JENN Training and Consultancy
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Province of the EASTERN CAPE EDUCATION

PHYSICAL SCIENCES

2025 SPRING SCHOOL

GRADE 12

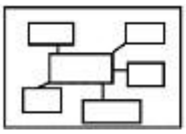
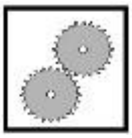
GUIDE FOR TEACHERS AND LEARNERS

PHYSICAL SCIENCES PROGRAMME FOR 2025 WINTER CLASSES

PAPER	TOPICS	TOTAL MARKS	WEIGHTING
WEEK 1 AND WEEK 2			
PHYSICS (PAPER 1)	Electric Circuits		
CHEMISTRY (PAPER 2)	Electrochemistry		
TOTAL			
Pre-test and Post-test to be administered since it's a revision of Term 1 & 2.			

CONTENTS PAGE

ICON DESCRIPTION

 MIND MAP	 EXAMINATION GUIDELINE	 CONTENTS	 ACTIVITIES
 BIBLIOGRAPHY	 TERMINOLOGY	 WORKED EXAMPLES	 STEPS

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SUBJECT: SUBJECT NAME

GRADE 12

2025 SPRING CLASSES

TEACHER AND LEARNER CONTENT MANUAL

Topic(s)

Electric Circuits

Electric Circuits

Examination guideline

Electric Circuits
(This section must be read in conjunction with the CAPS, p. 88–89 & 121.)

Ohm's law

- State Ohm's law in words: The potential difference across a conductor is directly proportional to the current in the conductor at constant temperature.
- Determine the relationship between current, potential difference and resistance at constant temperature using a simple circuit.
- State the difference between ohmic conductors and non-ohmic conductors and give an example of each.
- Solve problems using $R=\frac{V}{I}$ for series and parallel circuits (maximum four resistors).

Power, energy

- Define *power* as the rate at which work is done.
- Solve problems using $P = \frac{W}{\Delta t}$
- Solve problems using $P = VI$, $P = I^2R$ or $P = \frac{V^2}{R}$
- Solve circuit problems involving the concepts of power and electrical energy.
- Deduce that the kilowatt hour (kWh) refers to the use of 1 kilowatt of electricity for 1 hour.
- Calculate the cost of electricity usage given the power specifications of the appliances used, the duration and the cost of 1 kWh.

Internal resistance, series and parallel networks

- Solve problems involving current, voltage and resistance for circuits containing arrangements of resistors in series and in parallel (maximum four resistors excluding internal resistance).
- Define the term *emf* as the maximum energy provided by a battery per unit charge passing through it.
- Solve circuit problems using $\varepsilon = V_{load} + V_{internal\ resistance}$ or $\varepsilon = IR_{ext} + Ir$.
- Solve circuit problems, with internal resistance, involving series-parallel networks of resistors (maximum four resistors).

TERMS AND DEFINITIONS

TERMS AND DEFINITIONS	
Ohm's law	The potentiaL difference across a conductor is directly proportional to the current in the conductor at constant temperature. In symbols: R $=\frac{V}{I}$ The units: $\Omega = V \cdot A^{-1}$
Emf	Maximum energy provided / amount of work done by a battery per coulomb/unit charge passing through it. (It is the potential difference across the ends of a battery when there is NO current in the circuit.)
Terminal potential difference	The energy transferred to or the work done per coulomb of charge passing through the battery when the battery delivers a current. (It is the potential difference across the terminals of a battery when there IS a current in the circuit.)
Ohmic conductors	A conductor that obeys Ohm's law, i.e., the ratio of potential difference to current remains constant. (Resistance of the conductor remains constant.)
Non-ohmic conductors	A conductor that does NOT obey Ohm's law, i.e., the ratio of potential difference to current does NOT remain constant. (Resistance of the conductor increases as the current increases, e.g. a bulb.)
Potential difference	Potential difference is the amount of work done (or energy transferred) per coulomb of charge. It is measured in volt (V). In symbols: V $=\frac{W}{Q}$ The units: $V = J \cdot C^{-1}$
Current	Current is the rate of flow of charge. It is measured in ampere (A). In symbols: I $=\frac{Q}{\Delta t}$ The units: $A = C \cdot s^{-1}$
Resistance	Resistance is the opposition to the flow of charge (electric current). It is measured in ohm (Ω) and can be calculated by using the ratio of potential difference (V) to current (I). In symbols: R $=\frac{V}{I}$ The units: $\Omega = V \cdot A^{-1}$
Resistors in series	The total resistance of resistors in series is given by: $R_T = R_1 + R_2 + \cdots$ OR $R_S = R_1 + R_2 + \cdots$
Resistors in parallel	The effective resistance (do NOT use the word "total") of resistors in parallel is given by: $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$
Internal resistance	The resistance within a battery that causes a drop in the potential difference across the battery when there is a current in the circuit.
Power	Power is the rate at which work is done or rate at which energy is transferred. It is measured in watt (W). In symbols: P $=\frac{W}{\Delta t}$The units: $W = J \cdot s^{-1}$
	Other formulae for power: $P = VI$ $P = I^2R$ $P = \frac{V^2}{R}$

kilowatt hour (kWh) (This is an energy unit related to the formula $W = P\Delta t$.)	It is the use of 1 kilowatt of electricity for 1 hour.	
Other energy formulae (electric circuits)	$W = VQ$ $W = VI\Delta t$	$W = I^2R\Delta t$ $W = \frac{V^2}{R}\Delta t$

CONTENT

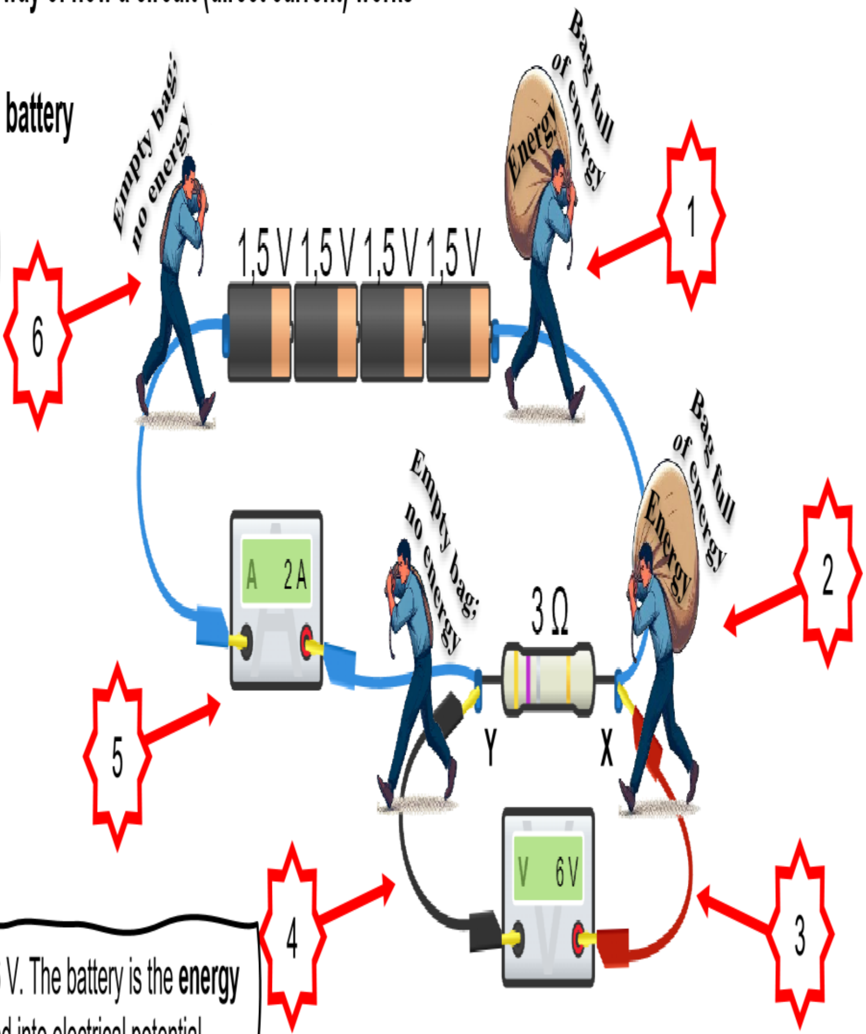
A simple way of how a circuit (direct current) works

Example 1: One resistor is connected in series with the battery

Read this first to understand the idea of the picture.

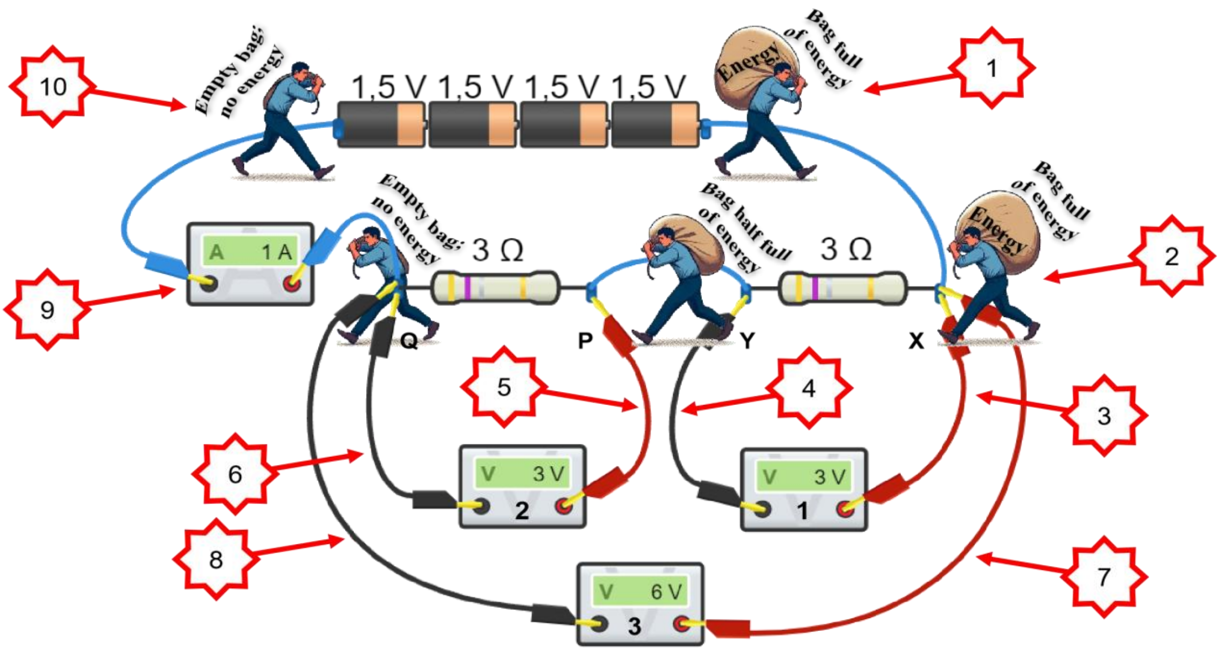
In this example, **one coulomb of charge** is represented by the **picture of the man**. He carries a bag initially filled with **energy**. The **same man** is represented at **different positions** in the circuit. Only ONE coulomb is represented here, but there are millions of charges behind and in front of this one doing the same things described in this example.

Follow the numbers below and study what happens in the circuit.



Each cell's emf is 1,5 V. For four cells (the battery), the emf is 6 V. The battery is the **energy factory**. Chemical potential energy of the chemicals is converted into electrical potential energy and the **charges are transporting the energy** to the resistor in the circuit.

Example 2: <u>Two</u> resistors are <u>connected in series</u> with the battery



1 **1.One coulomb** of charge leaves the battery with the **maximum amount of energy**. In this case it is 6 J·C^{-1} because the emf of the battery is 6 V.

2. This coulomb of charge arrives at the first resistor with 6 J of energy. If there are **more than one resistor in series**, the charges must **transfer energy to EACH of the resistors**. The amount of energy transferred depends on each resistor's resistance. In this example, the resistances are the same; hence, each one gets half of the energy.

3.Voltmeter 1 measures 6 J·C^{-1} at **X before** the energy is transferred to the resistor. Half of this energy is transferred to the first resistor. Hence, there is 3 J·C^{-1} of energy left.

4.Voltmeter 1 measures 3 J·C^{-1} at **Y after** the energy was transferred.

The reading on voltmeter 1 = reading at **X** - reading at **Y** = 6 J·C^{-1} - 3 J·C^{-1} = 3 J·C^{-1} = 3 V

5.The coulomb of charge flows further and reaches the second resistor where the remaining energy is transferred to the resistor. Voltmeter 2 measure 3 J·C^{-1} at **P before** the energy is transferred to the resistor. It is the same reading as at **Y** because no energy is transferred to the conductors.

6.Voltmeter 2 measures 0 J·C^{-1} at **Q after** the energy was transferred.

The reading on voltmeter 2 = reading at **P** - reading at **Q** = 3 J·C^{-1} - 0 J·C^{-1} = 3 J·C^{-1} = 3 V

7.Voltmeter 3 is connected **across BOTH resistors**. It therefore measures the amount of energy at **X** and **Q**. At **X** it measures 6 J·C^{-1}. All the energy is transferred to both resistors.

8.Voltmeter 3 measures 0 J·C^{-1} at **Q after** the energy was transferred.

The reading on voltmeter 3 = reading at **X** - reading at **Q** = 6 J·C^{-1} - 0 J·C^{-1} = 6 J·C^{-1} = 6 V

Note that the reading on voltmeter 3 is equal to the sum of the readings on voltmeters 1 and 2.

9.The charges flow **through** the ammeter. If one coulomb of charge flows through the ammeter in one second, the current is:

$I = \frac{Q}{\Delta t} = \frac{1}{1} = 1\,C \cdot s^{-1} = 1\,A.$

10.The coulomb of charge returns to the battery where the bag is again filled with energy and the process is then repeated for this coulomb of charge until the battery is flat.

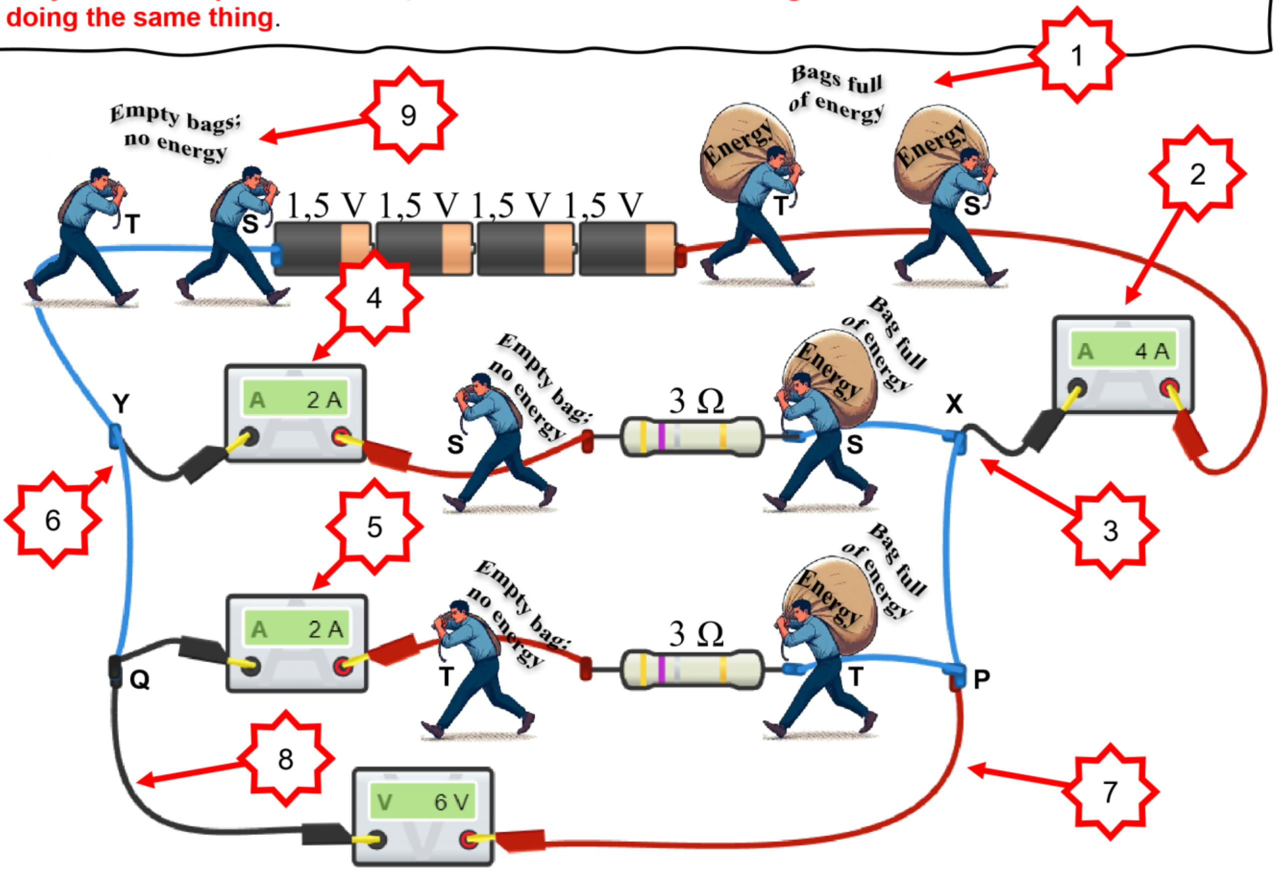
Note once again that:

- Each voltmeter measures the **potential difference at TWO points**.
- The voltmeter reading represents the energy per coulomb of charge transferred to the resistor that is **connected between its wires**. This is important. **The reading on any voltmeter is only applicable to the resistor(s) connected between its wires while charges are flowing**.

- All three **voltmeters** are connected in **parallel** with the resistors.
- **There is no change in the charges** itself. It is **only the energy that is transferred** to the resistor.
- The charges flow **through** the ammeter and the latter measures the current **at the point where it is connected**.

Example 3: Two resistors are connected in parallel with the battery

In this example, we look at **two coulomb of charge**, **each one** represented by the **picture of the man**. **Only TWO are represented here, but there are millions of charges behind and in front of those doing the same thing**.



1 **Each coulomb** of charge, labelled **S** and **T**, leaves the battery with the **maximum amount of energy**. In
   a. each case it is 6 J·C^{-1} because the emf of the battery is 6 V.
2. Both coulombs of charge flow **through** this ammeter because it is the **only path** for them to follow. This is what is called the **main current** of the circuit. If, for example, four coulomb of charge flows through this ammeter in one second, the **main current** I = $\frac{Q}{\Delta t} = \frac{4C}{1S} = 4A$
3. At point **X**, the main current splits into **two branch currents**. One branch is represented by **XY** and the other branch by **XPQY**. Some of the coulombs of charge (labelled **S**) flow through branch **XY** and the others (labelled **T**) flow through branch **XPQY**. **The ratio in which the main current splits into two branch currents depend on the ratio of the resistors in the branches.** In **this example** the **resistances** are **equal**; hence the main current splits into **two equal branch currents**.
4. This ammeter measures the current in branch **XY** only. Hence, it measures 2 A if the main current is 4 A with equal branch resistances.
5. This ammeter measures 2 A, which is the current in branch **XPQY**.
6. 2,4&5 **Very important: The sum of the two branch currents is equal to the main current**.
7. At point **Y**, the two branch currents combine again to form the main current.

Note that the voltmeter is connected across both resistors because they are connected in parallel.

1. The wire of the voltmeter is connected at **P**, but the reading on the voltmeter is also valid for **X** because there is just another wire between **P** and **X**. The coulomb of charge labelled **S** arrives at the resistor in branch **XY** with 6 J of energy. Hence, the voltmeter measures 6 J·C^{-1} at **X before** the energy is transferred to the resistor.
2. The voltmeter measures 0 J·C^{-1} at **Y after** the energy was transferred to the single resistor in branch **XY**.
3. The coulomb of charge labelled **T** arrives at the resistor in branch **XPQY** with 6 J of energy. Hence, the voltmeter also measures 6 J·C^{-1} at **P before** the energy is transferred to the resistor.
4. For branch **XPQY**, the voltmeter measures 0 J·C^{-1} at **Q after** the energy was transferred to the single resistor in branch **XPQY**.
    a. The reading on the voltmeter = reading at **P** (or **X**) - reading at **Q** (or **Y**)
5. = 6 J·C^{-1} - 0 J·C^{-1} = 6 J·C^{-1} = 6 V
6. **Very important: The reading on the voltmeter is the same for both resistors.**
7. The two coulombs of charge return to the battery where new energy is obtained from the battery and the process is then repeated until the battery is flat.
8. Let's confirm the readings on the ammeters and voltmeters in the three examples and make some important conclusions about the use of formulae.

Example 1

Known data is: emf = 6 V; external resistor = 3 Ω; internal resistance = 0 Ω

To calculate the reading on the ammeter, which is the total (main) current in the circuit:

$$R_{total} = \frac{V_{emf}}{I_{total}}$$

$$3 = \frac{6}{I_{total}}$$

$$I_{total} = 2\,A$$

The three variables deal with the **same situation** . The **total** resistance, the **total** current and the **emf**, which is the "maximum" potential difference.

To calculate the reading on the voltmeter, which is the potential difference across the specific resistor:

$$R = \frac{V}{I_{total}}$$

$$3 = \frac{V}{2}$$

$$V = 6\,V$$

Once again, the three variables deal with the **same situation** . The **specific** resistance, the current in **that** resistor and the potential difference across the **specific** resistor.

Example 2

Known data is: emf = 6 V; each external resistor = 3 Ω and they are connected in series; internal resistance = 0 Ω

To calculate the reading on the ammeter, which is the total (main) current in the circuit:

$$R_T = R_1 + R_2$$
$$= 3 + 3$$
$$= 6\ \Omega$$

$$R_T = \frac{V_{emf}}{I_{total}}$$
$$6 = \frac{6}{I_{total}}$$
$$I_{total} = 1\ A$$

The three variables in $R = \frac{V}{I}$ deal with the **same situation**. The **total** resistance, the **total** current and the **emf**.

To calculate the reading on voltmeter 1, which is the potential difference across **one** of the resistors:

$$R = \frac{V_1}{I_{total}}$$
$$3 = \frac{V_1}{1}$$
$$V_1 = 3\ V$$

The three variables deal with the **same situation**. The **specific** resistance, the current in **that** resistor and the potential difference across the **specific** resistor.

To calculate the reading on voltmeter 2, which is the potential difference across **one** of the resistors:

$$R = \frac{V_2}{I_{total}}$$
$$3 = \frac{V_2}{1}$$
$$V_2 = 3\ V$$

The three variables deal with the **same situation**. The **specific** resistance, the current in **that** resistor and the potential difference across the **specific** resistor.

To calculate the reading on voltmeter 3, which is the potential difference across **both** resistors:

$$R_T = \frac{V_3}{I_{total}}$$
$$6 = \frac{V_3}{1}$$
$$V_3 = 6\ V$$

The three variables deal with the **same situation**. The **total** resistance is used, the current in **both** resistors and the potential difference across **both** resistors.

Example 3

Known data is: emf = 6 V; each external resistor = 3 Ω and they are connected in parallel; internal resistance = 0 Ω

To calculate the reading on the ammeter that measures the **main** current in the circuit:

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2}$$
$$= \frac{1}{3} + \frac{1}{3}$$
$$R_P = 1{,}5\ \Omega$$

$$R_P = \frac{V_{emf}}{I_{total}}$$
$$1{,}5 = \frac{6}{I_{total}}$$
$$I_{total} = 4\ A$$

The three variables in $R = \frac{V}{I}$ deal with the **same situation**. The **effective** resistance, the **total** current and the **emf**.

To calculate the reading on the voltmeter, which is the potential difference across each resistor: (*)

$$R_P = \frac{V}{I_{total}}$$
$$1{,}5 = \frac{V}{4}$$
$$V = 6\ V$$

The three variables deal with the **same situation**. The **effective** resistance, the **total** current in both resistors and the potential difference across **one or both** resistors.

To calculate the reading on the ammeter in branch **XY**, which is **one** of the branch currents:

$$R = \frac{V}{I_{XY}}$$
$$3 = \frac{6}{I_{XY}}$$
$$I_{XY} = 2\ A$$

The three variables deal with the **same situation**. The **specific** resistance, the current in **that** resistor and the potential difference across the **specific** resistor.

To calculate the reading on the ammeter in branch **XPQY**, which is the **other** branch current:

$$R = \frac{V}{I_{XPQY}}$$
$$3 = \frac{6}{I_{XPQY}}$$
$$I_{XPQY} = 2\ A$$

The three variables deal with the **same situation**. The **specific** resistance, the current in **that** resistor and the potential difference across the **specific** resistor.

(*) In this solution, the voltmeter reading was calculated by using the main current, followed by the calculation of the two branch currents by using the voltmeter reading. If a branch current is available, it can also be used to calculate the voltmeter reading.

The most important conclusion to make from these examples is that you must always ensure that **variables** in an equation **address the same situation!**

That is true for any equation!

A few notes about internal resistance

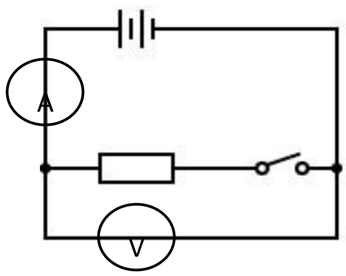
Questions usually indicate whether the cell or battery has internal resistance and therefore it is important to know how to deal with internal resistance if it must be taken into consideration.

The following are important aspects of internal resistance:

- Cells consists of chemicals and other materials and in real life it resists the flow of charge (the current) like an ordinary resistor. This resistance of a cell (or battery) is called "internal resistance".
- **Cells are connected in series with the external resistors**. Hence, the internal resistance must be seen as **connected in series** with the external resistors, irrespective if the external resistors are connected in series or parallel.

Voltmeter readings with or without internal resistance

Consider the following circuit and study the summary below to see how a voltmeter reading differs when internal resistance is present or not.



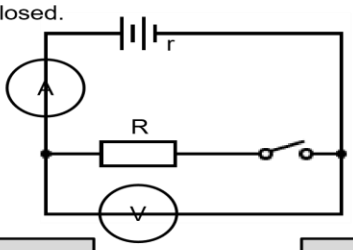
No internal resistance

Switch open	Switch closed
Ammeter reading is zero.	Ammeter measures the current. In this case the main current.
Voltmeter measures the emf.	The voltmeter measures the potential difference across the resistor, and it is **the SAME as** the emf.

With internal resistance

Switch open	Switch closed
Ammeter reading is zero.	Ammeter measures the current. In this case the main current.
Voltmeter measures the emf.	The voltmeter measures the potential difference across the resistor and it is **LESS THAN** the emf.

A mind experiment may further clarify the situation of internal resistance. Consider the circuit below. The battery has an internal resistance represented by *r*. Ammeter and voltmeter readings are taken; first with the switch open and then closed.



	Switch open	Switch closed
Ammeter reading (A)	0	0,3
Voltmeter reading (V)	3	2,7

Switch open

- Voltmeter measures emf.
- Reading can be **SEEN** on the voltmeter.
- Reading is 3 V.
- 3 V = 3 $J \cdot C^{-1}$ Each coulomb of charge receives 3 J of energy from the battery.

Switch closed

- Voltmeter measures potential difference across external resistor.
- Reading can be **SEEN** on the voltmeter.
- Reading is 2,7 V.
- 2,7 V = 2,7 $J \cdot C^{-1}$ Each coulomb of charge transfers 2,7 J of energy to the external resistor.

What happened to the 0,3 $J \cdot C^{-1}$, which is the **DIFFERENCE** between 3 $J \cdot C^{-1}$ and 2,7 $J \cdot C^{-1}$?

This 0,3 $J \cdot C^{-1}$ is the amount of energy used by the battery due to its internal resistance.

This number **CANNOT BE SEEN** on any voltmeter. It must be **CALCULATED**.

This number has a few names:

- Potential difference across the battery or cell;
- Potential drop across the battery or cell; or
- Lost volts (a term one tends to avoid).

Look at the following applications of the formula R = $\frac{V}{I}$ to see how it should be used correctly.

To calculate the external resistance R:

$$R = \frac{V}{I_{total}}$$
$$R = \frac{2,7}{0,3}$$
$$= 9\,\Omega$$

The three variables deal with the **same situation**. The **external** resistor, the current in **that** resistor and the potential difference across **that** resistor.

To calculate the total resistance R_T:

$$R_T = \frac{V_{emf}}{I_{total}}$$
$$= \frac{3}{0,3}$$
$$= 10\,\Omega$$

The three variables deal with the **same situation**. The **total** resistance (R+r), the current in **those** resistors and the **emf**.

To calculate the internal resistance r: (**)

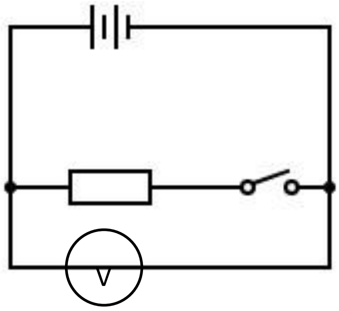
$$r = \frac{V_{cell}}{I_{total}}$$
$$= \frac{3-2,7}{0,3}$$
$$= 1\,\Omega$$

The three variables deal with the **same situation**. The **internal** resistance, the current **in the battery** and the potential drop across **the battery**.

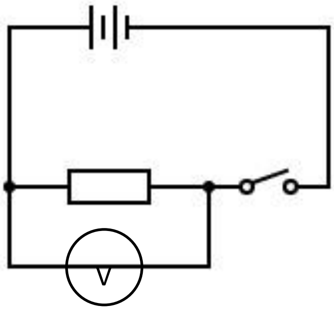
(**)The internal resistance is also the total resistance minus the external resistance, because $R_T = R + r$.

General useful hints about electric circuits

1. Check the connections of the voltmeters when emf is considered.



This voltmeter measures the emf. The switch is open and both wires are in contact with the battery.

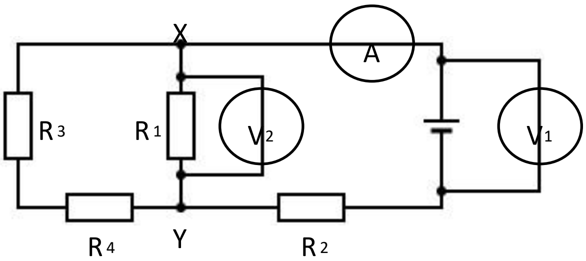


This voltmeter **does not** measure the emf although the switch is open. One of the wires is not in contact with the battery.

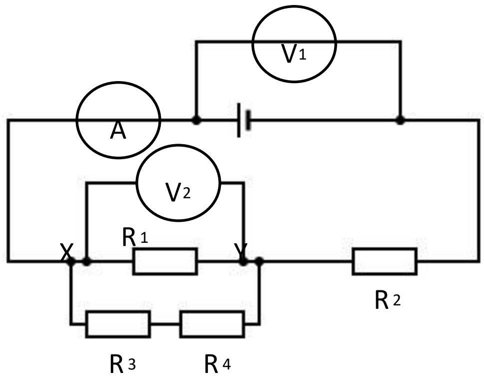
2.From examples 1 to 3 above you must remember that a voltmeter measures potential difference across the resistor(s) between its wires when there is a current in that resistor / those resistors.

3.

Simplify a circuit diagram if it is complicated.



Circuit 1



Circuit 2

Circuit 1 can be simplified to look like circuit 2 where all the resistors are put on one side of the circuit diagram. One way of doing it is as follows:

- Do the voltmeters after the battery, wires, resistors, ammeters and switches have been connected.
- Follow the direction of the conventional current from the positive terminal of the cell.
- The ammeter is reached first, and it measures the main current.
- The main current splits into two branch currents at **X** and combine again at **Y**.
- In one of the branches resistors $\mathbf{R_3}$ and $\mathbf{R_4}$ are connected in series.
- Resistor $\mathbf{R_1}$ is in the other branch, and $\mathbf{R_1}$ is connected in parallel with $\mathbf{R_3}$ and $\mathbf{R_4}$.
- From **Y** back to the negative terminal of the cell one has the main current again.
- Resistor $\mathbf{R_2}$ is between **Y** and the cell. In circuit 2 it is easy to see that $\mathbf{R_2}$ is connected in series with the parallel combination of resistors.
- Finally, consider the position of the voltmeters:
  - One of the wires of $\mathbf{V_1}$ is connected between the positive terminal of the cell and the ammeter. The other wire is connected between the negative terminal and $\mathbf{R_2}$. Looking at circuit 2 it is easy to see that $\mathbf{V_1}$ is actually connected across all four resistors. When no current exists, it measures the emf, and with current in the circuit, it measures the potential difference across all four external resistors (terminal potential difference).

- One of the wires of V_2 is connected between **X** and R_1. The other wire is connected between R_1 and **Y**. Looking at circuit 2 it is easy to see that V_2 is connected across the parallel set of resistors. It therefore measures the potential difference across R_1, but also the potential difference across R_3 and R_4. It has nothing to do with R_2.

Activity 1

1.1 A pump is connected to a water tank to pump rainwater into a house. The pump is rated 750W and it is connected to the 240 V main supply.

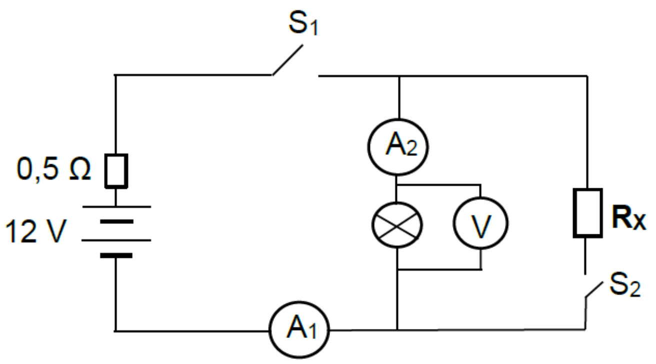
1.1.1 What current will the pump draw when operating on the 240 V supply? (3)

1.1.2 The cost of electricity is R1,20 per kilowatt hour. Calculate the cost of

using the pump continuously for 20 minutes. (3)

1.2 In the circuit represented below, the battery has an emf of 12 V and an

internal resistance of 0,5 Ω. The battery is connected as shown to a light bulb and resistor RX, both of unknown resistance. Ammeters have zero resistance, and the voltmeter has infinite resistance.



Switch S1 and switch S2 are initially both open.

1.2.1 Define emf. (2)

1.2.2 What will be the reading on the voltmeter, V, when both switches are open? (2)

Switch S1 is now closed, while S2 remains open. Ammeter A1 reads 1,6 A.

1.2.3 Determine the resistance of the bulb. (4)

1.2.4 Calculate the reading on the voltmeter, V. (3)

1.2.5 Calculate the rate of energy dissipation in the battery. (3)

1.2.6 Switch S2 is now closed so that both switches are closed. When switch S2 is closed, state whether the following will DECREASE, INCREASE or STAY THE SAME:

(a) the reading on ammeter A1. Explain your answer. (2)

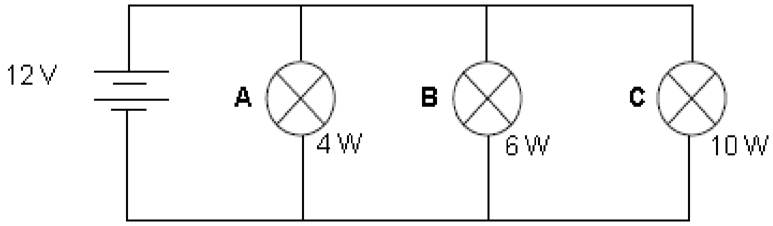
(b) the rate of energy dissipation in the battery. (2)

(c) the reading on voltmeter V. Explain your answer. (2)

[26]

ACTIVITY 2

2.1 In the diagram below, three light bulbs, **A**, **B** and **C**, are connected in parallel to a 12 V source of negligible internal resistance. The bulbs are rated at 4 W, 6 W and 10 W respectively and are all at their maximum brightness.



2.1.1 Calculate the resistance of the 4 W bulb. (3)

2.1.2 How will the equivalent resistance of the circuit change if the 6 W bulb burns out? Write down only INCREASES, DECREASES or NO CHANGE. (1)

2.1.3 How will the power dissipated by the 10 W bulb change if the 6 W bulb burns out? Write down only INCREASES, DECREASES or NON CHANGE. Give a reason for the answer. (2)

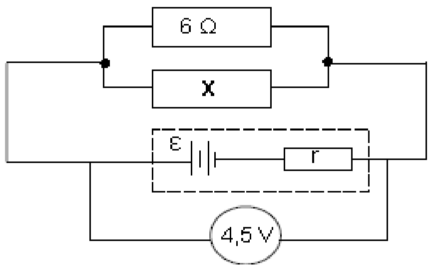
2.2 A learner connects a high-resistance voltmeter across a battery. The voltmeter reads 6 V. She then connects a 6 Ω resistor across the battery. The voltmeter now reads 5 V.

2.2.1 Calculate the internal resistance of the battery. (4)

The learner now builds the circuit below, using the same 6 V battery and the 6 Ω

resistor. She connects an unknown resistor **X** in parallel with the 6 Ω resistor. The voltmeter now reads 4,5 V.

2.2.2 Define the term *emf* of a cell. (2)



2.2.3 Calculate the resistance of **X** when the voltmeter reads 4,5 V. (5)

[17]

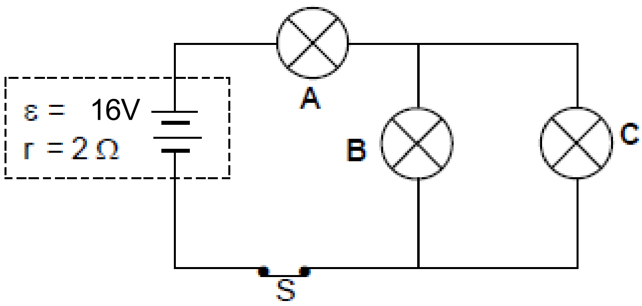
ACTIVITY 3

3.1 Three identical light bulbs, **A, B** and **C**, are each rated at 8 W, 16 V.

3.1.1 Define the term *power.* (2)

3.1.2 Calculate the resistance of EACH bulb when used as rated. (3)

The light bulbs are connected in a circuit with a battery having an emf (□) of 16 V and internal resistance (r) of 2 □. Refer to the diagram below. Assume that the resistance of each light bulb is the same as that calculated in QUESTION 10.1.2. Switch **S** is closed.

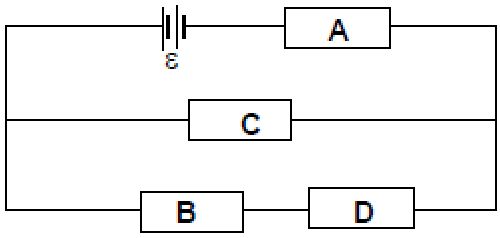


3.1.3 Calculate the total current in the circuit. (5)

3.1.4 Calculate the potential difference across light bulb **C**. (3)

3.1.5 Explain why light bulb **C** in the circuit will NOT burn at its maximum brightness (3)

3.2 Resistors **A, B, C** and **D** are connected to a battery having emf (□) and negligible internal resistance, as shown in the diagram below.



3.2.1 Give a reason why the current in resistor **A** is greater than that in resistor **C**. (2)

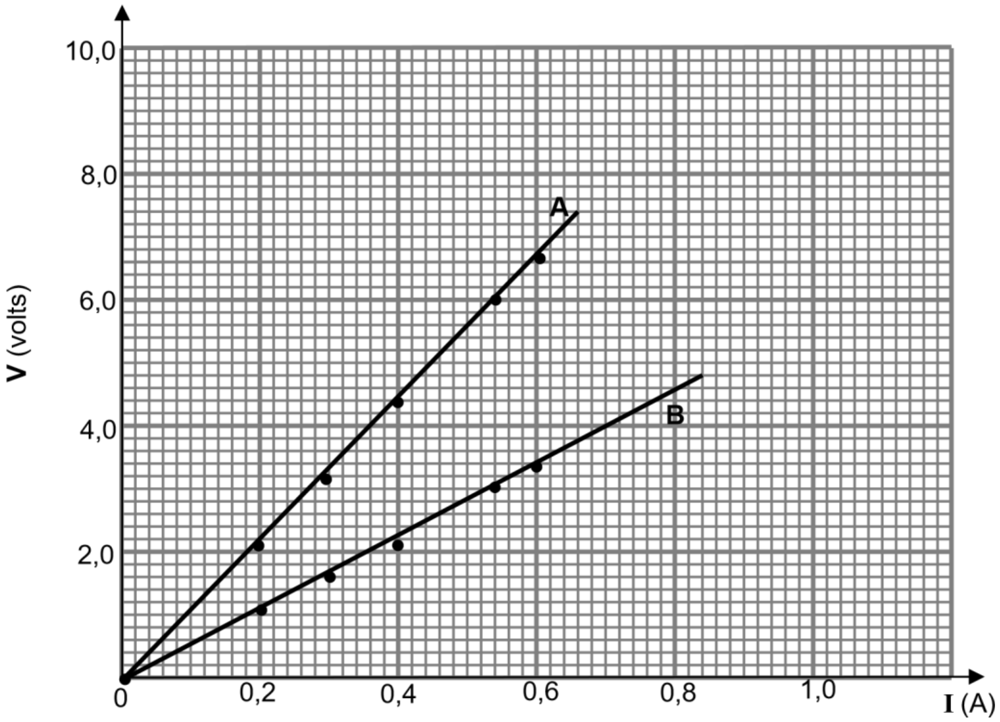
3.2.2 Resistor **C** is removed. How will the current in resistor **B** compare to the current in **A**? Give a reason for the answer. (2)

[20]

QUESTION 4

4.1 Learners want to construct an electric heater using one of two wires, **A** and **B**, of different resistances. They conduct experiments and draw the graphs as shown.

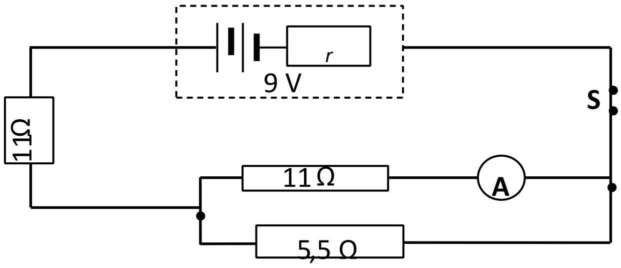
Graph of V versus I for resistors A and B



4.1.1 Apart from temperature, write down TWO other factors that the learners should consider to ensure a fair test when choosing which wire to use. (2)

4.1.2 Assuming all other factors are kept constant, state which ONE of the two wires will be the most suitable to use in the heater. Use suitable calculations to show clearly how you arrive at the answer. (8)

4.2 In the circuit below the reading on ammeter **A** is 0,2 A. The battery has an emf of 9 V and internal resistance *r*.



4.2.1 Calculate the current through the 5,5 Ω resistor. (3)

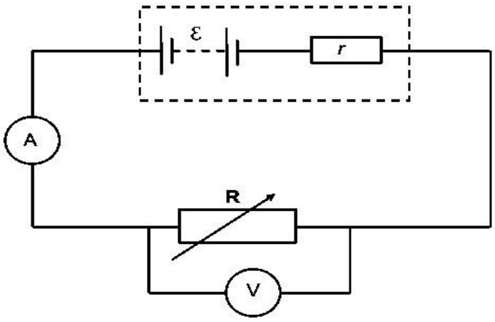
4.2.2 Calculate the internal resistance of the battery. (7)

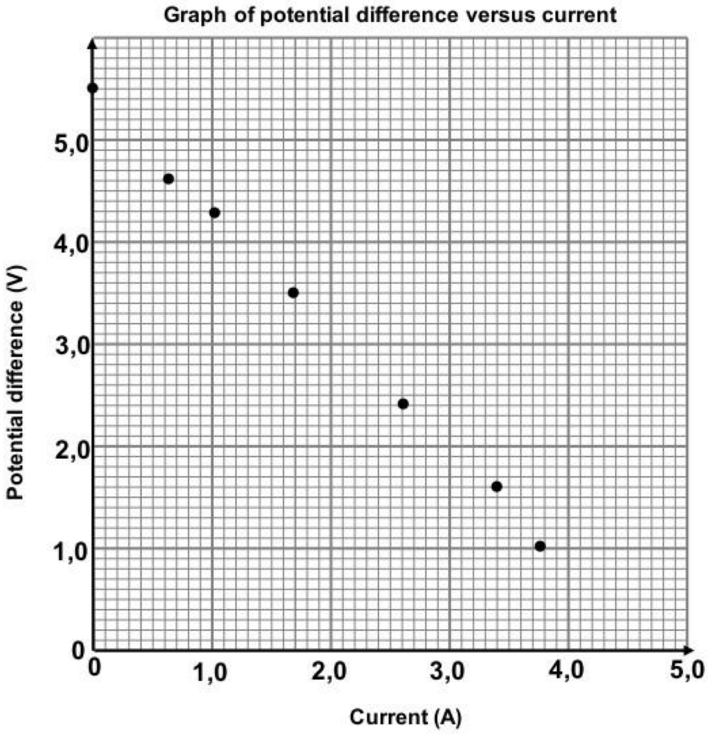
4.2.3 Will the ammeter reading INCREASE, DECREASE or REMAIN THE SAME if the 5,5 Ω resistor is removed? Give a reason for the answer. (2)

QUESTION 5

5.1 The emf and internal resistance of a certain battery were determined experimentally. The circuit used for the experiment is shown in the diagram below.

5.1.1 State Ohm's law in words. (2)





The data obtained from the experiment is plotted on the graph sheet alongside.

5.1.2 Draw the line of best fit through the plotted points. Ensure that the line cuts both axes. (2)

Use information in the graph to answer QUESTIONS 8.1.3 and 8.1.4.

5.1.3 Write down the value of the emf (ε) of the battery. (1)

5.1.4 Determine the internal resistance of the battery. (3)

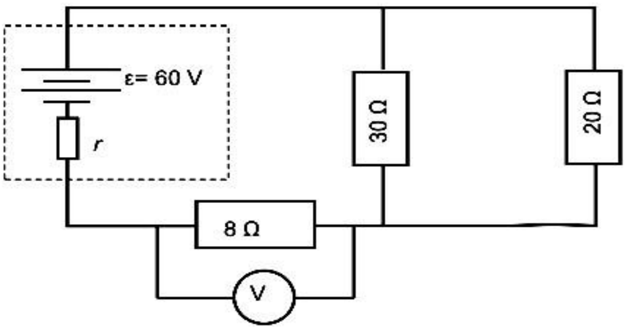
5.2 The circuit diagram shows a battery with an emf (ε) of 60 V and an unknown internal resistance r, connected to three resistors. A voltmeter connected across the 8 Ω resistor reads 21,84 V. Calculate the:

5.2.1 Current in the 8 Ω resistor (3)

5.2.2 Equivalent resistance of the resistors in parallel (2)

5.2.3 Internal resistance r of the battery .... (4)

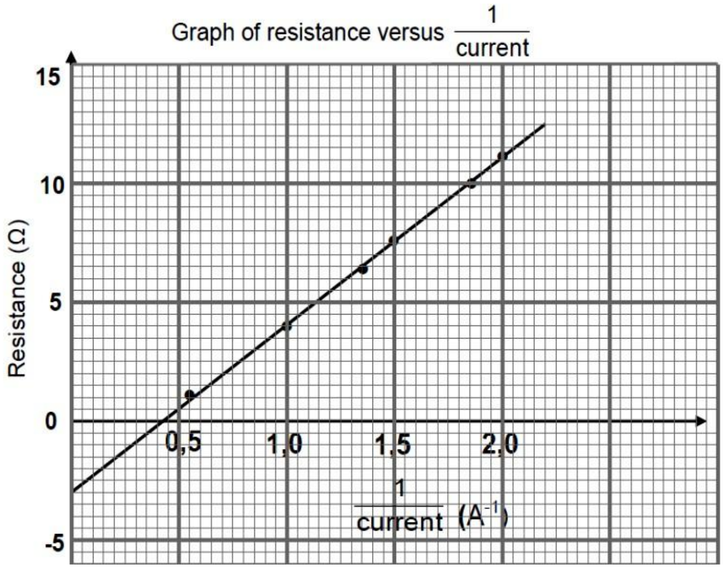
5.2.4 Heat dissipated in the external circuit in 0,2 seconds (3)

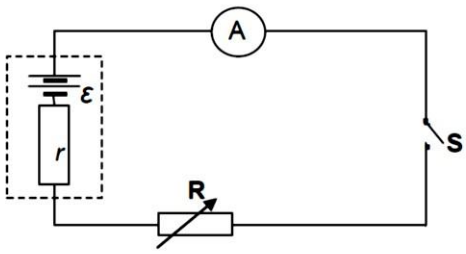


[20]

QUESTION 6

Learners perform an experiment to determine the emf (ε) and the internal resistance (*r*) of a battery using the circuit below. The learners use their recorded readings of current and resistance, together with the equation R = "ε" /"I" – r, to obtain the graph below.





6.1 Which variable has to be kept constant in the experiment? (1)

Refer to the graph.

6.2 Write down the value of the internal resistance of the cell. (2)

6.3 Calculate the emf of the battery. (3)

SUBJECT: SUBJECT NAME

GRADE 12

2025 SPRING CLASSES

TEACHER AND LEARNER CONTENT MANUAL

Topic(s)

Electrochemical Reactions

Examination guidelines

Electrochemical Reactions
(This section must be read in conjunction with the CAPS, p. 134–137.)

Galvanic cells

- Define the *galvanic cell* as a cell in which chemical energy is converted to electrical energy.
- Define *oxidation* and *reduction* in terms of electron (e^-) transfer:
- Oxidation is a loss of electrons. Reduction is a gain of electrons.
- Define *oxidation* and *reduction* in terms of oxidation numbers:
    - Oxidation: an increase in oxidation number
    - Reduction: a decrease in oxidation number
- Define an *oxidising agent* and a *reducing agent* in terms of oxidation and reduction:
- Oxidising agent: a substance that is reduced/gains electrons.
- Reducing agent: a substance that is oxidised/loses electrons.
- Define an *anode* and a *cathode* in terms of oxidation and reduction:
- Anode: the electrode where oxidation takes place
- Cathode: the electrode where reduction takes place
- Define an *electrolyte* as a substance of which the aqueous solution contains ions OR a substance that dissolves in water to give a solution that conducts electricity.
- **Relation of current and potential difference to rate and equilibrium**
- State that the potential difference of a galvanic cell (V_{cell}) is related to the extent to which the spontaneous cell reaction has reached equilibrium.
- State and use the qualitative relationship between V_{cell} and the concentration of product ions and reactant ions for the spontaneous reaction, namely V_{cell} decreases as the concentration of product ions increases and the concentration of reactant ions decreases until equilibrium is reached at which the V_{cell} = 0 (the cell is 'flat'). (Qualitative only. Nernst equation is NOT required.)
- **Understanding of the processes and redox reactions taking place in galvanic cells** □ Describe the movement of ions in the solutions.
- State the direction of electron flow in the external circuit.
- Write down the half-reactions that occur at the electrodes.
- State the function of the salt bridge.
- Use cell notation or diagrams to represent a galvanic cell.
- When writing cell notation, the following convention should be used:
- The $H_2|H^+$ half-cell is treated just like any other half-cell. o Cell terminals (electrodes) are written on the outside of the cell notation. o Active electrodes:
- reducing agent | oxidised species || oxidising agent | reduced species
- Inert electrodes (usually Pt or C):
- Pt | reducing agent | oxidised species || oxidising agent | reduced species | Pt
- Example: Pt | $C\ell^-$(aq) |$C\ell_2$(g) || F_2(g) | F^-(aq) | Pt
- Predict the half-cell in which oxidation will take place when two half-cells are connected.

- Predict the half-cell in which reduction will take place when connected to another half-cell.
- Write down the overall cell reaction by combining two half-reactions.
- Use the Table of Standard Reduction Potentials to calculate the emf of a standard galvanic cell.
- Use a positive value of the standard emf as an indication that the reaction is spontaneous under standard conditions.

- **Standard electrode potentials**
- Write down the standard conditions under which standard electrode potentials are determined.
- Describe the standard hydrogen electrode and explain its role as the reference electrode.
- Explain how standard electrode potentials can be determined using the reference electrode and state the convention regarding positive and negative values.

- **Electrolytic cells**
- Define the *electrolytic cell* as a cell in which electrical energy is converted into chemical energy
- Electrolysis: The chemical process in which electrical energy is converted to chemical energy OR the use of electrical energy to produce a chemical change

- **Understanding the processes and redox reactions taking place in electrolytic cells** Describe the movement of ions in the solution.
- State the direction of electron flow in the external circuit.
- Write equations for the half-reactions taking place at the anode and cathode.
- Write down the overall cell reaction by combining two half-reactions.
- Describe, using half-reactions and the equation for the overall cell reaction as well as the layout of the particular cell using a schematic diagram, the following electrolytic processes: o The decomposition of copper(II) chloride
- Electroplating, e.g. the electroplating of an iron spoon with silver/nickel o Refining of metals, e.g. copper
- The electrolysis of a concentrated solution of sodium chloride

GALVANIC CELLS

TERMS AND DEFINITIONS	
Galvanic cell	A cell in which chemical energy is converted into electrical energy. A galvanic (voltaic) cell has self-sustaining electrode reactions.
Anode	The electrode where oxidation takes place.
Cathode	The electrode where reduction takes place.
Electrolyte	A solution that conducts electricity through the movement of ions.
Salt bridge	The connection between two half-cells needed to ensure electrical neutrality in the cell. OR: A component used in a galvanic cell to complete the circuit.
Electrodes	An electrical conductor used in a galvanic cell to make contact with a non-metallic part of the circuit e.g. the electrolyte.
Cell notation	A short way to represent a galvanic cell. When writing cell notation, the following convention should be used: ○ The $H_2\|H^+$ half-cell is treated just like any other half-cell. ○ Cell terminals (electrodes) are written on the outside of the cell notation. ○ Active electrodes: reducing agent | oxidised species || oxidising agent | reduced species ○ Inert electrodes (usually Pt or C): Pt | reducing agent | oxidised species || oxidising agent | reduced species | Pt Example: Pt | $C\ell^-(aq)$ | $C\ell_2(g)$ || $F_2(g)$ | $F^-(aq)$ | Pt
Overall cell reaction	The reaction obtained by combining two half-reactions.
Positive value of the standard emf	The reaction is spontaneous under standard conditions.
Standard conditions for a galvanic cell	Temperature: 25 °C / 298 K Concentration: 1 $mol \cdot dm^{-3}$ Pressure (gases only): 101,3 kPa / 1 atmosphere
Standard hydrogen electrode	The reference electrode used to compile the Table of Standard Reduction Potentials. The hydrogen half-cell was given a standard reduction potential of 0 V. Half-cell notation: Pt | $H_2(g)$ | $H^+(aq)$ Half-reaction: $2H^+ + 2e^- \rightleftharpoons H_2$
Galvanic Cell	A cell in which chemical energy is converted to electrical energy.
Oxidation and reduction	Oxidation is a loss of electrons. Reduction is a gain of electrons.
Oxidation and Reduction in terms of oxidation numbers	Oxidation: an increase in oxidation number Reduction: a decrease in oxidation number
Oxidising agent and Reducing agent	• Oxidising agent: a substance that is reduced/gains electrons. • Reducing agent: a substance that is oxidised/loses electrons.

ELECTROLYTIC CELLS

	TERMS AND DEFINITIONS
Electrolytic cell	A cell in which electrical energy is converted into chemical energy.
Anode	The electrode where oxidation takes place.
Cathode	The electrode where reduction takes place.
Electrolyte	A solution that conducts electricity through the movement of ions.
Electrolysis	The chemical process in which electrical energy is converted to chemical energy OR the use of electrical energy to produce a chemical change.
Electrodes	An electrical conductor used in a galvanic cell to make contact with a non-metallic part of the circuit e.g. the electrolyte.
Electroplating	The covering of an object with a metal by making it the cathode in an electrolytic cell.
Oxidation and reduction	Oxidation is a loss of electrons. Reduction is a gain of electrons.
Oxidation and Reduction in terms of oxidation numbers	Oxidation: an increase in oxidation number Reduction: a decrease in oxidation number
Oxidising agent and Reducing agent	• Oxidising agent: a substance that is reduced/gains electrons. • Reducing agent: a substance that is oxidised/loses electrons.

CONTENT

Electrochemical cells can be divided into two basic groups:

•Electrolytic cells, in which electrical energy is transformed into chemical energy; a constant supply of electrical energy is needed.

•Galvanic cells, in which chemical energy is transformed into electrical energy; spontaneous chemical reactions drive the cell.

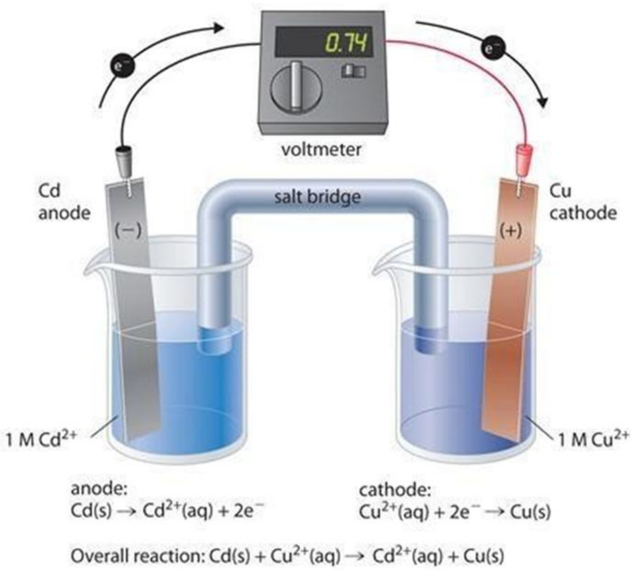
COMPARISON OF GALVANIC AND ELECTROLYTIC CELLS

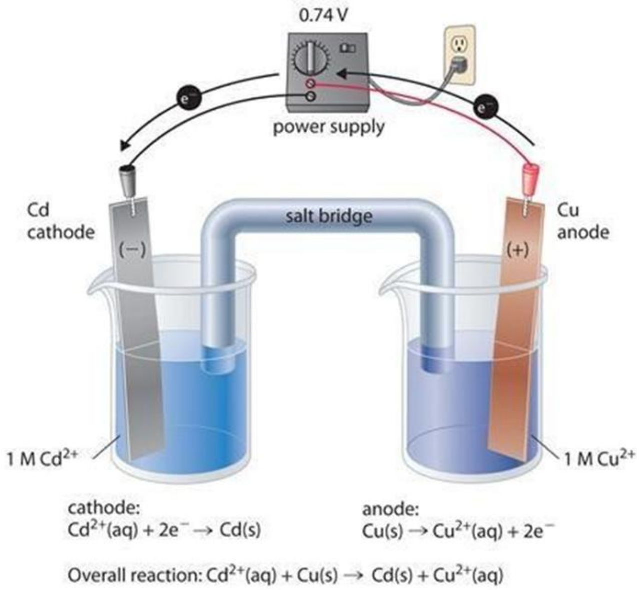
	Galvanic cell	Electrolytic cell
Basic Principle	A chemical reaction causes charges/electrons to flow	A flowing charge/electron causes a chemical reaction to occur
Energy Conversion	Chemical energy converted to electrical energy	Electrical energy converted to chemical energy
Polarity of electrodes	•**Anode** is negative (-) •**Cathode** is positive (+)	•**Anode** is positive(+) •**Cathode** is negative(-)

	Galvanic cell	Electrolytic cell
Appearance	•No external source of electricity i.e. no battery or cell in circuit •Consists of two half-cells containing different electrodes, each of which is in a solution of its salt. •There must either be a salt bridge or some sort of porous membrane separating the two half-cells to allow for the passage of ions between cells.	•Must have a cell or battery in the external circuit to supply electrical energy. •Consists of two electrodes, either inert (does not take part in the reaction) or active (takes part in the reaction) in the SAME solution (i.e. electrolyte).

	Galvanic cell	Electrolytic cell
Spontaneous/ Non spontaneous	•A **spontaneous** reaction produces electrical energy	•A **Non-Spontaneous** reaction is produced by electrical energy
E^0_{cell}	•E^0_{cell} = Positive(+)	•E^0_{cell} = Negative (-)
Uses	Batteries	•Extraction of Aluminium •Purification of metals •Electroplating •Chloro-alkali process

What **DIFFERENCES** can you spot between the two types of cells?





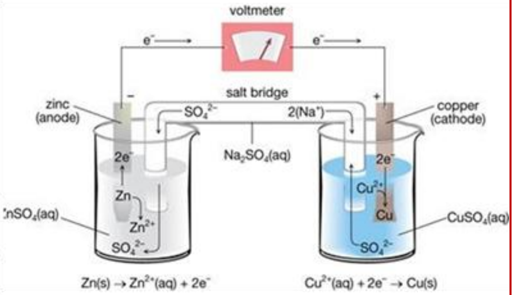
GALVANIC/VOLTAIC CELL

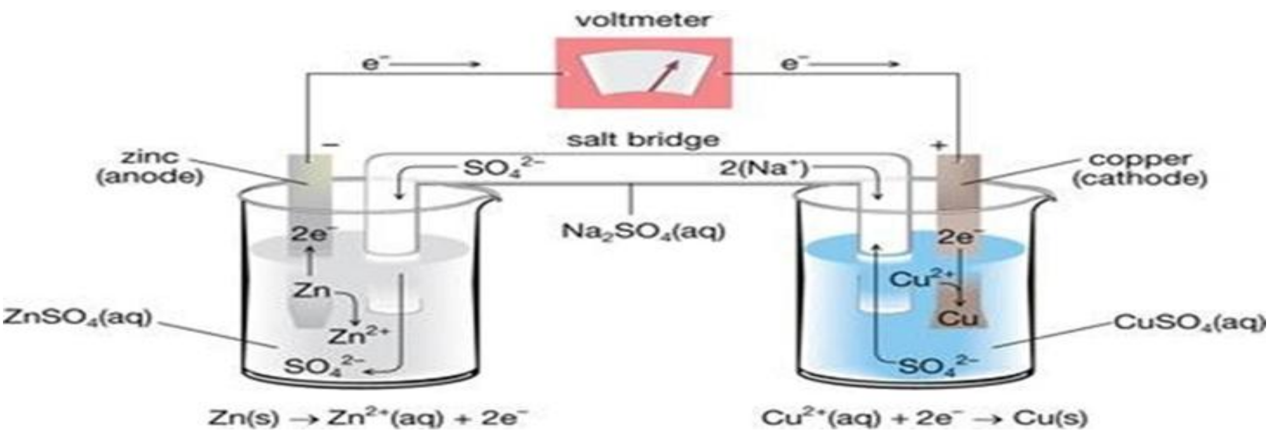
- **It is an electrochemical cell which converts electrical energy into chemical energy.**
- **The reactions in this cell are spontaneous and self-sustained.**
- **The cell is made up of two physically separate half-cells that is the anode half-cell and the cathode half-cell.**
- **Anode -is the electrode where oxidation occurs. It can be**

inert or reactive.

- **Cathode is the electrode where reduction occurs.**
- **Each electrolyte is dipped into a corresponding electrolyte e.g Zinc in Zinc sulphate and Copper in Copper(II) sulphate.**
- **When choosing electrolytes, always us a nitrate since all nitrates are soluble.**
- **We are going to analyse galvanic cells operating under standard conditions(not STP) :**
  - **Temperature of 250^0C/298K**
  - **Concentration of electrolyte of 1mol.dm^{-3}**
  - **Pressure of 1atm /1,013 x105 pa for gases.**

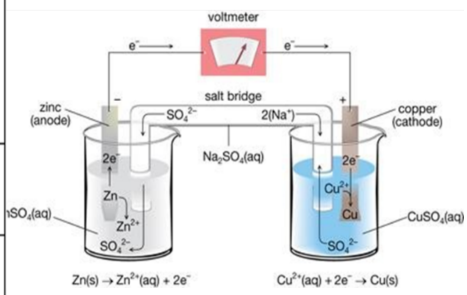
	ANODE	**CATHODE**
Identification	- Has a smaller E^θ value.(-076V) -Stronger reducing agent.(Zn)	-Has a larger E^θ value.(+0,34V) -Weaker reducing agent.(Cu)
Type of reaction	Oxidation	Reduction
Half-equation	$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$	$Cu^{2+} + 2e^-(aq) \rightarrow Cu(s)$
Observable changes on Electrode	-Mass decreases -It becomes corroded	-mass increases -it becomes thicker
Observable change in electrolyte	-remains colourless	-The intensity of the blue colour decrease. - a reddish brown precipitate is formed





Change in concentration of ions	$[Zn^{2+}]$ increases (product ion)	$[Cu^{2+}]$ decreases. (reactant ion)
Flow of electrons	Generally electrons flow from anode to cathode through the external circuit through the connecting wire(external circuit). In the Zn-Cu cell electrons flow from Zn to Cu	
Accumulation of charge	Positive charge accumulates in the anode(Zn) half-cell due to increase in concentration of cations(Zn^{2+})	Negative charge accumulates in the cathode half-cell due to a decrease in concentration of cations(Cu^{2+})
Flow of ions from salt bridge	Anions migrate from salt bridge to anode half-cell to neutralise the accumulating positive charge.	Anions migrate from salt bridge to cathode half-cell to neutralise the accumulating negative charge.

(The salt bridge completes the circuit and maintains electrical neutrality of electrolytes.)	
Net Reaction	$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$
Cell notation	$Zn/Zn^{2+} // Cu^{2+} / Cu$



4. The emf of the cell/cell potential is calculated as follows :

$$E_{cell} = E^{\theta}_{cathode} - E^{\theta}_{anode}$$
$$= 0,34 - (-076)$$
$$= 1.10V$$

Relation of current and Potential Difference to rate and equilibrium

• The redox reactions in the galvanic cells are REVERSIBLE. However, they have very large Kc values, hence they are usually represented as IRREVERSIBLE

• The galvanic cell has the capacity to deliver current until the reaction reaches chemical equilibrium or has run to completion.

• According to Le Châtelier's principle, all the factors that favour THE FORWARD reaction INCREASE the voltage of the galvanic cell e.g. Increasing the concentration of the reactants or decreasing the concentration of the products INCREASES voltage

• According to Le Châtelier's principle, all the factors that favour the REVERSE reaction DECREASE the voltage of the galvanic cell e.g. Increasing the concentration of the PRODUCTS or decreasing the concentration of the REACTANTS DECREASES voltage

Consider the net reaction for the Zn-Cu cell

$Zn + Cu^{2+} \leftrightharpoons Zn^{2+} + Cu(s)$

According to Le Chartelier's principle and increase in [Cu^{2+}] favours the forward reaction which is spontaneous thus increasing emf.

• Internal resistance is opposition to the flow of charge through the electrodes and electrolytes in a cell

• Increased surface area of the electrodes increases the rate of the reaction by lowering the internal resistance and increasing the maximum current that the cell can deliver, but does not affect the emf of the cell.

EMF of the Cell

• The EMF of a cell is the maximum potential difference between two half- cells in a galvanic cell.

• If determined under standard conditions, it is referred to as the standard EMF : E°cell

• The standard emf of a cell can be determined from Table 4A (or 4B), by applying one of the following formulae (these are given on exam info sheet)

E^0 cell = E^0 reduction – E^0 oxidation

= E^0 oxidising agent – E^0 reducing agent

= E^0 cathode – E^0 anode

An example: An electrochemical cell is constructed using the following half- reactions:

Pb2+(aq) + 2e- ⇌Pb(s) and Au3+(aq) +3e- ⇌Au(s)

a) Which is the anode and which the cathode?

b) What is the standard cell potential?

Using our simple rule …

Anode – oxidation: Pb (lead)

Cathode – reduction: Au (gold)

E° = E°(cathode) – E°(anode) = + 1,50 – (–0,13) = 1,63 V.

Remember:

When the cell EMF is POSITIVE, the reaction is SPONTANEOUS.

If the EMF is negative, the reaction is non-spontaneous

CELL NOTATION

The following guidelines apply to the writing of the cell notation for cells involving gases:

1. The H_2|H + cell is treated just like any other half-cell.

(Textbooks stating that it always written on the left is INCORRECT.)

2. Cell terminals (electrodes) are written on the outside of the cell notation.
3. Order always:
RA|oxidized species||OA|reduced species.

4. If inert electrodes are used:

Pt|RA|oxidized species||OA|reduced species|Pt.
NB:
(Pt (or C) appears only if an inert electrode is used, as in the stand. H_2|H+ half-cell.) Pt | reducing agent | oxidised species || oxidising agent | reduced species | Pt

Correct order Examples:
1. **Mg|Mg2+||H+ |H_2 |Pt (Correct)**
2. **Pt|H_2/H+ ||Cu^{2+} /Cu (Correct)**
3. **Mg|Mg^{2+} || F_2|F^-|Pt (Correct: order RA, oxidized species, OA, reduced species)**
4. **Pt|Cℓ- |Cℓ2|| F_2 |F^- |Pt (Correct: order RA, oxidized species, OA, reduced species)**

Incorrect Order Examples:
5. **Mg|Mg2+||F^- |F_2/Pt (Wrong - order)**
6. **Pt|$Cℓ_2$|$Cℓ^-$ ||F^-|F_2|Pt (Wrong - order)**

Explanation of relative strengths of reducing agents or oxidizing agents

Follow the following steps:
STEP 1: Identify the stronger oxidising agent *(or reducing agent)*.
STEP 2: Identify the species/substance with which it is compared i.e. the weaker oxidising agent *(or reducing agent).*
STEP 3: State the action i.e. which species will be reduced *(or oxidised).* **STEP 4:** State to what species will it be reduced *(or oxidised)*.

EXAMPLE 1:
Can a copper(II) sulphate solution be stored in a zinc container? Explain by referring to the Table of Standard Reduction Potentials.
ANSWER
In terms of relative strength of oxidising agents:

No. ✓
Cu^{2+} is a stronger oxidising agent ✓ than Zn^{2+} ✓ and will oxidise Zn ✓ to Zn^{2+}. ✓

Note: Species on the left of the double arrow in the Table of Standard Reduction Potentials are oxidising agents. Those to the right of the double arrow are reducing agents. When comparing, an oxidising agent should always be compared to another oxidising agent and not with a reducing agent (to the right of the double arrow in the Table of Standard Reduction Potentials).

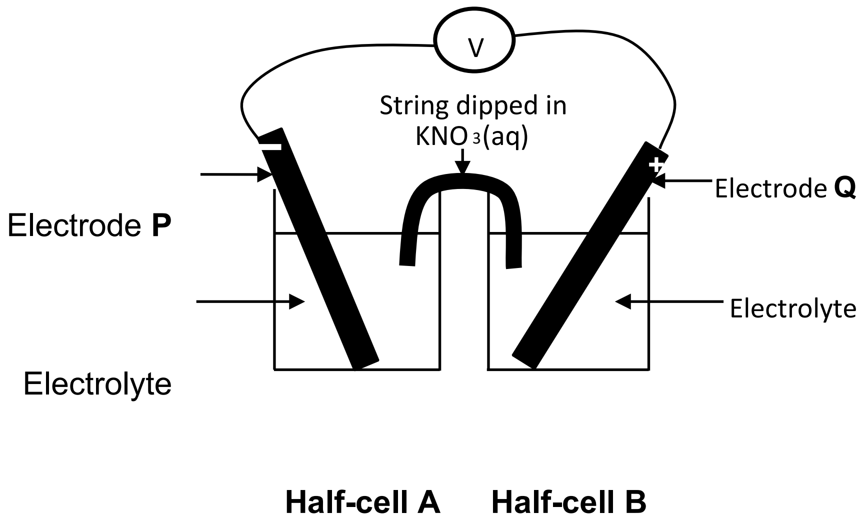
In terms of relative strengths of reducing agents:
No. ✓
Zn is a stronger reducing agent✓ than Cu ✓ and will reduce Cu^{2+} ✓ to Cu. ✓

EXAMPLE 2:
It is found that silver does not react with a hydrochloric acid solution. Refer to the relative strengths of reducing agents to explain this observation.

ANSWER
Ag is a weaker reducing agent ✓ than H_2 ✓ and Ag CANNOT reduce H^+ ✓ to H_2. ✓

WORKED EXAMPLES

EXAMPLE 1
Learners set up an electrochemical cell, shown in the simplified diagram below, using magnesium and lead as electrodes. Nitrate solutions are used as electrolytes in both half-cells.



1.1 What type of reaction (NEUTRALISATION, REDOX or PRECIPITATION) takes place in this cell? (1)

Answer: *Redox reaction ✓ (Elecrons are transfered.)*

1.2 Which electrode, **P** or **Q**, is magnesium? Give a reason for the answer. (2)

Answer: *P ✓ Negative electrode. / Mg is a stronger reducing agent/is oxidized/release electrons.* ✓

1.3 Write down the:

1.3.1 Standard conditions under which this cell functions (2)

Answer: *Temperature: 25 °C/298 K* ✓

Concentration: 1 mol·dm^{-3} ✓

1.3.2 Cell notation for this cell (3)

Answer: $Mg(s) \mid Mg^{2+}(aq)$ ✓|| ✓ $Pb^{2+}(aq) \mid Pb(s)$ ✓

1.3.3 NAME or FORMULA of the oxidising agent in the cell (1)

Answer: Pb^{2+} / $Pb(NO_3)_2$ / *lead(II) ions* ✓

1.4 Calculate the initial emf of the cell above under standard conditions (4)

Answer: $E^{\theta}_{cell} = E^{\theta}_{reduction} - E^{\theta}_{oxidation}$ ✓ = -0,13 ✓ – (-2,36) ✓ = 2,23 V

1.5 How will the voltmeter reading change if the:

(Write down only INCREASES, DECREASES or REMAINS THE SAME.)

1.5.1 Size of electrode **P** is increased (1)

Answer: *Remains the same* ✓

1.5.2 Initial concentration of the electrolyte in half-cell **B** is increased (1)

Answer: *Increases* ✓

[15]

<u>EXAMPLE 2</u>

2.1 When a piece of sodium metal (Na) is added to water in a test tube, hydrogen gas is released. When phenolphthalein indicator is added to the test tube, the solution turns pink.

2.1.1 Define the term *reduction* in terms of electron transfer. (2)

Answer: *Gain of electrons.* ✓✓ *(2 or 0)*

2.1.2 Write down the reduction half-reaction. (2)

Answer: $2H_2O(\ell) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$ ✓✓

2.1.3 Write down the balanced equation for the reaction that takes place.(3)

Answer: $2Na(s) + 2H_2O(\ell)$ ✓ $\rightarrow H_2(g) + 2OH^-(aq) + 2Na^+(aq)$ ✓ *Bal* ✓

2.1.4 Give a reason why the solution turns pink. (1)

Answer: *Formation of hydroxide ions/*OH^-*/sodium hydroxide/base/pH > 7* ✓

When a piece of copper is added to water in a test tube, no reaction Is observed.

2.1.5 Refer to the relative strengths of the REDUCING AGENTS to explain why no reaction is observed. (3)

Answer: *Cu is a weaker reducing agent* ✓ *than* H_2 *and* OH^- ✓ *and* H_2O *will not be reduced(to* H_2 *and* OH^-*)* ✓

Consider the cell

$Pb(s)/Pb^{2+}(aq) \,||\, Fe^{3+}(aq), Fe^{2+}(aq)\ Pt(s)$

2.1.6 What does the single line (|) in the cell notation above represent? (1)

Answer: *Phase separator* ✓

2.1.7 State the energy conversion that takes place in this cell. (1)

Answer: *Chemical (energy) to electrical (energy)*

2.1.8 Calculate the initial emf of the cell under standard conditions.(4)

Answer: $E_{cell}^{\theta} = E^0_{reduction} - E^0_{oxidation}$ ✓

$= 0,77$ ✓ $- (-0,13)$ ✓

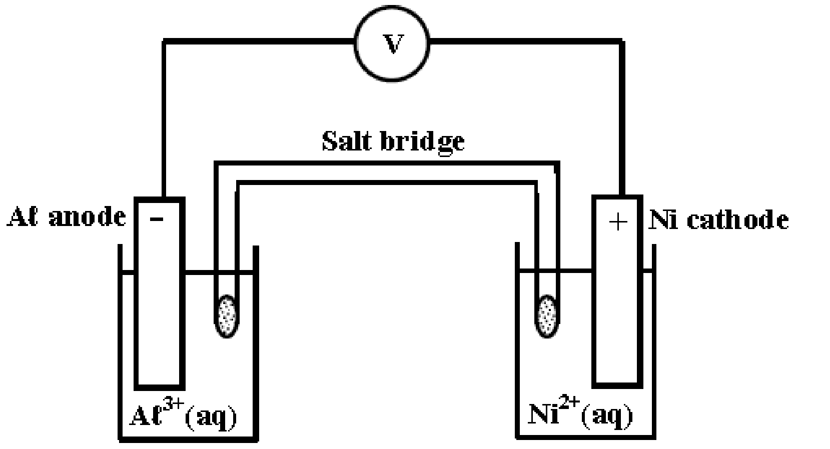
$E_{cell}^{\theta} = 0,90\ V$ ✓

[17]

GALVANIC CELL ACTIVITIES

ACTIVITY 1

A galvanic cell is set up under standard conditions using Aluminium and Nickel electrodes as shown in the diagram below.



1.1 State the energy conversion that takes place in this cell. (2)

1.2 Write down the cell notation for this cell. (Standard conditions need not be shown. (3)

1.3 Define:

1.3.1 *Oxidation.* (2)

1.3.2 *Oxidizing agent.* (2)

1.4 Give the symbol of the oxidizing agent in this cell. (1)

1.5 Calculate the initial *emf* of this cell under standard conditions (3)

1.6 State how each of the following changes affect the *emf* of this cell: (Answer only INCREASES, DECREASES or NO EFFECT.)

1.6.1 A soluble salt containing $Aℓ^{3+}$ ions is added to the anode half-cell. (1)

1.6.2 The galvanic cell approaches chemical equilibrium. (1)

1.7 The salt bridge is replaced by one which is wider, shorter and more conductive than that shown in the diagram. State how each of the following will be affected by this change:
(Answer only INCREASES, DECREASES or NO EFFECT.)

1.7.1 The *emf*. (1)

1.7.2 The internal resistance. (1)

1.7.3 The ability of the cell to deliver current. (1)

1.8 After the cell has been operating for a period of time, the gain in mass at the nickel cathode is 1, 77 g.

1.8.1 Calculate the number of moles of Nickel which have been deposited at the cathode. (2)

1.8.2 Calculate the subsequent loss in mass at the Aluminium anode. (3)

1.9 Another cell (cell **P**) is set up under standard conditions.

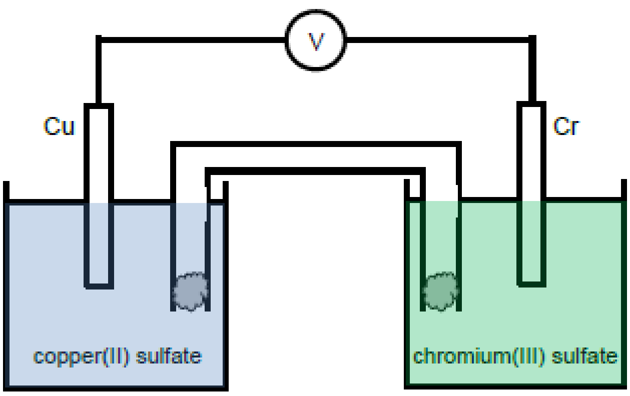
The following cell notation summarises cell **P**: $Mg/Mg^{2+}// A\ell^{3+} / A\ell$

Write down the balanced equation for the net (overall) reaction that takes place in cell **P.** (3)

[26]

ACTIVITY 2

In the standard cell shown in the diagram below, a copper electrode is placed into a solution of blue copper(II) sulfate, and a chromium electrode is placed into a green chromium(III) sulfate solution. The voltmeter registers a reading.

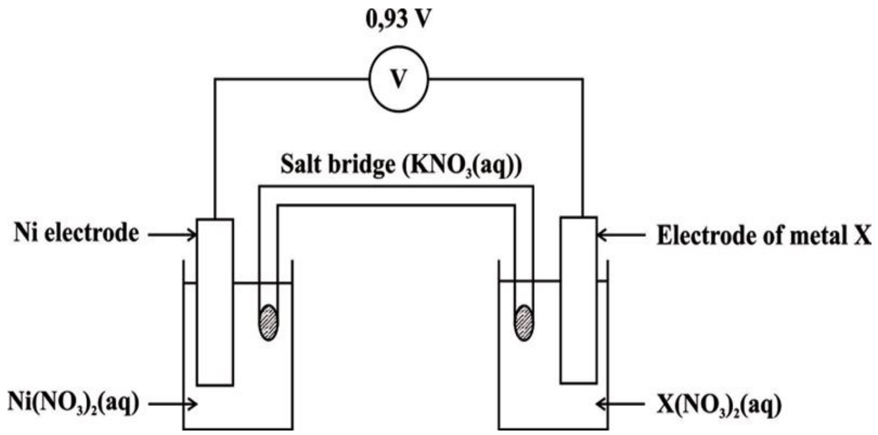


2.1 Class (1)

2.2	Write the formula of chromium(III) sulfate.		(1)
2.3	2.3.1	Write the reduction half-reaction.	(2)
	2.3.2	Identify the anode.	(1)
	2.3.3	Describe TWO observations that can be made in the chromium half-cell after the cell has delivered current for a significant amount of time.	(2)
2.4	Write a chemical equation for the net cell reaction that occurs in this cell.		(3)
2.5	2.5.1	Determine the initial reading on the voltmeter.	(3)
	2.5.2	If the initial concentration of copper(II) sulfate used was greater than 1 mol·dm^{-3}, fully explain the effect that this would have on the initial voltmeter reading.	(3)
2.6	2.6.1	Write the chemical formula for a suitable reagent that can be used in the salt bridge.	(1)
	2.6.2	Explain how the salt bridge maintains electrical neutrality in the chromium half-cell. In your answer, refer to the changing ionic conditions as well as the movement of ions.	(3)
2.7	Write the cell notation for this cell, including conditions and phase indicators.		(5)
			[25]

ACTIVITY 3

A galvanic cell is set up under standard conditions using nickel (Ni) and an unknown metalX as electrodes, as shown in the diagram below. The reading on the voltmeter while the cell is operating under standard conditions is 0,93 V. After the cell has been operating for a period of time, it is observed that **the mass of the nickel electrode has increased**.



3.1 Define the term *anode*. (2)

3.2 Which metal (nickel or metal **X**) is the cathode of this galvanic cell? Give a reason for your answer. (2)

3.3 Write down a chemical equation to show the half-reaction taking place at the nickel electrode. (2)

3.4 Calculate the standard electrode potential (E°) of metal **X** and hence determine the identity of metal. (4)

3.5 Write down the cell notation for this galvanic cell. Standard conditions do not need to be shown. (3)

3.6 The salt bridge used contains a concentrated solution of potassium nitrate. The saltbridge maintains electrical neutrality in the half-cells.

3.6.1 Why is it important that the solution of potassium nitrate is concentrated?(2)

3.6.2 Explain what the expression *'maintain electrical neutrality'* means. (2)

3.6.3 Explain why $\mathbf{K^+}$ ions are more suitable cations than $\mathbf{Fe^{3+}}$ ions for the salt bridge. (Refer to the table of Standard Electrode Potentials.) (3)

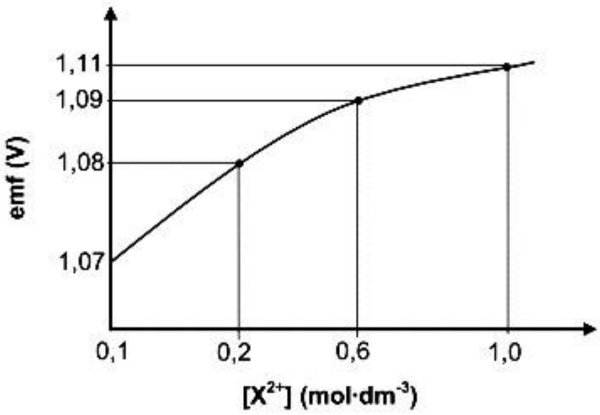
[19]

Activity 4

The electrochemical cell represented by the cell notation below is used to investigate the relationship between the concentration of X^{2+}(aq) and the emf of the cell. The concentration of Zn^{2+}(aq) and the temperature are kept at standard conditions.

Zn(s) | Zn^{2+}(aq) || X^{2+}(aq) | X(s) The graph shows the results obtained.

Graph of emf versus [X^{2+}]



4.1 For this investigation, write down the:

4.1.1 Dependent variable (1)

4.1.2 Name of an instrument needed to measure the emf of the cell (1)

4.1.3 Name of the component of the cell that ensures electrical neutrality (1)

4.1.4 Values of TWO standard conditions needed to ensure that the standard emf is obtained (2)

4.2 Write down the conclusion that can be drawn from the results. (2)

4.3 Identify electrode **X** with the aid of a calculation. (5)

4.4 Write down the overall (net) cell reaction that takes place when this cell is in operation. (3)

[15]

ELECTROLYTIC CELL CONTENT

Understanding the Processes and Redox Reactions Taking Place in Electrolytic Cells

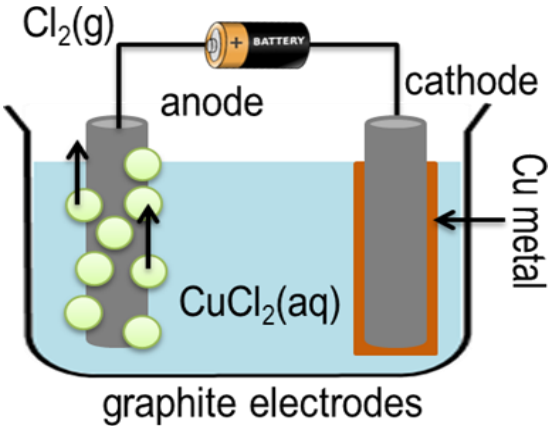
- **Describe the movement of ions in the solution.**
- **State the direction of electron flow in the external circuit.**
- **Write equations for the half reactions taking place at the anode and cathode.**
- **Write down the overall cell reaction by combining two half reactions.**
- **Describe, using half reactions and the equation for the overall cell reaction as well as the layout of the particular cell using a schematic diagram, the following electrolytic processes**
  - **The decomposition of copper(II) chloride**
  - **Electroplating, e.g. the electroplating of an iron spoon with silver/nickel**
  - **Refining of copper**
  - **The electrolysis of a concentrated solution of sodium chloride**

Summary:
Electrolysis of Concentrated NaCl Solution

The **half reactions** and **cell reactions** for the electrolysis of a saturated sodium chloride solution are as follows:

- Anode (oxidation): $2C\ell^-(aq) \rightarrow C\ell_2(g) + 2e^-$
- Cathode (reduction): $H_2O(\ell) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$
- Net-cell reaction: $2C\ell^-(aq) + 2H_2O(\ell) \rightarrow 2OH^-(aq) + C\ell_2(g) + H_2(g)$
- Cell reaction with spectator ions:
  $2NaC\ell(aq) + 2H_2O(\ell) \rightarrow 2NaOH(aq) + C\ell_2(g) + H_2(g)$

ELECTROLYSIS OF COPPER CHLORIDE SOLUTION



- The principles of electrochemistry (as above) are used in a variety of industrial processes. One is the decomposition of copper chloride ($CuCl_2$).
- $CuCl_2$ ionises in water to form Cu^{2+} and Cl^- ions. When a current is passed through the solution, Cu^{2+} is reduced, forming a metal layer around the cathode

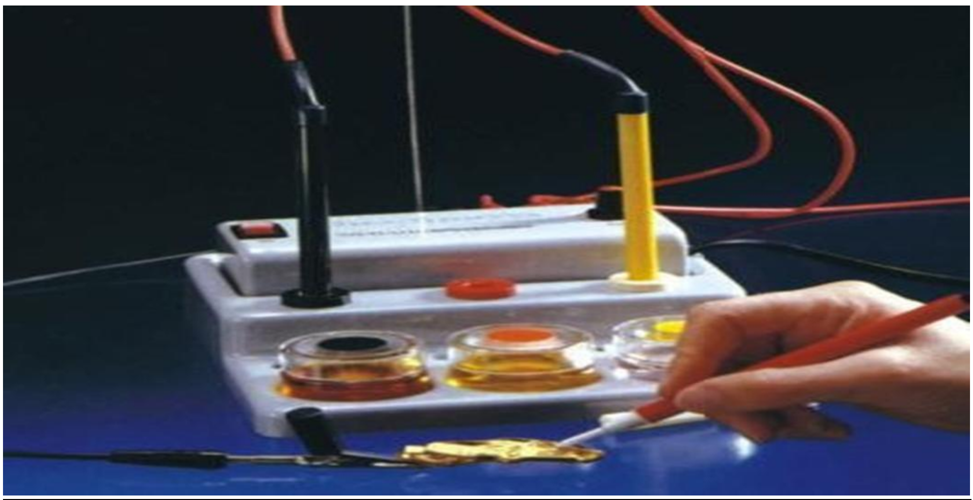
  $Cu^{2+} + 2e^- \rightarrow Cu$ (reduction reaction)
- At the same time, Cl^- ions migrate to the positive anode, losing the extra electron to be oxidised forming chlorine gas.

  $2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$ (oxidation reaction)
- The **net reaction**: $CuCl_2(aq) \rightarrow Cu(s) + Cl_2(g)$

  E°(cell) = E°(cath.) – E°(anode)

  = +0,34 – (+1,36) = *– 1,02 V*
- The reaction is *non-spontaneous*, as the need for a battery implies.

ELECTROPLATING



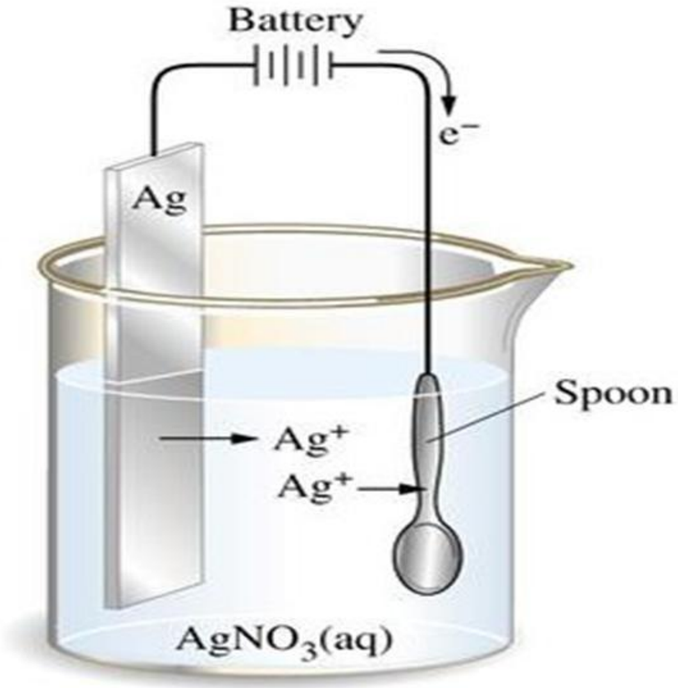
What is Electroplating ???

- Electroplating consists of depositing a thin layer of one metal on top of another, either to protect the inner layer or for the sake of appearance.
- The object which is being electroplated can be made of any metal, but most often it is made of brass, nickel or steel.

Electroplating Procedure

- The object to be electroplated is made at the cathode, i.e. it is connected to the negative terminal of the battery.
- The anode is usually a pure sample of the metal which is being used for plating. The anode is therefore active and ionises.
- The electrolyte must contain ions of the metal which is being used for plating.
- Examples of electroplating are chromium plating, silver plating and nickel plating.

ELECTROPLATING OF SPOON WITH SILVER



Anode (+): a pure silver plate

Cathode (–): iron spoon (object to be electroplated).

Electrolyte: a mixture of silver nitrate ($AgNO_3$) and potassium cyanide (KCN).

- The cyanide ensures a constant silver concentration, and increases the electrical conductivity of the electrolyte.
- The Ag^+ ions can move freely in the electrolyte.

Reaction at the Anode:

Ag (s) is oxidized at the anode to form Ag^+ .

$Ag (s) \rightarrow Ag^+ (aq) + e^-$, Ox. half reaction

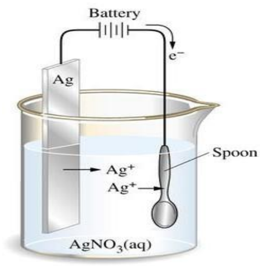
- The mass of the Ag electrode decreases and there is a constant supply of Ag^+ ions in the solution.

Reaction at The Cathode:

Ag^+ in solution are reduced at the cathode to form Ag (s)

$Ag^+ (aq) + e^- \rightarrow Ag (s)$, Red. half reaction

- The cathode (iron spoon) coated with a layer of silver.
- The mass of the cathode increases.



Example 2 – Nickel Plating
Electroplating a Nail with Nickel

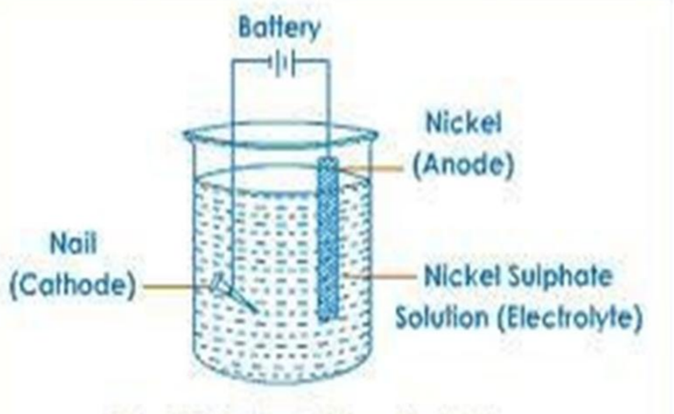


Fig. 4.12 Electroplating with nickel

- **At the anode:** Ni(s) → Ni^{2+}(aq) + $2e^-$
- **Oxidation** will occur whereby Ni metal atoms that made up the metal electrode will be oxidised to Ni^{2+}.
- **At the Cathode:** Ni^{2+}(aq) + $2e^-$ → Ni(s)
- **Reduction** will occur whereby Ni^{2+} ions are attracted to the cathode (the nail) are reduced to Ni metal which now coats the nail with a thin layer of Nickel.
- **Net ionic reaction:**

Ni(s) + Ni^{2+}(aq) → Ni^{2+}(aq) + Ni(s)

Summary:
Electro-refining of Copper

Reaction at the Anode:

Cu (s) atoms are oxidized at the anode to form Cu^{2+} .

Cu (s) → Cu^{2+} (aq) + $2e^-$, Ox. half

- The mass of the copper anode decreases and there is a constant supply of Cu^{2+} ions in the solution.
- The Cu^{2+} ions are attracted to the cathode and move through the solution.

Reaction at The Cathode:

- Cu^{2+} in solution are reduced at the anode to form Cu (s)

Cu^{2+} (aq) + $2e^-$ → Cu (s), Red. half reaction

- The mass of the cathode increases.

NB!

The **concentration of the electrolyte** during the reaction **remains the same**.

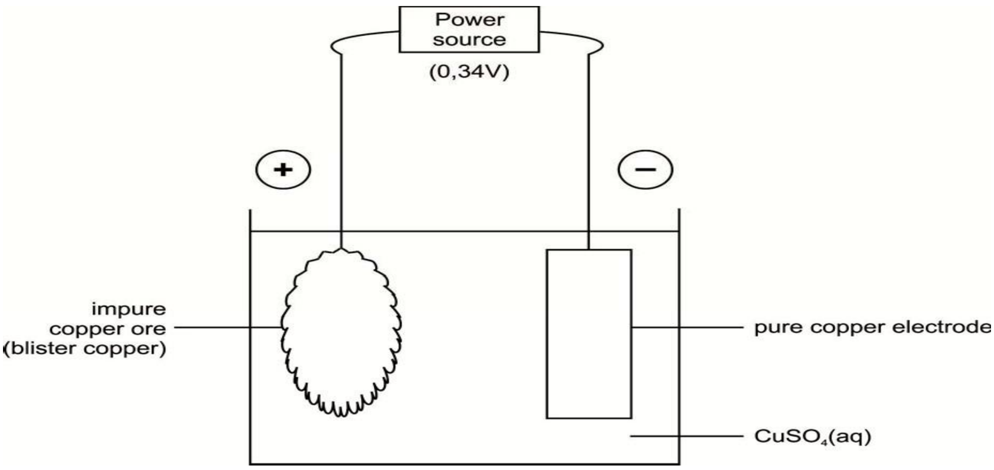
For each Cu (s) atom that oxidizes into Cu^{2+} at the anode, another Cu^{2+} ion in solution is reduced to Cu (s) atom at the cathode.

RATE OF OXIDATION = RATE OF REDUCTION

ELECTROLYTIC CELL

ACTIVITY 1

Copper is a metal that can be purified from its ore through an electrolytic technique. The impure copper ore, known as blister copper, is the anode of the cell while a pure copper plate is used as the cathode. These electrodes are placed in an electrolyte of aqueous copper sulphate as shown in the diagram below



Blister copper contains several metal impurities, most commonly silver (Ag), gold (Au), iron (Fe) and zinc (Zn).

1.1 Name the electrolytic technique described in this question. (1)

1.2 Write down the half reaction that occurs at the cathode. (2)

1.3 Use the table of Standard Electrode Potentials to explain each of the following:

1.3.1 Why copper metal and not water is oxidised at the anode. (2)

1.3.2 With reference to the potential difference applied in the purification, explain why iron and zinc will be oxidised at the anode, but gold and silver are not.
(3)

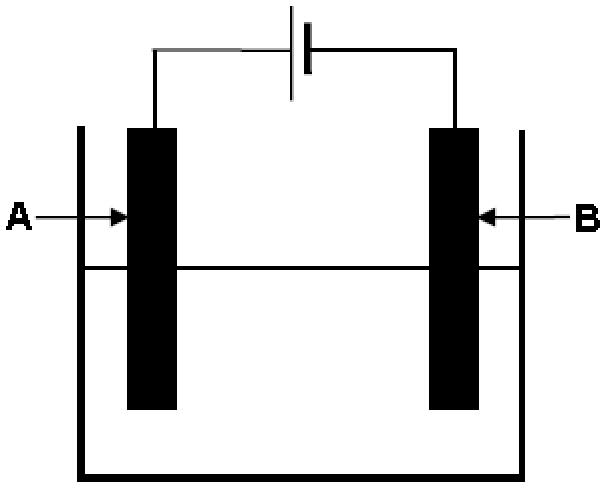
1.3.3 Why Fe^{2+}(aq) and Zn^{2+}(aq) are not reduced at the cathode. (2)

1.4 Write down the net cell reaction for the purification of impure copper metal. (2)

[11]

ACTIVITY 2

The diagram below shows an electrochemical cell used to purify copper. A solution that conducts electricity is used in the cell.



2.1 Write down:

2.1.1 ONE word for the underlined phrase above the diagram (1)
2.1.2 The type of electrochemical cell illustrated above (1)

2.2 In which direction (**from A to B** or **from B to A**) will electrons flow in the external circuit? (1)

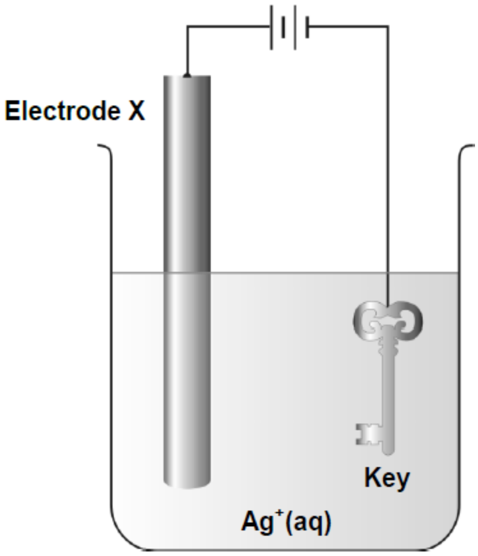
2.3 Which electrode (**A** or **B**) is the:

2.3.1 Cathode (1)
2.3.2 Impure copper (1)

2.4 How will the mass of electrode A change as the reaction proceeds? Choose from INCREASES, DECREASES or REMAINS THE SAME.

Give a reason for the answer. (2)

2.5 Nkhensani sets up the following electrolytic cell with the aim of coating a key with silver metal:



2.5.1 What is this electrolytic process called? (1)

2.5.2 Is the key the ANODE or the CATHODE? (1)

2.5.3 With reference to the relative strengths of the reacting substances (relative strengths of agents), explain why silver will be the predominant substance formed at the key. (3)

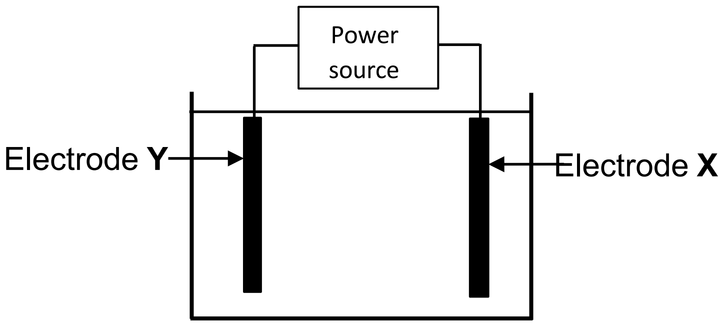
2.5.4 What is electrode **X** usually made from? (1)

[13]

ACTIVITY 3

The apparatus below is used to demonstrate the electrolysis of a concentrated sodium chloride solution. Both electrodes are made of carbon. A few drops of universal indicator are added to the electrolyte. The equation for the net cell reaction is:

$2NaC\ell(aq) + 2H_2O(\ell) \rightarrow C\ell_2(g) + H_2(g) + 2NaOH(aq)$



Initially the solution has a green colour. Universal indicator becomes red in acidic solutions and purple in alkaline solutions.

3.1 Define the term *electrolyte*. (2)

When the power source is switched on, the colour of the electrolyte around electrode **Y** changes from green to purple.

3.2 Write down the half-reaction that takes place at electrode **Y**. (2)

3.3 Write down the NAME or FORMULA of the gas released at electrode **X**. (1)

3.4 Refer to the Table of Standard Reduction Potentials to explain why hydrogen gas, and not sodium, is formed at the cathode of this cell. (2)

[7]

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