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EDEXCEL A LEVEL PHYSICS: QUESTIONS BY TOPIC

Electric Circuits (3)

A Level Physics Topic 3

116 questions · 628 marks · Mark schemes included

AS & A Level content · Pearson Edexcel 8PH0 / 9PH0 papers, 2016–2025

guidemygrades.com
@Guidemygrades
@Guidemygrades
@Guidemygrades
info@guidemygrades.com
Piccadilly Business Centre, Unit C, Aldow Enterprise Park
Blackett Street, Manchester, M12 6AE

HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.
Click any row below to jump straight to that sub-topic or question.
On every question page, click ANSWER in the top-right corner to jump to its mark scheme.
Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTIONS

116 questions · 628 marks · 6 sub-topics

SUB-TOPIC 3.1

CURRENT, CHARGE AND DRIFT VELOCITY

Sub-topic 3.1 · 15 questions · 57 marks · lowest tariff first

4 A hair dryer is used for 3 minutes. The operating current is 6 A.

What charge flows in this time?

- ☒ **A** 0.03 C
- ☒ **B** 2 C
- ☒ **C** 18 C
- ☒ **D** 1080 C

(Total for Question 4 = 1 mark)

3 Which of the following increases as the temperature of a metallic conductor increases?

- ☒ **A** amplitude of the vibrations of the lattice ions
- ☒ **B** distance travelled by the charge carriers between collisions
- ☒ **C** drift velocity of the conduction electrons
- ☒ **D** number of conduction electrons per unit volume

(Total for Question 3 = 1 mark)

4 A potential difference V is applied across the ends of a conductor. The drift velocity of the charge carriers in the conductor is v.

Which of the following expressions gives the relationship between drift velocity and potential difference?

☒ **A** $v \propto \frac{1}{V}$

☒ **B** $v \propto \frac{1}{V^2}$

☒ **C** $v \propto V$

☒ **D** $v \propto V^2$

(Total for Question 4 = 1 mark)

2 A constant current maintained in a copper wire causes the temperature of the wire to increase.

Which of the following does **not** increase?

- ☒ **A** amplitude of vibration of the lattice ions
- ☒ **B** number of conduction electrons per unit volume
- ☒ **C** rate of collision of conduction electrons with lattice ions
- ☒ **D** rate of energy transfer from conduction electrons to lattice ions

(Total for Question 2 = 1 mark)

5 A torch is switched on for 5 minutes. The current in the torch bulb is 6 mA.

Which of the following gives the charge, in coulombs, that flows in this time?

☒ **A** $6 \times 10^{-3} \times 5$

☒ **B** $\frac{6 \times 10^{-3}}{5}$

☒ **C** $\frac{6}{300}$

☒ **D** $6 \times 10^{-3} \times 300$

(Total for Question 5 = 1 mark)

4 A conductor has a resistance R. A constant potential difference is applied across the conductor. The drift velocity of the charge carriers in the conductor is v.

Which of the following is the relationship between R and v?

- ☒ **A** $v \propto R$
- ☒ **B** $v \propto \sqrt{R}$
- ☒ **C** $v \propto \frac{1}{R}$
- ☒ **D** $v \propto \frac{1}{\sqrt{R}}$

(Total for Question 4 = 1 mark)

1 Which of the following is the base unit for charge?

- ☒ **A** As
- ☒ **B** C
- ☒ **C** JV^{-1}
- ☒ **D** Q

(Total for Question 1 = 1 mark)

7 A length of wire has a non-uniform cross-sectional area. There is an electric current in the wire.

Which of the following is **not** constant along the length of this wire?

- ☒ **A** electric current
- ☒ **B** electron charge
- ☒ **C** electron drift velocity
- ☒ **D** number of free electrons per unit volume

(Total for Question 7 = 1 mark)

5 A copper wire has a cross-sectional area A and length l. There is a potential difference V across the wire. The resistance of the wire is R.

Copper has n conduction electrons per unit volume.

Which of the following expressions gives the drift velocity of the electrons along the wire?

☒ **A** $\frac{RnAe}{V}$

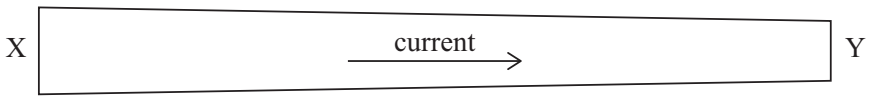
☒ **B** $\frac{R}{VnAe}$

☒ **C** $\frac{V}{RnAe}$

☒ **D** $\frac{VnAe}{R}$

(Total for Question 5 = 1 mark)

7 A wire of decreasing diameter is connected in a circuit. There is a current from X to Y in the wire, as shown.



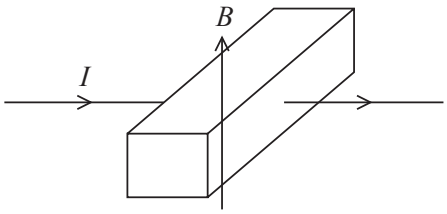
Which row of the table gives the current and the drift velocity of charge carriers at Y compared to X?

		Current	Drift velocity
☒	**A**	lower	higher
☒	**B**	lower	lower
☒	**C**	the same	higher
☒	**D**	the same	lower

(Total for Question 7 = 1 mark)

14 Some liquids conduct electricity. This property can be used to pump these liquids through pipes.

A short section of a rectangular pipe containing a liquid is shown in the diagram. The pipe is placed in a magnetic field of flux density B and a current I is passed through the liquid as shown.

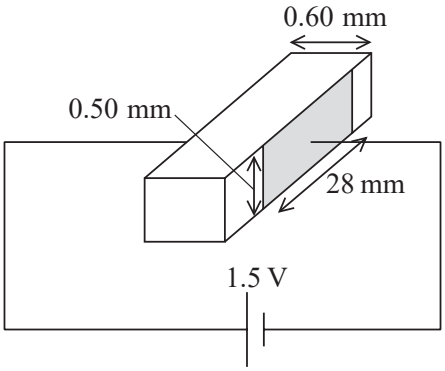


(a) Add an arrow to the diagram above to show the direction in which the liquid will move.

(1)

(b) A practical demonstration of this principle used two rectangular electrodes, opposite each other on either side of the pipe, a distance of 0.60 mm apart. The dimensions of the electrodes are shown in the diagram.

The electrodes were connected to a 1.5 V cell. Salt water was pumped using a magnetic field of magnetic flux density 0.40 T.



(i) Show that the current through the salt water is about 20 mA.

resistivity of salt water = 1.6 Ω m

(4)

(ii) Hence calculate the force on the salt water.

(2)

.....

.....

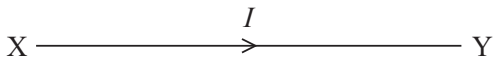
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.....

Force = ...

(Total for Question 14 = 7 marks)

12 An electrical conductor XY carries a current I as shown.



The current density j is defined as $j = \frac{I}{A}$ where A is the cross-sectional area of the conductor.

(a) Current density is a vector quantity.

State what is meant by a vector quantity.

(1)

.....

.....

(b) I is constant but A decreases towards end Y.

Explain how this affects the drift velocity of the free electrons in the conductor.

(2)

.....

.....

.....

.....

(c) The resistivity ρ of the conducting material is given by $\rho = \frac{E}{j}$

where E is the electric field strength.

Show that the units are the same on both sides of this equation.

(4)

(Total for Question 12 = 7 marks)

5 Fuse wire is made of a metal that has a low melting point. The wire melts when the current exceeds a maximum value.

A student investigated how the cross-sectional area affected the current at which a wire melted. She used wires of the same length and metal, but different diameters.

The student steadily increased the current through each wire and recorded the maximum current through the wire before it melted.

(a) Describe how the student could determine an accurate value for the cross-sectional area of a wire.

(4)

(b) (i) Explain why a current in a wire causes the resistance of the wire to change.

(3)

(ii) The length of a wire does not affect the value of current at which the wire melts.

Explain why. Assume the wire behaves as a black body.

(2)

.....

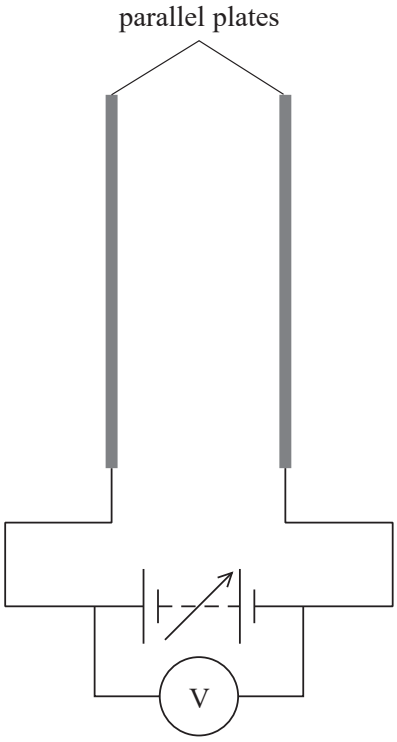
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(Total for Question 5 = 9 marks)

15 A teacher demonstrates the electric field produced between two parallel metal plates. The plates are connected to a variable power supply, as shown. The power supply has a very large internal resistance and includes a voltmeter that indicates its output.



(a) (i) Add to the diagram to show the electric field between the two plates.

(3)

(ii) Explain why the reading on the voltmeter indicates the e.m.f. of the power supply.

(2)

(b) The power supply output is increased until sparks are heard and are seen in the gap between the plates. Sparks form in air when the electric field strength exceeds $3.0 \times 10^6\,V\,m^{-1}$ and the air becomes conducting for a short time.

(i) Calculate the minimum potential difference across the plates for sparks to be created.

distance between parallel plates = 2.0 mm

(2)

Minimum potential difference = ...

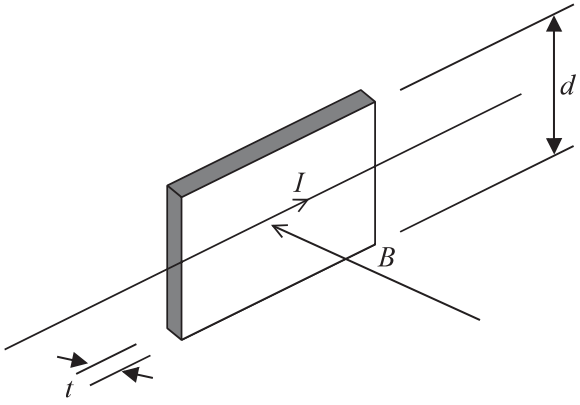
(ii) Explain why the voltmeter reading decreases significantly whenever sparks are produced.

(3)

(Total for Question 15 = 10 marks)

17 Tiny sensors in smartphones could be used to determine the position of the phone on the Earth's surface by measuring the Earth's magnetic flux density.

A current I and a magnetic field of flux density B are applied to a slice of semiconductor as shown. The slice has thickness t and depth d.



Electrons collect at the top edge of the slice and the bottom edge becomes positively charged. As a result a potential difference known as a Hall voltage V_{HALL} develops.

(a) Explain why electrons will collect at the top edge of the slice.

(2)

(b) Add to the diagram to show clearly two points between which V_{HALL} develops.

(1)

(c) Electrons continue to collect at the top edge of the slice, until the force on a moving electron due to the magnetic field is equal to the force on the electron due to the electric field.

Derive the following equation for V_{HALL}:

$$V_{HALL} = \frac{BI}{nte}$$

where n is the number of charge carriers per unit volume of the semiconductor.

(4)

(d) Show that the units are the same on each side of the equation

$$V_{HALL} = \frac{BI}{nte}$$

(3)

(e) The table gives the values of n and t for a number of material samples.

material	n / m^{-3}	t / m
copper	8.47×10^{28}	110×10^{-6}
germanium	2.25×10^{19}	1.10×10^{-6}
silicon	1.44×10^{16}	120×10^{-6}

Deduce which sample would result in the largest Hall voltage for a particular current and magnetic field.

(2)

(f) Two sensors in the smartphone were used to determine the horizontal component B_H and the vertical component B_V of the Earth's magnetic flux density.

Calculate the angle of the Earth's magnetic field to the horizontal.

$B_H = 19.0\,\mu T$

$B_V = 49.0\,\mu T$

(2)

Angle = ...

(Total for Question 17 = 14 marks)

SUB-TOPIC 3.2

POTENTIAL DIFFERENCE, POWER, ENERGY AND EFFICIENCY

Sub-topic 3.2 · 16 questions · 140 marks · lowest tariff first

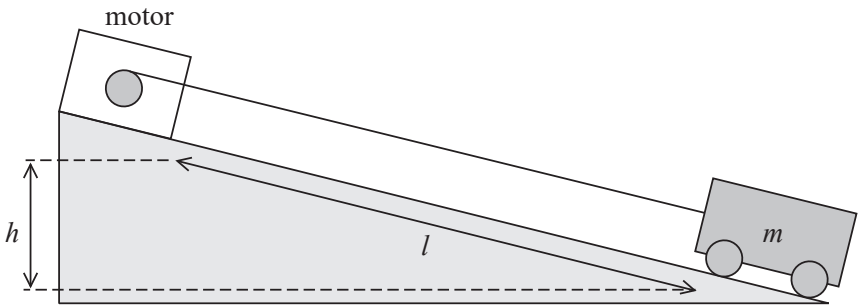
1 A volt can be defined as a

- ☒ **A** coulomb per joule.
- ☒ **B** coulomb per second.
- ☒ **C** joule per coulomb.
- ☒ **D** joule per second.

(Total for Question 1 = 1 mark)

6 The diagram shows an electric motor pulling a truck of mass m along a slope. The truck moves through a vertical height h and a distance l along the slope, during a time t.

There is a potential difference V across the motor and a current I in the motor.



Which of the following expressions gives the efficiency of the motor?

☒ **A** $\frac{VIt}{mgl}$

☒ **B** $\frac{VIt}{mgh}$

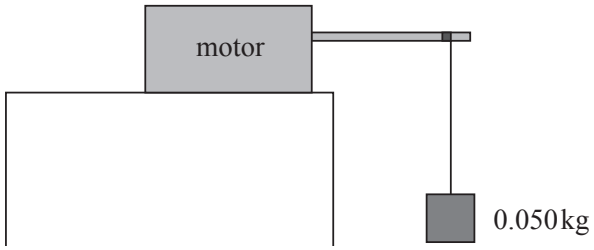
☒ **C** $\frac{mgl}{VIt}$

☒ **D** $\frac{mgh}{VIt}$

(Total for Question 6 = 1 mark)

9 A motor lifts a block of mass 0.050 kg at a constant velocity of 0.40 m s^{-1}.

The current in the motor is 85 mA and the potential difference across it is 3.0 V.



Calculate the efficiency of the motor.

(3)

Efficiency of the motor = ...

(Total for Question 9 = 3 marks)

12 Electrical power is transmitted from Norway to Britain using a cable laid under the North Sea.

The following information is published on a website.

> The cable has a diameter of 15 cm and a length of 720 km.
>
> It is made of copper of resistivity $1.7 \times 10^{-8}\,\Omega\,m$.
>
> The electrical power transmitted from Norway is 1400 MW and the transmission potential difference is 1100 kV.
>
> The efficiency of this process is almost 100%.

Deduce, by calculation, whether the claim for efficiency is correct.

(Total for Question 12 = 6 marks)

14 Power supplies provide either alternating or direct currents and potential differences.

(a) A power supply produces an alternating potential difference (p.d.). The p.d. has a period of 0.02 s and a peak value of 4.0 V.

(i) Calculate the frequency of the supply.

(1)

.....

Frequency = ...

(ii) Calculate the root-mean-square p.d.

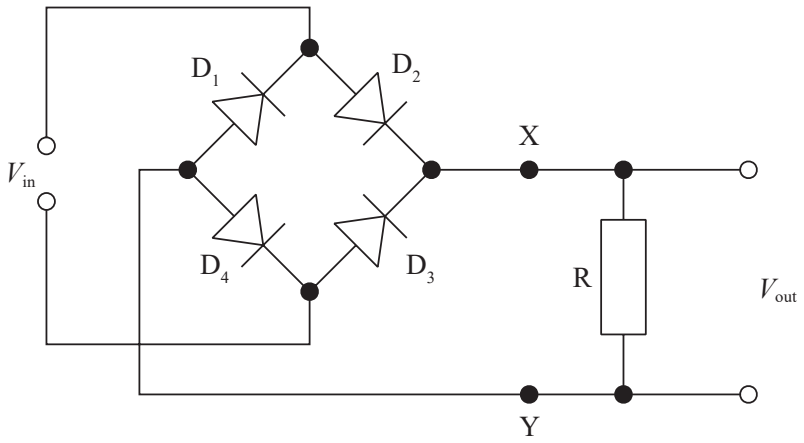
(1)

.....

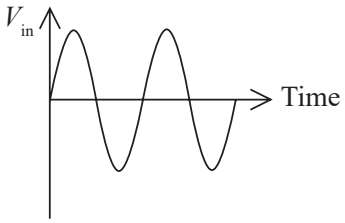
Root-mean-square p.d. = ...

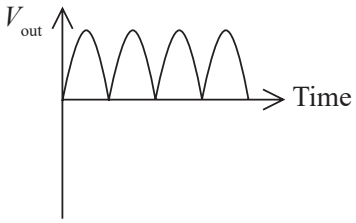
(b) It is possible to convert alternating currents and p.d.s, to direct currents and p.d.s using diodes.

The power supply provides an input V_{in} to the circuit shown. The circuit includes four diodes D_1, D_2, D_3 and D_4 and a resistor R. The circuit produces an output potential difference V_{out}.



A graph of V_{in} against time and a corresponding graph of V_{out} against time are shown below.



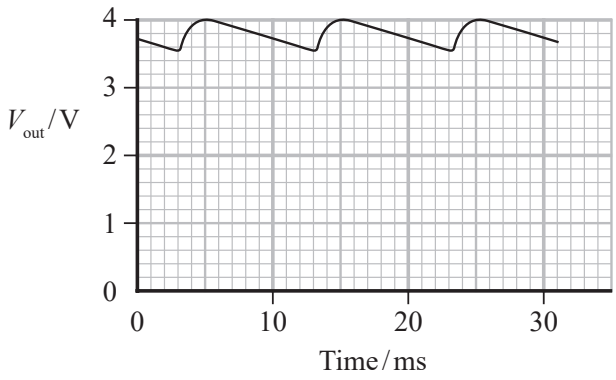


(i) Explain the operation of this circuit. Your answer should refer to D_1, D_2, D_3 and D_4.

(3)

(ii) A capacitor is added between points X and Y in the circuit.

The new graph of V_{out} against time is shown below.



Determine a value for the capacitance of the capacitor.

resistance of R = 2.2 kΩ

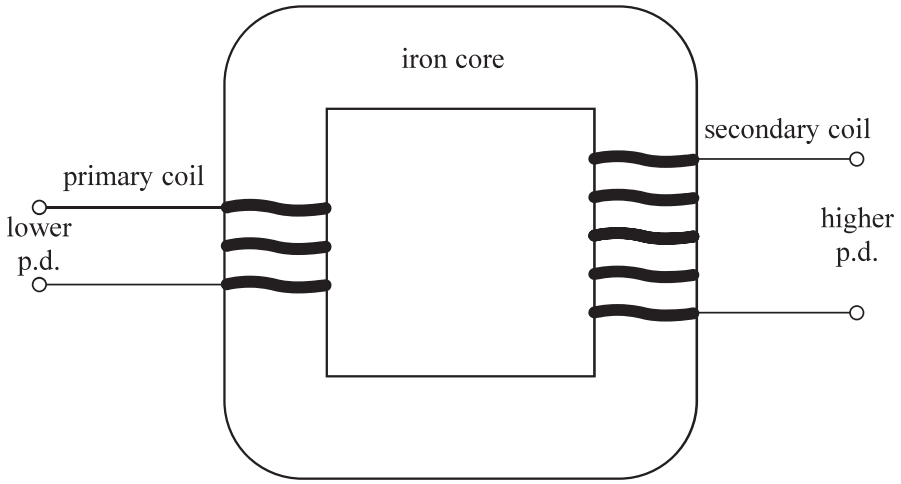
(3)

Capacitance = ...

(Total for Question 14 = 8 marks)

12 Electrical transmission systems are used to transmit electrical power from place to place. Transformers are used to change potential differences (p.d.) and power transmission cables are used to transmit power.

(a) The diagram shows a step-up transformer.



A step-up transformer is used to convert a lower p.d. to a higher p.d. An alternating p.d. is applied to the primary coil.

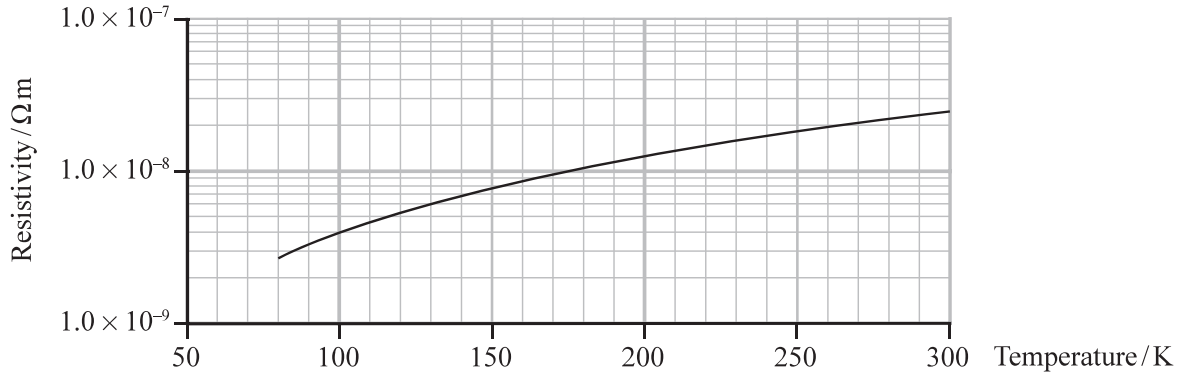
Explain how a higher p.d. is produced across the secondary coil.

(4)

(b) Efficient electrical transmission systems are being developed using superconductors. Superconductors have zero resistance at low temperatures, and therefore no power is wasted by transfer to thermal energy unlike copper cable systems.

In one project a 1.05 km length of copper cable at a temperature of 270 K has been replaced by a superconductor. The superconductor has a cooling system which requires power.

The graph shows the variation of resistivity with temperature for copper.



Deduce whether the power requirement of the superconductor cooling system is less than the power losses in the copper cable.

transmission power = 40 MW

transmission potential difference = 110 kV

cross-sectional area of copper cable = 145 mm^2

power requirement of cooling system for the superconductor = 7 kW

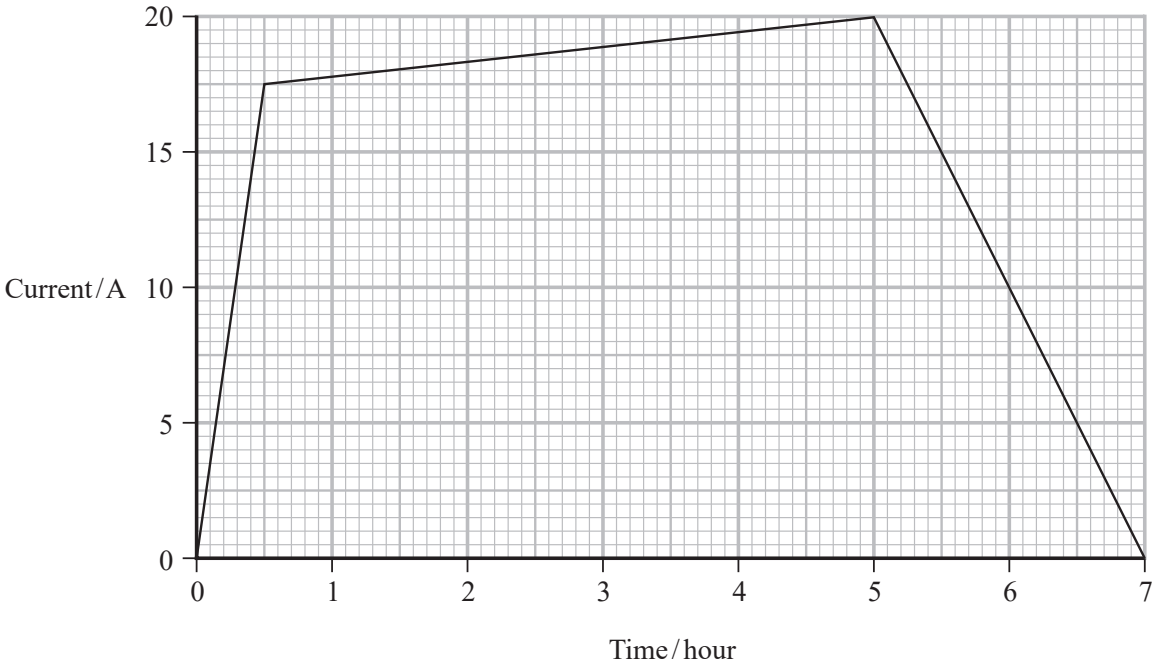
(5)

(Total for Question 12 = 9 marks)

15 Electric cars are powered by a large battery within the car.

(a) The manufacturer of an electric car states that the battery stores a maximum charge of 110 Ah.

The graph shows how the current through the battery varies with time as the battery is charged.



The manufacturer claims that it takes 5 hours to reach 90% of the maximum charge.

Criticise this statement.

(3)

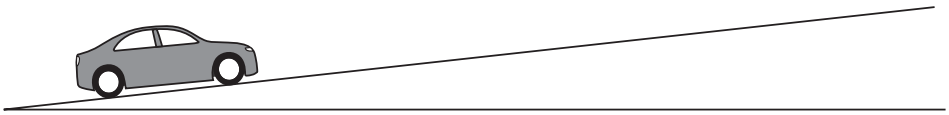
(b) The manufacturer tested the car by driving it at constant speed along a horizontal track. The manufacturer determined that the maximum range of the car was 160 km.

(i) Show that the average value for the resistive forces on the car was about 800 N.

efficiency of car = 85%
energy stored when battery has maximum charge = 42 kW h

(3)

(ii) The manufacturer repeated the test on a sloping track, as shown. This reduced the maximum range of the car. At the new maximum range, the car had moved upwards through a vertical height of 3.0 km.



Calculate the reduction in the maximum range of the car.

mass of car = 1300 kg

(3)

Reduction in maximum range = ...

(Total for Question 15 = 9 marks)

14 A mobile phone is powered by a lithium-ion battery. The information shown is taken from the battery.

3.82 V
6.91 W h

(a) (i) The watt-hour (W h) is an alternative unit for energy.

Show that the maximum energy that can be stored by the battery is about 25 kJ.
1 W h = 3600 J

(1)

(ii) Calculate the maximum charge that the battery can provide.

(2)

Maximum charge = ...

(iii) The mobile phone 'runs out of charge'.

Calculate the minimum time taken, in hours, for the battery to fully recharge.

charging current = 0.90 A

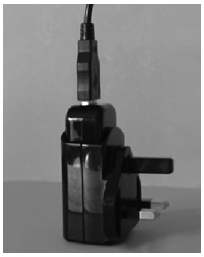
(3)

Minimum time = ... hours

(b) The mobile phone in part (a), when purchased, was supplied with a charging plug marked 1 A, 5 V. The mobile phone owner lost the original charging plug and replaced it with a charging plug marked 0.5 A, 5 V.



original charging plug
1A, 5 V



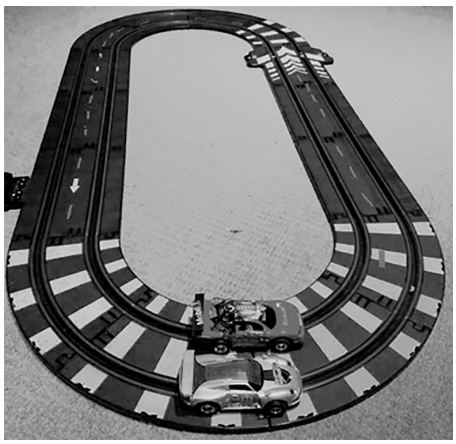
replacement charging plug
0.5A, 5 V

By evaluating the information given, discuss the suitability of using the replacement charging plug for this mobile phone. Include references to possible benefits, disadvantages and risks associated with using the replacement charging plug.

(4)

(Total for Question 14 = 10 marks)

13 The photograph shows a model racing car set. The curved parts of the track are semicircular. The car makes electrical contact with the track using metal brushes underneath the car.



(a) There is a maximum speed for the car to stay on the curved part of the track. Explain why the car will slip off the curved part of the track if the car exceeds the maximum speed.

(3)

(b) The following measurements are made for a car starting at rest on a straight piece of track.

distance travelled = 1.2 m

time taken = 0.77 s

(i) Show that the final velocity of the car is about 3 m s^{-1}.

Assume the acceleration is constant.

(2)

(ii) The final velocity calculated in (b)(i) is the maximum velocity before the car slips off the track.

Calculate the maximum horizontal force between the curved part of the track and the car.

mass of car = 0.050 kg

radius of curved part of track = 0.042 m

(2)

Maximum horizontal force = ...

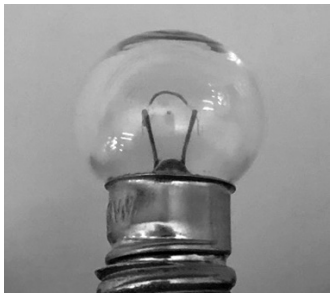
(c) The cars are controlled separately and so can be raced, with one car on the inner lane and the other on the outer lane. The cars are identical. Each car is raced at its highest speed for that lane.

Explain why the outcome of the race is difficult to predict.

(3)

(Total for Question 13 = 10 marks)

14 The photograph shows a filament bulb.



The filament is an emitter with 35% of the power output of a black body radiator of the same temperature.

(a) When a potential difference (p.d) of 2.0 V is applied across the bulb, there is a current of 0.37 A in the filament.

Calculate the temperature of the filament.

surface area of filament = $3.9 \times 10^{-6}\,m^2$

(3)

Temperature = ...

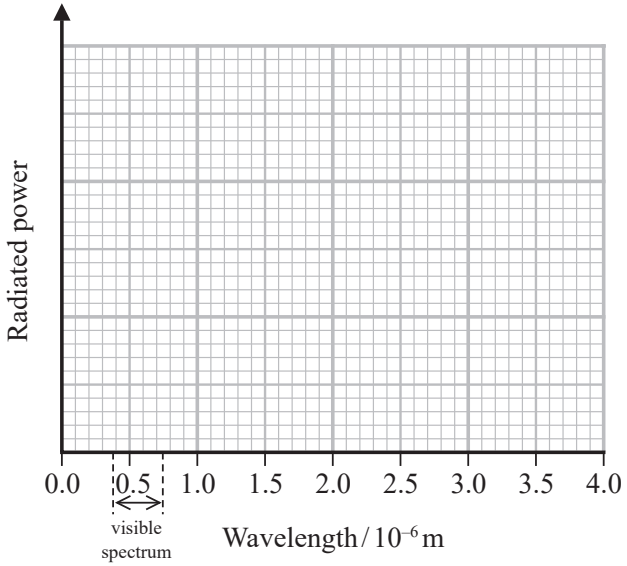
(b) In an experiment to investigate the efficiency of a filament light bulb a p.d. was applied. The p.d. and current were measured and the light bulb was observed. The p.d. was then increased and new measurements taken.

When a small p.d. is applied to the bulb, no light is visible. If the p.d. is gradually increased, the filament starts to glow and eventually appears white.

(i) Add to the graph to show the distribution of radiation from a black body at a temperature of 2026 K.

Your answer should include a calculation.

(5)



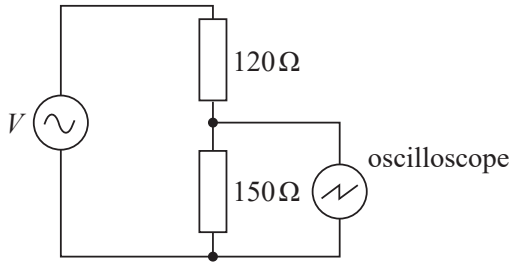
(ii) Use your graph to explain why filament light bulbs are considered inefficient.

(2)

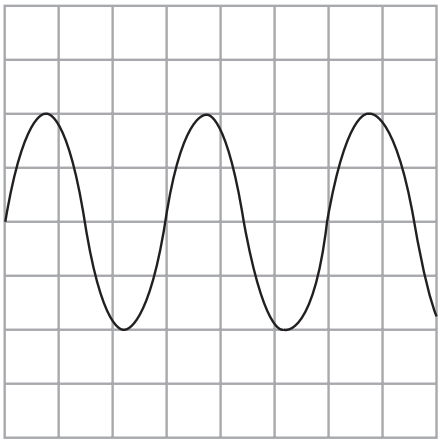
(Total for Question 14 = 10 marks)

7 A student connected the output from a source of alternating potential difference (p.d.) to a series resistor combination.

She connected an oscilloscope across the 150 Ω resistor as shown.



(a) The trace obtained on the oscilloscope is shown below.



(i) Determine the peak p.d. across the 150 Ω resistor.

y-sensitivity of oscilloscope = 2.0 V per division

(2)

.....

.....

.....

Peak p.d. across 150 Ω resistor = ...

(ii) Calculate the root mean square (r.m.s.) value of the current in the circuit.

(3)

r.m.s. value of current = ...

(iii) Calculate the power dissipated in the circuit.

(3)

Power dissipated in circuit = ...

(b) Another student suggested that a voltmeter would be more accurate than using an oscilloscope to determine the magnitude of the p.d.

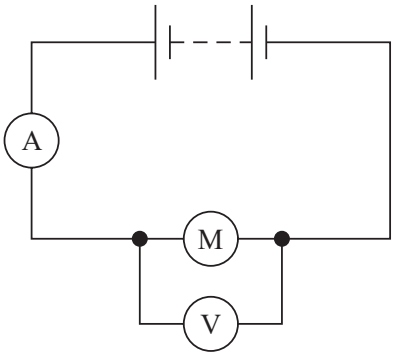
Comment on this suggestion.

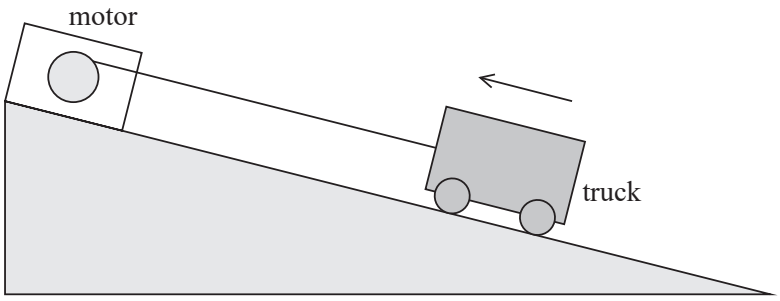
(3)

(Total for Question 7 = 11 marks)

15 An electric motor is used to pull a truck up a slope at a constant speed.

The electric motor circuit includes a battery with no internal resistance, an ammeter and a very high resistance digital voltmeter as shown.





(a) The truck moves through a vertical height of 0.20 m in 15 s. The current in the motor is 8.1 mA and the potential difference across the motor is 12 V.

mass of truck = 550 g

Calculate the efficiency of the motor.

(4)

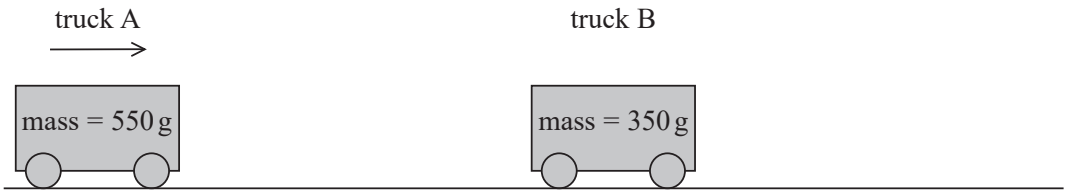
Efficiency = ...

(b) The digital voltmeter is replaced with an analogue voltmeter with much less resistance.

Deduce how this will affect the efficiency of the motor circuit.

(4)

(c) The string pulling the truck was cut. The truck (A) travelled down the slope onto a horizontal surface and collided with a second truck (B), which was stationary, as shown.



The velocity of truck A just before the collision was 5.4 m s^{-1} and just after the collision was 2.1 m s^{-1}.

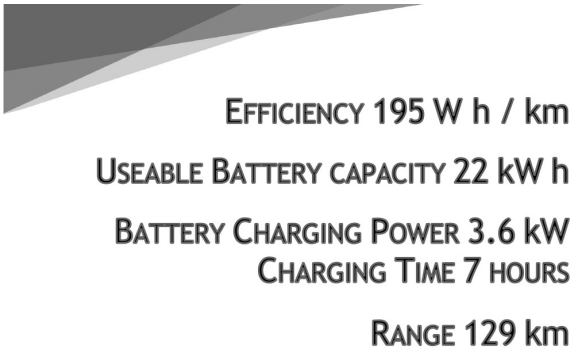
Determine the velocity of truck B after the collision.

(3)

Velocity of truck B = ...

(Total for Question 15 = 11 marks)

13 A website advertises an electric car with the following information.



(a) State why the 'efficiency' given on the website cannot be a value of efficiency as defined in physics.

(1)

.....

.....

(b) Explain why the kilowatt-hour (kW h) is a unit of energy.

(2)

.....

.....

.....

.....

(c) Calculate the efficiency of the battery.

(3)

.....

.....

.....

.....

.....

Efficiency = ...

.

(d) A comparable petrol car has a petrol consumption of 21 km / litre.

Show that the electric car is cheaper to run.

cost of 1 litre of petrol = £1.20

cost of 1 kW h of electricity = 13 p

(2)

(e) Give one environmental advantage of an electric car.

(1)

(f) The website provides the following additional information.

Maximum Engine Power 80 kW
Maximum Performance 0 to 28 ms^{-1} in 11.5 s
Mass of Car 1500 kg

Deduce whether the power of the engine is capable of producing this performance.

(3)

(Total for Question 13 = 12 marks)

10 The potential difference (p.d.) from a power pack alternates at a frequency of 50 Hz. The root-mean-square (r.m.s.) value of the output p.d. is measured to be 8.5 V using an a.c. voltmeter.

The output from the power pack is connected to a resistor of resistance 1.5 Ω.

(a) Show that the rate of power dissipation in the resistor is about 48 W.

(2)

(b) A lab technician used the resistor to heat $1.25 \times 10^{-4}\,m^3$ of milk in a beaker.

Calculate the time taken for the milk to increase in temperature by 12 °C.

specific heat capacity of milk = $3930\,J\,kg^{-1}\,K^{-1}$
density of milk = $1050\,kg\,m^{-3}$

(4)

Time = ...

(c) The lab technician used an oscilloscope to determine the supply frequency and check the r.m.s. output p.d. displayed by the voltmeter.

Describe the methods the technician should use.

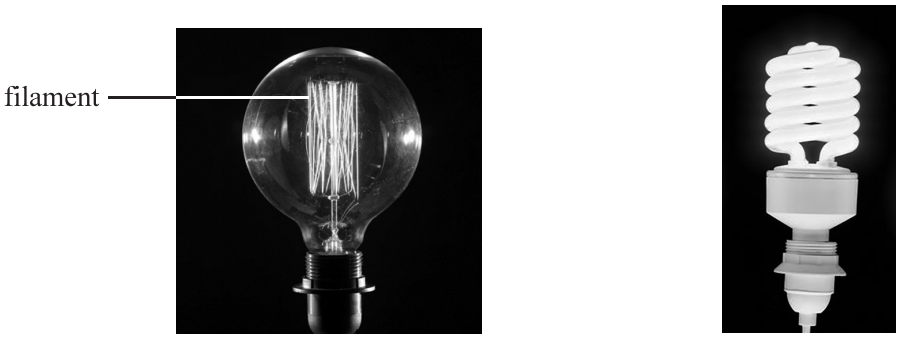
(6)

(Total for Question 10 = 12 marks)

16 Filament and fluorescent are two types of light bulb.

Filament light bulbs contain a tightly coiled wire filament, surrounded by an inert gas and encased in a thin glass bulb. When the potential difference (p.d.) across the bulb is sufficient, the filament heats up, emitting visible light.

Fluorescent light bulbs use a long tube of glass containing a small amount of mercury. When a sufficient p.d. is applied across the ends of the tube, electrons moving through the tube cause the mercury to become a vapour and emit photons in the ultraviolet part of the electromagnetic spectrum. The collisions of these photons with the phosphor coating of the tube result in the emission of photons of visible light.



Filament bulb

Fluorescent bulb

(a) (i) Explain how the wire in the filament lamp gets hot when a p.d. is applied.

(2)

(ii) Explain how the fluorescent bulb emits photons when sufficient p.d is applied.

(2)

(b) A filament bulb contains a tungsten filament of diameter 3.8×10^{-5} m and uncoiled length 1.6 m. As the temperature of the filament increases, the resistance of the filament increases to a maximum which is 14 times greater than the initial resistance at room temperature.

(i) Determine the power of the filament at maximum brightness.

p.d. across filament = 240 V
resistivity of tungsten at room temperature = $5.6 \times 10^{-8}\,\Omega$ m

(5)

Power = ...

(ii) Filament bulbs are designed to last for thousands of hours of use. Over time the filament may wear away, becoming thinner at one point. This can cause the filament to melt and break at that point.

Assess whether the filament is more likely to break as the bulb is switched on or when it is in use.

(4)

(Total for Question 16 = 13 marks)

14 Since 2008, the Scottish island of Eigg has generated almost all its electrical power from renewable energy sources. The main source of power for the island is produced by hydroelectric generators.

(a) Water falls through a height of 124 m as it flows through a pipe to a hydroelectric generator.

(i) Calculate the maximum power input of the generator.

mass flow rate of the water = 130 kg s^{-1}

(2)

Maximum power input = ...

(ii) Explain why the power input of the generator is always less than this value.

(2)

(b) When demand for power is low on Eigg, excess energy is stored in a number of batteries. The batteries have a total capacity of 4400 Ah when fully charged.

When demand for power is greater than the output from the renewable sources, energy is supplied by the batteries. The batteries supply an average power of 20 kW.

Calculate the total time, in hours, for which the batteries can supply energy before they need recharging.

total output potential difference of batteries = 48 V

(3)

Total time = ... hours

(c) Each house on Eigg is allowed a maximum power of 5 kW.

(i) Show that the maximum current in an electrical cable to a house is about 22 A.

mains potential difference = 230 V

(2)

(ii) On Eigg the cables to the houses are made of aluminium instead of copper.

The rate of energy transfer to the environment is limited to 0.05 W per metre of cable.

The engineers claimed that using aluminium instead of copper reduced the cost of the electrical cables by 90%.

Evaluate this claim by comparing a 1 m length of cable made from each material.

Assume the current in each cable is 22 A.

Material	Resistivity / Ω m	Cost in £ per m^3
Copper	1.68×10^{-8}	77 090
Aluminium	2.65×10^{-8}	6070

(5)

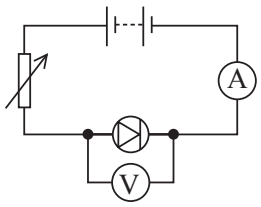
(Total for Question 14 = 14 marks)

SUB-TOPIC 3.3

RESISTANCE, RESISTIVITY AND I-V CHARACTERISTICS

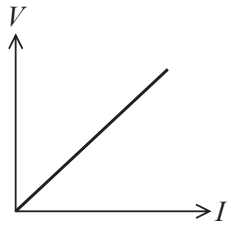
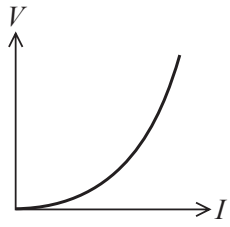
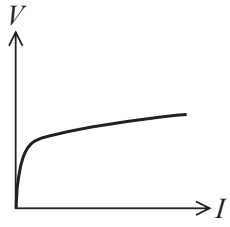
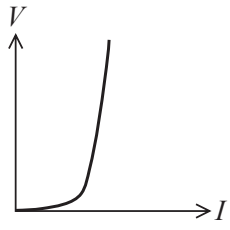
Sub-topic 3.3 · 34 questions · 176 marks · lowest tariff first

8 A student carried out an experiment to investigate the current-potential difference characteristics of a diode using the circuit below.



He plotted the graph of potential difference V on the y-axis against the corresponding current I on the x-axis.

Which graph would be obtained by the student?

☒ **A**	
☒ **B**	
☒ **C**	
☒ **D**	

(Total for Question 8 = 1 mark)

4 A light dependent resistor is connected across a cell of negligible internal resistance. The light intensity is increased.

Which of the following statements about the current is correct?

☒ **A** It decreases because there is an increase in the number of conduction electrons.

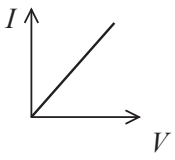
☒ **B** It increases because there is an increase in the number of conduction electrons.

☒ **C** It decreases because the amplitude of lattice vibrations decreases.

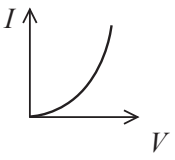
☒ **D** It increases because the amplitude of lattice vibrations increases.

(Total for Question 4 = 1 mark)

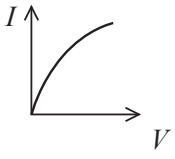
5 Which of the following graphs shows how the current varies with potential difference for a filament lamp?



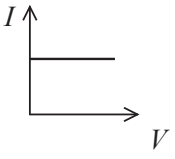
A



B



C



D

☒ **A**

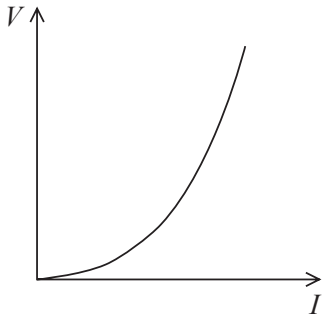
☒ **B**

☒ **C**

☒ **D**

(Total for Question 5 = 1 mark)

4 The graph shows how the potential difference V varies with the current I for a circuit component.

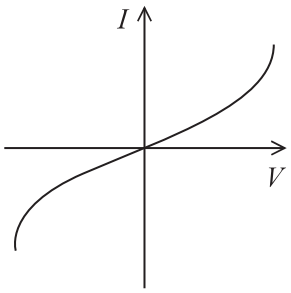


Which of the following could be the circuit component?

- ☒ **A** diode
- ☒ **B** filament bulb
- ☒ **C** ohmic resistor
- ☒ **D** thermistor

(Total for Question 4 = 1 mark)

6 The diagram shows a graph of current I against potential difference V for an electrical component.



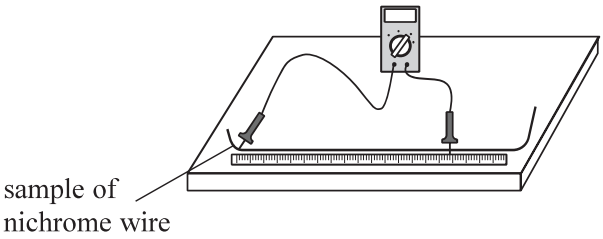
Which of the following components would produce a graph of this shape?

- ☐ **A** filament bulb
- ☐ **B** metallic conductor
- ☐ **C** negative temperature coefficient thermistor
- ☐ **D** ohmic conductor

(Total for Question 6 = 1 mark)

Questions 6 and 7 refer to the information below.

An ohmmeter was used to measure the resistance R of a length l of nichrome wire as shown. This was then repeated for different values of l.



6 The diameter of the wire was measured and the cross-sectional area A of the wire calculated.

A graph was plotted. The gradient of the graph was equal to the resistivity of nichrome.

Which row of the table shows the quantities which were plotted on the y-axis and the x-axis?

	y-axis	x-axis
☒ **A**	l	RA
☒ **B**	lA	R
☒ **C**	R	Al
☒ **D**	RA	l

(Total for Question 6 = 1 mark)

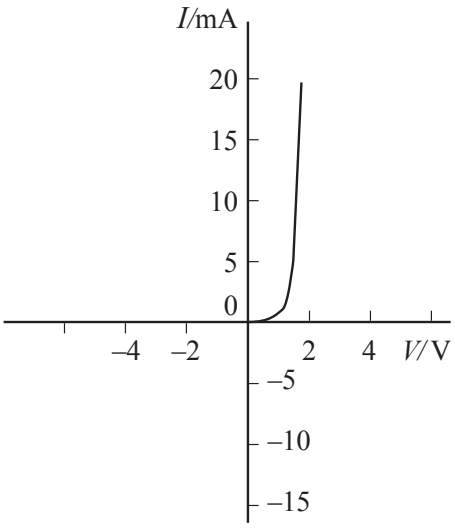
7 The intensity of light incident on a light dependent resistor (LDR) can vary both its electrical resistance R and the number of charge carriers per unit volume n. The light intensity on an LDR is increased.

Which row of the table describes the effect on R and n?

		R	n
☒	**A**	decreases	decreases
☒	**B**	decreases	increases
☒	**C**	increases	decreases
☒	**D**	increases	increases

(Total for Question 7 = 1 mark)

8 The graph shows the variation of current I with potential difference V for a diode.

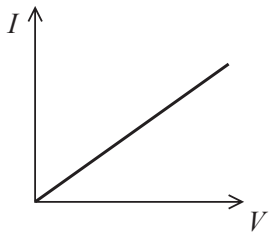


Which of the following statements is correct?

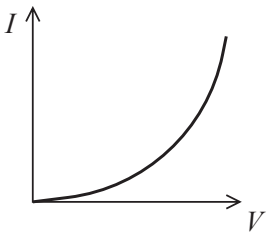
- ☒ **A** The diode has zero resistance when connected in the forward direction.
- ☒ **B** The diode has zero resistance when connected in the reverse direction.
- ☒ **C** The diode starts to conduct when the potential difference is about 0.7 V.
- ☒ **D** The diode stops conducting when the potential difference is about –0.7 V.

(Total for Question 8 = 1 mark)

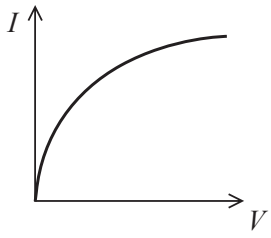
1 Which of the following graphs shows how the current I through a thermistor varies with the potential difference V across the thermistor?



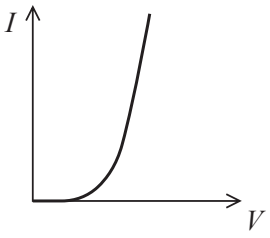
A



B



C



D

- ☒ **A**
- ☒ **B**
- ☒ **C**
- ☒ **D**

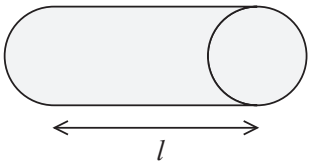
(Total for Question 1 = 1 mark)

2 Which of the following is the SI base unit for resistance?

- ☒ **A** Ω
- ☒ **B** VA^{-1}
- ☒ **C** $kgm^2s^{-3}A^{-2}$
- ☒ **D** $kgm^2s^{-1}C^{-2}$

(Total for Question 2 = 1 mark)

4 A piece of conducting putty is shaped into a cylinder of uniform cross-sectional area, as shown. The length of the cylinder is l. The resistance between the two ends is 8.0 Ω.



The piece of putty is then rolled out until the length is $2l$.

Which of the following is now the value of the resistance between the two ends?

- ☒ **A** 2.0 Ω
- ☒ **B** 4.0 Ω
- ☒ **C** 16.0 Ω
- ☒ **D** 32.0 Ω

(Total for Question 4 = 1 mark)

4 A wire of resistance R has a circular cross-sectional area.

A second wire has the same length and is made of the same material. The diameter of the second wire is double the diameter of the first wire.

Which of the following is the resistance of the second wire?

☒ **A** $4R$

☒ **B** $2R$

☒ **C** $\frac{R}{2}$

☒ **D** $\frac{R}{4}$

(Total for Question 4 = 1 mark)

2 As the temperature of a negative temperature coefficient thermistor increases, the resistance of the thermistor changes.

Which of the following statements is correct?

☒ **A** Resistance decreases as lattice ions vibrate with decreased amplitude.

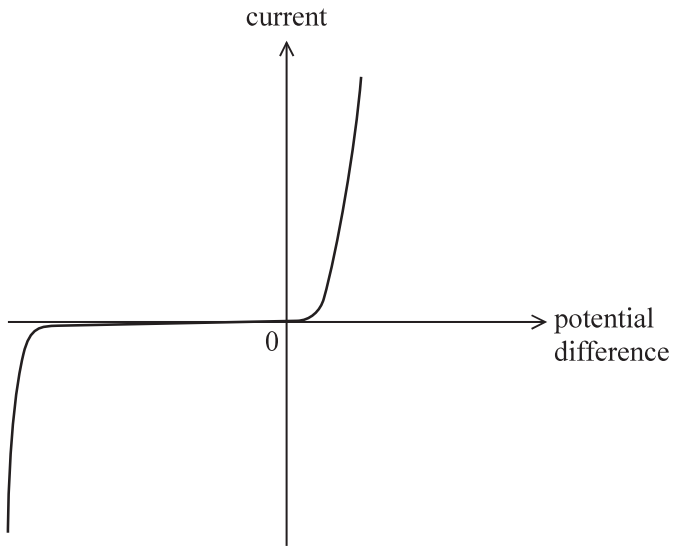
☒ **B** Resistance increases as lattice ions vibrate with increased amplitude.

☒ **C** Resistance decreases as the number of conduction electrons increases.

☒ **D** Resistance increases as the number of conduction electrons decreases.

(Total for Question 2 = 1 mark)

9 The graph shows how current varies with potential difference for a component in a circuit.

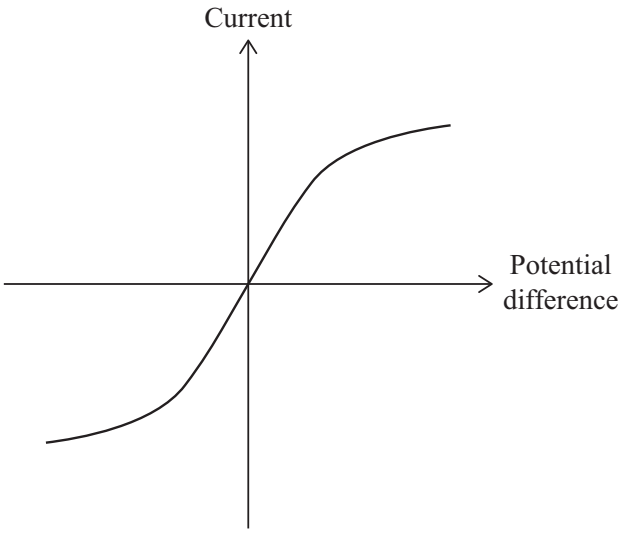


Explain how the graph shows what the component is.

(3)

(Total for Question 9 = 3 marks)

9 The graph shows how current varies with potential difference for a component in a circuit.



Explain how the graph shows what the component is.

.....

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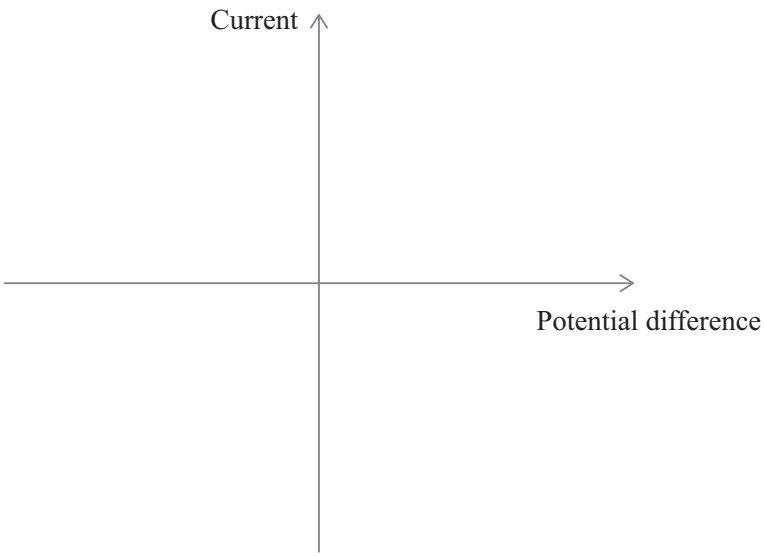
.....

(Total for Question 9 = 3 marks)

11 Diodes are used in a variety of electrical circuits.

(a) Sketch the current-potential difference graph for a diode.

(2)



(b) A package containing a light emitting diode (LED) is marked

"20 mA 3.2 V to operate normally".

A student uses a 5 V power supply of negligible internal resistance to operate the LED.

Calculate the resistance of a protective resistor required to operate the LED normally from this power supply.

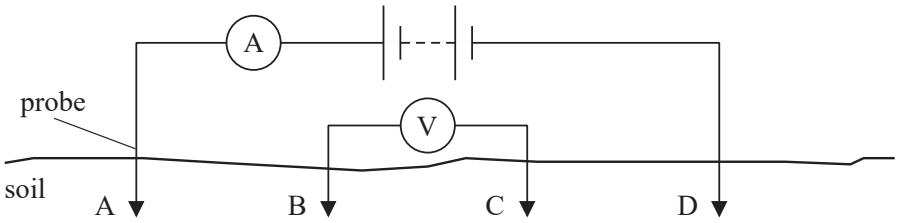
(3)

Resistance = ...

(Total for Question 11 = 5 marks)

13 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.

(a) Explain how the reading on the voltmeter will change if the length BC increases.

(2)

(b) 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.

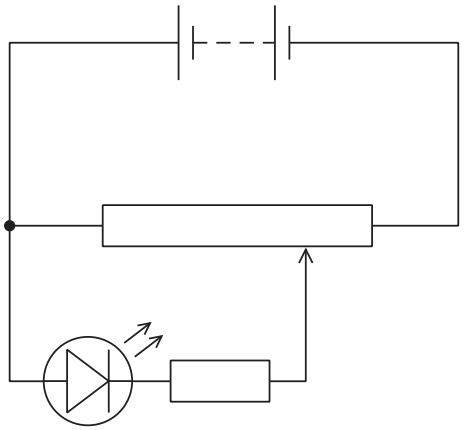
It can be assumed that the sample of soil under investigation has a cross-sectional area of 0.65 m^2.

Deduce two possible materials that could be present in the soil between positions A and D.

(4)

(Total for Question 13 = 6 marks)

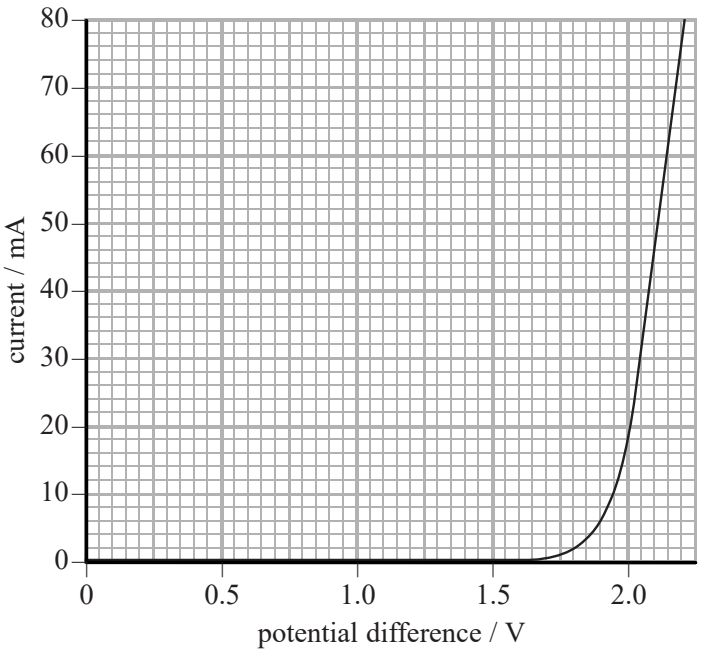
8 A student wanted to plot a graph of current against potential difference for a light emitting diode (LED). He used the circuit shown.



(a) Add an ammeter and a voltmeter to the circuit diagram that would enable the data to be collected.

(1)

(b) The graph of current against potential difference obtained by the student is shown.



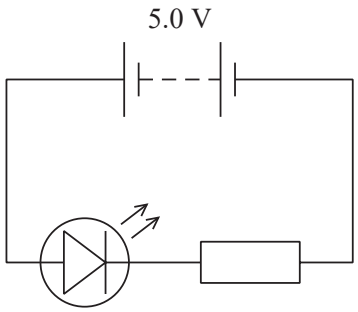
(i) The student wrote the following conclusion.

"The graph shows that in general the LED is not an ohmic conductor. However, for potential differences greater than +2 V, Ohm's law is obeyed since the graph is linear in this region."

Criticise the student's conclusion.

(2)

(ii) The student used the LED with a 5.0 V power supply as shown in the circuit.



To be lit to normal brightness the current through the LED must be 18 mA.

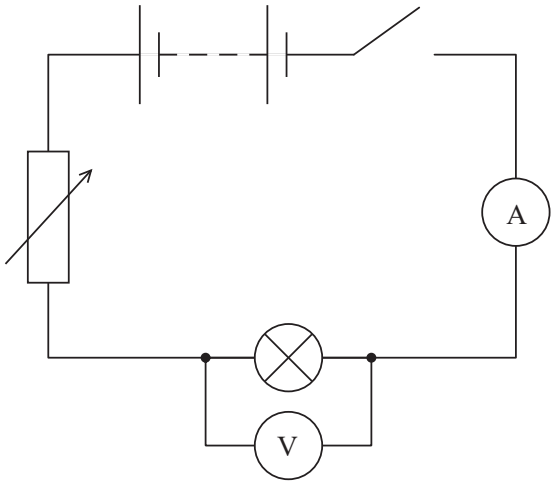
Calculate the resistance of the resistor needed in the circuit.

(4)

Resistance = ...

(Total for Question 8 = 7 marks)

4 A student set up the circuit shown and measured the current I through the filament lamp for a range of values of potential difference (p.d.) V.



The student's data is shown in the table.

V / V	I / A
3.0	0.6
4.0	0.75
6.0	1.00
8.0	1.20
10.0	1.35
12.0	1.5

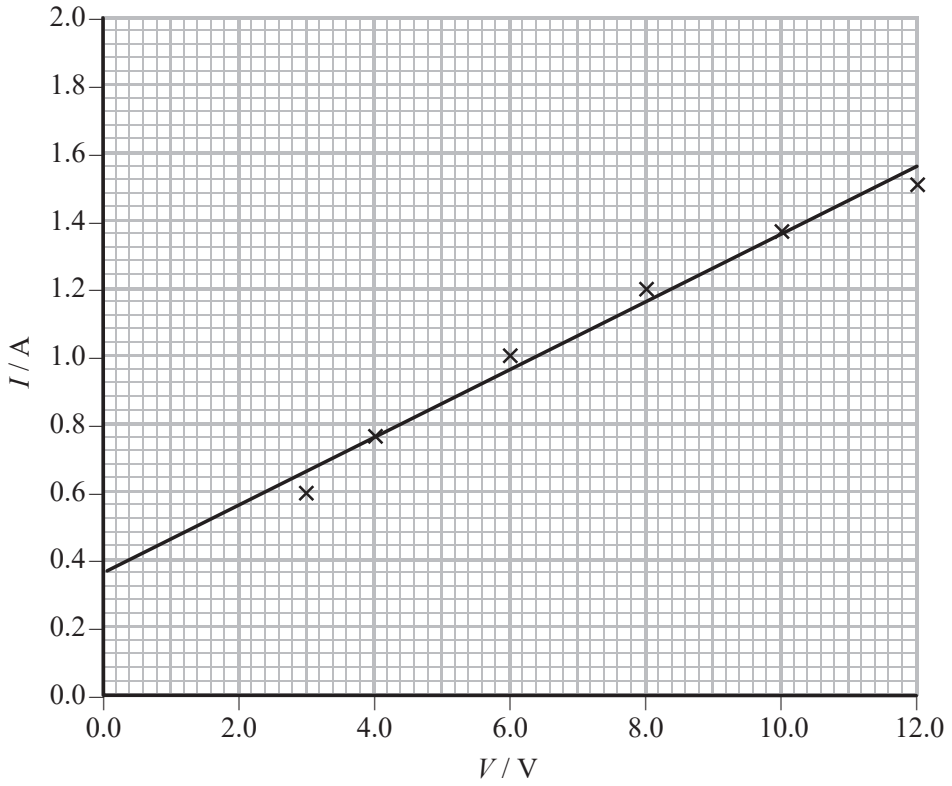
(a) Criticise the student's recording of the data.

(1)

.....

.....

(b) The student drew a graph of how current varies with p.d. She drew a straight line on the graph and claimed that the data demonstrates that the filament lamp obeys Ohm's law because the graph is linear.



Assess the validity of the student's statement.

(4)

(c) Using the circuit shown the student was unable to obtain data for p.d.s less than 2.5 V.

Draw a diagram of a circuit the student could have used to enable a full range of p.d.s from 0 to 12 V to be investigated.

(2)

(Total for Question 4 = 7 marks)

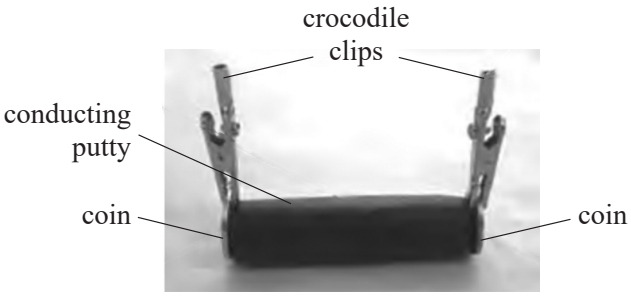
18 A student was given a block of conducting putty of mass 43 g.

(a) (i) Show that the volume of the block of conducting putty was about $8 \times 10^{-6}\,m^3$.

density of conducting putty = $5300\,kg\,m^{-3}$

(2)

(ii) The student formed the putty into a cylinder. Coins were pushed onto the ends of the cylinder as shown. The coins each had a crocodile clip attached and an ohmmeter was connected across the putty.



Determine the resistance of the cylinder of putty.

diameter of cylinder = 12 mm
resistivity of conducting putty = $4.0 \times 10^{-3}\,\Omega\,m$

(3)

Resistance = ...

(b) The student then made a cylinder that had a larger resistance.

Explain how the student used the putty to make a larger resistance.

(2)

.....

.....

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.....

(Total for Question 18 = 7 marks)

11 A student investigates how the resistance of a length of nichrome wire changes with temperature.

(a) The student takes measurements to determine the resistance of the wire at different temperatures.

(i) Draw a diagram of the circuit the student could use.

(1)

(ii) The wire has a thin electrically insulating coating so that it can be coiled up without causing a short circuit.

The student places the coil of wire into a water bath so the temperature of the wire can be varied.

Describe how the student could determine the temperature of the wire accurately.

(2)

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(b) Explain, in terms of particle behaviour, why the resistance of the nichrome wire changes as temperature increases.

(4)

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(Total for Question 11 = 7 marks)

12 A wire-wound resistor consists of a long length of wire wound around an insulating core. A technician finds a wire-wound constantan resistor labelled 80 Ω.

(a) Calculate the length of the constantan wire used to make the resistor.

resistivity of constantan wire at room temperature = 4.9×10^{-7} Ω m
diameter of wire = 0.28 mm

(3)

Length = ...

(b) A potential difference of 9.8 V is applied across the resistor and the current in the resistor is 0.12 A.

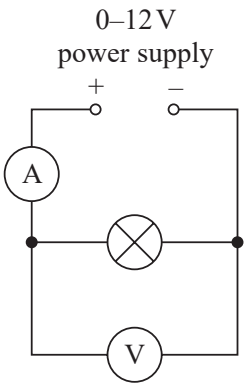
Deduce whether the value labelled on the resistor is supported by these data.

uncertainty in the potential difference = ±0.1 V
uncertainty in the current = ±0.01 A

(4)

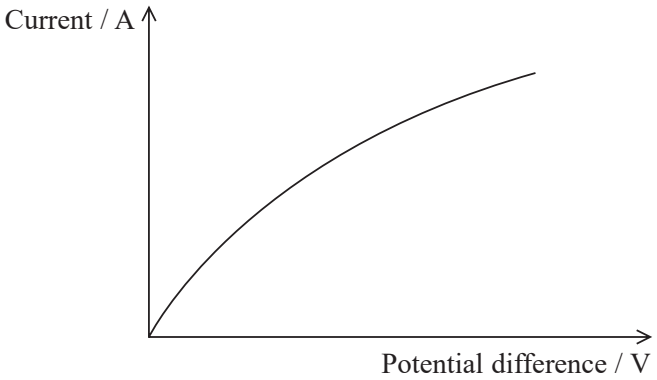
(Total for Question 12 = 7 marks)

16 A student investigated the current-potential difference relationship for a filament bulb.
She set up the circuit as shown.



The student increased the output from the power supply from 0 V to 12 V in steps of 2 V.
She recorded corresponding currents from the ammeter.

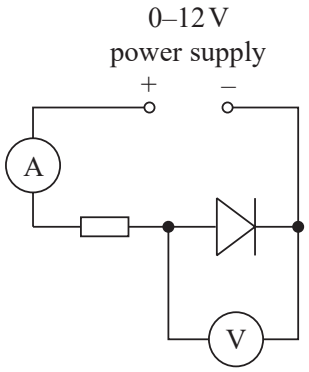
(a) A graph of her results is shown.



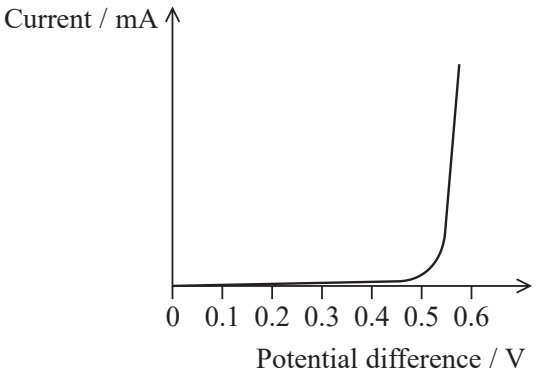
Explain the shape of the graph.

(4)

(b) The student replaced the bulb in the circuit with a diode in forward bias and a resistor as shown.



The graph shows how current varies with potential difference for a diode in forward bias.



Describe how the student could adapt her method to plot the variation of current with potential difference for the diode in forward bias.

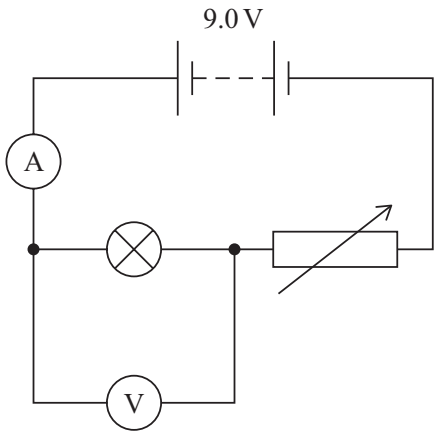
You should include any changes to the circuit.

(3)

(Total for Question 16 = 7 marks)

1 A student investigated the variation of current with applied potential difference (p.d.) for a filament bulb. Under normal working conditions the potential difference across the bulb is 3.0 V.

(a) The circuit diagram shows the circuit the student used.



Comment on the suitability of the student's circuit.

(3)

(b) When the p.d. across the bulb was 3.0 V, the student recorded a value of 1.29 A for the current.

In his conclusion he stated

> This will give an accurate value for the working resistance, as the value of current is precise.

Assess the validity of the student's statement. You do not need to carry out a calculation.

(4)

(Total for Question 1 = 7 marks)

5 The photograph shows a statue of Buddha in Sri Lanka, which is protected by a lightning conductor.



© Valery Shanin/123RF

(a) During a storm, a potential difference of 2.7 MV was generated between a cloud and the top of the lightning conductor on the statue. A flash of lightning passed between the cloud and the lightning conductor, producing a current of 25 kA for a time of 7.5 ms.

Calculate the energy transferred by the lightning strike.

(3)

.....

.....

.....

.....

Energy transferred = ...

(b) The lightning conductor is a length of copper wire with a diameter of 1.2×10^{-2} m and a resistance of 4.3×10^{-3} Ω. It runs along the back of the statue from the base to a height of 1.5 m above the top of the statue.

A guidebook claims that the statue is over 30 m high.

Assess the validity of this claim.

resistivity of copper = 1.7×10^{-8} Ω m

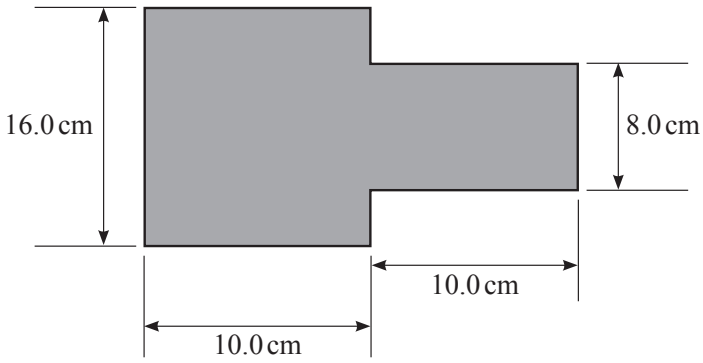
(4)

(c) Give a reason why the lightning conductor should be taller than the statue.

(1)

(Total for Question 5 = 8 marks)

14 Carbon paper is an electrically conducting paper. A student cut a sheet of this paper into the shape shown, to carry out an investigation.

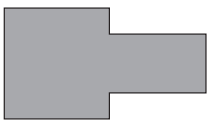


The student followed the procedure below to set up a potential divider circuit:

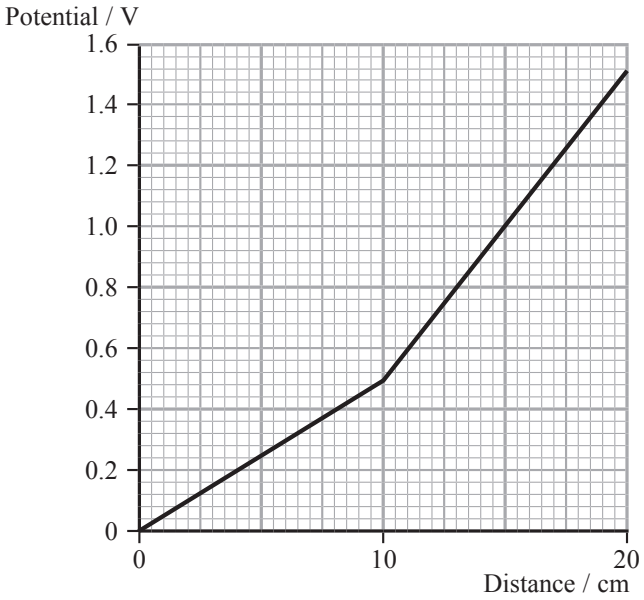
- connect the 16 cm and 8 cm wide ends to a 1.5 V cell
- connect the 16 cm wide end to the negative (0 V) terminal of the cell
- connect a voltmeter so that it measures the potential at a point 15 cm from the 16 cm wide end.

(a) Add a circuit diagram to the diagram below to show how the carbon paper is connected.

(2)



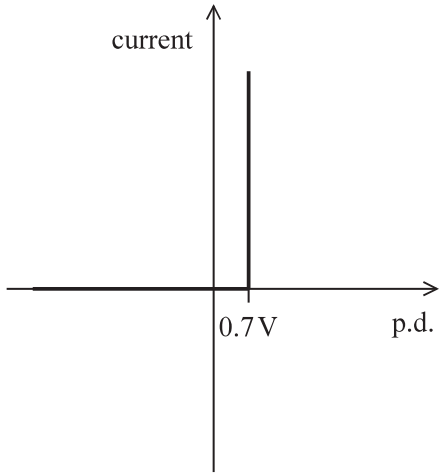
*(b) The following graph was plotted from an investigation in which the potential was measured at various distances from the 16.0 cm wide end of the shape.



Explain the shape of this graph. **(6)**

(Total for Question 14 = 8 marks)

15 The graph shows how current varies with potential difference (p.d.) for an ideal diode.



(a) Describe how the current through this diode varies for positive p.d.s and negative p.d.s.

(2)

.....

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(b) An alternating p.d. V_{IN} has a peak value of 3.4 V.

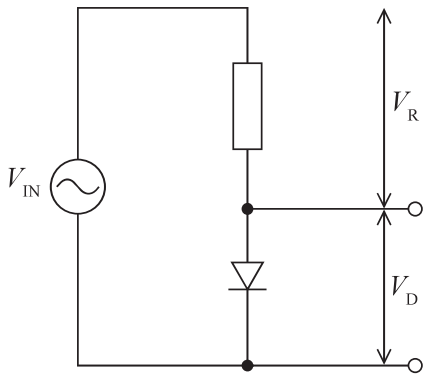
(i) Calculate the r.m.s. value.

(2)

.....

r.m.s. value = ...

(ii) V_{IN} is applied to a diode and resistor as shown.



The p.d. across the resistor is V_R and the p.d. across the diode is V_D. V_D is the output.

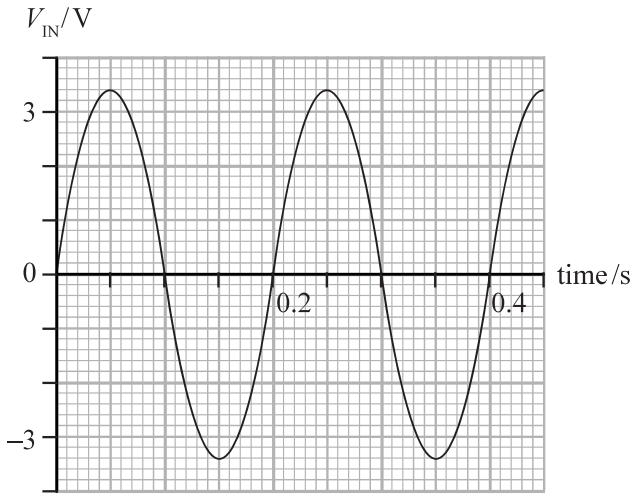
Explain why $V_{IN} = V_R + V_D$ at any given time.

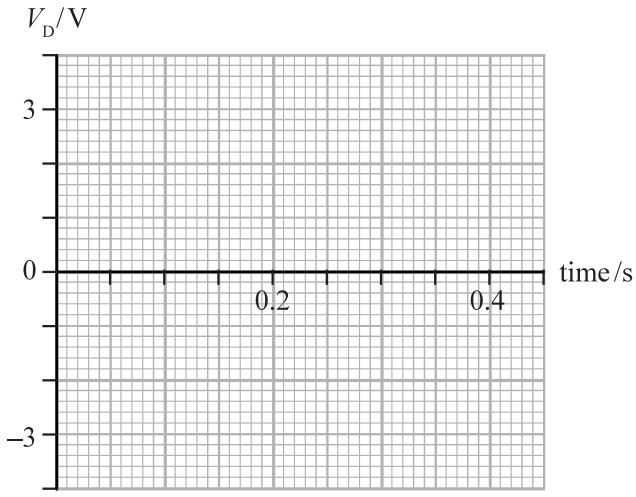
(2)

(iii) The graph shows how V_{IN} varies with time.

Sketch a graph of V_D against time using the axes provided below.

(3)

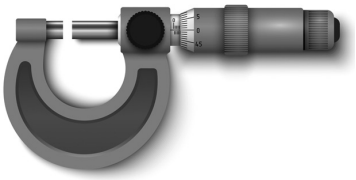




(Total for Question 15 = 9 marks)

12 The resistivity of a metal is an important property of wire used in an electric circuit.

(a) A student carried out an experiment to determine the resistivity of a type of wire.
He used a micrometer to measure the diameter d of the wire.



(Source: © Viktor Chursin/Shutterstock)

He recorded the following values.

d_1 / mm	d_2 / mm	d_3 / mm	d_4 / mm
1.40	1.44	1.42	1.41

(i) Calculate the percentage uncertainty in the mean diameter of the wire.

(3)

.....

.....

.....

.....

% uncertainty in mean diameter of wire = ...

(ii) The student used an ohmmeter to measure the resistance R of a 1.65 m length of the wire.

He looked up the resistivity values of some materials.

Material	Titanium	Constantan	Stainless Steel
Resistivity / $10^{-7}\,\Omega\,m$	4.2	4.7	6.9

Identify the material of the wire.

$R = 0.72\,\Omega$

(3)

(b) Nichrome wire is often used in heating elements. Nichrome wire is used to make a coil for a 65 W mains powered heater. The nichrome wire has a resistance per metre of $87.5\,\Omega\,m^{-1}$.

Calculate the length of wire required.

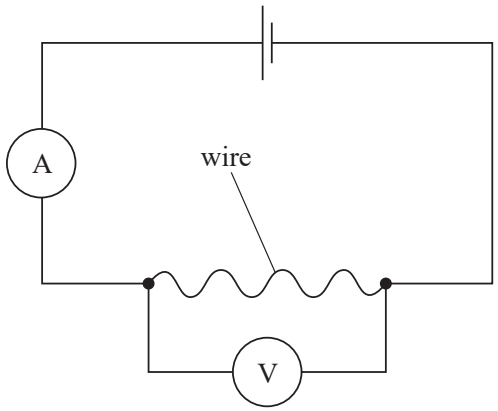
potential difference across the coil = 230 V

(3)

Length of wire required = ...

(Total for Question 12 = 9 marks)

12 A student carried out an experiment to determine the resistivity of a metal alloy.
The student used a wire made of the alloy and connected it in a circuit, as shown.



(a) Describe how the student could have measured the diameter of the wire accurately.

(2)

(b) The student made the following measurements:

voltmeter reading = 1.96 V
ammeter reading = 0.57 A
diameter of wire = 0.58 mm
length of wire = 83.5 cm

Calculate the resistivity of the metal alloy.

(4)

Resistivity = ...

(c) The student stated that the ammeter reading was the most significant source of uncertainty in the calculated value of resistivity.

The percentage uncertainty in the ammeter reading was 0.9%.
The percentage uncertainty in the measurement of diameter was 0.8%.
The percentage uncertainty in the measurement of length was 0.1%.
The percentage uncertainty in the voltmeter reading was 0.3%.

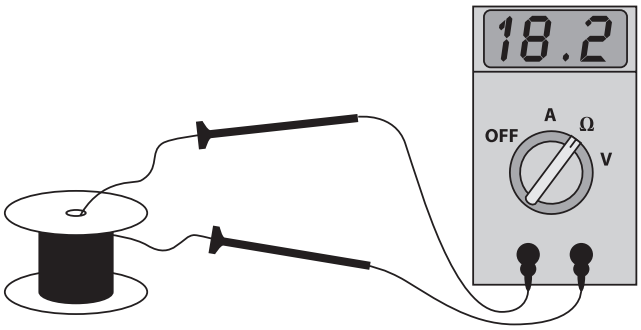
Assess the validity of the student's statement.

(3)

(Total for Question 12 = 9 marks)

6 A student carried out an experiment to determine the resistivity of nichrome wire.

He used an ohmmeter to measure the resistance of a length of nichrome wire as shown.



The diameter of the wire was measured as 0.27 mm ± 0.01 mm.
The length of the wire was measured as 1.25 m ± 0.05 m.

(a) Determine which of the three measurements introduces the greatest uncertainty into the value for the resistivity.
Your answer should include calculations.

(4)

(b) Explain how the student could reduce the uncertainty in the measurement of the diameter.

(2)

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(c) Calculate the minimum value of resistivity possible from the student's data.

(4)

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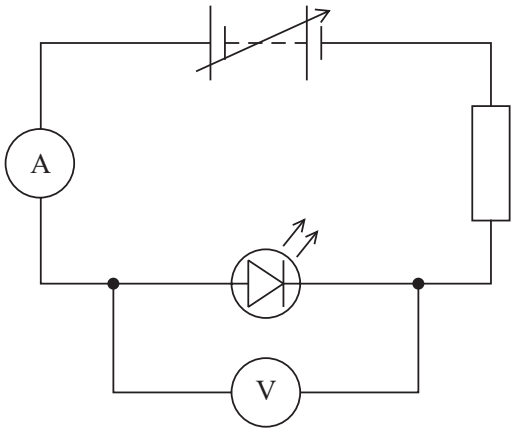
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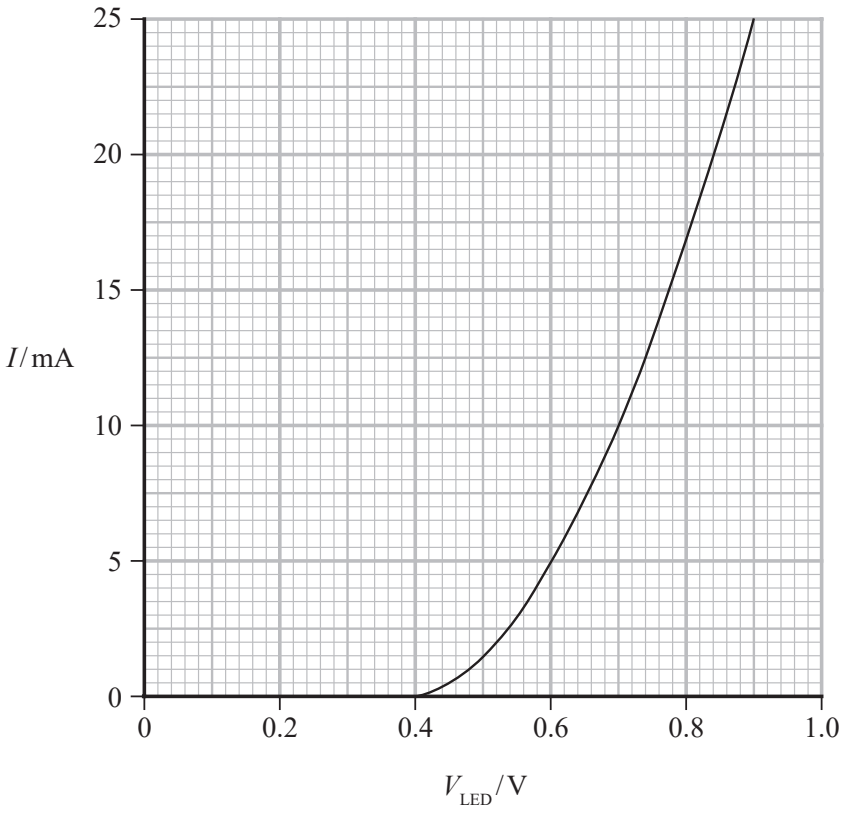
Minimum resistivity = ...

(Total for Question 6 = 10 marks)

14 A light emitting diode (LED) is placed in a circuit with a fixed resistor and a variable power supply. An ammeter and a high resistance voltmeter are also connected, as shown.



The graph shows how the current I through the LED varies with the potential difference V_{LED} across the LED.



(a) When the potential difference across the variable power supply is 6.0 V, the ammeter reading is 12.5 mA.

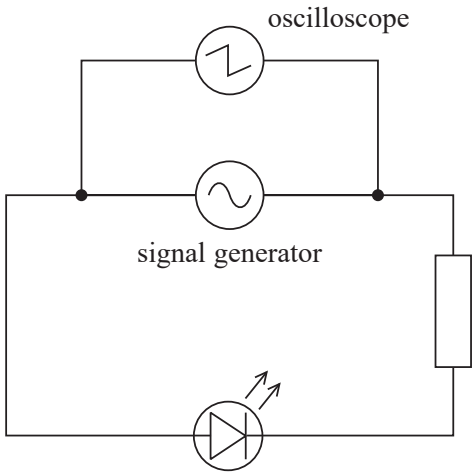
Calculate the resistance of the fixed resistor.

(4)

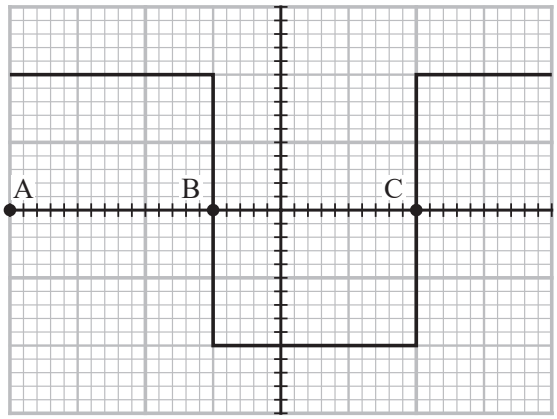
Resistance = ...

*(b) The ammeter and voltmeter were removed from the circuit.

The variable power supply was replaced by a signal generator and an oscilloscope, as shown.



The output from the signal generator is shown on the oscilloscope screen below.
The output varies between +6 V and –6 V.
Points A, B and C represent instants of time.

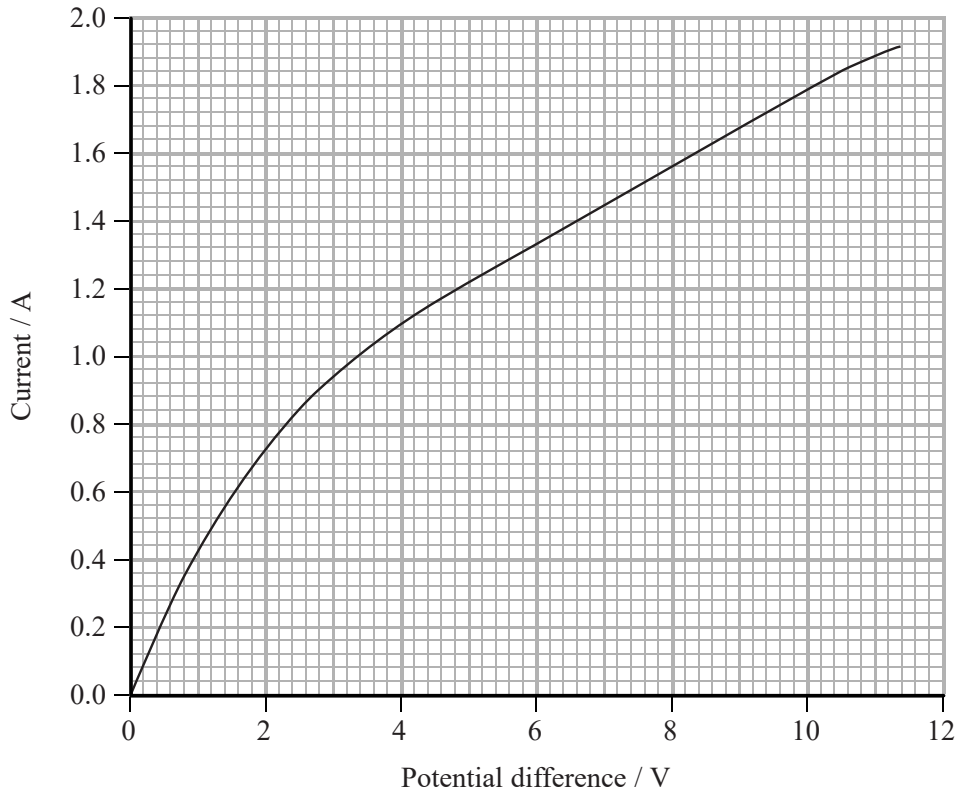


Explain why the LED flashes. Your answer should refer to the output between times A and C.

(6)

(Total for Question 14 = 10 marks)

14 The graph shows how the current through a filament bulb varies with the potential difference across the bulb.



(a) Determine the resistance of the filament bulb when the potential difference is 7.0 V.

(2)

.....

.....

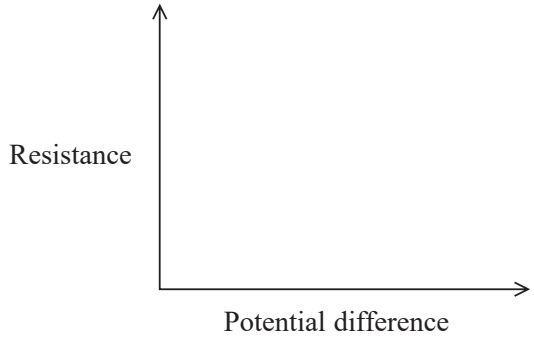
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Resistance = ...

(b) Sketch a graph of resistance against potential difference for the filament bulb over the range 0 V to 7 V.

(3)

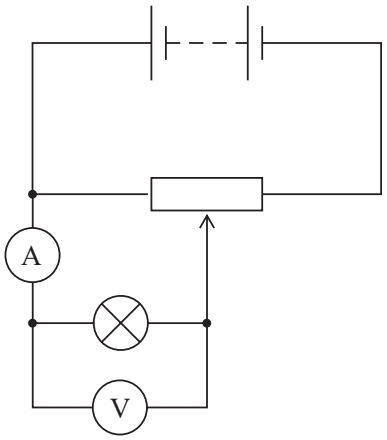


*(c) Explain the variation of resistance with potential difference for the filament bulb in terms of particle behaviour.

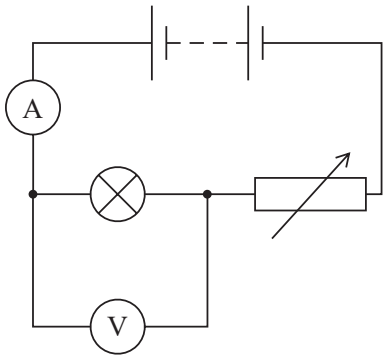
(6)

(Total for Question 14 = 11 marks)

9 A student is planning to collect data to produce a current-potential difference graph for a filament lamp. Her teacher suggests two circuits that she could use.



Circuit 1



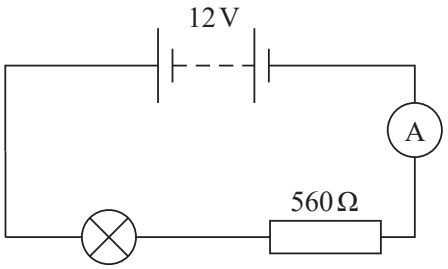
Circuit 2

Circuit 1 uses a potential divider and circuit 2 uses a variable resistor to vary the potential difference across the filament lamp.

*(a) Discuss the suitability of each circuit to collect the data.

(6)

(b) The student sets up the following circuit with the filament lamp. The battery has negligible internal resistance.



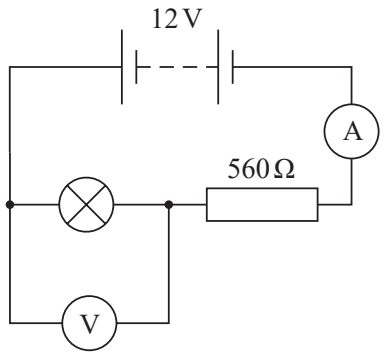
(i) The reading on the ammeter is 17.5 mA.

Calculate the value of the potential difference (p.d.) across the filament lamp.

(2)

p.d. across filament lamp = ...

(ii) When a voltmeter with a resistance of 1.5 kΩ is connected as shown, the p.d. across the filament lamp decreases.



Explain why the p.d. across the filament lamp decreases.

(3)

(Total for Question 9 = 11 marks)

16 A student is investigating circuits that include a filament bulb. The filament bulb is labelled '1.5 V, 0.50 W'.

(a) Show that the resistance of the filament bulb when operating normally is about 5 Ω.

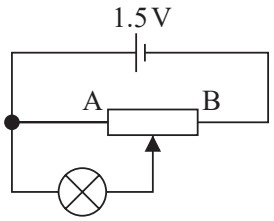
(2)

.....

.....

.....

*(b) The student wishes to control the brightness of the filament bulb using a potentiometer. The student connects the circuit shown. The total resistance of the potentiometer is very much larger than the resistance of the filament bulb.



Explain how the brightness of the filament bulb changes as the potentiometer slider is moved from A to B.

(6)

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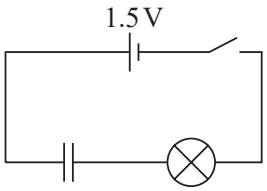
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(c) The student connects the filament bulb in the circuit shown below. The capacitor is initially uncharged and has a capacitance of 1.2 F.

The resistance of the filament bulb is 5 Ω.



Explain how the brightness of the filament bulb will vary as the switch is closed.

(4)

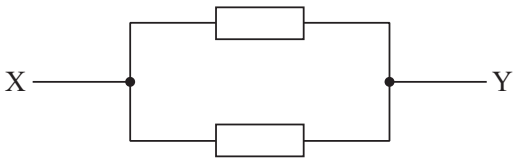
(Total for Question 16 = 12 marks)

SUB-TOPIC 3.4

SERIES AND PARALLEL CIRCUITS

Sub-topic 3.4 · 14 questions · 41 marks · lowest tariff first

3 The two resistors shown each have resistance R.



Which expression gives the correct resistance between point X and point Y?

☒ **A** $\frac{R}{2}$

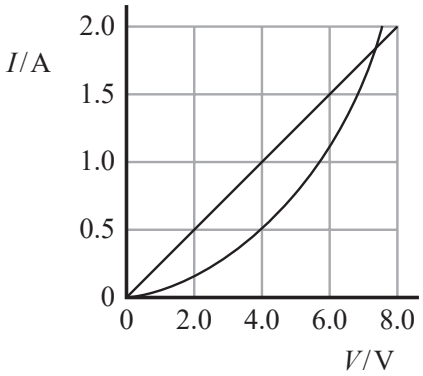
☒ **B** R

☒ **C** $2R$

☒ **D** R^2

(Total for Question 3 = 1 mark)

10 The current-potential difference graphs for a resistor and a thermistor are shown.



The resistor and thermistor are connected in series to a 6 V battery.

What is the current, in amps, in the resistor?

- ☒ **A** 0.5
- ☒ **B** 1.0
- ☒ **C** 1.5
- ☒ **D** 2.0

(Total for Question 10 = 1 mark)

5 A student is deriving an equation for the total resistance of resistors in series.

She writes the following steps but does not justify them.

Step 1 $V = V_1 + V_2$
Step 2 *but* $V = IR$
Step 3 *so* $IR = I_1R_1 + I_2R_2$
Step 4 *but* $I = I_1 = I_2$
Step 5 *Therefore* $R = R_1 + R_2$

Which step is justified using conservation of charge?

☒ **A** Step 1

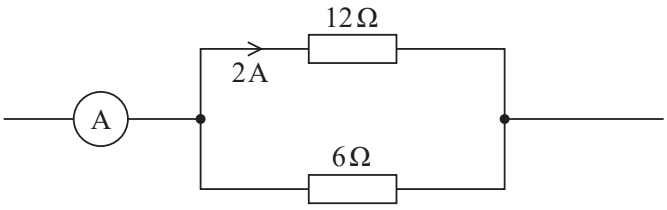
☒ **B** Step 2

☒ **C** Step 3

☒ **D** Step 4

(Total for Question 5 = 1 mark)

1 Part of an electric circuit is shown.

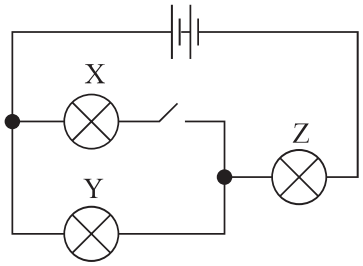


What is the current shown by the ammeter?

- ☒ **A** 3 A
- ☒ **B** 4 A
- ☒ **C** 5 A
- ☒ **D** 6 A

(Total for Question 1 = 1 mark)

4 A circuit consists of three identical 1.5 V bulbs connected to two 1.5 V cells.

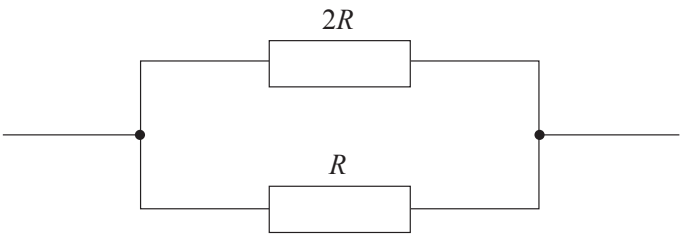


The switch is closed.
Which row describes the change in brightness of bulb Y and bulb Z?

	Y	Z
☒ **A**	brighter	brighter
☒ **B**	brighter	dimmer
☒ **C**	dimmer	brighter
☒ **D**	dimmer	dimmer

(Total for Question 4 = 1 mark)

7 Part of an electric circuit consists of two resistors. One resistor has a resistance $2R$ and the other resistor has a resistance R as shown.



Which of the following is the equivalent resistance of this combination?

☒ **A** $\frac{R}{3}$

☒ **B** $\frac{2R}{3}$

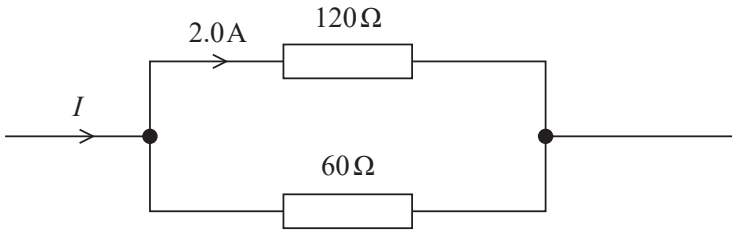
☒ **C** $\frac{3R}{2}$

☒ **D** $3R$

(Total for Question 7 = 1 mark)

Questions 4 and 5 refer to the information below.

Two resistors are connected in parallel and the current in one of them is 2.0 A, as shown.



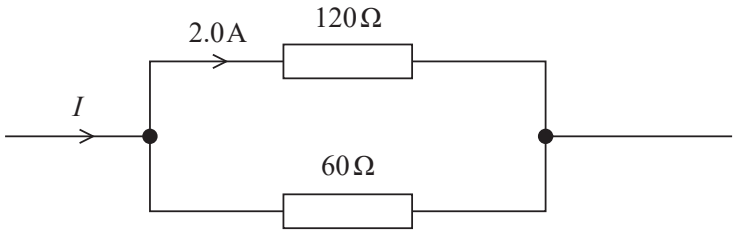
4 Which of the following is the current I in ampere?

- ☒ **A** 3.0
- ☒ **B** 4.0
- ☒ **C** 5.0
- ☒ **D** 6.0

(Total for Question 4 = 1 mark)

Questions 4 and 5 refer to the information below.

Two resistors are connected in parallel and the current in one of them is 2.0 A, as shown.

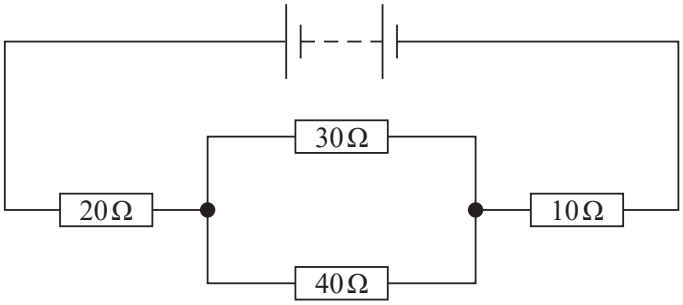


5 Which of the following is the total resistance of the resistors in parallel?

- ☒ **A** 20 Ω
- ☒ **B** 40 Ω
- ☒ **C** 90 Ω
- ☒ **D** 180 Ω

(Total for Question 5 = 1 mark)

9 A circuit was constructed as shown.

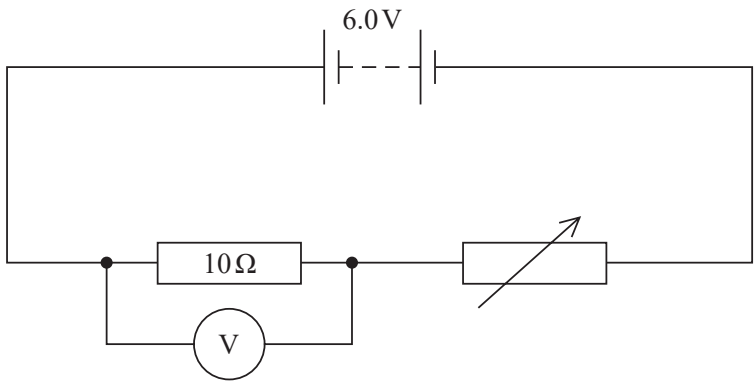


Calculate the total resistance of the resistors in the circuit.

Total resistance = ...

(Total for Question 9 = 3 marks)

9 A student connects the circuit shown. The battery has negligible internal resistance.



The student increases the resistance of the variable resistor from 0 Ω to 40 Ω.

Determine the range of readings on the voltmeter.

.....

.....

.....

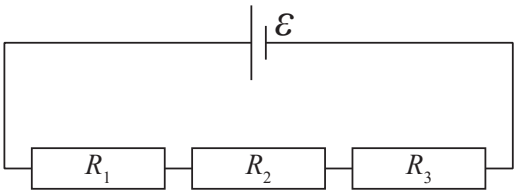
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Maximum reading on voltmeter = ...

Minimum reading on voltmeter = ...

(Total for Question 9 = 3 marks)

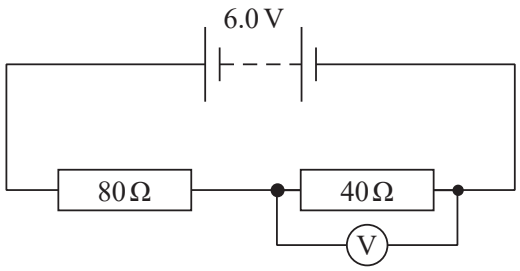
9 (a) Three resistors, of resistance R_1, R_2 and R_3, are connected in series across a cell. The cell has electromotive force (e.m.f.) $\mathcal{E}$ with negligible internal resistance. The current through the cell is I.



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

(3)

(b) 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)

Resistance of voltmeter = ...

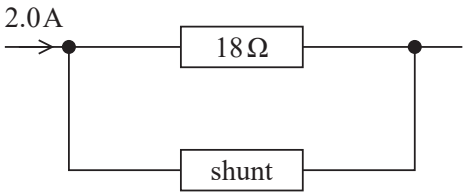
(Total for Question 9 = 6 marks)

12 Analogue ammeters were used before digital meters became widely available.
The analogue ammeter shown will measure a maximum current of 1.0 mA and has a resistance of 18 Ω.



(Source: © David J. Green/Alamy Stock Photo)

The analogue ammeter can be adapted to measure a larger current by adding a resistor, known as a shunt, in parallel with the ammeter. The arrangement is shown below.
The analogue ammeter is represented by the 18 Ω resistor.



The maximum current through the 18 Ω resistor remains as 1.0 mA.

(a) Show that the shunt would need to have a resistance of about 0.01 Ω to adapt this ammeter to read up to a maximum current of 2.0 A.

(3)

(b) A shunt of this resistance was usually made from Manganin wire.

Calculate the length of Manganin wire of radius 0.95 mm required to make this shunt.

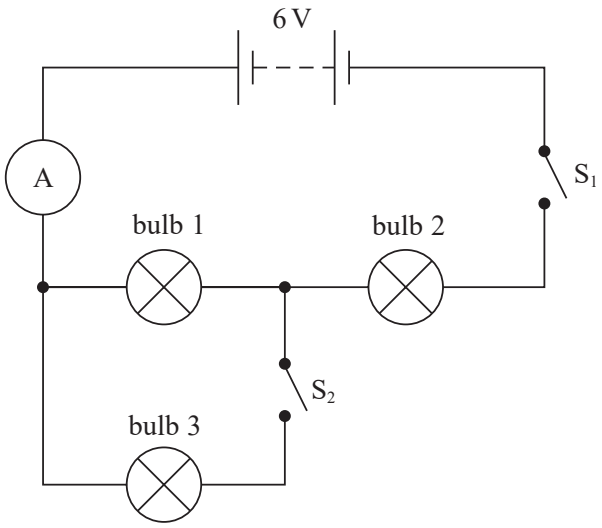
resistivity of Manganin = $4.55 \times 10^{-7}\,\Omega\,m$

(3)

Length = ...

(Total for Question 12 = 6 marks)

***3** A student connects three identical 3 V bulbs to a 6 V battery of negligible internal resistance. The circuit includes two switches, S_1 and S_2, as shown.



The student closes S_1 and records the brightness of each bulb.

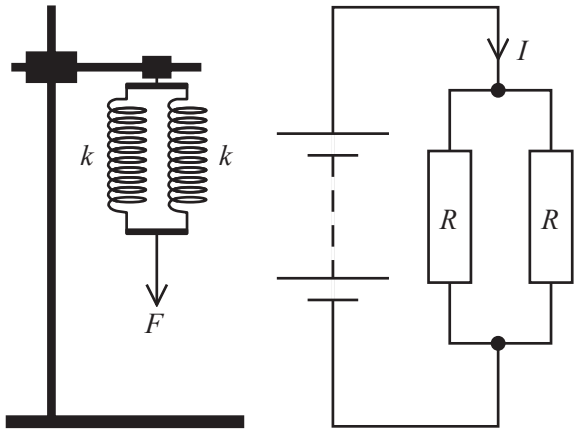
With S_1 still closed, the student closes S_2.

Explain how the brightness of bulb 1 compares with the brightness of bulb 2 before and after S_2 is closed.

(Total for Question 3 = 6 marks)

6 A student is experimenting with different combinations of springs and recalls that in physics it is often possible to model different physical situations in similar ways.

The student suggests that a parallel combination of springs could be a model for a parallel combination of resistors in a circuit.



(a) Derive an expression for the effective resistance R_{eff} of two resistors R_1 and R_2 connected in parallel in a circuit.

(3)

(b) Assess the validity of the student's suggestion by considering the effective stiffness of two identical springs in parallel.

(6)

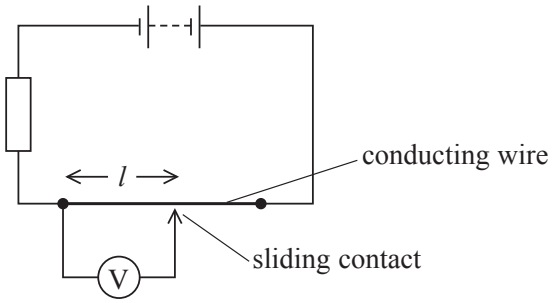
(Total for Question 6 = 9 marks)

SUB-TOPIC 3.5

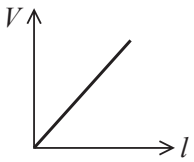
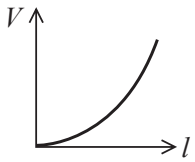
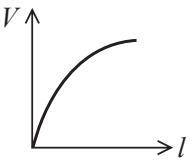
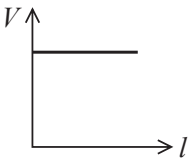
POTENTIAL DIVIDERS AND SENSORS

Sub-topic 3.5 · 20 questions · 147 marks · lowest tariff first

3 A student set up the circuit below and moved a sliding contact along a uniform conducting wire.
The student recorded the potential difference V across each length of wire l under test.

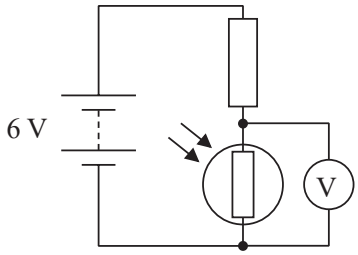


Which graph correctly shows how V varies with l?

			
☒ **A**	☒ **B**	☒ **C**	☒ **D**

(Total for Question 3 = 1 mark)

6 A light-dependent resistor (LDR) and resistor are connected in series with a 6 V battery as shown. A voltmeter measures the potential difference across the LDR.



In daylight the voltmeter reads 3.0 V.

Which reading is most likely if the circuit is now in total darkness?

☒ **A** a little above 0 V

☒ **B** a little below 3 V

☒ **C** a little above 3 V

☒ **D** a little below 6 V

(Total for Question 6 = 1 mark)

7 A series circuit consists of two resistors with resistances R_1 and R_2 and a battery of potential difference V.

Which of the following gives the potential difference across the resistor with resistance R_2?

☒ **A** $\frac{R_1}{R_2} V$

☒ **B** $\frac{R_2}{R_1} V$

☒ **C** $\frac{R_1}{R_1 + R_2} V$

☒ **D** $\frac{R_2}{R_1 + R_2} V$

(Total for Question 7 = 1 mark)

8 A light dependent resistor and a negative temperature coefficient thermistor are connected in series.

Which of the following combinations of illumination and temperature will result in the highest combined resistance?

☒ **A** dark and cold

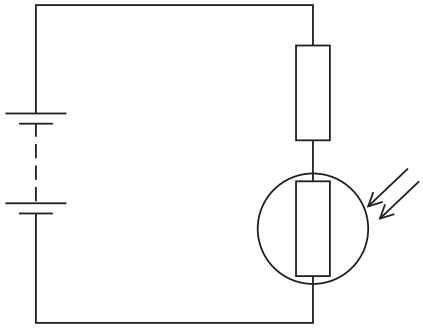
☒ **B** dark and hot

☒ **C** light and cold

☒ **D** light and hot

(Total for Question 8 = 1 mark)

7 A light dependent resistor (LDR) and a resistor are connected to a battery, as shown.



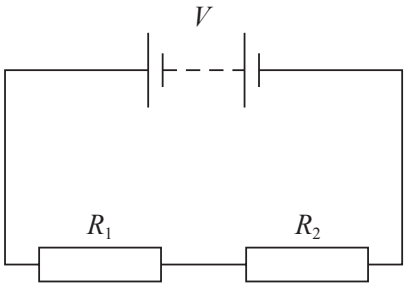
The intensity of light incident on the LDR increases.

Which row of the table describes the change in the resistance of the LDR and the change in the potential difference across the resistor?

		Resistance of LDR	Potential difference across the resistor
☒	**A**	decreases	decreases
☒	**B**	decreases	increases
☒	**C**	increases	decreases
☒	**D**	increases	increases

(Total for Question 7 = 1 mark)

7 Two resistors of resistance R_1 and R_2 are connected to a battery as shown.
The terminal potential difference of the battery is V.



Which of the following gives the potential difference across the resistor of resistance R_1?

☒ **A** $\frac{R_1}{R_2} \times V$

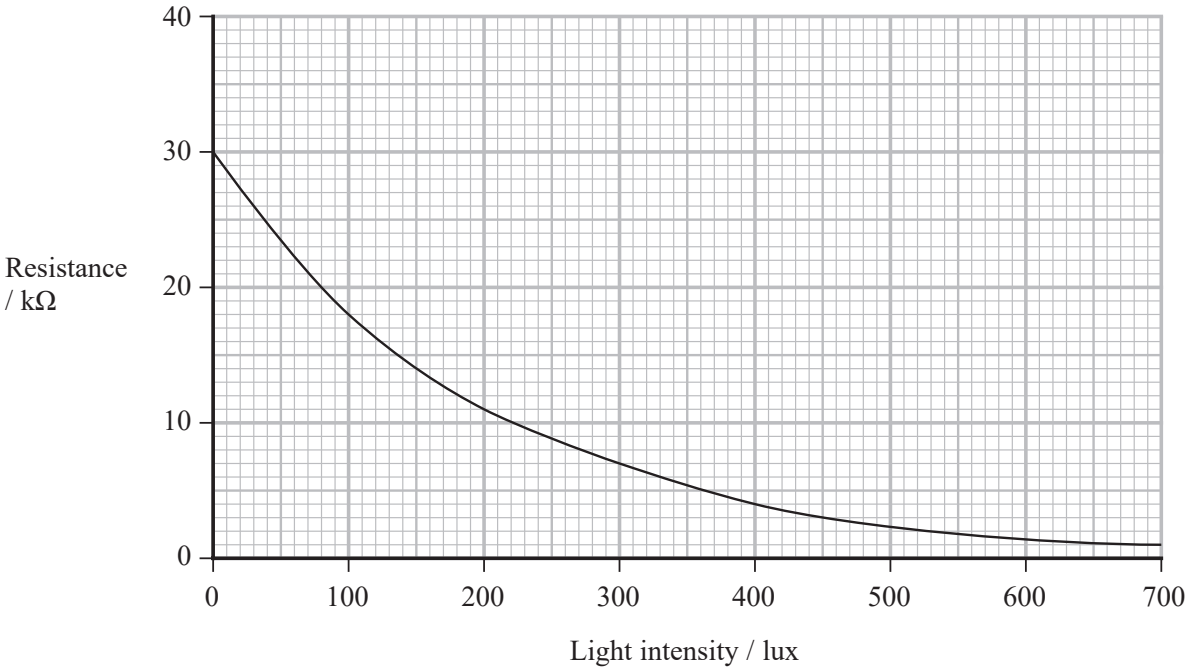
☒ **B** $\frac{R_1}{R_1 + R_2} \times V$

☒ **C** $\frac{R_2}{R_1} \times V$

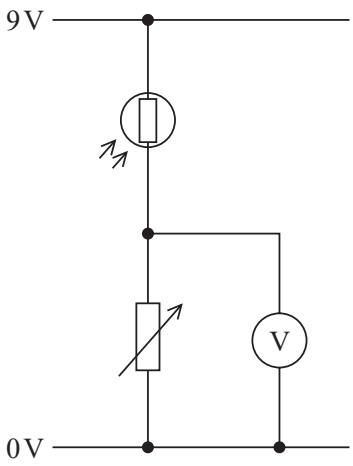
☒ **D** $\frac{R_2}{R_1 + R_2} \times V$

(Total for Question 7 = 1 mark)

11 The graph shows how the resistance of a light dependent resistor (LDR) varies with the incident light intensity, measured in lux.



A student used the LDR in the light-sensing circuit shown below.



(a) The student increased the resistance of the variable resistor whilst the light intensity was constant. The voltmeter recorded the potential difference across the variable resistor.

Explain what happened to the reading on the voltmeter.

(3)

(b) The variable resistor was set at a resistance of 4.5 kΩ.

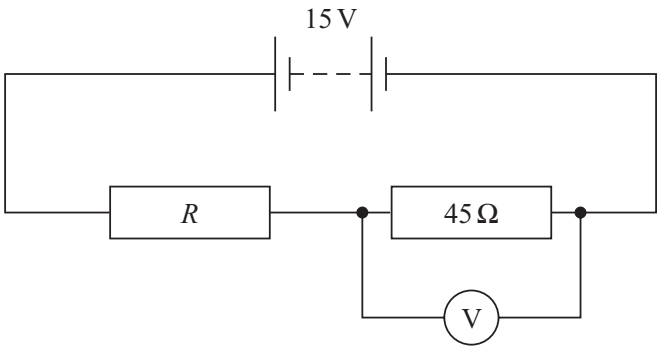
Determine the light intensity when the potential difference shown on the voltmeter was 2.5 V.

(3)

Light intensity = ... lux

(Total for Question 11 = 6 marks)

11 Two resistors are connected in series in a circuit, as shown. The power supply has negligible internal resistance.



(a) Calculate the resistance R of the resistor when the voltmeter reads 5.5 V.

(3)

R = ...

(b) A student uses the circuit to power an electric motor. He connects the motor in parallel with the 45 Ω resistor.

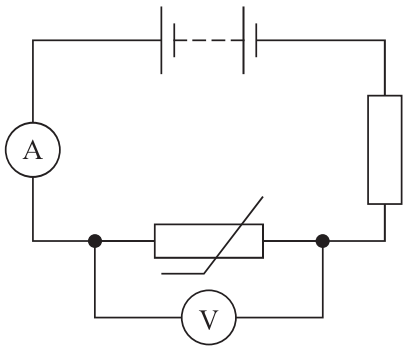
The electric motor has a resistance of 45 Ω and a normal working potential difference of 5.5 V.

Deduce how the motor performs when connected to the circuit. You do not need to do a further calculation.

(3)

(Total for Question 11 = 6 marks)

11 A student investigated the effect of temperature on the resistance of a thermistor, using the circuit shown.



(a) The voltmeter was an analogue voltmeter of resistance 45 kΩ.

The thermistor was placed in a beaker of ice and the current and potential difference (p.d.) at a temperature of 0 °C were recorded.

The manufacturer of the thermistor states that at 0 °C the thermistor has a resistance of 9.7 kΩ.

(i) Comment on the suitability of using the analogue voltmeter for measuring the p.d. across the thermistor. Your answer should include a suitable calculation.

(3)

(ii) Explain why connecting the voltmeter across both the ammeter and the thermistor would improve the experiment. The ammeter had negligible resistance.

(2)

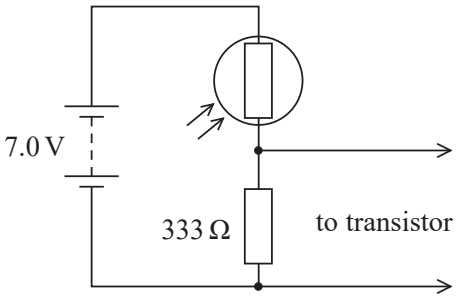
(b) A negative temperature coefficient thermistor was used in this circuit.

With reference to the charge carriers in the thermistor, explain what happens to the p.d. across the thermistor as the temperature increases.

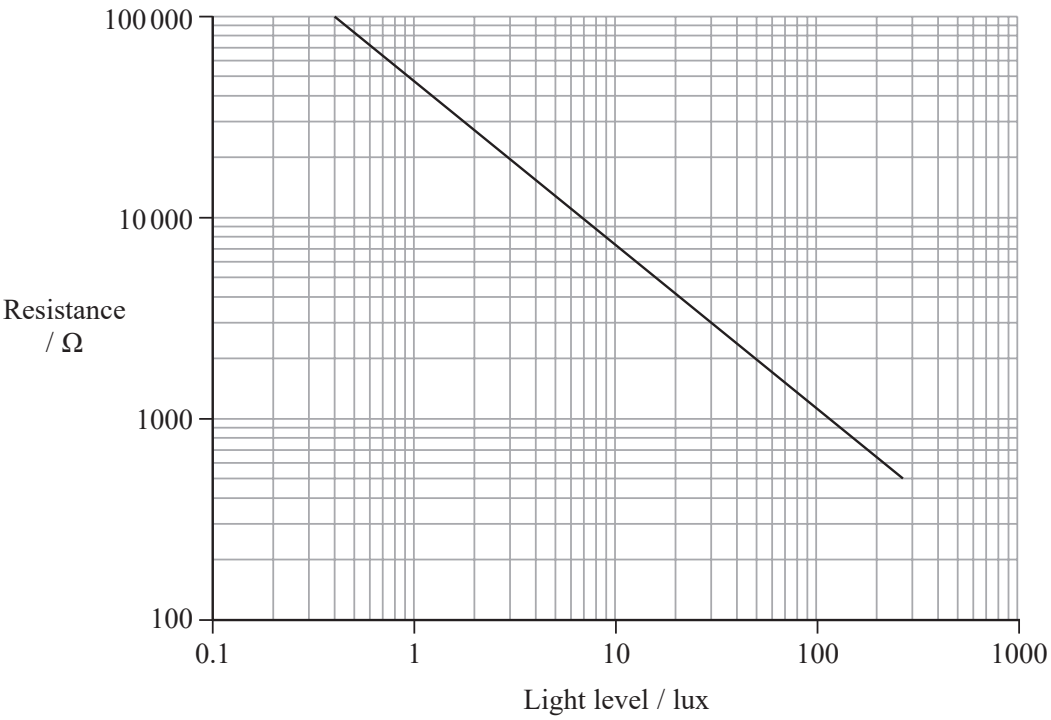
(3)

(Total for Question 11 = 8 marks)

13 The circuit shown provides an input to a transistor. A transistor is a type of electronic switch and in this circuit it can be assumed to have infinite resistance.



The resistance of the LDR varies with light level as shown below.



The transistor switches on when the potential difference across the input increases above 0.7 V. This should happen as the light level reaching the LDR increases above 30 lux.

(a) Deduce whether this circuit responds as required.

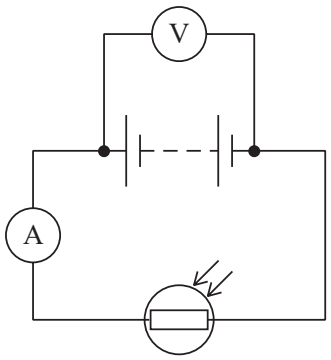
(6)

(b) Explain how the resistance of the LDR changes as the light level increases.

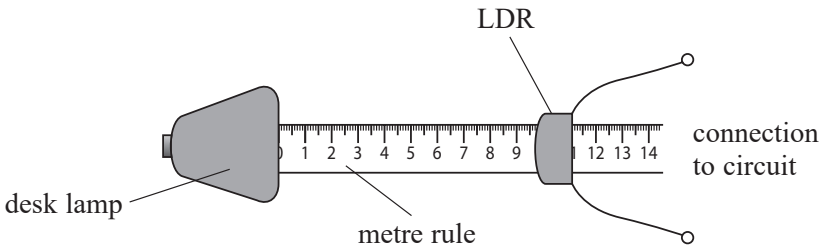
(2)

(Total for Question 13 = 8 marks)

9 A student carried out an experiment with a light dependent resistor (LDR). He connected the LDR in series with an ammeter and a power supply, as shown in the circuit diagram.



The student placed the LDR a known distance from a desk lamp, as shown.



The student noted the reading on the ammeter as he brought the LDR closer to the lamp.

(a) The student planned to vary the intensity of light incident upon the LDR by adjusting the distance x between the LDR and the lamp.

He thought that the intensity of light on the LDR would increase uniformly if he decreased x by equal intervals. He therefore planned to take ammeter readings as he decreased x from 20.0 cm to 10.0 cm in equal intervals.

(i) Criticise the student's plan for data collection.

(3)

(ii) Explain one precaution that the student should take to ensure that results are accurate.

(2)

(b) Explain why the ammeter reading increased as the LDR was brought closer to the lamp. Your answer should include reference to the charge carriers in the LDR.

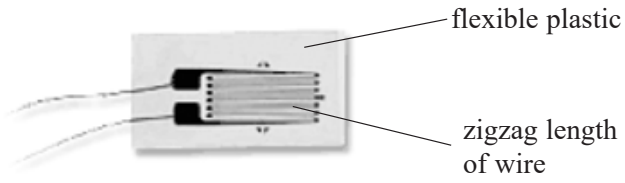
(3)

(Total for Question 9 = 8 marks)

16 A medical scanner uses a moving table to position the patient. Strain gauges are used to monitor the shape of the table which enables a more precise positioning of the patient.



Strain gauges consist of a thin length of wire attached, in a zigzag pattern, to a small flexible piece of plastic. The strain gauge is attached to the table. When the table is subjected to forces, the dimensions of the plastic change. This causes a change in the length of the wire and hence a change in the resistance of the wire.

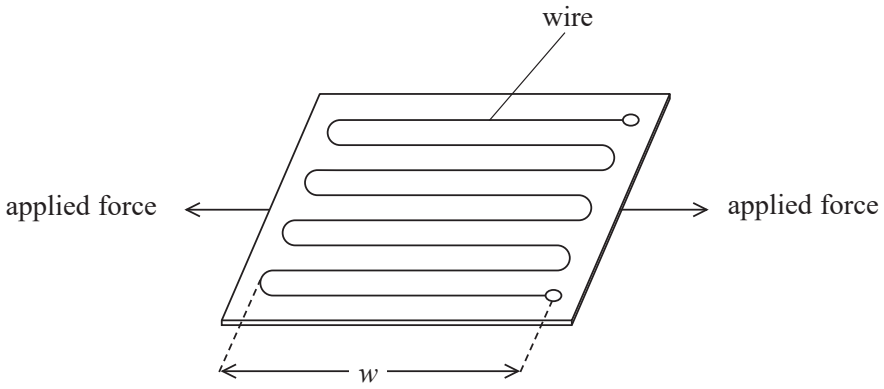


(a) Resistance can be measured directly using an ohmmeter or indirectly using measurements from a voltmeter and ammeter.

Describe **two** benefits of using an ohmmeter compared to using a voltmeter and an ammeter.

(2)

(b) The diagram shows forces applied to a strain gauge. The 'width' of the strain gauge is defined by the distance *w*.



(i) State and justify how the applied forces change the resistance of the wire.

(2)

(ii) The gauge factor GF of a strain gauge is given by

$$GF = \frac{\Delta R}{\varepsilon R}$$

where ε is the strain
R is the initial resistance
ΔR is the change in resistance

When forces are applied to the strain gauge, the resistance of the gauge changes by 0.10%.

Calculate the change in the width of the strain gauge.

$w = 5.0$ cm
$GF = 2.0$

(3)

Change in width = ...

(c) Explain the benefit of arranging the wire in a zigzag pattern.

(2)

(Total for Question 16 = 9 marks)

11 A "metre bridge" is a circuit which can be used to measure an unknown resistance accurately. The metre bridge includes a metre length of nichrome wire.

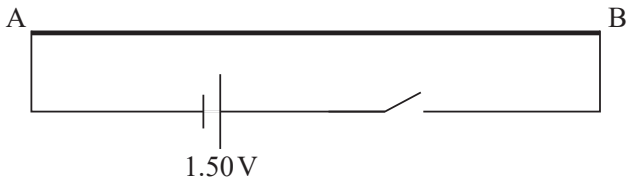
(a) Calculate the resistance of a 1.00 m length of the nichrome wire.

(3)

resistivity of nichrome = 1.12×10^{-6} Ωm
diameter of wire = 4.00×10^{-4} m

Resistance = ...

(b) This metre length of wire, labelled AB, is connected to a 1.50 V cell of negligible internal resistance and a switch as shown.



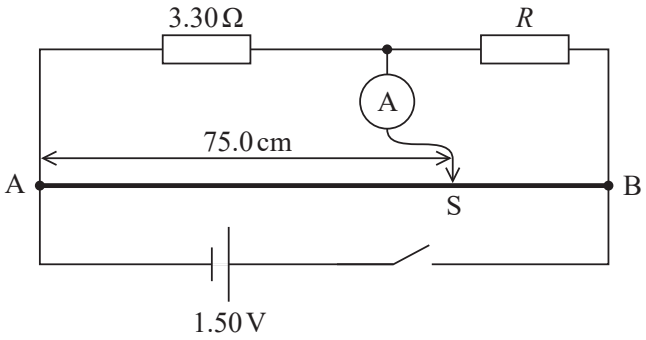
(i) Explain how the potential along this wire varies with distance from A when the switch is closed.

(2)

(ii) Show that the potential difference between A and a point 75.0 cm along the wire from A is about 1.1 V.

(2)

(c) The metre bridge circuit is shown. The circuit includes a resistor of resistance 3.30 Ω, a very sensitive ammeter and a resistor of unknown resistance *R*.



A metal slider S can be moved along the nichrome wire and pressed firmly against it to make an electrical connection.

When the switch is closed and S is 75.0 cm along the nichrome wire, the ammeter reads 0 A because the potential difference across the ammeter is zero.

Calculate *R*.

(2)

R = ...

(Total for Question 11 = 9 marks)

17 A photographer uses a light meter to measure the intensity of light entering a camera. A simple light meter consists of a light dependent resistor (LDR) connected in a circuit.

(a) The resistance of an LDR depends on the intensity of light incident on the LDR.

Explain how the change in resistance may be modelled in terms of conduction electrons.

(4)

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(b) The light meter records an intensity of $1100\,W\,m^{-2}$. The LDR in the light meter has a surface area of $4.0 \times 10^{-5}\,m^2$.

Calculate the energy that is transferred to the LDR every 60 seconds.

(2)

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.....

.....

Energy = ...

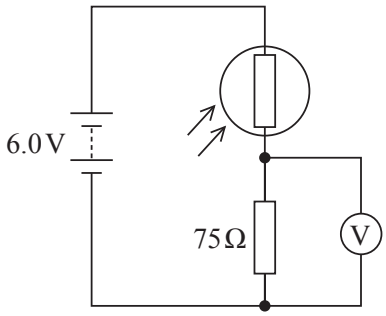
(c) The light incident on the camera lens is unpolarised. The photographer places a polarising filter in front of the camera lens.

Explain how the polarising filter affects the intensity of light incident on the camera lens.

(4)

(Total for Question 17 = 10 marks)

12 A student set up a circuit containing a light dependent resistor (LDR) in series with a fixed resistor as shown.



(a) As the student moved a lamp towards the circuit she observed the potential difference (p.d.) changing across the fixed resistor.

With reference to the electrons in the LDR explain this observation.

(5)

(b) When the lamp was at a distance of 10 cm from the LDR, the reading on the voltmeter was 2.4 V.

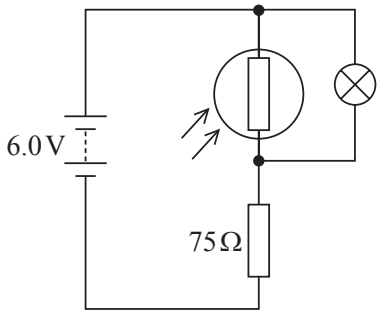
Calculate the resistance of the LDR at this distance.

(3)

Resistance of the LDR = ...

(c) The student wants to modify the circuit so that a light bulb lights up when the room goes dark.

She modifies the circuit as shown below. When working normally the resistance of the light bulb is 3 Ω and the p.d. across it is 3 V.



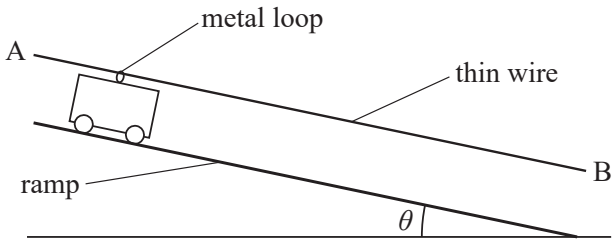
Explain, without further calculation, whether this circuit would work as intended.

(3)

(Total for Question 12 = 11 marks)

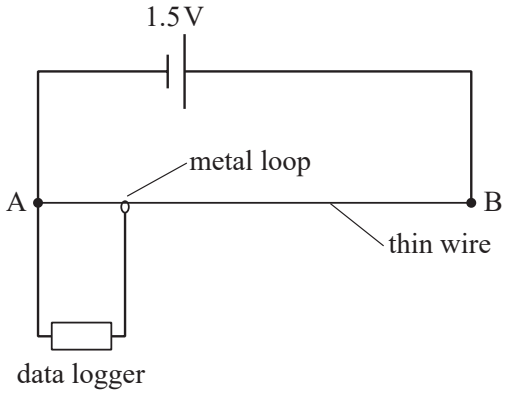
17 A student investigates the motion of a friction-free trolley down a ramp. On the top of the trolley there is a metal loop which makes contact with a length of thin resistance wire, AB, fixed above the ramp. The resistance wire has a uniform diameter.

The trolley accelerates down the ramp and the metal loop stays in contact with the wire along the full length of the ramp.



The student uses a protractor to measure the angle θ between the ramp and the horizontal and records a value of 4° with an uncertainty of ±1°.

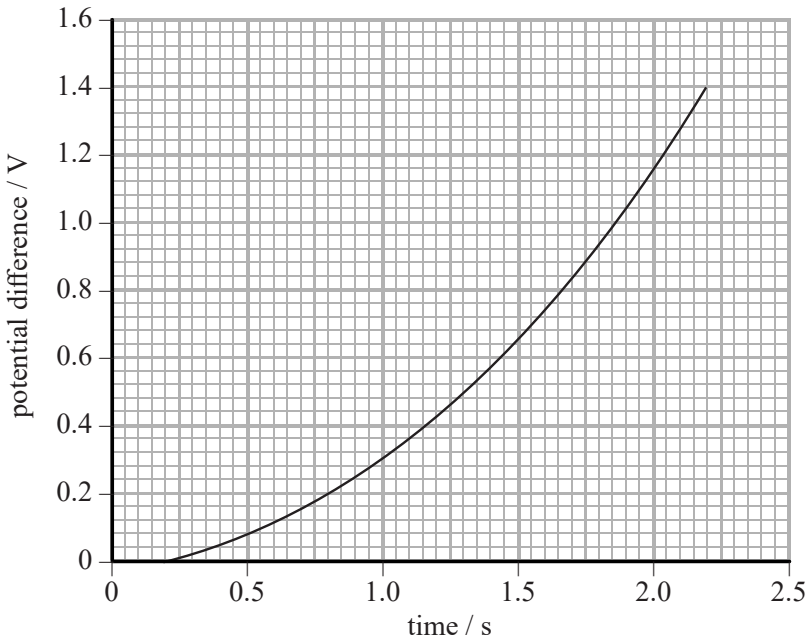
(a) The two ends of the wire are connected to a 1.5 V cell. A data logger, set to measure potential difference, is connected to the metal loop and to the negative terminal of the cell.



Explain how the potential difference recorded by the data logger will vary as the loop moves along the length of the wire AB.

(3)

(b) The graph shows the data obtained from the data logger.



Determine the velocity of the trolley at 1.5 s.

1.5 V represents a distance of 2.00 m.

(4)

Velocity = ...

(c) The student calculated the velocity of the trolley at 2.0 s to be 1.5 m s^{-1}.

By considering the acceleration of the trolley, determine whether the student's measurement of θ was within the uncertainty quoted.

(4)

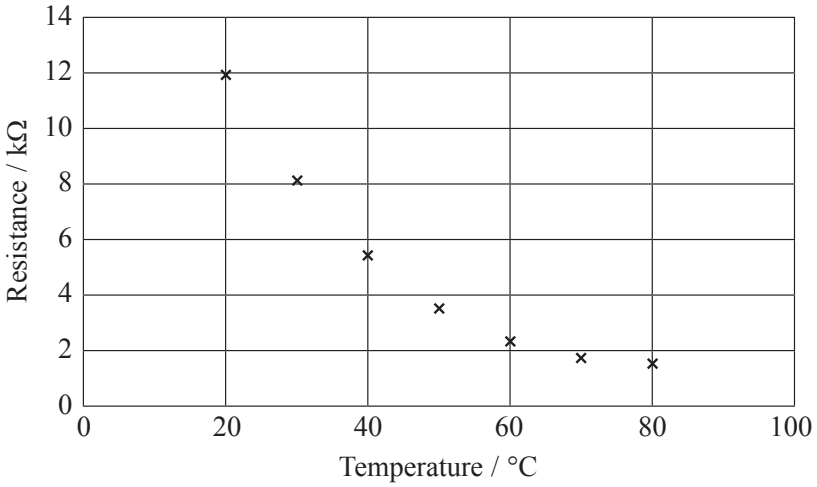
(Total for Question 17 = 11 marks)

12 A student wants to investigate how the resistance R of a negative temperature coefficient thermistor varies with its temperature T.

(a) Write a set of instructions that the student could follow and include one safety precaution.

(6)

(b) The following graph was plotted from the results of another student's experiment for the same topic.



Give two modifications to the experimental procedure that could improve these results.

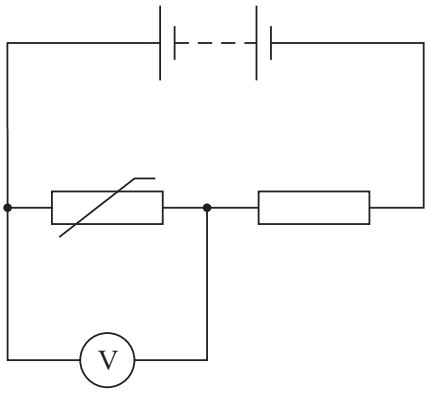
(2)

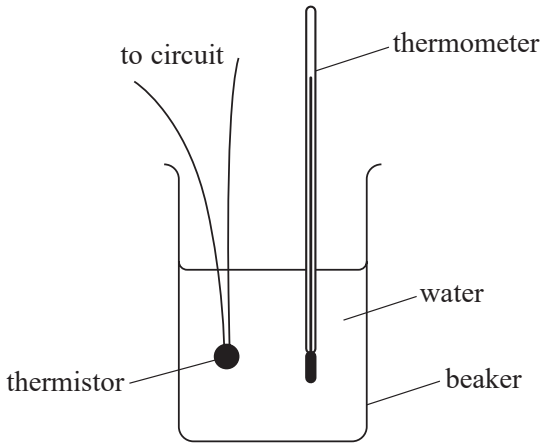
(c) Explain, in terms of particle behaviour, why the resistance of the thermistor decreases as temperature increases.

(4)

(Total for Question 12 = 12 marks)

11 A student carried out an experiment to calibrate a thermistor. She connected the thermistor in series with a resistor and a power supply as shown. Then she placed the thermistor in a beaker of hot water and used a thermometer to record the temperature θ of the water.





The student recorded θ and corresponding values of the reading V on the voltmeter as the water cooled.

(a) Explain, making reference to charge carriers, why V increased as the water cooled.

(3)

(b) Over a limited temperature range V varies with θ according to the expression

$$V = V_0 e^{-b\theta}$$

where b and V_0 are constants.

(i) Explain why a graph of $\ln V$ against θ would give a straight line.

(2)

(ii) The student's data is shown in the table below.

θ/°C	V/V	
89.0	1.9	
74.0	2.9	
53.5	4.9	
32.5	9.1	
18.5	12.6	
3.5	18.7	

Plot a graph of $\ln V$ against θ on the grid opposite. Use the column provided to show any processed data.

(5)

(iii) Determine values for b and V_0.

(4)

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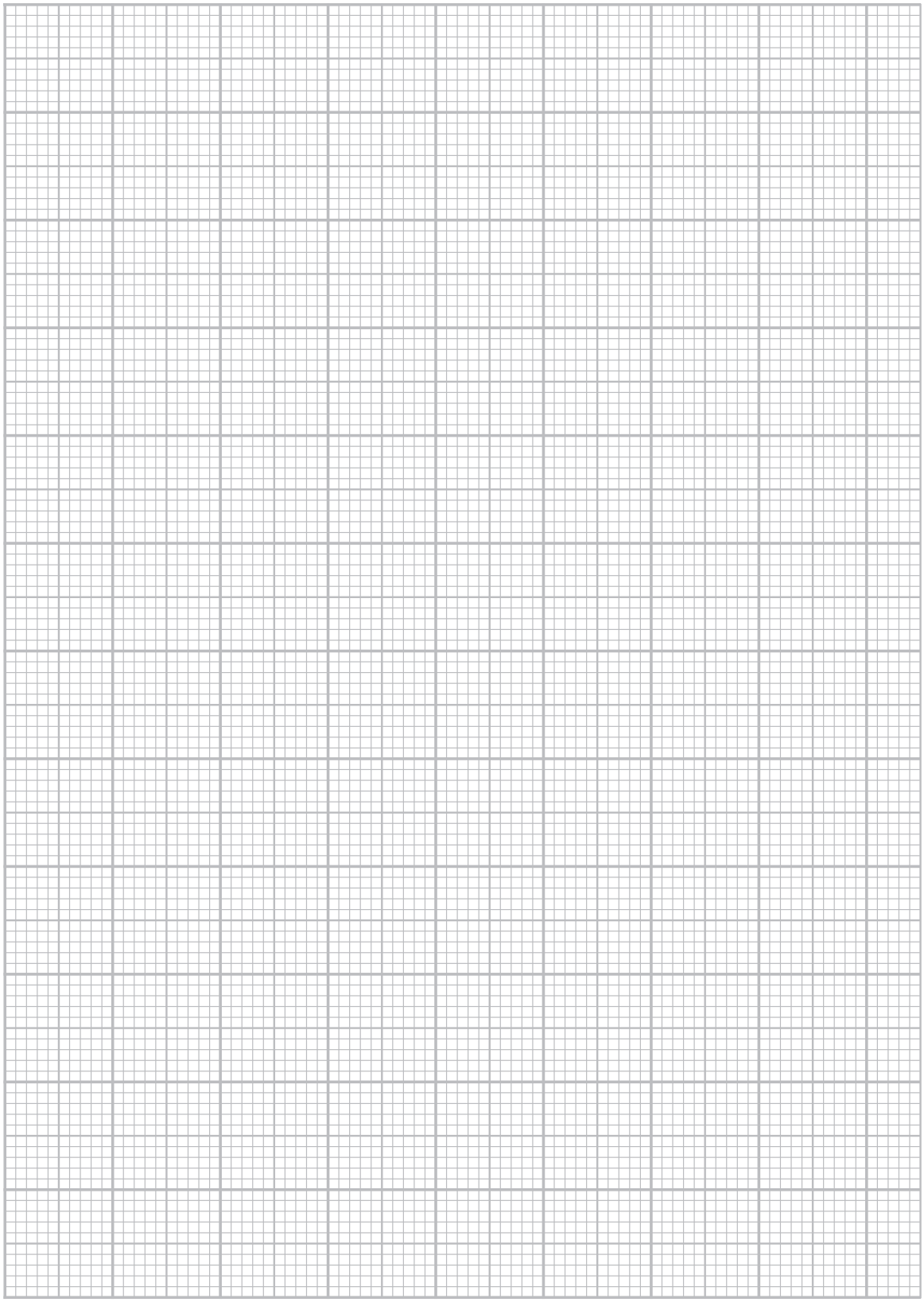
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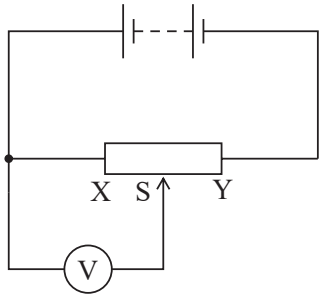
b = ...

V_0 = ...



(Total for Question 11 = 14 marks)

11 A student connected a voltmeter to a potential divider, as shown in the circuit diagram.



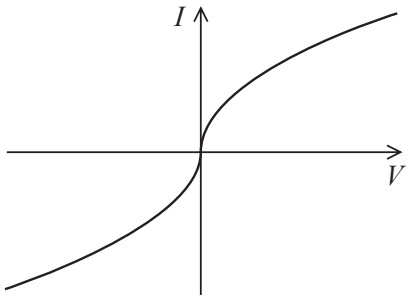
(a) The potential divider was adjusted by moving sliding contact S from position X to position Y.

Explain how the voltmeter reading V depends upon the position of S.

(3)

(b) A filament bulb and ammeter were connected to the potential divider. The potential divider was used to vary V across the filament bulb. The ammeter gave the corresponding current I in the filament.

I varied with V, as shown in the graph below.



Explain the shape of the graph.

(2)

(c) The temperature T of the filament varies with the potential difference V across the filament according to the expression

$$T = aV^b$$

where a and b are constants.

(i) Explain why a graph of $\log T$ against $\log V$ would give a straight line.

(2)

.....

.....

.....

.....

(ii) Data for T and V is shown in the table below.

T / K	V / V		
1480	5.03		
1680	6.89		
1850	8.95		
2010	11.11		
2140	12.94		
2280	15.06		

Plot a graph of $\log T$ against $\log V$ on the grid opposite. Use the extra columns provided to show any processed data.

(5)

(iii) Determine a value for b using your graph.

(2)

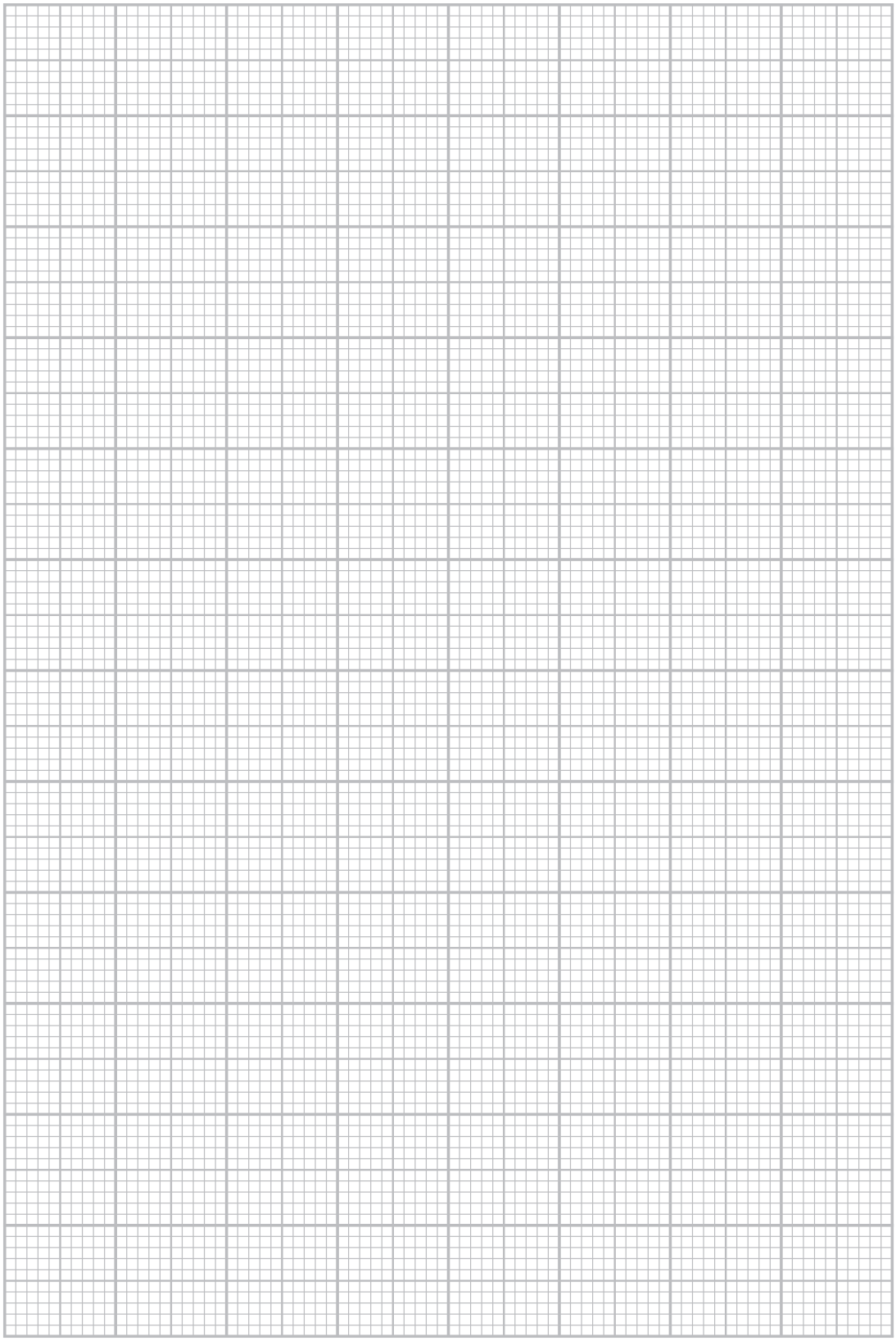
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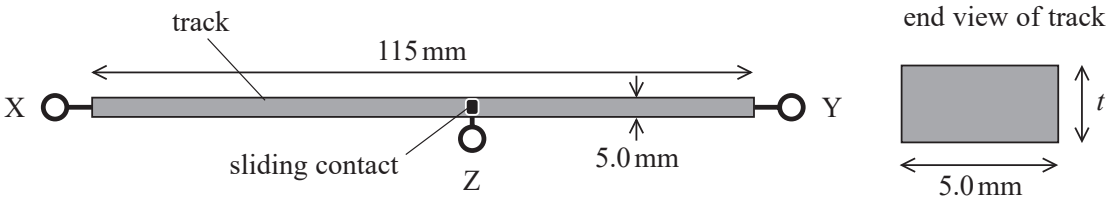
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b = ...



(Total for Question 11 = 14 marks)

18 A potential divider circuit may contain a component known as a potentiometer. One type of potentiometer consists of a track with terminals X and Y at either end. There is a sliding contact that can move along the track connected to a terminal Z as shown.



The length of the track is 115 mm and the width is 5.0 mm.

(a) The resistance of the track between terminal X and terminal Y is 12.0 kΩ.

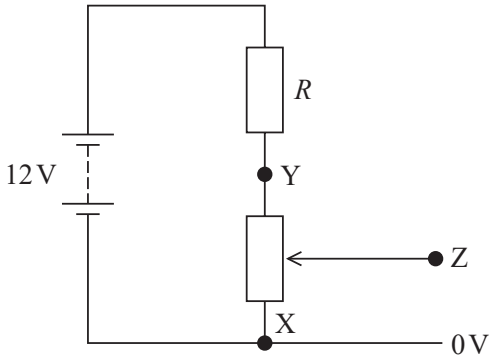
Calculate the thickness t of the track.

resistivity of track material = 0.49 Ω m

(3)

t = ...

(b) The potentiometer is used to monitor the displacement of a moving tool on a machine in a production line. The tool is attached to the sliding contact. The potentiometer is connected to a resistor of resistance R and a potential difference is applied as shown. The tool moves through a maximum displacement of 60 mm from end X, producing a maximum potential difference of 5.0 V between Z and X.



(i) Show that the potential difference between X and Y is about 10 V.

(2)

(ii) Calculate the value of R.

(3)

R = ...

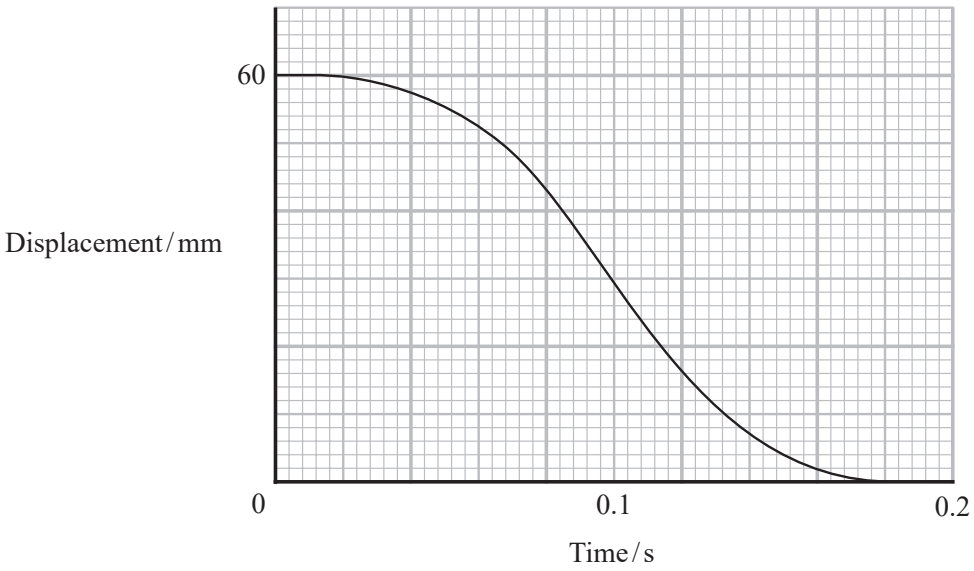
(iii) When the circuit is assembled, using the correctly calculated resistance value and a battery of e.m.f. 12 V, it is found that the maximum output from the potentiometer is slightly less than 5.0 V.

Explain why the maximum output is slightly less than predicted.

(3)

(iv) The tool on the machine should not travel with a speed any larger than $0.8\,m\,s^{-1}$.

The graph shows how the displacement varies with time for the downward stroke of the moving tool.



Deduce whether this speed is exceeded by the moving tool.

(4)

(Total for Question 18 = 15 marks)

SUB-TOPIC 3.6

EMF AND INTERNAL RESISTANCE

Sub-topic 3.6 · 17 questions · 67 marks · lowest tariff first

4 Which of the following correctly defines electromotive force?

- ☒ **A** Force per unit charge to move a charge across a component.
- ☒ **B** Force per unit charge to move a charge around a circuit.
- ☒ **C** Work done per unit charge to move a charge across a component.
- ☒ **D** Work done per unit charge to move a charge around a circuit.

(Total for Question 4 = 1 mark)

2 A cell is connected across a resistor. After a while the internal resistance of the cell increases.

Which row of the table correctly shows the change in the current in the circuit and the change in the terminal potential difference across the cell?

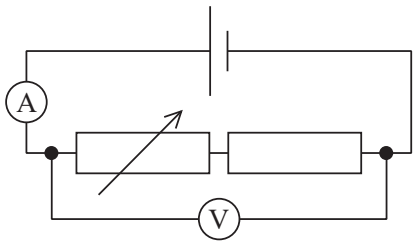
	Current	Terminal potential difference
☒ **A**	decreases	decreases
☒ **B**	decreases	increases
☒ **C**	increases	decreases
☒ **D**	increases	increases

(Total for Question 2 = 1 mark)

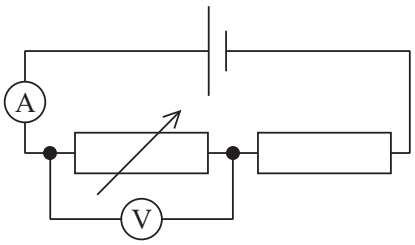
7 A student carried out an experiment to determine the electromotive force (e.m.f.) of a cell. The current in a circuit was changed by adjusting a variable resistor. A graph was plotted of the voltmeter reading on the *y*-axis against the ammeter reading on the *x*-axis.

Using the data obtained, the value of the intercept on the *y*-axis was the e.m.f. of the cell.

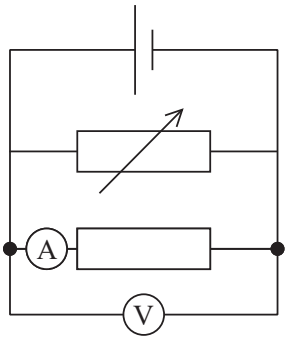
Which of the following circuits should have been used?



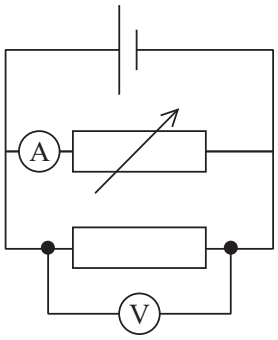
A



B



C

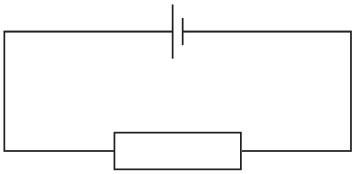


D

- ☒ **A**
- ☒ **B**
- ☒ **C**
- ☒ **D**

(Total for Question 7 = 1 mark)

5 A cell of e.m.f. 1.5 V is connected to a 5.0 Ω resistor. The terminal potential difference across the cell is 1.0 V.

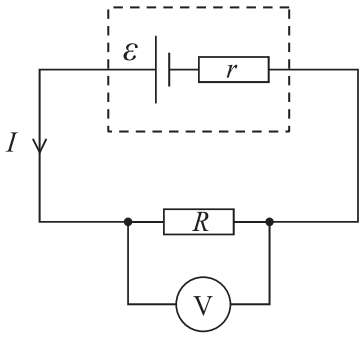


Which of the following is the current in the circuit?

- ☒ **A** 0.1 A
- ☒ **B** 0.2 A
- ☒ **C** 0.3 A
- ☒ **D** 0.5 A

(Total for Question 5 = 1 mark)

1 A cell of e.m.f ε and internal resistance r is connected across a fixed resistor of resistance R. There is a current I in the circuit and a potential difference V across the fixed resistor.



The term 'lost volts' refers to the difference between the e.m.f. and the terminal potential difference.

Which of the following is an expression for the lost volts?

☒ **A** $I\,(R + r)$

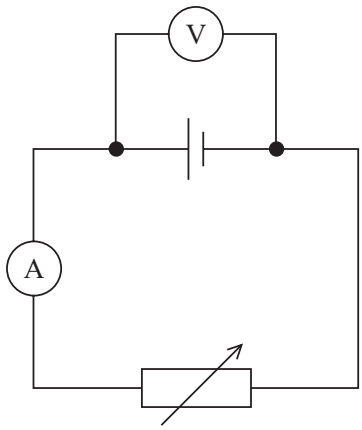
☒ **B** Ir

☒ **C** IR

☒ **D** $I(R - r)$

(Total for Question 1 = 1 mark)

5 A variable resistor is connected in a circuit as shown. The cell has internal resistance.



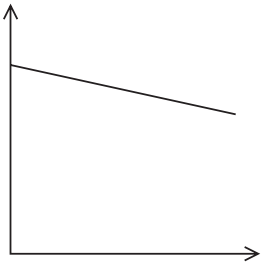
The resistance of the variable resistor is increased.

Which row of the table is correct?

		Ammeter reading	Voltmeter reading
☒	**A**	increases	increases
☒	**B**	increases	decreases
☒	**C**	decreases	increases
☒	**D**	decreases	decreases

(Total for Question 5 = 1 mark)

7 A student investigated the e.m.f. and internal resistance of a battery. The student produced the following sketch graph.

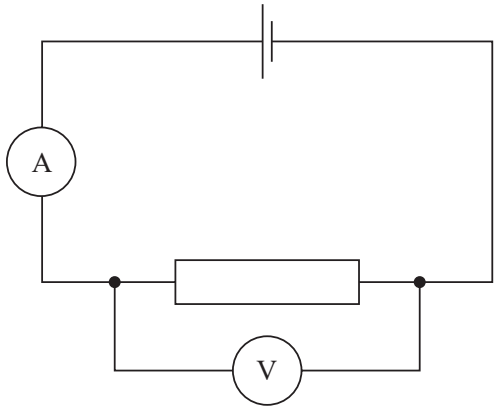


Which row of the table gives the quantities plotted?

		y-axis	*x*-axis
☒	**A**	e.m.f.	circuit resistance
☒	**B**	e.m.f.	current
☒	**C**	terminal potential difference	circuit resistance
☒	**D**	terminal potential difference	current

(Total for Question 7 = 1 mark)

4 The circuit shown contains a cell with internal resistance.



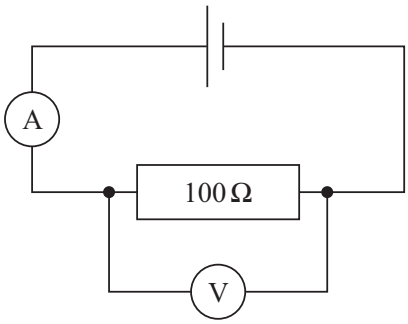
The cell is replaced with another cell, with the same e.m.f. but greater internal resistance.

Which row of the table shows what happens to the ammeter reading and voltmeter reading?

	Ammeter reading	Voltmeter reading
☒ **A**	increases	increases
☒ **B**	increases	decreases
☒ **C**	decreases	increases
☒ **D**	decreases	decreases

(Total for Question 4 = 1 mark)

4 A circuit consists of a cell of e.m.f. 1.50 V connected to a 100 Ω resistor. A voltmeter is connected across the 100 Ω resistor, as shown. The voltmeter reading is 1.45 V.



Which of the following gives the internal resistance, in Ω, of the cell?

☒ **A** $\frac{(1.50 - 1.45) \times 100}{1.45}$

☒ **B** $\frac{1.50 \times 100}{1.45}$

☒ **C** $\frac{(1.50 - 1.45) \times 100}{1.50}$

☒ **D** $\frac{1.45 \times 100}{1.50}$

(Total for Question 4 = 1 mark)

11 A student modelled the behaviour of a circuit containing a cell of emf 1.5 V with internal resistance 3.0 Ω, using a spreadsheet. In this model the cell is connected across a resistor. The student used the model to investigate how the power P dissipated by the resistor varies with its resistance R.

	A	B	C
1	R / Ω	Current / A	P / W
2	0.5	0.43	0.09
3	1.0	0.38	0.14
4	1.5	0.33	0.17
5	2.0	0.30	0.18
6	2.5	0.27	0.19
7	3.0	0.25	0.19
8	3.5	0.23	0.19
9	4.0	0.21	0.18
10	4.5	0.20	0.18

(a) Show how the value in B2 is calculated.

(1)

(b) Show how the value in C5 is calculated.

(1)

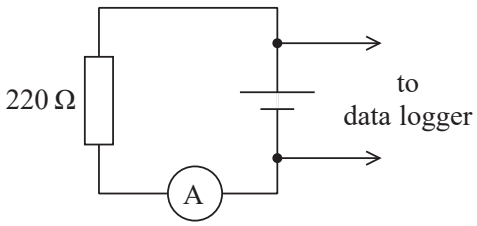
(c) The student concluded that the power dissipated by the resistor is a maximum when R is between 2.5 Ω and 3.5 Ω.

Explain how this spreadsheet could be improved so that this maximum can be located more precisely.

(2)

(Total for Question 11 = 4 marks)

2 A student is investigating how the internal resistance of a dry cell varies over time.
She sets up the circuit shown to draw current from the cell.



The student proposes to use a data logger to monitor the terminal potential difference (p.d.) of the cell over a period of time.

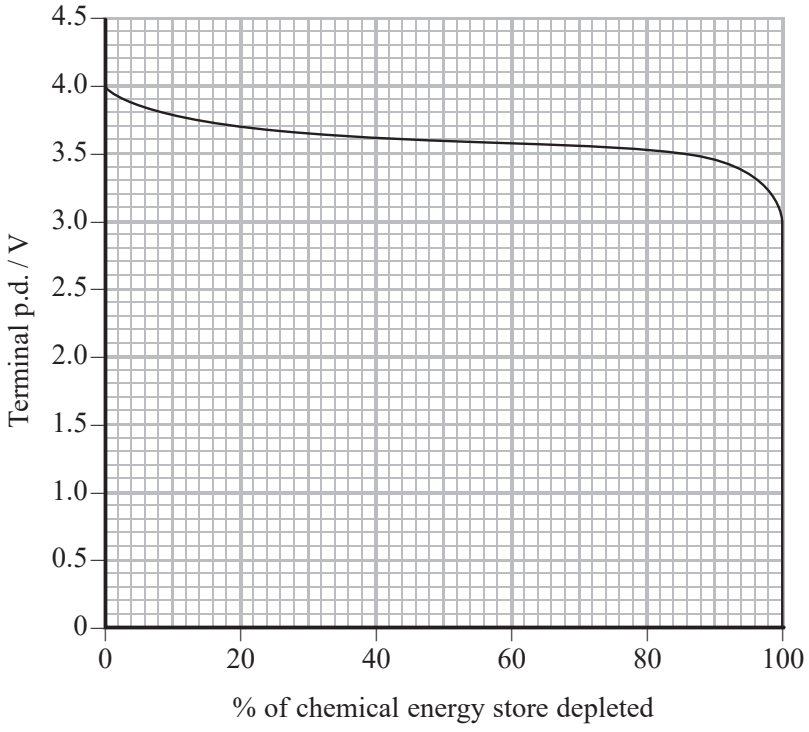
(a) State why a data logger would be suitable to collect data in this investigation.

(1)

.....

.....

(b) The graph shows how the terminal p.d. varies as the chemical energy store in the cell is depleted.



(i) Explain, using the graph, why the current drawn from the cell decreases as the chemical energy store in the cell is depleted.

(2)

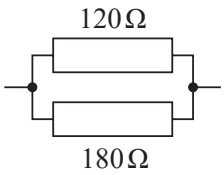
(ii) Determine the internal resistance of the cell when its chemical energy store is 80% depleted. Assume that the e.m.f. of the cell remains constant at 4.0 V.

(3)

Internal resistance = ...

(Total for Question 2 = 6 marks)

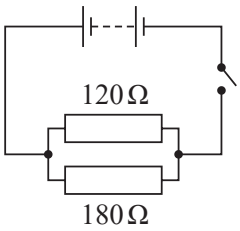
10 Two resistors are connected as shown.



(a) Show that the resistance of the combination is about 70 Ω.

(2)

(b) This resistor combination is connected to a battery of e.m.f. ε and internal resistance r.



The switch is closed for 5 minutes.

Calculate the energy dissipated in the resistor combination.

$\varepsilon = 9.0\,\text{V}$
$r = 2.5\,\Omega$

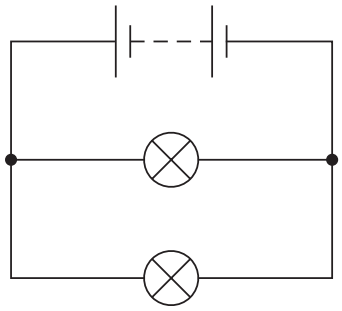
(4)

Energy dissipated in resistor combination = ...

(Total for Question 10 = 6 marks)

***14** A student connects a filament bulb to a battery. The battery has internal resistance.

The student connects an identical bulb in parallel with the first bulb, as shown.



He continues to connect identical bulbs in parallel.

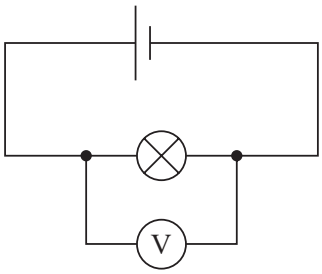
The student observes that the bulbs get dimmer as more bulbs are connected. He also observes that the temperature of the battery increases.

Explain these observations.

(Total for Question 14 = 6 marks)

9 A torch uses a 1.5 V dry cell. Over time, the light intensity produced by the torch decreases as the cell 'goes flat'.

(a) Student A sets up the following circuit in an attempt to measure the e.m.f. of a cell.



Explain why the voltmeter reading will **not** be the e.m.f. of the cell.

(2)

.....

.....

.....

.....

(b) Student B correctly determined the e.m.f. of an unused cell as 1.63 V and its internal resistance as 1.15 Ω.

He repeated this after the cell had been used for several weeks. When a voltmeter was connected directly across the used cell, the reading was 1.36 V.
A bulb of resistance 5.92 Ω was then connected across the used cell and the reading fell to 0.84 V.

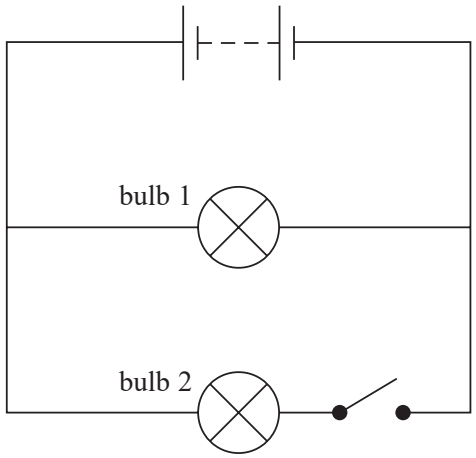
Student A suggests that the cell goes flat as it is used because the e.m.f. decreases.
Student B suggests it is because the internal resistance increases.

Determine whether either student is correct about the changes in the cell as it goes flat.

(5)

(Total for Question 9 = 7 marks)

2 A battery has an e.m.f. of 12 V and an internal resistance of 0.50 Ω. The battery is connected into a circuit, as shown.



Each bulb has a normal working power of 40 W when a potential difference (p.d.) of 12 V is applied.

(a) Initially the switch is open.

Calculate the terminal p.d. of the battery when bulb 1 is lit. Assume that the resistance of the bulb has its normal working value.

(4)

Terminal p.d. of battery = ...

(b) Explain how the brightness of bulb 1 changes when the switch is closed. No further calculations are necessary.

(3)

.....

.....

.....

.....

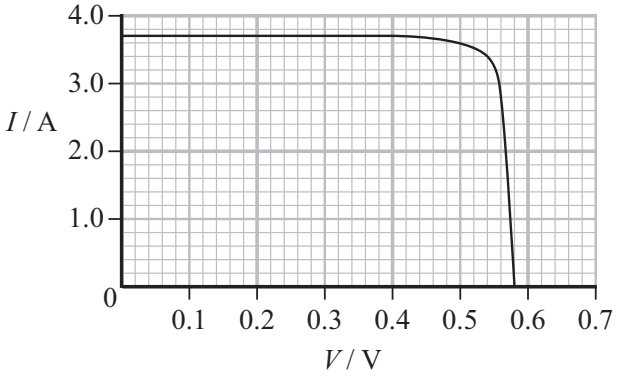
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.....

(Total for Question 2 = 7 marks)

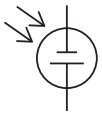
13 Solar cells are being used in increasing numbers around the world.

The current I from a solar cell can be varied by connecting it to a variable resistor.
The graph shows how I and the terminal potential difference V across a solar cell vary.



(a) Complete the circuit diagram below to show how the data for the graph could be obtained.

(2)



(b) (i) Show that the maximum power output from the solar cell is about 2 W. You should use values from the graph.

(2)

.....

.....

.....

.....

(ii) The area of the solar cell is 104 cm^2.

Determine the efficiency of the solar cell when operating at maximum power.

intensity of sunlight = 1000 $W\,m^{-2}$

(3)

Efficiency = ...

(iii) Calculate the internal resistance of the solar cell when operating at maximum power.

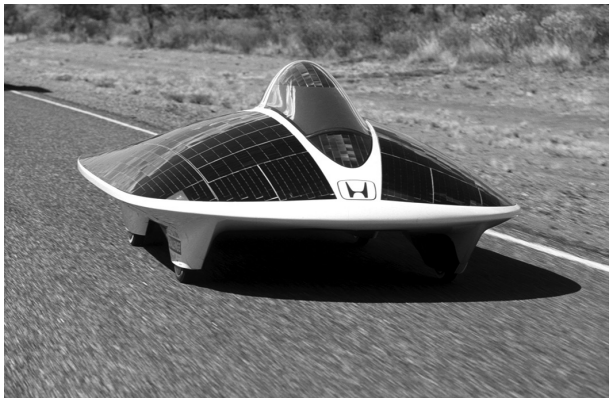
(3)

Internal resistance = ...

(Total for Question 13 = 10 marks)

14 The world solar challenge is set every two years, in Australia. The challenge is to complete a three thousand kilometre route with a vehicle powered only by the Sun.

Vehicles have their surfaces fitted with solar panels, as shown in the photograph.



(Source: © LAURENT DOUEK/LOOK AT SCIENCES/SCIENCE PHOTO LIBRARY)

(a) One of the solar panels has an e.m.f. of 8.2 V when in sunlight. The terminal potential difference is 5.5 V when a current of 0.45 A is drawn from the solar panel.

Calculate the internal resistance of the solar panel in these conditions.

(3)

Internal resistance = ...

(b) A bank of 380 of these solar panels is used to charge the battery in a vehicle. The panels are connected in parallel and the current provided by each panel is 0.45 A. When fully charged, the energy stored in the battery is 12 kW h.

Calculate the time, in hours, to fully charge this battery if the solar panels are in sunlight. Assume the efficiency of charging this battery is 100%.

(3)

Time = ... hours

(c) The vehicle can reach a maximum speed of 34 m s^{-1} on flat ground. The electric motor used to move the vehicle has a power of 4.5 kW.

(i) Calculate the initial acceleration of the vehicle as it starts from rest.

mass of vehicle and driver = 420 kg

(3)

Initial acceleration = ...

(ii) State one assumption made in this calculation.

(1)

(d) Solar power alone would not be suitable for a family car because it is not sunny all the time.

Give two further reasons why solar power alone would not be suitable.

(2)

(Total for Question 14 = 12 marks)

MARK SCHEMES

official mark schemes

Question Number	Answer	Mark
4	**D 1080 C**	**1**
	Incorrect Answers: A – current divided by time, with the time in seconds B – current divided by time, with the time in minutes C – correct formula of current × time but the time is in minutes and not seconds	

Question Number	Answer	Mark
3	**A amplitude of the vibrations of the lattice ions**	**1**
	Incorrect Answers: B – the distance travelled by charge carriers between collisions will **decrease** if the temperature increases C – the drift velocity of conduction electrons will **decrease** if the temperature increases D – the number of conduction electrons per unit volume will **remain constant** if the temperature increases	

Question Number	Acceptable answers	Additional guidance	Mark
4	C		1

Question Number	Answer	Additional Guidance	Mark
2	**B is the only correct answer**	A is incorrect because amplitude does increase C is incorrect because rate of collision does increase D is incorrect because rate of energy transfer does increase	1

Question Number	Answer	Additional Guidance	Mark
5	**D is the only correct answer**	A is incorrect because the time has not been converted to seconds B is incorrect because $Q = It$ and time has not been converted to seconds C is incorrect because $Q = It$	1

Question Number	Answer	Mark
4	**C** $v \propto \frac{1}{R}$	**1**
	A – this answer is incorrect B – this answer is incorrect D – this answer is incorrect	

Question Number	Acceptable answers	Additional guidance	Mark
1	**The only correct answer is A** B is not the correct answer, as C is not a base unit. C is not the correct answer, as J and V are not base units. D is not the correct answer, as Q is not a unit.		1

Question Number	Acceptable answers	Additional guidance	Mark
7	**The only correct answer is C** A is not the correct answer, as I, n and e all constant. B is not the correct answer, as I, n and e all constant. D is not the correct answer, as I, n and e all constant.		**1**

Question Number	Answer	Mark
5	**The only correct answer is C** $\frac{V}{RnAe}$ **this comes from the rearrangement of** $I = nqvA$**, and substitution for** I **using** $R = \frac{V}{I}$ **A** *is not correct because this answer is rearranged incorrectly* **B** *is not correct because this answer is rearranged incorrectly* **D** *is not correct because this answer is rearranged incorrectly*	**1**

7	**C – current is the same, drift velocity is higher**	**1**
	Incorrect Answers: A – current is constant B – current is constant D – as cross-sectional area decreases, drift velocity increases as current is constant	

Question Number	Acceptable answers	Additional guidance	Mark
14(a)	Direction out of page (1)	The arrow needs to be parallel to the length of the pipe by eye.	**1**
14(b)(i)	• Use of $R=\rho l/A$ (1) • Using $A=0.5\times28$ ($\times10^{-6}$ m^2) (1) • Use of $V=IR$ (1) • I = 22 (mA) (1)	Example of calculation $R=\frac{1.6\Omega\text{m}\times0.6\times10^{-3}\text{m}}{0.5\times10^{-3}\text{m}\times28\times10^{-3}\text{m}}$ $R=68.6\Omega$ $1.5V=I\times68.6\Omega$ $I=1.5\text{V}/68.6\Omega$ $I=0.022\text{A}=22\text{mA}$	**4**
14(b)(ii)	• Use of $F=BIL$ ecf values from (b)(i) (1) • Force = 5.3×10^{-6} N (1)	Use of show that values gives 4.8×10^{-6} N Example of calculation $F=0.40\text{T}\times0.022\text{A}\times0.6\times10^{-3}\text{m}$ $F=5.3\times10^{-6}\text{N}$	**2**

(Total for Question 14 = 7 marks)

Question Number	Acceptable answers	Additional guidance	Mark
12(a)	• A vector has magnitude and direction **(1)**		1
12(b)	An explanation that makes reference to the following points: • States $I = nqvA$ **Or** n and q stated as constant **Or** $v \propto \frac{1}{A}$ **(1)** • v must increase (if A decreases) MP2 dependent on MP1 **(1)**		2
12(c)	**Either** • j has units A m^{-2} **(1)** • E has units V m^{-1} or N C^{-1} **(1)** • ρ has units of Ω m **(1)** • Algebra to show units the same on both sides **(1)** **Or** If formulas have been used: **(1)** • Substitution using $\rho = RA/l$ **(1)** • Substitution using $E = V/d$ **(1)** • Substitution using $R = V/I$ • The equations above and $j = I/A$ need to be rearranged and simplified with Ω (or R) appearing on either side **(1)**	Example: Units of $\frac{E}{j} = \frac{\text{Vm}^{-1}}{\text{Am}^{-2}}$ = Ωm and these are the units of ρ **Or** find agreements for both sides using options shown below: Units of $\frac{E}{J}$ are $\frac{\text{N C}^{-1}}{\text{Am}^{-2}} = \frac{\text{Nm}^2}{\text{AC}} = \frac{\text{Jm}}{\text{AC}} = \frac{\text{kgms}^{-2}\,\text{m}^2}{\text{A}^2\text{s}} = \frac{\text{kgm}^3\text{s}^{-3}}{\text{A}^2}$ Units of $\rho = \Omega\text{m} = \frac{\text{V}}{\text{A}}\text{m} = \frac{\text{Nm}^2}{\text{CA}} = \frac{\text{Jm}}{\text{CA}}$ $= \frac{\text{kgms}^{-2}\text{m}^2}{\text{A}^2\text{s}} = \frac{\text{kgm}^3\text{s}^{-3}}{\text{A}^2}$	4

(Total for Question 12 = 7 marks)

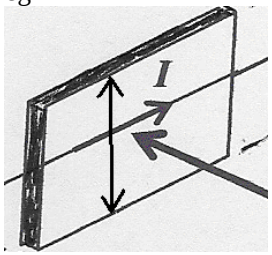
Question Number	Acceptable Answer	Additional Guidance	Mark
5(a)	• Use a micrometer screw gauge **(1)** • Check (and correct) for zero error **Or** Use the ratchet on the micrometer **(1)** • Measure diameter at different positions along wire and calculate a mean **Or** Measure diameter at different orientations and calculate a mean **(1)** • Calculate cross sectional area using $\frac{\pi d^2}{4}$ **Or** Calculate radius and then use πr^2 **(1)**	Allow digital calipers not vernier calipers	**4**
5(b)(i)	An explanation that makes reference to the following points: • Electrons collide with (lattice) ion and transfer energy **Or** Current in wire causes temperature of wire to increase **(1)** • So the amplitude of vibration (of the lattice ions) increases **(1)** • Electrons make more frequent collisions (with lattice ions), so the resistance increases **(1)**		**3**

5(b)(ii)	Max **TWO** from: • (For a black body radiator) Stefan(-Boltzmann) law applies **Or** (For a black body radiator) $L = \sigma AT^4$ **(1)** • The rate of energy transfer from the wire is determined by its surface area **(1)** • Increasing the length increases the surface area, so more energy is radiated away (and the temperature does not change) **(1)**		**2**

(Total for Question 5 = 9 marks)

Question Number	Acceptable answers		Additional guidance	Mark
15(a)(i)	• At least three straight horizontal parallel lines	**(1)**		**3**
	• Equispaced	**(1)**		
	• Arrow to indicate direction to the right	**(1)**		
15(a)(ii)	• As no current drawn from supply	**(1)**		**2**
	• Terminal potential difference is equal to e.m.f. **Or** no potential difference across internal resistance	**(1)**	Accept no "lost volts"	
15(b)(i)	• Use of $E = V / d$	**(1)**	Example of calculation 3×10^6 V m^{-1} = V / 0.002 m	**2**
	• V = 6000 V	**(1)**	V = 6000 V	
15(b)(ii)	• (A spark is) a current (drawn from the supply)	**(1)**		**3**
	• A potential difference is produced across the internal resistance of the supply	**(1)**	Accept "lost volts" are present/increases	
	• According to $V = E - Ir$ V decreases **Or** (the decrease in V) is large because the internal resistance is large	**(1)**	Accept reduces the terminal potential difference which is shown on the voltmeter	

(Total for Question 15 = 10 marks)

Question Number	Acceptable answers	Additional guidance	Mark
17(a)	• The current and magnetic field are perpendicular **(1)** • By (Flemings) left hand rule the force on the electrons is upwards **(1)**	alt. force results from current not parallel to a magnetic field	**(2)**
17(b)	• indication at top and bottom of conductor **(1)**	eg 	**(1)**
17(c)	• Equates $F=Bev$ and $F=eE$ **(1)** • Substitutes $E = V/d$ **(1)** **Or** $F = eV / d$ seen • Replaces v with I / neA **(1)** • Substitute $A = d \times t$ and leads to given equation **(1)** Alternative: • Equates $F = BIl$ and $F = QE$ with Q identified as total charge **(1)** • Substitutes $E = V/d$ **Or** $F = QV / d$ seen	Example of derivation: $Bev = eE$ $Bev = eV/d$ $\frac{BI}{neA} = \frac{V_H}{d}$ $V_H = \frac{BI}{net}$ Alternative: $BIl = QE$ Total charge $Q = neAl$ $BIl = neAlE$ $BI = neAV_H / d$ $V_H = BI / net$	**(4)**

	• Substitutes $Q = neAl$ and cancels l • Substitute $A = d \times t$ and leads to given equation		
17(d)	• Uses V = J/C **(1)** **Or** V = Nm/C **Or** V = Wb s^{-1} • Use of T = N/Cms^{-1} **(1)** **Or** T = N/Am **Or** T = Wb m^{-2} **Or** Sub of $B=F/IL$ and cancels I's • Uses units of n = m^{-3} and completes agreement **(1)** Alternative with base units: • Uses base unit of force = kg m s^{-2} **(1)** **Or** base unit of energy = kg m^2 s^{-2} • Uses base unit of charge = A s **Or** uses A = Cs^{-1} **(1)** **Or** Sub of $B=F/IL$ and cancel I's or A's • Uses base units of n = m^{-3} and completes agreement **(1)**	Example of unit simplification: J/C should equal $\frac{\text{N}}{\text{Am}} \times \text{A} \div \text{m}^{-3}\text{Cm}$ $= \frac{\text{Nm}}{C} = \frac{\text{J}}{\text{C}}$	**(3)**

17(e)	• Calculates a product *nt* for at least one sample • (Largest value of V_H) smallest value of *nt* which is silicon **Or** • Calculates 1/*nt* for at least one sample • (Largest value of V_H) largest value of 1/*nt* which is silicon	**(1)** **(1)** **(1)** **(1)**	Example of calculation of *nt*: Copper = $8.47 \times 10^{28} \times 110 \times 10^{-6} = 9.31 \times 10^{24}$ Germanium = $2.25 \times 10^{19} \times 1.10 \times 10^{-6} = 2.48 \times 10^{13}$ Silicon = $1.44 \times 10^{16} \times 120 \times 10^{-6} = 1.73 \times 10^{12}$ Example of calculation of 1/*nt*: Copper = 1.07×10^{-25} Germanium = 4.03×10^{-14} Silicon = 5.79×10^{-13}	**(2)**
17(f)	• Uses $\tan\theta = B_V \div B_H$ **Or** uses $\tan\theta = B_H \div B_V$ • Angle = 69°	**(1)** **(1)**	Example of calculation: $\tan\theta = 49/19$ $\theta = 68.8°$ Accept use of vector triangle as alternative to calculation	**(2)**

(Total for Question 17 = 14 marks)

Question Number	Acceptable answers	Additional guidance	Mark
1	C	joule per coulomb.	**1**
	Incorrect Answers: A is reciprocal of volt B is definition of amp D is definition of watt		

Question Number	Answer	Mark
6	**D** $\frac{mgh}{VIt}$ Incorrect Answers: A – this answer is incorrect B – this answer is incorrect C – this answer is incorrect	1

Question Number	Acceptable Answer	Additional Guidance	Mark
9	• Use of $P = VI$ **Or** use of $\triangle E_{grav} = mg\triangle h$ **(1)** • Use of efficiency = $\frac{\text{useful power output}}{\text{total power input}}$ **(1)** • Efficiency = 0.75 to 0.78 (or 75 % to 78%) **(1)**	Accept use of efficiency = $\frac{\text{useful energy output}}{\text{total energy input}}$ with corresponding times Example of calculation P_{motor} = (85×10^{-3}) A × 3.0 V = 0.255 W P_{block} = 0.05 kg × 9.81 N kg^{-1} × 0.40 m s^{-1} = 0.196 W Efficiency = $\frac{0.196\ \text{W}}{0.255\ \text{W}}$ = 0.77 (no unit)	**3**

(Total for Question 9 = 3 marks)

Question Number	Acceptable answers	Additional guidance	Mark
12	• Use of $P = VI$ **(1)** • Use of $A = \pi r^2$ **(1)** • Use of $R = \rho l/A$ **(1)** • Use of $P = I^2R$ **(1)** • Use of efficiency = power out/power in **(1)** • 100% and consistent conclusion **(1)** (MP6 dependent on fully correct method)	Accept for MP5 power loss/power in <u>Example of calculation</u> 1400×10^6 W = 1100×10^3 V × I I = 1273 A radius = 0.15 m /2 = 0.075 m $A = \pi(0.075)^2$= 0.0177 m^2 R = 1.7 ×10^{-8} Ω m ×720 000 m / π (0.075 m)^2 R = 0.693 Ω P_{lost} = (1273 A)^2 × 0.693 Ω = 1.12 MW Efficiency calculation (1400−1.12) MW / 1400 MW or 1.12 MW / 1400 W Efficiency = 99.9 % OR 1 – 0.0008 = 99.9 %	**6**

(Total for Question 12 = 6 marks)

Question Number	Acceptable answers	Additional guidance	Mark
14a(i)	• Frequency = 50 Hz **(1)**	Example of calculation $f = \frac{1}{0.02\ \text{s}} = 50\ \text{Hz}$	**1**
14a(ii)	• Root mean square potential difference = 2.8 V **(1)**	Example of calculation $V_{\text{rms}} = \frac{4}{\sqrt{2}} = 2.83\ \text{V}$	**1**
14b(i)	An answer which makes reference to: • Diode only lets current through in one direction **(1)** • (In positive half cycle of input) D2 and D4 conduct **Or** In positive half cycle of input D2 conducts **Or** (In negative half cycle of input) D3 and D1 conduct **(1)** **Or** negative half cycle D3 conducts • Current towards X **Or** down through *R* **Or** X to Y **(1)**		**3**
14b(ii)	• Read off corresponding values of *V* and *t* from graph **(1)** • Use of $lnV = lnV_o - \frac{t}{RC}$ **(1)** • $C = 3.5 \times 10^{-5}$ F **(1)** range 2.7×10^{-5} F to 3.5×10^{-5} F Alternate method • Use of $I = V/R$ • Use of $Q = It$ and $C = \Delta Q/\Delta V$ • $C = 2.7 \times 10^{-5}$ F to 3.5×10^{-5} F	eg this can be any *t* (in ms) and corresponding *V* Example of calculation $ln3.5 = ln4 - \frac{0.008\ \text{s}}{2200\ \Omega \times C}$ $C = 2.7 \times 10^{-5}$ F Alternate: $I = 3.8\ \text{V} / 2.2\ \text{k}\Omega = 1.73\ \text{mA}$ $Q = 1.73\ \text{mA} \times 8\ \text{ms} = 13.8 \times 10^{-6}\ \text{C}$ $C = 13.8 \times 10^{-6}\ \text{C} / 0.4\ \text{V} = 3.4 \times 10^{-5}$ F	**3**

(Total for Question 14 = 8 marks)

Question Number	Acceptable answers		Additional guidance	Mark
12(a)	• Alternating current/a.c. (in primary) produces changing/alternating magnetic flux/field	**(1)**		**(4)**
	• The magnetic flux/field is linked to the secondary coil by the iron core	**(1)**		
	• The changing magnetic flux/field induces an emf in the secondary coil	**(1)**	alt. to changing magnetic flux is $\Delta N\phi$	
	• More turns on the secondary (will increase the rate of change of flux linkage according to Faraday's law).	**(1)**	alt. quote of $V_1/V_2 = N_1/N_2$	
12(b)	• 270K corresponds to a resistivity of 2×10^{-8} (Ω m)	**(1)**	range allow 2×10^{-8} Ω m to 2.1×10^{-8} Ω m	**5**
	• Use of $P=VI$	**(1)**		
	• Use of $R=\rho l/A$	**(1)**	Example of calculation: $40\times10^{6}\ \text{W} = 110\times10^{3}\ \text{V}\times I$	
	• Use of $P=I^2R$	**(1)**	$I = 364\ \text{A}$	
	• Power losses from copper cables 19 kW so more than7 kW and that the superconductor would save energy. MP5 dependant on MP2,3,4	**(1)**	$R = \dfrac{2\times10^{-8}\ \Omega\text{m}\times1.050\times10^{3}\ \text{m}}{145\times10^{-6}\ \text{m}^2} = 0.145\ \Omega$	
	(Acceptable range for Power losses: 9.6 kW to 34 kW)		$P = 364^2\ \text{A}^2 \times 0.145\ \Omega = 19.2\ \text{kW}$	

(Total for Question 12 = 9 marks)

Question Number	Acceptable answers		Additional guidance	Mark
15(a)	• Use of charge = area under the graph	**(1)**	Q = 0.5(0.5 h ×17.5 A) + 0.5(4.5 h × 2.5 A) + (17.5 h × 4.5 A)	
	• Charge in 5 hours = 89 (A h)	**(1)**	Q = 88.8 A h 90% charge = 0.9 × 110 = 99 A h	
	• 90% charge is 99 (A h) so statement is not correct Or 89 (A h) is 81% charge so statement is not correct	**(1)**	MP3 dependent on MP1	**3**
15(b)(i)	• Use of efficiency = $\frac{\text{useful energy output}}{\text{total energy input}}$ and conversion of kW h to J	**(1)**	Example Calculation Useful energy output = 0.85 × 42 000 × 3600 Useful energy output = 1.29×10^8 J 1.29×10^8 J = $F \times 160 \times 10^3$ m F = 803 N	
	• Use of $\Delta W = F\Delta s$	**(1)**		
	• $F = 803$ (N)	**(1)**		**3**
15(b)(ii)	• Use of $mg\Delta h$	**(1)**	Example Calculation ΔE_{grav} = 1300 kg × 9.81 Nkg^{-1} × 3000m ΔE_{grav} = 3.8×10^7 J 1.29×10^8 J = (803 × s) + (3.8×10^7 J) s = 113 km Reduction in range = 160 km – 113 km = 47 km	
	• Use of useful energy output = work done against frictional forces + ΔE_{grav} (allow ecf from (b)(i)) **Or** Use of ΔE_{grav} = reduction in work done against frictional forces	**(1)**		
	• Reduction in range = 47 km	**(1)**		**3**

(Total for Question 15 = 9 marks)

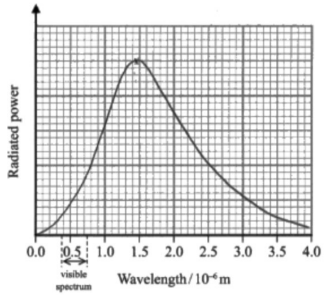
(Total for Section A = 60 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
14(a)(i)	Use of 3600 × W h to give energy stored = 24 900 (J)	**(1)**	Example of calculation 6.91 W h = 6.91 × 3600 s = 24 876 J	**1**
14(a)(ii)	• Use of $V = W/Q$ • Q = 6510 C	**(1)** **(1)**	Example of calculation $Q = \frac{24\,876\text{ J}}{3.82\text{ V}} = 6512$ C (ecf for calculated energy from (a)(i)) (show that value gives Q = 6545 C)	**2**
14(a)(iii)	• Use of $Q = It$ **Or** $W = VIt$ • Use of $\frac{\text{time in seconds}}{3600}$ • t = 2.0 (h)	**(1)** **(1)** **(1)**	Example of calculation $t = \frac{6512\text{ C}}{0.9\text{ A}} = 7235.6$ s $t = \frac{7235.6\text{ s}}{3600} = 2.01$ h (ecf for calculated charge from (a)(i)) (show that value gives t = 2.02 h)	**3**
14(b)	• The replacement charger will still have to supply the same charge (6510 C) • The replacement charging plug takes more time to charge **Or** the old charging plug takes less time to charge • Replacement charging plug uses a lower current therefore reduces heating effect • The phone may try and draw a current of 1 A which may damage the charging plug	**(1)** **(1)** **(1)** **(1)**	MP1: may be awarded for use of 6510 C in a calculation for MP2 MP2 calculation to support this using t = Q/I Or if the phone uses 1A the time to charge will be the same	**4**

(Total for Question 14 = 10 marks)

Question Number	Acceptable answers		Additional guidance	Mark
13a	• A (resultant) force *F* is required to maintain circular motion	**(1)**	alt: A (resultant) force acts to the centre of the circle.	**3**
	• This force is friction (between car/slider and track)	**(1)**		
	• As *v* increased *F* required increased until it exceeds friction and car slides off track	**(1)**		
13bi	• use of $s = \frac{(u+v)}{2} \times t$	**(1)**	Example of calculation: 1.1 $m = \frac{(0+v)}{2} \times 0.77$ s $v = 3.1$ m s^{-1}	**2**
	• $v = 3.1$ (m s^{-1})	**(1)**		
13bii	• use of $F = mv^2/r$	**(1)**	Example of calculation: $F = \frac{0.050 \text{ kg} \times 3.1^2 \text{ (m s}^{-1})^2}{0.042 \text{ m}}$ $F = 11.4$ N "show that value" gives $F = 10.7$ N	**2**
	• $F = 11$ N (allow ecf from (i))	**(1)**		
13c	• inner lane covers a smaller distance	**(1)**		**3**
	• inner lane has a smaller radius of curvature	**(1)**		
	• (maximum horizontal force is the same for both cars) therefore maximum speed is greater for the car on the outside lane (so outcome unclear)	**(1)**		

(Total for Question 13 = 10 marks)

Question Number	Acceptable answers	Additional guidance	Mark
14 (a)	• Use of $P = IV$ **(1)** • Use of $L = A\sigma T^4$ **(1)** • $T = 1800$ K **(1)**	Example of calculation $P = 2.0\text{ V} \times 0.37\text{ A} = 0.74\text{ W}$ $0.74\text{ W} = 0.35 \times 3.9 \times 10^{-6}\text{ m}^2 \times 5.67 \times 10^{-8}\text{ Wm}^{-2}\text{K}^{-4}\text{ W} \times T^4$ $T^4 = 9.56 \times 10^{12}\text{ K}^4$ $T = 1758$ K	**3**
14 (b)(i)	• Use of $\lambda_{max}\ T = 2.898 \times 10^{-3}$ m K **(1)** • $\lambda_{max} = 1.4 \times 10^{-6}$ (m) **(1)** • correct black body radiation shape **(1)** • peak at correct wavelength **(1)** • line not zero at long wavelength **and** not positive at 0.0 on wavelength axis **(1)**	Example of calculation and graph $\lambda_{max} \times 2026\text{ K} = 2.898 \times 10^{-3}$ m K $\lambda_{max} = 1.43 \times 10^{-6}$ m  	**5**
14 (b) (ii)	• Most radiation at infrared **or** λ_{max} isn't in the visible spectrum **or** only a small proportion of radiation/power in visible spectrum **(1)** • Ratio of useful output/input is therefore very small **Or** so proportion of energy transfer that is useful is small **(1)**		**2**
			(Total for Question 14 = 10 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
7(a)(i)	• Use of y-sensitivity value **(1)** • $V_0 = 4.0$ V **(1)**	Example of calculation: $V_0 = 2 \times 2.0\ V = 4.0$ V	2
7(a)(ii)	• Use of $I = \frac{V}{R}$ **(1)** • Use of $I_{rms} = \frac{I_0}{\sqrt{2}}$ **Or** use of $V_{rms} = \frac{V_0}{\sqrt{2}}$ **(1)** • $I_{rms} = 0.019$ A ECF from(i) **(1)**	Example of calculation $I_0 = \frac{4.0\text{ V}}{150\ \Omega} = 0.0267$ A $I_{rms} = \frac{0.0267\text{ A}}{\sqrt{2}} = 0.0189$ A	3
7(a)(iii)	• Use of $R = R_1 + R_2$ **(1)** • Use of $P = I^2R$ (or other valid power equation) **(1)** • $P = 0.096$ W ECF from(i) and (ii) **(1)**	Example of calculation: $R = 150\ \Omega + 120\ \Omega = 270\ \Omega$ $P = I^2R = (0.019\text{ A})^2 \times 270\ \Omega = 0.0964$ A	3
7(b)	**MAX 3** • Voltmeter must measure alternating p.d.s **Or** voltmeter would indicate zero for a.c. **(1)** • A.C. voltmeter would give an r.m.s. p.d. directly **(1)** • Voltmeter may draw current and affect the circuit it was connected to **Or** oscilloscope would have little effect on the circuit it was connected to **(1)** • Accuracy would depend upon the calibration of the voltmeter **(1)** • A (digital) voltmeter would give better resolution than measuring trace height on an oscilloscope. **(1)**	Accept "voltmeter reading would change too fast to measure"	3

(Total for Question 7 = 11 marks)

Question Number	Acceptable answers	Additional guidance	Mark
15(a)	• Use of $E_{grav} = mgh$ **(1)** • Use of $P = IV$ and $P = \frac{E}{t}$ **(1)** • Use of Efficiency $= \frac{\text{useful power output}}{\text{total power input}}$ **Or** • Use of Efficiency $= \frac{\text{useful energy output}}{\text{total energy input}}$ **(1)** • Efficiency = 0.74 **(1)**	Example of Calculation $E_P = 0.55\ kg \times 9.81\ ms^{-2} \times 0.20\ m$ $E_P = 1.08\ J$ Useful power $= \frac{1.08\ J}{15\ s} = 0.072\ W$ $P = 8.1 \times 10^{-3}\ A \times 12\ V$ Input power = 0.0972 W Input energy = 0.0972 × 15 = 1.46 J Efficiency $= \frac{1.08\ J}{1.46\ J} = 0.74$	**4**
15(b)	• There is now a (greater) current in the voltmeter **(1)** • The current in the battery/circuit increases **Or** Energy/power is dissipated in the voltmeter **(1)** • Power/energy output from the battery increases **(1)** • Efficiency of the motor circuit decreases **(1)** (MP4 dependent on MP3)	Accept reference to the resistance in the circuit decreasing for MP1. Accept power input to circuit for MP3.	**4**

15(c)	• Use of $p = mv$ **(1)** • Use of principle of conservation of momentum **(1)** • $v = 5.2$ ms^{-1} **(1)**	<u>Example of calculation.</u> 0.55 kg × 5.4 ms^{-1} = (0.55 kg × 2.1 ms^{-1}) + (0.35 kg × v) 2.97 = 1.16 + 0.35v v = 5.2 ms^{-1}	**3**

(Total for Question 15 = 11 marks)

Question Number	Acceptable answers	Additional guidance	Mark
13a	• Efficiency shouldn't have any units **Or** efficiency should be a ratio of energies **Or** efficiency should be a ratio of powers **Or** number < 1		**1**
13b	• Quote $P = E/t$ **(1)** • (k)W is unit of P and h unit of t so equivalent to E **(1)**		**2**
13c	• Use of Efficiency = useful energy output/energy input **(1)** • Uses Energy input is power (kW) × time (h) **(1)** • Efficiency = 0.87 **(1)**	<u>Example of calculation</u> $\text{Efficiency} = \frac{22\ \text{kWh}}{3.6\ \text{kW} \times 7\text{h}}$ Efficiency = 0.873	**3**

Question Number	Acceptable answers	Additional guidance	Mark
13d	• converts battery input to a cost **(1)** • comparison of petrol and electric cost for same range **Or** comparison of petrol and electric range for same cost **(1)**	Example of calculation Cost of charging the battery = 3.6 kW ×7 h× 13 p = £3.28 This is a cost per km of $\frac{3.28}{129}$ = 2.54 p **Or** use of website figures: 0.195 kW h x 13 p/kW h = 2.54 p. Petrol car: cost per km is $\frac{1.20}{21}$ = 5.71 p Alternative: to calculate cost for 129 km £3.276 for electric and £7.36 for petrol	**2**
13e	• no exhaust particulates **Or** no lead emission **Or** less carbon dioxide emission **Or** less greenhouse gases **Or** no polluting gases		**1**
13f	• use of $E_k = ½ mv^2$ **(1)** • use of $P = E/t$ **(1)** • power required is 51 kW, less than engine power so it does have enough power **(1)**	Example of calculation $E_k = \frac{1}{2}$1500 kg 28^2 (m s^{-1})^2 = 5.88×10^5 J P = 5.88×10^5 J / 11.5 s = 51.1 kW	**3**

(Total for Question 13 = 12 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
10(a)	• Use of $P = \frac{V^2}{R}$ **(1)** • $P = 48.2$ (W) **(1)**	Example of calculation $P = \frac{(8.5\ \text{V})^2}{1.5\ \Omega} = 48.2\ \text{W}$ Bald answer of 48.2 can score MP2 only Bald answer of 48 scores 0	**2**
10(b)	• Use of $\rho = \frac{m}{V}$ **(1)** • Use of $\Delta E = mc\Delta\theta$ **(1)** • Use of $P = \frac{\Delta W}{\Delta t}$ **(1)** • Time = 128 s (ecf from (a)) **(1)**	Example of calculation $m = 1.25 \times 10^{-4}\ \text{m}^3 \times 1050\ \text{kg m}^{-3} = 0.131\ \text{kg}$ $t = \frac{0.131\ \text{kg} \times 3930\ \text{J kg}^{-1}\ \text{K}^{-1} \times 12\ \text{K}}{48.2\ \text{W}} = 128\ \text{s}$ Allow 130s Show that value gives 129 s	**4**

10(c)	• (Connect oscilloscope to the a.c. supply and) adjust time base so that a complete wave can be seen on the screen **(1)** • Measure the (horizontal) distance from peak to peak **(1)** • Use the time base setting × distance between peaks (to determine the time for one cycle) **(1)** • Use $f = \frac{1}{T}$ to calculate the supply frequency **(1)** • Use the voltage sensitivity and amplitude (of a peak to determine the peak p.d.) **(1)** • Use $V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$ (to calculate the r.m.s. p.d. and compare with the voltmeter reading) **(1)**	Accept several complete cycles for MP1, but in that case require measurement across several cycles for MP2.	**6**

(Total for Question 10 = 12 marks)

Question Number	Acceptable answers	Additional guidance	Mark
16(a)(i)	• (Moving) electrons collide with lattice/ions **(1)** • Transfer of energy to (lattice) ions so they vibrate with larger amplitude/speed (and the temperature increases) **(1)**		**2**
16(a)(ii)	• Electrons/ions in the tube collide with mercury/phosphor atoms and excite electrons (in the mercury/phosphor atoms) **(1)** • Energy is released in the form of photons as the electrons move back down (to the ground state) **(1)**	Mention of work function scores 0 MP2 Allow de-excite for move back down	**2**
16 (b)(i)	• Use of cross-sectional area = πr^2 **Or** $\frac{\pi d^2}{4}$ **(1)** • Use of $R = \frac{\rho l}{A}$ **(1)** • Correct use of factor of 14 **(1)** • Use of $P = \frac{V^2}{R}$ **(1)** • P = 52 W **(1)**	<u>Example of calculation</u> $A = \pi(1.9 \times 10^{-5}\ \text{m})^2 = 1.134 \times 10^{-9}\ \text{m}^2$ $R = \frac{(5.6 \times 10^{-8}\ \Omega\text{m})(1.6\ \text{m})}{1.134 \times 10^{-9}\ \text{m}^2} = 79.01\ \Omega$ $R_{max} = 14 \times 79.01\ \Omega = 1106.2\ \Omega$ $P = = \frac{(240\ V)^2}{1106.2\ \Omega} = 52.1$ W	**5**

16 (b)(ii)	**Either** • Initially(the resistance is low so) current will be the greatest • As $P = I^2R$, the greatest power is transferred • Change in current has more effect as it is squared • Heating effect greatest when R is lowest, so breaks when switched on. **OR** • p.d. is constant • $P = V^2/R$ • Power is greatest when R is lowest • Heating effect is greatest when R is lowest, so breaks when switched on **OR** • p.d. is constant • Initially (resistance is low so) current will be the greatest • As P=IV the greatest power is transferred • Heating effect is greatest when R is lowest, so breaks when switched on	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)**		**4**

(Total for Question 16 = 13 marks)

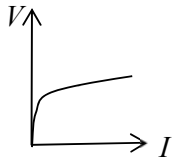
Question Number	Acceptable Answer	Additional Guidance	Mark
14(a)(i)	• Use of $\Delta E_{grav} = mg\Delta h$ and $P = \frac{E}{t}$ **(1)** • $P = 1.6 \times 10^5$ W **(1)**	Example of calculation E_{grav} per second = 130 kg × 9.81 m s^{-2} × 124 m $P = 1.6 \times 10^5$ W	**2**
14(a)(ii)	An explanation that makes reference to the following points: • Frictional forces between water and pipe **(1)** • Do work transferring energy to the surroundings **(1)**	Allow reference to process is less than 100% efficient for MP1	**2**
14(b)	**EITHER** • Use of $V = \frac{W}{Q}$ **(1)** • Use of $P = \frac{E}{t}$ **(1)** • t = 11 h **(1)** **OR** • Use of $P = VI$ **(1)** • Use of $I = Q/t$ or $W = VIt$ **(1)** • t = 11 h **(1)**	Example of calculation $Q = 4400 \times 3600 = 1.6 \times 10^7$ C $W = 1.6 \times 10^7$ C × 48 V = 7.6×10^8 J $t = 7.6 \times 10^8$ J / 20×10^3 W = 3.8×10^4 s $t = 3.8 \times 10^4$ s / 3600 = 10.6 h **Or** W = 4400 Ah × 48 V = 2.1×10^5 V A h $t = 2.1 \times 10^5$ V A h / 20×10^3 W = 10.6 h	**3**

14(c)(i)	• Use of $P = IV$ **(1)** • $I = 21.7$ (A) **(1)**	Example of calculation $I = 5 \times 10^3$ W / 230 V = 21.7 A	**2**

14(c)(ii)	• Use of $P = I^2R$ **(1)** • Use of $R = \frac{\rho l}{A}$ **(1)** • Use of $V = Al$ and the cost per m^3 **(1)** • Cost of copper per m = £12.54 **Or** Cost of aluminium per m = £1.56 **(1)** • The cost reduction is 88% which is close to 90% so the claim is correct (ecf from (c)(i)) (Conclusion consistent with calculated percentage) **(1)**	Example of calculation $R_{1\text{ m of cable}} = 0.05$ W / (22 A)$^2 = 1.03 \times 10^{-4}$ Ω For 1 m of copper cable $A = (1.68 \times 10^{-8}$ Ω m × 1) / 1.03×10^{-4} Ω = 1.63×10^{-4} m^2 $V = 1.63 \times 10^{-4}$ m^2 × 1 m = 1.63×10^{-4} m^3 Cost = 1.63×10^{-4} m^3 × £77 090 = £12.54 For 1 m of aluminium cable $A = (2.65 \times 10^{-8}$ Ω m × 1) / 1.03×10^{-4} Ω = 2.57×10^{-4} m^2 $V = 2.57 \times 10^{-4}$ m^2 × 1 m = 2.57×10^{-4} m^3 Cost = 2.57×10^{-4} m^3 × £6070 = £1.56 Cost reduction using Al = (£12.54 − £1.56) / £12.54 = 88%	**5**

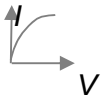
(Total for Question 14 = 14 marks)

(Total for Section A = 57 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
8	**C** 		**1**

(Total for Multiple Choice Questions = 8 marks)

Question Number	Acceptable answers	Additional guidance	Mark
4	**The only correct answer is B** A *is not correct because R decreases as more conduction electrons* C *is not correct because lattice vibrations not affected* D *is not correct because lattice vibrations not affected*	It increases because there is an increase in the number of conduction electrons.	**1**

Question Number	Acceptable answers	Additional guidance	Mark
5	**The only correct answer is C** A *is not correct because it shows constant resistance* B *is not correct because it shows decreasing resistance* D *is not correct because it shows an I independent of V*		**1**

Question Number	Answer	Mark
4	**B** filament bulb	1
	Incorrect Answers: A – this is not the graph for a diode C – this is not the graph for an ohmic resistor D – this is not the graph for a thermistor	

Question Number	Acceptable answers	Additional guidance	Mark
6	C		**1**

Question Number	Acceptable answers	Additional guidance	Mark
6	D		1

7	**The only correct answer is B** **decreases** | **increases**	C and D are incorrect as the resistance decreases A is incorrect as *n* increases	**1**

8	**C** The diode starts to conduct when the potential difference is about 0.7 V.	**1**
	Incorrect Answers: **A** – The diode has zero resistance when connected in the forward direction **B** – The diode has zero resistance when connected in the reverse direction. **D** – The diode stops conducting when the potential difference is about −0.7 V.	

(Total for Multiple Choice Questions = 8 marks)

Question Number	Answer	Mark
1	**B thermistor graph**	**1**
	Incorrect Answers: A – ohmic conductor graph C – filament lamp graph D – diode graph	

Question Number	Answer	Mark
2	**C kg m^2 s^{-3} A^{-2}**	**1**
	Incorrect Answers: A – Ω is not a base unit B – V is not a base unit D – C is not a base unit	

Question Number	Answer	Mark
4	**D** Incorrect Answers: A – doubling the length doubles the resistance, the cross sectional area also halves which doubles the resistance as well B – doubling the length doubles the resistance, the cross sectional area also halves which doubles the resistance as well C – doubling the length doubles the resistance, the cross sectional area also halves which doubles the resistance as well	**1**

Question Number	Acceptable Answer	Additional Guidance	Mark
4	**The only correct answer is D** $\frac{R}{4}$ A is not the correct answer, as $R = \rho l/A$ and A is four times larger B is not the correct answer, as $R = \rho l/A$ and A is four times larger C is not the correct answer, as $R = \rho l/A$ and A is four times larger		**1**

Question Number	Answer	Mark
2	**C - Resistance decreases as the number of conduction electrons increases.**	1
	Incorrect Answers: A – vibration of lattice ions is not the deciding factor for a semi conductor B – vibration of lattice ions is not the deciding factor for a semi conductor D – increasing temperature increases the number of conduction electrons	

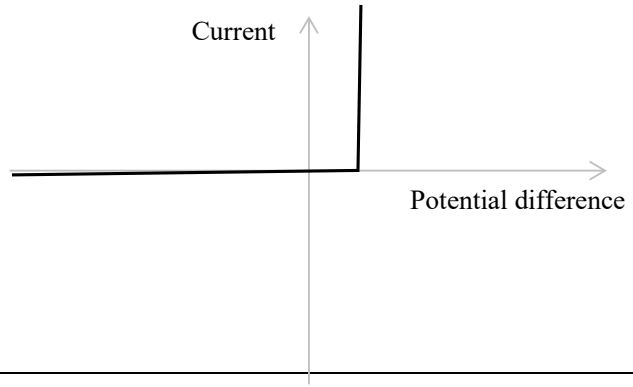
Question Number	Acceptable answers		Additional guidance	Mark
9	• Diode	**(1)**	MP3 allow threshold voltage	**3**
	• It conducts/allows current in one direction only	**(1)**		
	• The diode conducts when the p.d. is beyond 0.2-0.7V **Or** For negative p.d.s the <u>resistance</u> is (very) high **Or** in the reverse/backward direction the <u>resistance</u> is (very) high **Or** at breakdown/large voltage the diode will conduct in the reverse direction	**(1)**		

(Total for Question 9 = 3 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
9	An explanation that makes reference to the following points: • Equal increases in potential difference produce gradually decreasing increases in current **(1)** • So resistance of component increases with potential difference **Or** • So resistance of component increases with current **(1)** • Component is a filament bulb **(1)**	Accept: As potential difference on graph increases, current increases at decreasing rate	**3**

(Total for Question 9 = 3 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark

Question Number	Acceptable Answer		Additional Guidance	Mark
11(a)	• $I = 0$ for V less than 0 [Ignore any breakdown pd]	(1)	Allow I close to 0 Allow curve or positively sloping straight line rather than abrupt right angle <u>Example of graph</u>  	2
	• $I = 0$ from 0 to a positive value of V and then increases with a steep gradient	(1)		
11(b)	• Use of $E = V_1 + V_2$	(1)		3
	• Use of $V = IR$	(1)	<u>Example of calculation</u> $5\ \text{V} - 3.2\ \text{V} = 20 \times 10^{-3}\ \text{A} \times R$	
	• Resistance = 90 Ω	(1)	$R = 90\ \Omega$	

(Total for Question 11 = 5 marks)

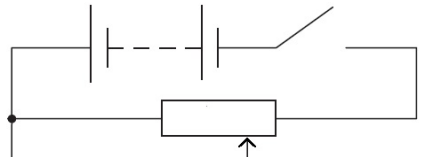
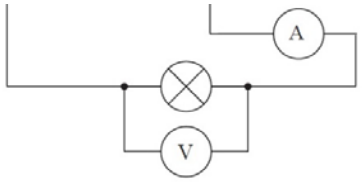
Question Number	Acceptable answers		Additional guidance	Mark
13(a)	• The (voltmeter) reading will increase • Resistance increases (with length) **Or** resistance ∝ length	**(1)** **(1)**	MP2: accept idea of a potential divider i.e. the ratio of the of BC to the total length AD will be greater, so the 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**
13(b)	• Use of $V = IR$ • Use of $R = \rho l/A$ • (Min) resistivity = 160 (Ω m) **Or** (max) resistivity = 730 (Ω m) • Compacted clay pathways **and** limestone are present in the soil	**(1)** **(1)** **(1)** **(1)**	Example of calculation $R_{min} = \frac{1.8\text{ V}}{9.5 \times 10^{-3}\text{ A}} = 189.5\ \Omega$ $R_{max} = \frac{8.0\text{ V}}{9.5 \times 10^{-3}\text{ A}} = 842.1\ \Omega$ $\rho_{min} = \frac{RA}{l} = \frac{189.5\ \Omega \times 0.650\text{ m}^2}{0.75\text{ m}} = 164.2\ \Omega\text{ m}$ $\rho_{max} = \frac{RA}{l} = \frac{842.1\ \Omega \times 0.650\text{ m}^2}{0.75\text{ m}} = 729.8\ \Omega\text{ m}$ conclusion to be consistent with calculated values	**4**

(Total for Question 13 = 6 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
8(a)	• Ammeter in series with LED **and** voltmeter in parallel with LED **(1)**		**1**
8(b)(i)	• The IV graph of an ohmic conductor is a straight line through the origin **Or** V is directly proportional to *I* **(1)** • Hence Ohm's law is not obeyed for the LED **(1)**	MP1 accept converse argument MP2 dependent on MP1	**2**
8(b)(ii)	**Either** **(1)** • $V_{LED} = 2\,V$ (from graph) **(1)** • Use of $V_{LED} + V_R = 5\,V$ **(1)** • Use of $R = \frac{V}{I}$ **(1)** • R = 170 Ω **Or** • Use of $R = \frac{V}{I}$ **(1)** • $V_{LED} = 2\,V$ (from graph) **(1)** • Use of $R_{LED} + R = 278\,\Omega$ **(1)** • R = 170 Ω **(1)**	Example of calculation: $2\,V + V_R = 5\,V$ $\therefore V_R = 3\,V$ $R = \frac{3\,V}{18 \times 10^{-3}\,A} = 167\,\Omega$	**4**

(Total for Question 8 = 7 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark

Question Number	Acceptable Answer	Additional Guidance	Mark
4(a)	• all I values should be recorded to the same number of decimal places **Or** all I values should be recorded to the same resolution **(1)**	Do not accept same number of significant figures	**1**
4(b)	• Ohm's law requires current to be (directly) proportional to the (applied) p.d **(1)** • Hence the line should pass through the origin **(1)** • (There is scatter around the line drawn by the student so) the correct line may be a curve **(1)** • Conclusion that this graph does not meet the conditions for Ohm's law so the student's statement is invalid **(1)**	For MP1 accept Ohm's law requires $I \propto V$ In MP2, credit students who check values from graph to see if I doubles when V doubles In MP3, credit students who draw a curve onto the graph MP4 dependent upon MP2 OR MP3	**4**
4(c)	• potential divider circuit diagram drawn as shown **(1)** • correctly incorporated into the given circuit **(1)**	 Switch not essential, accept potential divider with arrow drawn through resistor 	**2**

(Total for Question 4 = 7 marks)

Question Number	Acceptable answers	Additional guidance	Mark
18(a)(i)	• Use of $\rho = \frac{m}{V}$ **(1)** • V = 8.1 x 10^{-6} (m^3) **(1)**	Example of Calculation. $V = \frac{0.043 \text{ kg}}{5300 \text{ kgm}^{-3}}$ $V = 8.1 \times 10^{-6} \text{ m}^3$	**2**
18(a)(ii)	• Use of $A=\pi r^2$ and $V = Al$ **(1)** • Use of $R = \frac{\rho l}{A}$ **(1)** • R = 2.5 Ω (ecf from (a)(i)) **(1)**	Show that value gives 2.50 Ω Example of Calculation. $A = \pi(6 \times 10^{-3} \text{ mm})^2 = 1.13 \times 10^{-4} \text{ m}^2$ $8.1 \times 10^{-6} \text{ m}^3 = (1.13 \times 10^{-4} \text{ m}^3)\ l$ $l = 0.0716$ m $R = \frac{(4.0 \times 10^{-3} \ \Omega \text{ m})(0.0716 \text{ m})}{(1.13 \times 10^{-4} \text{ m}^3)}$ R = 2.54 Ω	**3**
18(b)	• Makes a cylinder of longer length **Or** Makes a cylinder of smaller radius/area **(1)** • As $R = \frac{\rho l}{A}$, this change will increase the resistance **(1)** [MP2 dependent on MP1]		**2**

(Total for Question 18 = 7 marks)

Question Number	Acceptable answers	Additional guidance	Mark
11(a)(i)	• Power source in series with coil of wire and ammeter **and** voltmeter correctly placed **Or** Ohmmeter in series with wire **(1)**	Allow power supply/cell/battery Wire must be clear Ignore extra components as long as circuit would still work	1
11(a)(ii)	• Measure temperature of water with a thermometer **(1)** • Stir the water **Or** Keep thermometer near to coil **Or** Allow time to ensure coil is at thermal equilibrium **Or** Use small current (so electrical heating of wire is minimised) **(1)**		2
11(b)	An explanation that makes reference to the following points: • Kinetic energy of (lattice) ions increases **Or (**Lattice) ions vibrate with greater amplitude **(1)** • The frequency of collisions between electrons and ions increases **(1)** • (Drift) velocity of electrons decreases, so current decreases (for the same p.d.) **(1)** • So resistance of nichrome wire increases **(1)** [Dependent upon MP1, MP2 or MP3]		4

(Total for Question 11 = 7 marks)

Question Number	Acceptable answers		Additional guidance	Mark
12(a)	• Calculates area • Use of $R = \frac{\rho l}{A}$ • l = 10 m	(1) (1) (1)	Example of calculation Cross sectional area = $\pi\frac{(0.28\times10^{-3}\text{ m})^2}{4} = 6.2\times10^{-8}\text{ m}^2$ 80 Ω = (4.9 × 10^{-7} Ω m × l) / 6.2 × 10^{-8} m^2 l = 10.1 m	3
12(b)	**EITHER** • Percentage uncertainty calculated for either I or V • Percentage uncertainties for I and V added • Lower limit of R = 74 Ω **Or** uncertainty in R = 8 Ω • Conclusion consistent with calculated value of lower limit **OR** • (Upper/lower) limit of V calculated **and** (upper/lower) limit of I calculated • Minimum value of R calculated **Or** maximum value of R calculated • Lower limit of R = 75 Ω • Conclusion consistent with calculated value of lower limit	(1) (1) (1) (1) (1) (1) (1) (1)	Example of calculation $\%U_I$ = (0.01 A / 0.12 A) × 100 = 8.3 % $\%U_V$ = (0.1 V / 9.8 V) × 100 = 1.0 % R = 9.8 V / 0.12 A = 82 Ω $\%U_R$ = 8.3 % + 1.0 % = 9.3 % Lower limit of R = 82 Ω × (1 − 0.093) = 74 Ω 80 Ω is within limit, so agree with experimental results	4

(Total for Question 12 = 7 marks)

Question Number	Acceptable answers	Additional guidance	Mark
16(a)	**MAX 4** • The current increases (non-linearly) with p.d. **(1)** • The rate of increase of current (with p.d.) decreases **(1)** • The temperature of the bulb increases so the resistance increases **(1)** • Increasing the amplitude of lattice vibration **(1)** • The frequency of collisions between electrons and ions increases **(1)**		**4**
16(b)	**MAX 3** • Use potentiometer **Or** Connect variable resistor into circuit **(1)** • Use a smaller range of p.d. **(1)** • Use smaller increment changes to p.d. **Or** Measure smaller changes in current **Or** Record more values where graph is changing most **(1)** • Replace ammeter with milliammeter		**3**

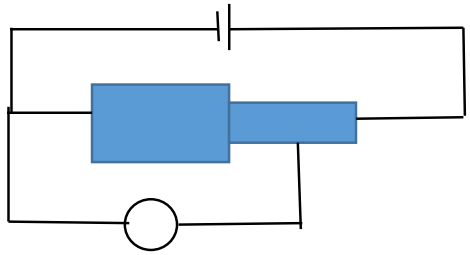
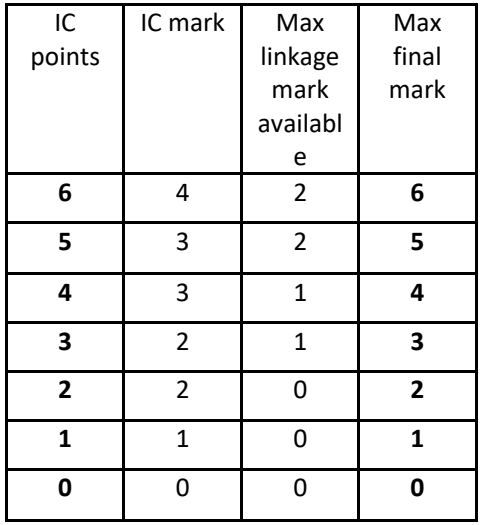
(Total for Question 16 = 7 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
1(a)	• The ammeter is in series with the bulb and the voltmeter is in parallel with the bulb **Or** Adjusting the variable resistor will vary the current/p.d. **(1)** • The circuit may not be able to give a full range of applied p.d.s **Or** Reducing the variable resistance will place a p.d. across the bulb much larger than 3 V **(1)** • Comment on suitability consistent with stated characteristics of circuit **(1)**	Allow "the measurements of current and p.d. will be valid"	**3**
1(b)	• Precision is the closeness of agreement (consistency) between (repeated) measurements **(1)** • As the student has only taken a single value of current, the student cannot say the current is precise **(1)** • Accuracy is how close the measured value is to the true value **(1)** • The true value is not known, so the student cannot say the value will be accurate **Or** There may be a systematic error, so the student cannot say the value will be accurate **(1)**		**4**

(Total for Question 1 = 7 marks)

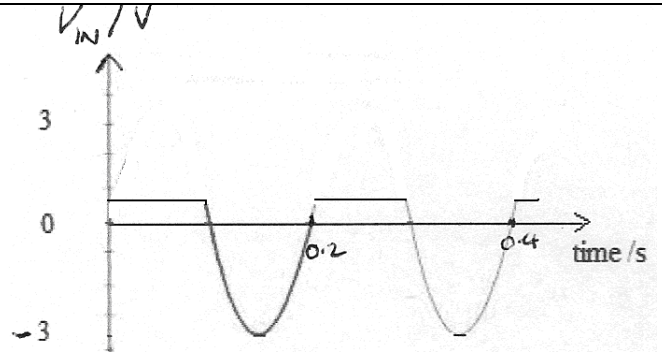
Question Number	Acceptable Answer		Additional Guidance	Mark
5(a)	• use of $Q = It$ • use of $V = \frac{W}{Q}$ • $W = 5.1 \times 10^8$ J	**(1)** **(1)** **(1)**	Allow calculations based on power i.e. $VI = \frac{W}{t}$ Example of calculation: $Q = It = 25 \times 10^3 \text{A} \times 7.5 \times 10^{-3} \text{s} = 188 \text{ C}$ $W = QV = 188 \text{ C} \times 2.7 \times 10^6 \text{V} = 5.08 \times 10^8 \text{ J}$	**3**
5(b)	• Use of $A = \frac{\pi d^2}{4}$ Or use of πr^2 • Use of $R = \frac{\rho l}{A}$ • Calculates $l - 1.5$ • Height = 27.1 m so it is not taller than 30 m **OR** • Use of $A = \frac{\pi d^2}{4}$ Or use of πr^2 • Calculate wire length wire for 30 m statue [$l = 31.5$ m] • Use of $R = \frac{\rho l}{A}$ • R = 4.7×10^{-3} Ω (> 4.3×10^{-3} Ω) so statue is not taller than 30 m	**(1)** **(1)** **(1)** **(1)**	Example of calculation: $A = \frac{\pi d^2}{4} = \frac{\pi \times (1.2 \times 10^{-2} \text{m})^2}{4} = 1.13 \times 10^{-4} \text{m}^2$ $l = \frac{RA}{\rho} = \frac{4.3 \times 10^{-3} \Omega \times 1.13 \times 10^{-4} \text{m}^2}{1.7 \times 10^{-8} \Omega \text{ m}}$ $= 28.6$ m Height = 28.6 m – 1.5 m = 27.1 m	**4**
5(c)	• So that the lightning makes contact with the conductor rather than the statue	**(1)**		**1**

(Total for Question 5 = 8 marks)

Question Number	Acceptable answers	Additional guidance	Mark
14a	• cell connected to both ends of paper with correct polarity **(1)** • voltmeter with one end connected to 0V end of paper and other to halfway along narrow strip of paper **(1)**		**2**
***14b**	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. • Use of $R = \rho l/A$ • the wider section will be half the resistance of the narrow section • The p.d. will be divided into 0.5V across wide section and 1.0V across the narrow section • The potential will vary linearly along each resistance section (as R is proportional to l) • This is because current is constant throughout length • When the voltmeter is across the whole length it will read the p.d. across the cell/ 1.5V **Or** when the voltmeter terminals are together it will read 0 V		**6**

IC points	IC mark	Max linkage mark available	Max final mark
6	4	2	**6**
5	3	2	**5**
4	3	1	**4**
3	2	1	**3**
2	2	0	**2**
1	1	0	**1**
0	0	0	**0**

(Total for Question = 8 marks)

Question Number	Acceptable answers	Additional guidance	Mark
15(a)	• The diode only conducts (current) when the potential difference across it is (at least +) 0.7V **(1)** • The diode does not conduct current when the p.d. is negative/reversed. **(1)**		**(2)**
15(b)(i)	• Use of $V_{rms} = \frac{V_o}{\sqrt{2}}$ **(1)** • V_{rms}= 2.4 V **(1)**	Example of calculation: $V_{rms}=\frac{3.4}{\sqrt{2}}$= 2.4 V	**(2)**
15(b)(ii)	• Energy is conserved **Or** Kirchoff's law **Or** potential difference is energy per unit charge **(1)** • So the sum of p.d.s in a series circuit must equal the e.m.f. applied (MP2 is dependent on MP1) **(1)**	accept work done for energy accept V_{in} for emf Alternative: Current is the same in both components (1) $IV_{IN} = IV_R + IV_D$ and I cancels (1)	**(2)**
15(b)(iii)	• Alternate half cycles of sine curve (with peak about 3 V) **(1)** • Horizontal line in 1st half cycle and negative half cycle of a sine curve in 2nd half cycle **(1)** • horizontal lines/spaces at a value of potential difference of 0.6 V to 0.8 V **(1)**		**(3)**

(Total for Question 15 = 9 marks)

Question Number	Acceptable answers		Additional guidance	Mark
12(a)(i)	• Calculation of mean • Use of half range **Or** maximum difference from the mean • % uncertainty = 1.4%	**(1)** **(1)** **(1)**	Example of calculation $\bar{d} = \frac{(1.40+1.44+1.42+1.41)\ \text{mm}}{4} = 1.42\ \text{mm}$ $\%U = \frac{(1.44-1.40)\ \text{mm}/2}{1.42\ \text{mm}} \times 100\% = 1.41\%$	**3**
12(a)(ii)	• Use of $A = \pi r^2$ • Use of $R = \frac{\rho l}{A}$ • $\rho = 6.9 \times 10^{-7}$ (Ω m), so wire is made from stainless steel	**(1)** **(1)** **(1)**	Example of calculation $A = \pi\left(\frac{1.42 \times 10^{-3}\text{m}}{2}\right)^2 = 1.58 \times 10^{-6}\ \text{m}^2$ $\rho = \frac{0.72\ \Omega \times 1.58 \times 10^{-6}\ \text{m}^2}{1.65\ \text{m}} = 6.9 \times 10^{-7}\ \Omega\ \text{m}$	**3**
12(b)	• Use of $P = \frac{V^2}{R}$ • Use of resistance per unit length • $l = 9.3$ m	**(1)** **(1)** **(1)**	Example of calculation $P = \frac{(230\ \text{V})^2}{65\ \text{W}} = 813.8\ \text{m}$ $l = \frac{813.8\ \text{m}}{87.5\ \Omega\ \text{m}^{-1}} = 9.30\ \text{m}$	**3**

(Total for Question 12 = 9 marks)

Question Number	Acceptable Answer		Additional guidance	Mark
12(a)	• Uses a micrometer screw gauge • Repeats readings at different places/orientations and calculates a mean	(1) (1)	Accept digital vernier callipers	2
12(b)	• Use of $R = \frac{V}{I}$ • Use of $A = \frac{\pi d^2}{4}$ • Use of $R = \frac{\rho l}{A}$ • $\rho = 1.1 \times 10^{-6}\ \Omega\,\text{m}$	(1) (1) (1) (1)	Example Calculation R= 1.96 V / 0.57 A R = 3.44 Ω $A = (\pi \times (0.58 \times 10^{-3}\ \text{m})^2) / 4$ $A = 2.64 \times 10^{-7}\ \text{m}^2$ $\rho = (3.44\ \Omega \times 2.64 \times 10^{-7}\ \text{m}^2) / 0.835\ \text{m}$ $\rho = 1.1 \times 10^{-6}\ \Omega\,\text{m}$	4
12(c)	• The area is determined by d^2 • Percentage uncertainty in diameter is doubled. %U = 2 % • The student's statement is incorrect as percentage uncertainty in diameter squared is the greatest percentage uncertainty	(1) (1) (1)	Example Calculation %U(diameter^2) = 2 × 0.8 % = 1.6 % MP3 dependent on MP1 and 2	3

(Total for Question 12 = 9 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
6(a)	• The measurement of resistance has an uncertainty of 0.6 %	(1)	MP1 accept use of 0.05 giving 0.3 % Example of calculation: Uncertainty in $R = \frac{0.1\Omega}{18.2\Omega} \times 100\% = 0.55\%$ Uncertainty in $L = \frac{0.05\,\text{m}}{1.25\,\text{m}} \times 100\% = 4.0\%$ Uncertainty in $d = \frac{0.01\,\text{m}}{0.27\,\text{m}} \times 100\% = 3.7\%$	4
	• The measurement of the length has an uncertainty of 4 %	(1)		
	• The measurement of the diameter has an uncertainty of 4 %	(1)		
	• The % uncertainty in diameter is doubled giving the greatest amount of uncertainty into the value for the resistivity	(1)		
6(b)	• Measured diameter in multiple places / orientations **and** calculate a mean	(1)	Treat references to resolution of instrument and thickness of wire as neutral	2
	• Calculating a mean reduces the effect of random error	(1)		
6(c)	• Use of $A = \pi r^2$ with r	(1)	MP3 accept $R = 18.15\ \Omega$ MP3. Allow calculation of ρ using given values and subtraction of total % uncertainty. Example of calculation: $A = \pi r^2 = \pi \times (0.13 \times 10^{-3}\,\text{m})^2 = 5.31 \times 10^{-8}\,\text{m}^2$ $\rho = \frac{RA}{L} = \frac{18.1\Omega \times 5.31 \times 10^{-8}\,\text{m}^2}{1.30\,\text{m}} = 7.39 \times 10^{-7}\,\Omega\,\text{m}$	4
	• Use of $R = \frac{\rho L}{A}$	(1)		
	• With at least one of the following values $R = 18.1\ \Omega \quad L = 1.30\ \text{m} \quad A = \pi \times (0.13 \times 10^{-3}\,\text{m})^2$	(1)		
	• $\rho = (7.3 \rightarrow 7.4) \times 10^{-7}\,\Omega\,\text{m}$	(1)		

(Total for Question 6 = 10 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark

Question Number	Acceptable Answer	Additional guidance	Mark
14(a)	• V_{LED} = 0.74 V (read from graph) **(1)** • Use of $V_R = V_{PS} - V_{LED}$ **Or** Use of $R_R = R_{TOTAL} - R_{LED}$ **Or** Use of potential divider principle **(1)** • Use of $V = IR$ **(1)** • R_R = 420 Ω **(1)**	<u>Example of Calculation</u> V_R = 6.0 V – 0.74 V = 5.26 V R_R = 5.26 V / 12.5 × 10^{-3} A R_R = 420 Ω	**4**

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional guidance</th><th>Mark</th></tr>
<tr><td>*14(b)</td><td>
This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
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<tr><td>3-2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
Indicative content
IC1 Positive potential difference from A (to B)

IC2 So there is a current (12.5 mA) in the LED

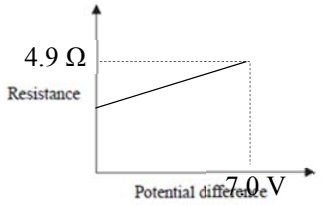
IC3 Therefore LED is lit

IC4 Negative potential difference from B (to C)

IC5 So there is no current in the LED
Or
So resistance of LED is (very) high

IC6 Therefore LED is not lit
</td><td>
The following table shows how the marks should be awarded for structure and lines of reasoning
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</table>
Linkage marks
<table>
<tr><td>Number of indicative content points awarded</td><td>Possible linkage marks</td></tr>
<tr><td>0, 1, 2</td><td>0</td></tr>
<tr><td>3, 4</td><td>1</td></tr>
<tr><td>5, 6</td><td>2</td></tr>
</table>
</td><td>6</td></tr>
</table>

(Total for Question 14 = 10 marks)

Question Number	Acceptable answers	Additional guidance	Mark
14(a)	• Use of $R = V/I$ using pair of points from the graph **(1)** • $R = 4.9\ \Omega$ **(1)**	Example of calculation $R = 7.00\ \text{V} / 1.44\ \text{A}$ $R = 4.86\ \Omega$	**2**
14(b)	• Calculated resistance point plotted correctly at (4.9 Ω, 7.0 V) **(1)** • Resistance increases (constantly) with potential difference **(1)** • Positive intercept with y-axis (less than value from (a)) **(1)**	 MP3 conditional on MP2 being awarded.	**3**

***14(c)**

This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for structure and lines of reasoning

Number of indicative points seen in answer	Number of marks awarded for indicative points
6	4
5-4	3
3-2	2
1	1
0	0

Indicative content

- (As *V* increases) acceleration/velocity/energy of electrons increases
- greater energy transfer in collisions with lattice / ions
- increasing the temperature of metal/filament/ions
- amplitude of vibrations of lattice/ ions increases
- collision (rate) between lattice /ions and electrons increases
  Or shorter distance between collisions
  Or greater chance of collision
- due to the increase in resistance, current doesn't increase in proportion to potential difference
  Or due to the increase in resistance the ratio of I/V decreases

The following table shows how the marks should be awarded for structure and lines of reasoning

	Number of marks awarded for structure and lines of reasoning
Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkage between points and is unstructured	0

Accept charge carriers for electrons and only penalise once for omission of charge carriers or lattice ions

Linkage marks

Number of indicative content points awarded	**Possible linkage marks**
0, 1	**0**
2, 3	**1**
4, 5, 6	**2**

MP1 don't award for 'increased rate of flow'

MP2 to award mark there must be the idea of increased/greater energy transfer between electrons and ions

6

(Total for Question 14 = 11 marks)

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>*9(a)</td><td>This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning.

Indicative content:

IC1 Both circuits are suitable because they allow readings of p.d./current for the lamp

IC2 For circuit 1 the minimum p.d. across the lamp is 0 V (when the slider is at the left)
Or For circuit 2 the minimum p.d. across the lamp is greater than 0 V

IC3 For circuit 1 the maximum p.d. across the lamp is the supply p.d (when the slider is at the right)

IC4 For circuit 2 adjusting the resistor changes the circuit resistance (so the current is varied)
Or for circuit 2 the battery p.d. is shared between lamp and variable resistor

IC5 So for circuit 2 the minimum p.d. depends upon the resistance of the variable resistor,

IC6 Circuit 1 is better because it allows a bigger range
Or Circuit 1 is better because it allows p.d.s down to 0 V to be used</td><td>Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.

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Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning
<table><tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table></td><td>6</td></tr>
<tr><td>9(b)(i)</td><td>• Use of $R = V/I$ (1)
• $V = 2.2$ V (1)</td><td><u>Example of calculation</u>
$V = 17.5 \times 10^{-3}\ \text{A} \times 560\ \Omega = 9.8\ \text{V}$
$\therefore V_{\text{LED}} = (12 - 9.8)\text{V} = 2.2\ \text{V}$</td><td>2</td></tr>
</table>

9(b)(ii)	An explanation that makes reference to the following points: **Either** • The effective resistance of the combination is less than the resistance of the lamp **(1)** • The combination has a smaller fraction of the total circuit resistance **(1)** • Hence a smaller fraction of the supply p.d. falls across the lamp **(1)** **OR** • The effective resistance of the combination is less than the resistance of the lamp **(1)** • The total circuit resistance decreases and the current increases **(1)** • So the p.d. across the resistor increases (so the p.d. across the lamp must decrease) **(1)** **OR** **(1)** • Current flows through voltmeter • So circuit current increases **(1)** **Or** current through resistor increases **(1)** • So the p.d. across the resistor increases		**3**

(Total for Question 9 = 11 marks)

<table>
<tr><th>Question Number</th><th>Acceptable answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr><td>16(a)</td><td>• Use of $P = V^2/R$ (1)
• $R = 4.5\ (\Omega)$ (1)</td><td><u>Example of calculation</u>
$0.50\ W = (1.5\ V)^2 / R$
$R = 4.5\ \Omega$</td><td>2</td></tr>
<tr><td>*16(b)</td><td>This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for indicative content.

Indicative content:

IC1 When slider is at A bulb not lit Or when slider is at A p.d. (across bulb) is zero

IC2 When slider is at B bulb will be lit normally / maximum

IC3 When slider is at B p.d. (across bulb) is 1.5 V

IC4 The brightness of the bulb will increase as slider moves towards B

IC5 The potential difference/current in bulb increases as the slider is moved towards B

IC6 Resistance to right of slider decreases Or resistance of section of potential divider in series with bulb decreases Or bulb lights just before B</td><td><table><tr><th>IC points</th><th>IC mark</th><th>Max linkage mark available</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table>
Accept "supply voltage" for 1.5 V

Accept resistance to left of slider increases Or resistance of section of potential divider in series with bulb is large</td><td>6</td></tr>
</table>

16(c)	• Initial p.d. across the capacitor is zero **Or** Initial p.d. across bulb will be 1.5 V/maximum **Or** initial current is maximum • Bulb will be bright/lit initially • As capacitor charges the brightness of bulb decreases • Exponential decrease **Or** The time constant is 6.0 s (so the process will be of the order of 25 − 35 s)	**(1)** **(1)** **(1)** **(1)**	Accept pd across capacitor increasing so brightness of bulb decreases MP4 for correct calculation of time constant Example of calculation $RC = 5.0\ \Omega \times 1.2\ \text{F} = 6.0\ \text{s}$	**4**

(Total for Question 16 = 12 marks)

Question Number	Acceptable answers	Additional guidance	Mark
3	A uses the parallel resistors equation $\frac{1}{R_T} = \frac{1}{R} + \frac{1}{R} = \frac{2}{R}$	$\frac{R}{2}$	**1**
	B assumes resistors in parallel have the same total R as each individual R C is the addition of both resistances as if they were in series D is the product of both resistances		

10	A The p.d. across the resistor added to the p.d. across the thermistor must equal 6 V. This occurs when the current is 0.5 A.	0.5	**1**
	B assumes all the p.d. is across the thermistor C assumes that resistor and thermistor connected in parallel D assumes that the p.d. across the resistor and thermistor is more than 6 V		

(Total for Multiple Choice Questions = 10 marks)

5	**D Step 4**	**1**
	Incorrect Answers: A – this step uses the conservation of energy B – this step is just a statement of Ohm's law C – this step uses the conservation of energy	

Question Number	Acceptable answers	Additional guidance	Mark
1	**The only correct answer is D** A *is not correct because as it is 2A + 1A* B *is not correct because 2A +2A* C *is not correct because 2A + 3A*	6 A	**1**

Question Number	Acceptable answers	Additional guidance	Mark
4	C		**1**

7	**B** Equivalent R = $(1/R + 1/2R)^{-1}$	**1**
	Incorrect Answers: **A** – wrong expression **C** – wrong expression **D** – wrong expression	

Question Number	Acceptable answers	Additional guidance	Mark
4	**The only correct answer is D** A is not correct as current through 60 Ω is 4 A so $I = 6$ A B is not correct as current through 60 Ω is 4 A so $I = 6$ A C is not correct as current through 60 Ω is 4 A so $I = 6$ A		1

Question Number	Acceptable answers	Additional guidance	Mark
5	**The only correct answer is B** A is not correct as 120 Ω / 3 = 40 Ω C is not correct as 120 Ω / 3 = 40 Ω D is not correct as 120 Ω / 3 = 40 Ω		1

Question Number	Acceptable answers	Additional guidance	Mark
9	• Use of $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2}$ for resistors in parallel **(1)** • Use of $R_T = R_1 + R_2$ for resistors in series **(1)** • R_T = 47 Ω **(1)**	Example Calculation $\frac{1}{R_P} = \frac{1}{30} + \frac{1}{40}$ R_P = 17 Ω R_T = 20+17+10 = 47 Ω	**3**

(Total for Question 9 = 3 marks)

Question Number	Acceptable answers	Additional guidance	Mark
9	• When variable resistor is 0 Ω voltmeter reading = 6.0 V **(1)** • Use of principle of potential divider **Or** use of $V = IR$ **(1)** • When variable resistor is 40 Ω voltmeter reading = 1.2 V **(1)**	Example of calculation V = (10 Ω / 50 Ω) × 6 V = 1.2 V	**3**

(Total for Question 9 = 3 marks)

Question Number	Acceptable answers	Additional guidance	Mark
9(a)	• 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
9(b)	**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)** • $R_v = 240$ (Ω) **(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)** • $R_v = 240$ (Ω) **(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

(Total for Question 9 = 6 marks)

Question Number	Acceptable answers	Additional guidance	Mark
12a	• use of $V = IR$ for the ammeter **(1)** • calculates current through the shunt **(1)** • Shunt resistance = 9.0×10^{-3} (Ω) (dependent on MP2) **(1)** Alternative if using $1/R$ rule for parallel resistors • use of $V = IR$ for the ammeter • Calculates equivalent resistance of the circuit • Uses $1/R$ rule to calculate shunt resistance = 9.0×10^{-3} (Ω)	Example of calculation: $V = 1.0 \times 10^{-3}\ \text{A} \times 18\ \Omega = 0.018\ \text{V}$ $I = 2.0A - 0.001\ \text{A} = 1.999\ \text{A}$ $R = \frac{0.018\ \text{V}}{1.999\ \text{A}} = 9.0 \times 10^{-3}\ \Omega$ Alternative: $V = 1.0 \times 10^{-3}\ \text{A} \times 18\ \Omega = 0.018\ \text{V}$ $R_T = \frac{0.018\ \text{V}}{2\text{A}} = 0.009\ \Omega$ $\frac{1}{0.009} = \frac{1}{18} + \frac{1}{R_S}$ $R_S = 9.0 \times 10^{-3}\ \Omega$	**3**
12b	• Use of πr^2 **(1)** • Use of $R = \rho l/A$ **(1)** • Length = 0.056 m **(1)**	Example of calculation: Area $= \pi(0.95 \times 10^{-3}\text{m})^2 = 2.8(4) \times 10^{-6}\ \text{m}^2$ $l = \frac{9.0 \times 10^{-3}\Omega \times 2.8(4) \times 10^{-6}\ \text{m}^2}{4.55 \times 10^{-7}\ \Omega\ \text{m}} = 0.0\ 56\ \text{m}$ "Show that" value $l = 0.062$ m	**3**

(Total for Question 12 = 6 marks)

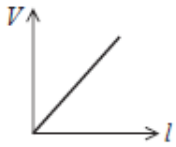
<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>*3</td>
<td>This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning.

Indicative content:
IC1 Before closing S2, bulb 1 and bulb 2 have the same p.d./current so both bulbs have equal brightness
IC2 Closing switch S2 allows current to flow in bulb 3 Or Closing switch S2 places the same p.d. across bulb 3 as bulb 1.
IC3 Bulb 1 and bulb 3 are in parallel, so the resistance of the combination decreases
IC4 The p.d. across bulb 1 (and bulb 3) decreases Or The p.d. across bulb 2 increases
IC5 The current in circuit/bulb 2 increases so the brightness/power of bulb 2 increases Or current in bulb 1 decreases so the brightness/ power of bulb 1 decreases Or $P = \frac{V^2}{R}$, so power of bulb 2 increases [power of bulb 1 decreases]
IC6 (When S2 closed) bulb 1 is not as bright as bulb 2.</td>
<td>Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
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</table>
</td>
<td>6</td>
</tr>
</table>

(Total for Question 3 = 6 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
6(a)	• See $I = I_1 + I_2$ • Use of $I = \frac{V}{R}$ with the same V for every term • Algebra to show $\frac{1}{R_{\text{eff}}} = \frac{1}{R_1} + \frac{1}{R_2}$	**(1)** **(1)** **(1)**	If student assumes that $R_1 = R_2 = R \rightarrow R_{\text{eff}} = \frac{R}{2}$, then MP1 and MP2 only For MP3, can assume algebra if equation seen Example of derivation $I = I_1 + I_2 \quad I = \frac{V}{R}$ $\therefore \frac{V}{R_{\text{eff}}} = \frac{V}{R_1} + \frac{V}{R_2}$	**3**
6(b)	• If two springs are added in parallel the stretching force is shared between the springs • Hence the extension for a given force is half of what it would be for a single spring • So parallel combination has twice the stiffness of a single spring • For two identical resistors in parallel $\frac{1}{R_{\text{eff}}} = \frac{1}{R} + \frac{1}{R}$ • So, adding two equal resistors in parallel halves the effective resistance of the combination • This is in contrast to the springs and so the student's suggestion is invalid (dependent upon MP3 and MP5)	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	MP3: Allow parallel combination has a greater stiffness than a single spring MP5: Allow adding two resistors in parallel decreases the effective resistance of the combination Equivalent points for MP4 – MP6 • For two identical resistors in series, $R_{\text{eff}} = R + R$ • So adding two equal resistors in series doubles/increases the effective resistance • This is equivalent to parallel springs, so the student's statement is invalid (dependent upon MP3 and MP5)	**6**

(Total for Question 6 = 9 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
3	**A** 		1

Question Number	Acceptable answers	Additional guidance	Mark
6	D In the dark the resistance of the LDR will be very large so practically all the potential difference of 6V will be across it.	a little below 6 V	**1**
	A assumes the resistance of the LDR decreases to almost zero B assumes the resistance of the LDR decreases a little C assumes the resistance of the LDR increases a little		

7	**D** $\frac{R_2}{R_1+R_2}V$	**1**
	Incorrect Answers: A – this looks similar to the correct formula but has an incorrect resistance as the numerator and does not have the total resistance as the denominator B – this looks similar to the correct formula with the correct resistance as the numerator but does not have the total resistance as the denominator C – This would give the PD across resistor R_1 and not R_2	

8	**A dark and cold**	**1**
	Incorrect Answers: B – correct description for LDR but incorrect for thermistor C – incorrect description for LDR but correct for thermistor D – incorrect description for LDR and incorrect for thermistor	

(Total for Multiple Choice Questions = 8 marks)

Question Number	Acceptable answers	Additional guidance	Mark
7	**The only correct answer is B** A is not correct as the p.d. across the resistor will increase C is not correct as the resistance of the LDR will decrease D is not correct as the resistance of the LDR will decrease		1

Question Number	Answer	Additional Guidance	Mark
7	**B is the only correct answer**	A is incorrect because this does not give the correct ratio C is incorrect because this does not give the correct ratio D is incorrect because this does not give the correct ratio	**1**

Question Number	Acceptable answers	Additional guidance	Mark
11(a)	• Current (in the circuit) decreases **(1)** • P.d. across the LDR decreases **(1)** • Voltmeter reading increases **(1)** (MP3 dependent on MP1 or MP2)	Accept approaches using potential divider theory • Pd from supply divides in ratio of resistances of the two components, eg. $V_{\text{LDR}} = \frac{R_{\text{LDR}}}{R_{\text{R}} + R_{\text{LDR}}} \times V_{\text{Total}}$ • As R_R increases, but R_{LDR} stays constant • So voltmeter reading increases (MP3 dependent on MP1)	**3**
11(b)	• Use $V=IR$ to calculate current **(1)** • Use $V=IR$ with V = 6.5 V to calculate LDR resistance **(1)** • Light intensity = 185 (lux) (accept answers in range 180 lux -190 lux) **(1)** **OR** • Use of potential divider principle **(1)** • Use of $R_T = R_{LDR} + 4.5k\Omega$ to calculate LDR resistance **(1)** **Or** Use of V_{LDR} = 6.5 V to calculate LDR resistance • Light intensity = 185 (lux) (accept answers in range 180 lux -190 lux) **(1)**	Example of Calculation. 2.5 V = $I \times 4.5\text{x}10^3\ \Omega$ $I = 5.6 \times 10^{-4}$ A 6.5 V = $0.56\text{x}10^{-3}$ A × R $R = 11700\ \Omega$	**3**

(Total for Question 11 = 6 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
11(a)	• Use of $R = \frac{V}{I}$ for the 45 Ω resistor	(1)	Example of calculation I = 5.5 V / 45 Ω = 0.12 A R_{total} = 15 V / 0.12 A = 125 Ω $R_{variable\ resistor}$ = 125 Ω – 45 Ω = 80 Ω	
	• Use of $R = \frac{V}{I}$ for the whole circuit **Or** Use of $R = \frac{V}{I}$ for the resistor R	(1)		
	• $R_{variable\ resistor}$ = 80 (Ω)	(1)		
	OR		e.g. ratio of resistances equated to ratio of p.d.s	
	• Applies the principles of a potential divider circuit	(1)		
	• Use of $R_{total} = R_{variable\ resistor}$ + 45 Ω **Or** Use of 15 V = $V_{variable\ resistor}$ + 5.5 V	(1)		
	• $R_{variable\ resistor}$ = 80 (Ω)	(1)		**3**

11(b)	EITHER • Decreased resistance for parallel combination of motor with 45 Ω resistor **(1)** • So lower (proportion of the total) potential difference across motor, **(1)** • hence potential difference is too low and motor runs slowly **(1)** OR • higher total current in circuit/battery **(1)** • potential difference across R increases, so potential difference across motor decreases **(1)** • hence potential difference is too low and motor runs slowly **(1)**		**3**

(Total for Question 11 = 6 marks)

Question Number	Acceptable answers	Additional guidance	Mark
11 (a)(i)	• Use of $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$ to determine the total resistance of the parallel branch **(1)** • R_{TP} = 8.0 kΩ **(1)** • Comparison of measured to actual resistance **(1)** **OR** • Same p.d. across thermistor and voltmeter **(1)** • Calculation of ratio of currents **(1)** • States that current through voltmeter is significant **(1)**	Example of calculation $\frac{1}{R_{TP}} = \frac{1}{9.7\ \text{k}\Omega} + \frac{1}{45\ \text{k}\Omega}$ R_{TP} = 7.98 kΩ MP3: 7.98 kΩ is significantly less than 9.7 kΩ, so unsuitable MP3 dependent on MP2	**3**
11(a)(ii)	• Current flows through the voltmeter **(1)** • But in the new arrangement, the ammeter would read only the current passing through the thermistor **Or** current through ammeter equals current through thermistor **(1)**		**2**

11(b)	• As temperature increases number of (free) charge carriers (in thermistor) increases so its resistance decreases **Or** As temperature increases number of charge carriers in conduction band increases so (thermistor) resistance decreases **(1)** • Thermistor resistance as a proportion of total resistance decreases **Or** Current increases so p.d. across resistor increases **(1)** • P.D. (across thermistor) decreases **(1)**	Accept electrons for charge carriers	**3**

(Total for Question 11 = 8 marks)

Question Number	Acceptable answers	Additional guidance	Mark
13(a)	• 30 lux corresponds to 3000 Ω **(1)** • Use of ratio of resistances **(1)** • Use of corresponding ratio of p.d.s **(1)** • To a p.d. of 0.7 (V) **(1)** • if light goes above this level then resistance of LDR decreases **(1)** • so p.d. to transistor increases so does perform as required **(1)** MP6 dependent on MP5	Example of calculation $\frac{V}{7.0} = \frac{333}{333 + 3000}$ $V = 0.70$ V Alternative for MP2 and MP3 • Use of $I = V/R$ for whole circuit • Use of $V = IR$ for 333 Ω resistor Example of calculation $I = 7.0$ V/ $(333 + 3 \times 10^3)$ Ω $= 2.1 \times 10^{-3}$ A $V = 2.1 \times 10^{-3}$ A ×333 Ω = 0.7 V	6
13(b)	An explanation that makes reference to the following points: • more electrons move into a conduction band **Or** more electrons become free **(1)** • with (increased light level) so resistance decreases **(1)** MP2 dependent on MP1		2

(Total for Question 13 = 8 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
9(a)(i)	**MAX 3** • Intensity of light varies as an inverse square law **Or** reference to $I = \frac{P}{4\pi d^2}$ **(1)** • the light intensity would not increase uniformly (decreasing the distance as suggested) **(1)** • The student should decrease the distance at decreasing intervals **(1)** • The student should use a greater range (of distances, as lamp is not a point source of light) **(1)**		**3**
9(a)(ii)	An explanation that makes reference to the following points: **EITHER** • Carry out experiment under subdued lighting **(1)** • As the ambient lighting will increase the ammeter reading [dependent upon MP1] **(1)** **OR** • Take readings at eye level **(1)** • As this will reduce parallax error [dependent upon MP3] **(1)** **OR** • Take multiple readings of intensity and calculate a mean **(1)** • As this will reduce the effect of <u>random</u> error [dependent upon MP5] **(1)**	Allow: Keep the intensity of the lamp constant **Or** Keep angle of lamp constant As this would change the ammeter reading [dependent upon MP1	**2**

9(b)	An explanation that makes reference to the following points: • <u>Photons</u> incident upon LDR promoted electrons into conduction band **Or** <u>photons</u> incident upon LDR released conduction electrons **(1)** • Number of free electrons (per unit volume) increases **(1)** • Current $I = nqvA$ so the current increases **Or** $I \propto n$ so the current increases **(1)**	If no other marks scored, allow MAX 1 for resistance decreases and so current increases. Accept "charge carriers" for "free electrons"	**3**

(Total for Question 9 = 8 marks)

Question Number	Acceptable Answers	Additional Guidance	Mark
16(a)	A description that makes reference to **two** of the following: • No need for further calculation **Or** gives a value for resistance without calculation **(1)** • No need for an additional power supply **(1)** • Uncertainties caused by two devices is (possibly) greater than that caused by one device **(1)**	Do not accept more precise **or** no parallax **or** quicker	**2**
16(b)(i)	• (As applied force increases) the length (*l*) (of wire) increases/stretches **Or** the wire is longer **(1)** • the resistance increases with reference to $R = \frac{\rho l}{A}$ **(1)**	Reference to formula may be in terms of proportionality or direct quote of equation Do not accept change in resistivity	**2**
16(b)(ii)	• Use of $GF = \frac{\Delta R}{\epsilon R}$ **(1)** • Substitution of $\epsilon = \frac{\Delta w}{w}$ into GF equation **(1)** • $\Delta w = 2.5 \times 10^{-5}$ m **(1)**	(*x* may seen in place of *w*) Example of calculation: $GF = \frac{\Delta R}{\epsilon R}$ $2 = \frac{0.001}{\Delta w / (5 \times 10^{-2})}$ $\Delta w = 2.5 \times 10^{-5}$ m Accept 2.5×10^{-3} cm / 2.5×10^{-2} mm	**3**
16(c)	An explanation that makes reference to the following: • As small changes (in w) are multiplied many times **Or** can use a longer wire (on a small gauge) **Or** to achieve a greater change in the length **(1)** • (So) greater sensitivity **Or** larger changes in R (for a given change in width) **(1)**		**2**

(Total for Question 16 = 9 marks)

Question Number	Acceptable answers		Additional Guidance	Mark
11a	• Use of $R = \frac{\rho l}{A}$ • Use of area formula with correct value of radius • $R = 8.9\ \Omega$	**(1)** **(1)** **(1)**	Use of: any dimensionally correct substitutions eg using a diameter squared Accept R=8.62 as due to rounding Area Example of calculation: $R = 1.12 \times 10^{-6}\ \Omega\,m \times 1m / \pi(0.2\times10^{-3})^2\ m^2$	**3**
11bi	• As resistance increases with length of wire • potential (difference) proportional to length of wire	**(1)** **(1)**	Alt to MP1: Current same through whole length of wire and $V=IR$	**2**
11bii	• Use of ratio of lengths = ratio of potentials • Potential at P = 1.13 V	**(1)** **(1)**	Alternative method uses ratio of resistances. Example of calculation: $= \frac{75.0}{100} \times 1.50$ $= 1.125V$	**2**
11(c)	**Either** • Calculates current correctly using $I=V/R$ • $R = 1.10\ \Omega$ **Or** • Use of ratios of lengths = ratios of resistances • $R = 1.10\ \Omega$ **Or** • Use ratio of resistances = ratio of p.d.s • $R = 1.10\ \Omega$	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	Show that value gives 1.2 Ω Example of calculation: $I = \frac{1.125}{3.30} = 0.34A$ $R = \frac{0.375}{0.34} = 1.1\Omega$ Or $\frac{R}{3.30} = \frac{25}{75}$	**2**

(Total for Question 11 = 9 marks)

Question Number	Acceptable Answers	Additional Guidance	Mark

Question Number	Acceptable Answers	Additional guidance	Mark
17(a)	• Increasing light intensity increases rate of photons/energy arriving at LDR (1) • More electrons gain enough energy to be released/free to conduct (1) • Greater number of conduction electrons per unit volume (1) • $I = nAvq$ so current increases and resistance decreases (1)		4
17(b)	• Use of $I = \frac{P}{A}$ **and** $P = \frac{E}{t}$ (1) • $E =$ 2.6 J (1)	Example of calculation $P = 1100\ W\ m^{-2} \times 4.0 \times 10^{-5}\ m^2 = 4.4 \times 10^{-2}\ W$ $E = 4.4 \times 10^{-2}\ W \times 60\ s = 2.64\ J$	2
17(c)	• Unpolarised light oscillates in many planes (1) • The light perpendicular to the plane of polarisation of the filter is absorbed **Or** only light parallel to the plane of polarisation of the filter is transmitted (1) • So polarised light oscillates in only one plane (1) • So light intensity is reduced (1)	dependent upon MP2 or MP3	4

(Total for Question 17 = 10 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
12(a)	An explanation that makes reference to the following: • The idea that the <u>electrons</u> gain energy from the light **(1)** • (As the lamp is moved towards the LDR) the intensity/brightness/illumination of light falling on the LDR increases **(1)** • This increased the number of (conduction) electrons **(1)** • Which reduced the resistance of the LDR **(1)** • decreasing the potential difference across the LDR **Or** increasing the potential difference across the fixed resistor/voltmeter **(1)**	MP1 e.g. If the frequency of the light is high enough the electrons will gain energy from the light (and jump to the conduction band) MP2 assume the answer is in terms of the lamp moving towards the LDR unless stated otherwise MP3 accept charge carrier (density) for electrons	**5**

12(b)	• potential difference across the LDR = 3.6 V **Or** $\frac{R}{(R+75\ \Omega)}$ seen **Or** $\frac{75\ \Omega}{(R+75\ \Omega)}$ seen **(1)** • Use of $V = IR$ **(1)** **Or** resistance ratio × 6.0 V = corresponding p.d. **(1)** • $R = 110\ \Omega$	MP2 use of $V = IR$ with 2.4 V or 3.6 V only <u>Example of calculation</u> $I = 2.4\ V/75\ \Omega = 0.032\ A$ Voltage across LDR = 6.0 V – 2.4 V = 3.6 V $R = \frac{3.6\ V}{0.032A}$ $R = 112.5\ \Omega$ **Or** use of ratios $\frac{75\ \Omega}{(R+75\ \Omega)} \times 6.0\ V = 2.4\ V$ $R = 112.5\ \Omega$	**3**
12(c)	An explanation that makes reference to the following: • Combined resistance of (light) bulb and LDR is about 3 Ω (in the dark) **Or** the combined resistance is less than the resistance of bulb/LDR **(1)** • The combined resistance is always much less than the (75 Ω) fixed resistance **(1)** • The p.d. across the bulb will be much less than 3 V and so the bulb will **not** come on (in the dark). **(1)**	MP3: accept the idea that the p.d. across the bulb is never high enough to make the bulb come on in the dark	**3**

(Total for Question 12 = 11 marks)

Question Number	Acceptable answers	Additional guidance	Mark
17(a)	• V at top/start = 0V **Or** recognition "potential divider" **Or** V increases (by implication) **Or** V at bottom = 1.5V **(1)** • Two sections of wire act as series resistors **Or** $R=\rho l/A$ **Or** comment about R proportional to length **Or** $\frac{V}{1.5}=\frac{R}{R_T}$ **(1)** • potential difference proportional to length of wire **(1)**	**Alternative MS** Constant Current (I) in wire (1) p.d. across section of wire = Ir between A and loop (1) Increases from 0V to 1.5V linearly (1)	**3**
17(b)	• Tangent drawn at 1.5 s **(1)** • Scales p.d. to give distance **(1)** • Gradient determined using a base of triangle of at least 1.0 s **Or** use of $s=\frac{(u+v)}{2}t$ **and** correct V read from graph **(1)** • velocity = 1.0 m s^{-1} – 1.3 m s^{-1} **(1)**	Example of calculation Gradient = $\frac{1.1\text{V}-0.2\text{V}}{1.0\text{s}}=0.9\text{Vs}^{-1}$ As 1.5 V represents 2.00 m v = 0.9 Vs^{-1} × $\frac{2.00\text{m}}{1.5\text{V}}$ = 1.2 ms^{-1}	**4**
17(c)	• Use of $v=u+at$ **(1)** • Use of $a=g\sin\theta$ **(1)** • Calculates a value for a, θ or v (using a SUVAT AND $a=g\sin\theta$) **(1)** • Valid comparison of their calculated quantity and the stated quoted uncertainty. **(1)**	Example of calculation $1.5\,\text{ms}^{-1}=1.2\,\text{m s}^{-1}+\text{a}\times0.5\,\text{s}$ $a=\frac{0.3\,\text{m s}^{-1}}{0.5}=0.6\,\text{m s}^{-2}$ $0.6\,\text{m s}^{-2}=9.81\,\text{m s}^{-2}\sin\theta$ $\theta=3.6^{\circ}$	**4**

(Total for Question 17 = 11 marks)

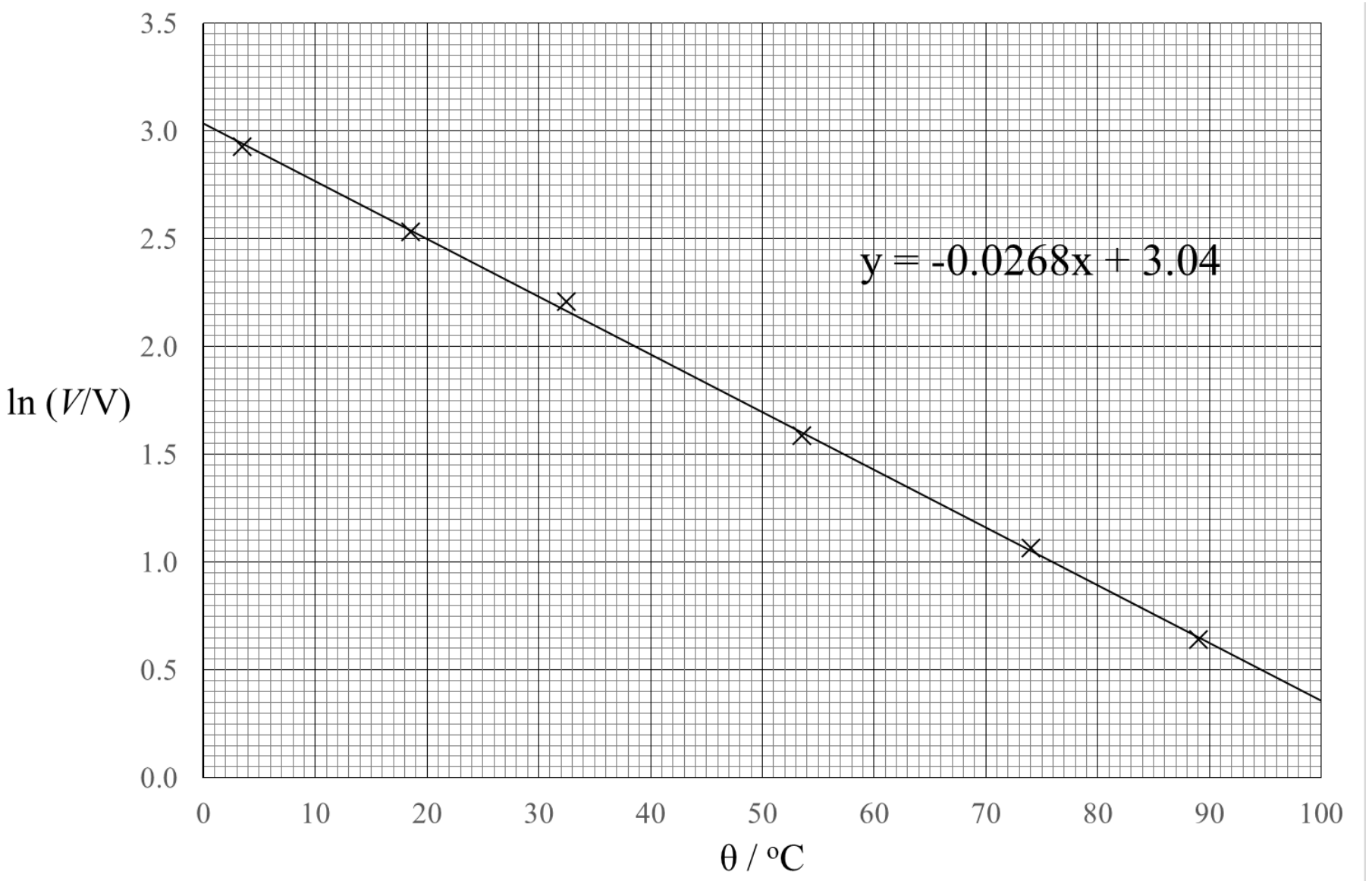
Question Number	Acceptable answers	Additional guidance	Mark
12(a)	• connect thermistor to an ohmmeter to measure its resistance **(1)** • Use a water bath eg beaker of water and immerse the thermistor **(1)** • measure the temperature of the water using a thermometer **(1)** • vary temperature and measure the resistance at fixed intervals **(1)** • Thermometer held in retort stand to make beaker stable **Or** Leads clamped to make beaker stable **(1)** • detailed point such as stir water **(1)**	alt based on ammeter/voltmeter combination alternative methods eg vary *T* by using boiling water from a kettle and allow to cool alternative safety: plenty of space around apparatus **Or** Safety glasses in case of splashes stand **Or** heatproof mat as boiling water alternative detail: ensure eye level with thermometer **Or** adjust ohmmeter to give maximum sig fig without final figure varying randomly **Or** allow time for thermistor to reach water temperature **Or** keep thermometer and thermistor close to one another	**6**

12(b)	• resistance values have been taken every 10° take more values say at 25 °C and 35 °C when *R* is changing more **(1)** • Widen the range – can find *R* up to 100 °C ie boiling water Or decrease *t* below room temperature by adding ice **(1)** • Repeat experiment measuring *R* at the same temperatures then average *R*'s **(1)**		**2Max**
12(c)	• Increased temperature causes more energy transfer to lattice ions / atoms **(1)** • More charge carriers released / available **(1)** • $I = nAvq$, so relative increase in *I* **(1)** • Reference to $R = V / I$ to justify decrease in *R* **(1)**	Or reverse argument	**4**

(Total for Question = 12 marks)

Question Number	Acceptable Answer		Additional Guidance	
11(a)	An explanation that makes reference to the following points: • The number of (free) charge carriers (per unit volume) in the thermistor decreased • (Hence) the resistance of the thermistor increased • And a larger fraction of supply p.d. is across the thermistor	**(1)** **(1)** **(1)**	MP1: Electrons okay for charge carriers MP3: Current in circuit decreases, so p.d. across fixed resistor decreases, therefore p.d. across thermistor increases	**3**
11(b)(i)	An explanation that makes reference to the following points: • Shows expansion $\ln(V) = \ln(V_0) - b\theta$ • Compares with $y = mx + c$ and shows that m is $(-)b$	**(1)** **(1)**		**2**
11(b)(ii)	• Ln values correct and to 2 or 3 decimal places • Labels and unit • Scales • Plots • Line of best fit	**(1)** **(1)** **(1)** **(1)** **(1)**	θ /°C | V /V | ln (V/V) | ln (V/V) 89.0 | 1.9 | 0.642 | 0.64 74.0 | 2.9 | 1.065 | 1.06 53.5 | 4.9 | 1.589 | 1.59 32.5 | 9.1 | 2.208 | 2.21 18.5 | 12.6 | 2.534 | 2.53 3.5 | 18.7 | 2.929 | 2.93	**5**
11(b)(iii)	• Gradient determined using large triangle • b in range (0.026 → 0.028) °C^{-1} to 2 or 3 sf with unit • Inverse ln of intercept determined • V_0 in range (19 → 22) V	**(1)** **(1)** **(1)** **(1)**	MP2: unit can be K^{-1} Example of calculation: $\text{gradient} = \frac{(3.04 - 0.35)}{(0 - 100)\ ^{o}\text{C}} = -0.027\ ^{o}\text{C}^{-1}$ $V_0 = e^{3.0}\ \text{V} = 20.1\ \text{V}$	**4**

(Total for Question 11 = 14 marks)


y = -0.0268x + 3.04
ln (V/V)
θ / °C
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
70
80
90
100

Question Number	Acceptable Answer	Additional Guidance	Mark
11(a)	An explanation that makes reference to the following points: • When S is at end X, V is zero **Or** When S is at end Y, V equals supply (terminal) p.d. **(1)** • The resistance (between X and S) is proportional to the length XS **Or** As S is moved towards Y the supply p.d. is divided in proportion to the resistance to the left and right of S **(1)** • V increases as the slider moves from X to Y **(1)**	If both versions of MP1 given, then give MP3 too.	**3**
11(b)	An explanation that makes reference to the following points: • (As V increases) I increases, so the temperature of the filament increases **(1)** • So the resistance of the filament increases (so the increase in current per unit increase in p.d. decreases) **(1)**	Allow filament heats up for "temperature of filament increases"	**2**
11(c)(i)	An explanation that makes reference to the following points: • Shows expansion $\log(T) = \mathrm{b}\log V + \log a$ **(1)** • Compares with $y = mx + c$ and states/indicates that the gradient is b (which is a constant) **(1)**		**2**

<table>
<tr>
<td>11(c)(ii)</td>
<td>
• Log values correct and to 2 or 3 decimal places (1)
[Allow either a consistent number of d.p. or s.f. in values for logV]

• Labels and unit (1)
[check correct representation of units on graph]

• Scales (1)
[Must not be an awkward scale, points must be spread over at least half the graph grid]

• Plots (1)
[check the 2 points furthest from the line, if all points on line check any 2 points]

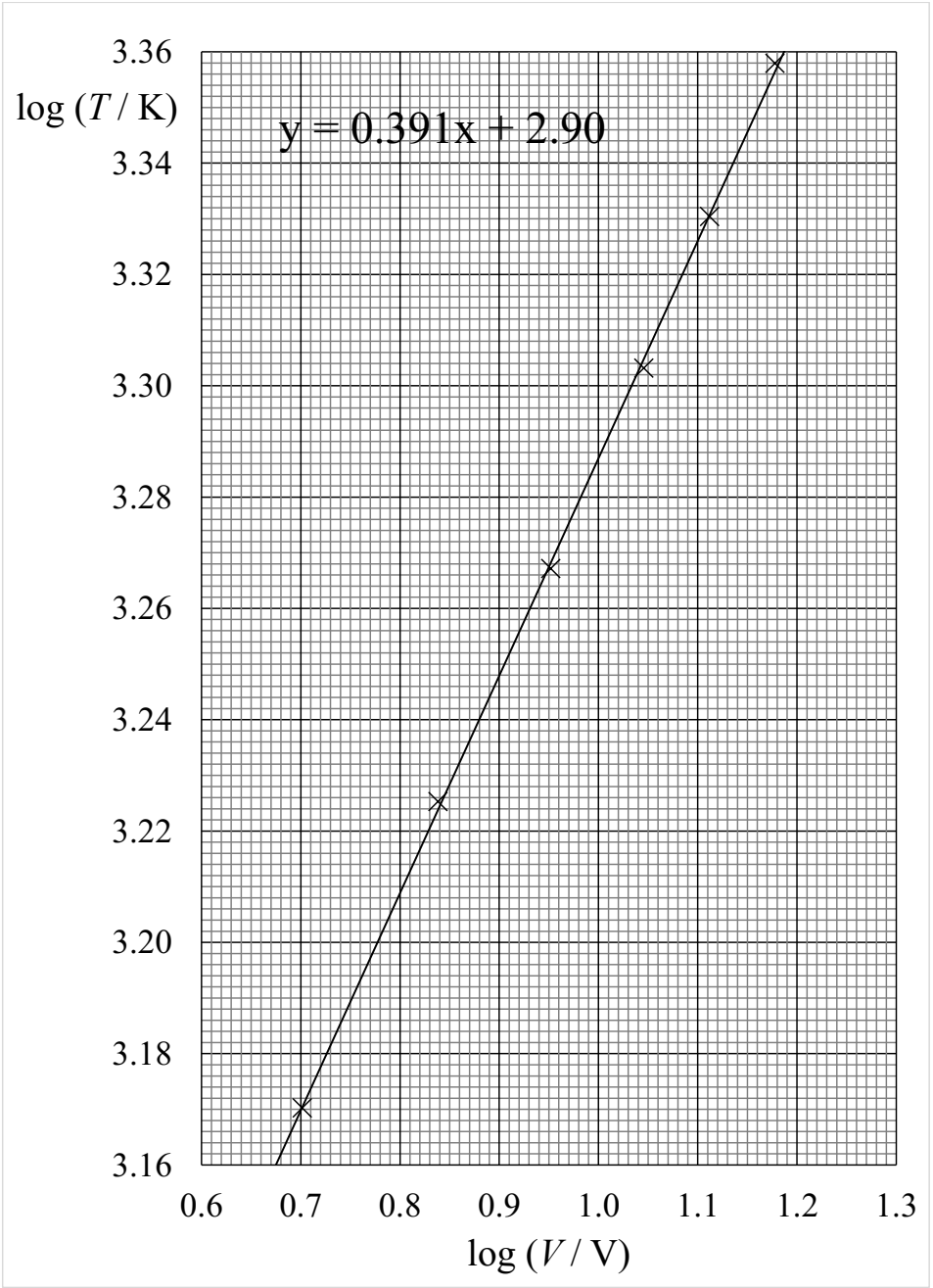
• Line of best fit (1)
[If not all points on line, look for balanced spread of points above and below line]
</td>
<td>
<table>
<tr><th>V / V</th><th>T / K</th><th>log (V / V)</th><th>log (T / K)</th></tr>
<tr><td>5.03</td><td>1480</td><td>0.702</td><td>3.170</td></tr>
<tr><td>6.89</td><td>1680</td><td>0.838</td><td>3.225</td></tr>
<tr><td>8.95</td><td>1850</td><td>0.952</td><td>3.267</td></tr>
<tr><td>11.11</td><td>2010</td><td>1.046</td><td>3.303</td></tr>
<tr><td>12.94</td><td>2140</td><td>1.112</td><td>3.330</td></tr>
<tr><td>15.06</td><td>2280</td><td>1.178</td><td>3.358</td></tr>
</table>

<table>
<tr><th>V / V</th><th>T / K</th><th>ln (V / V)</th><th>ln (T / K)</th></tr>
<tr><td>5.03</td><td>1480</td><td>1.615</td><td>7.300</td></tr>
<tr><td>6.89</td><td>1680</td><td>1.930</td><td>7.427</td></tr>
<tr><td>8.95</td><td>1850</td><td>2.192</td><td>7.523</td></tr>
<tr><td>11.11</td><td>2010</td><td>2.408</td><td>7.606</td></tr>
<tr><td>12.94</td><td>2140</td><td>2.560</td><td>7.669</td></tr>
<tr><td>15.06</td><td>2280</td><td>2.712</td><td>7.732</td></tr>
</table>
</td>
<td>5</td>
</tr>
<tr>
<td>11(c)(iii)</td>
<td>
• Gradient determined using large triangle (1)

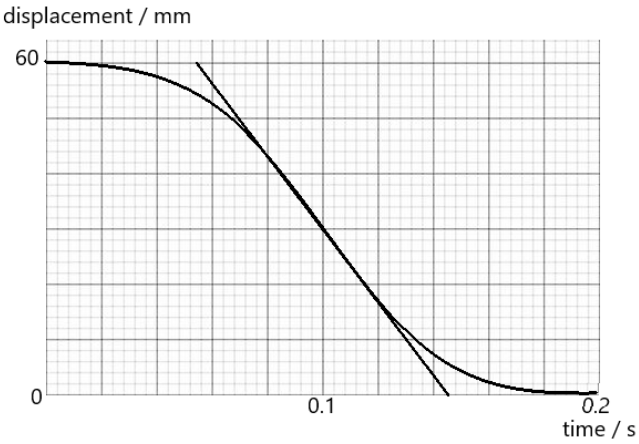
• b = 0.38 0.40 (2 or 3 sf) (1)
</td>
<td>
<u>Example of calculation</u>

$\text{gradient} = \frac{3.32 - 3.18}{1.09 - 0.73} = 0.389$
</td>
<td>2</td>
</tr>
</table>

(Total for Question 11 = 14 marks)


y = 0.391x + 2.90
log (T / K)
3.36
3.34
3.32
3.30
3.28
3.26
3.24
3.22
3.20
3.18
3.16
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
log (V / V)

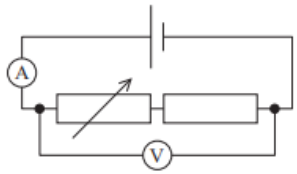
Question Number	Answer		Additional Guidance	Mark
18(a)	• Use of Area = width × thickness • Use of $R = \frac{\rho l}{A}$ • thickness = 9.4×10^{-4} m	**(1)** **(1)** **(1)**	Example of calculation: $12 \times 10^{3}\,\Omega = \frac{0.49\ \Omega\ \text{m} \times 0.115\ \text{m}}{0.0050\ \text{m} \times t}$ thickness = 9.4×10^{-4} m	**3**
18(b)(i)	• uses ratio of lengths to determine p.d. across potentiometer • V = 9.6 (V)	**(1)** **(1)**	Example of calculation: p.d. across potentiometer = $\frac{115\ \text{mm}}{60\ \text{mm}} \times 5\ \text{V} = 9.6\ \text{V}$	**2**
18(b)(ii)	• determines p.d. across R • apply $V = IR$ to potentiometer to determine current **Or** uses ratio of resistances = ratio of p.d.s • R = 3000 Ω	**(1)** **(1)** **(1)**	Example of calculation: current in circuit = $\frac{9.6\ \text{V}}{12000\ \Omega} = 8.0 \times 10^{-4}$ A p.d. across R = 12 – 9.6 = 2.4 V $R = {}^{2.4\ \text{V}}/_{8.0 \times 10^{-4}\text{A}}$ R = 3000 Ω (show that value gives 2400 Ω)	**3**
18(b)(iii)	• A battery has internal resistance • There is a p.d. across the internal resistance • Terminal p.d. less (than e.m.f.) **Or** refers to $V = E - Ir$	**(1)** **(1)** **(1)**	Accept “lost volts” for MP2 V must be the subject	**3**

18(b)(iv)	• tangent drawn on the curve • uses a triangle base of at least 0.06 s • attempt to find a gradient • velocity = 0.68 m s^{-1} so velocity not exceeded allow range from to 0.60 m s^{-1} to 0.80 m s^{-1}	**(1)** **(1)** **(1)** **(1)**	MP2 dependent on MP1  v = gradient = $\frac{60 \text{ mm}}{0.144 - 0.056}$ v = 682 mm s^{-1}	**4**

(Total for Question 18 = 15 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
4	**D** Work done per unit charge to move a charge around a circuit.		**1**

Question Number	Acceptable answers	Additional guidance	Mark
2	**The only correct answer is A** B *is not correct because V decreases as I decreases* C *is not correct because I decreases as R increases* D *is not correct because I decreases as R increases*	decreases decreases	**1**

7	**A**  	**1**
	Incorrect Answers: B – the ammeter would measure the current in the cell, but the voltmeter would not be measuring the p.d. across the cell C – the voltmeter would measure the p.d. across the cell but the ammeter would not be measuring the current in the cell D – the voltmeter would measure the p.d. across the cell but the ammeter would not be measuring the current in the cell	

Question Number	Acceptable answers	Additional guidance	Mark
5	B		1

Question Number	Acceptable answers	Additional guidance	Mark
1	B		1

Question Number	Answer	Mark
5	**C ammeter reading decreases, voltmeter reading increases**	**1**
	A – the ammeter reading does not increase B – neither occurs D – the voltmeter reading does not decrease	

7	**The correct answer is D** Incorrect Answers: A – emf is a constant B – emf is a constant C – as resistance increases, the terminal p.d. increases	**1**

Question Number	Answer	Mark
4	**The only correct answer is D ammeter reading decreases and voltmeter decreases** **A** *is not correct because the overall resistance of the circuit is increasing, so the current must decrease.* **B** *is not correct because the overall resistance of the circuit is increasing, so the current must decrease.* **C** *is not correct because the current decreases, but as V=IR this would not increase the voltmeter reading*	**1**

Question Number	Answer	Mark
4	**A – (1.50-1.45) × 100 / 1.45**	1
	Incorrect Answers: B – this gives the total resistance of the fixed resistor and the internal resistance C – the denominator should be the potential difference across the 100Ω resistor D – the denominator should be the potential difference across the 100Ω resistor	

Question Number	Acceptable Answer	Additional guidance	Mark
11(a)	• $I = 1.5 / (3 + 0.5)$ **(1)**	Or ref to cells eg $I = 1.5 / (3 + A2)$	**1**
11(b)	• $P = 0.30^2 \times 2.0$ **(1)**	Or ref to cells eg $P = (B5)^2 \times A5$	**1**
11(c)	• use smaller increments for resistance **(1)** • around area of peak **(1)**		**2**

(Total for Question 11 = 4 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
2(a)	• The data has to be collected over a long period of time	**(1)**		**1**
2(b)(i)	An explanation that makes reference to the following: • The (terminal) p.d. (of the cell) decreases. • $I = \frac{V}{R}$, so the current decreases as the (external) resistance in the circuit stays constant	**(1)** **(1)**	In MP1 do not accept voltage for p.d. MP2: Accept $I \propto V$ because (external) resistance in the circuit is constant, so the current decreases	**2**
2(b)(ii)	• Use of $I = \frac{V}{R}$ with R = 220 Ω or (220 + r) • (Sum of e.m.f. = sum of p.d. leading to) use of $r = \frac{(\varepsilon - V)}{I}$ with I from MP1 • r = 30 Ω (allow answers in range 28 Ω – 32 Ω)	**(1)** **(1)** **(1)**	Answer in range with no working shown scores MP3 only Example of calculation $I = \frac{3.52\ \text{V}}{220\ \Omega} = 1.60 \times 10^{-2}\text{A}$ $r = \frac{\varepsilon - V}{I} = \frac{(4.0\text{-}3.52)\ \text{V}}{1.60 \times 10^{-2}\text{A}} = 30.0\ \Omega$	**3**

(Total for Question 2 = 6 marks)

Question Number	Acceptable answers	Additional guidance	Mark
10(a)	• Use of $\frac{1}{R}+\frac{1}{R_1}=\frac{1}{R_2}$ **(1)** • $R = 72\ (\Omega)$ **(1)**	Example of calculation $\frac{1}{R}=\frac{1}{120\ \Omega}+\frac{1}{180\ \Omega}=0.0139\ \Omega^{-1}$ $\therefore R=\frac{1}{0.0139\ \Omega^{-1}}=72.0\ \Omega$	**2**
10(b)	• Use of $V = IR$ **(1)** • Use of $P = I^2R$ **(1)** • Use of $P=\frac{E}{t}$ **(1)** • $E = 320$ J ECF from (a) [show that answer gives 323 J] **(1)** **Or** • Use of $V = IR$ to find I **(1)** • Use of $V = IR$ to find terminal pd **(1)** • Use of $W = VIt$ **(1)** • $E = 320$ J ECF from (a) [show that answer gives 323 J] **(1)**	Example of calculation $I=\frac{9\ \text{V}}{(72+2.5)\ \Omega}=0.121\ \text{A}$ $P=(0.121\ \text{A})^2\times 72\ \Omega=1.05\ \text{W}$ $E=1.05\ \text{W}\times 300\ \text{s}=316\ \text{J}$	**4**

(Total for Question 10 = 6 marks)

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional guidance</th><th>Mark</th></tr>
<tr>
<td>*14</td>
<td>
This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for structure and lines of reasoning
<table>
<tr><th></th><th>Number of marks awarded for structure and lines of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr>
<tr><td>Answer has no linkage between points and is unstructured</td><td>0</td></tr>
</table>
Indicative content
IC1 The resistance of the circuit decreases (as more bulbs are added) Or there are more paths for the current (as more bulbs are added)
IC2 (So) current in battery increases
IC3 p.d. across internal resistance increases
IC4 Terminal p.d. of battery decreases and bulbs get dimmer
IC5 (More) energy/power transferred in battery
IC6 So thermal energy increases in battery
</td>
<td>
Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning
<table>
<tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr>
<tr><td>6</td><td>4</td><td>2</td><td>6</td></tr>
<tr><td>5</td><td>3</td><td>2</td><td>5</td></tr>
<tr><td>4</td><td>3</td><td>1</td><td>4</td></tr>
<tr><td>3</td><td>2</td><td>1</td><td>3</td></tr>
<tr><td>2</td><td>2</td><td>0</td><td>2</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>
</td>
<td>6</td>
</tr>
</table>

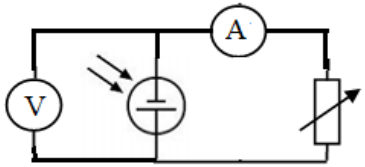
(Total for Question 14 = 6 marks)

Question Number	Acceptable answers	Additional guidance	Mark
9(a)	• Due to the internal resistance of the cell **(1)** • There is a potential difference across the internal resistance of the cell **Or** there will be 'lost volts' **Or** $V = \mathcal{E} . - Ir$ **(1)**		**2**
9(b)	• Identifies $\mathcal{E}$ = 1.36 V **(1)** • Use of $I = V/R$ with R = 5.92 Ω and V = 0.84 V **(1)** • Use of $\mathcal{E} = V + Ir$ **Or** equivalent to determine r **(1)** • r = 3.7(Ω) **(1)** • Both are correct (because r has increased and $\mathcal{E}$ has decreased) **(1)**	MP1: This may be implied in a calculation MP3: allow either e.m.f. to be sub for the use of mark MP5: descriptions of r and V both required MP5: conditional mark on MP4 <u>Example calculation</u> I = 0.84 V / 5.92 Ω I = 0.142 A 1.36 V = 0.84 V + 0.142 A × r r = 3.66 Ω	**5**

(Total for Question 9 = 7 marks)

2(b)	An explanation that makes reference to the following points: **EITHER** • Current (from battery) increases **(1)** • Therefore terminal p.d. decreases **(1)** • So brightness of bulb 1 decreases **(1)** **OR** • The resistance of the (external) circuit decreases **(1)** • So there is a smaller proportion of p.d across the bulbs **(1)** • So brightness of bulb 1 decreases **(1)**	MP3 dependent upon MP2 MP3 dependent upon MP2	**3**

(Total for Question 2 = 7 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
13(a)	• Voltmeter in parallel with solar cell **(1)** • Ammeter in series with variable resistor **(1)**	Example of circuit diagram 	**2**
13(b)(i)	• Use of $P = IV$ **(1)** • $P = 1.8$ (W) **(1)**	<u>Example of calculation</u> $P = 0.54\ \text{V} \times 3.4\ \text{A}$ $P = 1.84\ \text{W}$ Allow range of values calculated between points on the graph from 0.50 V 3.6 A [gives 1.80 W] to 0.55 V 3.2 A [gives 1.76 W]	**2**
13(b)(ii)	• Use of $I = P / A$ **(1)** • Use of efficiency = P_{out} / P_{in} **(1)** • Efficiency = 0.18 **Or** 18 % (allow ecf from (b)(i)) **(1)**	<u>Example of calculation</u> Power of sunlight = $1000\ \text{W m}^{-2} \times 104 \times 10^{-4}\ \text{m}^2 = 10.4\ \text{W}$ Efficiency = 1.84 W / 10.4 W = 0.177 [Show that value gives 0.19]	**3**
13(b)(iii)	• Recognise $E = 0.58$ V **(1)** • Determine p.d. across internal resistance **(1)** • Internal resistance = 0.012 Ω **(1)** [allow ecf from (b)(i) ie pair of values for V and I that were out of range]	<u>Example of calculation</u> Internal resistance = $\frac{0.58\ \text{V} - 0.54\ \text{V}}{3.4\ \text{A}} = 0.012\ \Omega$	**3**

(Total for Question 13 = 10 marks)

Question Number	Acceptable Answers		Additional Guidance	Mark
14(a)	• Calculates p.d. across internal resistance • Use of $R = V / I$ • Internal resistance = 6 Ω	**(1)** **(1)** **(1)**	Example of calculation: $VV_{\pi\pi} = 8.2\text{V} - 5.5\text{V} = 2.7\text{V}$ $rr = \frac{2.7\ \text{V}}{0.45\ \text{A}}$ r = 6.0 Ω	**3**
14(b)	• Use of $P = VI$ for panel • Use of $PP = \frac{EE}{tt}$ • Time = 13 hours	**(1)** **(1)** **(1)**	Example of calculation: Total Power of panels = 380 × 5.5 V × 0.45 A = 940.5 W Time to charge = 12000 / 940.5 = 12.8 hours	**3**
14(c)(i)	• Use of $\Delta W = F\Delta s$ and $P = W / t$ • Use of $F = ma$ • a = 0.32 m s^{-2}	**(1)** **(1)** **(1)**	Example of calculation: In 1 second $WW = FF\Delta ss$ 4500 W = FF × 34 m s^{-1} Force applied by motor = 132.4 N $FF = mmaa$ 132.4 N = 420 kg × aa a = 0.315 m s^{-2}	**3**
14(c)(ii)	• Neglect friction forces when it starts from rest **Or** Motor/Driving force independent of speed	**(1)**	Do not accept "force" without a description	**1**

14(d)	Max 2 • normal car would have much more mass **(1)** • too much area of solar cell needed so impractical **(1)** • going uphill would need far more power **(1)**		**2**

(Total for Question 14 = 12 marks)