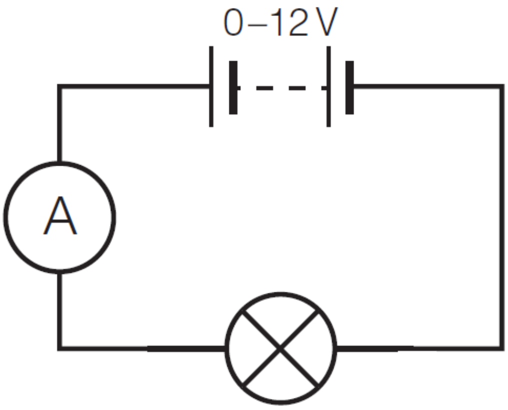
Page 222 Test yourself on prior knowledge

1



2 **a)** Ampere, A

b) Volt, V

c) Ohm, Ω

d) Coulomb, C

3 $I = \frac{Q}{t}$

$= \frac{0.6\ C}{40\ s}$

= 0.015 A

4 $V = \frac{W}{Q}$

$\Rightarrow W = QV$

= 0.25 C × 12 V

= 3 J

Pages 225–226 Test yourself

1 **a)** A s

b) J C^{-1}

c) C s^{-1}

2 a) $I = \frac{Q}{t} \Longrightarrow t = \frac{Q}{I}$;

PC USB t $= \frac{Q}{I}$

$= \frac{5112\ C}{0.5\ A}$

= 10 224 s = 2.84 hrs = 2 hrs 50 mins 24 secs

iPhone charger t $= \frac{Q}{I}$

$= \frac{5112\ C}{1.0\ A}$

= 5112 s = 1.42 hrs = 1 hr 25 mins 12 secs

iPad charger t $= \frac{Q}{I}$

$= \frac{5112\ C}{2.1\ A}$

= 2434.3 s = 0.68 hrs = 0 hr 40 mins 34 secs

b) 1420 mAh = 1.42 A × 3600 s = 5112 C

3 $I = \frac{\Delta Q}{\Delta t}$

$= \frac{285\ C}{3.5 \times 10^{-3} s}$

= 81 000 A (2 sf)

4 $\Delta Q = n \times e = I\Delta t$

$\Rightarrow n = \frac{I\Delta t}{e}$

$= \frac{25 \times 10^{-3}\ A \times 1.0\ s}{1.60 \times 10^{-19} C}$

= 1.6×10^{17} electrons

5 $I = \frac{\Delta Q}{\Delta t}$

$= \frac{n \times e}{\Delta t}$

$= \frac{15 \times 10^{6} \times 1.60 \times 10^{-19} C}{1\ s}$

= 2.4×10^{-12} A (2sf)

6 $I = \frac{\Delta Q}{\Delta t}$

$= \frac{80 \times 10^{-9}\ C}{46\ s}$

$= 1.7 \times 10^{-9}$ A (2 sf)

$I = \frac{\mathrm{d}n}{\mathrm{d}t} \times e$ where $\frac{\mathrm{d}n}{\mathrm{d}t}$ = number of ions per second

$\frac{\mathrm{d}n}{\mathrm{d}t} = \frac{I}{e}$

$= \frac{1.7 \times 10^{-9}\mathrm{A}}{1.6 \times 10^{-19}\mathrm{C}}$

$= 1.1 \times 10^{10}$ ions per second

7 **a)** $\Delta Q = N_A \times e$

$= 6.0 \times 10^{23} \times 1.60 \times 10^{-19}$ C

= 96 000 C (2 sf)

b) 1 mole of Pb releases 2 Faradays of charge = 192 000 C

Energy per coulomb of charge = $\frac{24 \times 10^{3}\ J}{192000\ C}$ = 0.125 V (1 V = 1 JC^{-1})

c) If each cell produces 0.125 V, then $\frac{12\ V}{0.125\ V}$ = 96 cells would be needed.

d) $\Delta Q = n \times e = I\Delta t$

$\Rightarrow n = \frac{I\Delta t}{e}$

$= \frac{15\ A \times 1.0\ s}{1.60 \times 10^{-19} C}$

$= 9.4 \times 10^{19}$ electrons (2 sf)

e) Number of moles of electrons flowing per second = $\frac{n}{N_A}$

$= \frac{9.4 \times 10^{19}}{6.0 \times 10^{23}}$

$= 1.6 \times 10^{-4}$ moles

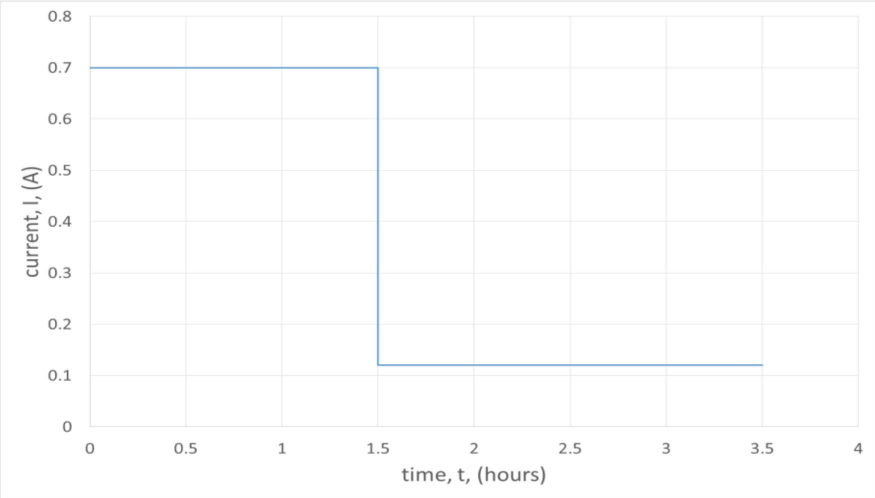
f) If each Pb atom loses 2 electrons then the number of moles of Pb atoms reacting per second = (No. moles of electrons)/2 = 8.0×10^{-5} moles.
The molar mass of Pb is 207.2 g, so the mass of lead reacting per second is ($8.0 \times 10^{-5} \times 207.2$ g) = 0.017 g (2 sf).

g) Time to run out = $\frac{\text{Total mass available}}{\text{mass reacting per second}}$

$= \frac{640\ g}{0.017\ g}$

= 38 000 S (2 sf) (about 10.5 hours)

8 **a)** The graph should look similar to this:



b) Total charge = area under graph = (0.70 A × (90 × 60) s) + (0.12 A × (120 × 60) s)

= 3780 + 864

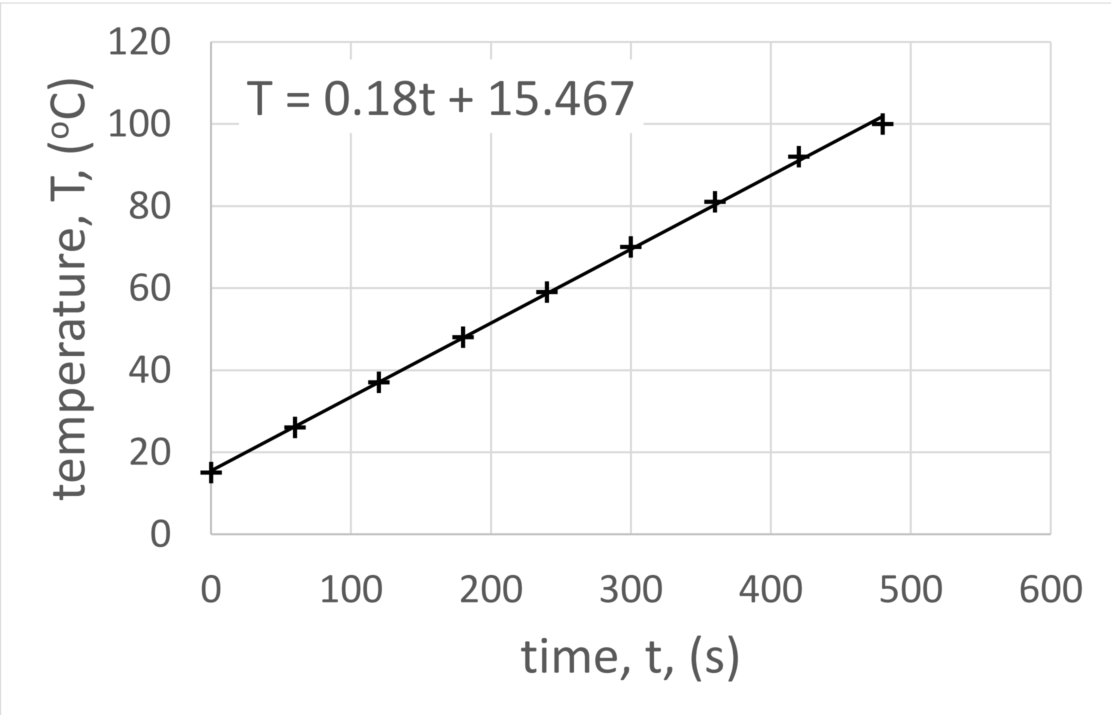
= 4644 C = 4600 C (2 sf)

Page 228 Activity

Investigating the ability of a travel mug heating element to boil water

1 and 2 The graph and line of best fit should look similar to the one below

(from Excel best-fit) = 0.18 °Cs^{-1}



3 Gradient of line is rate of increase of temperature.

4 $\Delta Q = mc\Delta\theta$

$= 0.180 \text{ kg} \times 4200 \text{ J kg}^{-1}{}^{\circ}\text{C}^{-1} \times 1{}^{\circ}\text{C}$

$= 756 \text{ J}$

5 After 2 minutes (120 s),

$\Delta T = 37\ {}^{\circ}\text{C} - 15\ {}^{\circ}\text{C} = 22\ {}^{\circ}\text{C}$

$\Rightarrow \Delta Q = 756 \times 22$

$= 16\,632 \text{ J}$ (17 000 J 2 sf)

6 Heater is 11.1 A,

so charge transferred $= I \times t$

$= 11.1 \text{ A} \times 120 \text{ s}$

$= 1332 \text{ C}$

7 Potential difference = energy / charge

= 16632 J / 1332 C

= 12.5 V (13 V 2 sf)

8

Hazard	Risk	Control measures
Hot heating element	Skin burn	Ensure that the element is allowed to cool before handling.
Hot water	Scald	Perform experiment away from edge of bench. Allow water to cool before handling.
Sharp edged glass (from e.g. broken thermometer)	Skin cut	Visual inspection of glassware before handling.

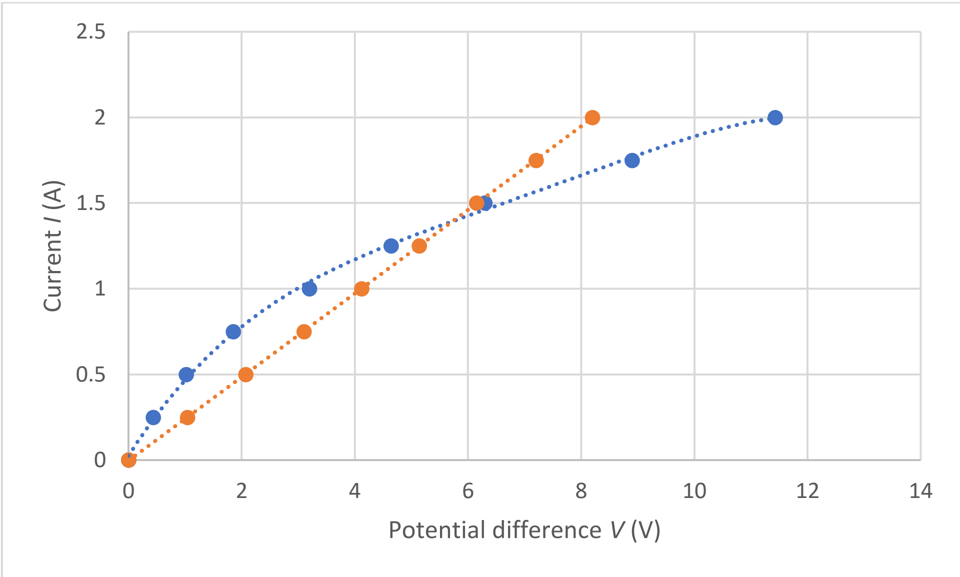
9

Measurement	Source of uncertainty	Way of reducing uncertainty
Mass of water	Precision of balance	Use more precise balance
Temperature of water	Non-uniform temperature of water	Stir water during experiment
	Precision of thermometer	Use datalogger, thermometer probe or digital thermometer
Time	Human error of not recording temperature at correct time	Use datalogger to record temperatures

Page 232 Activity

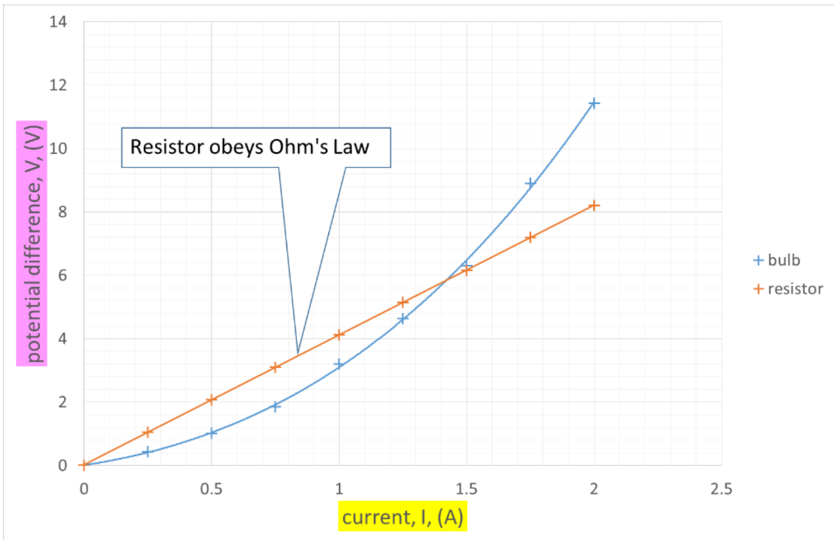
Plotting electrical characteristics

1



2 The resistor obeys Ohm's law.

3



4 Gradient of *V*-*I* graph is linear, hence, $V \propto I$. As Ohm's Law is $V = IR$, then gradient of straight line is numerically equal to R.

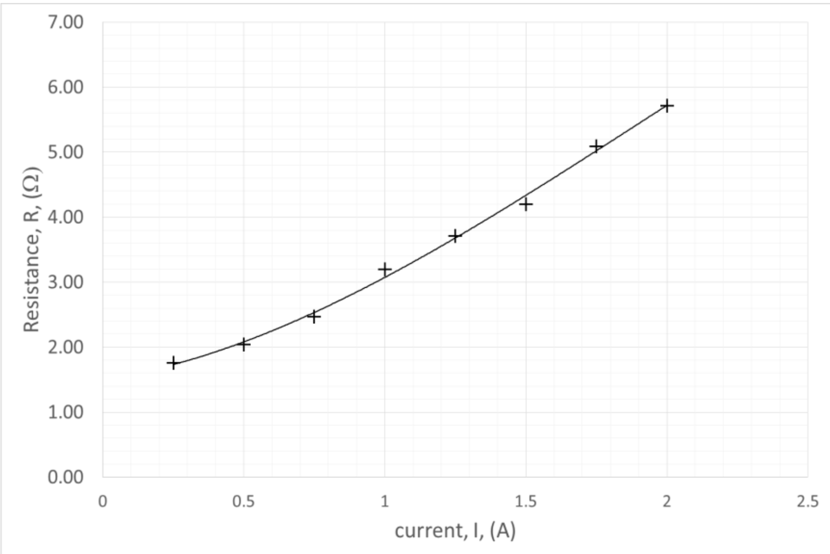
5 Excel fits a best-fit line to be 4.1 Ω.

6 From the graph, both lines cross at $I \approx 1.42$ A

7

Current, *I*, (A)	Bulb potential difference V_{bulb}, (V)	Resistance of bulb, R, (Ω)
0.00	0.00	
0.25	0.44	1.76
0.50	1.02	2.04
0.75	1.85	2.47
1.00	3.20	3.20
1.25	4.64	3.71
1.50	6.30	4.20
1.75	8.90	5.09
2.00	11.43	5.72

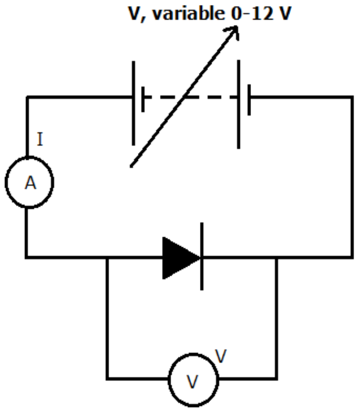
8



9 As *I* increases, the temperature of the filament increases due to more collisions between the free conducting electrons and the positive ion cores of the wire. This increases the resistance.

10 Using the graph and extrapolating backwards, as *I* tends to zero, the best-fit line tends to 1.5 Ω.

11 a) Assemble apparatus as shown in circuit diagram; b) set ammeter reading to zero; c) record voltmeter and ammeter readings; d) increase ammeter reading by 0.25 A; e) repeat steps c) and d) up to an ammeter reading of 2.0 A; e) Reverse polarity of the diode and repeat procedure.



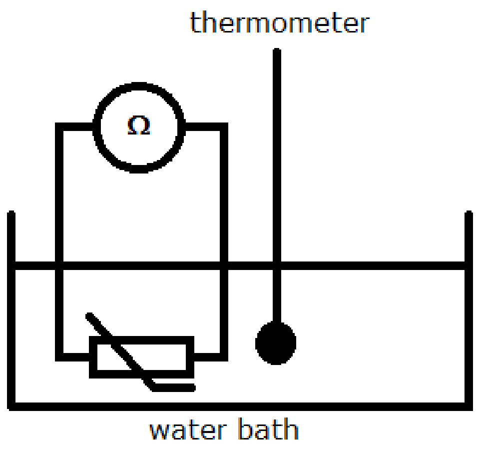
Page 234 Activity

The resistance of a thermistor

Description of variables:

Variable	Range	Intervals	Values	Suitable measuring apparatus
Independent – Temperature of water (thermistor assumed to be in thermal equilibrium)	0-90°C	10°C	0, 10, 20, 30, …, 90°C	Digital thermometer
Dependent – Resistance of thermistor (varies by thermistor)	1000-25 Ω	N/A		Digital multimeter set to measure resistance (ohmmeter)
Control – resistance of connecting wires	Kept constant	N/A		N/A
Control – pd of ohmmeter	Dictated by type of multimeter and its power circuitry (e.g. 9V)	N/A		N/A

Diagram of experiment



List of equipment

- Variable-temperature waterbath, (0–90 °C) – Celsius setting
- Beaker to fill waterbath (1 l)
- Digital thermometer (–50 °C to +200 °C, ±0.1 °C) – Celsius setting
- NTC thermistor e.g 300 Ω at 25 °C operational range –50 °C to 125 °C.
- Digital multimeter (0–2000kΩ), set on 0–2000 Ω range, ±0.1 Ω
- 2 × connecting wires and crocodile clips (approx. 50 cm)

Statement of how to minimise error:

- Have thermometer very close to thermistor.
- Stir water.
- Repeat measurements 3 times, remove outliers/anomalies, calculate average.
- Wait for temperature and resistance measurement to stabilise before recording value.

Method

1. Setup apparatus as in diagram.
2. Add ice to water in waterbath.
3. Wait until thermometer reads 0 °C.
4. Measure and record temperature and resistance.
5. Turn on waterbath and set to 10 °C.
6. Wait until thermometer reads required temperature.
7. Repeat 4).
8. Increase temperature of water in waterbath by 10 °C.
9. Repeat 6) to 8) up to 90 °C. Turn off waterbath and allow to cool.
10. Remove water from waterbath and repeat whole experiment two more times.

Risk assessment

Hazard	**Risk**	**Control measure**
Hot water	Skin scald	Allow water to cool before handling
Sharp edges to glassware	Skin cut	Visual inspection of glassware before use
Sharp point to thermometer	Skin/eye puncture	Keep pointed end downwards at all times
Hot thermistor/wires	Skin burn	Allow to cool before handling

Table of primary data

Temperature, T, (°C)	**Resistance, R, (Ω)**			
	1	2	3	Average
0				
10				
20				
…				
90				

Calculations/Uncertainty

- You will need to calculate average values of R for each value of T.
- If you are using a voltmeter/ammeter method, you will need to calculate values of R from $R=V/I$ before averaging.
- You can calculate the uncertainty of each average measurement of R by working out a value for half the range of the data for each set of R.

Pages 234–235 Test yourself

9 $E = Q \times V$

$= 325\ \text{C} \times 200\ 000\ 000\ \text{V}$

$= 6.5 \times 10^{10}\ \text{J}$

10 a) $R = \frac{V}{I}$

$= \frac{95\ V}{0.8\times10^{-3}\ A}$

= 118 750 Ω

= 1 × 10^5 Ω (1 sf)

b) $\Delta Q = n \times e = I\Delta t$

$\Rightarrow n = \frac{I\Delta t}{e}$

$= \frac{0.8\times10^{-3}\ A \times 1.0\ s}{1.60\times10^{-19} C}$

= 5 × 10^{15} electrons

11 a) B

b) At I = 50 mA, $R_A = \frac{3.9\ V}{0.05\ A} = 78\ \Omega;\ R_B = \frac{0.9\ V}{0.05\ A} = 18\ \Omega;\ R_C = \frac{0.3\ V}{0.05\ A} = 6\ \Omega;$

At I = 100 mA, $R_A = \frac{4.6\ V}{0.1\ A} = 46\ \Omega;\ R_B = \frac{1.8\ V}{0.1\ A} = 18\ \Omega;\ R_C = \frac{0.85\ V}{0.1\ A} = 8.5\ \Omega;$

C (ratio V/*I* increases with *I*)

12 a) Prevents too much current flowing through the LED and damaging it so that it will not work anymore.

b) $\mathcal{E} = V_{resistor} + V_{LED}$

$\Rightarrow V_{resistor} = \mathcal{E} - V_{LED}$

= 6.0 V – 2.2 V = 3.8 V

$R = \frac{V_{resistor}}{I}$

$= \frac{3.8\ V}{20\times10^{-3}\ A}$

= 190 Ω

13 a) i) At 30 mA

$R_{yellow} = \frac{V_{yellow}}{I}$

$= \frac{2.4\ V}{30\times10^{-3} A}$

= 80 Ω (2 sf)

$R_{red} = \frac{V_{red}}{I}$

$= \frac{2.1\ V}{30\times10^{-3} A}$

= 70 Ω (2 sf)

ii) At 10 mA

$R_{yellow} = \frac{V_{yellow}}{I}$

$= \frac{2.0\ V}{10\times10^{-3} A}$

= 200 Ω (2 sf)

$R_{red} = \frac{V_{red}}{I}$

$= \frac{1.7\ V}{10\times10^{-3} A}$

= 170 Ω (2 sf)

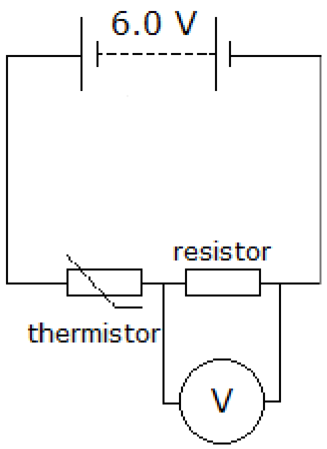
b) LEDs have different striking voltages (the voltage where the LED starts to conduct) (Yellow = 1.8 V; red = 1.5 V).

14 a) i) At 24 °C; $\frac{\Delta R}{\Delta T} \approx \frac{(1000-600)\ \Omega}{(20-30)^o C} \approx -40\ \Omega\ ^oC^{-1}$

ii) At 84 °C; $\frac{\Delta R}{\Delta T} \approx \frac{(170-150)\ \Omega}{(80-90)^o C} \approx -2\ \Omega\ ^oC^{-1}$

b) At 24 °C because there is a larger resistance change per degree.

15 a)



b) At 25 °C, $R_{thermistor}$ = 780 Ω.

Total resistance of circuit = (780 + 250) Ω = 1030 Ω.

Current drawn from supply, I $= \frac{V}{R_{total}}$

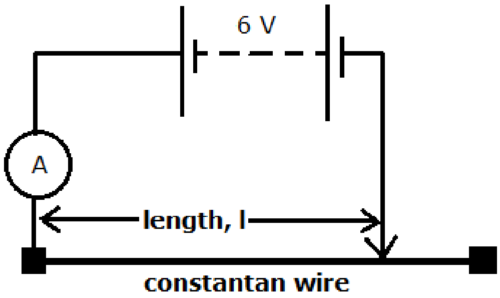
$= \frac{6.0\ V}{1030\ \Omega}$

= 0.0058 (2 sf)

Page 237 Required practical 5

Determination of resistivity of a wire using a micrometer, ammeter and voltmeter

1



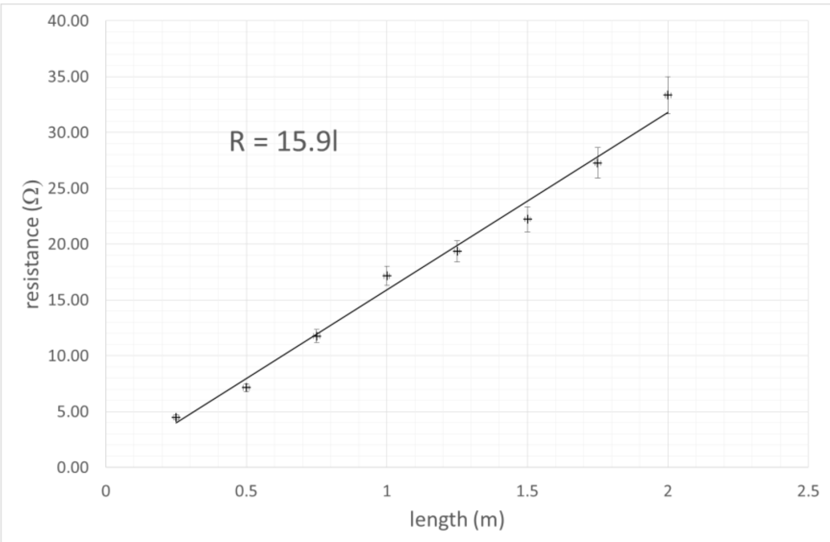
2 Micrometer

3 (0.19 ± 0.01) mm

4

Length of wire (m)	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00
Current (A)	Short circuit	1.34	0.84	0.51	0.35	0.31	0.27	0.22	0.18
Resistance (Ω)	N/A	4.48	7.14	11.76	17.14	19.35	22.22	27.27	33.33

5 and 6



7 Excel should calculate the gradient to be 15.9 Ωm^{-1}.

8 $R = \frac{\rho}{A} l$

$\Rightarrow \text{gradient} = \frac{\rho}{A} = \frac{4\rho}{\pi d^2}$

$\Rightarrow \rho \quad = \frac{\pi d^2}{4} \times gradient$

$= \frac{\pi(0.19\times10^{-3} mm)^2}{4} \times 15.9\ \Omega m^{-1}$

$= 4.5 \times 10^{-7}\ \Omega m$

9 $\frac{45}{49} \times 100 = 91.8\% \approx 8\%$ error

10 Difference in temperature = 20°C. So resistivity increases by a factor of

$(1 + (8 \times 10^{-6}\ °C^{-1} \times 20)) = 1.00016$

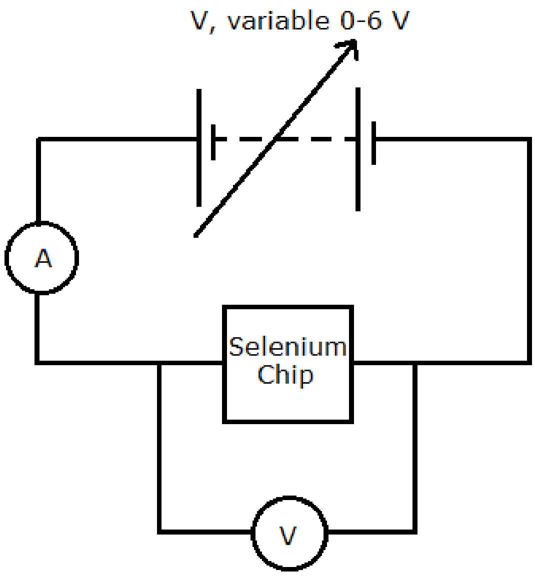
Using this value gives $\rho_{20} = 49.008 \times 10^{-8}\ \Omega m$. This is very close to the stated value at 0°C.

Extension

Using the spread of the error bars, a maximum gradient of 18 Ωm^{-1} and a minimum gradient of 14 are calculated. Using these values gives $\rho = (4.5 \pm 0.6) \times 10^{-7}\ \Omega m$ (an uncertainty of 13%). The value from Kaye and Laby lies within the uncertainty of the measurement from the spread of the error bars.

Page 238 Test yourself

16 a)



b) Temperature (kept constant) – digital thermometer situated close to chip; pd, V across selenium chip – digital voltmeter connected across the chip; current, *I* in circuit – digital ammeter/milliammeter connected in series with the chip; length, width and depth of chip, *l*, *w* and *d* – Vernier calliper (take 3 readings of each and average).

c) $R = \frac{\rho \times l}{A}$

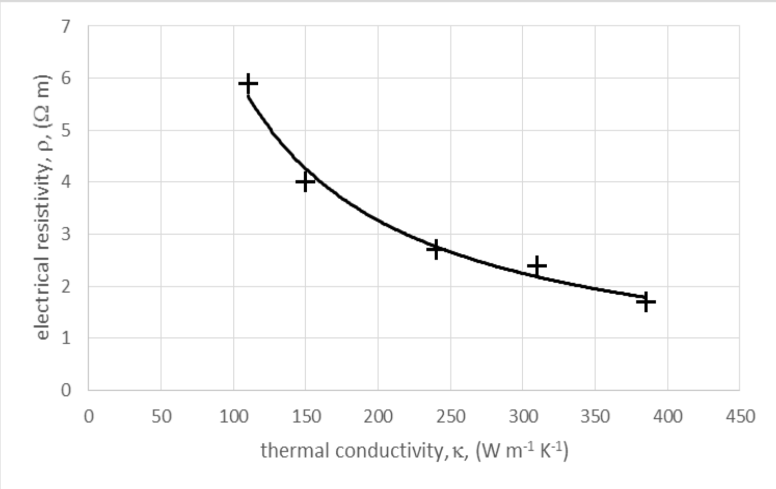
$\Rightarrow \frac{V}{I} = \frac{\rho \times l}{w \times d}$

$\Rightarrow V = \left(\frac{\rho \times l}{w \times d}\right) \times$ I; so a graph of *V* against *I* should be a straight line with a positive gradient coefficient = $\frac{\rho \times l}{w \times d}$

And so $\rho = \frac{\text{gradient} \times w \times d}{l}$

d) Answers could include: repeat measurements and take averages; use measuring instruments with greater precision; check measuring instruments for offset (zero) errors.

17 a) The graph should look similar to the one below.



b) As the thermal conductivity increases so the electrical resistivity decreases (but at a lower rate). The thermal conductivity of metals depends upon the microscopic structure of the metal – in particular, the arrangement of the lattice of positive ion cores and the number of free conducting electrons. Both thermal and electrical conduction increase if there are more free electrons and if the structure is more ‘open’. As resistivity is a measure of the opposition of a material to the conduction by the free electrons, as thermal conductivity increases, the resistivity will decrease.

18 a) × 2

b) × 4

19 $R = \frac{\rho \times L}{A}$

$= \frac{1.7 \times 10^{-8}\ \Omega\text{m} \times 17.0 \times 10^{-4}\ m}{4.0 \times 10^{-10} m^2}$

= 0.072 Ω (2 sf)

Pages 239–242 Test yourself

1 C

2 A

3 A

4 B

5 B

6 A

7 B

8 D

9 D

10 B

11 a) 0.4 A [1]

b) Current at normal operating temperature = horizontal portion of graph = 0.2 A. [1]

$R = \frac{V}{I} = \frac{6\ V}{0.2\ A} = 30\ \Omega$ [1]

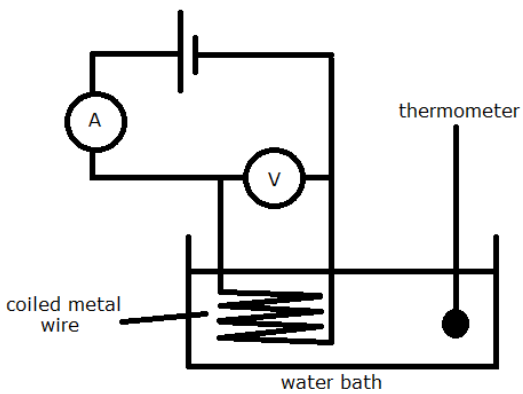
c) The metal in the filament of the bulb is initially cold. This means its resistance is low and a larger amount of current can flow through the filament [1].

The filament heats up as more current passes through it and the resistance increases, gradually limiting the current to a maximum value [1].

d) Total charge, ΔQ = area under I-t graph from 0-500 ms. This can be approximated by dividing the area under the graph into regular shapes and calculating each shape's area-charge, OR you could use a square counting technique – where each small square is equivalent to (0.1 A $\times$ 20 $\times$ 10^{-3} s) = 2 $\times$ 10^{-3} C.

[1 mark for correct method; 1 mark for correct answer]

12 a) [1 mark for correct electrical circuit; 1 mark for suitable apparatus to vary T]



b) **i)** Set-up apparatus as in Figure 7.

ii) Adjust temperature to 0°C using ice.

iii) Measure and record current, pd and temperature. [1]

iv) Change temperature on water bath to 10°C.

v) Repeat iii.

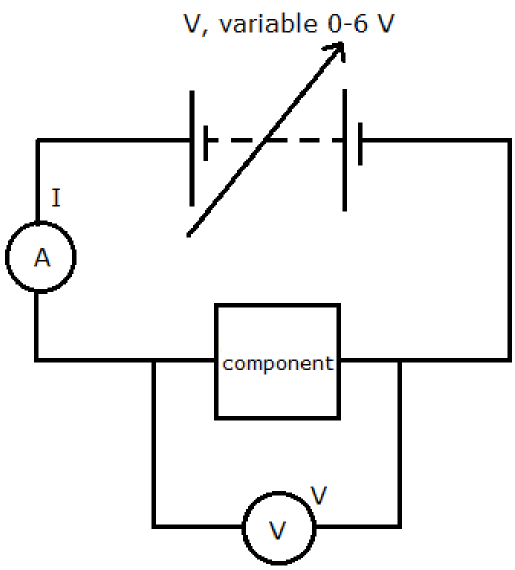
vi) Repeat for 10°C temperature increments up to 100°C. [1]

vii) Calculate values of R for each temperature using, $R = \frac{V}{I}$. [1]

c) The temperature at and below which [1] a material becomes superconducting. [1]

13 a) A conductor that obeys Ohm's Law ($I \propto V$). [1]

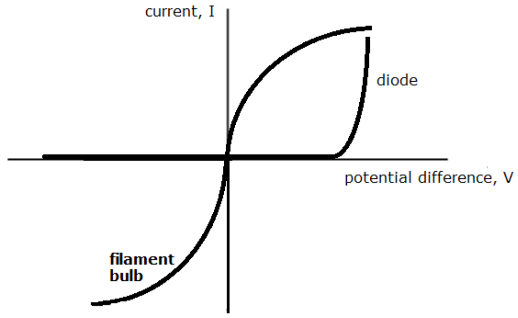
b)



[1 mark for correct electrical circuit; 1 mark for suitable apparatus]

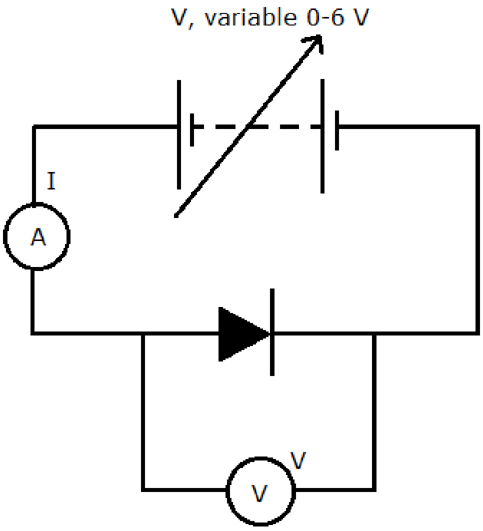
c) *i)* Adjust power supply so that voltmeter reads 1.0 V;
ii) measure and record pd, V and current, I [1];
iii) Alter pd, V across the component in increments of 1.0 V;
iv) repeat *ii* [1];
v) reverse bias the component [1];
vi) repeat *i* to *iv* recording values as negative [1];
vii) calculate values of: $R = \frac{V}{I}$, for each current, pd pair [1];
viii) if the component is 'ohmic' then the values of R will all be very similar with no trend [1].

14 a) [1 mark for correct diode; 1 mark for correct filament bulb]



b) Resistance, $R = \frac{V}{I}$. As V increases, so does I, but proportionately less than the increase in V [1]. This indicates that the ratio $R = \frac{V}{I}$ increases with V [1].

c)



[1 mark for correct symbols; 1 mark for correct connections]

d) *i)* Adjust power supply so that voltmeter reads 0.5 V;
ii) measure and record pd, V and current, I [1];
iii) alter pd, V across the component in increments of 0.5 V up to 3.0 V;
iv) repeat *ii* [1];
v) reverse bias the component [1];
vi) repeat *i* to *iv* recording values as negative [1].

15 a) $V = 6.0\ V - 1.8\ V = 4.2\ V$ [1]

b) $I = \frac{V}{R} = \frac{4.2\ V}{1.4 \times 10^3\ \Omega}$ [1]
$I = 3.0 \times 10^{-3}\ A\ (2\ sf)$[1]

c) $R = \frac{V}{I} = \frac{1.8\ V}{3.0 \times 10^{-3}\ \text{A}}$[1]

$R = 600\ \Omega\ (2\ sf)$ [1]

d) Higher resistance in the circuit will result in a smaller current [1] and hence a lower value of V [1].

16 a) $A = \pi r^2 \Longrightarrow R = \frac{\rho l}{\pi r^2} = \frac{0.82\ \Omega\text{m} \times 8.0\times10^{-2}\ m}{\pi\times(1.4\times10^{-2}\ m)^2}$ [1]

$R = 106.5\ \Omega = 110\ \Omega\ \ (2\text{ sf})[1]$

b) Increasing length x 4 = increasing resistance x 4 [1].
Halving the radius means that the area decreases by a factor of x4 [1]
The overall effect is for the resistance to increase by a factor of 16 to 1760 Ω [1].

17 a) $R = \frac{\rho l}{A} = \frac{1.7\times10^{-8}\ \Omega\text{m} \times 0.60\ m}{1.3\times10^{-7}\ m^2}$ [1]

$R = 0.078\ \Omega\ (2\text{ sf})[1]$

b) $V = IR[1]$

$V = 2.2 \times 0.078 = 0.156\text{ V [1]};$

c) pd across terminals of the supply $V_T = V_{wire\ 1} + V_{wire\ 2} + V_{lamp}$ [1]

= 0.156 V + 0.156 V + 12.0 V = 12.3 V [1]

Pages 242-243 Stretch and challenge

18 A

19 a) Current flows and power is converted/heat energy produced (in the thermistor).
(Calculation: $P = V^2/R = 25/120 = 0.2$ W.)
This causes the temperature of the thermistor to rise and its resistance to fall.
Increased current flow means more heat energy is produced.
Cycle continues until thermistor overheats/is destroyed.

b) 50 Ω as the variation of $R_{thermistor}$ would be relative to (50 + 120) Ω. (The change in potential is the change in $R_{thermistor}$ relative to the smallest total resistance).

c) 50 Ω is the smallest resistance and might be too little to prevent the "thermal runaway" described in part (a).

20 a) $A = \frac{V}{l}$

$R = \frac{\rho}{V/l} = \frac{\rho l^2}{V}$

b) $\frac{V}{\rho} = \frac{l^2}{R}$ OR $\frac{\rho}{V} = \frac{R}{l^2}$

c) $\frac{R_{old}}{l_{old}^2} = \frac{R_{new}}{l_{new}^2}$

$\frac{2.7}{32^2} = \frac{R_{new}}{120^2}$

$R_{new} = 38\ \Omega$