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TOPIC 4: ELECTROLYSIS

THE ABOUT

CHAPTER ANALYSIS

TIME

- Very **difficult** chapter
- **4** electrolytic cell set-up
- **1** simple electric cell set-up

EXAM

- Usually tested in both MCQ & Paper 2
- Will need prior knowledge from other chapters: Oxidation & Reduction, Chemical Equations

WEIGHTAGE

- Medium overall weightage
- Constitute to **4%** of marks for past 5 year papers

Chapter Overview

This is probably one of the most difficult chapter in 'O' Level Chemistry.

So let's break down the chapter first before proceeding.

USING REACTIVE ELECTRODE

- 4 ions present
- Selectively discharged
- **Electroplating** can occur if object is placed at cathode as metal cations would deposit itself onto the object

ELECTROLYSIS & ELECTRIC CELL

MOLTEN

- Only 2 ions present
- Both ions will definitely be discharged

DILUTE

- 4 ions present
- Selectively discharge based on **ease of discharge**

CONCENTRATED

- 4 ions present
- Cation follows normal **ease of discharge**
- Anion **follows 'concentrated' ease of discharge**

SIMPLE ELECTRIC CELL

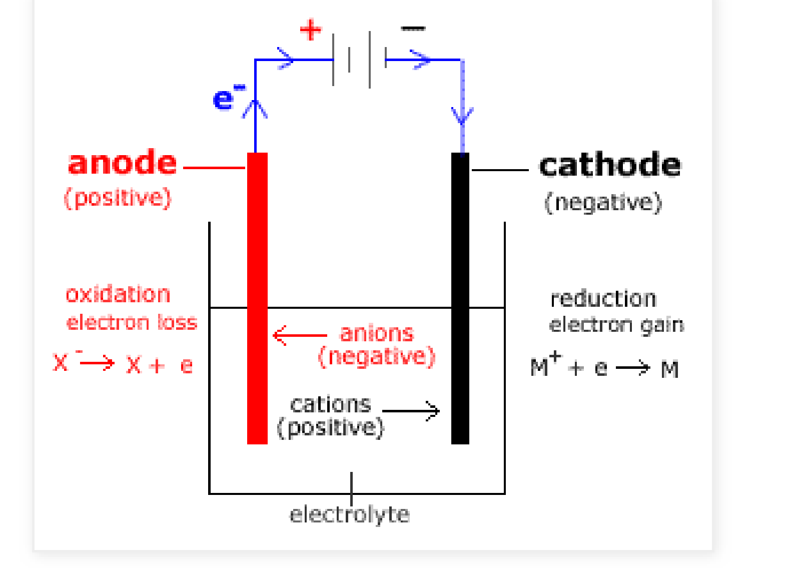
- Use chemical reaction to produce electricity
- Require **2 metals of differing reactivity**
- Does not require electric source

KEY CONCEPT

All of the 4 scenarios falls under electrolytic cell.
Let's aim to get our basics right!

ELECTROLYTIC CELL
MOLTEN IONIC COMPOUND
AQUEOUS IONIC COMPOUND
CONCENTRATED IONIC COMPOUND
ELECTROPLATING

ELECTROLYTIC CELL

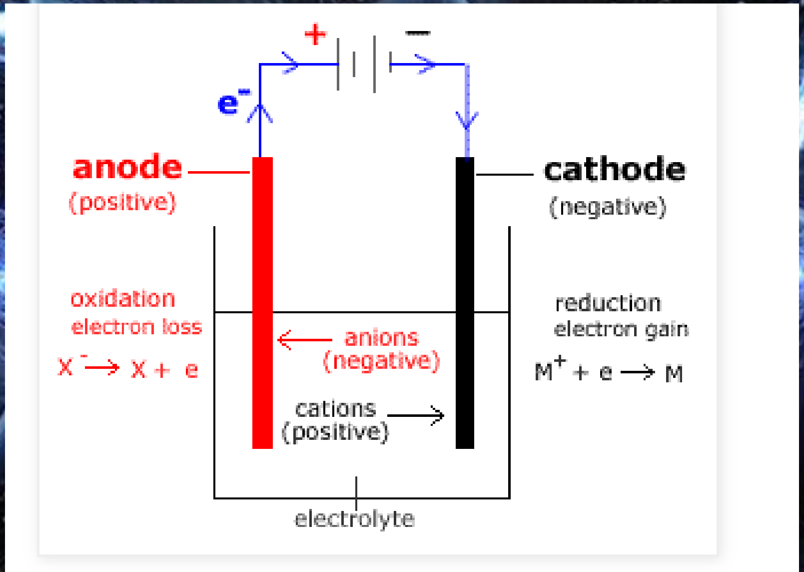


ELECTROLYTIC CELL

An electrolytic cell is the set-up used for electrolysis.

Key components:
Electrolyte is the ionic compound, either in its molten or aqueous state, that would dissociate into ions when a current is passed through it.
Electrodes are made of a conductive material. For inert electrodes, it is usually made of lead or platinum.
Anode is the positively-charged electrode that is connected to the positive terminal of the electrical source. (Anode is positively charged & **attracts anions**, hence its called 'anode'.)
Cathode is the negatively-charged electrode that is connected to the negative terminal of the electrical source. (Cathode is negatively charged & **attracts cations**, hence its called 'cathode'.)
Battery/power source causes electrons to always flow from the anode to the cathode. (For those who take physics, under 'electricity', recall that electron flow is from the negative terminal to the positive terminal of the battery.)

ELECTROLYTIC CELL



I advise all students to try and understand this concept rather than memorising.

Try and understand the logic. Opposite charges attract, so ions move to the respective electrodes that attract them. At the electrodes, they either gain or lose electrons, in order to become neutral again.

It is a logical process that once you understand the 'why', you no longer need to memorise.

ELECTROLYTIC CELL

Anode is the **positively-charged** electrode, as it is connected to the positive terminal of the battery.

During electrolysis, anions are attracted to the positively charged anode.

Anions are **negatively charged** and are looking to **lose electrons** to become neutral.

Hence, as anions lose electrons **at the anode**, they undergo **oxidation**.

Cathode is the **negatively-charged** electrode, as it is connected to the negative terminal of the battery.

During electrolysis, cations are attracted to the negatively charged anode.

Cations are **positively charged** and are looking to **gain electrons** to become neutral.

Hence, as cations gain electrons **at the cathode**, they undergo **reduction**.

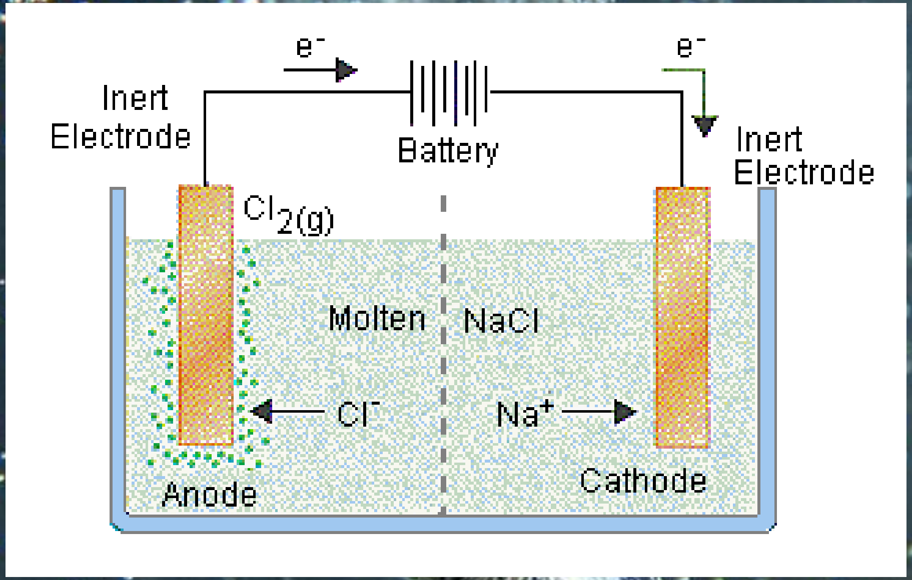
AOCR ANODE OXIDATION CATHODE REDUCTION

3 variations

All 3 variations of electrolytic cell follows the same concept you have learnt in the previous 2 slides.

Let's run through how the concept applies and what's the difference between the 3 set-ups.

Electrolysis of molten ionic compound



This is the most simple set up. There are only 2 ions present: **Na^+** and **Cl^-**.

Cl^- goes to anode and gets oxidised to **Cl_2 (g).**

Na^+ goes to cathode and gets reduced to **Na (l)**.

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ELECTROLYSIS OF MOLTEN SODIUM CHLORIDE

Component	Explanation
Ions present	Na^+ , Cl^-
Observation	Tiny globules of molten sodium, a silvery liquid, would begin to form at the cathode and float to the surface. Yellow-green chlorine gas is produced at the anode which would turn moist blue litmus paper red and bleaches it.
At the anode (positive terminal)	$2Cl^-$ (l) → Cl_2 (g) + $2e^-$ Chloride ions are attracted to the anode and are oxidised to chlorine gas which will turn damp blue litmus paper red, and bleach it white.
At the cathode (negative terminal)	Na^+(l) + e^- → Na (l) Sodium ions are attracted to the cathode and are reduced to globules of liquid sodium metal.
Overall change	2NaCl (l) → 2Na (l) + Cl_2 (g) (redox reaction)

EASE OF DISCHARGE

Cations (goes to cathode & undergo reduction)
K^+
Na^+
Ca^{2+}
Mg^{2+}
Al^{3+}
Zn^{2+}
Fe^{2+}
Pb^{2+}
H^+
Cu^{2+}
Ag^+
Au^+

Anions (goes to anode & undergo oxidation)	
DILUTE	**CONCENTRATED**
SO_4^{2-}	SO_4^{2-}
NO_3^-	NO_3^-
F^-	**OH^-**
Cl^-	F^-
Br^-	Cl^-
I^-	Br^-
OH^-	I^-

Ease of discharge increases down the series

EASE OF DISCHARGE

Before we move on to the electrolysis of dilute aqueous solution, we need to understand **ease of discharge.**

As there are usually the presence of 2 cations and 2 anions in a dilute aqueous solution, **ease of discharge** helps us **identify which cation & anion gets selectively discharged.**

For cations, the less reactive is it on the reactivity series, the more easily it can get discharged.

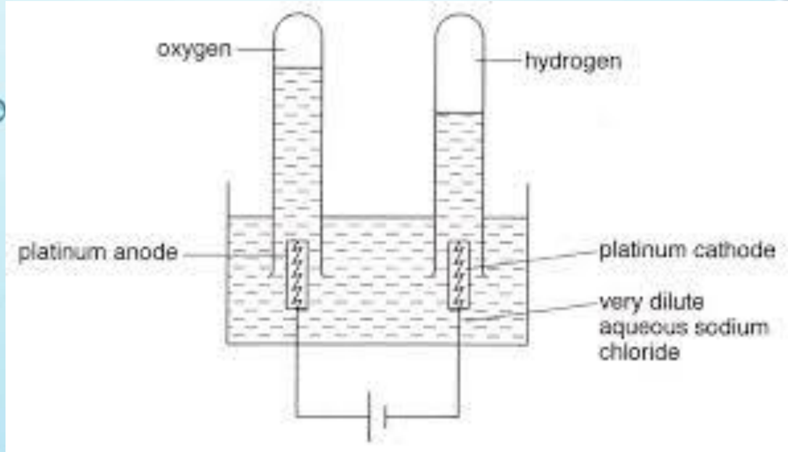
For anions, OH^- is the easiest to discharge, followed by halogens, then the common anions.

(Group VII, reactivity decreases down the group. The less reactive, the more easily it will get discharged.)

However, when it is a concentrated solution/the solution becomes concentrated, **concentration effect** will result in the **halogens** to be preferentially discharged over OH^- ions.

*Quick tip: For a normal aqueous ionic compound (excluding copper), H^+ & OH^- is usually the ones who get discharged.

Electrolysis of dilute ionic compound



This is the most common set up. There are 4 ions present: **Na^+ H^+, Cl^- , OH^-**

Therefore, we have to use the ease of discharge table to decide which ions get preferentially discharged.

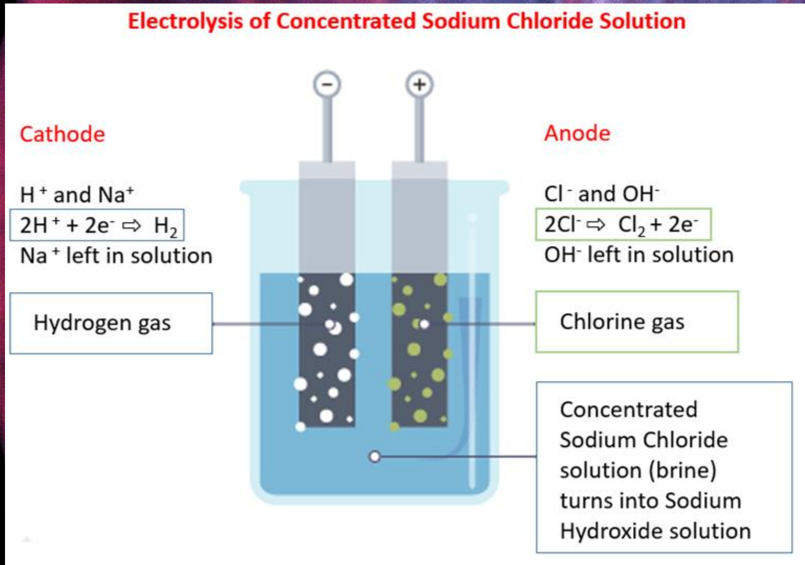
AOCR still applies. Anode Oxidise, Cathode Reduce.

AOCR

ELECTROLYSIS OF DILUTE SODIUM CHLORIDE

Component	Explanation
Ions present	Na^+, Cl^- , H^+, OH^-
Observation	When current is switched on, colourless hydrogen gas bubbles and is formed at the cathode while colourless oxygen gas bubbles and is formed at the anode.
At the anode (positive terminal)	$4OH^-$ (aq) → O_2 (g) + $2H_2O$ (l) + $4e^-$ Both Cl^- and OH^- ions are attracted to the anode, but OH^- is preferentially discharged and is oxidised. Oxygen gas is formed, which will relight a glowing splint.
At the cathode (negative terminal)	$2H^+$ (aq) + $2e^-$ → H_2 (g) Both Na^+ and H^+ ions are attracted to the cathode, but H^+ is preferentially discharged and is reduced. Hydrogen gas is formed, which will extinguish a lighted splint with a 'pop' sound.
Overall change	$2H_2O$ (l) → O_2 (g) + $2H_2$ (g) (redox reaction) Since only H^+ and OH^- ions are discharged and the pH of the solution remains the same. However, the solution becomes more concentrated.

Electrolysis of concentrated ionic compound



Anions (goes to anode & undergo oxidation)	
DILUTE	CONCENTRATED
SO_4^{2-}	SO_4^{2-}
NO_3^-	NO_3^-
F^-	**OH^-**
Cl^-	F^-
Br^-	Cl^-
I^-	Br^-
OH^-	I^-

Since this is a **concentrated solution**, so the ease of discharge for anions will be different.

Halogens will be preferentially discharged over OH^- ions.

No change for cations. Still H^+.

AOCR still applies. Anode Oxidise, Cathode Reduce.

AOCR

ELECTROLYSIS OF CONCENTRATED SODIUM CHLORIDE

Component	Explanation
Ions present	Na^+, Cl^-, H^+, OH^-
Observation	When current is switched on, bubbling of colourless hydrogen gas forms at the cathode, yellowish-green chlorine gas appear at the anode.
At the anode (positive terminal)	$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$ Both Cl^- and OH^- ions are attracted to the anode, but Cl^- is selectively discharged due to concentration effect, and being oxidised to chlorine gas. Bubbling of chlorine gas is formed, which will turn damp blue litmus paper red and bleaches it white.
At the cathode (negative terminal)	$2H^+(aq) + 2e^- \rightarrow H_2(g)$ Both Na^+ and H^+ ions are attracted to the cathode, but H^+ is preferentially discharged and undergoes reduction. Bubbling of hydrogen gas is formed, which will extinguish a lighted splint with a 'pop' sound.
Overall change	$2NaCl(aq) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g) + Cl_2(g)$ (redox reaction) Since Na^+ and OH^- ions remain in the solution, the solution becomes more alkaline.

Quick Recap

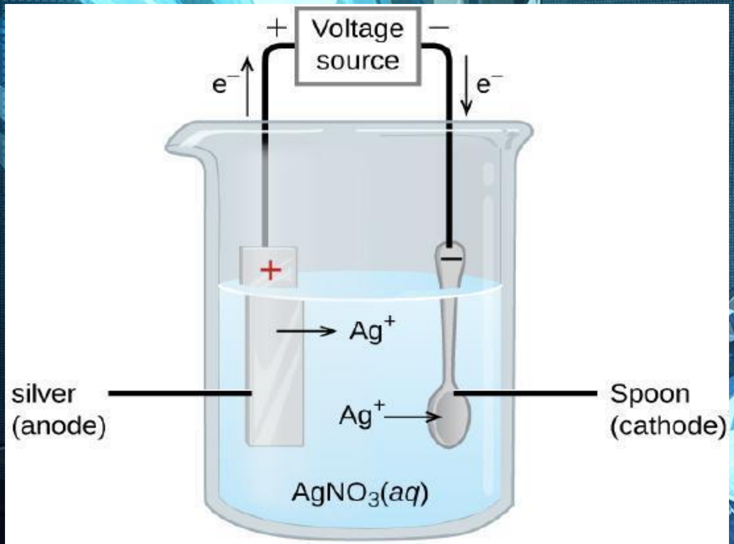
All 3 variations of electrolytic cell will result in *slightly different* outcomes, however, the application of electrolytic cell remains the same.

AOCR

So far, our electrodes has been **inert (unreactive).**

Next, let's explore what happens when we use **reactive electrodes**.

Electroplating using silver electrodes



AOCR still applies. Anode Oxidise, Cathode Reduce.

The difference is that instead of anions from the solution getting oxidised, the silver anode (reactive) gets oxidised to form **Ag^+ ions** instead.

At the cathode, **Ag^+** ions are selectively discharged and reduced back to silver metal, which causes the silver metal to be **electroplated** onto the spoon.

AOCR

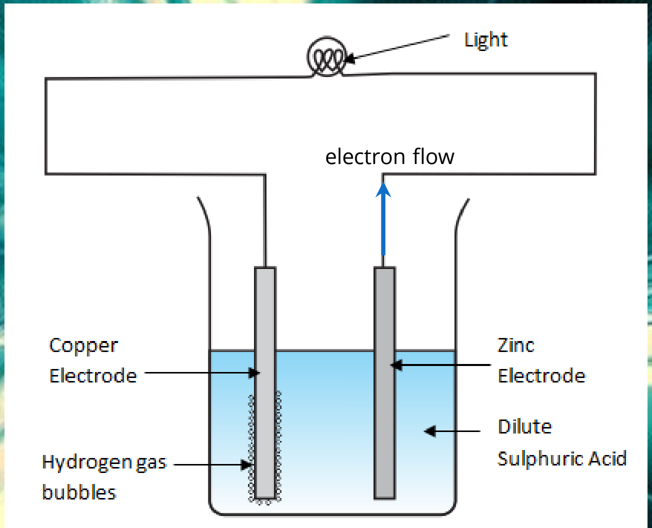
ELECTROPLATING

Component	Explanation
Ions present	Ag^+, NO_3^-, H^+, OH^-
Observation	When the current is switched on, silver metal forms at the cathode while bubbles of colourless hydrogen gas appear at the anode.
At the anode (positive terminal)	$Ag (s) \rightarrow Ag^+ (aq) + e^-$ Both NO_3^- and OH^- ions are attracted to the anode, but neither of them gets discharged. Instead, the silver anode is oxidised to silver ions flowing into the solution.
At the cathode (negative terminal)	$Ag^+ (aq) + e^- \rightarrow Ag (s)$ As silver is below hydrogen in the reactivity series, Ag^+ ions are selectively discharged. They undergo reduction to become silver metal which is deposited onto the surface of the object. The object becomes silver-plated.
Overall change	The object becomes silver plated and increasing in mass while the silver anode loses mass and reduce in size. The silver ions discharged at the cathode are continuously replaced by the oxidation of silver metal at the anode, resulting in the amount of silver ions in the solution remaining the same.

KEY CONCEPT

ELECTRIC CELL
SIMPLE ELECTRIC CELL

Simple Electric Cells



AOCR still applies. Anode Oxidise, Cathode Reduce.

The more reactive metal undergoes oxidation and gives up electrons.

The electrons then goes to the less reactive metal where reduction occurs.

AOCR

SIMPLE ELECTRIC CELL

Electric cells uses **chemical energy to produce electricity**, unlike electrolysis, which uses electricity to cause chemical changes.

A simple, typical electric cell contains **two different electrodes** placed in an electrolyte.

More reactive metal (Zinc)

The more reactive metal gives up electrons more readily and is the negative electrode. The metal is **oxidised** here, hence this is the **anode**.

$$Zn\ (s) \rightarrow Zn^{2+}\ (aq) + 2e^-$$

Less reactive metal (Copper)

The less reactive metal would be the positive electrode. As **reduction** occurs here, this is the **cathode.**

$$2H^+\ (aq) + 2e^- \rightarrow H_2\ (g)$$

Overall

The more reactive metal's electrons would flow to the less reactive metal.

The voltmeter will detect a **potential difference** between the two metals. *(electricity produced)*

The **further apart** the two metals are in the reactivity series, the **greater the voltage** shown on the voltmeter or the brighter the light bulb.

ADVANCED

word of advice

Learning the basics is one thing, being able to **apply and solve questions** is way more important.

Please be **diligent** and do some practices and see if you are able to **apply the concepts**!

AOCR

The one and only constant through the chapter, electrolytic cell or electric cell.

If you cannot remember anything from this chapter, the minimum is:
Anode Oxidise, Cathode Reduce.

Selective discharge and Concentration effect

Take notice of which ions gets discharged for different scenarios.

Most of the time:

$$\textbf{ANODE: } 4OH^-\,(aq) \rightarrow O_2\,(g) + 2H_2O\,(l) + 4e^-$$
$$\textbf{CATHODE: } 2H^+\,(aq) + 2e^- \rightarrow H_2\,(g)$$

But if there is **Cu^{2+}** or if its **molten/ concentrated**, we need to apply selective discharge or concentration effect.

Leftover ions

After the respective discharge at the anode and cathode, there will be **the leftover ions** in the solution that did not discharge.

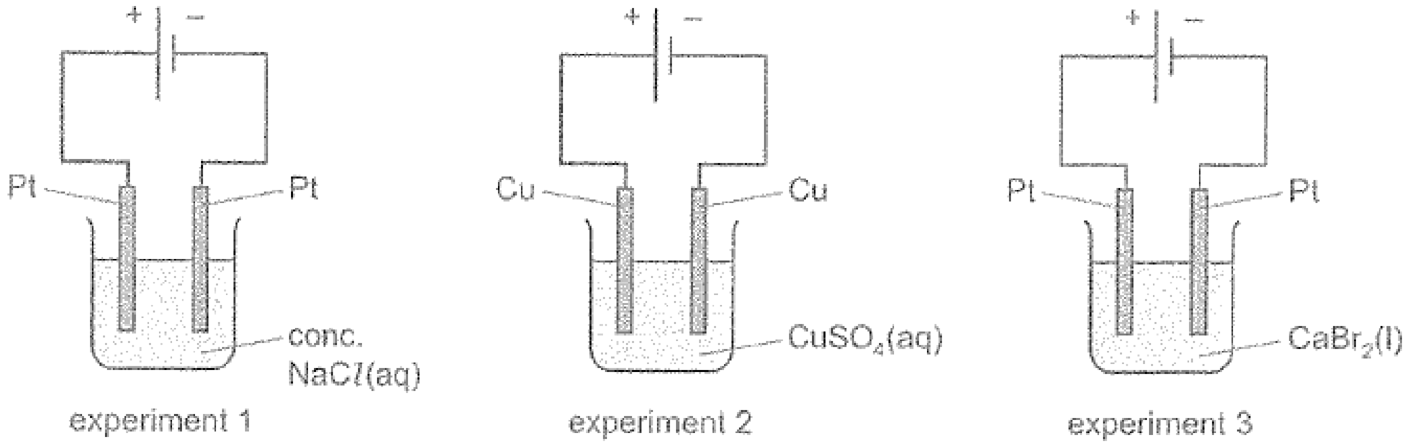
These ions can cause a **difference to the solution**.

For example, for a **$CuSO_4$** solution, Cu^{2+} & OH^- gets discharged while **H^+ & SO_4^{2-} remains.**

The solution turns **less blue** as Cu^{2+} is discharged and **more acidic** as H_2SO_4 remains.

Try it yourself! (TYS Question)

18. Three different compounds are electrolysed.



Which experiments produce a gas at the negative electrode? (N2020/P1/Q12)

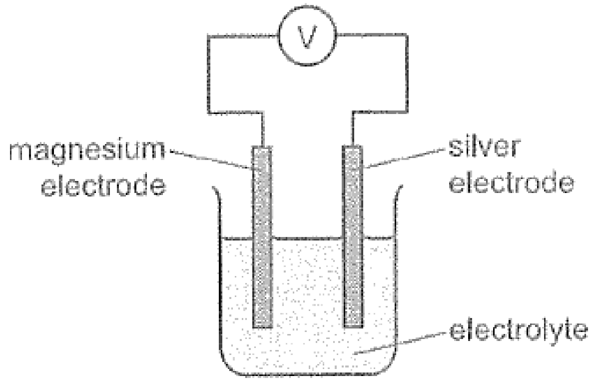
A 1 only **B** 2 only
C 1 and 3 **D** 2 and 3 (   )

Answer:

18. **A**
The negative electrode attracts cations (positive ions) which get reduced by gaining electrons.
In experiment 1, the product at the negative electrode is H_2.
In experiment 2, the product at the negative electrode is Cu.
In experiment 3, the product at the negative electrode is Ca.

Try it yourself! (TYS Question)

19. The diagram shows a cell.



Which statement about the cell is correct? (N2020/P1/Q13)

A Electrons pass from the magnesium electrode to the silver electrode through the electrolyte.
B The cell shows that silver is more reactive than magnesium.
C The magnesium electrode loses electrons.
D The silver electrode is oxidised. ( )

Answer:

19. **C**
The more reactive metal loses electrons.

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