DC CIRCUITS
WORKSHEET
AS-Level Physics 9702

ON24/21/Q7

1 **(a)** Fig. 7.1 shows two resistors connected in series with a cell of electromotive force (e.m.f.) 1.50 V and internal resistance 0.28 Ω.

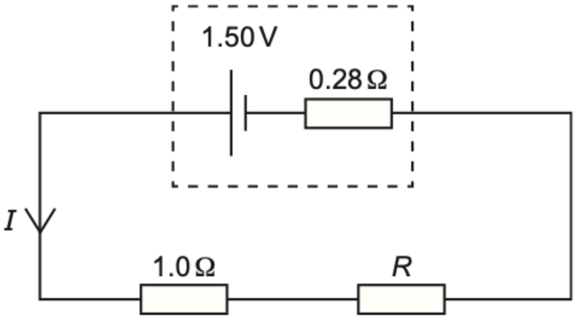

Fig. 7.1

One of the resistors has resistance 1.0 Ω. The other resistor has resistance *R*.
The terminal potential difference (p.d.) across the cell is 1.36 V.

(i) Show that the current *I* in the circuit is 0.50 A.

[2]

(ii) Calculate the combined resistance of the two resistors.

resistance = ... Ω [2]

(iii) Use your answer in **(a)(ii)** to determine resistance *R*.

R = ... Ω [1]

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(b) The circuit in Fig. 7.1 is disconnected and the two resistors are reconnected to the cell, now in parallel with each other.

(i) On Fig. 7.2, complete the circuit diagram to show this arrangement.

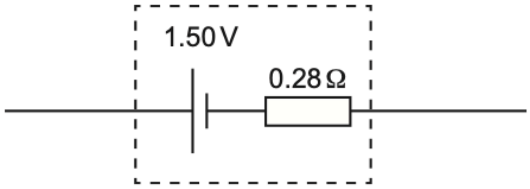

Fig. 7.2

[1]

(ii) Explain, without calculation, whether the terminal p.d. across the cell is now less than, equal to or greater than 1.36 V.

....

....

.... [2]

[Total: 8]

MJ24/21/Q6

2 (a) State Kirchhoff's first law.

....

.... [1]

(b) A cell with internal resistance r is connected to two resistors of resistances R_1 and R_2 as shown in Fig. 6.1.

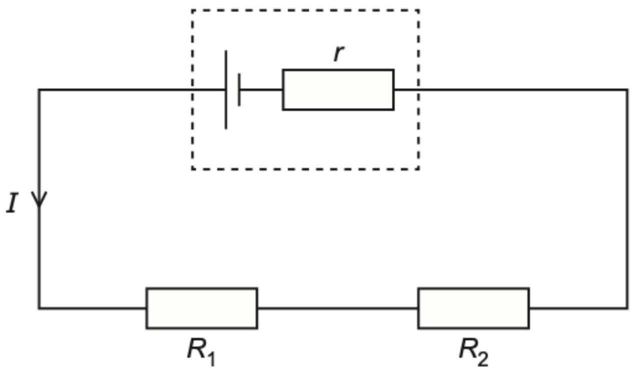

Fig. 6.1

The potential differences (p.d.s) across R_1 and R_2 are V_1 and V_2 respectively.
The terminal p.d. across the cell is V.
The current in the circuit is I.

Use Kirchhoff's laws to show that the total resistance R_T of the external circuit is given by

$$R_T = R_1 + R_2 .$$

[2]

(c) The electromotive force (e.m.f.) of the cell in Fig. 6.1 is 1.50 V.

The values of R_1 and R_2 are 10 Ω and 15 Ω respectively. The terminal p.d. of the cell is 1.35 V.

Calculate the internal resistance r of the cell.

r = ... Ω [3]

(d) A resistor of resistance R_3 is added to the circuit in Fig. 6.1, so that the circuit is as shown in Fig. 6.2.

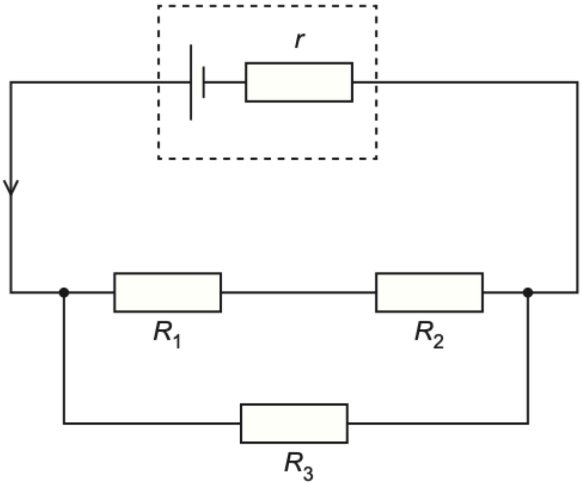

Fig. 6.2

State and explain the effect, if any, of this change on:

(i) the current in the cell

....

....

.... [2]

(ii) the terminal p.d. of the cell.

....

....

.... [2]

[Total: 10]

MJ24/23/Q5

3 (a) (i) State Kirchhoff's second law.

....

....

.... [1]

(ii) State the conservation law that gives rise to Kirchhoff's second law.

.... [1]

(b) A circuit contains a cell of internal resistance r and two resistors of resistances R_1 and R_2, as shown in Fig. 5.1.

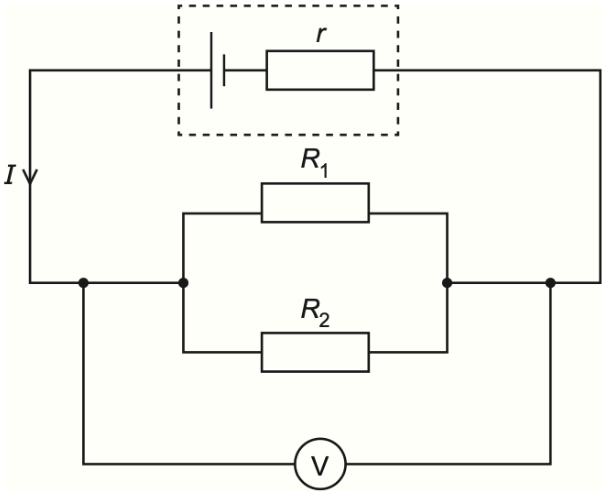

Fig. 5.1

The potential difference (p.d.) across the two resistors is V.

The current in the cell is I.

(i) Use Kirchhoff's laws to show that the total resistance R_T of the external circuit is given by

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}.$$

[2]

(ii) The electromotive force (e.m.f.) of the cell is 1.50 V.

When the values of R_1 and R_2 are 10 Ω and 15 Ω respectively, the p.d. measured by the voltmeter is 1.38 V.

Calculate the internal resistance r of the cell.

r = ... Ω [3]

(c) A third resistor is added in parallel with R_1 and R_2 in the circuit in Fig. 5.1.

State and explain the effect, if any, of this change on:

(i) the current in the cell

....

....

.... [2]

(ii) the p.d. measured by the voltmeter.

....

....

....40.. [2]

[Total: 11]

March24/22/Q7

4 **(a)** Define electric potential difference.

....

.... [1]

(b) A cell of electromotive force (e.m.f.) 1.8 V and internal resistance *r* is connected in parallel with a resistor of resistance 6.0 Ω and a filament lamp, as shown in Fig. 7.1.

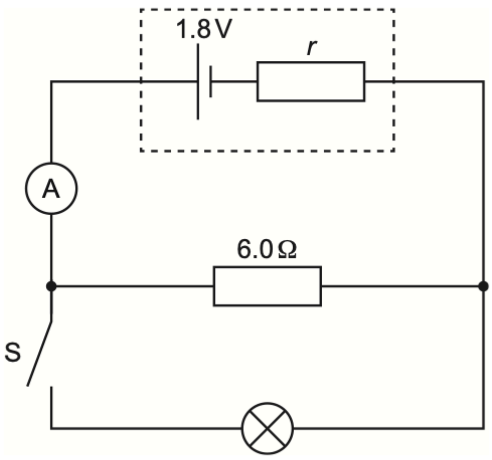

Fig. 7.1

The switch S is open. The ammeter reading is 0.25A.

Determine the internal resistance r of the cell.

r = ... Ω [3]

(c) At time t_1 switch S in Fig. 7.1 is closed. Fig. 7.2 shows the variation with time t of the ammeter reading I.

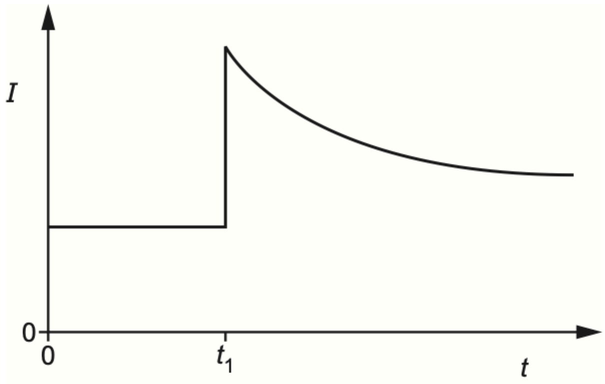

Fig. 7.2

(i) State whether the e.m.f. of the cell after t_1 is greater than, less than or the same as it was before t_1.

.... [1]

(ii) By considering the effect of the lamp on the total resistance of the circuit, explain the variation of the ammeter reading shown in Fig. 7.2.

....

....

....

....

....

.... [3]

[Total: 8]

5 **(a)** State Ohm's law. **ON23/23/Q7**

....

....

.... [2]

(b) A battery of electromotive force (e.m.f.) 6.2 V and negligible internal resistance is connected in a circuit to a uniform resistance wire, a voltmeter, a fixed resistor and a switch, as shown in Fig. 7.1.

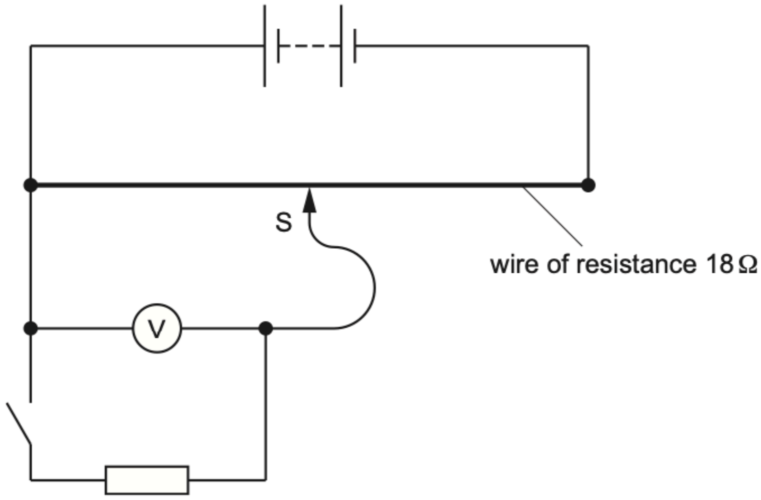

Fig. 7.1

The resistance wire has resistance 18 Ω, length 0.94 m and cross-sectional area $7.2 \times 10^{-8}\,m^2$. The slider S is positioned half-way along the length of the wire.

(i) Calculate the resistivity ρ of the material of the resistance wire.

ρ = ... Ωm [2]

(ii) The switch is open.
State the reading on the voltmeter.

voltmeter reading = ... V [1]

(iii) The switch is now closed.

State whether there is an increase, decrease or no change to:

- the current in the battery

....

- the voltmeter reading.

....
[2]

(iv) The switch remains closed. The slider S is moved along the resistance wire so that the voltmeter reading is 3.1 V.

On Fig. 7.1, draw a cross (×) on the resistance wire to show a possible new position of the slider. [1]

(c) The circuit in **(b)** is altered by changing the battery for one of a different e.m.f. The switch is open.

A student records the following data for the resistance wire:

current in the wire	0.93A
mean drift speed of charge carriers	$1.3 \times 10^{-3}\,\text{m}\,\text{s}^{-1}$
number density of charge carriers	$9.0 \times 10^{28}\,\text{m}^{-3}$.

(i) Determine the charge q of a charge carrier in the wire suggested by this data.

q = ... C [2]

(ii) With reference to the value of q, explain why the data recorded by the student cannot be correct.

....

.... [1]

[Total: 11]

6 **(a)** A battery of electromotive force (e.m.f.) 9.0 V and negligible internal resistance is connected to a light-dependent resistor (LDR) and a fixed resistor, as shown in Fig. 7.1.

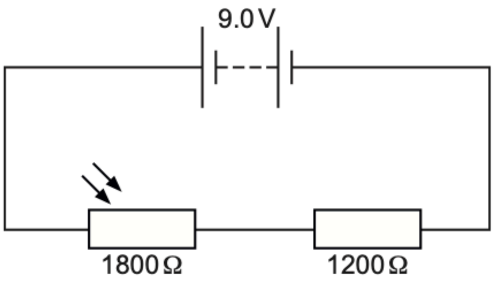

Fig. 7.1

The LDR and fixed resistor have resistances of 1800 Ω and 1200 Ω respectively.

Calculate the potential difference across the LDR.

potential difference = ... V [2]

(b) The circuit in **(a)** is now modified by adding a uniform resistance wire XY and a galvanometer, as shown in Fig. 7.2.

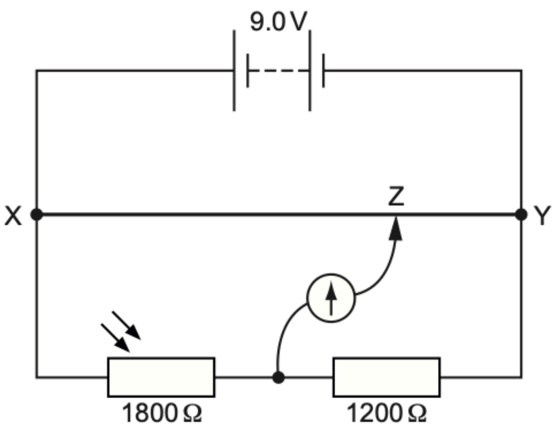

Fig. 7.2 (not to scale)

The length of the wire XY is 1.2 m. The movable connection Z is positioned on the wire XY so that the galvanometer reading is zero.

(i) Calculate the length XZ along the resistance wire.

length XZ = ... m [2]

(ii) The environmental conditions change causing a decrease in the resistance of the LDR. The temperature of the LDR remains constant.

State whether there is a decrease, increase or no change to:

- the intensity of the light illuminating the LDR

....

- the total power produced by the battery

....

- the length XZ so that the galvanometer reads zero.

....
[3]

[Total: 7]

March23/22/Q6

7 **(a)** Define the potential difference across a component.

....

.... [1]

(b) The variation with potential difference V of the current I in a semiconductor diode is shown in Fig. 6.1.

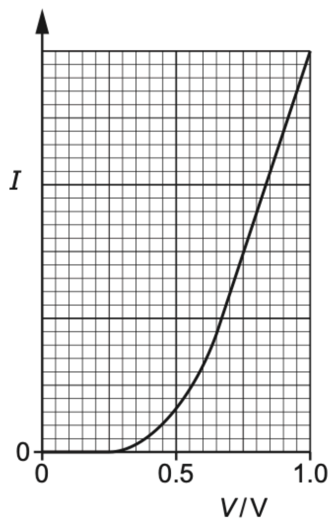

Fig. 6.1

Use Fig. 6.1 to describe qualitatively:

(i) the resistance of the diode in the range $V = 0$ to $V = 0.25\,V$

.... [1]

(ii) the variation, if any, in the resistance of the diode as V changes from $V = 0.75\,V$ to $V = 1.0\,V$.

.... [1]

(c) A battery of electromotive force (e.m.f.) 12V and negligible internal resistance is connected to a uniform resistance wire XY, a fixed resistor and a variable resistor, as shown in Fig. 6.2.

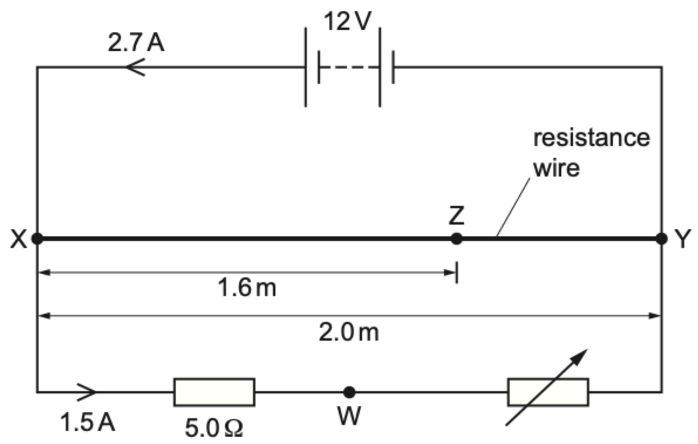

Fig. 6.2 (not to scale)

The fixed resistor has a resistance of 5.0Ω. The current in the battery is 2.7A and the current in the fixed resistor is 1.5A.

(i) Calculate the current in the resistance wire.

current = ...A [1]

(ii) Determine the resistance of the variable resistor.

resistance = ... Ω [2]

(iii) Wire XY has a length of 2.0 m. Point Z on the wire is a distance of 1.6 m from point X. The fixed resistor is connected to the variable resistor at point W.

Determine the potential difference between points W and Z.

potential difference = ... V [3]

(iv) The resistance of the variable resistor is now increased.

By considering the currents in every part of the circuit, state and explain whether the total power produced by the battery decreases, increases or stays the same.

....

....

....

....

....

.... [3]

[Total: 12]

ON22/22/Q6

8 **(a)** Define electric potential difference.

....

.... [1]

(b) A battery is connected to two resistors X and Y, as shown in Fig. 6.1.

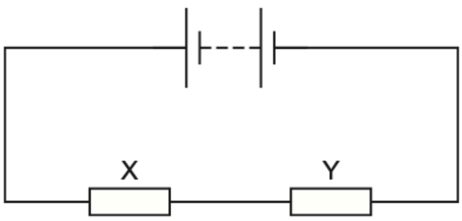

Fig. 6.1

The resistance of resistor X is greater than the resistance of resistor Y.

State and explain which resistor dissipates more power.

....

....

....

....

.... [3]

(c) A battery of electromotive force (e.m.f.) 9.0 V and internal resistance *r* is connected to two resistors P and Q, as shown in Fig. 6.2.

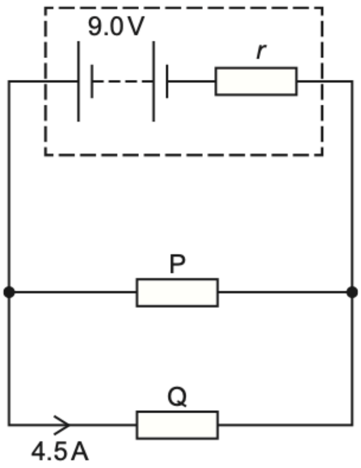

Fig. 6.2

A total charge of 650 C moves through resistor P in a time interval of 540 s. During this time resistor P dissipates 4800 J of energy. The current in resistor Q is 4.5 A. Assume that the e.m.f. of the battery remains constant.

Calculate:

(i) the current in resistor P

current = ... A [2]

(ii) the potential difference across resistor P

potential difference = ... V [2]

(iii) the internal resistance *r* of the battery.

r = ... Ω [2]

[Total: 10]

ON22/23/Q5

9 **(a)** State Kirchhoff's second law.

....

....

.... [2]

(b) Three identical cells, each of electromotive force (e.m.f.) 1.5 V and internal resistance 590 mΩ, are connected in parallel across a conductor, as shown in Fig. 5.1.

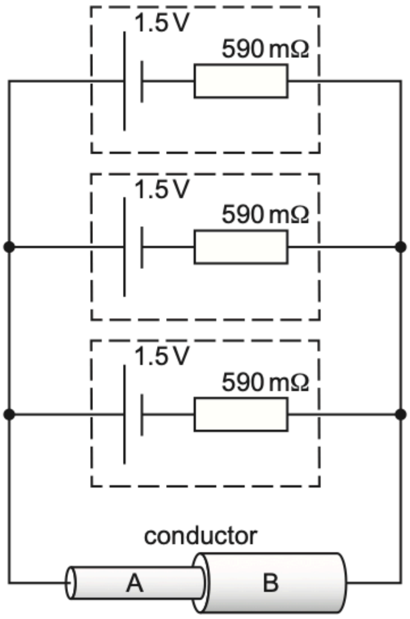

Fig. 5.1

The conductor is composed of two cylindrical sections A and B.
The total resistance of the circuit is 2.2 Ω.

(i) Show that the resistance of the conductor is 2.0 Ω.

[2]

(ii) Calculate the current in the conductor.

current = ... A [2]

(c) The two cylindrical sections A and B of the conductor in Fig. 5.1 are made from the same material and have the same length.
The diameter of section A is 4.3 mm and the diameter of section B is 7.6 mm.
The resistance of section A is R_A and the resistance of section B is R_B.

(i) Calculate the ratio $\frac{R_A}{R_B}$.

$\frac{R_A}{R_B}$ = ... [3]

(ii) Calculate the ratio

$$\frac{\text{average drift speed of free electrons in section A}}{\text{average drift speed of free electrons in section B}}.$$

Explain your reasoning.

ratio = ... [2]

(d) The circuit of Fig. 5.1 is altered by removing one of the cells.

State and explain the effect, if any, of this change on the potential difference across the conductor.

....

....

....

....

.... [3]

[Total: 14]

MJ22/22/Q6

10 **(a)** A network of three resistors of resistances R_1, R_2 and R_3 is shown in Fig. 6.1.

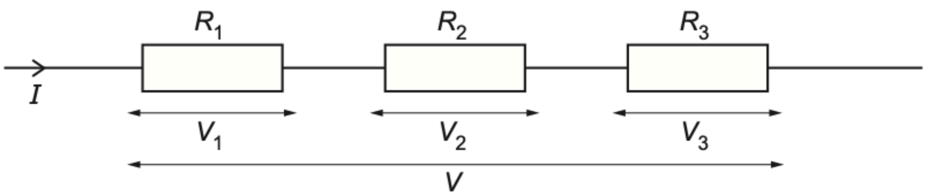

Fig. 6.1

The individual potential differences across the resistors are V_1, V_2 and V_3. The current in the combination of resistors is I and the total potential difference across the combination is V.

Show that the combined resistance R of the network is given by

$$R = R_1 + R_2 + R_3.$$

[2]

(b) A battery of electromotive force (e.m.f.) 8.0 V and negligible internal resistance is connected to a thermistor, a switch X and two fixed resistors, as shown in Fig. 6.2.

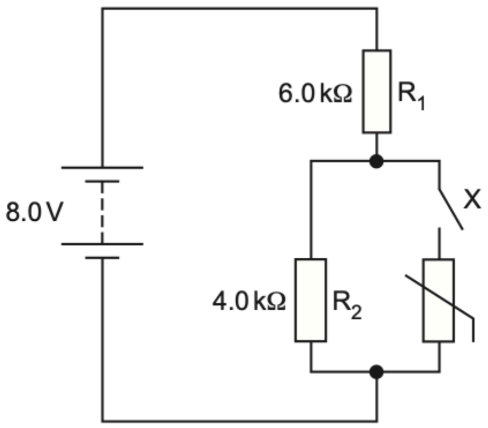

Fig. 6.2

Resistor R_1 has resistance 6.0 kΩ and resistor R_2 has resistance 4.0 kΩ.

(i) Switch X is open.

Calculate the potential difference across R_1.

potential difference = ... V [2]

(ii) Switch X is now closed. The resistance of the thermistor is 12.0 kΩ.

Calculate the current in the battery.

current = ... A [2]

(c) The switch X in the circuit in **(b)** remains closed. The temperature of the thermistor decreases.

By reference to the current in the battery, state and explain the effect, if any, of the decrease in temperature on the power produced by the battery.

....

....

....

....

.... [3]

[Total: 9]

11 **(a)** State Kirchhoff's first law.

....

....

.... [2]

(b) The circuit shown in Fig. 5.1 contains a battery of electromotive force (e.m.f.) *E* and negligible internal resistance connected to four resistors R_1, R_2, R_3 and R_4, each of resistance *R*.

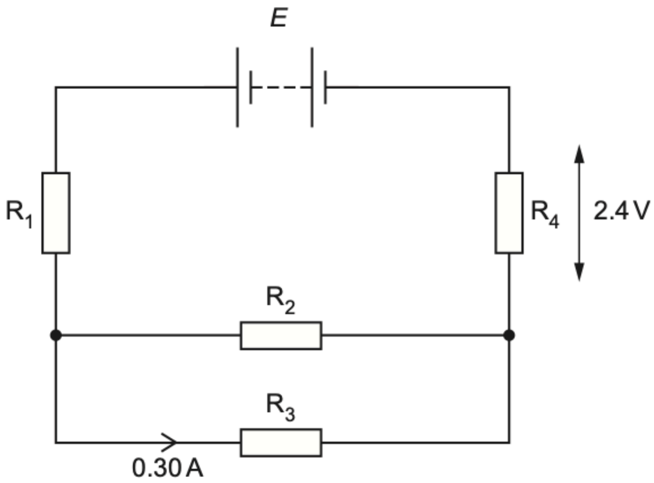

Fig. 5.1

The current in R_3 is 0.30 A and the potential difference (p.d.) across R_4 is 2.4 V.

(i) Show that *R* is equal to 4.0 Ω.

[2]

(ii) Determine the e.m.f. *E* of the battery.

E = ... V [2]

(c) The battery in **(b)** is replaced with another battery of the same e.m.f. *E* but with an internal resistance that is not negligible.

State and explain the change, if any, in the total power produced by the battery.

....

....

.... [2]

(d) The resistors in the circuit of Fig. 5.1 are made from nichrome wire of uniform radius 240 μm. The length of this wire needed to make each resistor is 0.67 m.

Calculate the resistivity of nichrome.

resistivity = ... Ωm [3]

[Total: 11]

ON21/22/Q6

12 A cell of electromotive force (e.m.f.) 0.48 V is connected to a metal wire X, as shown in Fig. 6.1.

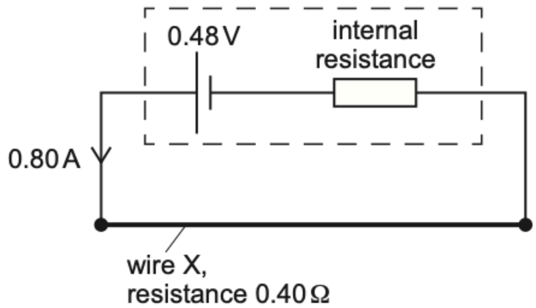

Fig. 6.1

The cell has internal resistance. The current in the cell is 0.80A.

Wire X has length 3.0 m, cross-sectional area 1.3×10^{-7} m^2 and resistance 0.40 Ω.

(a) Calculate the charge passing through the cell in a time of 7.5 minutes.

charge = ... C [2]

(b) Calculate the percentage efficiency with which the cell supplies power to wire X.

efficiency = ... % [3]

(c) There are 3.2×10^{22} free (conduction) electrons contained in the volume of wire X.

For wire X, calculate:

(i) the number density *n* of the free electrons

n = ... m^{-3} [1]

(ii) the average drift speed of the free electrons.

average drift speed = ... $m s^{-1}$ [2]

(d) A wire Y has the same cross-sectional area as wire X and is made of the same metal. Wire Y is longer than wire X.

Wire X in the circuit is now replaced by wire Y. Assume that wire Y has the same temperature as wire X.

State and explain whether the average drift speed of the free electrons in wire Y is greater than, the same as, or less than that in wire X.

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....

....

.... [3]

[Total: 11]

13 **(a)** A resistance wire of uniform cross-sectional area $3.3 \times 10^{-7}\,m^2$ and length 2.0 m is made of metal of resistivity $5.0 \times 10^{-7}\,\Omega\,m$.

Show that the resistance of the wire is 3.0 Ω.

[2]

(b) The ends of the resistance wire in **(a)** are connected to the terminals X and Y in the circuit shown in Fig. 6.1.

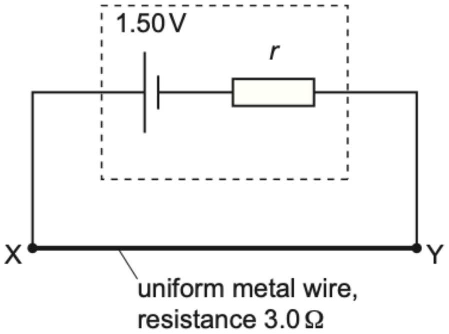

Fig. 6.1

The cell has an electromotive force (e.m.f.) of 1.50 V and internal resistance *r*. The potential difference between X and Y is 1.20 V.

Calculate:

(i) the current in the circuit

current = ... A [1]

(ii) the internal resistance *r*.

r = ... Ω [2]

(c) A galvanometer and a cell of e.m.f. *E* with negligible internal resistance are connected to the circuit in **(b)**, as shown in Fig. 6.2.

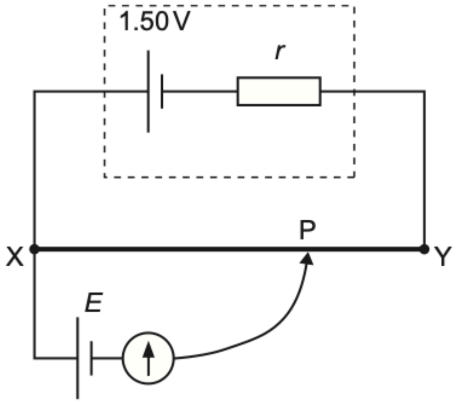

Fig. 6.2

The resistance wire between X and Y has a length of 2.0 m. The galvanometer has a reading of zero when the connection P is adjusted so that the length XP is 1.4 m.

Determine the e.m.f. *E* of the cell.

E = ... V [2]

(d) The circuit in Fig. 6.2 is modified by replacing the original resistance wire with a second resistance wire. The second wire has the same length as the original wire and is made of the same metal.

The second wire has a smaller cross-sectional area than the original wire.

Connection P is adjusted on the second wire so that the galvanometer has a reading of zero.

State and explain whether length XP for the second wire is shorter than, longer than or the same as length XP for the original wire when the galvanometer reading is zero.

....

....

....

....

.... [3]

[Total:10]

14 **(a)** State Kirchhoff's second law.

....

....

.... [2]

(b) A battery has electromotive force (e.m.f.) 4.0 V and internal resistance 0.35 Ω. The battery is connected to a uniform resistance wire XY and a fixed resistor of resistance R, as shown in Fig. 5.1.

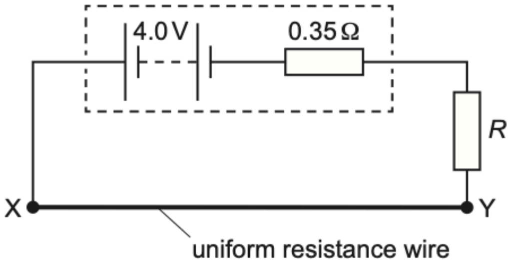

Fig. 5.1

Wire XY has resistance 0.90 Ω. The potential difference across wire XY is 1.8 V.

Calculate:

(i) the current in wire XY

current = ... A [1]

(ii) the number of free electrons that pass a point in the battery in a time of 45 s

number = ... [2]

(iii) resistance R.

R = ... Ω [2]

(c) A cell of e.m.f. 1.2 V is connected to the circuit in **(b)**, as shown in Fig. 5.2.

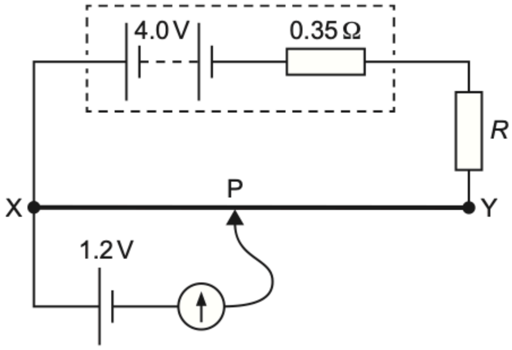

Fig. 5.2

The connection P is moved along the wire XY. The galvanometer reading is zero when distance XP is 0.30 m.

(i) Calculate the total length L of wire XY.

L = ... m [2]

(ii) The fixed resistor is replaced by a different fixed resistor of resistance greater than R.

State and explain the change, if any, that must be made to the position of P on wire XY so that the galvanometer reading is zero.

....

....

....

.... [2]

[Total: 11]

15 **(a)** Define the *ohm*.

....

.... [1]

(b) A wire is made of metal of resistivity ρ. The length L of the wire is gradually increased. Assume that the volume V of the wire remains constant as its length is increased.

Show that the resistance R of the extending wire is proportional to L^2.

[2]

(c) A battery of electromotive force (e.m.f.) E and internal resistance r is connected to a variable resistor of resistance R, as shown in Fig. 5.1.

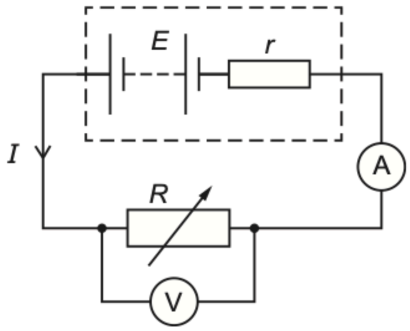

Fig. 5.1

An ammeter measures the current I in the circuit. A voltmeter measures the potential difference V across the variable resistor.

The resistance R is now varied to change the values of I and V.

The variation with I of V is shown in Fig. 5.2.

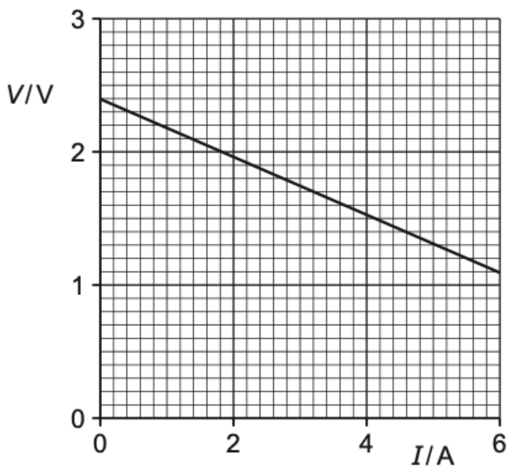

Fig. 5.2

(i) Use Fig. 5.2 to state the e.m.f. E of the battery.

E = ... V [1]

(ii) Use Fig. 5.2 to determine the power dissipated in the variable resistor when there is a current of 5.0A.

power = ... W [3]

(iii) State what is represented by the value of the gradient of the graph.

.... [1]

[Total: 8]

MJ21/23/Q5

16 (a) Define the *electromotive force* (*e.m.f.*) of a source.

....

....

.... [2]

(b) The circuit shown in Fig. 5.1 contains a battery of e.m.f. E that has internal resistance r, a variable resistor, a voltmeter and an ammeter.

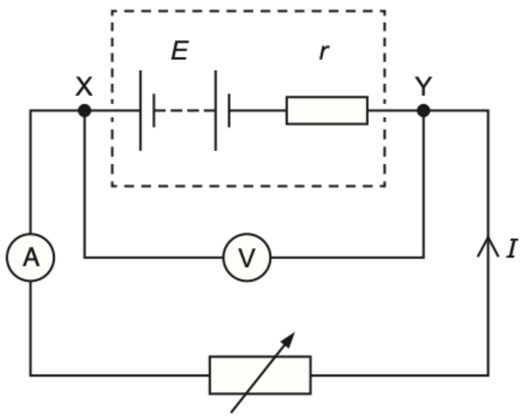

Fig. 5.1

Readings from the two meters are taken for different settings of the variable resistor. The variation with current I of the potential difference (p.d.) V across the terminals XY of the battery is shown in Fig. 5.2.

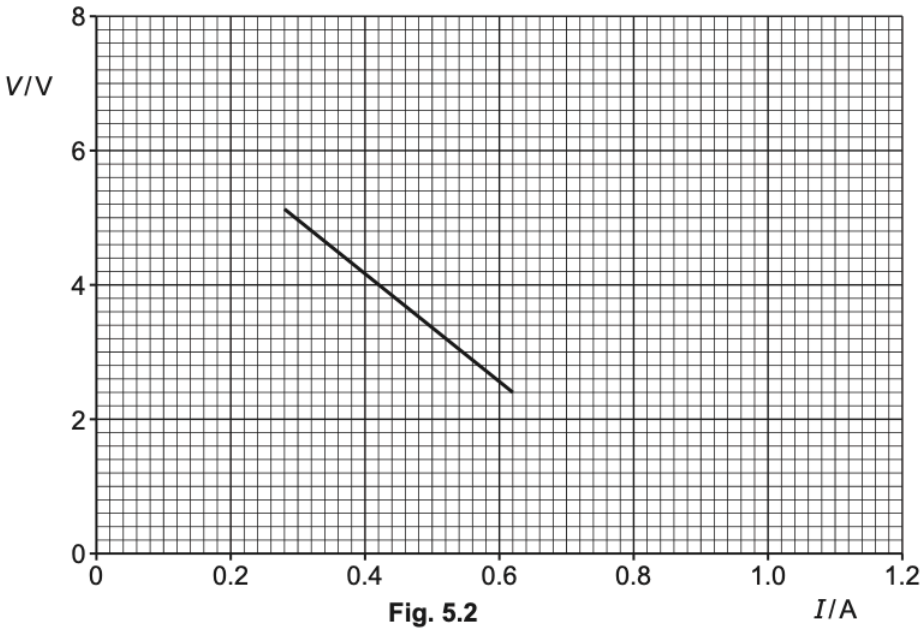

Fig. 5.2

Explain why V is not constant.

....

....

....

.... [3]

(c) For the battery in **(b)**, use Fig. 5.2 to determine:

(i) the e.m.f. E

E = ... V [1]

(ii) the maximum current that the battery can supply

maximum current = ... A [1]

(iii) the internal resistance r.

r = ... Ω [2]

(d) On Fig. 5.2, sketch a line to show a possible variation with I of V for a battery with a lower e.m.f. and a lower internal resistance than the battery in **(b)**. Your line should extend over at least the same range of currents as the original line. [2]

[Total: 11]

17 **(a)** State Kirchhoff's first law.

....

.... [1]

(b) A battery of electromotive force (e.m.f.) 12.0V and internal resistance r is connected to a filament lamp and a resistor, as shown in Fig. 6.1.

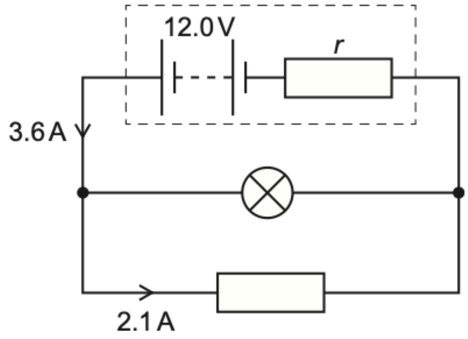

Fig. 6.1

The current in the battery is 3.6A and the current in the resistor is 2.1A. The I-V characteristic for the lamp is shown in Fig. 6.2.

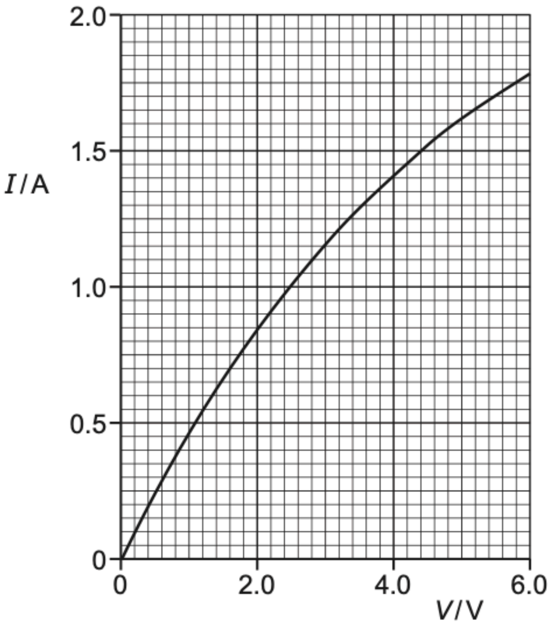

Fig. 6.2

(i) Determine the resistance of the lamp in Fig. 6.1.

resistance = ... Ω [3]

(ii) Determine the internal resistance *r* of the battery.

r = ... Ω [2]

(iii) The initial energy stored in the battery is 470 kJ. Assume that the e.m.f. and the current in the battery do not change with time.

Calculate the time taken for the energy stored in the battery to become 240 kJ.

time = ... s [2]

(iv) The filament wire of the lamp is connected in series with the adjacent copper connecting wire of the circuit, as illustrated in Fig. 6.3.

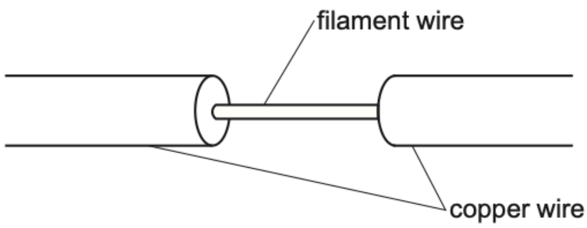

Fig. 6.3 (not to scale)

Some data for the filament wire and the adjacent copper connecting wire are given in Table 6.1.

Table 6.1

Table 6.1

	filament wire	copper wire
cross-sectional area	A	$360A$
number density of free electrons	n	$2.5n$

Calculate the ratio

$$\frac{\text{average drift speed of free electrons in filament wire}}{\text{average drift speed of free electrons in copper wire}}.$$

ratio = ... [2]

[Total: 10]

18 **(a)** Define the *ohm*. **ON20/21/Q7**

....

.... [1]

(b) A uniform wire has resistance 3.2 Ω. The wire has length 2.5 m and is made from metal of resistivity 460 nΩ m.

Calculate the cross-sectional area of the wire.

cross-sectional area = ... m^2 [3]

(c) A cell of electromotive force (e.m.f.) *E* and internal resistance *r* is connected to a variable resistor of resistance *R*, as shown in Fig. 7.1.

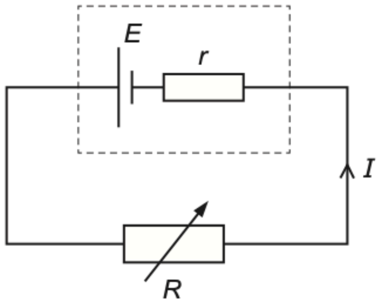

Fig. 7.1

The current in the circuit is *I*.

(i) State, in terms of energy, why the potential difference across the variable resistor is less than the e.m.f. of the cell.

....

.... [1]

(ii) State an expression for *E* in terms of *I*, *R* and *r*.

E = ... [1]

(iii) The resistance *R* of the variable resistor is changed so that it is equal to *r*.

Determine an expression, in terms of only *E* and *r*, for the power *P* dissipated in the variable resistor.

P = ... [2]

[Total: 8]

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19 **(a)** A network of three resistors of resistances R_1, R_2 and R_3 is shown in Fig. 6.1.

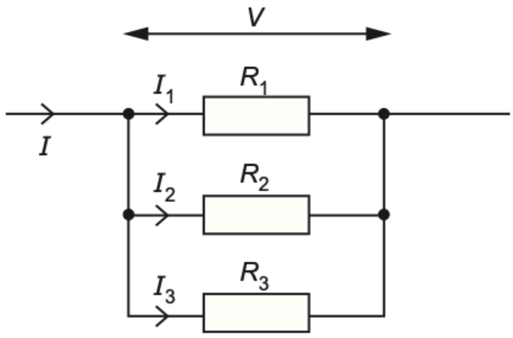

Fig. 6.1

The individual currents in the resistors are I_1, I_2 and I_3. The total current in the combination of resistors is I and the potential difference across the combination is V.

Show that the combined resistance R of the network is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}.$$

[2]

(b) A battery of electromotive force (e.m.f.) 8.0 V and internal resistance r is connected to three resistors X, Y and Z, as shown in Fig. 6.2.

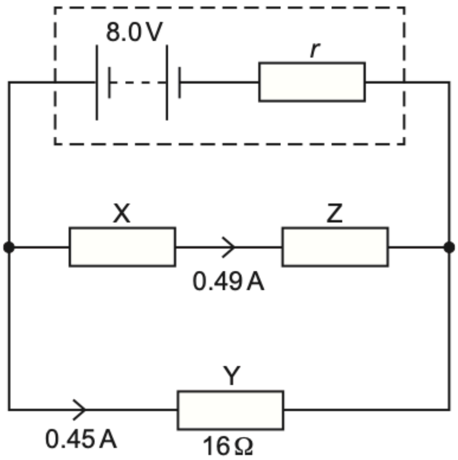

Fig. 6.2

Resistor Y has a resistance of 16 Ω. The current in resistor X is 0.49 A and the current in resistor Y is 0.45 A.

Calculate:

(i) the current in the battery

current = ... A [1]

(ii) the internal resistance *r* of the battery.

r = ... Ω [2]

(c) Resistors X and Y in Fig. 6.2 are made from wires of the same material and cross-sectional area. The average drift speed of the free electrons in X is $2.1 \times 10^{-4}\,\text{m s}^{-1}$.

Calculate the average drift speed *v* of the free electrons in Y.

v = ... m s^{-1} [2]

(d) Resistor Z in Fig. 6.2 is replaced by a new resistor of smaller resistance.

State and explain the effect, if any, on the terminal potential difference of the battery.

....

....

.... [2]

[Total: 9]

ON20/23/Q6

20 **(a)** Define *electric potential difference* (*p.d.*).

....

.... [1]

(b) A wire of cross-sectional area A is made from metal of resistivity ρ. The wire is extended. Assume that the volume V of the wire remains constant as it extends.

Show that the resistance R of the extending wire is inversely proportional to A^2.

[2]

(c) A battery of electromotive force (e.m.f.) E and internal resistance r is connected to a variable resistor of resistance R, as shown in Fig. 6.1.

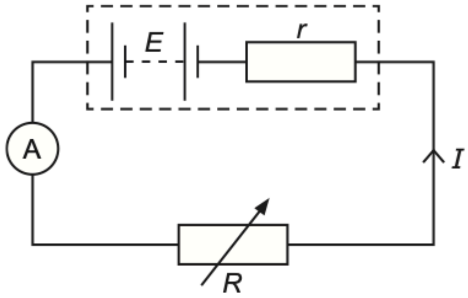

Fig. 6.1

The current in the circuit is I.

Use Kirchhoff's second law to show that

$$R = \left(\frac{E}{I}\right) - r.$$

[1]

(d) An ammeter is used in the circuit in **(c)** to measure the current I as resistance R is varied. Fig. 6.2 is a graph of R against $\frac{1}{I}$.

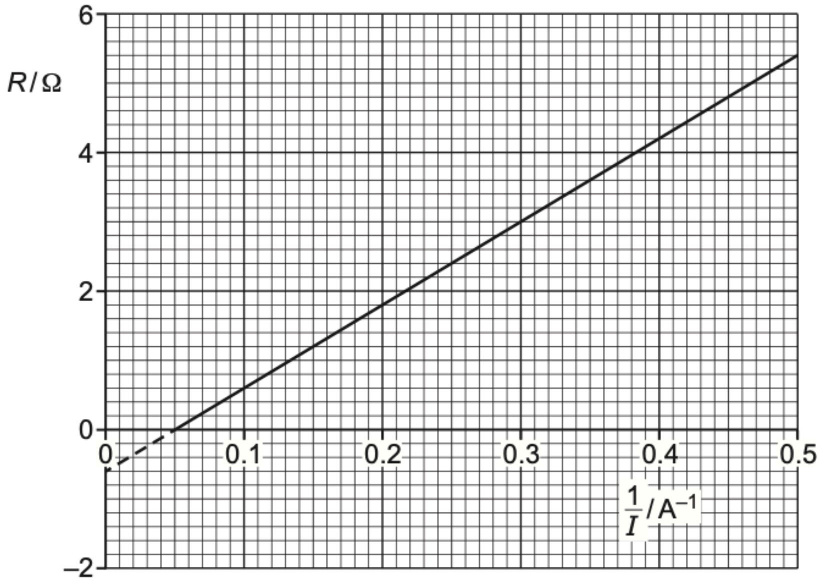

Fig. 6.2

(i) Use Fig. 6.2 to determine the power dissipated in the variable resistor when there is a current of 2.0 A in the circuit.

power = ... W [3]

(ii) Use Fig. 6.2 and the equation in **(c)** to:

1. state the internal resistance r of the battery

r = ... Ω

2. determine the e.m.f. E of the battery.

E = ... V
[3]

[Total: 10]

1 a)(i)	(V =) 1.50 – 1.36 (= 0.14 V)	**B1**
	current = V / R = 0.14 / 0.28 = 0.50 A	**A1**
7(a)(ii)	resistance = V / I	**C1**
	= 1.36 / 0.50 = 2.7 Ω	**A1**
7(a)(iii)	R = 2.7 – 1.0 = 1.7 Ω	**A1**
7(b)(i)	two resistors correctly shown in parallel with cell and no other components	**B1**
7(b)(ii)	(external) resistance is now smaller **and** (so) current (in cell) is greater / (external) resistance smaller fraction of total resistance / internal resistance larger fraction of total resistance	**B1**
	(greater p.d. across internal resistance so) terminal p.d. is less	**B1**

2 a)	<u>sum of</u> current(s) entering a junction = <u>sum of</u> current(s) leaving (the same junction) **or** (algebraic) sum of current (s) at a junction is zero	**B1**
6(b)	(by Kirchhoff's second law) $V = V_1 + V_2$	**B1**
	so $IR_T = IR_1 + IR_2$ (and cancelling I gives) $R_T = R_1 + R_2$ **or** $V / I = V_1 / I + V_2 / I$ (and substituting R gives) $R_T = R_1 + R_2$	**B1**
6(c)	current in circuit = 1.35 / (10 + 15) (= 0.054 A)	**C1**
	$r = (E - V) / I$	**C1**
	= (1.5 – 1.35) / 0.054 = 2.8 Ω	**A1**
	or	
	by potential divider principle $\frac{0.15}{1.35} = \frac{r}{25}$	**(C2)**
	r = 2.8 Ω	**(A1)**
	or	
	I = 1.35 / (10 + 15) (= 0.054 A)	**(C1)**
	total resistance = 1.50 / 0.054 (= 27.8 Ω) r = 27.8 – 25	**(C1)**
	r = 2.8 Ω	**(A1)**
6(d)(i)	the (total) resistance (of the circuit) has decreased (and e.m.f. is unchanged)	**M1**
	(the current (in the cell) will) increase	**A1**
6(d)(ii)	(as the current is greater and so there is a) larger p.d. across the internal resistance	**M1**
	(terminal p.d. will) decrease	**A1**

3 (a)(i)	sum of electromotive force(s) = sum of potential difference(s) around a (closed) loop **or** the (algebraic) sum of the p.d.(s) and e.m.f.(s) is zero around a (closed) loop	**B1**
5(a)(ii)	(law of conservation of) energy	**B1**
5(b)(i)	(by Kirchhoff's first law) $I = I_1 + I_2$	**B1**
	$V / R_T = V / R_1 + V / R_2$ therefore $1 / R_T = 1 / R_1 + 1 / R_2$	**B1**
5(b)(ii)	resistance of parallel combination = (15 × 10) / (15 + 10) (= 6.0 Ω)	**C1**
	$r = (E – V) / I$	**C1**
	I = 1.38 / 6.0 = 0.23 A r = (1.50 – 1.38) / 0.23 = 0.52 Ω	**A1**
	or	
	(by potential divider principle) $r / R_T = Ir / V$	**(C1)**
	r / 6.0 = 0.12 / 1.38 r = 0.52 Ω	**(A1)**
	or	
	(by potential divider equation) $V = E \times R_T / (R_T + r)$	**(C1)**
	1.38 = 1.5 × 6.0 / (6.0 + r) r = 0.52 Ω	**(A1)**
5(c)(i)	as the (total) resistance has decreased (and e.m.f. is unchanged)	**M1**
	current will (in the cell) increase	**A1**
5(c)(ii)	(as greater current means a) bigger drop in p.d. across the internal resistance	**M1**
	p.d. (on voltmeter) will decrease	**A1**

4 a)	energy (transferred) per (unit) charge	**B1**
7(b)	V = 0.25 × 6 =1.5	**C1**
	$Ir = E – IR$ Ir = 1.8 – 1.5 = 0.3	**C1**
	r = 0.3 / 0.25 = 1.2 Ω	**A1**
	or (Total) R = 1.8 / 0.25 = 7.2 $E / I = (R + r)$	**(C1)**
	1.8/0.25 = 6 + r	**(C1)**
	r = 7.2 – 6 = 1.2 Ω	**(A1)**
7(c)(i)	The same	**B1**
7(c)(ii)	Any 3 from: • before t_1 / when current constant, the (total) resistance is constant • at t_1 / when current increases, the (total) resistance decreases (due to decrease of external resistance) • (after t_1) temperature (of lamp) increases (so the resistance of the lamp increases) • (after t_1) resistance **of lamp** increases (so total resistance increases so the current in the ammeter decreases)	**B3**

5 (a)	current (through a conductor is directly) proportional to potential difference (across the conductor) or vice versa	**M1**
	(provided that) temperature (of conductor remains) constant	**A1**
7(b)(i)	$R = \rho L / A$	**C1**
	$\rho = (18 \times 7.2 \times 10^{-8}) / 0.94$ $= 1.4 \times 10^{-6}\ \Omega\ \text{m}$	**A1**
7(b)(ii)	voltmeter reading = 3.1 V	**A1**
7(b)(iii)	current in the battery: increase	**B1**
	voltmeter reading: decrease	**B1**
7(b)(iv)	cross marked on the resistance wire to right of the arrowhead of S, but not touching the right-hand end of the resistance wire	**B1**
7(c)(i)	$I = Anvq$ $q = 0.93 / [(7.2 \times 10^{-8}) \times (9.0 \times 10^{28}) \times (1.3 \times 10^{-3})]$	**C1**
	$q = 1.1 \times 10^{-19}$ C	**A1**
7(c)(ii)	charge / q (value) is below 1.6×10^{-19} (C) **or** charge cannot be below 1.6×10^{-19} (C) **or** (the charge carriers / q) should have a charge of 1.6×10^{-19} (C)	**B1**

6 a)	$V / 9.0 = 1800 / (1800 + 1200)$	**C1**
	$V = 5.4$ V	**A1**
	or	
	$I = 9.0 / (1800 + 1200) = 3.0 \times 10^{-3}$ (A) $V = 3.0 \times 10^{-3} \times 1800$	**(C1)**
	$= 5.4$ V	**(A1)**
7(b)(i)	$L / 1.2 = 5.4 / 9.0$ **or** XZ / 1.2 = 5.4 / 9.0	**C1**
	$L = 0.72$ m	**A1**
	or	
	$L / 1.2 = 1800 / (1800 + 1200)$ **or** XZ / 1.2 = 1.8 / (1.8 + 1.2)	**(C1)**
	$L = 0.72$ m	**(A1)**
7(b)(ii)	• (intensity) increase	**B1**
	• (power) increase	**B1**
	• (length XZ) decrease	**B1**

7 a)	energy (transferred from electrical to other forms) per unit charge	**B1**
6(b)(i)	(resistance is) infinite / very high	**B1**
6(b)(ii)	(resistance) decreases (as V increases)	**B1**
6(c)(i)	current = 2.7 – 1.5 = 1.2 A	**A1**
6(c)(ii)	$12 = (1.5 \times 5.0) + (1.5 \times R)$ **or** $R = (12 / 1.5) – 5.0$	**C1**
	$R = 3.0\ \Omega$	**A1**

6(c)(iii)	$V_{(XZ)}$ = (1.6 / 2.0) × 12 (= 9.6 V)	**C1**
	$V_{(XW)}$ = 1.5 × 5.0 (= 7.5 V)	**C1**
	potential difference = 9.6 – 7.5 = 2.1 V	**A1**
	or	
	$V_{(ZY)}$ = (0.4 / 2.0) × 12 (= 2.4 V)	**(C1)**
	$V_{(WY)}$ = 1.5 × 3.0 (= 4.5 V)	**(C1)**
	potential difference = 4.5 – 2.4 = 2.1 V	**(A1)**
6(c)(iv)	current in (fixed / variable) resistor decreases	**B1**
	current in (resistance) wire is unchanged	**B1**
	(so) current in battery decreases, (same e.m.f. so) power decreases	**B1**

8 a)	energy transferred per (unit) charge (from electrical to other forms)	**B1**
6(b)	same/equal current (in X and Y)	**B1**
	$P = I^2R$ (and $R_X > R_Y$) **or** $P = VI$ **and** $V_X > V_Y$	**M1**
	(so) X (dissipates more power)	**A1**
6(c)(i)	$I = Q / t$	**C1**
	= 650 / 540 = 1.2 A	**A1**
6(c)(ii)	$V = W / Q$ **or** W / It	**C1**
	= 4800 / 650 **or** 4800 / (1.2 × 540) = 7.4 V	**A1**
	or	
	$V = P / I$ **and** $P = W / t$	**(C1)**
	= 8.9 / 1.2 = 7.4 V	**(A1)**
6(c)(iii)	I = 4.5 + 1.2 (= 5.7 A)	**C1**
	9.0 = 7.4 + 5.7r **or** 9.0 = 5.7 (1.3 + r) r = 0.28 Ω	**A1**

9 (a)	sum of e.m.f.(s) = sum of p.d.(s) **or** (algebraic) sum of e.m.f.(s) and p.d.(s) is zero	**M1**
	around a loop / around a closed circuit	**A1**
5(b)(i)	1 / $r_{(T)}$ = 1 / 0.59 + 1 / 0.59 + 1 / 0.59	**B1**
	($r_{(T)}$ =) 0.197 (Ω) (R =) 2.2 – 0.197 = 2.0 Ω	**A1**
	or	
	I = 1.5 / 2.2 (= 0.68 A) **and** i = 0.68 / 3 (where I is the circuit current and i is the current from each cell)	**(B1)**
	($E = IR + ir$ =) 1.5 = 0.68R + (0.68 / 3) × 0.59 **and** R = 2.0 Ω	**(A1)**

5(b)(ii)	current = 1.5 / 2.2	C1
	= 0.68 A	A1
	or	
	p.d. across cell = p.d. across conductor $1.5 - 0.59I = 3I \times 2.0$ so $I = 0.228$ A (where I is current in cell) current = 3 × 0.228	(C1)
	= 0.68 A	(A1)
	or	
	current in conductor = 3 × current in cell $V / 2.0 = 3 \times (1.5 - V) / 0.59$ (where V is p.d. across conductor) $V = 1.37$ V current = 1.37 / 2.0	(C1)
	= 0.68 A	(A1)
5(c)(i)	$R = \rho L / A$	C1
	$R = 4\rho L / \pi d^2$ (ρ and L are the same so) $R_A / R_B = 7.6^2 / 4.3^2$	C1
	= 3.1	A1
5(c)(ii)	$I = Anvq$ and I, n, q are same / equal / constant	B1
	$\frac{v_A}{v_B} = \frac{A_B}{A_A} = \frac{d_B^2}{d_A^2}$ ratio = $7.6^2 / 4.3^2$ = 3.1	A1
5(d)	combined internal resistance (of the cells) will be greater **or** total / circuit resistance (of circuit) greater (because a parallel resistance removed)	B1
	more 'lost volts' (inside each cell) **or** internal resistances take a greater share of total p.d. **or** conductor gets a smaller share of the total p.d. **or** current in conductor/total current decreases	M1
	(so) potential difference (across conductor) decreases	A1

10 (a)	$V = V_1 + V_2 + V_3$	B1
	$IR = IR_1 + IR_2 + IR_3$ **or** $(V / I) = (V_1 / I) + (V_2 / I) + (V_3 / I)$ **and** $R = R_1 + R_2 + R_3$	B1
6(b)(i)	$V / 8.0 = 6.0 \times 10^3 / (4.0 \times 10^3 + 6.0 \times 10^3)$ **or** $I = 8.0 / (4.0 \times 10^3 + 6.0 \times 10^3) = 8.0 \times 10^{-4}$ $V = 8.0 \times 10^{-4} \times 6.0 \times 10^3$	C1
	$V = 4.8$ V	A1
6(b)(ii)	total resistance in parallel = 3.0×10^3 (Ω) **or** 3.0 (kΩ)	C1
	current = $8.0 / (3.0 \times 10^3 + 6.0 \times 10^3)$ = 8.9×10^{-4} A	A1
6(c)	thermistor resistance increases	B1
	(thermistor resistance increases so total resistance increases so) current decreases (in battery)	M1
	($P = EI$ and E constant so) power decreases	A1

11 a)	sum of current(s) in = sum of current(s) out **or** (algebraic) sum of current(s) is zero	**M1**
	at a junction (in a circuit)	**A1**
5(b)(i)	(current in R_4 or R_1 =) 0.30 + 0.30 (= 0.60 A)	**B1**
	(R =) 2.4 / 0.60 = 4.0 (Ω)	**A1**
	or	
	(p.d. across R_3 or R_2 =) 2.4 / 2 (= 1.2 V)	**(B1)**
	(R =) 1.2 / 0.30 = 4.0 (Ω)	**(A1)**
5(b)(ii)	E = 2.4 + 2.4 + 1.2	**C1**
	= 6.0 V	**A1**
	or	
	total resistance = 10 (Ω)	**(C1)**
	E = 10 × 0.60 = 6.0 V	**(A1)**
5(c)	total resistance increases	**B1**
	current decreases (in battery) so total power decreases	**B1**
5(d)	resistivity = RA / L	**C1**
	= 4.0 × π × (240 × 10^{-6})^2 / 0.67	**C1**
	= 1.1 × 10^{-6} Ω m	**A1**

12 6(a)	$Q = It$	**C1**
	= 0.80 × 7.5 × 60 = 360 C	**A1**
6(b)	$P = EI$ **or** $P = VI$ **or** $P = I^2R$ **or** $P = V^2 / R$	**C1**
	0.80^2 × 0.40 (= 0.256 W) **or** 0.48 × 0.80 (= 0.384 W)	**C1**
	efficiency = (0.256 / 0.384) × 100 = 67%	**A1**
6(c)(i)	n = 3.2 × 10^{22} / (1.3 × 10^{-7} × 3.0) = 8.2 × 10^{28} m^{-3}	**A1**
6(c)(ii)	$I = Anvq$ v = 0.80 / (1.3 × 10^{-7} × 8.2 × 10^{28} × 1.60 × 10^{-19})	**C1**
	= 4.7 × 10^{-4} m s^{-1}	**A1**
6(d)	(wire Y has) larger resistance / resistance increases	**M1**
	(wire Y has) smaller current / current decreases	**M1**
	(average drift) speed is less (in wire Y)	**A1**

13 a)	$R = \rho L / A$	**C1**
	(R =) 5(.0) × 10^{-7} × 2(.0) / 3.3 × 10^{-7} = 3.0 Ω	**A1**
6(b)(i)	I = 1.2 / 3.0 = 0.40 A	**A1**
6(b)(ii)	r = (1.50 – 1.20) / 0.40 **or** 1.50 / 0.40 – 3.0	**C1**
	= 0.75 Ω	**A1**
6(c)	E / 1.20 = 1.4 / 2.0	**C1**
	E = 0.84 V	**A1**
	or	
	R_{XP} = (1.4 / 2.0) × 3.0 (= 2.1 Ω) E = 2.1 × 0.40	**(C1)**
	E = 0.84 V	**(A1)**
6(d)	(second wire has) larger resistance/resistance increases	**M1**
	p.d. across XY is larger/increases (for second wire) **or** p.d. across the (second) wire is larger/increases	**M1**
	(so) length XP (for second wire) is shorter	**A1**

14 a)	<u>sum of</u> e.m.f.(s) = <u>sum of</u> p.d.(s) **or** (algebraic) sum of e.m.f.(s) and p.d.(s) is zero	**M1**
	around a loop/around a <u>closed</u> circuit	**A1**
5(b)(i)	I = 1.8 / 0.90 = 2.0 A	**A1**
5(b)(ii)	$Q = It$	**C1**
	number = (2.0 × 45) / 1.60 × 10^{-19} = 5.6 × 10^{20}	**A1**
5(b)(iii)	4.0 = 1.8 + [2.0 × (0.35 + R)] **or** 4.0 = 2.0 × (0.90 + 0.35 + R)	**C1**
	R = 0.75 Ω	**A1**
5(c)(i)	1.2 / 1.8 = 0.30 / L	**C1**
	L = 0.45 m	**A1**
5(c)(ii)	p.d. across XY decreases/p.d. across XP decreases	**B1**
	(so) P is moved towards Y/away from X/to the right	**B1**

15 (a)	volt / ampere	**B1**
5(b)	$R = \rho L / A$	**B1**
	($A = V / L$) (so) $R = \rho L^2 / V$ (with ρ and V constant so $R \propto L^2$)	**B1**
5(c)(i)	E = 2.4 V	**A1**
5(c)(ii)	$P = VI$ **or** I^2R **or** V^2 / R	**C1**
	= 1.3 × 5.0 **or** 5.0^2 × 0.26 **or** 1.3^2 / 0.26	**C1**
	= 6.5 W	**A1**
5(c)(iii)	(–) internal resistance **or** (–) r	**B1**

16 (a)	energy per unit charge	**B1**
	energy transferred by source driving charge around the complete circuit **or** energy transferred from other forms to electrical energy	**B1**
5(b)	there is a p.d. across the internal resistance/*r*	**B1**
	change in current/*I* results in a change in p.d. across the internal resistance	**B1**
	V = *E* – p.d. across internal resistance **or** change in p.d. across *r* causes a change in *V* (as e.m.f. is constant)	**B1**
5(c)(i)	$E = 7.4$ V	**A1**
5(c)(ii)	maximum current = 0.92 A	**A1**
5(c)(iii)	$r = E / I_{MAX}$ **or** (–)gradient	**C1**
	e.g. $r = 7.4 / 0.92$ $= 8.0\ \Omega$	**A1**
5(d)	straight line with negative gradient that is smaller in magnitude than the original line	**B1**
	line which would have intercept on *V*-axis below the original line	**B1**

17 (a)	<u>sum of</u> current(s) into junction = <u>sum of</u> current(s) out of junction or (algebraic) sum of current(s) at a junction is zero	**B1**
6(b)(i)	$I = 3.6 – 2.1$ $= 1.5$	**C1**
	$V = 4.4$	**C1**
	$R = 4.4 / 1.5$ $= 2.9\ \Omega$	**A1**
6(b)(ii)	$12.0 = 4.4 + 3.6r$ or $12.0 = 3.6\ (1.2 + r)$	**C1**
	$r = 2.1\ \Omega$	**A1**
6(b)(iii)	$t = (470 \times 10^3 – 240 \times 10^3) / (12 \times 3.6)$	**C1**
	$= 5300$ s	**A1**
6(b)(iv)	$I = Anvq$ ratio = $(360A / A) \times (2.5n / n)$ or 360×2.5	**C1**
	$= 900$	**A1**

18 (a)	volt / ampere	**B1**
7(b)	$R = \rho L / A$	**C1**
	$A = 460 \times 10^{-9} \times 2.5 / 3.2$	**C1**
	$= 3.6 \times 10^{-7}\ m^2$	**A1**
7(c)(i)	energy is dissipated in the internal resistance/*r*	**B1**
7(c)(ii)	$E = IR + Ir$ **or** $E = I\ (R + r)$	**B1**
7(c)(iii)	$P = I^2R$ **or** $P = I^2r$	**C1**
	$I = E / 2r$ (so) $P = E^2 / 4r$	**A1**

19 (a)	$I = I_1 + I_2 + I_3$	**B1**
	$(V / R) = (V / R_1) + (V / R_2) + (V / R_3)$ **or** $(I / V) = (I_1 / V) + (I_2 / V) + (I_3 / V)$ **and** $1 / R = 1 / R_1 + 1 / R_2 + 1 / R_3$	**B1**
6(b)(i)	current = 0.49 + 0.45 = 0.94 A	**A1**
6(b)(ii)	8.0 = (0.94 × *r*) + (0.45 × 16)	**C1**
	r = 0.85 Ω	**A1**
6(c)	$I = Anvq$ $v = (0.45 / 0.49) \times 2.1 \times 10^{-4}$	**C1**
	$= 1.9 \times 10^{-4}\ \text{m s}^{-1}$	**A1**
6(d)	total/combined resistance decreases	**B1**
	(current in battery increases so terminal) potential difference decreases	**B1**

20 (a)	$\dfrac{\text{work (done) / energy (transferred from electrical to other forms)}}{\text{charge}}$	**B1**
6(b)	$R = \rho L / A$	**B1**
	$V = LA$ **and** (so) $R = \rho V / A^2$ (with ρ and V constant)	**B1**
6(c)	$E = IR + Ir$ **or** $E = I(R + r)$ **or** $E - Ir = IR$ **and** $R = (E / I) - r$	**A1**
6(d)(i)	$P = I^2R$ **or** $P = IV$ **or** $P = V^2 / R$	**C1**
	R = 5.4 (Ω) **or** V = 10.8 (V)	**C1**
	$P = 2.0^2 \times 5.4$ = 22 W	**A1**
6(d)(ii)	**1.** *r* = 0.60 Ω	**A1**
	2. *E* = gradient	**C1**
	= e.g. 5.4 / 0.45 = 12 V	**A1**