Page 245–246 Test yourself on prior knowledge

1 $P = \frac{E}{t}$

$= \frac{360 \times 10^3\ J}{(3 \times 60\ s)}$

$= 2000$ W

2 $P = VI$

$\Rightarrow I = \frac{P}{V}$

$= \frac{2000\ W}{230\ V}$

$= 8.70$ A $= 9$ A (1 sf)

3 All in volts, V: 1.39; 1.45; 1.47; 2.84; 2.86; 2.92; 4.31

4 a) $V = IR$

$= 0.6 \times 10^{-3}$ A $\times$ 470 Ω

$= 0.282$ V $= 0.3$ V (1 sf)

b) $V_1 = 1.5$ V – 0.282 V

$= 1.218$ V $= 1$ V (1sf)

c) $R_1 = \frac{V_1}{I}$

$= \frac{1.218\ V}{0.6 \times 10^{-3}\ A}$

$= 2030$ Ω $= 2000$ Ω (1 sf)

d) $R_T = R_1 + R$

$= 2030$ Ω + 470 Ω

$= 2500$ Ω $= 3000$ Ω (1 sf)

5 a) $I_T = 0.90$ A + 0.41 A + 0.19 A = 1.5 A

b) $R_1 = \frac{V}{I_1} = \frac{9.0\ V}{0.90\ A}$

$= 10$ Ω

$R_2 = \frac{V}{I_2} = \frac{9.0\ V}{0.41\ A}$

$= 21.95$ Ω $= 22$ Ω (2 sf)

$R_3 = \frac{V}{I_3} = \frac{9.0\ V}{0.19\ A}$

$= 47.37$ Ω $= 47$ Ω (2 sf)

Page 247 Test yourself

1 $R = \frac{V^2}{P}$

$= \frac{230^2 V^2}{2.2 \times 10^3 W}$

= 24.045 Ω = 24 Ω (2 sf)

2 a) A

b) C

c) B

d) E

3 $P = \frac{V^2}{R}$

$\Rightarrow V = \sqrt{P \times R}$

$= \sqrt{25\ W \times 330\ \Omega}$

= 90.83 V = 91 V (2 sf)

4 a) $P = IV$

$\Rightarrow I = \frac{P}{V}$

$= \frac{0.30\ W}{3.8\ V}$

= 0.0789 A = 0.079 A (2 sf)

b) Capacity (current × time) = charge stored

= 1560 × 10^{-3} A × 3600 s

= 5616 C = 5600 C (2 sf)

c) $t = \frac{Q}{I}$

$t = \frac{5616\ \text{C}}{0.0789\text{A}} = 70975\text{s} \approx$ 19 hours 43 minutes

5 a) $P = IV$

substituting $I = \frac{V}{R}$

$= \left(\frac{V}{R}\right) \times V$

$= \frac{V^2}{R}$

b) If V is doubled, P increases by a factor of 4.
If the resistance is halved, then the power doubles.
The overall effect is P increases by a factor of 8.

P = 0.068 W × 8 = 0.544 W = 0.54 W (2 sf).

OR numerically:

$$P = \frac{(3.0\ V)^2}{16.5\ \Omega} = 0.54\ W$$

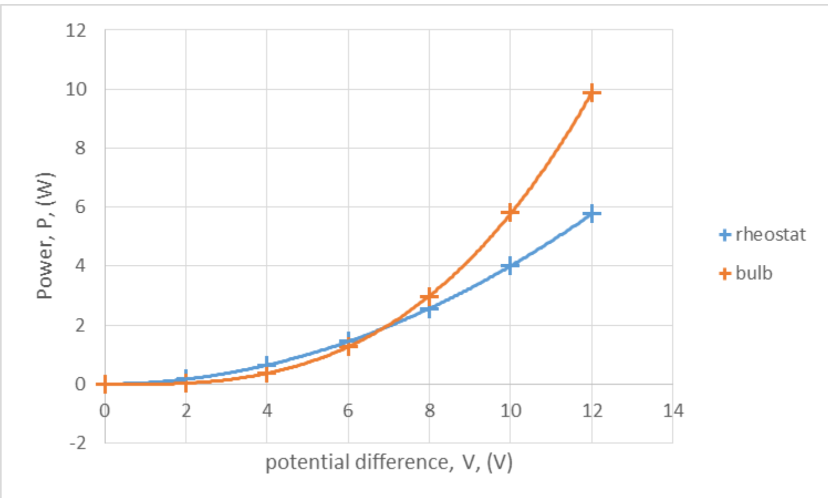
Page 248 Activity

Comparing the power of a 12 V bulb and a rheostat

1

Potential difference, *V*, (V), ±0.01 V	Current, *I*, (A), ± 0.01 A		Power, *P*, (W)	
	Rheostat	Bulb	Rheostat	Bulb
0.00	0.00	0.00	0.00	0.00
2.00	0.08	0.02	0.16	0.04
4.00	0.16	0.09	0.64	0.36
6.00	0.24	0.21	1.44	1.26
8.00	0.32	0.37	2.56	2.96
10.00	0.40	0.58	4.00	5.80
12.00	0.48	0.83	5.76	9.96

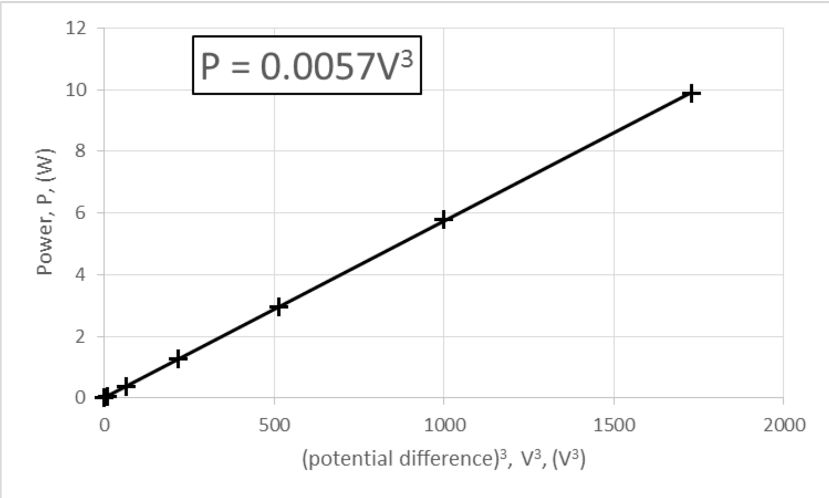
2



3 In both cases, P increases with V. The bulb increases in the form $P = kV^3$ (using Excel to fit best-fit curve) and the rheostat increases in the form $P = V^2/R$. The rheostat initially has P increasing at a greater rate than for the bulb. At V = 5 V, both components have the same power. As V increases the power of the bulb increases at a higher rate than the rheostat.

4 $R = V/I$, which equals 25 Ω, for each *V*-*I* combination.

5 Using Excel to plot a graph of P against V^3, produces the graph shown below. A best-fit line is fitted to the data and Excel calculates the gradient, hence k, to be 0.0057.



6 $P = V^2/R$. The resistance of the rheostat is constant, hence *P* only varies with V^2. In the bulb, *R* increases with *V*, adding another term to the power equation in terms of *V* – this means $P \propto V^3$ – from best-fit.

Extension

The maximum uncertainty in the resistance calculation of the rheostat occurs when the values are lowest (non-zero), i.e. at V = 2.00 V and *I* = 0.08 A. The percentage uncertainty in V is therefore 0.5% and the percentage uncertainty in *I* is 12.5%, giving a combined uncertainty of 13%, this drops to just over 2% when V = 12.00 V.

Page 251–252 Test yourself

6 a) $V = IR$

$= 300 \times 10^{-3}\ \text{A} \times 4.8\ \Omega$

$= 1.44\ \text{V} = 1.4\ \text{V}$ (2 sf)

b) There is always a pd across the internal resistance, which reduces the pd across the output terminals of the cell.

c) The current is constant at 300 mA for 5 hours. After this time the current reduces to zero in 30 minutes at a rate of approximately 10 mA per minute.

d) The current output by the cell depends upon the chemical reactions occurring inside the cell, each reaction producing the same emf. When the chemicals to react run out, the emf drops rapidly to zero.

e) Total charge = area under *I*-t graph. Approximating the shape under the graph as a rectangle and a triangle:

ΔQ= (300 × 10^{-3} A × 5 hr × 3600 s) + ($\frac{1}{2}$ × 300 10^{-3} A × 30 min × 60 s)

= 5670 C = 5700 C (2 sf)

7 The internal resistance of the cell = gradient of V-*I* graph:

$$r = \frac{(8.7\,V - 1.8\,V)}{(18.0\,A - 0.80\,A)} = 0.40\,\Omega$$

8 **a)** X

b) X

c) Y

d) X

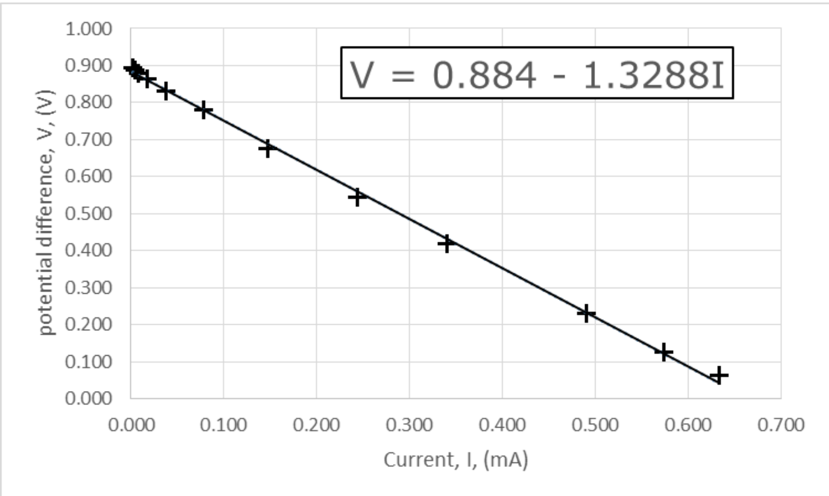
Page 253–254 Required practical 6

Investigation of the emf and internal resistance of electric cells and batteries by measuring the variation of the terminal p.d. of the cell with current in it

1

Avg. I (mA)	0.633	0.573	0.490	0.340	0.244	0.147	0.078	0.038	0.018	0.008	0.004	0.002
Avg. V (V)	0.062	0.125	0.229	0.418	0.544	0.675	0.781	0.832	0.864	0.880	0.889	0.893

2



3 $\mathcal{E} = I(R + r) = IR + Ir,$
$but\ V = IR$

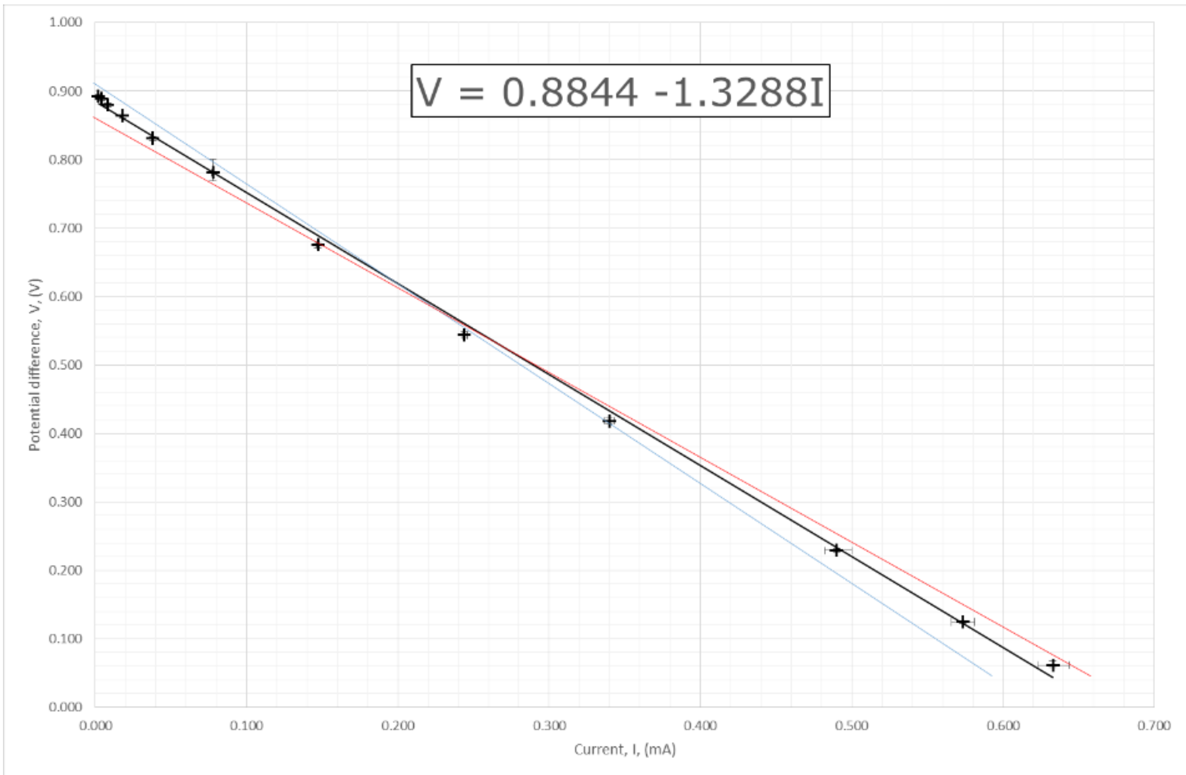
$so,\ \mathcal{E} = V + IR,\ or\ V = \mathcal{E} - Ir$

4 $\mathcal{E} = 0.884\ V$ from graph (Excel plot and best-fit straight line).

5 Excel measures the gradient to be 1.3288, but this is with the current in mA, so r = 1328.8 Ω or 1330 Ω (3 sf).

Extension

Using the spread of the data and the uncertainties in the precision of the ammeter and voltmeter to produce error bars on each point produces graph shown below. Two further fit lines can be drawn using the spread of the error bars to estimate the uncertainty on the true best-fit line, one with a higher gradient (in blue) and one with a lower gradient (in red).



The blue line yields $\mathcal{E}$ = 0.910 *V* and *r* = 1458 Ω.

The red line yields $\mathcal{E}$ = 0.860 *V* and *r* = 1240 Ω.

Using half the range as the uncertainty leads to:

$\mathcal{E}$ = (0.884 ± 0.025) *V* and *r* = (1330 ± 10^{9}) Ω (all 3 sf).

Page 255 Test yourself

9 **a)** B

b) A

c) E

d) D

e) A

10 a) The current in bulb P is *less than* that in bulb Q.

b) The p.d. across lamp P is *the same as* that in bulb Q.

c) The electrical power of bulb Q is *greater than* that in bulb P.

d) The electrical resistance of bulb Q is *less than* that in bulb P.

Page 258 Test yourself

11 $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

$= \frac{3}{R}$ since all resistors are equal

$= \frac{3}{3.3\times10^3\,\Omega}$

$\Rightarrow R_T = \frac{3.3\times10^3\,\Omega}{3} = 1.1 \times 10^3\ \Omega$

12 a) $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$

$= \frac{1}{1\times10^3\,\Omega} + \frac{1}{330\times10^3\,\Omega}$

$\Rightarrow R_T = 997\ \Omega = 1\ \text{k}\Omega\ (1\ \text{sf})$

b) $I = \frac{V}{R}$

$= \frac{12\ V}{997\ \Omega}$

= 0.012 A = 0.01 A (1 sf)

13 a) Resistance of two resistors in parallel,

$\frac{1}{R} = \frac{1}{47\times10^3\ \Omega} + \frac{1}{47\times10^3\ \Omega}$

$= \frac{2}{47\times10^3\ \Omega} \Longrightarrow R = 23.5\times10^3\ \Omega$

Total resistance of circuit = $47 \times 10^3 + 23.5 \times 10^3$

$= 70.5 \times 10^3\ \Omega$

$= 71 \times 10^3\ \Omega$

b) Current through 47 kΩ resistor in series, $I_{series} = \frac{V}{R_{Total}}$

$= \frac{12\ V}{70.5\times10^3\,\Omega}$

$= 1.7 \times 10^{-4}$ A

As the two parallel resistors are the same, the current through each of the parallel resistors is the same and will be half the total current = 0.85×10^{-4} A

$I_{parallel} = 8.5 \times 10^{-5}$ A (2 sf)

14 a) *I* $= \frac{V}{R}$

$= \frac{6.0\ V}{2.2\ \Omega}$

= 2.72 A = 2.7 A (2 sf)

b) Total Resistance of circuit = 2.2 Ω + 0.3 Ω = 2.5 Ω

c) Current flowing, *I* $= \frac{V}{R} \quad = \frac{6.0\ V}{2.5\ \Omega}$

= 2.4 A

d) The total resistance in the circuit is higher.

e) The resistance of the ammeter could be reduced.

The ammeter could have a built in 'offset' that takes the inherent resistance into account.

f) Zero

g) 3.0 V (by inspection)

h) 23.5 kΩ

i) 2.0 V (by ratio)

j) The resistance between X and Y in Circuit 3 is larger than the resistance between X and Y in Circuit 4.

k) As: $\frac{1}{R_T} = \frac{1}{R} + \frac{1}{R_{voltmeter}}$

$\Rightarrow$ As $R_{voltmeter} \longrightarrow \infty$, then $\frac{1}{R_{voltmeter}} \longrightarrow 0$, and $\frac{1}{R_T} \longrightarrow \frac{1}{R}$ $and\ R_T \longrightarrow R$

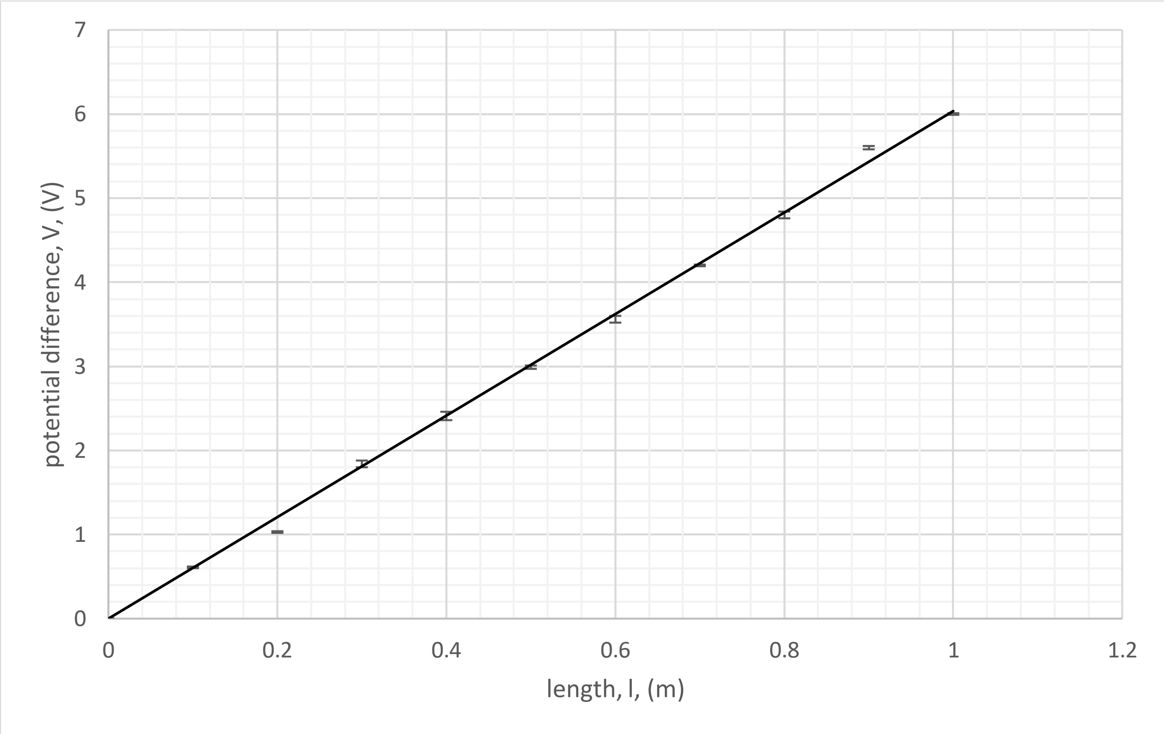
Page 260 Activity

Analysing the results from a wire potentiometer

1, 2 and 3 Anomalous results ignored in calculation of averages shown in blue

Length of wire, l1, (m), ±0.002 m	pd across wire, V, (V), ±0.01 V				
	1	2	3	Average	Uncertainty
0.000	0.00	0.00	0.00	0.00	0.00
0.100	0.60	0.80	0.61	0.61	0.01
0.200	1.20	1.04	1.02	1.03	0.01
0.300	1.80	1.87	1.86	1.84	0.04
0.400	2.40	2.37	2.46	2.41	0.05
0.500	3.00	2.84	2.97	2.99	0.02
0.600	3.60	3.52	3.56	3.56	0.04
0.700	4.20	4.19	4.37	4.20	0.01
0.800	4.80	4.77	4.84	4.80	0.04
0.900	5.40	5.48	5.24	5.60	0.02

4



5 Refer to graph – yes, (0,0) should be a point, but it is not a definite one as there may be systematic uncertainties in the equipment used.

6 Excel fits a best-fit line where V = 6.03 l.

7 The error bars can be used as a guide to fit the best-fit line. This line should go through the majority of the spread of the data including the error bars.

8 If the voltmeter has a lower resistance, then the total resistance of the circuit will decrease, increasing the total current drawn, and V decreases. The voltmeter will read a lower value than it should.

Page 263 Test yourself

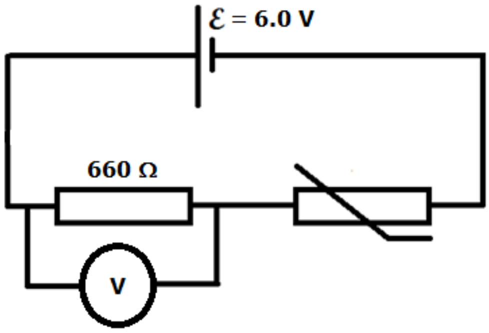
15 a) Ratio: $\frac{pd\ across\ resistor}{pd\ across\ LDR} = \frac{R_{resistor}}{R_{LDR}} = \frac{330\ \Omega}{450\ \Omega} = 0.73$

b) $V_R = \frac{V_T}{R_T} R = \frac{6.0\ V}{(330\ \Omega + 450\ \Omega)} \times 330\ \Omega = 2.54\ \text{V} = 2.5\ \text{V}\ (2\ \text{sf})$

c) Ratio: $\frac{pd\ across\ resistor}{pd\ across\ LDR} = \frac{R_{resistor}}{R_{LDR}} = \frac{330\ \Omega}{470\ k\Omega} = 7.0 \times 10^{-4}$

d) $V_R = \frac{V_T}{R_T} R = \frac{6.0\ V}{(330\ \Omega + 470\ k\Omega)} \times 330\ \Omega = 0.0\ \text{V}\ (2\ \text{sf})$

16 a)



b) $I = \frac{V}{R_T}$

$= \frac{6.0\ V}{(660\ \Omega + 1500\ \Omega)}$

$= 0.0027$ A

c) $V = IR$

$= 0.0027\ \text{A} \times 660\ \Omega$

$= 1.83$ V $= 1.8$ V (2 sf)

d) As temperature increases and resistance decreases, total current increases, so V increases:

$V = \frac{6.0\ V}{(660\ \Omega + 220\ \Omega)} \times 660\ \Omega = 4.5$ V

e) P $= I^2R$

$= 0.4^2 \times 220$

$= 35.2$ W $= 35$ W (2 sf)

f) Thermistor will probably heat up and be destroyed, as the power loss will be so high.

Pages 264–269 Practice questions

1 A

2 A

3 C

4 B

5 C

6 B

7 A

8 C

9 A

10 C

11 a) Electromotive force (emf) is defined as the electrical work done per unit (coulomb) of charge as it flows through a source of electrical energy such as a cell, generator or power supply unit (psu). [1]

Internal resistance is the resistance inside a source of emf which leads to electrical energy being transferred to heat inside the source of emf. [1]

b) $V = \mathcal{E} - Ir$ [1]

$V = 12\ V - (500\ A\ \times 5.0 \times 10^{-3}\ \Omega) = 9.5\ V$ [1]

12 a) As the two resistors in parallel have the same resistance,

$R_T = 50\ \Omega + \frac{800\ \Omega}{2}$ [1]

$R_T = 450\ \Omega$ (or $500\ \Omega$ 1 sf) [1]

b) $P = \frac{V^2}{R} \Longrightarrow V = \sqrt{PR}$ [1]

$P = \sqrt{(2.0\ W \times 800\ \Omega)} = 40\ V$ [1]

c) Current through 50 Ω resistor = 2 × current through 800 Ω resistor

Current through 800 Ω resistor = $\sqrt{\frac{P}{R}} = \sqrt{\frac{2.0\ W}{800\ \Omega}} = 0.050\ A$ [1]

Current through 50 Ω resistor = 0.10 A [1]

d) PD across 50 Ω resistor = IR = 0.10 × 50 = 5 V

⇒ EMF = 40 V + 5 V = 45 V [1]

13 a) As the two resistors in parallel have the same resistance,

$R_T = 5\ \Omega + \frac{5\ \Omega}{2}$ [1]

$R_T = 7.5\ \Omega$ (or $8\ \Omega$ 1 sf) [1]

b) EMF of P and Q in parallel = 1.2 V
⇒ Total EMF = 3 × 1.2 V = 3.6 V [1]

c) $Total\ current, I_T = \frac{\mathcal{E}}{R_T} = \frac{3.6\ V}{7.5\ \Omega} = 0.48\ A$ [1]

$\Longrightarrow current\ through\ Q = 0.24\ A$ [1]

d) Total charge through Q each second = current through Q [1]
= 0.24 C [1]

e) P and Q will supply electrical energy for the longest period of time. This is because the charge flowing through P and Q per second is half the charge through R and S per second. [1]
To create the same emf as R and S, P and Q need only supply half the energy to each unit of charge, and so will supply energy for longer. [1]

14 a) PD across 330 Ω resistor = IR = 14.0×10^{-3} A × 330 Ω [1]

PD across 330 Ω resistor = 4.62 V = 4.6 V (2 sf) [1]

b) $V_{1\,k} = \mathcal{E} - V_{330} = 12\ V - 4.62\ V$ [1]

$V_{1\,k} = 7.38\ V = 7.4\ V\ (2\ sf)$ [1]

c) $Total\ resistance, R_T = \frac{V}{I_T}$ [1]

$$R_T = \frac{7.4\ V}{14.0 \times 10^{-3}\ \text{A}} = 530\ \Omega \quad [1]$$

d) $\frac{1}{R_T} = \frac{1}{R} + \frac{1}{R_{Th}}$ [1]

$\frac{1}{530} - \frac{1}{1000} = \frac{1}{R_{Th}}$ [1]

$R_{Th} = 1130\ \Omega$ [1]

e) As T increases, the resistance of the ntc thermistor drops and the total resistance of the circuit also drops. [1]

As $I \propto \frac{1}{R}$ the current measured by the ammeter increases. [1]

15 a) $R_{A-E} = 10\ k\Omega + 10\ k\Omega = 20\ k\Omega$ [1]

$R_{B-F} = 5\ k\Omega + 2.5\ k\Omega = 7.5\ k\Omega$ [1]

$\frac{1}{R_T} = \frac{1}{20 \times 10^3} + \frac{1}{7.5 \times 10^3}$

$\Longrightarrow R_T = 5454\ \Omega = 5500\ \Omega$ (2 sf) [1]

b) $Total\ current, I_T = \frac{\mathcal{E}}{R_T} = \frac{6\ V}{5454\ \Omega} = 1.1 \times 10^{-3}\ A$ [1]

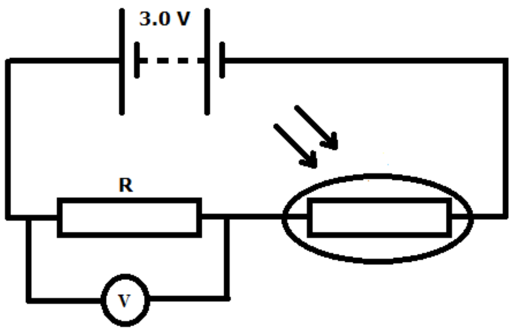
c)

Position of the voltmeter	pd, V, (V)
C-E	3
D-F	2
C-D	1

d) i) pd across A-E remains constant as the connections are directly across the battery [1], this means the pd across C-E remains constant as well. [1]

ii) As the resistance of the thermistor decreases, the pd across D-F decreases [1] as $V \propto R$. [1]

16 a) [1 mark for correct symbols; 1 mark for correct connection]



b) $V_{LDR} = \mathcal{E} - V_{resistor}$ [1]

$V_{LDR} = 3.0\ V - 0.80\ V = 2.2\ V$ [1]

c) $I_T = \frac{V}{R_T}$ [1]

$I_T = \frac{2.2\ V}{1500\ \Omega} = 1.46 \times 10^{-3}\ A = 1.5 \times 10^{-3}\ A\ (2\ sf)$

d) $R_{resistor} = \frac{V}{I_T}$ [1]

$R_{resistor} = \frac{0.80\ V}{1.46 \times 10^{-3}\ \mathrm{A}} = 547.9\ \Omega = 550\ \Omega\ (2\ \mathrm{sf})$ [1]

e) As the resistance falls so the total current increases. [1]
This causes the pd across the fixed resistor to increase because $V \propto I$. [1]

f) If the resistance of the voltmeter is the same as the fixed resistor, their combined resistance is half the resistance of the fixed resistor. [1]
This means the total resistance of the circuit drops and the total current will increase. [1]

17 a) $R_T = \frac{\mathcal{E}}{I_T}$ [1]

$R_T = \frac{12\ V}{2.2\ \mathrm{A}} = 5.45\ \Omega = 5.5\ \Omega\ (2\ \mathrm{sf})$ [1]

b) $R_T = R + \left(\frac{1}{\frac{1}{R}+\frac{1}{2R}}\right)$ [1]

$R_T = R + \frac{2R^2}{2R + R} = \frac{5}{3}R = 5.45\ \Omega$ [1]

$\Longrightarrow \mathrm{R} = 3.27\ \Omega = 3.3\ \Omega\ (2\ \mathrm{sf})$ [1]

c) The pd across QR

$V_{parallel} = IR_{parallel} = 2.2\ A \times (5.45\ \Omega - 3.27\ \Omega) = 4.796\ V = 4.8\ V\ (2\ sf)$ [1]

The current through Q and R, $I_{parallel} = \frac{V_{parallel}}{2R}$ [1]

$I_{parallel} = \frac{4.796\ V}{(2 \times 3.27\ \Omega)} = 0.73\ A$ [1]

d) $P = I^2R = (2.2\ \mathrm{A})^2 \times 3.27\ \Omega$ [1]

P = 15.83 W = 16 W (2 sf) [1]

18 a) Pd across R_2 is 12 V – 7.5 V = 4.5 V

$I = \frac{V}{R2} = \frac{4.5\ V}{150\ \Omega} = 0.030\ A$ [1]

b) $P = I^2R$ [1]

$P = (0.030)^2 \times 150\ \Omega = 0.135\ \mathrm{W} = 0.14\ \mathrm{W}$ (2 sf) [1]

c) $R_1 = \frac{V}{I}$ [1]

$R_1 = \frac{7.5\ V}{0.030\ A} = 250\ \Omega$ [1]

d) The room temperature resistance of the thermistor is likely to be much higher than 250 ohm so the voltmeter across the fixed resistor will initially show a constant small reading. [1] As the current flows, the thermistor gets hotter, its resistance decreases, and the reading on the voltmeter begins to increase. It will be at a new constant value when the thermistor's temperature is again stable (when the rate at which it is converting electrical energy to heat equals the rate at which the heat is being dissipated to the surroundings). [1]

19 a) Total resistance = sum of all resistors, $R_T = 120\ k\Omega + 8.0\ k\Omega + 42\ k\Omega = 170\ k\Omega$ [1]

Total current, $I_T = \frac{\mathcal{E}}{R_T} = \frac{9.0\ V}{170 \times 10^3\ \Omega} = 5.29 \times 10^{-5}\ A = 5.3 \times 10^{-5}\ A\ (2\ sf)$ [1]

b) $V = IR = 5.29 \times 10^{-5}\ A \times 8.0 \times 10^3\ \Omega$ [1]

$V = 0.4232\ V = 0.42\ V\ (2\ sf)$ [1]

c) As the resistance of the LDR drops, so the total current increases. [1]
This causes the pd across R to increase as $V \propto I$. [1]

d) If pd across R is 0.90 V, then the current through R must be

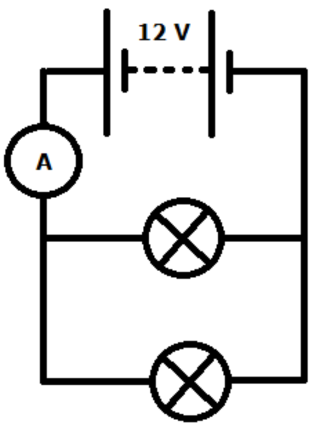
$I = \frac{V}{R} = \frac{0.90\ V}{8.0 \times 10^3\ \Omega} = 1.125 \times 10^{-4}$ A.

Total resistance must therefore be

$R_T = \frac{\mathcal{E}}{I} = \frac{9.0\ V}{1.125 \times 10^{-4}\ A} = 80000\ \Omega$ [1]

$\Rightarrow R_{variable} = 80000\ \Omega - 12000\ \Omega - 8000\ \Omega = 60\ 000\ \Omega$ [1]

20 a) [1 mark for correct symbols; 1 mark for correct connection]



b) Current flowing through each bulb, $I = \frac{P}{V} = \frac{32}{12} = 2.6\ A$ [1]

$\Rightarrow I_T = 2 \times 2.6\ A = 5.2\ A$ [1]

c) $P = \frac{V^2}{R} \Rightarrow R = \frac{V^2}{P}$ [1]

$R = \frac{(12\ V)^2}{32\ W} = 4.5\ \Omega$ [1]

d) If ammeter has a higher resistance, the total resistance of the circuit will increase, causing the total current drawn from the battery to decrease. [1]
This reduces the current flowing through each bulb, reducing their power and brightness. [1]

e) PD across each bulb in series $= \frac{12\ V}{2} = 6.0\ V$

$P = \frac{V^2}{R} = \frac{(6.0\ V)^2}{4.5\ \Omega} = 8.0\ W$ [1]

Power is therefore ¼ of power in parallel – the bulbs will be substantially dimmer. [1]

f) If one bulb malfunctions, the other will still work, increasing safety. [1]

21 a) Current flowing through X, $I_X = \frac{P_X}{V_X}$ [1]

$I_X = \frac{36\ W}{12\ V} = 3.0\ A$ [1]

Current flowing through Y, $I_Y = \frac{P_Y}{V_Y} = \frac{2.0\ W}{4.5\ V} = 0.44\ A$ [1]

b) As pd across X = 12 V [1]

then pd across R_1 = 24 V – 12 V = 12 V [1]

c) Current through R_1 = 3.0 A + 0.4 A = 3.4 A [1]

d) $R_{R_1} = \frac{V_{R_1}}{I_{R_1}} = \frac{12\ V}{3.4\ A} = 3.53\ \Omega = 3.5\ \Omega\ (2\ \text{sf})$ [1]

e) $V_{R_2} = 12\ V - 4.5\ V = 7.5\ V$ [1]

f) $R_2 = \frac{V_{R_2}}{I_{R_2}}$ [1]

$R_2 = \frac{7.5\ V}{0.40\ A} = 18.75\ \Omega = 19\ \Omega\ (2\ \text{sf})$ [1]

g) Total resistance of circuit increases. Total current drawn decreases. [1]

PD across R_1 decreases. [1]

h) The PD across R_1 decreases, so the PD across X increases, [1] so bulb X gets brighter and might blow. [1]

22 a) $V = \mathcal{E} - Ir$, so as I increases Ir increases [1]

and $\mathcal{E} - Ir$ decreases [1]

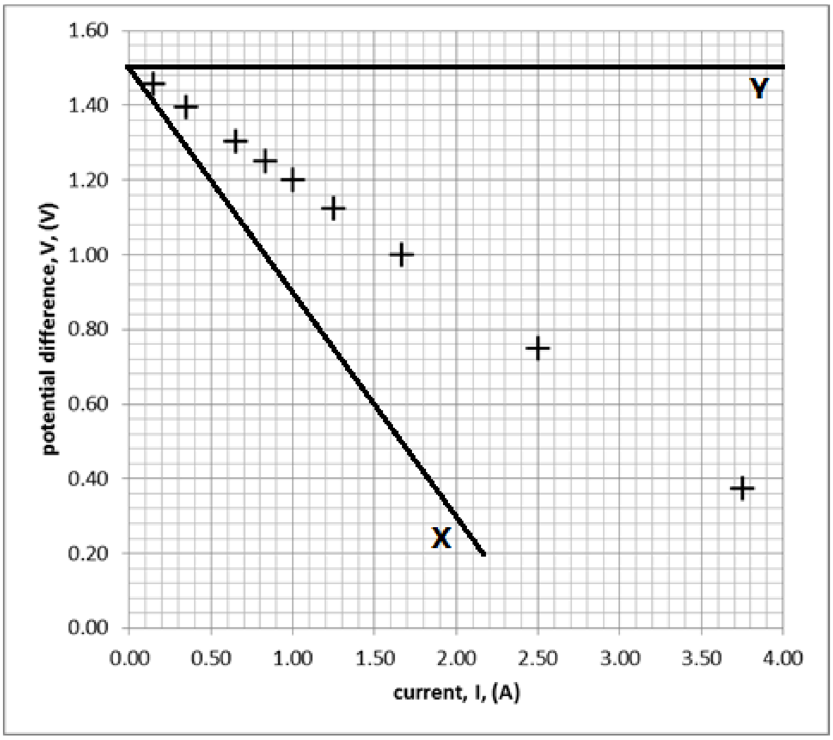
b) $\mathcal{E}$ = *y*-intercept of V-I graph =1.50 V [1]

$-r$ is the gradient of V-I graph = $\frac{(1.46-0.38)}{(0.15-3.75)}$ [1]

$r = 0.30\ \Omega$ [1]

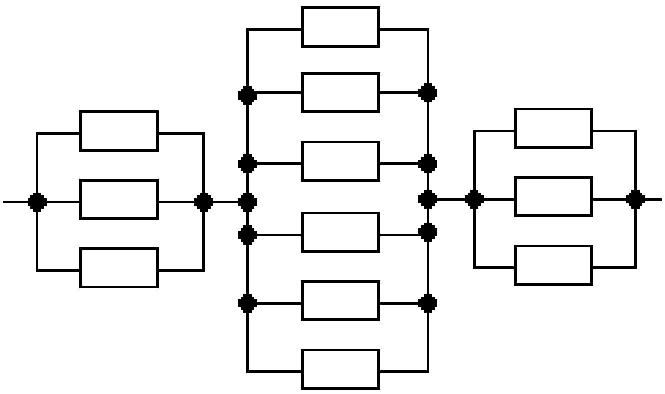
c) see graph below: same intercept [1]; gradient doubled [1]

d) see graph below: horizontal line [1]; same intercept [1]



Pages 269-273 Stretch and challenge questions

23 a) The circuit is equivalent the one shown below:



b) Resistance of 3 1Ω resistors in parallel = $^1/_3\ \Omega$;

Resistance of 6 1Ω resistors in parallel = $^1/_6\ \Omega$;

Total resistance = $^1/_3 + {}^1/_6 + {}^1/_3\ \Omega = 0.83\ \Omega$.

24 C

25 B

26 A

27 D

28 A

29 a) By considering AC:

$R_1 + R_2 = 1.5\ \text{V} / 37.5\ \text{mA}$

$R_1 + R_2 = 40\ \Omega$ **(1)**

By considering BD:
$R_3 + R_4 = 1.5\ \text{V} / 25\ \text{mA}$

$R_3 + R_4 = 60\ \Omega$ **(2)**

By considering AB:

$R_1 + R_5 + R_3 = 1.5\ \text{V} / 30\ \text{mA}$

$R_1 + R_5 + R_3 = 50\ \Omega$ **(3)**

By considering CD:

$R_2 + R_5 + R_4 = 1.5\ \text{V} / 15\ \text{mA}$

$R_2 + R_5 + R_4 = 100\ \Omega$ **(4)**

b) For R_5: **(3)** + **(4)** gives:

$R_1 + R_5 + R_3 + R_2 + R_5 + R_4 = 50 + 100\ \Omega$

Substituting from **(1)** and **(2)** we obtain:

$40\ \Omega + 60\ \Omega + 2\ R5 = 150\ \Omega$

So $R_5 = 25\ \Omega$

c) With CD connected together, we have $R_2 + R_4$ in parallel with R_5, $25\ \Omega$

Substituting for R_5 in **(4)** shows $R_2 + R_4 = 75\ \Omega$ **(5)**

$75\ \Omega$ in parallel with $25\ \Omega$ is $18.75\ \Omega$

And this is in series with $R_1 + R_3$ which, from **(3)** is $50\ \Omega - 25\ \Omega = 25\ \Omega$

$R_1 + R_3 = 25\ \Omega$ **(6)**

So total resistance is $25\ \Omega + 18.75\ \Omega = 44\ \Omega$ (2sf).

d) From above: $R_1 + R_3 = 25\ \Omega$ and $R_2 + R_4 = 75\ \Omega$

So an intuitive guess that the fault is ¼ of the distance from A or C (15 metres).

More formally:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

Substituting for R_3 in **(6)**

$$So\ R_1 + \frac{R_1 R_4}{R_2} = 25$$

$$R_1\left(1 + \frac{R_4}{R_2}\right) = 25$$

(5) can be rewritten as:

$$R_2\left(1 + \frac{R_4}{R_2}\right) = 75$$

$$\frac{R_1}{R_2} = \frac{1}{3} = \frac{15\ \text{metres}}{45\ \text{metres}}$$

OR, similarly:

$$R_3 + \frac{R_2 R_3}{R_4} = 25 \text{ from } \textbf{(6)}$$

$$R_3\left(1 + \frac{R_2}{R_4}\right) = 25$$

and

$$R_4\left(1 + \frac{R_2}{R_4}\right) = 75 \text{ from } \textbf{(5)}$$

$$\frac{R_3}{R_4} = \frac{1}{3} = \frac{15\ \text{metres}}{45\ \text{metres}}$$

30 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 so more heat energy produced.

Cycle continues until thermistor overheats/is destroyed.

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

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

31 a) 40 V.

B is at the same potential as X because no current flows along BX.

b) i) 200 – 40 = 160 V

ii) $\frac{(200\ V - 40\ V)}{d} = \frac{160}{d} V m^{-1}$

c) 40 V

d) So that X is at the same potential and then the same current flows into the ground through R.

e) $\frac{(300\ V - 40\ V)}{(50 - d)m} = \frac{260}{(50 - d)} Vm^{-1}$

f) i) Because the same currents flowed along AX and BX, so

$I = \frac{V_{AX}}{R_{AX}} = \frac{V_{BX}}{R_{BX}}$ and R is proportional to length.

ii) $\frac{160\ m}{d} = \frac{260\ m}{(50\ m - d)}$

$260d = 50 \times 160 - 160d$

$420d = 8000$

$d = 19$ km (2sf)

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

$\Longrightarrow P = (I \times R) \times I = I^2 R$

$and\ P = V \times \left(\frac{V}{R}\right) = \frac{V^2}{R}$

b) A fixed voltage is applied to the heater, so P is inversely proportional to R meaning the student is correct: a low R is needed.

c) Case 1: same pd across each wire, so $\frac{V^2}{R}$ implies smaller R for larger power, so copper glows firest (because R is lower).

Case 2: same current through each wire, so $I^2 R$ implies larger R for a larger power, so iron glows first (larger R).

d) From information in question: $I = kV^4$

So, for this material, P = VI = kV^5

$6\ W = k \times (230\ V)^5$

$\Longrightarrow k = 9.3 \times 10^{-12}\ WV^{-5}$

So $P_{1200} = 9.3 \times 10^{-12} WV^{-5} \times (1200\ V)^5 = 23\ kW$

Or $P_{1200} = 6\ W \times \left(\frac{1200\ V}{230\ V}\right)^5 = 23\ kW$