Exam Papers Practice

5.2 Heating Effect of Electric Currents

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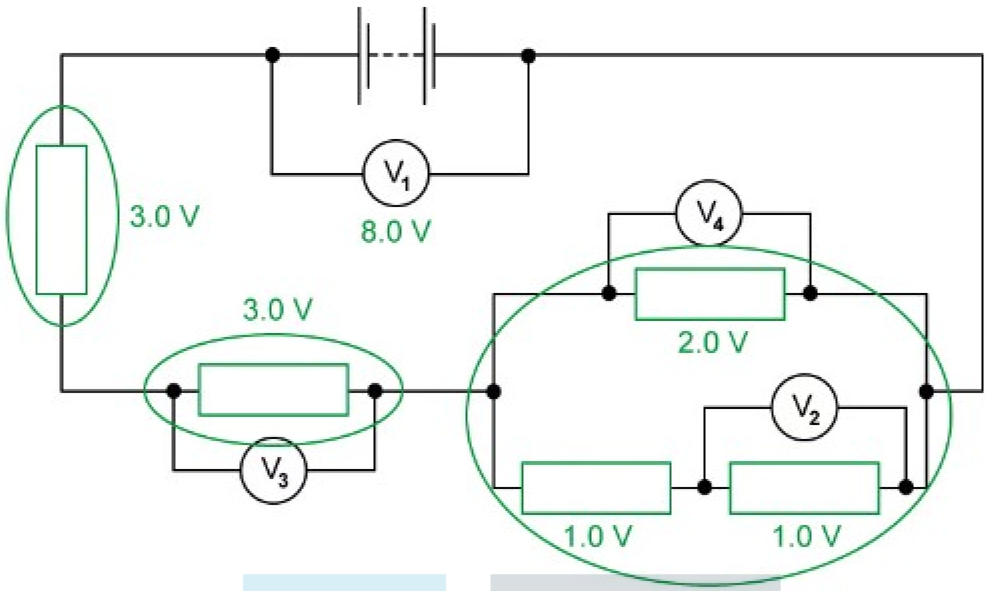
Course	DP IB Physics
Section	5. Electricity & Magnetism
Topic	5.2 Heating Effect of Electric Currents
Difficulty	Medium

To be used by all students preparing for DP IB Physics SL
Students of other boards may also find this useful

1

The correct answer is **B** because:

- Let the resistance of each resistor be *R*
- V_2 = 1.0 V
  - Therefore, the p.d. across the resistor just left of V_2 is also 1.0 V since the resistance is the same and they are in the same branch, so, the same current flows through them both
- So, the total p.d. in the lower branch of the parallel combination is equal to:
  - 0 + 1.0 = 2.0 V
  - The total p.d. across any branch of a parallel combination is the same according to Kirchhoff's Second Law
  - Therefore, V_4 = 2.0 V
- The complete circuit may be described as a series combination of the two single resistors and the parallel combination
- The p.d. across the vertical resistor is the same as V_3 since they have the same resistance and the same current through them, thefore:
  - V_1 = total e.m.f in circuit = 8.0 V
  - The sum of p.d's in any loop is equal to the e.m.f in the circuit
  - $V_3 + V_3 + 2.0 = 8.0$
  - $2V_3 = 6.0$ V
- So, V_3 = 3.0 V



The underlying principle that will help you understand this question is the conservation of charge. Charge is always carried in units of the elementary charge ($e = \pm 1.6 \times 10^{-19}$ C) so since the conducting spheres in this question are identical, when they are brought into contact a **finite** amount of charge will spread evenly across them. The total charge is therefore distributed symmetrically.

2

The correct answer is **B** because:

- From the data booklet:
  - $P = (IR)I = I^2R$
- The power dissipated in **X** is:
  - $P_x = I^2R$
- The power dissipated in **Y** is:
  - $P_y = \left(\frac{1}{2}\right)^2 (2R) = \frac{2I^2R}{4} = \frac{I^2R}{2}$
- Therefore, the ratio:
  - $\frac{power\ dissipated\ in\ Y}{power\ dissipated\ in\ X} = \frac{I^2R}{2} \times \frac{1}{I^2R} = \frac{1}{2}$

A is incorrect as	the resistance in **Y** is twice the resistance in **X** so $P_y = \left(\frac{I}{2}\right)^2 (2R) = \frac{2I^2R}{4} = \frac{I^2R}{2}$ and not $(R) = \frac{I^2R}{4}$
C is incorrect as	the equation is: $\frac{\textit{power dissipated in } \mathbf{Y}}{\textit{power dissipated in } \mathbf{X}}$ and not $\frac{\textit{power dissipated in } X}{\textit{power dissipated in } Y}$
D is incorrect as	the equation is: $\frac{\textit{power dissipated in } \mathbf{Y}}{\textit{power dissipated in } \mathbf{X}}$ and not $\frac{\textit{power dissipated in } X}{\textit{power dissipated in } Y}$ and the resistance in **Y** is twice the resistance in **X**

3

The correct answer is **D** because:

- The cell has an e.m.f., *E*
- The negative terminal of the cell is conventionally taken to be at a potential of 0 V while the positive terminal is taken to be at a potential of *E*
- So, the positive terminal is at a higher potential than the negative terminal
- No component is connected between the positive terminal and point X, so they are at the same potential
- Therefore, point **X** is at potential *E*, while point **Y** is at the same potential as the negative terminal of the cell, so, the potential at **Y** is zero
    - This means we can eliminate graphs **A** and **B**

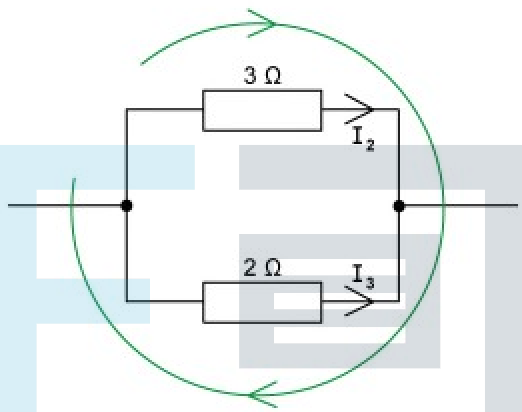
- Ohm's Law states that:
  - $V = IR$
  - Therefore, the p.d. across the 3 Ω resistor must be less than the p.d. across the 6 Ω resistor
- We can write $\frac{\Delta V}{\Delta x}$ = I × $\frac{\Delta R}{\Delta x}$ where $\frac{\Delta V}{\Delta x}$ represents the gradient of the graph, which is the change in potential difference with distance along XY
  - Since we can assume the length of wire in both resistors is the same, Δ is the same across both resistors
  - However, by Ohm's law, ΔV is less across the 3 Ω resistor than it is for the 6 Ω resistor
  - This means the gradient of the line is smaller across the 3 Ω resistor than it is across the 6 Ω resistor
  - This is illustrated in graph **D**

A & B are incorrect as	the potential at point **X** is E and point **Y** is zero so the graph should start at a maximum and decrease to zero
C is incorrect as	Ohm's Law tells us that , so the gradient should be steeper across the 6 Ω resistor and shallower across the 3 Ω resistor

4

The correct answer is **A** because:

- Kirchhoff's loop law (second law) states that $\Sigma V = 0$ where $V = IR$
  - Inside the dotted loop, there are two potential differences across the 3 Ω resistor and the 2 Ω resistor
- We can choose a clockwise direction around the loop as shown:



  - The voltage is therefore negative across the 3 Ω resistor
  - The voltage is therefore positive across the 2 Ω resistor
- Following this clockwise direction, the corresponding loop equation is $0 = -3I_2 + 2I_3$ or $0 = 2I_3 - 3I_2$

B is incorrect as	the potential difference through the 3Ω resistor is $3I_2$ and not $3I_3$ the potential difference through the 2Ω resistor is $2I_3$ and not $2I_2$
C is incorrect as	current I_1 is not inside the dotted loop
D is incorrect as	the currents are going in opposite directions, so one is positive and the other negative

Recall the rules for signs of voltages when applying Kirchhoff's loop law. It does not matter what direction you choose, as long as you are consistent, namely:

- Moving in the same direction as current across a component means the voltage can be taken as **negative** (i.e., a potential difference 'drop')
- Moving in the opposite direction to current across a component means the voltage can be taken as **positive** (i.e., a potential difference 'gain')

Check that you get the same equation for the dotted in loop in this question if the chosen direction within the loop is **anticlockwise**. This would mean the voltage across the 2 Ω resistor is negative (i.e., $V = -2I_3$) and the voltage across the 3 Ω resistor is positive (i.e., $V = +3I_2$).

5

The correct answer is **D** because:

- The potential divider equation says $V_{out} = \epsilon \times \frac{R_1}{R_1 + R_2}$
    - We can set ϵ = 15 V and R_1 as the resistor across which the output potential difference V_{out} is measured
- Therefore, when the variable resistor is set to a maximum resistance R_2 = 12 Ω:
    - $V_{out} = 15 \times \frac{3}{3 + 12} = 3$ V
- When the variable resistor is set to a minimum resistance R_2 = 0 Ω:
    - $V_{out} = 15 \times \frac{3}{3 + 0} = 15$ V
- Therefore, the range of potential differences across the 3 Ω resistance is 15 – 3 = 12 V

A is incorrect as	this is V_{out} at 12 Ω and not the range of potential differences
B is incorrect as	this is V_{out} at 12Ω + V_{out} at 12 Ω and not the range of potential differences
C is incorrect as	this is V_{out} at 0 Ω and not the range of potential differences

6

The correct answer is **A** because:

- The 8 Ω resistors are connected in parallel
  - Therefore, the effective resistance can be calculated as $\frac{1}{R_T} = \frac{1}{8} + \frac{1}{8} = \frac{2}{8}$
  - Hence, the effective resistance at this point in the circuit $R_T = \frac{8}{2} = 4$ Ω
- Therefore, the 2 Ω resistor is in series with an effective resistor of 4 Ω
  - Since they are in series, they can be combined into another effective resistance $R_T = 2 + 4 = 6$ Ω
- This 6 Ω effective resistance is in parallel with the 6 Ω resistor, so the total resistance in the circuit is calculated by:
  - $\frac{1}{R_T} = \frac{1}{6} + \frac{1}{6} = \frac{2}{6}$
  - So, $R_T = \frac{6}{2} = 3$ Ω

- This is the total resistance in a circuit with e.m.f., $\epsilon = 6$ V
  - Therefore, the current in the battery $I = \frac{\varepsilon}{R} = \frac{6}{3} = 2$ A

Practice identifying where resistors can be combined into effective resistances, e.g., by identifying parallel and series networks. This circuit can be simplified in the following steps, sketched out below:

7

The incorrect answer is **B** because:

- The equation for resistivity is:
  - $\rho = \frac{RA}{L}$
- Using dimensional analysis (i.e., analysing the units):
  - $[\rho] = \frac{[R][A]}{[L]} = \frac{\Omega\, m^2}{m} = \Omega$ m
  - Therefore, option **D** is a possible unit (the standard unit!) of resistivity
- We can use the other electricity equations to provide substitutions for these units:
  - $[V] = [I][R] \rightarrow$ V = A Ω
  - $[Q] = [I][t] \rightarrow$ C = A s
  - $[V] = \frac{[W]}{[Q]} \rightarrow$ V = J C^{-1}
- From the above equations, we get:
  - $\Omega = \frac{V}{A}$
  - Hence, substituting this into $[\rho] = \frac{\Omega\, m^2}{m} = \frac{V\, m^2}{A\, m} = \frac{V\, m}{A} = \frac{J\, m}{C\, A} = \frac{J\, m}{A^2 s}$ = J m s^{-1} A^{-2}
  - Therefore, option **B** must be incorrect

A is incorrect as	$[\rho] = \frac{V\ m}{A} = \text{V m A}^{-1}$
C is incorrect as	$[\rho] = \text{J m s}^{-1}\text{A}^{-2}$
D is incorrect as	$[\rho] = \frac{[R][A]}{[L]} = \frac{\Omega\ m^2}{m} = \Omega\ \text{m}$

You must read this question carefully as it asks which statement is incorrect.

8

The correct answer is **D** because:

Method 1: Power Equation

- Use the equation for power $P = I^2R$
- First, consider the whole circuit:
  - V = e.m.f. = 10 V
  - $R_T = (\frac{1}{2} + \frac{1}{2}) + 4 = 5\ \Omega$
- Use Ohm's Law to calculate the current in the whole circuit:
  - $I = \frac{V}{R} = \frac{\text{e.m.f.}}{R_T} = \frac{10}{5} = 2$ A
- So, $P = I^2R = 2^2 \times 5 = 4 \times 5 = 20$ W
- Now, consider the power across a 2 Ω resistor:
  - The 2 A are split evenly between the paths because the resistors are the same size.
  - So, 1 A of current passes through a 2 Ω resistor

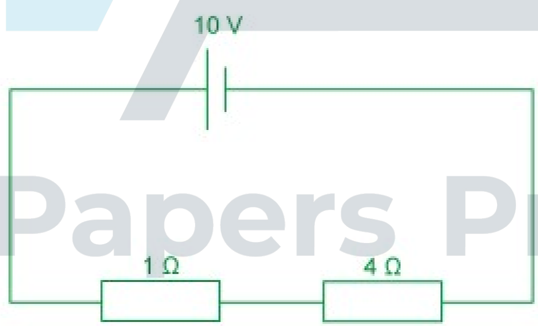
- Use the equation for power, $P = I^2R = 1^2 \times 2 = 1 \times 2 = 2$ W

- So, the correct answer is option **D**

Method 2: Potential Divider Equation

- Power $P = \frac{V^2}{R}$
  - The 2 Ω resistors are in parallel with each other, so their effective resistance R_T can be calculated by $= \frac{1}{2} + \frac{1}{2} = 1$
  - Hence, $R_T = 1$ Ω

- This effective resistor is in series with the 4 Ω resistor, such that the circuit is a potential divider as shown below:



- Hence using the potential divider equation $V_{out} = V_{in} \times \frac{R_1}{R_1 + R_2}$
  - We can set $V_{in} = 10$ V and choose $R_1 = 1$ Ω and $R_2 = 4$ Ω
  - Then the potential difference across the 1 Ω effective resistor $V_{out} = 10 \times \frac{1}{5} = 2$ V
- This is the potential difference across each of the 2 Ω resistors which form the effective resistance, since they are in parallel
  - Therefore, the power dissipated across one of them, $P = \frac{2^2}{2} = 2$ W

- We can apply Kirchhoff's loop law (second law) to the potential divider circuit:
  - Total, p.d. $\Sigma V = 0$
  - Hence, $0 = 10 - 2 - V$ (where V is the potential difference across the 4 Ω resistor)
  - $V = 10 - 2 = 8$ V
- Hence, the power dissipated across the 4 Ω resistor $P = \frac{8^2}{4} = 16$ W
- There are two 2 Ω resistors, each dissipating a power of 2 W:
  - Therefore, the total power dissipated in the circuit $P = (2 \times 2) + 16 = 20$ W
  - So, the correct answer is option **D**

A is incorrect as	the resistance across $R_1 = 1$ Ω. This is not the same as the power across the resistor which is 2 W there are two 2 Ω resistors, each dissipating a power of 2 W and not just one, so total power dissipated in the circuit $P = (2 \times 2) + 16 = 20$ W and not $P = (1 \times 2) + 16 = 18$ W
B is incorrect as	the resistance across $R_1 = 1$ Ω. This is not the same as the power across the resistor which is 2 W
C is incorrect as	there are two 2 Ω resistors, each dissipating a power of 2 W and not just one, so total power dissipated in the circuit $P = (2 \times 2) + 16 = 20$ W and not $P = (1 \times 2) + 16 = 18$ W

9

The correct answer is **C** because:

- When the switch is opened, the loop containing lamp W and lamp X is not a complete circuit
- However, the loop containing lamp W and lamp Y is a complete circuit
    - Therefore, we can eliminate option **A** and option **D** since lamp X must be off when the switch is open
- When the switch is closed, lamp X and Y are in parallel with each other
    - Therefore, removing lamp X from the circuit by opening the switch increases the overall resistance of the circuit
    - Hence, the overall current in the circuit decreases
- We know each of the lamps are identical, hence, they each have the same resistance *R*
    - Therefore, the power dissipated in lamp W, $P = I^2R$ must decrease since the resistance stays constant but the current through it decreases
    - Hence, the brightness across lamp W must decrease
- Opening the switch will also increase the potential difference across lamp Y
    - Hence, the power dissipated in lamp Y, $P = \frac{V^2}{R}$ will increase, since the resistance stays constant
    - Hence, the brightness across lamp Y will increase
- Therefore, the correct answer is **C**

A is incorrect as	lamp **X** is off when the switch is open, as the circuit for this lamp is no longer complete
B is incorrect as	the brightness of lamp **Y** will increase when the switch is opened because the current is no longer split between the two parallel branches
D is incorrect as	lamp **X** is off when the switch is open, as the circuit for this lamp is no longer complete

This question requires you to slowly eliminate the different options until you are left with the correct one.

10

The correct answer is **C** because:

- The power rating on devices is correct for the country / mains voltage where they are sold
  - Therefore the power dissipated in the UK is the same as the value written on the bulb
  - Only **B** or **C** can be correct
- To find the power dissipated when using a different voltage, use the equation $P = \frac{V^2}{R}$
- Since the same bulb is being used, *R* is constant, therefore set up a ratio to compare the UK and Canada
  - $\frac{V_{uk}^{\ 2}}{P_{uk}} = \frac{V_c^{\ 2}}{P_c}$ therefore $\frac{240^2}{60} = \frac{100^2}{P_c}$
- Power dissipated in Canada, P_c = 10.42 W