An ohmic conductor is connected to an ideal ammeter and to a power supply of output voltage V.

The following data are available for the conductor:
density of free electrons = $8.5 \times 10^{22}$ cm$^{-3}$
resistivity $\rho = 1.7 \times 10^{-8}$ $\Omega$m
dimensions $w \times h \times l = 0.020$ cm $\times 0.020$ cm $\times 10$ cm.
The ammeter reading is 2.0 A.

1a. Calculate the resistance of the conductor. [2 marks]

Markscheme

\[
1.7 \times 10^{-8} \times \frac{0.10}{(0.02 \times 10^{-2})^2}
\]

0.043 «\(\Omega\)»

[2 marks]

1b. Calculate the drift speed $v$ of the electrons in the conductor in cm s$^{-1}$. State your answer to an appropriate number of significant figures. [3 marks]

Markscheme

\[
v = \frac{I}{neA} = \frac{2}{8.5 \times 10^{22} \times 1.60 \times 10^{-19} \times 0.02^2}
\]

0.368 «cm$^{-1}$»

0.37 «cm$^{-1}$»

Award [2 max] if answer is not expressed to 2 sf.

[3 marks]
An electron moves in circular motion in a uniform magnetic field.

The velocity of the electron at point P is $6.8 \times 10^5$ m s$^{-1}$ in the direction shown.
The magnitude of the magnetic field is 8.5 T.

2a. State the direction of the magnetic field.  

**Markscheme**  
out of the page plane / ⊙  

*Do not accept just “up” or “outwards”.*  

[1 mark]

2b. Calculate, in N, the magnitude of the magnetic force acting on the electron.  

**Markscheme**  
$1.60 \times 10^{-19} \times 6.8 \times 10^5 \times 8.5 = 9.2 \times 10^{-13} \text{ N}$  

[1 mark]

2c. Explain why the electron moves at constant speed.  

**Markscheme**  
the magnetic force does not do work on the electron hence does not change the electron’s kinetic energy  

*OR*  
the magnetic force/acceleration is at right angles to velocity  

[1 mark]

2d. Explain why the electron moves on a circular path.  

[2 marks]
The diagram shows a potential divider circuit used to measure the emf \( E \) of a cell X. Both cells have negligible internal resistance.

3a. State what is meant by the emf of a cell. 

**Markscheme**

the work done per unit charge
in moving charge from one terminal of a cell to the other / all the way round the circuit

*Award [1] for “energy per unit charge provided by the cell”/“power per unit current”*

*Award [1] for “potential difference across the terminals of the cell when no current is flowing”*

*Do not accept “potential difference across terminals of cell”*

**[2 marks]**

AB is a wire of uniform cross-section and length 1.0 m. The resistance of wire AB is 80 \( \Omega \). When the length of AC is 0.35 m the current in cell X is zero.

3b. Show that the resistance of the wire AC is 28 \( \Omega \).

**Markscheme**

the resistance is proportional to length / see 0.35 \( \text{AND} \ 0.00 \)
so it equals 0.35 \( \times \) 80
\( \approx 28 \ \Omega \)

**[2 marks]**
3c. Determine $E$.

**Markscheme**

current leaving 12 V cell is $\frac{12}{80} = 0.15 \text{ «A»}$

**OR**

$E = \frac{12}{80} \times 28$

$E = \langle 0.15 \times 28 \rangle = 4.2 \text{ «V»}$

Award [2] for a bald correct answer

Allow a 1sf answer of 4 if it comes from a calculation.

Do not allow a bald answer of 4 «V»

Allow ECF from incorrect current

[2 marks]

Electrical resistors can be made by forming a thin film of carbon on a layer of an insulating material.

A carbon film resistor is made from a film of width 8.0 mm and of thickness 2.0 µm. The diagram shows the direction of charge flow through the resistor.

4a. The resistance of the carbon film is 82 Ω. The resistivity of carbon is $4.1 \times 10^{-5}$ Ω m. [1 mark]

Calculate the length $l$ of the film.

**Markscheme**

$$l = \frac{RA}{\rho} = \frac{82 \times 8 \times 10^{-3} \times 2 \times 10^{-6}}{4.1 \times 10^{-5}}$$

0.032 «m»

4b. The film must dissipate a power less than 1500 W from each square metre of its surface to avoid damage. Calculate the maximum allowable current for the resistor. [2 marks]
**Markscheme**

\[
power = 1500 \times 8 \times 10^{-3} \times 0.032 \approx 0.384
\]

\[
\text{current} \leq \sqrt{\frac{\text{power}}{\text{resistance}}} = \sqrt{\frac{0.384}{82}}
\]

0.068 «A»

*Be aware of ECF from (a)(i)*

*Award [1] for 4.3 «A» where candidate has not calculated area*

4c. State why knowledge of quantities such as resistivity is useful to scientists. [1 mark]

**Markscheme**

quantities such as resistivity depend on the material

OR

they allow the selection of the correct material

OR

they allow scientists to compare properties of materials

4d. The current direction is now changed so that charge flows vertically through the film. [2 marks]

![Diagram](image)

Deduce, without calculation, the change in the resistance.

**Markscheme**

as area is larger and length is smaller

resistance is «very much» smaller

*Award [1 max] for answers that involve a calculation*

4e. Draw a circuit diagram to show how you could measure the resistance of the carbon-film resistor using a potential divider arrangement to limit the potential difference across the resistor. [2 marks]
A heater in an electric shower has a power of 8.5 kW when connected to a 240 V electrical supply. It is connected to the electrical supply by a copper cable.

The following data are available:

Length of cable = 10 m
Cross-sectional area of cable = 6.0 mm$^2$
Resistivity of copper = $1.7 \times 10^{-8}$ Ω m

5a. Calculate the current in the copper cable.  [1 mark]

**Markscheme**

$I = \frac{8.5 \times 10^3}{240} = 35$ A

5b. Calculate the resistance of the cable.  [2 marks]

**Markscheme**

$R = \frac{1.7 \times 10^{-8} \times 10}{6.0 \times 10^{-6}}$

$= 0.028$ Ω

*Allow missed powers of 10 for MP1.*

5c. Explain, in terms of electrons, what happens to the resistance of the cable as the temperature of the cable increases.  [3 marks]
Markscheme

«as temperature increases» there is greater vibration of the metal atoms/lattice/lattice ions

OR

increased collisions of electrons

drift velocity decreases «so current decreases»

«as V constant so» $R$ increases

Award [0] for suggestions that the speed of electrons increases so resistance decreases.

5d. The heater changes the temperature of the water by 35 K. The specific heat capacity of water is 4200 J kg$^{-1}$ K$^{-1}$.

Determine the rate at which water flows through the shower. State an appropriate unit for your answer.

Markscheme

recognition that power = flow rate $\times$ c$\Delta$ T

flow rate $= \frac{\text{power}}{c\Delta T}$ $= \frac{8.5 \times 10^3}{4200 \times 35}$

$= 0.058$ «kg s$^{-1}$»

kg s$^{-1}$ / g s$^{-1}$ / l s$^{-1}$ / ml s$^{-1}$ / m$^3$ s$^{-1}$

Allow MP4 if a bald flow rate unit is stated. Do not allow imperial units.

A cable consisting of many copper wires is used to transfer electrical energy from a generator to an electrical load. The copper wires are protected by an insulator.

6a. The copper wires and insulator are both exposed to an electric field. Discuss, with reference to charge carriers, why there is a significant electric current only in the copper wires. [3 marks]
 Markscheme  

when an electric field is applied to any material «using a cell etc» it acts to accelerate any free electrons.

 electrons are the charge carriers «in copper»

 Accept “free/valence/delocalised electrons”.

 metals/copper have many free electrons whereas insulators have few/no free electrons/charge carriers.

The cable consists of 32 copper wires each of length 35 km. Each wire has a resistance of 64 $\Omega$. The resistivity of copper is $1.7 \times 10^{-8} \Omega \cdot m$.

6b. Calculate the radius of each wire. \hspace{1cm} [2 marks]

 Markscheme  

area = $\frac{1.7 \times 10^{-8} \times 35 \times 10^3}{64} \approx 9.3 \times 10^{-6} \text{m}^2$  

6c. There is a current of 730 A in the cable. Show that the power loss in 1 m of the cable is about 30 W. \hspace{1cm} [2 marks]

 Markscheme  

«resistance of cable = 2$\Omega$»

power dissipated in cable = $730^2 \times 2 \approx 1.07 \text{ MW}$

power loss per meter = $\frac{1.07 \times 10^{-6}}{35 \times 10^3}$ or 30.6 «W m$^{-1}$»

 Allow [2] for a solution where the resistance per unit metre is calculated using resistivity and answer to (b)(i) (resistance per unit length of cable = $5.7 \times 10^{-5}$ m)

6d. When the current is switched on in the cable the initial rate of rise of temperature of the cable is 35 mK s$^{-1}$. The specific heat capacity of copper is 390 J kg$^{-1}$ K$^{-1}$. Determine the mass of a length of one metre of the cable. \hspace{1cm} [2 marks]
The graph shows how current $I$ varies with potential difference $V$ for a resistor $R$ and a non-ohmic component $T$.

7a. (i) State how the resistance of $T$ varies with the current going through $T$. [3 marks]
(ii) Deduce, without a numerical calculation, whether $R$ or $T$ has the greater resistance at $I=0.40$ A.
Markscheme

i

\( R_T \) decreases with increasing \( I \)

OR

\( R_T \) and \( I \) are negatively correlated

Must see reference to direction of change of current in first alternative.

Do not allow “inverse proportionality”.

May be worth noting any marks on graph relating to 7bii

ii

at 0.4 A: \( V_R > V_T \) or \( V_R = 5.6 \text{ V} \) and \( V_T = 5.3 \text{ V} \)

Award [0] for a bald correct answer without deduction or with incorrect reasoning.

Ignore any references to graph gradients.

so \( R_R > R_T \) because \( V = IR \vdash V \propto R \) «and \( I \) same for both»

Both elements must be present for MP2 to be awarded.

7b. Components \( R \) and \( T \) are placed in a circuit. Both meters are ideal.

[3 marks]

Slider \( Z \) of the potentiometer is moved from \( Y \) to \( X \).

(i) State what happens to the magnitude of the current in the ammeter.

(ii) Estimate, with an explanation, the voltmeter reading when the ammeter reads 0.20 A.
In an experiment a student constructs the circuit shown in the diagram. The ammeter and the voltmeter are assumed to be ideal.

8a. State what is meant by an ideal voltmeter. [1 mark]

**Markscheme**

```
i
decreases
**OR** becomes zero at X

ii
realization that V is the same for R and T
**OR** identifies that currents are 0.14 A and 0.06 A

Award [0] if pds 2.8 V and 3.7 V or 1.4 V and 2.6V are used in any way. Otherwise award **[1 max]** for a bald correct answer. Explanation expected.

2 V = 2 V OR 2.0 V

Infinite resistance **OR** draws no current from circuit/component **OR** has no effect on the circuit

*Do not allow “very high resistance”*.```
8b. The student adjusts the variable resistor and takes readings from the ammeter and voltmeter. The graph shows the variation of the voltmeter reading $V$ with the ammeter reading $I$.

Use the graph to determine

(i) the electromotive force (emf) of the cell.

(ii) the internal resistance of the cell.

**Markscheme**

(i)

«vertical intercept = emf» $= 8.8 - 9.2 \text{ V}

(ii)

attempt to evaluate gradient of graph

$= 0.80 \Omega$

Accept other methods leading to correct answer, eg using individual data points from graph.

Allow a range of $0.78 - 0.82 \Omega$.

If $\varepsilon = I(R + r)$ is used then the origin of the value for $R$ must be clear.
8c. A connecting wire in the circuit has a radius of 1.2mm and the current in it is 3.5A. The number of electrons per unit volume of the wire is $2.4 \times 10^{28} \text{m}^{-3}$. Show that the drift speed of the electrons in the wire is $2.0 \times 10^{-4} \text{ms}^{-1}$.

**Markscheme**

$$3.5 = 2.4 \times 10^{28} \pi (1.2 \times 10^{-3})^2 \times 1.6 \times 10^{-19} \times v \Rightarrow v = 2.0 \times 10^{-4} \text{ms}^{-1}$$

8d. The diagram shows a cross-sectional view of the connecting wire in (c).

**Markscheme**

$$F = qvB = 1.6 \times 10^{-19} \times 2.0 \times 10^{-4} \times 0.25 \Rightarrow 8.1 \times 10^{-24} \text{N}$$
directed down OR south