5.3 Electric Cells

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Course	DP IB Physics
Section	5. Electricity & Magnetism
Topic	5.3 Electric Cells
Difficulty	Medium

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

1

The correct answer is **C** because:

- A charge of 240 C flows through the resistor in a time of 2 minutes = 120 s
- Calculating current:
  - $I = \frac{\Delta Q}{\Delta t} = \frac{240}{120} = 2$ A
- Power dissipated $P = I^2R$ and power is defined as the rate of transfer of energy
  - Therefore, energy $E = P \times t = I^2R \times t$
  - So, $1440 = (2)^2 R \times 120$
  - Hence, $R = \frac{1440}{(2)^2 \times 120} = \frac{12}{480} = 3\ \Omega$
- The emf of a circuit $\epsilon = I(R + r) = 9.0$ V
  - Therefore, the total resistance in the circuit $(R + r) = \frac{9.0}{I} = \frac{9.0}{2} = 4.5\ \Omega$
- Therefore, since $R = 3$
  - $3 + r = 4.5$
  - Therefore $r = 4.5 - 3 = 1.5\ \Omega$

A is incorrect as	this is the resistance of the resistor and not the internal resistance of the e.m.f.
B is incorrect as	this is the current in the circuit and not the internal resistance of the e.m.f.
D is incorrect as	this is the total resistance in the circuit and not the internal resistance of the e.m.f.

The power dissipated is the energy per time from Power = $\frac{Energy}{Time}$. Look carefully that the units 1440 is measured in J, so to calculate the energy use Energy = Power × Time.

2

The correct answer is **D** because:

- The electromotive force ϵ is defined as the work done per unit charge in moving charge from one terminal of the battery to the other
  - The work, or energy transferred, between terminals is chemical
- The electromotive force can be written as:
  - $\epsilon = \frac{W}{Q}$ such that the energy transferred (or work done) $W = \epsilon Q$
- However, this chemical energy is deliverable as electrical energy to both the load resistance and the internal resistance
- Therefore, ϵQ is equal to the total energy dissipated in the battery due to the internal resistance as well is externally (the load resistance)

A is incorrect as	the work done around the circuit is not chemical, it is electrical, and is equal to VQ, where V is the terminal potential difference
B is incorrect as	the work done between the terminals is not electric, it is chemical
C is incorrect as	the load resistance is usually given the symbol R. ϵQ is a quantity of energy, not resistance

Read each of the answer options carefully and don't just jump to a conclusion without considering them all!

3

The correct answer is **A** because:

- There are two unknowns, so we must set up two unique simultaneous equations
- The emf $\epsilon = I(R + r) = V + Ir$ where V is the terminal potential difference
  - Therefore, when V = 5.0 V and I = 1.0 A, $\epsilon = 5 + r$ (equation 1)
  - When V = 4.0 V and I = 1.5 A, $\epsilon = 4 + 1.5r$ (equation 2)
- Equating the two equations to eliminate ϵ gives:
  - $5 + r = 4 + 1.5r$
  - $1 = 0.5r$
  - Therefore, $r = \frac{1}{0.5} = 2.0\ \Omega$
- Using this value for r in equation 1 gives:
  - $\epsilon = 5 + 2 = 7.0$ V

B is incorrect as	The internal resistance $r = 2\ \Omega$ because $1 = 0.5r$ so, $\frac{1}{0.5} = 2.0\ \Omega$ and not $0.5\ \Omega$
C is incorrect as	$\epsilon = 5 + 2 = 7.0$ V and not $\epsilon = 5 - 2 = 3.0$ V
D is incorrect as	The internal resistance $r = 2\ \Omega$ because $1 = 0.5r$ so, $\frac{1}{0.5} = 2.0\ \Omega$ and not $0.5\ \Omega$ $\epsilon = 5 + 2 = 7.0$ V and not $\epsilon = 5 - 2 = 3.0$ V

If there are **two** unknowns in each question, don't panic! This is a huge flag that you are required to set up **two** simultaneous equations and solve them. In more extended questions, you may even sometimes have **three** unknowns – but as you might expect, this just means you then need to set up **three** unique simultaneous equations and perform a bit more algebra to manipulate and solve them. Anytime you have the same number of unknowns as you have equations – think simultaneous equations!

4

The incorrect statement is **B** because:

- The lifetime of a cell depends on the current drawn from it, not on the amount of charge it stores (a measure of the cell's capacity)
- A cell's capacity can be measured by drawing a constant current until it is discharged
  - The charge delivered during the time it takes to fully discharge is the cells capacity

A is correct as	capacity can be measured by drawing a constant current from a cell until it is discharged. The area under the corresponding current-time graph, which would be the total charge delivered, is a measure of the cell's capacity. A larger current would reduce the lifetime of the cell, not its capacity
C is correct as	larger currents discharge cells more quickly, because cells can only deliver a finite amount of charge to a circuit over its lifetime (its capacity)
D is correct as	the internal resistance of a cell gradually increases over a cell's lifetime, due to several factors, including chemical and structural degradation of the terminals

5

The correct answer is **A** because:

- The cell emf $\epsilon = I(R + r)$
  - Therefore, this can be rearranged into the form of a straight line
  - $I = \frac{\varepsilon}{R + r}$ hence $\frac{1}{I} = \frac{R + r}{\varepsilon} = \frac{R}{\varepsilon} + \frac{r}{\varepsilon}$
  - If $y = mx + c$, then $\frac{1}{I}$ on the y-axis and R on the x-axis is a straight line with a gradient equal to $\frac{1}{\varepsilon}$

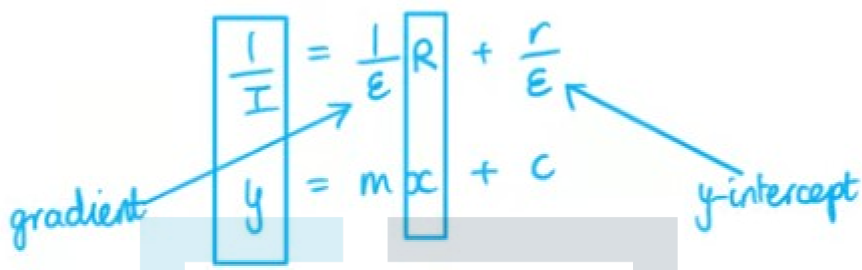
B is incorrect as	$I = \frac{\varepsilon}{R + r}$ so $\frac{1}{I} = \frac{R + r}{\varepsilon} = \frac{R}{\varepsilon} + \frac{r}{\varepsilon}$ and not $\frac{1}{R}$. R is a quantity on the x-axis, so it is not possible to have a straight-line graph with a gradient of $\frac{1}{quantity}$
C is incorrect as	$I = \frac{\varepsilon}{R + r}$ so $\frac{1}{I} = \frac{R + r}{\varepsilon} = \frac{R}{\varepsilon} + \frac{r}{\varepsilon}$ and not $\frac{1}{r}$
D is incorrect as	$I = \frac{\varepsilon}{R + r}$ so $\frac{1}{I} = \frac{R + r}{\varepsilon} = \frac{R}{\varepsilon} + \frac{r}{\varepsilon}$ and not r

You should be comfortable, for the Standard Level Diploma Programme, with recognising linear equations and rearranging them so that they match a given graph. The method for this question is sketched out in more detail below:

$$\varepsilon = I(R + r)$$

$$I = \frac{\varepsilon}{R + r}$$

$$\frac{1}{I} = \frac{R + r}{\varepsilon} = \frac{R}{\varepsilon} + \frac{r}{\varepsilon}$$



6

The correct answer is **D** because:

- Applying Kirchhoff's loop law, starting at the negative terminal of the primary cell and moving round the circuit anticlockwise:
  - $\Sigma V = 0 = 10 - 4I - 2 - 4I$
  - Therefore, $0 = 8 - 8I$
  - $8I = 8$ so $I = 1$ A
- This means statement C is incorrect
- The power of an emf, ε is given by $P = \epsilon I$
  - Therefore, the power generated by the primary battery $P = 10 \times 1 = 10$ W
  - The power stored in the secondary battery $P = 2 \times 1 = 2$ W
- This means statement B is incorrect, and:
  - Since $\frac{2}{10} = 0.2 = 20\%$, statement D is correct

A is incorrect as	primary cells are not rechargeable, only secondary cells are charged from the primary cell
B is incorrect as	this is not true. The power generated in the primary cell is not equal to the power stored in the secondary cell
C is incorrect as	the current in the circuit is 1 A as shown

You should remember that primary cells can only be used once (until it runs out). Therefore, statement A is incorrect. Secondary batteries are rechargeable and can be reused.

7

The incorrect statement is **C** because:

- An ideal battery is one for which the internal resistance is zero
- Hence, since $\epsilon = I(R + r) = V + Ir$, where V is the terminal potential difference, I is the current and r is the internal resistance,
    - If the internal resistance is zero, then the terminal potential difference (i.e., that which is measurable) would be exactly equal to the emf ϵ

A is correct as	non-ideal batteries have internal resistance. Hence, the terminal pd $V = \epsilon - Ir$, and so is always less than the emf ϵ
B is correct as	$V = \epsilon - Ir$. Hence, if the current $I = 0$, then $V = \epsilon$
D is correct as	the terminal potential difference for non-ideal batteries decreases with time as current is drawn from it, due to the battery's internal resistance

8

The incorrect answer is **C** because:

- The internal resistance of a cell must have units equivalent to the ohm, Ω
  - $[R] = \Omega = \frac{[V]}{[I]} = \text{V A}^{-1}$
  - Therefore, option A is correct
- The Volt, V is defined by the equation $V = \frac{W}{q}$:
  - $[V] = \text{V} = \frac{[W]}{[q]} = \text{J C}^{-1}$
  - Since $[Q] = [I][t]$, then C = A s
  - Substituting this into $\Omega = \text{V A}^{-1} = (\text{J C}^{-1})\,\text{A}^{-1} = \text{J}\,(\text{A}^{-1}\,\text{s}^{-1})\,\text{A}^{-1}$
  - Therefore, $\Omega = \text{J s}^{-1}\,\text{A}^{-2}$ so option B is correct
- The Joule, J is defined by the equation $W = Fd$:
  - $[W] = [F][d] = \text{N m}$
  - Since $[F] = [m][a]$ then $[\text{F}] = \text{N} = \text{kg m s}^{-2}$
  - Substituting this into $[W] = \text{J} = \text{N m} = (\text{kg m s}^{-2})\,\text{m} = \text{kg m}^2\,\text{s}^{-2}$
  - Therefore, $\Omega = (\text{kg m}^2\,\text{s}^{-2})\,\text{s}^{-1}\,\text{A}^{-2} = \text{kg m}^2\,\text{A}^{-2}\,\text{s}^{-3}$
- Therefore, option D is correct
  - So, option C cannot be units for internal resistance

Make sure you read this question carefully. It says incorrect and not correct. Do not just start and then assume A is correct.

9

The correct answer is **B** because:

- The terminal potential difference V_X and V_Y can be written in terms of the emf ϵ:
  - Treating the circuit as a potential divider, with the 3 Ω resistor in series with the internal resistance r = 0.5 Ω, then $V_X = \epsilon \times \frac{R}{R + r} = \frac{1.5 \times 3}{3 + 0.5} = \frac{9}{7}$
  - Similarly, $V_Y = \epsilon \times \frac{R}{R + r} = \frac{3 \times 1.5}{3 + 2} = \frac{9}{10}$
  - Therefore, $V_X > V_Y$ since the denominator is smaller for V_X
- The power dissipated across the resistor, P_X and P_Y, can be written in terms of the terminal potential differences V_X and V_Y:
  - $P_X = \frac{V_X^2}{R} = \frac{V_X^2}{3}$
  - $P_Y = \frac{V_Y^2}{R} = \frac{V_Y^2}{3}$
  - Since $V_X > V_Y$, $P_X > P_Y$
  - Therefore, row B is correct

A is incorrect as	the power is greater in X than in Y. Consider the equation for power, $P = IV$ then if V is greater then P will also be greater.
C is incorrect as	both the power and potential difference are greater in X than in Y, as $V_X > V_Y$ as $\frac{9}{7} > \frac{9}{10}$ and consider the equation for power, $P = IV$ then if V is greater then P will also be greater.

D is correct as	the potential difference is greater in X than in Y, as $V_X > V_Y$ as $\frac{9}{7} > \frac{9}{10}$

10

The correct answer is **D** because:

- The terminal potential difference $V = \epsilon - Ir$
  - If the resistance R decreases, then current in the circuit increases
  - Therefore, the terminal potential difference V decreases as well
  - The power dissipated in the cell (that is, across the internal resistance) $P = I^2r$, which therefore becomes large
- Hence, statement (1) is correct
- If the resistance R is made very large, this causes a very small current in the circuit
  - The power supplied by the cell $P = \epsilon I = I^2(R + r) = I^2R + I^2r$
  - The power dissipated by the resistor R is given by the term I^2R, which dominates since R is now very large
  - Therefore, most of the power supplied by the cell is dissipated across the resistor R
- Hence, statement (2) is correct
- If the resistance of R is made very small, then the current in the circuit will increase
  - Hence, the charge delivered by the cell (its capacity) will rapidly deplete, resulting in a shorter lifetime

Walking through each step in this question is useful practise for you to understand the difference components of a circuit, in terms of the external (or load) resistance R and the internal resistance r. Imagining these as two distinct components, over which power supplied by the emf of the cell is dissipated, is very good exam technique.