Electricity Answers

Current, Potential Difference, Resistor Networks, Resistance and Resistivity

1. Resistance calculations
   Evidence of 20 Ω for one arm (1)
   \[ \frac{1}{R} = \frac{1}{20} + \frac{1}{20} \] (1)
   \[ R = 10 \, \Omega \] (1) 3
   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) 2 [5]

2. Statement 1
   Statement is false (1)
   Wires in series have same current (1)
   Use of \( I = nAe^\nu \) with \( n \) and \( e \) constant (1) 3
   [The latter two marks are independent]
   Statement 2
   Statement is true (1)
   Resistors in parallel have same p.d. (1)
   Use of Power = \( V^2/R \) leading to \( R \uparrow \), power \( \downarrow \) (1) 3
   OR as \( R \uparrow \), \( I \downarrow \) leading to a lower value of \( VI \) 3rd mark consequent on second [6]
3. **Charge calculation**
   \[ Q = 20\ 000 \times 4.0 \times 10^{-4} \text{ s [substitution]} \]
   \[ Q = 8.0 \text{ C/A s} \]

**Resistance calculation**

\[ R = \frac{\rho l}{A} \]

\[ = \frac{(1.7 \times 10^{-8} \Omega)(50 \text{ m})}{(1.0 \times 10^{-3} \text{ m}^2)} \]

\[ R = 8.5 \times 10^{-4} \Omega \]

**Formula** (1)

**Correct substitution** (1)

**Answer** (1)

3

**Potential difference calculation**

\[ V = IR \]

\[ = (20\ 000 \text{ A}) \times (85 \times 10^{-5} \Omega) \text{ [or their value]} \]

\[ = 17 \text{ V [Allow full e.c.f]} \]

2

**Explanation**

For the tree: R or p is larger (1)

1


4. **Diagram**

Labelled wire and a supply (1)

Ammeter in series and voltmeter in parallel (1)

OR

Labelled wire with no supply (1)

Ohmmeter across wire (1)

2

**Readings**

Current and potential difference OR resistance (consistent with diagram) (1)

Length of wire (1)

Diameter of wire (1)

3
Use of readings

\[ R = \frac{V}{I} \text{ OR } \rho = \frac{RA}{l} \]

Awareness that A is cross-sectional area (may be seen above and credited here) \((1)\)

Repetition of calculation OR graphical method \((1)\) \(3\)

Precaution

Any two from:

- Readings of diameter at various places / different orientations
- Contact errors
- Zeroing instruments
- Wire straight when measuring length
- Wire not heating up / temperature kept constant \((1)\) \((1)\) \(2\)

5. (a) Io and Jupiter: Time taken for electrons to reach Jupiter

\[ t = \frac{s}{\nu} = \frac{(4.2 \times 10^8 \text{ m})/(2.9 \times 10^7 \text{ m s}^{-1})}{1} = 14.48 \text{ s} \]

Correct substitution in \(\nu = \frac{s}{t}\) (ignore powers of ten) \((1)\)

Answer: 14.48 s, 14.5 s [no ue] \((1)\) \(2\)

(b) Estimate of number of electrons

\[ Q = ne = It \]

\[ n = \frac{It}{e} \]

\[ n = (3.0 \times 10^6 \text{ A}) (1\text{s})/(1.6 \times 10^{-19} \text{ C}) \]

Use of \(ne = It\) \((1)\)

\((1.8 – 2.0) \times 10^{25} \text{} \((1)\) \(2\)

(c) Current direction

From Jupiter (to Io) / to Io / to the moon \((1)\) \(1\)

6. Charge

Charge is the \textit{current} × \textit{time} \((1)\) \(1\)

Potential difference

Work done per unit charge [flowing] \((1)\) \(1\)

Energy

\[ 9 \text{ V} \times 20 \text{ C} \text{} \]

\[ = 180 \text{ J} \text{} \]

\[ = 180 \text{ J} \text{} \text{(1)} \text{} \] \(2\)

\[ 10 \text{ \ }} \]

\[ 5 \text{ \ }} \]

\[ 4 \text{ \ }} \]
7.  

(a) **p.d. across 4 Ω resistor**

\[1.5 \text{ (A)} \times 4 \text{ (Ω)} = 6 \text{ V} \] (1)

(b) **Resistance R_2**

Current through R_2 = 0.5 A (1)

\[R_2 = \frac{6 \text{ (V)}}{0.5 \text{ (A)}} = 12 \text{ Ω} \] (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 A (1)

\[R_1 = \frac{2 \text{ (V)}}{2 \text{ (A)}} = 1 \text{ Ω} \] (1)

[allow ecf of pd from (a) if less than 12 V]

Alternative method

Parallel combination = 3Ω (1)

Circuit resistance = 12(V)/2 (A) = 6Ω (1)

\[R_1 = 6 - (3 + 2) = 1 \text{ Ω} \] (1)

[allow ecf of pd from (a) and R from (b)] 

[6]
8. Definition of symbols:

\[ n = \text{number of electrons/carriers per unit volume (per } m^3) \]

OR

\[ n = \text{electron (or carrier) density (1)} \]

\[ \nu = \text{average (OR drift) velocity (OR speed) (1)} \]

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Value</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{n_y}{n_x} )</td>
<td>1</td>
<td>Same material (1) (1)</td>
</tr>
<tr>
<td>( \frac{l_y}{l_x} )</td>
<td>1</td>
<td>Connected in series/Kirchoff’s 1st law/conservation of charge/current is the same (1) (1)</td>
</tr>
<tr>
<td>( \frac{v_y}{v_x} )</td>
<td>2</td>
<td>( A ) is halved so ( v ) double [Accept qualitative, e.g. ( A \downarrow ) so ( v \uparrow ), or good analogy] (1) (1)</td>
</tr>
</tbody>
</table>

[Accept e.g. \( ny = nx \ldots \).]  
[No e.c.f.]  
[NB Mark value first, without looking at explanation. If value correct, mark explanation. If value wrong, don’t mark explanation except if \( \frac{\nu_y}{\nu_x} = \frac{1}{2} \) or 1:2, see if explanation is correct physics, and if so give (1). No e.c.f.] [8]

9. Metal wire:  
straight line through origin

Semiconductor diode:  
line along V axis for negative I  
curve up in first quadrant  
\[ \text{in gap} \]  
p.d. across it (4.5 – 1.9) V  
\[ \therefore R_s = \frac{2.6V}{20 \times 10^{-3}A} = 130\Omega \] [6]

10. Resistance of strain gauge

State \( R = \frac{\rho l}{A} \) (1)  
Use of formula (1)  
x 6 (1)  
\( R = 0.13 \Omega \) [ecf their \( l \)] (1) [4]
\[
R = \frac{\rho l}{A} = \frac{9.9 \times 10^{-8} \Omega m \times 2.4 \times 10^{-2} m \times 6}{1.1 \times 10^{-7} m^2} = 129.6 \times 10^{-3} \Omega
\]

\[R = 0.13 \Omega\]

**Change in resistance**

\[
\Delta R = 0.13 \Omega \times 0.001
\]

\[
\Delta R = 1.3 \times 10^{-4} (\Omega) \text{ [no e.c.f.]}
\]

OR

\[
\Delta R = 0.02 \times 0.001
\]

\[
\Delta R = 2.0 \times 10^{-5} \Omega
\]

0.1% \rightarrow 0.001 (1)

Correct number for \(\Delta R\) (1)

2

**Drift velocity**

Stretching causes \(R\) to increase (1)

Any two from:

- Current will decrease
- \(I = nA\nu Q\)
- Drift velocity \(\nu\) decreases
- \(nAe\) constant (1) (1)

3

[9]

[For \(R\) decreasing, max 1:]

Any one from:

- \(I\) will increase
- \(I = nA\nu Q\)
- \(\nu\) will increase
- \(nAe\) constant]

11. **Definition of e.m.f. of a cell**

Work/energy (conversion) per unit charge

for the whole circuit / refer to total (energy)

OR

Work/energy per unit charge

converted from chemical to electrical (energy)
E = \frac{W}{Q} \text{ for whole circuit} \hspace{1cm} 1

All symbols defined \hspace{1cm} 1

OR

E = \frac{P}{I} \text{ for whole circuit} \hspace{1cm} 1

All symbols defined \hspace{1cm} 1

[Terminal p.d. when no current drawn scores 1 mark only]

Circuit diagram

\[ \text{A in series} \hspace{1cm} \text{R (can be variable)} \hspace{1cm} 2 \\
\text{A} \hspace{1cm} \text{and V correct} \hspace{1cm} 1 \\
\text{V as shown} \hspace{1cm} \text{Or across R + A} \hspace{1cm} \text{Or across battery} \hspace{1cm} 1 \]

[2\textsuperscript{nd} mark is consequent on R(fixed, variable) or lamp]

Sketch graph

\[ \text{Graph correctly drawn with axes appropriately labelled and consistent with circuit drawn} \hspace{1cm} 1 \]

\[ \text{Intercept on R axes} \hspace{1cm} \text{Gradient} \equiv (-)r \text{ [Gradient mark consequent} \hspace{1cm} 1 \]

\[ \equiv (-)r \text{ on graph mark} \]

[Gradient may be indicated on graph] \hspace{1cm} [6]

12. (a) (i) Potential difference = work (done)/(unit) charge

OR Potential difference = Power/current (1)

(ii) \hspace{1cm} J = \text{kg m}^2\text{ s}^{-2} (1)

\hspace{1cm} C = \text{A s or W} = \text{J s}^{-1} (1)

\hspace{1cm} V = \text{kg m}^2\text{ A}^{-1}\text{ s}^{-3} (1)

(b) Converts 2 minutes to 120 seconds (1)
Multiplication of \( VI \Delta t \) or \( V \Delta Q \) (1)
Energy = 1440 J (1)

Example of answer:
Energy = 6.0 V \( \times \) 2.0 A \( \times \) 120 s
= 1440 J

13. Current in heating element

\[ p = VI \]
\[ p = \frac{V^2}{R} \]

\[ I = \frac{500 \text{ W}}{230 \text{ V}} \]
\[ R = \frac{230^2}{500} / 105.8(\Omega) \]

\[ I = 2.2 \text{ A} \]

Drift velocity
Drift velocity greater in the thinner wire / toaster filament

Explanation
Quality of written communication
See \( I = nAQ\nu \)
\( I \) is the same (at all points )
(probably) \( n \) (and \( Q \)) is the same in both wires

14. Current:
Conversion, i.e. \( 0.94 \times 10^{-3} \text{ m s}^{-1} \) (1)
Use of \( 1.6 \times 10^{-19} \text{ C} \) (1)
Answer 3.0 A
\( 1.0 \times 10^{29} \text{ m}^{-3} \times 0.20 \times 10^{-6} \text{ m}^2 \times 1.6 \times 10^{-19} \text{ C} \times 0.94 \times 10^{-3} \text{ mm s}^{-1} \) (1)
Current = 3.0 A [Accept 2.8 A if \( 0.9 \times 10^{-3} \) used.] 3

Resistance:
Recall \( R = \frac{pI}{A} \) (1)
Substitution:
\[ R = \frac{1.7 \times 10^{-8} \Omega \text{ m} \times 4.0 \text{ m}}{0.20 \times 10^{-6} \text{ m}^2} \] (1)
Resistance = 0.34 \( \Omega \) (1)

Potential difference:
Potential difference = 3.0 A \( \times \) 0.34 \( \Omega \) (1)
= 1.0 V (1.02 V)
[Mark for correct substitution of their values or for the answer of 1.0 V] 1
Explaination:

(Increasing resistivity) increases resistance (1)
Leads to a smaller current (1) 2

Comparison:

Drift velocity decreases (in second wire) (1) 1
[Allow $V_1/V_2 = I_1/I_2$]
[Allow e.c.f. answer consistent with their current answer]
[Resistivity up, current down $\rho$ up, $I$ down / 2 (2$^\text{nd}$ mark)]

15. Calculation of voltages:

Any use of
Voltage = current x component resistance (1)
Ballast = 150 V (1)
Filament = 25 V (1) 3

Voltages on diagram:
3 voltages (150,25,25) marked on diagram near component; ignore units (1)
[Minimum 150 ÷(1 × 25)]
$V_{\text{starter}} = 30$ V (marked on diagram) (1)

Fundamental change necessary:

(Free) charge carriers or free electrons, ionised, particles need to be charged (1) (1)
[NOT T ↑] 3

Calculation of power dissipated:

$V_{\text{ballast}} = 230$ V $-110$ V (1)
$I = 120$ V$\div300$ Ω
$= 0.40$ A (1)
Power = $230$ V $\times 0.40$ A [e.c.f for current]
$= 92$ W (1) 3

Faulty component:

Starter is not breaking the circuit/starter still conducting (1) 1 [10]
16. | Word Equation | Quantity Defined |
<table>
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<tbody>
<tr>
<td>Voltage ÷ Current</td>
<td>Resistance</td>
</tr>
<tr>
<td>Voltage × Current</td>
<td>Power</td>
</tr>
<tr>
<td>Charge ÷ Time</td>
<td>Current</td>
</tr>
<tr>
<td>Work done ÷ Charge</td>
<td>Voltage/p.d./e.m.f</td>
</tr>
</tbody>
</table>

17. Demonstration that resistance is 0.085 Ω:

\[ R = \frac{\rho l}{A} \quad (1) \]

\[ = 1.7 \times 10^{-8} \text{ m} \times 20 \text{ m} / (4.0 \times 10^{-6} \text{ m}^2) \quad (1) \]

Calculation of voltage drop:

\[ V = 37 \text{ A} \times 0.085 \text{ Ω} \quad (1) \]

\[ = 3.1 \text{ V} \times 2 = 6.3 \text{ V} \quad [\text{Not if } V_{\text{shower}} \text{ then found}] \quad (1) \]

[Only one conductor, leading to 3.1 V, gets 1st mark]
[Nothing if wires in parallel]

Explanation:

Lower resistance/R = 0.057 Ω/less voltage drop/new \( \frac{2}{3} \) old \( V \) (1)

Power dissipated in cable/energy wasted/wire not so hot
OR more p.d/current/power to shower
OR system more efficient (1) 2

18. Proof:

\[ V = V_1 + V_2 \quad V = V_1 + V_2 \quad (1) \]

\[ V = IR \quad V_1 = IR_1 \quad V_2 = \div I \quad (1) \]

\[ IR_2 \]

Substitute and cancel I \quad Sub using \( R = \) (1) 3

Explanation of why it is a good approximation:

Resistance of connecting lead is (very) small (1)

So \( I \times R_{(\text{very}) \text{ small}} = (\text{very}) \text{ small} \text{ p.d./e}^{-1} \text{s do little work so p.d. small/r small} \)

compared with rest of the circuit so p.d. small (1) 2
Circumstances where approximation might break down:

If current is large \textbf{OR} resistance of rest of circuit is small \hfill (1)

\textbf{[Not high voltage/long lead/thin lead/high resistivity lead/hot lead]} \hfill 1

Calculation:

\[ R = \frac{\rho l}{A} \text{ with } A \text{ attempted } \times \text{sectional area} \] \hfill (1)

Correct use of 16 \hfill (1)

Use of \( V = IR \) \hfill (1)

0.036 V \hfill (1)

\[ 4 \]

\[ \text{[10]} \]

19. Number of carriers or electrons per unit volume / per m\(^3\) /carrier density/electron density \hfill (1)

\textbf{[Not charge density / concentration]}

Drift velocity OR drift speed OR average/mean/net/overall velocity \hfill (1) \hfill 2

\textbf{[Not just velocity; not speed unless drift]}

m\(^{-3}\) \hfill (1)

m\(^2\) As m s\(^{-1}\) \hfill (1)

Multiply and reduce to A \hfill (1) \hfill 3

\textbf{[Base units not needed]}

\textbf{[Mixed units and symbols could get the third mark]}

[mA = m\(^{-1}\) loses 1 mark]

Metal:

M: \( n \) large so there is a current \hfill n: \( n \) in metal \textbf{much} larger \hfill (1)

Insulator

I: \( n \) zero (negligible)/very small so less current (or zero current) \hfill Current in metal is larger \hfill (1) \hfill 2

\textbf{[Ignore anything about } \textbf{v}. \text{ Allow e.g. electron density for } n]
20. No, because $V$ is not proportional to $I$ OR not straight line through origin / (1) Only conducts above 0.5 V / resistance changes

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

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

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<td>$\div I$</td>
<td>$-$ diode resistance [9] Correct substitutions</td>
<td>Correct substitutions (1)</td>
<td></td>
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103 $\Omega$ [100 – 106] (1)

[If not vertical line, 0/2]

| 0.7 (1) (1) | $\neq 0.7$ (0) | 0.7 (1)(1) Anything (gap, curve, below axis) |

[Otherwise 0 0 ]

21. Use $R = \rho l/A$ OR correct rearrangement OR plot $R \rightarrow l$ gradient = $\rho /A$ (1) [Symbols or words]

With $A = tw$ (1)

\[ l = RA/\rho \quad [\text{Rearrangement mark symbols or numbers}] (1) \]

Use of $A = tw$ (1)

[Correct physical quantities substituted but ignoring unit errors, powers of 10]

= 110 m

[111 m] (1)

Reduce width/$w$ of strip OR use thinner/$t$ foil [Not reduce $A$; not increase $T, V, I$] (1)

Smaller $w/t/A$ will be less accurate OR have larger error OR larger $R$ will be more accurate (1)

[Increase $w$ or $t$, could give e.c.f. to increased accuracy]
22. \[ I^2 \frac{R}{(\varepsilon - I^2 r)} \frac{(\varepsilon - Ir)^2}{R} \] (1)

\[ I^2 \frac{r}{(\varepsilon - I^2 r)} \frac{(\varepsilon - Ir)^2}{R} \] (1)

\[ \varepsilon I \text{ OR } I^2 R + I^2 r / \varepsilon^2 / \left( R + r \right) \] (1)

\[ \varepsilon I = I^2 R + I^2 r \text{ OR } \left( It = I^2 RT + I^2 rt / \text{ their (iii)} = \text{ their (i)} + \text{ their (ii)} \right) \] (1)

Cancel \( I \) (OR \( I \) and \( t \)) and arrange \[ \text{[only if energy equation is correct]} \] (1) 5

Maximum current occurs when \( R = 0 \) (1)

\[ I_{\text{max}} = \varepsilon / r \] (1)

OR larger \( r \) means smaller \( I \) (1 mark)

1 M\( \Omega \) [Could be underlined OR circled] (1)

It gives the smallest current (1)

[If 100 k\( \Omega \) this reason: 1 only] 2