is R_0. Because R_0 is always positive and α is positive for a metal, the gradient of the resistance–temperature graph for a metal is always positive.

Semi-conductors

The resistance of an intrinsic semiconductor decreases with an increase in temperature. This is because the number of conduction electrons increases when the temperature is increased. This means that a semiconductor has a negative temperature coefficient. A typical thermistor, made from an intrinsic semiconductor, has a resistance–temperate graph with a negative gradient as shown in Figure 1. The graph is also non-linear.

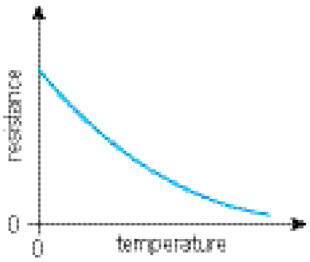

Figure 1 *Resistance variation with temperature for a thermistor*

It is important to remember that you cannot apply the straight-line-graph equation to problems involving semiconductors / thermistors.

Questions

S1. The temperature coefficient of resistance for a copper alloy wire is 4.3×10^{-3} °C^{-1}.
Calculate the change in resistance for the wire coil of a motor made using this wire, if the initial resistance is 100 Ω and the temperature of the motor increases by 50 °C during its operation.

[2 Marks]

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S2. A coil of platinum wire has a resistance of 1.36 Ω at 0 °C and a resistance of 1.89 Ω at 100 °C. Calculate the temperature at which the resistance will be 2.30 Ω.

[4 Marks]

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S3. A coil of wire has a resistance of 6.00 Ω at 60 °C and 5.25 Ω at 15 °C. Calculate the temperature coefficient of resistance of the wire.

[4 Marks]

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S4. A copper wire has a resistance of 2.46 Ω at 15 °C and a resistance of 2.88 Ω at 70 °C.
Calculate

S4.1 the temperature coefficient of copper

[4 Marks]

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S4.2 the resistance of the wire at 100 °C.

[2 Marks]

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S5. A power supply which provides a constant pd of 6.0 V is connected in series with a resistor of constant resistance 100 Ω and a thermistor. The resistance of the thermistor is 380 Ω at 25 °C but falls to 28 Ω at 100 °C. Calculate the pd between the ends of the resistor at

S5.1 25 °C

[2 Marks]

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S5.2 100 °C.

[2 Marks]

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S6. The resistance of the filament in a new type of lightbulb is 27 Ω at 0 °C. If the temperature coefficient of resistance of the filament is 5.6×10^{-3} °C^{-1} and the mains voltage is 240 V, calculate

S6.1 the resistance of the filament at a temperature of 2100 °C

[2 Marks]

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S6.2 the ratio power of lamp when first switched on: power of lamp at 2400 K

[3 Marks]

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S7. A constant pd of 2.0 V is applied to the ends of a metal strip of length 0.30 m, width 4.0 mm, and thickness 1.0×10^{-5} m. The metal has a resistivity of 1.5×10^{-7} Ω m at 0 °C and a temperature coefficient of resistance of 3.3×10^{-3} °C^{-1}. Calculate

S7.1 the resistance of the strip at 20 °C

[4 Marks]

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S7.2 the electrical power dissipated when the strip is at a uniform temperature of 20 °C.

[2 Marks]

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ANSWERS

S1. 22 Ω to two significant figures (21.5 Ω) (*2 marks*)

S2. (a = 3.9 × 10^{-3} °C^{-1})
T = 180 °C to two significant figures (177 °C) (*4 marks*)

S3. 3.3 × 10^{-3} °C^{-1} (*4 marks*)

S4.1 3.3 × 10^{-3} °C^{-1} to two significant figures (3.26 × 10^{-3} °C^{-1}) (*4 marks*)

S4.2 3.1 Ω (*2 marks*)

S5.1 1.3 V to two significant figures (1.25 V) (*2 marks*)

S5.2 4.7 V to two significant figures (4.69 V) (*2 marks*)

S6.1 340 Ω to two significant figures (344.5 Ω) (*2 marks*)

S6.2 13: 1 (12.8 : 1) (*3 marks*)

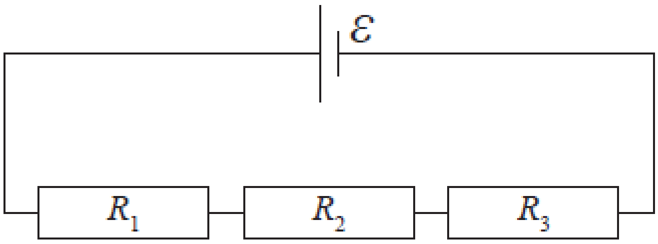
S7.1 (1.125 Ω at 0 °C)
1.2 Ω (to two significant figures) at 20 °C (*4 marks*)

S7.2 3.3 W to two significant figures (3.33 W) (*2 marks*)

CHALLENGE QUESTION

To assess your understanding, answer the following higher-level question on this topic.

1. Three resistors, of resistance R_1, R_2 and R_3, are connected in series across a cell. The cell has electromotive force (e.m.f.) ε with negligible internal resistance. The current through the cell is I.



1.1 Derive the formula for the total resistance R_T of the circuit in terms of R_1, R_2 and R_3.

[3 Marks]

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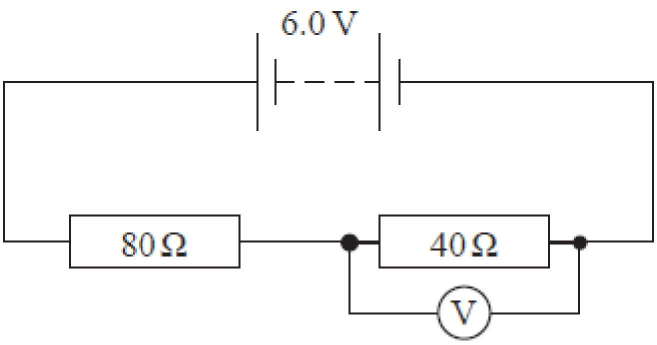
1.2 The circuit diagram shows two resistors in series across a battery of e.m.f. 6.0 V and negligible internal resistance. A voltmeter with low resistance is connected across the 40 Ω resistor.



The reading on the voltmeter is 1.8 V.
Calculate the resistance of the voltmeter.

[3 Marks]

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Reference: EdExcel AS Level Physics Paper 1 June 2018 Examination

ANSWERS

Question Number	Acceptable answers	Additional guidance	Mark
1.1	• A statement applying the conservation of energy to the circuit (1) • Use of Ohm's law for each term /individual pd leading to the cancelling of currents in the equation (1) • $R_T = R_1 + R_2 + R_3$ (1)	Example of calculation $\mathcal{E} = V_1 + V_2 + V_3$ $\mathcal{E} = \cancel{I}R_T = \cancel{I}R_1 + \cancel{I}R_2 + \cancel{I}R_3$ $R_T = R_1 + R_2 + R_3$	3
1.2	**Either** • Use of equation(s) to determine the total resistance of the voltmeter and 40 Ω resistor in parallel (34.3 Ω) i.e. potential divider formula or Ohm's law (1) • Use of $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$ (1) • $R_v = 240\ (\Omega)$ (1) **Or** • Use of Ohm's law to determine the current through voltmeter (0.0075 A) i.e. current in 40 Ω resistor calculated (0.045 Ω) **and** subtracted from current in 80 Ω resistor (0.0525 Ω) (1) • Use of Ohm's law with 1.8 V to calculate the resistance of the voltmeter (1) • $R_v = 240\ (\Omega)$ (1)	Example of calculation $\left(\frac{R}{80\ \Omega + R}\right) 6\text{ V} = 1.8\text{ V}$ $R = 34.29\ \Omega$ $\frac{1}{34.29\ \Omega} = \frac{1}{40\ \Omega} + \frac{1}{R_V}$ $R_V = 240.2\ \Omega$	3

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	$= \frac{4}{3}\pi r^3$

Particle Physics

Class	Name	Symbol	Rest energy/MeV
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	$e^\pm$	0.510999
	muon	$\mu^\pm$	105.659
mesons	π meson	$\pi^\pm$	139.576
		π^0	134.972
	K meson	$K^\pm$	493.821
		K^0	497.762
baryons	proton	p	938.257
	neutron	n	939.551

Properties of quarks

antiquarks have opposite signs

Type	Charge	Baryon number	Strangeness
u	$+\frac{2}{3}e$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}e$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}e$	$+\frac{1}{3}$	-1

Properties of Leptons

		Lepton number
Particles:	e^-, ν_e ; μ^-, ν_μ	$+1$
Antiparticles:	e^+, $\overline{\nu_e}$, μ^+, $\overline{\nu_\mu}$	-1

Photons and energy levels

photon energy $E = hf = hc/\lambda$

photoelectricity $hf = \phi + E_{k\,(max)}$

energy levels $hf = E_1 - E_2$

de Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{mv}$

Waves

wave speed $c = f\lambda$ *period* $f = \frac{1}{T}$

first harmonic $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$

fringe spacing $w = \frac{\lambda D}{s}$ *diffraction grating* $d \sin\theta = n\lambda$

refractive index of a substance s, $n = \frac{c}{c_s}$

for two different substances of refractive indices n_1 *and* n_2,

law of refraction $n_1 \sin\theta_1 = n_2 \sin\theta_2$

critical angle $\sin\theta_c = \frac{n_2}{n_1}$ for $n_1 > n_2$

Mechanics

moments moment $= Fd$

velocity and acceleration $v = \frac{\Delta s}{\Delta t}$ $a = \frac{\Delta v}{\Delta t}$

equations of motion $v = u + at$ $s = \left(\frac{u+v}{2}\right)t$

$v^2 = u^2 + 2as$ $s = ut + \frac{at^2}{2}$

force $F = ma$

force $F = \frac{\Delta(mv)}{\Delta t}$

impulse $F\,\Delta t = \Delta(mv)$

work, energy and power $W = F\,s\cos\theta$

$E_k = \frac{1}{2}m\,v^2$ $\Delta E_p = mg\Delta h$

$P = \frac{\Delta W}{\Delta t}$, $P = Fv$

$efficiency = \frac{useful\ output\ power}{input\ power}$

Materials

density $\rho = \frac{m}{V}$ *Hooke's law* $F = k\,\Delta L$

Young modulus $= \frac{tensile\ stress}{tensile\ strain}$ *tensile stress* $= \frac{F}{A}$

tensile strain $= \frac{\Delta L}{L}$

energy stored $E = \frac{1}{2}F\Delta L$

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	$Q = ml$
gas law	$pV = nRT$
	$pV = NkT$
kinetic theory model	$pV = \frac{1}{3}Nm(c_{\mathrm{rms}})^2$
kinetic energy of gas molecule	$\frac{1}{2}m(c_{\mathrm{rms}})^2 = \frac{3}{2}kT = \frac{3RT}{2N_A}$

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

Magnetic fields

force on a current $F = BIl$

force on a moving charge $F = BQv$

magnetic flux $\Phi = BA$

magnetic flux linkage $N\Phi = BAN\cos\theta$

magnitude of induced emf $\varepsilon = N\dfrac{\Delta\Phi}{\Delta t}$

$N\Phi = BAN\cos\theta$

emf induced in a rotating coil $\varepsilon = BAN\omega\sin\omega t$

alternating current $I_{rms} = \dfrac{I_0}{\sqrt{2}}$ $V_{rms} = \dfrac{V_0}{\sqrt{2}}$

transformer equations $\dfrac{N_s}{N_p} = \dfrac{V_s}{V_p}$

$efficiency = \dfrac{I_s V_s}{I_p V_p}$

Nuclear physics

the inverse square law for γ radiation $I = \dfrac{k}{x^2}$

radioactive decay $\dfrac{\Delta N}{\Delta t} = -\lambda N,\ N = N_0 e^{-\lambda t}$

activity $A = \lambda N$

half-life $T_{½} = \dfrac{\ln 2}{\lambda}$

nuclear radius $R = R_0 A^{1/3}$

energy-mass equation $E = mc^2$

OPTIONS

Astrophysics

1 astronomical unit = 1.50×10^{11} m

1 light year = 9.46×10^{15} m

1 parsec = 206265 AU = 3.08×10^{16} m
= 3.26 light year

Hubble constant, H = 65 km s^{-1} Mpc^{-1}

$M = \dfrac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$

in normal adjustment $M = \dfrac{f_o}{f_e}$

Rayleigh criterion $\theta \approx \dfrac{\lambda}{D}$

magnitude equation $m - M = 5\log\dfrac{d}{10}$

Wien's law $\lambda_{max} T = 2.9 \times 10^{-3}$ m K

Stefan's law $P = \sigma A T^4$

Schwarzschild radius $R_s \approx \dfrac{2GM}{c^2}$

Doppler shift for v << c $\dfrac{\Delta f}{f} = -\dfrac{\Delta\lambda}{\lambda} = \dfrac{v}{c}$

red shift $z = -\dfrac{v}{c}$

Hubble's law $v = Hd$

Medical physics

lens equations $P = \dfrac{1}{f}$

$m = \dfrac{v}{u}$

$\dfrac{1}{f} = \dfrac{1}{u} + \dfrac{1}{v}$

threshold of hearing $I_0 = 1.0 \times 10^{-12}$ W m^{-2}

intensity level $\text{intensity level} = 10\log\dfrac{I}{I_0}$

absorption $I = I_0 e^{-\mu x}$

$\mu_m = \dfrac{\mu}{\rho}$

ultrasound imaging $Z = \rho c$

$\dfrac{I_r}{I_i} = \left(\dfrac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$

half-lives $\dfrac{1}{T_E} = \dfrac{1}{T_B} + \dfrac{1}{T_P}$

Engineering physics

moment of inertia $I = \Sigma mr^2$

angular kinetic energy $E_k = \frac{1}{2}I\omega^2$

equations of angular motion

$\omega_2 = \omega_1 + \alpha t$

$\omega_2{}^2 = \omega_1{}^2 + 2\alpha\theta$

$\theta = \omega_1 t + \frac{\alpha t^2}{2}$

$\theta = \frac{(\omega_1 + \omega_2)\,t}{2}$

torque $T = I\,\alpha$

$T = F\,r$

angular momentum $\text{angular momentum} = I\omega$

angular impulse $T\Delta t = \Delta(I\omega)$

work done $W = T\theta$

power $P = T\omega$

thermodynamics $Q = \Delta U + W$

$W = p\Delta V$

adiabatic change $pV^{\gamma} = \text{constant}$

isothermal change $pV = \text{constant}$

heat engines

efficiency $= \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H}$

maximum theoretical efficiency $= \frac{T_H - T_C}{T_H}$

work done per cycle = area of loop

input power = calorific value × fuel flow rate

indicated power = (area of $p - V$ loop) × (number of cycles per second) × (number of cylinders)

output or brake power $P = T\omega$

friction power = indicated power – brake power

heat pumps and refrigerators

refrigerator: $COP_{ref} = \frac{Q_C}{W} = \frac{Q_C}{Q_H - Q_C}$

heat pump: $COP_{hp} = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_C}$

Turning points in physics

electrons in fields $F = \frac{eV}{d}$

$F = Bev$

$r = \frac{mv}{Be}$

$\frac{1}{2} mv^2 = eV$

Millikan's experiment $\frac{QV}{d} = mg$

$F = 6\pi\eta rv$

Maxwell's formula $c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$

$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$

special relativity $t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$

$l = l_0\sqrt{1 - \frac{v^2}{c^2}}$

$E = mc^2 = \frac{m_0c^2}{\sqrt{1 - \frac{v^2}{c^2}}}$

Electronics

resonant frequency $f_0 = \frac{1}{2\pi\sqrt{LC}}$

Q-factor $Q = \frac{f_0}{f_B}$

operational amplifiers: open loop $V_{out} = A_{OL}(V_+ - V_-)$

inverting amplifier $\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$

non-inverting amplifier $\frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_1}$

summing amplifier $V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \cdots\right)$

difference amplifier $V_{out} = (V_+ - V_-)\frac{R_f}{R_1}$

Bandwidth requirement:

for AM $\text{bandwidth} = 2f_M$

for FM $\text{bandwidth} = 2(\Delta f + f_M)$

Acknowledgements

This document has been produced by Mr J Turnbull.

All relevant information has been credited in the document.

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