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IB · DP · Physics

🕐 3 hours   ❓ 15 questions

Structured Questions

5.2 Heating Effect of Electric Currents

5.2.1 Circuits / 5.2.2 Resistance & Resistors / 5.2.3 Kirchhoff's Circuit Laws / 5.2.4 I-V Characteristics / 5.2.5 Resistivity / 5.2.6 Investigating Resistivity / 5.2.7 Series & Parallel Circuits / 5.2.8 Heating Effect of Current / 5.2.9 Potential Divider Circuits

Easy (5 questions)	/66
Medium (5 questions)	/60
Hard (5 questions)	/33
Total Marks	**/159**

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Easy Questions

1 (a) In circuit building a set of agreed symbols is in use worldwide to represent components.

For each description below, write the name and draw the correct symbol which would be used in a circuit diagram.

      (i)   A resistor whose resistance depends on the light intensity.

                  [2]

      (ii)   A component with zero resistance which measures the current in the circuit.

                  [2]

      (iii)   The component which is used to convert ac current to dc current; it also allows current to flow in only one direction.

                  [2]

(6 marks)

(b) In each case select the word to correctly describe an ammeter.

- In a circuit the **current/voltage/resistance** is measured using an ammeter, which is always connected in **series/parallel** within a circuit.

- An ideal ammeter should have **very high/zero** resistance. This prevents the ammeter taking any energy from the **electrons/positive ions** flowing through it.

- If the electrons transferred their **electricity/energy/motion** to the ammeter this would change the circuit by **reducing/increasing** the value of the current it is meant to measure.

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(3 marks)

(c) A charge of 15.0 C passes through a resistor at a constant rate in 60 s. The potential difference across the resistor is 2.0 V.

Calculate the resistance R of the resistor.

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(3 marks)

(d) The resistance of a wire is affected by factors including the resistivity of the material it is made from.

      (i)   Define resistivity.

                                                             [2]

      (i)   State two other factors apart from temperature which affects the resistance of a wire. For each one identify whether the relationship is directly or inversely proportional to resistance.

                                                             [2]

(4 marks)

2 (a) A student is building a circuit using three resistors, each with a value of 5.0 Ω. The student arranges the resistors first in series and then in parallel, as shown.
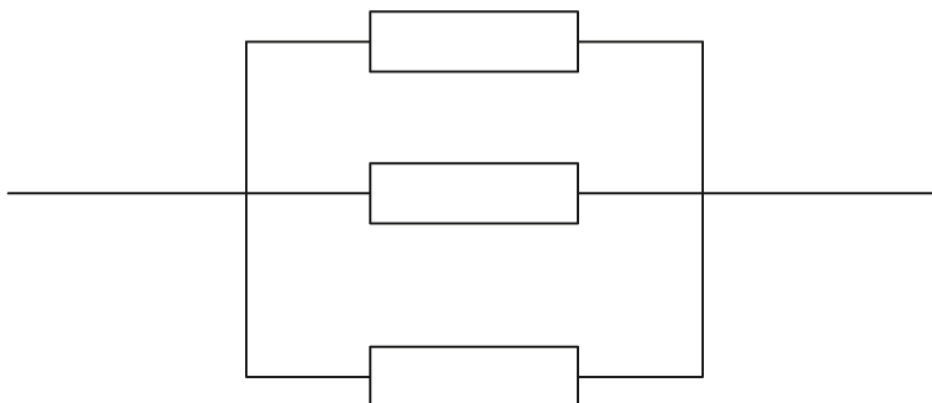
Determine the total resistance in each case.

      (i)   Three 5.0 Ω resistors in series

[2]

      (ii)   Three 5.0 Ω resistors in parallel

[2]

(4 marks)

(b) The student arranges the identical 5.0 Ω resistors so that they are in a combination of series and parallel as shown.
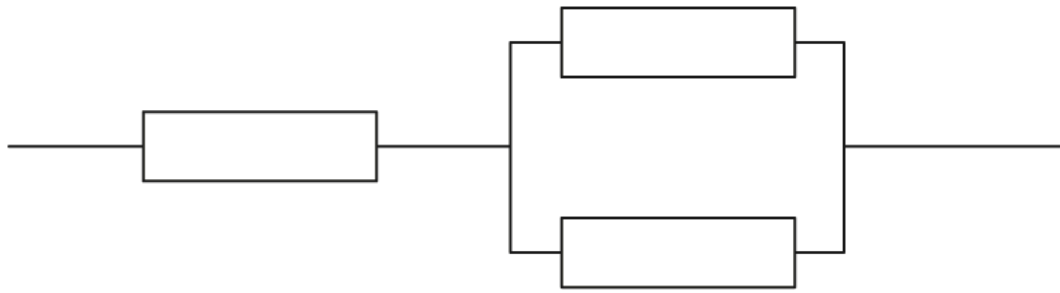
Calculate the new combined resistance.

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(3 marks)

(c) An electrically-conducting wire is made from copper. Copper has resistivity $\rho = 1.7 \times 10^{-8}$ Ω m.

The wire has diameter d = 2.0 mm and length L = 20 mm as shown.

For the wire calculate
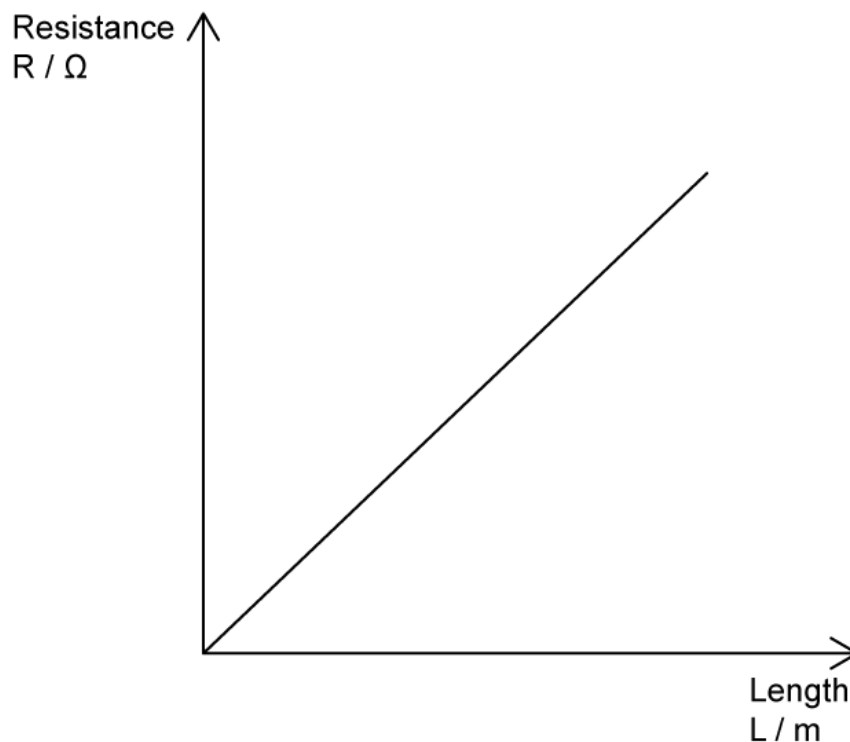
       (i)   The cross-sectional area of the wire

                                                             [2]

       (ii)   The resistance of the wire

                                                               [2]

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(4 marks)

(d) A student investigating the resistivity of a sample of wire has plotted a graph of resistance against length as shown.

Explain how the graph can be used to determine the resistivity of the wire.

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(3 marks)

3 (a) Define resistance.

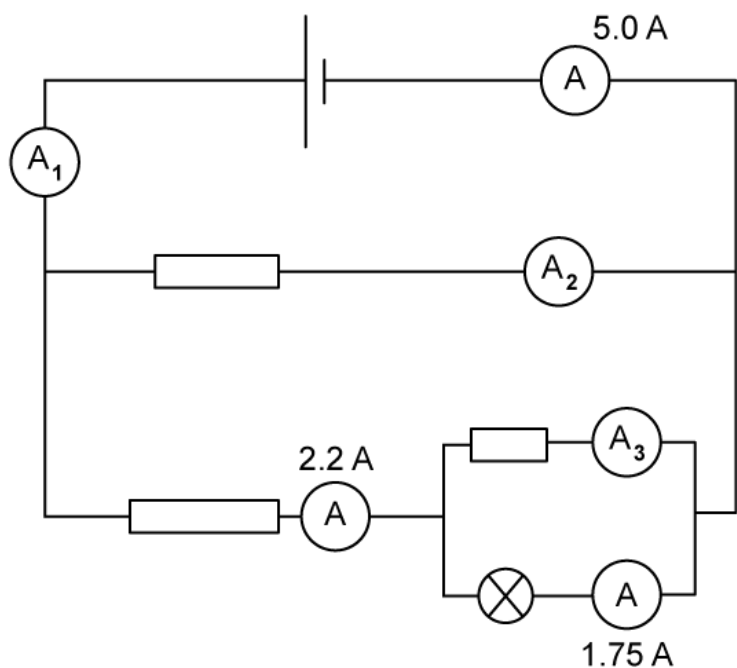**(2 marks)**

(b) The simple circuit diagram shown illustrates Kirchoff's First Law.
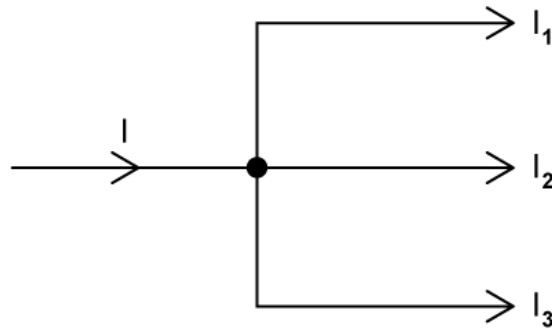
State the law in words.

(2 marks)

(c) For the circuit shown determine the values on the ammeters. A_1, A_2 and A_3.

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(3 marks)

(d) For Kirchhoff's second law

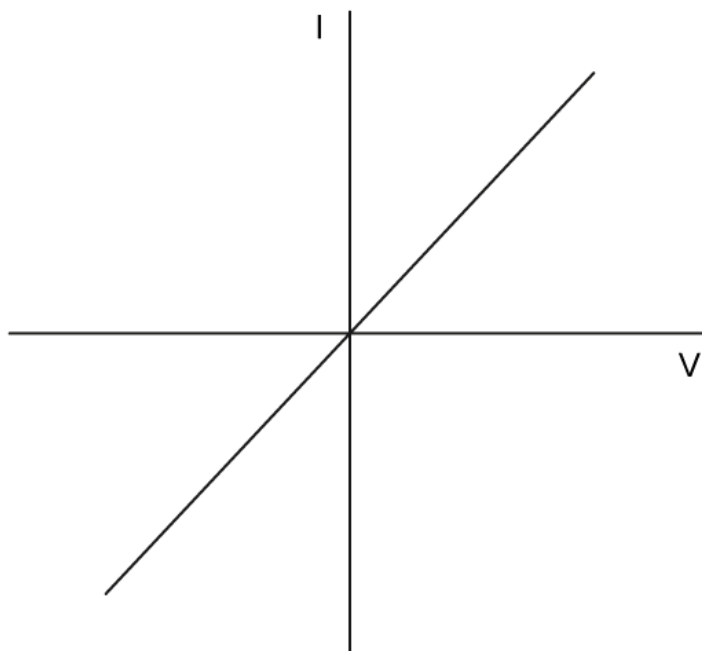   (i)   State Kirchhoff's Second Law.

                                       [2]

    (ii)   Complete the sentence;
                Kirchhoff's First Law is a consequence of the conservation of _____ while
                Kirchhoff's Second Law is a consequence of the conservation of _____.

                                       [2]

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4 (a) The graph shown represents current and potential difference for an Ohmic resistor.

State the features of the graph which show that the resistor obeys Ohm's Law.

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(2 marks)

(b) A student investigating the I-V characteristics of various components plots the graph shown.
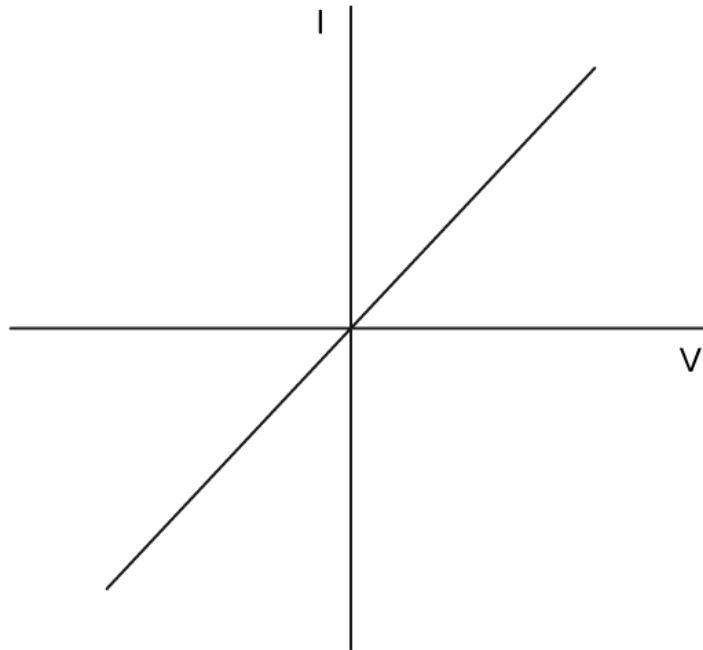
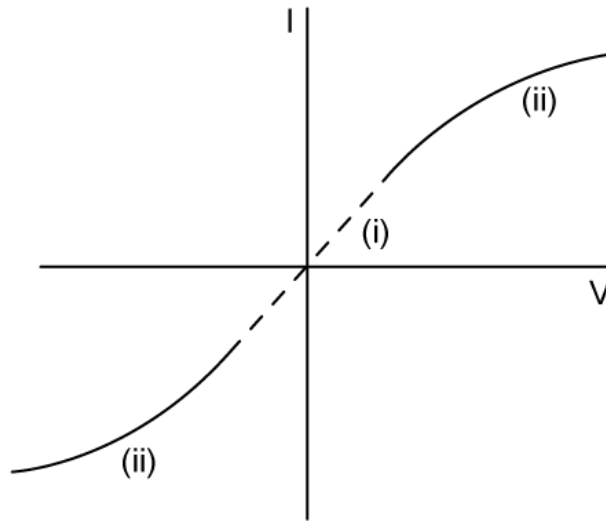Outline how to find the resistance of the component from the graph.

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(3 marks)

(c) The graph shown represents the I-V characteristics of a non-Ohmic resistor such as a lamp.

The graph consists of three distinct parts.

      (i)   For the section labelled (i) outline the behaviour of the resistor.

[2]

      (ii)   For the two similar sections labelled (ii) outline the behaviour of the resistor.

[3]

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(5 marks)

(d) Heating is typically seen in electrical components and must be accounted for so that they operate safely and efficiently.
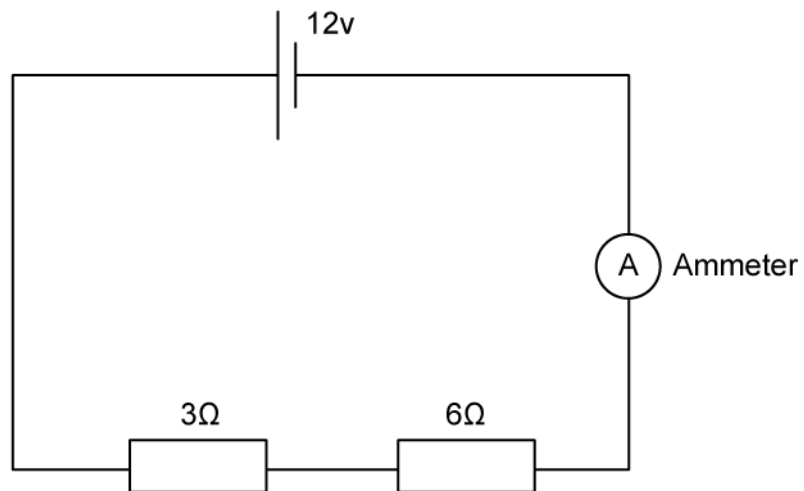
State two factors which increase the amount of heat output.

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5 (a) For the series circuit shown, calculate

(i) Total resistance.

[2]

(ii) Current measured by the ammeter

[2]

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(4 marks)

(b) For the parallel circuit shown, calculate

(i) Total resistance.

[2]
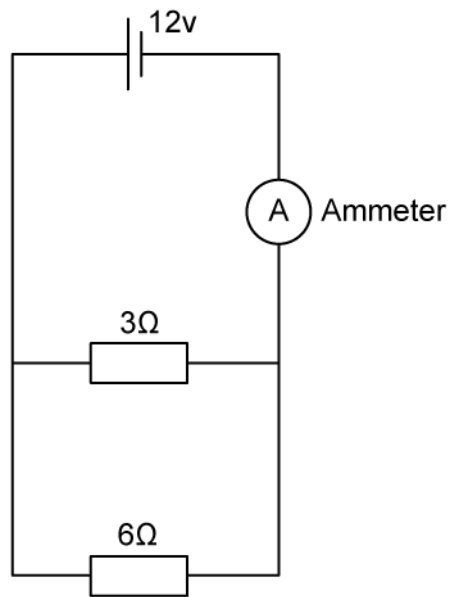
(ii) Current measured by the ammeter

[2]

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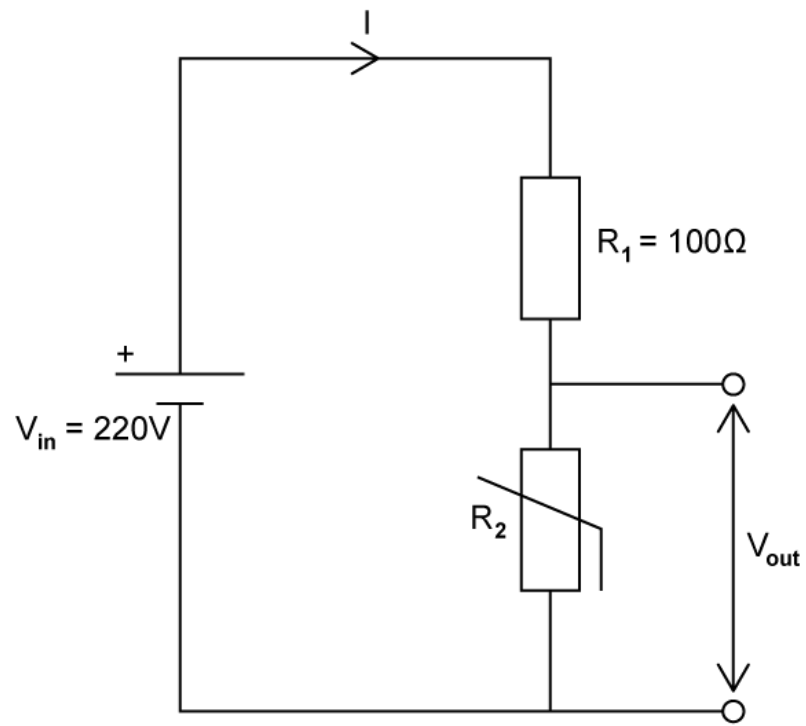
(4 marks)

(c) The potential divider circuit shown is to be adapted to become a sensing circuit for temperature.
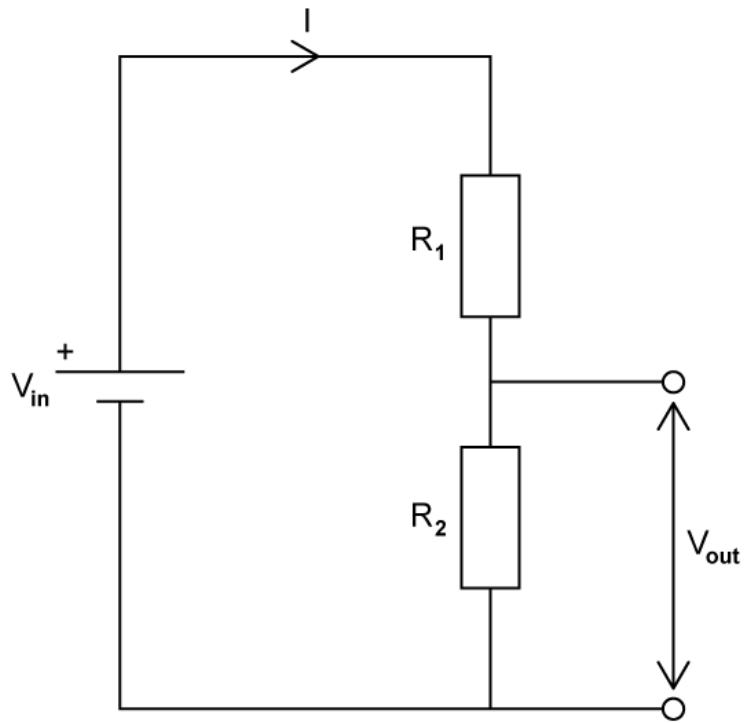
Suggest a change which would enable this.

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(2 marks)

(d) The sensing circuit in part (c) has been built using a thermistor placed in parallel to the output voltage, with a fixed resistor R_1 of 100 Ω, and an input voltage, V_{in} of 220 V as shown.

At a certain temperature the thermistor has resistance $R_2 = 20\ \Omega$.

Determine the output voltage at this temperature.

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(3 marks)

Medium Questions

1 (a) Deborah is an aspiring electrical engineer who sets out to investigate the resistivity of a metal wire. The material of the wire is unknown.

She measures the diameter of the wire using a micrometer screw gauge and takes a reading from the main scale and micrometer scale.

Main scale and micrometer
scales shown enlarged
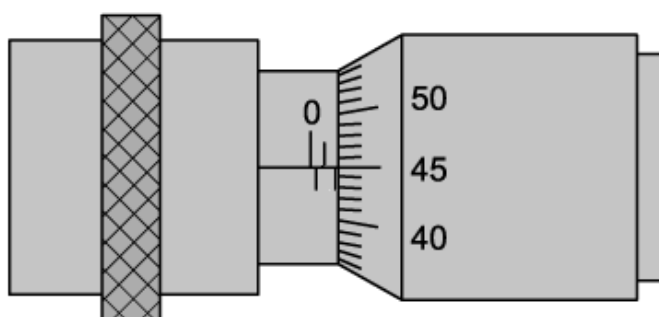
Determine the cross-sectional area of Deborah's wire.

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(3 marks)

(b) Deborah then uses an ohmmeter to measure the resistance R for different lengths L of the wire.

Length L / cm	Resistance R / Ω	
80.0	7.94	
70.0	6.99	
60.0	5.89	
50.0	4.93	
40.0	4.27	

Use Deborah's measurements to complete the final column in the table and then determine the resistivity of the wire.

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(4 marks)

(c) Suggest and explain two improvements to Deborah's experimental method that would reduce the uncertainty in the final value of resistivity.
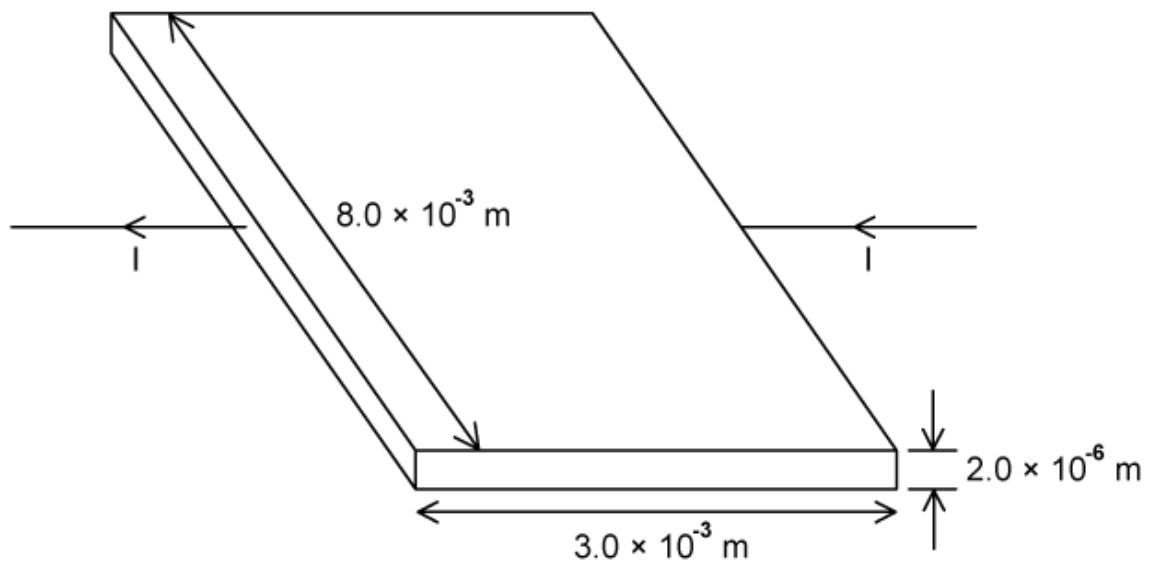
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(4 marks)

(d) Deborah swaps the sample of wire used in her experiment for a thin film of carbon.
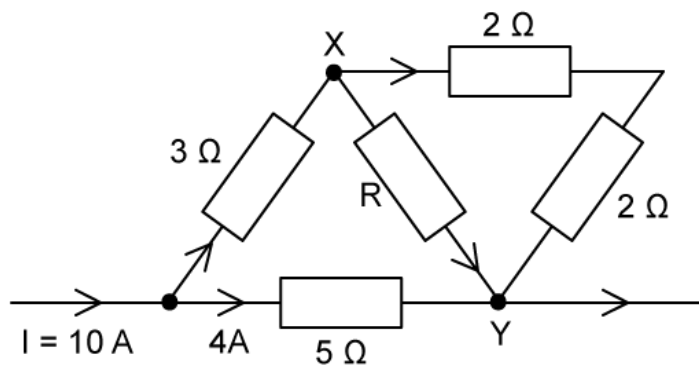
Calculate the current which passes through the carbon film in the diagram for an applied voltage of 2.5 mV.

The resistivity of carbon is 4.0×10^{-5} Ω m.

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(3 marks)

2 (a) A current *I* = 10 A flows through a network of six resistors as shown.

The potential difference across the line XY is 8 V.

Calculate the value of the unknown resistance *R*.

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(4 marks)

(b) Another network, comprised of four identical resistors each of resistance 2 Ω, is connected to a 6 V battery with negligible internal resistance.
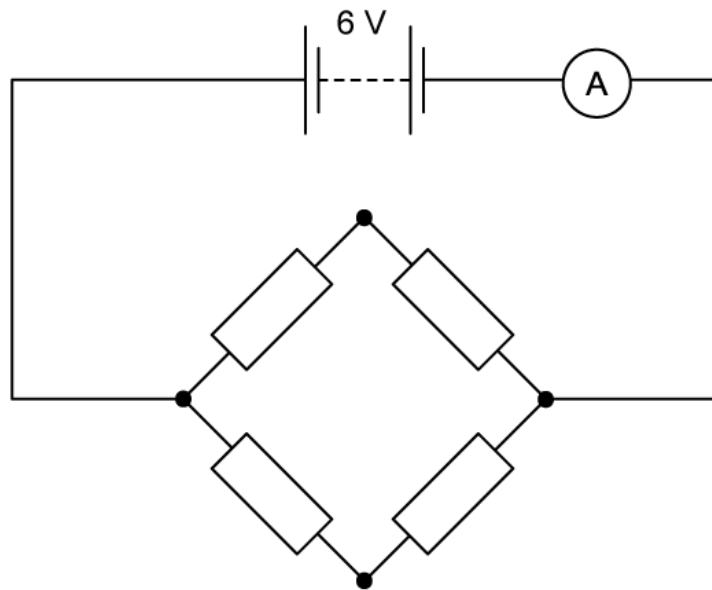
Determine the reading on the ammeter.

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(3 marks)

(c) A resistor is made by connecting two uniform cylinders X and Y of the same material and equal in length, in series.

Cylinder Y has a resistance of 5 Ω and is twice the diameter of cylinder X.
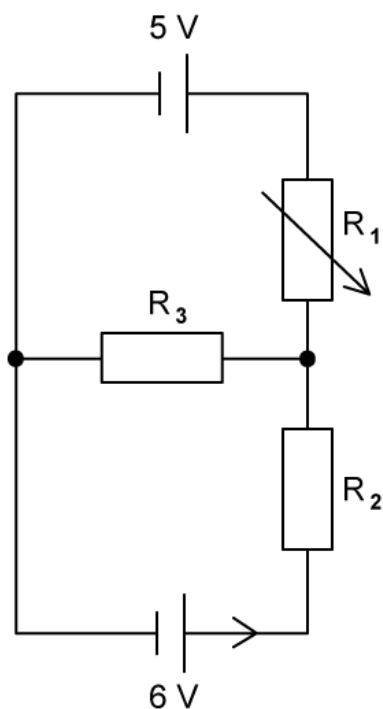
Calculate the total resistance of this series combination.

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(1 mark)

(d) State and explain why knowledge of quantities like resistivity is useful to scientists.

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(2 marks)

3 (a) A variable resistor R_1 has a resistance that varies between 0 and 10 Ω is connected to two resistors R_2 and R_3 and two cells of e.m.f. 5 V and 6 V.

Use Kirchhoff's junction law to deduce an equation for three currents I_1, I_2 and I_3 at the junction between the resistors R_1, R_2 and R_3.
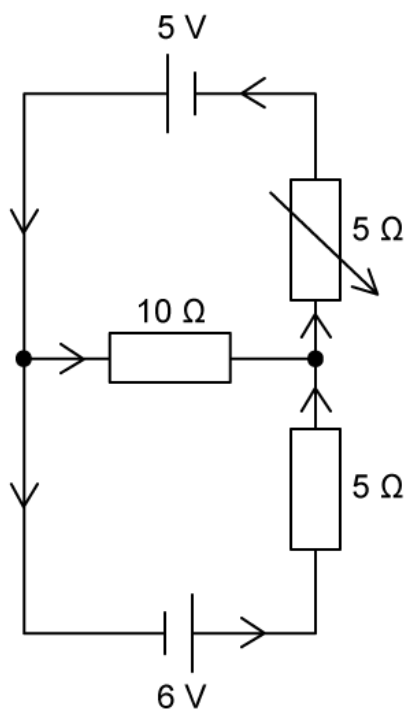

(2 marks)

(b) Initially, the variable resistor R_1 is set to 0 Ω.

If R_2 is 5 Ω and R_3 is 10 Ω, determine the current through resistor R_2.

(4 marks)

(c) The terminals of the 5 V cell are reversed, and the variable resistor is set to a resistance of 5 Ω.
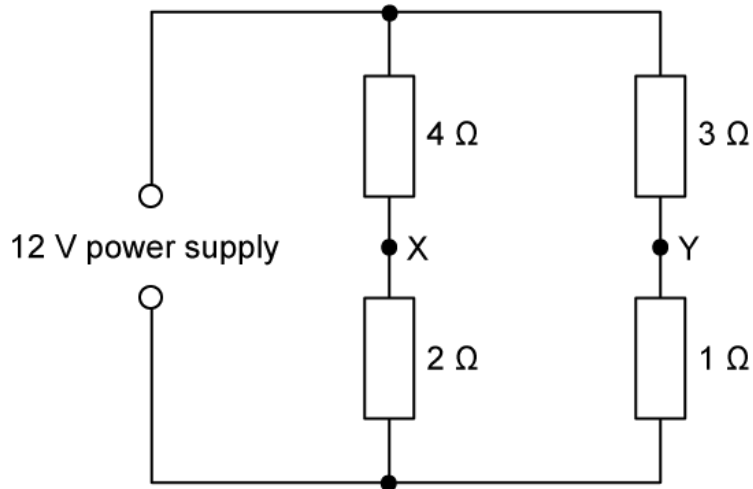

Using the current directions indicated, write:

(i)   Two unique equations using Kirchhoff's circuit law for loops.

(ii)   One equation using Kirchhoff's circuit law for junctions.

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(3 marks)

(d) Hence, calculate the power dissipated in R_3.

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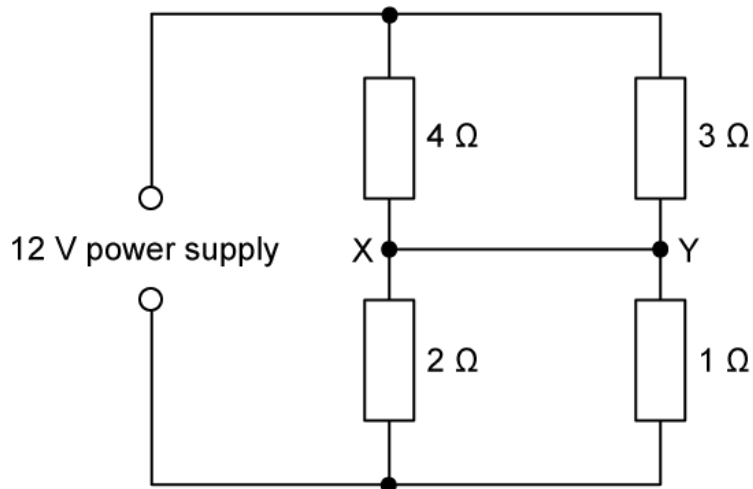
4 (a) A circuit containing four resistors is connected to a 12 V power supply.

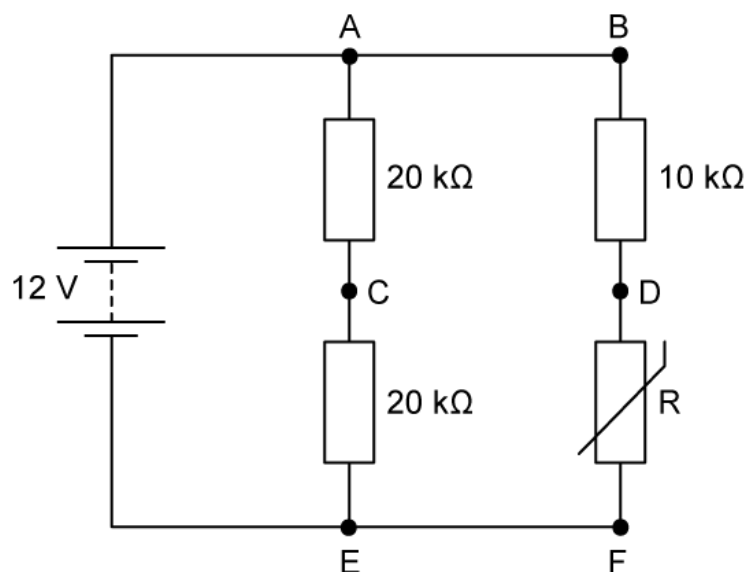Show that the potential difference between X and Y is 1 V.

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(2 marks)

(b) A wire joins X and Y in the circuit.

Assuming current flows anticlockwise from the power supply, state and explain the direction of current along the line XY.

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(3 marks)

(c) Another potential divider circuit includes a thermistor with resistance R.

The battery has an e.m.f. of 12 V, with negligible internal resistance. At room temperature, the resistance of the thermistor is 4.0 kΩ.

Calculate the current in the battery at room temperature, giving your answer to an appropriate number of significant figures.

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(4 marks)

(d) For temperatures higher than room temperature, describe and explain how the power dissipated varies across:

        (i)   AE

        (ii))   BD

(4 marks)

5 (a) An electronic circuit contains two resistors connected as shown.
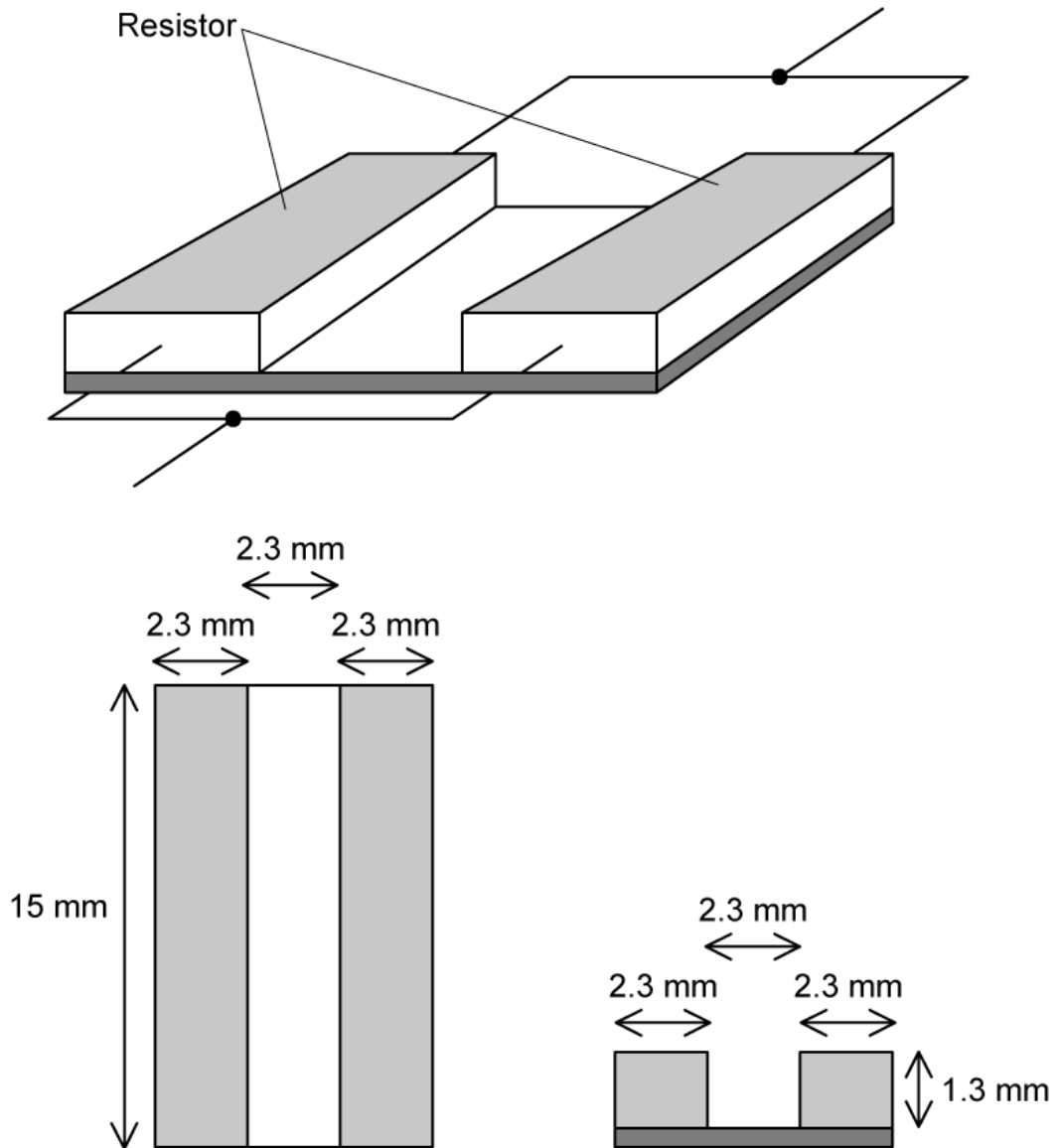
The material from which each resistor is made has a resistivity of 2.0×10^5 Ω m and both resistors have dimensions of 15 mm by 2.3 mm by 1.3 mm.

Calculate the total resistance of the electronic circuit.

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(2 marks)

(b) The circuit is designed such that changes to the dimensions of each resistor by a common factor x are easily accomplished.

Show that if the dimensions of each resistor are increased by a factor of x then the resistance decreases by the same factor.

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(2 marks)

(c) An electrical heating element is made of nichrome wire of resistivity 1.1×10^{-6} Ω m. It is required to dissipate 800 W when connected to the 230 V mains supply. The radius of the wire is 0.17 mm.

Calculate the length of wire required for the heating element.

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(4 marks)

(d) Suggest **two** properties that the nichrome wire must have to make it suitable as an electrical heating element.

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(2 marks)

Hard Questions

1 (a) A combination of identical resistors each with resistance *R* has a total resistance of 250 Ω.
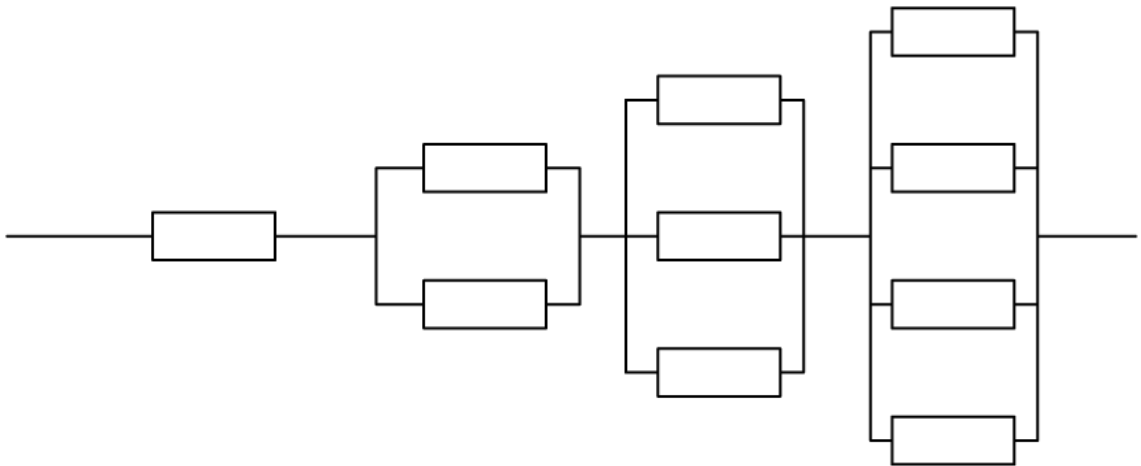
Show, without the use of a calculator, how to find the value of resistance of each resistor and hence determine the value of *R*.

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(2 marks)

(b) A student is provided with four fixed resistors of the following sizes:

$$1 \times 5.0 \ \Omega$$

$$1 \times 10.0 \ \Omega$$

$$2 \times 20.0 \ \Omega$$

Calculate the maximum power which can be drawn from a circuit which uses all four resistors connected to a variable power supply with terminal voltage ranging from 2-12 V. Include a sketch of the circuit you have outlined in your answer.

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(4 marks)

(c) A physics class planned an investigation into electromotive force (emf) and internal resistance. When the students arrived the equipment had not been set out as they expected. They were provided with the circuit diagram shown, and a set of ten fixed resistors, ranging from 10-200 Ω in regular increments which could be used in place of the resistor, *R*.
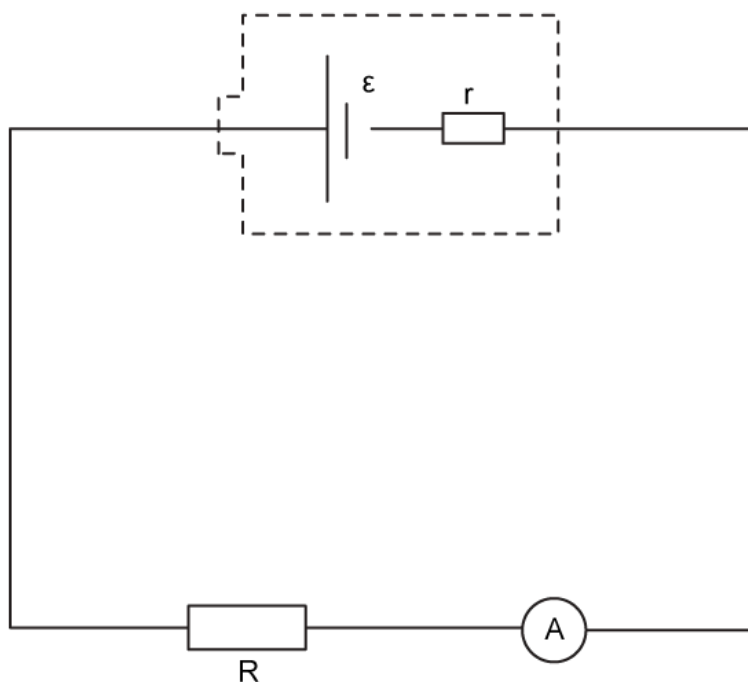
Comment on how the students can use their results to find both the emf and the internal resistance of the cell and hence suggest the outcome of this investigation.

Assume that the ammeter is suitable to measure all the currents which this circuit may produce. No additional equipment may be used.
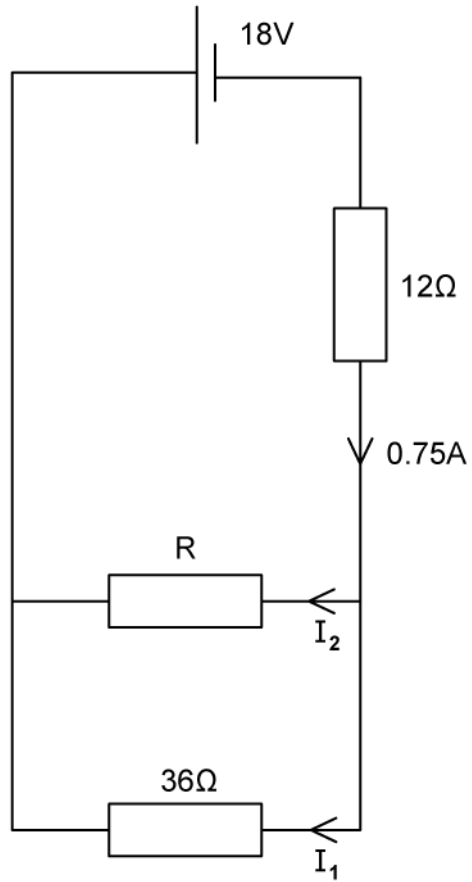
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(3 marks)

(d) The circuit diagram shows a battery which has negligible internal resistance connected to three resistors which have different values of resistance.

(i)   Calculate current I_1.

[1]

(ii)   Calculate resistance, R.

[1]

(2 marks)

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2 (a) A current of 2.0 mA flows in an ammeter for 90 minutes.

Calculate the approximate number of electrons which pass through the ammeter in this time.

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(1 mark)

(b) Human skin tissue has much higher resistivity than muscle tissue. Typical values for the resistivity of particular tissue types vary. For this question use the data in the table below.

Tissue	Resistivity / Ω m
Muscle	8.3
Dry skin	3.0×10^4

A person grasps a wire which has a diameter of 0.5 cm at a potential of 12 V. The wire is not insulated and the person is well earthed. The skin of the hand is 1.0 mm thick and is in contact with the whole wire for a distance of 10 cm.

(i) Calculate the current in mA which passes through the person as a result of this accident.

[2]

(ii) Comment on the change as the current passes through the skin and into the muscle tissue.

[2]

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(1 mark)

(c) Following the accident in part (b) the teacher sets a research homework, where students are asked to discuss electrical safety.

By comparing the factors given in the question

      (i)   Suggest how the magnitude of the current passing into the body could have been affected.

[2]

   (ii)   Outline safety precautions which the student should have taken before handling the wire.

[3]

(1 mark)

(d) High voltage electrical accidents can cause deep burns throughout the body, which often require major surgery and can lead to permanent disability or death.
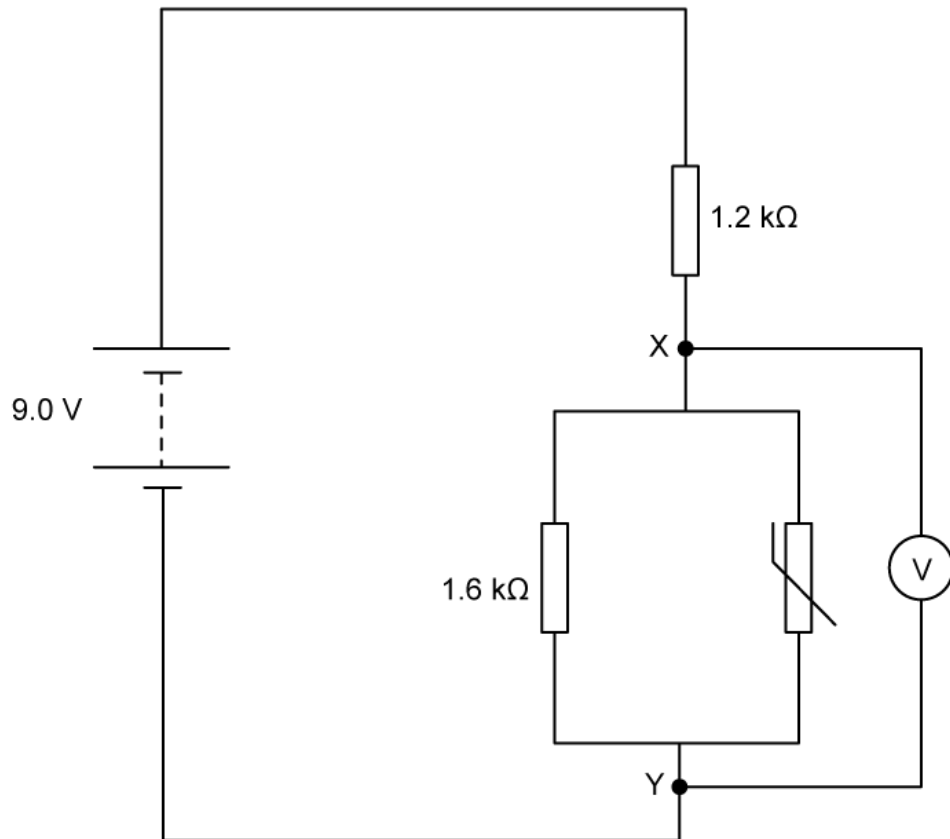
Outline the reasons for this level of injury, stating two assumptions that you have made in your explanation.

(4 marks)

3 (a) The variation with temperature of the resistance, R_T of a thermistor with temperature is shown.
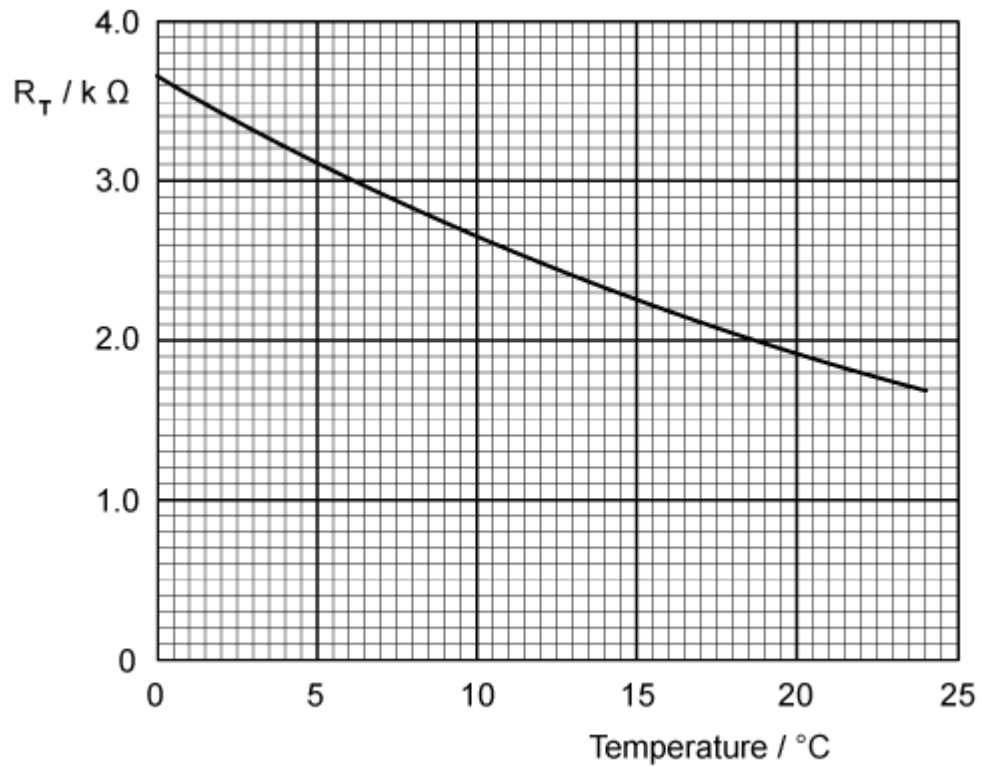
The thermistor is connected into a circuit using a power source with negligible internal resistance. The temperature is 22.5 °C.

Show, without the use of a calculator, how to determine the reading on the voltmeter, giving the answer to two significant figures.

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(1 mark)

(b) The temperature is changed so that the voltmeter reads 4.0 V.

Determine the new temperature.

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(2 marks)

4 (a) Show that $I^2 R = \dfrac{V^2}{R}$ and hence express the unit represented by these equations in S.I. units.

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(2 marks)

(b) A family on a tight budget needs to buy a new electric heater. The retailer's website, written (it claims) by electrical engineers, suggests that the best value-for-money heater has very high resistance because $P = I^2 R$.

The family, who all study physics, think that a low resistance heater would be better, because $P = \dfrac{V^2}{R}$.
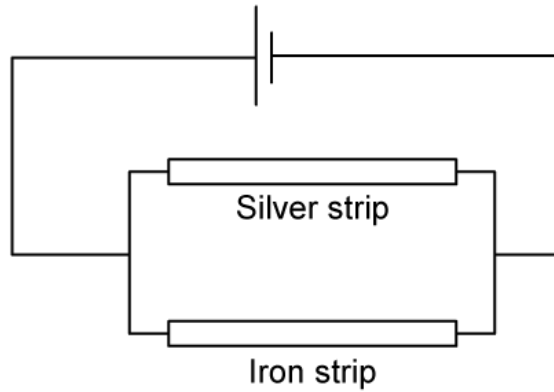
Explain who is correct.

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(2 marks)

(c) Two thin strips of silver and of iron have the same dimensions. The strips are connected to a circuit, first in series and then in parallel. A potential difference is applied in the positions shown, and the voltage increased incrementally until one of the two wires begins to glow.

(i)

Silver strip   Iron strip

(ii)

Silver strip

Iron strip
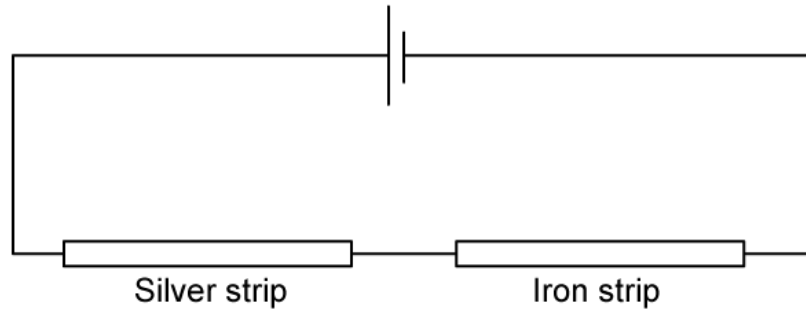
Explain which metal strip will glow first

(i)   For the series arrangement.

[2]

(ii)   For the parallel arrangement.

[2]

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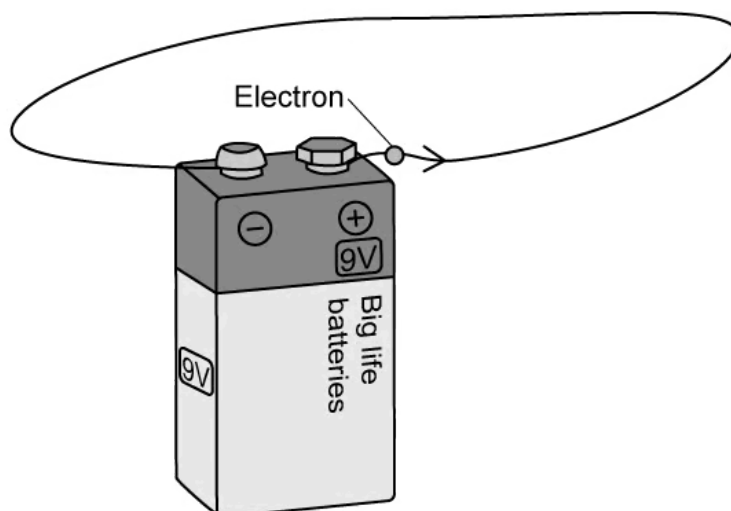
(4 marks)

5 (a) In a thought experiment a teacher asks students to imagine an electron passing through a cell with a terminal voltage of 9 V.

The electron passes along a wire until it reaches the positive terminal of the cell. In the thought experiment, students are asked to assume that there is no obstruction to the movement of the electron within the wire.

Using energy considerations, calculate the final speed of the electron.

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(2 marks)

(b) The teacher points out that the thought experiment is fundamentally flawed, since it breaks a certain law of physics.

Explain the teacher's comment, and hence use a simple observation from daily experience to prove that the teacher is correct.

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(2 marks)