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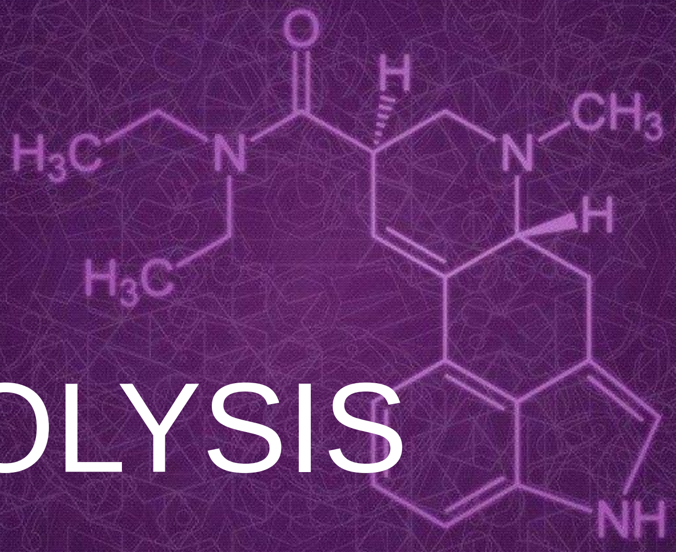
TOPIC 4: ELECTROLYSIS



THE ABOUT

CHAPTER ANALYSIS

TIME

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

EXAM

- Usually tested in Section B
- Will need prior knowledge from other chapters: Oxidation & Reduction, Chemical Equations

WEIGHTAGE

- Medium overall weightage
- Constitute to **3%** 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

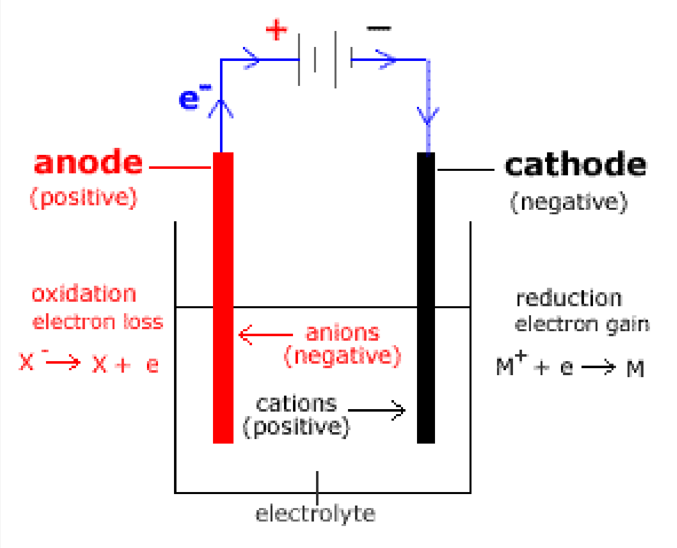
KEY CONCEPT

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 apparatus used for electrolysis.

Key components:

Electrolyte is the ionic compound that dissociates into ions when a current is passed through it when it is in its molten or aqueous state.

Electrodes are made of a conductive material. There are two electrodes – anode & cathode.

Anode is the **positively-charged** electrode, connected to the positive terminal of the electrical source.

(Anode is positively charged & attracts anions, hence its called 'anode'.)

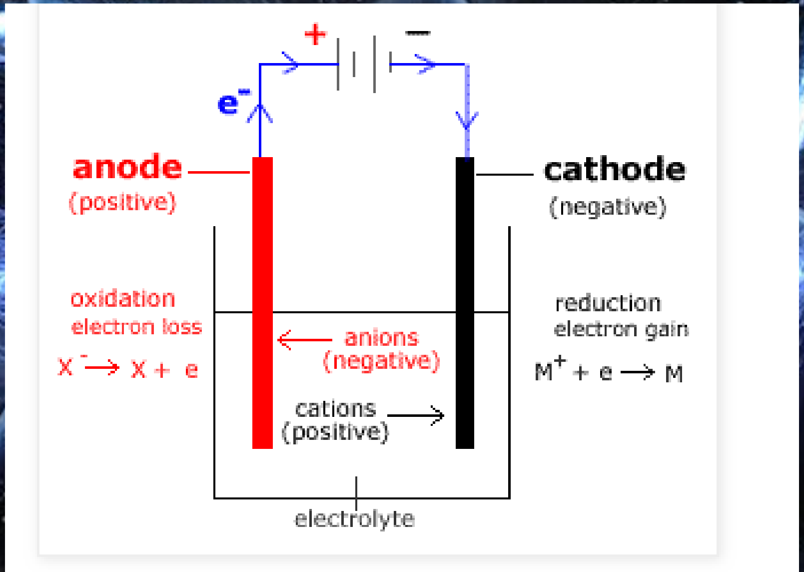
Cathode is the **negatively-charged** electrode that is connected to the negative terminal of the electrical source.

(Cathode is negatively charged & attracts cations, hence its called 'cathode'.)

Battery/power source acts as an electron pump that 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 comprehend the logic. Opposite charges attract, so ions move to the respective electrodes. They then 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, connected to the positive terminal of the electrical source.

During electrolysis, anions flock to the positively charged anode.

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

Hence **oxidation occurs at the anode** as anions lose electrons, becoming oxidised in the process.

Cathode is the **negatively-charged** electrode, connected to the negative terminal of the electrical source.

During electrolysis, cations flock to the negatively charged anode.

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

Hence **reduction occurs at the cathode** as cations gain electrons, becoming reduced in the process.

AOCR

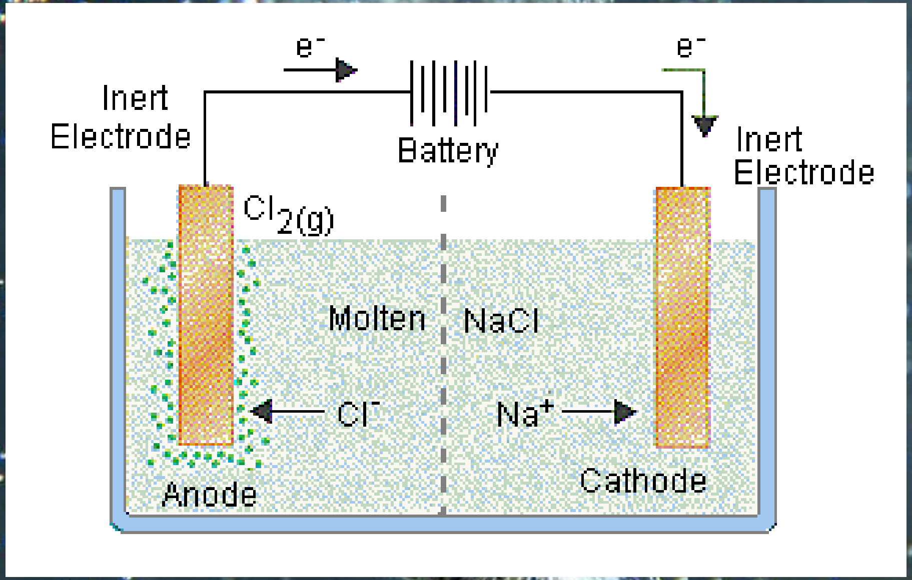
ANODE OXIDATION
CATHODE REDUCTION

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)**.

ELECTROLYSIS OF MOLTEN SODIUM CHLORIDE

Component	**Explanation**
Ions present	**Na^+ , Cl^-**
Observation	When current is passed through molten sodium chloride, electrolysis occurs. Tiny globules of molten sodium, a silvery liquid, form at the cathode and float to the surface. They burn in air with a yellow flame. Yellow-green chlorine gas evolves at the anode which turns moist blue litmus paper red and bleaches it.
At the anode (positive terminal)	**$2Cl^-$ (l) → Cl_2 (g) + $2e^-$** Electrons flow out of the anode and into the positive terminal of the battery, causing the anode to be positively charged. 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)** Electrons flow out of the negative terminal and into the cathode, causing the cathode to be negatively charged. 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)
Electrodes	The carbon electrodes are **inert** electrodes and do not take part in the 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

<u>EASE OF DISCHARGE</u>

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

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

For cations, the less reactive a metal, the more easily it can get discharged.

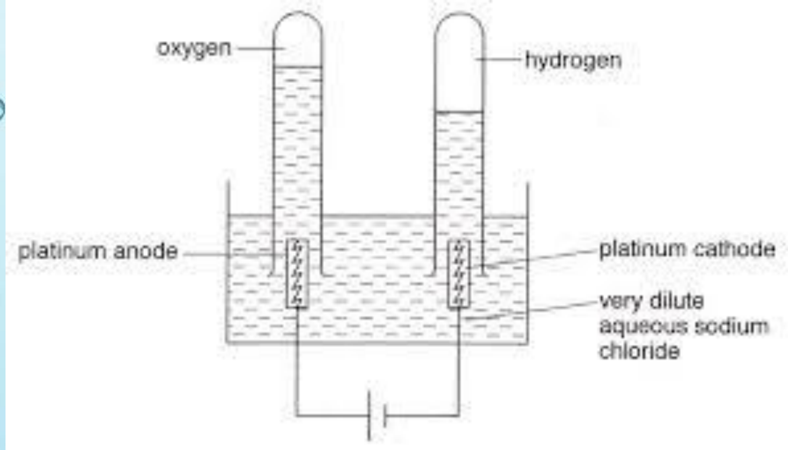
For anions, OH^- is the easiest to discharge, followed the halogens, then the common anions.

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

However, when it is a concentrated solution, **concentration effect** will cause the **halogens** to preferentially discharge 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.

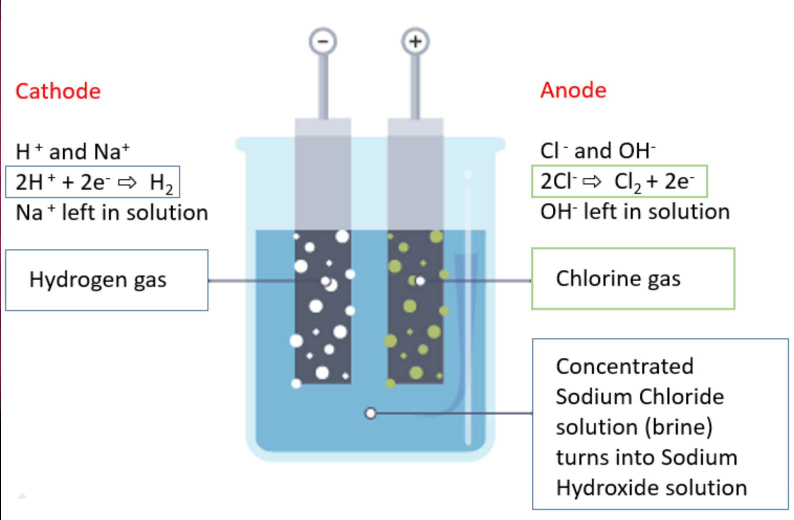
AOCR

ELECTROLYSIS OF DILUTE SODIUM CHLORIDE

Component	Explanation
Ions present	**Na^+, Cl^- , H^+, OH^-**
Observation	When current is passed through, bubbles of colourless hydrogen gas forms at the cathode while bubbles of colourless oxygen gas forms at the anode.
At the anode (positive terminal)	**$4OH^-$ (aq) → O_2 (g) + $2H_2O$ (l) + $4e^-$** Both Cl^- and OH^- are attracted to the anode, but **OH^- is preferentially discharged** and is **oxidised**. Bubbles of oxygen gas form, which will relight a glowing splint.
At the cathode (negative terminal)	**$2H^+$ (aq) + $2e^-$ → H_2 (g)** Both Na^+ and H^+ are attracted to the cathode, but **H^+ is preferentially discharged** and is **reduced**. Bubbles of hydrogen gas form which will extinguish a lighted splint with a 'pop' sound.
Overall change	**$2H_2O$ (l) → O_2 (g) + $2H_2$ (g)** (redox reaction) Since H^+ and OH^- ions are discharged and there is no change in the pH of the solution. However, the solution becomes more concentrated.
Electrodes	The carbon electrodes are **inert** electrodes and do not take part in the reaction.

Electrolysis of concentrated ionic compound

Electrolysis of Concentrated Sodium Chloride Solution



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^-

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

So halogens will get 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 passed through, bubbles 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 **$OH^-$** are attracted to the anode, but **Cl^-** is selectively discharged due to **concentration effect**, and oxidised to chlorine gas. Bubbles of chlorine gas form which will turn damp blue litmus paper red and bleach it white.
At the cathode (negative terminal)	**$2H^+ (aq) + 2e^- \rightarrow H_2 (g)$** Both Na^+ and H^+ are attracted to the cathode, but **H^+ is preferentially discharged** and is **reduced**. Bubbles of hydrogen gas form 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) This is a redox reaction. Since Na^+ and OH^- ions are not discharged and remain in the solution, the solution changes from neutral to alkaline.
Electrodes	The carbon electrodes are **inert** electrodes and do not take part in the reaction.

Quick Recap

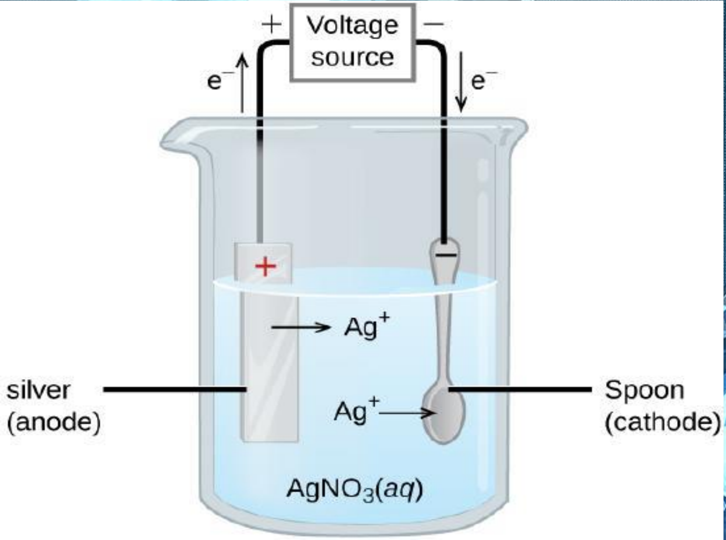
All 3 variations of electrolytic cell will result in *slightly different* outcomes, however, the application of electrolytic cell remains the same.

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 getting oxidised, the silver anode (reactive) gets oxidised into **Ag^+** instead.

At the cathode, **Ag^+** is selectively discharged and reduced back to silver metal, which is **electroplated** onto the object.

AOCR

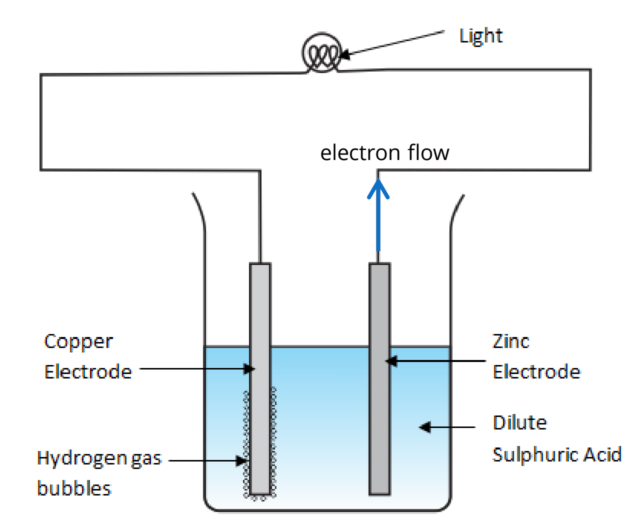
ELECTROPLATING

Component	Explanation
Ions present	**Ag^+, NO_3^-, H^+, OH^-**
Observation	When a current is passed through, 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 **$OH^-$** are attracted to the anode, but neither is discharged. Instead, the **silver anode erodes** as the silver goes into the solution to form **silver ions**.
At the cathode (negative terminal)	**$Ag^+\ (aq) + e^- \rightarrow Ag\ (s)$** Silver is below hydrogen in the reactivity series. Hence, **Ag^+** is selectively discharged and gets reduced to silver metal which is deposited onto the object. The object becomes **silver-plated**.
Overall change	The object becomes silver plated while the **silver anode loses mass and becomes smaller.** The silver ions discharged at the cathode are continuously replaced by the oxidation of silver metal at the anode.
Electrodes	The silver electrodes are reactive and are selectively discharged at both the cathode and the anode.

KEY CONCEPT

ELECTRIC CELL
SIMPLE ELECTRIC CELL

Simple Electric Cells



AOCR still applies. Anode Oxidise, Cathode Reduce.

The more reactive metal get oxidised and gives up electrons.

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

AOCR

SIMPLE ELECTRIC CELL

Electric cells use **chemical energy to produce electricity**. This is the opposite of electrolysis, which uses electricity to produce 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 becomes the negative electrode. At this **anode**, the metal is **oxidised**.

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

Less reactive metal (Copper)

The less reactive metal thus becomes the positive electrode. At this **cathode, reduction** occurs here.

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

Overall

The electrons flow from the more reactive metal to the less reactive metal.

A **redox reaction** has occurred as there is a flow of electrons from zinc to hydrogen to produce electricity.

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:

ANODE: $4OH^- (aq) \rightarrow O_2 (g) + 2H_2O (l) + 4e^-$
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.