1. (a) pd = 3.6 V (1)
   
   Example of answer;
   p.d. = 0.24 A × 15 Ω = 3.6 V
   
   (b) Calculation of pd across the resistor (1)
   [6.0 − 3.6 = 2.4 V]
   Recall V = IR (1)
   $I_1$ calculated from their pd / 4Ω (1)
   
   [correct answer is 0.60 A. Common ecf is 6V/4Ω gives 1.5 A]
   
   Example of answer:
   $I_1 = \frac{2.4 V}{4.0 \Omega} = 0.6 \text{ A}$
   
   (c) Calculation of $I_2$ from $I_1 − 0.24$ [0.36 A] (1)
   [allow ecf of their $I_1$. common value = 1.26 A]
   Substitution V = 3.6 V (1)
   $R = 10 \Omega$ (1)

2. (a) p.d. across 4 Ω resistor
   
   1.5 (A) × 4 (Ω)
   = 6 V (1)
   
   (b) Resistance $R_2$
   Current through $R_2 = 0.5 \text{ A}$ (1)
   $R_2 = \frac{6 (V)}{0.5 (A)}$
   $R_2 = 12 \Omega$ (1)
   [allow ecf their pd across 4 Ω]
   
   (c) Resistance $R_1$
   p.d. across $R_1 = 12 − 6 − 4$
   = 2 V (1)
   Current through $R_1 = 2 \text{ A}$ (1)
   $R_1 = \frac{2 (V)}{2 (A)} = 1 \Omega$ (1)
   [allow ecf of pd from (a) if less than 12 V]
   Alternative method
   Parallel combination = 3Ω (1)
   Circuit resistance = $12(V)/2 (A) = 6\Omega$ (1)
   $R_1 = 6 − (3 + 2) = 1 \Omega$ (1)
   [allow ecf of pd from (a) and R from (b)]

3. Charge
Charge is the current × time (1)

Potential difference
Work done per unit charge [flowing] (1)

Energy
9 V × 20 C (1)
= 180 J (1)

4. The power supplies in the two circuits shown below are identical.

Write down the relationship between $I_1$, $I_2$ and $I$ which must hold if the combined resistance of the parallel pair, $R_1$, and $R_2$, is to equal $R_T$.

$I = I_1 + I_2$ (1 mark)

Hence derive the formula for the equivalent resistance of two resistors connected in parallel.

From Ohm’s law:

$I_1 = \frac{V}{R_1}$
$I_2 = \frac{V}{R_2}$

$\therefore \frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2}$ (1)

and $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$ (1)

(3 marks)

Use your formula to show that the resistance between the terminals of a low-resistance component is hardly changed when a high-resistance voltmeter is connected in parallel with it.

If $R_v >> R_{\text{low}}$ then $1/R_v >> 1/R_{\text{low}}$ (1)

and $R_T \approx R_{\text{low}}$ (1)

Allow method based on numerical example

(2 marks)

[Total 6 marks]
5. **Resistance calculations**

Evidence of 20 Ω for one arm (1)

\[
\frac{1}{R} = \frac{1}{20} + \frac{1}{20} \quad (1)
\]

\[R = 10 \, \Omega \quad (1)
\]

**Comment**

This combination used instead of a single 10 Ω resistor [or same value as before] (1)
because a smaller current flows through each resistor/reduce heating in any one resistor/average out errors in individual resistors (1)

6. **Circuit**

Ammeters and two resistors in series (1)

[1 mark circuit penalty for line through cell or resistor]

Cell e.m.f

\[E = 150 \times 10^{-6} \, (A) \times 40 \times 10^3 \, (\Omega) \, \text{total} \quad (1)\]

Powers of 10 (1)

\[E = 6.0 \, (V)\]

**New circuit**

Voltmeter in parallel with 25 (kΩ) resistor (1)

**Resistance of voltmeter**

\[\frac{6(V)}{170 \times 10^{-6}(A)} = (35.3 \, k\Omega) \quad (1)\]

(Resistance of ll combination) = 35 – 15 kΩ

\[\frac{1}{20} = \frac{1}{25} + \frac{1}{R_V} \quad (1)\]

\[\frac{1}{R_V} = \frac{5 - 4}{100} \quad (1)\]

\[R_V = 100 \, k\Omega \quad [108 \, k\Omega \, \text{if} \, R_T \, \text{calculated correctly}] \quad (1)\]

**Alternative route 1:**

p.d. across 15 kΩ = 2.55 V

(∴ p.d. across ll combination = 3.45 V)

resistance combination = 20 kΩ

\[\rightarrow R_V = 100 \, k\Omega \quad (1)\]

**Alternative route 2:**

p.d. across parallel combination = 3.45 V

\[I \, \text{through} \, 25 \, k\Omega = 138 \, \mu A \quad (1)\]

\[\rightarrow R_V = 100 \, k\Omega \quad (1)\]
7. The circuit shows a battery of negligible internal resistance connected to three resistors.

![Circuit diagram]

Calculate current $I_1$.

Voltage drop across 4Ω resistor = 3V \hspace{1cm} (1)

\[ I_2 = \frac{(9 \text{ V} - 3 \text{ V})}{24 \Omega} \hspace{1cm} (1) \]

\[ I_1 = 0.25 \text{ A} \hspace{1cm} (1) \]

Calculate resistance $R$

\[ I_2 = 0.75 \text{ A} - 0.25 \text{ A} = 0.50 \text{ A} \hspace{1cm} (1) \]

\[ R = \frac{6 \text{ V}}{0.50 \text{ A}} = 12 \Omega \hspace{1cm} (1) \]

$R = 12 \Omega$

(3 marks)

(2 marks)

[Total 5 marks]

8. Diagram of torch circuit:

The lamp will light

Correct circuit 2

[Circuit showing one cell only is allowed one mark only unless the cell is labelled 4.5 V. If a resistor is included, allow first mark only unless it is clearly labelled in some way as an internal resistance.]

![Torch circuit diagram]

Voltage across each circuit component and current in lamp:

Either 3.5 V/3 shown across the terminals of one cell or 3.5 V across all three cells

3.5 V shown to be across the lamp

0.3 A flowing in the lamp [i.e. an isolated 0.3 A near the lamp does not score]

Calculation of internal resistance of one of the cells:

3
Lost volts = 4.5 V - 3.5 V or 1.5 V – \frac{3.5V}{3}

or total resistance = \frac{(4.5 V)/0.3 A}{3} = 15 K\Omega

Internal resistance of one cell = \frac{[1.0 V]/(0.3 A)]}{3}

or \frac{(0.33 V) (0.3 A)\text{ or lamp resistance} = \frac{(3.5 V)}{(0.3 A)} = 11.7 \Omega}{\text{or} \quad \frac{(3.5\Omega)/3}{\text{or} \quad \frac{(3.3 \Omega)/3}{1.1 \Omega}}}

[Some of these latter marks can be read from the diagram if it is so labelled]

9. Proof:

\begin{align*}
V &= V_1 + V_2 \\
V &= IR \\
V_1 &= IR_1 \\
V_2 &= IR_2 \quad \div I \\
\text{Substitute and cancel} \ I \\
\text{Sub using} \ R &= \frac{1}{3}
\end{align*}

\begin{align*}
\text{Explanation of why it is a good approximation:} \\
\text{Resistance of connecting lead is (very) small} \\
\text{So} \ I \times R_{(very)} \text{ small p.d./e}^{-1} \text{s do little work so p.d. small/r small} \\
\text{compared with rest of the circuit so p.d. small}
\end{align*}

\begin{align*}
\text{Circumstances where approximation might break down:} \\
\text{If current is large OR resistance of rest of circuit is small} \\
\text{[Not high voltage/long lead/thin lead/high resistivity lead/hot lead]} \quad \text{1}
\end{align*}

\begin{align*}
\text{Calculation:} \\
\text{Use of} \ R = \frac{\rho l}{A}\text{ with } A \text{ attempted } \times \text{ sectional area} \\
\text{Correct use of 16} \\
\text{Use of} \ V = IR \\
0.036 \text{ V}
\end{align*}

\begin{align*}
\quad \text{4}
\end{align*}

[10]
10. No, because \( V \) is not proportional to \( I \) OR not straight line through origin \( (1) \)

only conducts above 0.5 V / resistance changes \( (1) \)

Use of \( R = 0.74 \) / current from graph \( (1) \)

\[
= 9.25 \Omega \ [9.0 – 9.5 \Omega] \ [\text{Minimum 2 significant figures}] \ (1)
\]

<table>
<thead>
<tr>
<th>Calculation of p.d. across ( R ) [8.26]</th>
<th>Calculation of total resistance[109 – 115]</th>
<th>Ratio ( R ): ratio ( V )</th>
<th>( E = \Sigma IR ) ( (1) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>÷ ( I )</td>
<td>– diode resistance [9]</td>
<td>Correct substitutions</td>
<td>Correct substitutions ( (1) )</td>
</tr>
</tbody>
</table>

103 \( \Omega \) [100 – 106] \( (1) \)

[If not vertical line, 0/2]

\[
\begin{array}{ccc}
0.7 & \neq 0.7 & 0.7 \\
(1) & (0) & (1)(1) \\
\end{array}
\]

[Otherwise 0 0 ] \( [8] \)

11. Circuit diagram

Resistor with another variable resistor/potential divider/variable power pack \( (1) \)

Ammeter reading current through resistor \( (1) \)

Voltmeter in parallel with resistor \( (1) \)

Graph labels

Straight line – resistor
Curve – lamp

Both labelled \( (1) \)

Potential difference

At 0.5 A p.d. = 3.5 V / 3.4 V + 7.8 V / idea of adding p.d. [for same current] \( (1) \)

\[
= 11.2 \ V/11.3 \ V \ (1)
\]

[Accept 11.0 – 11.5 V]

Resistance of lamp

\[
\frac{3.5 \ V}{0.5 \ A} \ [\text{OR their value of p.d. across lamp ÷ 0.5 A}] \ (1)
\]

\[
= 7.0 \ \Omega \ (1)
\]

[e.c.f. their value] \( [8] \)
12. Show that

- states p.d. same across each resistor (1)
- use of \( I = I_1 + I_2 + I_3 \) [symbols or words] (1)

\[
\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad (1)
\]

\([I = V / R \text{ stated somewhere gains one mark}]

Networks
First network: 2.5(\(\Omega\)) (1)
Second network: 25 (\(\Omega\)) (1)
Third network: 10 (\(\Omega\)) (1)

Meter readings
Ammeter: 25 (mA) (1)
Voltmeter \(V_1\): 25 \(\times\) 10 OR 50 \(\times\) 5 [ignore powers of 10] (1)
\[= 0.25 \text{ V} \quad (1)\]
Voltmeter \(V_2\): 50 \(\times\) 25 [ignore powers of 10] (1)
\[= 1.25 \text{ V} \quad (1)\]

[Allow full e.c.f. for their resistance for 2\textsuperscript{nd} network OR their \(V_1\) answer]

13. Readings on voltmeter

Use of any resistor ratio OR attempt to find current in either circuit (1)

At 950 k\(\Omega\)
\[
V = \frac{10 \text{ k}\Omega \times 6 \text{ V}}{960 \text{ k}\Omega} = 0.063 \text{ V} \quad (1)
\]

At 1.0 k\(\Omega\)
\[
V = \left(\frac{10 \text{ k}\Omega \times 6 \text{ V}}{11 \text{ k}\Omega}\right) = 5.45 \text{ V} \quad (1)
\]

Use of circuit as lightmeter
Maximum resistance corresponds to low light intensity/resistance down as light intensity up (1)

\(\therefore\) lightmeter or voltmeter reading will increase as light intensity increases [or reverse] (1)

[Can ecf for 2\textsuperscript{nd} mark if resistance/light intensity incorrect and/or p.d. calculation wrong]