Topic 4 Electric Circuits
4A Electrical quantities

4A.1 Electric current

1 (a) 0.625 A

(b) 7.6 C

(c) 2.35×10^{-8} s

2 (a) 0.167 s

(b) 1.25×10^{11}

3 1.4 A

4A.2 Electrical energy transfer

1 Emf measures energy transferred to electrical energy (a supply voltage); pd measures energy transferred from electrical to other stores

2 (a) 1.58 V

(b) 9.26 V

3 (a) 6.0 eV

(b) 7.68×10^{-13} J

4 Students should include discussion of at least the following ideas in their evaluation of the strengths and weaknesses of the snowpark model of an electric circuit:

The representation of charge carriers – small individual units within a large system is good; different types (snowboarders and skiers) going in the same direction is less good (could be complex electrolysis, but unusual).

A complete circuit is needed – the piste is rather open, but it is the case that skiers will need to follow snow routes all the way and return to the ski lift every time.

Gravitational potential as the analogy for electrical energy – good: easy to understand; both caused by field potentials.

The ski lift as a cell – good modelling of energy input from transfers; height lifted analogy to emf also good.

The snowpark obstacles as components using electrical energy – some energy transferred to kinetic on obstacles rather than only into heat/sound (other stores).

Differing speeds by different skiers – likely to be a poor model as we assume electron drift velocity to be constant all round a circuit.

5 Students' own answers

4A.3 Current and voltage relationships

1 The current between two points is directly proportional to the voltage across them.

resistance = $\frac{\text{voltage}}{\text{current}}$

2 120 Ω

3 An ohmic conductor has a constant resistance over a wide range of voltages, assuming the temperature remains constant. Non-ohmic conductors have changing resistance with voltage applied.

4 If the resistor is ohmic, then the gradient of the straight line would give the same answer as the resistance value.

5 Component A has a higher resistance of 50 Ω, whilst the resistance of component B is 20 Ω.

4A.4 Resistivity

1 0.71 Ω

2 Maintain constant temperature; measure wire diameter in several places and in right-angled pairs of readings; use longest possible wire length in order to minimise percentage error in length

3 Polyethene: $\sigma = 5.0 \times 10^{-12}$ S m^{-1}

Copper: $\sigma = 5.9 \times 10^{7}$ S m^{-1}

Copper is a much better conductor than polythene, so it has a higher value for conductivity.

4 (a) Resistance = 2.3×10^{-4} Ω

so resistance of each arm of ring in circuit = 4.6×10^{-4} Ω

Cross-sectional area = 1.5×10^{-6} m^2

Length = half circumference = 0.0314 m

so $\rho = 2.2 \times 10^{-8}$ Ω m

(b) The high current is dangerous; the percentage error in the diameter and cross-section measurements will be large

5 Students' own answers, using cylinder volume, $V = \pi r^2 h$:

e.g. If the estimated length is 2 cm and the estimated diameter is 1 mm:

$r = 5 \times 10^{-2}$ m

$V = \pi r^2 h = 3.14 \times (5 \times 10^{-4})^2 \times 0.02 = 1.6 \times 10^{-8}$ m^3

4A.5 Conduction and resistance

1 The net rate of movement of the electrons as they cause a current flow

2 $v = 6.0 \times 10^{-4}$ m s^{-1}

3 Conduction electrons have to travel further through the lattice of fixed metal atoms, so there are a greater number of collisions to reduce the drift velocity, reducing the current, which is an effective increase in resistance.

4 Students' own answers; their explanations should include reference to at least the following ideas:

Movement of charge carriers

Fixed lattice ions

Collisions between ions and charge carriers

Increased vibrations of fixed lattice ions with temperature

An evaluation of the strengths and weaknesses of their model

5 Students' own answers, using cylinder volume, $V = \pi r^2 h$ and number density for copper, $n = 8.4 \times 10^{28}$ m^{-3}:

e.g. estimated height is 1 mm; estimated diameter is 2 cm:

$r = 1 \times 10^{-2}$ m

$V = \pi r^2 h = 3.14 \times (1 \times 10^{-2})^2 \times 0.001 = 3.1 \times 10^{-7}$ m^3

$N = nV = 8.4 \times 10^{28} \times 3.1 \times 10^{-7} = 2.6 \times 10^{22}$ electrons

4A.6 Semiconductors

1 Higher temperature gives electrons more energy, so more electrons move up to the conduction band and the charge carrier density increases, thereby increasing current and effectively reducing resistance.

2 If lead is cooled below 7.2 K, its resistance falls to zero.

3 The impurities will need to provide charge carriers for conduction. So the impurities will have a low enough energy band gap that the electrons will be in the conduction band at room temperature.

4A Exam practice

1 C

2 D

3 C

4 A

5 pd is a measure of electrical energy transferred between two points, or the electrical energy transferred to other stores

emf is a measure of the energy supplied to a circuit

6 $I = \frac{(2.6 \times 10^{26} \times 1.6 \times 10^{-19}\ \text{C})}{15\ \text{s}}$

$I = 2.77 \times 10^{6}$ A

7 (a) Use of $I = nqvA$ with e 1.6×10^{-19} C and 8×10^{-3} A

$v = 2.8 \times 10^{-7}$ m s^{-1}

(b) Value for semiconductor is much greater

n for semiconductor (much) less than for conductor

(c) Its resistance decreases because as temperature increases n increases

OR there are more electrons / charge carriers

8 (a) Resistivity is a constant for the material

OR resistivity is a property of the material

Resistance depends on resistivity and length / area / dimensions as $R = \frac{pl}{A}$

(b) $R = \frac{(1.7 \times 10^{-8}\ \Omega\ \text{m} \times 0.5\ \text{m})}{1 \times 10^{-6}\ \text{m}^2}$

$R = 0.0085\ \Omega$

9 (a) Resistivity is a property of a material OR is constant for a material

Resistance is a property of a wire / component and depends upon the dimensions of the wire / component

(b) Circuit diagram: wire and power supply with an ammeter in series and a voltmeter in parallel with the wire

Quantities measured: current and potential difference OR resistance; length of wire; diameter / thickness of wire

Graph: plot R against l OR plot V against l OR plot R against $\frac{l}{A}$ OR plot RA against l

Determination of resistivity: the gradient of relevant graph, correctly processed to find ρ

10 (a) Current through a conductor is directly proportional to the potential difference across it (providing the temperature of conductor remains constant OR external conditions remain constant)

(b) Ohmic conductor: fixed resistor horizontal straight line

Filament lamp: graph showing increasing resistance (straight line or curve) from a non-zero resistant start

(c) As the temperature of the filament increases resistance of conductor changes OR the ions vibrate more

11 (a) Diode / LED

(b) Infinite OR very high

(c) $R = \frac{0.70\ \text{V}}{0.41\ \text{A}}$

$R = 1.7\ \Omega$

(d) Any one from:

To protect components / circuits

Rectification

Restricts current / flow (of charge) to one direction

AC to DC

Produce DC supply

Power indicator light

Light source, e.g. Christmas tree light, torch

Regulate voltage

12 (a) Voltmeter, ammeter, low voltage supply, build complete circuit incorporating ink circle so current flows from A to B.

Measure current and voltage between A and B

R = V/I

(b) Resistance inversely proportional to area of conductor

- so doubling cross-sectional area halves the resistance