Lesson on Electrolysis

This lesson package includes a lesson plan, a worksheet for students, and teachers' notes on the worksheet.

Activity	**5E**– Engage, Explore, Explain, Elaborate, Evaluate **PRO** – Principles, Reasoning, Outcome	**Modes of representation**
Lesson 1 (50 min-2 Period lesson) Teacher explains (page 1 to 2 of worksheet) a) what electrolysis is b) the parts and functions of an electrolytic cell c) what electrolytes are		
Step 1- Teacher shows video from YouTube [https://youtu.be/NfNIn4R8tg4]. Video shows experiment using solid and then molten NaCl for electrolysis. Students to note down their observations, the possible reasons for the observations, and the possible underlying principles (page 3 of worksheet)	Students explore the scenario through watching-experiments Students explain the phenomena observed (attempting PRO) Note: If students have not been taught PRO structure previously, may use this task to teach them the structure.	Visual (in worksheet and through video) Written
Step 2- Teacher to teach sections 4 and 5. Emphasis on section 4.	Teacher may model the PRO structure in his/her explanation	
Step 3 – Students attempt the concept test (pg 4 of the worksheet)	Students attempt the concept test by applying the PRO structure	Written

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Activity	**5E**– Engage, Explore, Explain, Elaborate, Evaluate **PRO** – Principles, Reasoning, Outcome	**Modes of representation**
Lesson 2 & 3 (1h 50 min - 4 Period lesson, lessons were swopped to allow for longer duration) Step 1 – 8 stations with 8 groups of students. 2 identical stations for each different set-up. (refer to pages 7-10 of worksheet) At each station, students draw a required diagram, indicate what they observed, and attempt to explain the chemistry behind what they observed. Teacher facilitates students' discussion by moving from group to group to listen to their explanation and asking questions to clarify their explanation. Teacher may use the PRO structure to probe students' explanation. Step 2: Selected students present their answers Teacher facilitates the presentation by clarifying (if necessary) a) electrolysis of aqueous solutions of ionic compounds b) selective discharge of cations c) selective discharge of anions d) selective discharge of anions due to effect of concentration	Students to explain the chemistry behind what was observed. Explore: Teacher, while moving from group to group, may choose to drop some indicator (e.g. universal indicator) into the set up and ask students to explain what they see and to link to what they understood from the reactions happening at each electrode	Visual Written : in explaining their explanation to the teacher Verbal Verbal

Activity	**5E**– Engage, Explore, Explain, Elaborate, Evaluate **PRO** – Principles, Reasoning, Outcome	**Modes of representation**
and asks about phenomenon that happened unexpectedly.		
Step 3. Teacher revisits the stations and uses 4.1 to model how PRO can be done	Explore: e.g. after electrolysis of aqueous NaCl, the solution becomes concentrated, so their later observation would be different. Students to explore why this would be the case.	
Step 4- After teacher's modeling of PRO (based on station 4), the students fill in "My refined explanation" for stations 1 to 3	Students refine and elaborate on their explanation, explicitly applying the PRO structure this time	Written
*HW: Students to consolidate their learning (pg 11 and 12).	Students provide an explanation based on the scenario provided.	Written and Visual (diagram required – may also get students to use a different colour to indicate P R and O)
Lesson 4 (50 min) Step 1: Review HW with students		
Step 2: Students attempt to explain a given case scenario (pg 13) on the Electrolysis of copper (II) sulfate solution using INERT electrodes	Students explain the phenomena observed using a diagram and writing	Visual Written
Step 3- Students attempt a concept test (pg 13)	Students use the PRO structure taught for the concept test	Written
Teacher explains the electrolysis of copper (II) sulfate solution using reactive electrodes		

Activity	**5E**– Engage, Explore, Explain, Elaborate, Evaluate **PRO** – Principles, Reasoning, Outcome	**Modes of representation**
Teacher explains applications of what was learnt a) purification of impure copper b) electroplating Teachers explains the concept of simple cells Teacher sums up the differences between an electrolytic cell and a simple cell		

Electrolysis

Electrolysis

(a) describe electrolysis as the conduction of electricity by an ionic compound (an electrolyte), when molten or dissolved in water, leading to the decomposition of the electrolyte

(b) describe electrolysis as evidence for the existence of ions which are held in a lattice when solid but which are free to move when molten or in solution

(c) describe, in terms of the mobility of ions present and the electrode products, the electrolysis of molten sodium chloride, using inert electrodes

(d) predict the likely products of the electrolysis of a molten binary compound

(e) apply the idea of selective discharge based on
- **(i)** cations: linked to the reactivity series
- **(ii)** anions: halides, hydroxides and sulfates (e.g. aqueous copper(II) sulfate and dilute sodium chloride solution (as essentially the electrolysis of water))
- **(iii)** concentration effects (as in the electrolysis of concentrated and dilute aqueous sodium chloride)

(In all cases above, inert electrodes are used.)

(f) predict the likely products of the electrolysis of an aqueous electrolyte, given relevant information

(g) construct ionic equations for the reactions occurring at the electrodes during the electrolysis, given relevant information

(h) describe the electrolysis of aqueous copper(II) sulfate with copper electrodes as a means of purifying copper (no technical details are required)

(i) describe the electroplating of metals, e.g. copper plating, and state one use of electroplating

(j) describe the production of electrical energy from simple cells (i.e. two electrodes in an electrolyte) linked to the reactivity series and redox reactions (in terms of electron transfer)

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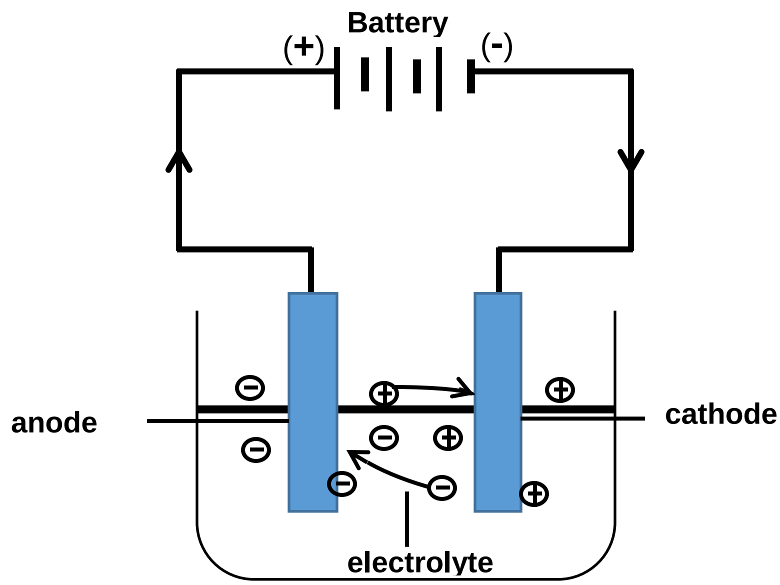
1 Introduction

Electrolysis is the process of using electricity to break down or decompose a compound. It has an important use in the **extraction of useful elements from compounds.**

2 Parts of an electrolytic cell



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• attracts negatively charged ions
• oxidation occurs</td><td>• connected to (-) terminal of battery
• attracts positively charged ions
• reduction occurs</td></tr>
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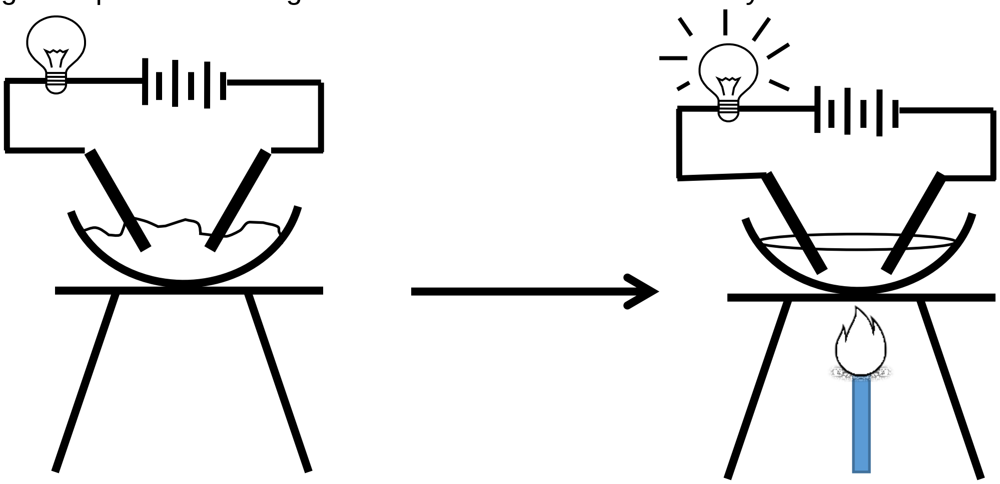
3 Electrolytes

Electrolytes are **ionic compounds** that **can conduct electricity** either in molten or aqueous states.

E.g. Comparison of using solid and molten NaC*l* for electrolysis.



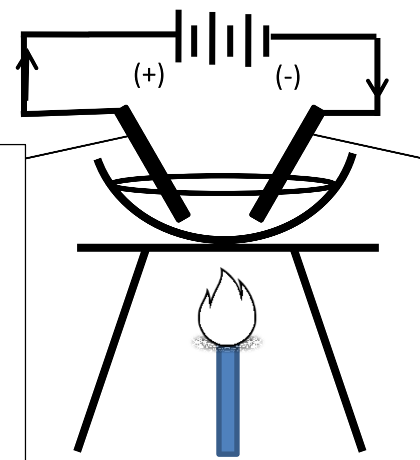
Solid NaC*l*	Molten NaC*l*
Observation:	**Observation:**
Reason: .	**Reason:**
Principle:	**Principle:**

4. Electrolysis of Molten Ionic Compounds

Molten ionic compounds are usually **binary. This** means it **contains only two elements**, a metal cation (e.g. Na^+) and a non-metal anion (e.g. Cl^-).

When such binary compounds, e.g. Na*Cl*, undergoes electrolysis, a metal (Na) and a non metal (Cl_2) are produced.

4.1 *The electrolysis of molten NaCl ♡



Carbon anode

- Attracts negative ions (Cl^-)
- Cl^- ions are discharged via the process of oxidation:

$2Cl^-\ (aq) \rightarrow Cl_2\ (g) + 2e$

Carbon cathode

- Attracts positive ions (Na^+)
- Na^+ ions are discharged via the process of reduction:

$Na^+\ (aq) + e \rightarrow Na\ (l)$

4.2 *Use of carbon electrodes

Chlorine formed at the carbon anode is highly reactive. Hence, the choice of electrode is important. Carbon is inert (does not react easily with other chemicals), so its use as an electrode can prevent further reaction with the chlorine formed at the anode.

Concept Test

1 Molten lithium chloride is electrolysed using carbon electrodes.

P	
R	
O	

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5. Electrolysis of Aqueous solutions of Ionic Compounds

In an aqueous solution of ionic compounds, it is important to recognise the presence of water in the solution. As such, apart from the metal cation and non-metal anion, there is also the presence of H^+ and OH^- (both coming from water).

E.g. In an aqueous solution of NaC*l*, the following ions are present: Na^+, Cl^-, H^+, OH^-

Since there are 2 cations and 2 anions competing to be discharged at the electrodes, selective discharge of ions will occur such that only one cation and one anion will be discharged; the others will remain as ions in the solution.

Selective discharge depends on 3 factors:

1. Selective discharge of cations
2. Selective discharge of anions
3. Anion concentration

5.1 Selective discharge of cations

Reactivity	Elements	Cations	Ease of discharge
most reactive ↑	Potassium	K^+	**most difficult** ↓
	Sodium	Na^+	
	Calcium	Ca^{2+}	
	Magnesium	Mg^{2+}	
	Zinc	Zn^{2+}	
	Iron	Fe^{2+}	
	Lead	Pb^{2+}	
	Hydrogen	H^+	
	Copper	Cu^{2+}	
least reactive	silver	Ag^+	**easiest**

E.g. Given an aqueous/ dilute solution of sodium chloride, the cations present are:

- Na^+ (from NaC*l*)
- H^+ (from H_2O)

With reference to table 5.1, the ease of discharge of hydrogen ions is much easier than sodium; hence, hydrogen ions will be discharged:

Reduction half-equation at cathode: $2H^+ (aq) + e^- \rightarrow H_2 (g)$

5.2 Selective discharge of anions

anions	Ease of discharge
SO_4^{2-}	**most difficult**
NO_3^-	↓
Cl^-	
Br^-	
I^-	
OH^-	**easiest**

E.g. Given an aqueous/ dilute solution of sodium chloride, the anions present are:

- Cl^- (from $NaCl$)
- OH^- (from H_2O)

With reference to table 5.2, the ease of discharge of hydroxide ions is much easier than chloride; hence, hydroxide ions will be discharged:

Oxidation half-equation at anode: $4OH^- (aq) \rightarrow 2H_2O (l) + O_2 (g) + 4e^-$

5.3 Selective Discharge of Anions due to Effect of Concentration

Generally, the selective discharge of anions follows table 5.2 above. However, in the case when one **anion** is present in **larger concentration** compared to the other, the

____.

E.g. Given concentrated sodium chloride, the anions present are:

- Cl^- (from concentrated $NaCl$) ~present in large amount
- OH^- (from H_2O) ~present in smaller amount

Although the ease of discharge of hydroxide ions is easier than chloride ions, chloride is preferably discharged because of higher concentration.

Oxidation half-equation at anode: $2 Cl^- (aq) \rightarrow Cl_2 (g) + 2e^-$

***Note: This is true for anions only!**

Stations

Station 1: water	
Draw a well-labelled diagram of the electrolysis of water in the space below. Show clearly the apparatus used, electron flow, and movement of ions.	[2]
What did you observe from the setup? __________ __________ __________	[2]
Explain the chemistry behind what you observed. __________ __________ __________ __________ __________ __________	[4]
My refined explanation. __________ __________ __________ __________ __________ __________	

Station 2: dilute aqueous copper (II) sulfate
Draw a well-labelled diagram of the electrolysis of copper(II) sulfate in the space below. [2] Show clearly the apparatus used, electron flow, and movement of ions
What did you observe from the setup? [2] ____________________ ____________________ ____________________
Explain the chemistry behind what you observed. [4] ____________________ ____________________ ____________________ ____________________ ____________________ ____________________
My refined explanation. ____________________ ____________________ ____________________ ____________________ ____________________ ____________________

Station 3: concentrated aqueous sodium chloride
Draw a well-labelled diagram of the electrolysis of concentrated sodium chloride in the space below. Show clearly the apparatus used, electron flow, and movement of ions. [2]
What did you observe from the setup? [2] ____________________ ____________________ ____________________
Explain the chemistry behind what you observed. [4] ____________________ ____________________ ____________________ ____________________ ____________________ ____________________
My refined explanation. ____________________ ____________________ ____________________ ____________________ ____________________ ____________________

Station 4: dilute aqueous sodium chloride
Draw a well-labelled diagram of the electrolysis of dilute sodium chloride in the space below. Show clearly the apparatus used, electron flow, and movement of ions. [2]
What did you observe from the setup? [2] ____
Explain the chemistry behind what you observed. [4]
My refined explanation.

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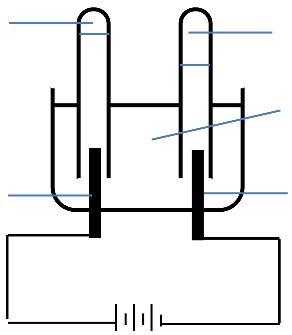
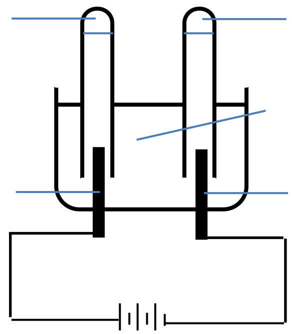
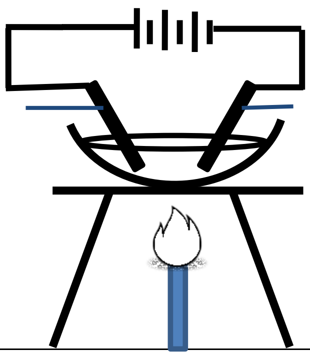
Concept Test

The diagrams for the electrolysis of sodium chloride are shown below. Complete the information in the table.
Fill in: direction of electron flow; charge on the battery; carbon anode, carbon cathode; identity of the electrolyte; level of gas collected in each test tube

Aqueous solution/ dilute sodium chloride	**Concentrated sodium chloride**	**Molten sodium chloride**
		
<u>At cathode</u> Cations present: Reaction: Selective discharge of cation: Half-equation:	<u>At cathode</u> Cations present: Reaction: Selective discharge of cation: Half-equation:	<u>At cathode</u> Cations present: Reaction: Selective discharge of cation: Half-equation:
<u>At anode</u> Anions present: Reaction: Selective discharge of anion: Half-equation:	<u>At anode</u> Anions present: Reaction: Selective discharge of anion: Half-equation:	<u>At anode</u> Anions present: Reaction: selective discharge of anion: Half-equation:
<u>Overall</u>:	<u>Overall</u>:	<u>Overall</u>:

Exercise

Caroline was trying an electrolysis experiment using graphite electrodes. For the electrolyte, she dissolved a little sodium sulphate into water and added a few drops of universal pH indicator, turning the solution green. When the electrolysis began, the solution turned red around one electrode, and blue-violet around the other electrode.

Draw a well-labelled diagram to illustrate the experiment and explain why the red and blue-violet colouration around the electrodes was observed.

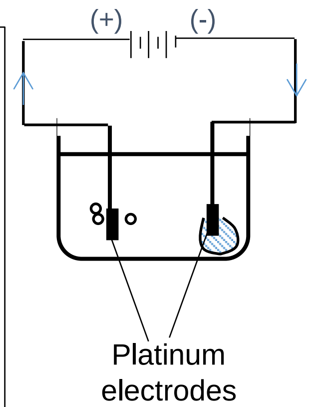
Diagram: [2]
Explanation: [4]

6 Electrolysis of copper (II) sulfate solution using INERT electrodes

When copper(II) sulfate undergoes electrolysis using an inert electrode, e.g. platinum, a reddish-brown deposit is found at the cathode and bubbling is observed at the anode.

With an aid of a diagram, explain the observations above.

At anode:



At cathode:

Oxygen is produced at the anode, accounting for the bubbling of gas observed.

The reddish-brown deposit found at the cathode is the copper metal formed from the selective discharge of Cu^{2+} ions.

Notice that both sulfate ions and hydrogen ions are left in the solution:

The resulting electrolyte becomes ______________________.

Concept Test (think PRO!)

Predict the substances produced at the anode and cathode when a solution of potassium sulfate is electrolysed using platinum electrode.

Write ionic equations that occur at the electrodes.

Anode:

Cathode:

Overall equation:

Describe what happens to the resulting electrolyte.

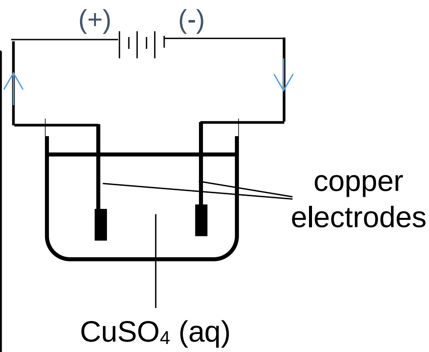
7 Electrolysis of copper (II) sulfate solution using <u>reactive</u> electrodes

When copper(II) sulfate is electrolysed using reactive copper electrodes, the reactive copper electrode is preferentially discharged at the anode.

<u>At Anode (oxidation occurs)</u>

Since copper is a reactive electrode, it will be preferentially discharged (oxidised).

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



<u>At cathode (reduction occurs)</u>

Although copper is a reactive electrode, it does NOT discharge here as the copper metal is already at its lowest oxidation state.

Hence, between Cu^{2+} and H^+ ions present in the electrolyte, Cu^{2+} is preferentially discharged.

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

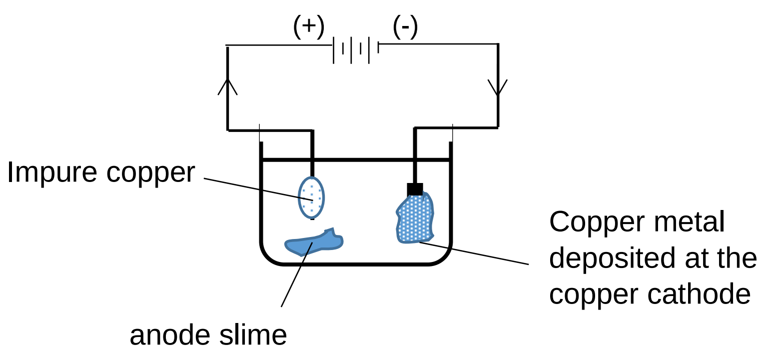
Observation:

The copper electrode at the anode becomes smaller as the copper metal is oxidised to Cu^{2+}. These Cu^{2+} ions together with those originally present in the electrolyte were discharged at the cathode.

Hence, the copper electrode at the cathode will become bigger.

7.1 Purification of impure copper

The above method is commonly used in the purification of impure copper where the anode is replaced with the impure copper. As such, as the copper at the anode is discharged to form Cu^{2+} (aq) ions, the impurities (e.g. silver, platinum) fall to the bottom forming “anode slime”.



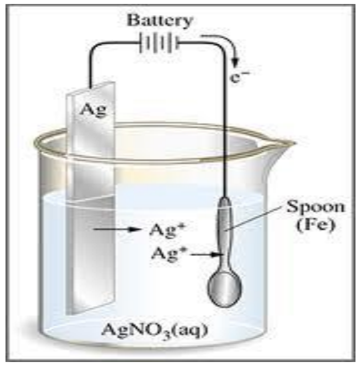
7.2 Electroplating

Electroplating is the process of coating a metal object with another metal by transferring the metal electrode at the anode onto the metal object at the cathode.

<u>At anode</u>

Silver is a reactive electrode and is discharged:

Ag(s) → Ag^{+}(aq) + e^{-}



<u>At cathode</u>

Silver ions are deposited onto the spoon:

Ag^{+}(aq) + e^{-} → Ag(s)

*You'll need to know and be able to identify the 2 industrial application of electrolysis (see 7.1 and 7.2)

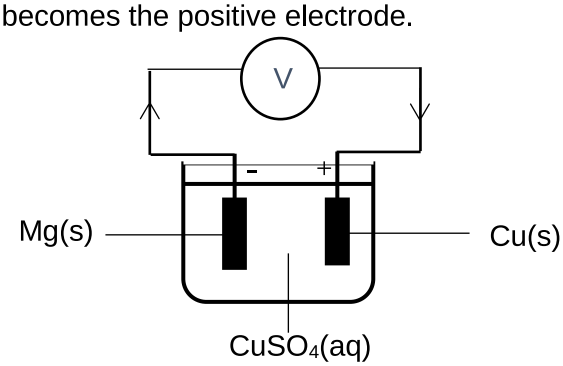
8 Simple Cells

A simple cell also known as an electric cell, is one that ____________________________.

A simple cell is established when 2 different metals electrodes are placed into the same electrolyte, causing a chemical reaction to occur and hence producing a ______________ ____ between the metal electrodes.

The **further apart** the 2 metals are in the reactivity series, **the greater the voltage** produced.
In a simple cell, the more reactive metal becomes the negative electrode and the less reactive metal becomes the positive electrode.

Example:



Since **magnesium is more reactive**, the **magnesium metal plate takes the negative electrode where oxidation occurs:**

Oxidation: Mg(s) → Mg^{2}(aq) + $2e^{-}$

The copper electrode is therefore playing the role of the positive electrode where reduction occurs. Possible ions present for reduction includes Mg^{2+}, Cu^{2+} and H^{+}.

Cu^{2+} ions are preferentially discharged, forming more copper metal that is deposited onto the copper metal electrode.

Reduction: $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

Observation: The magnesium electrode reduces in size; the copper electrode increases in size.

Overall equation: $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

Concept Test

With reference to the above example of a simple cell, answer the following:

(a) What happens to the voltage if Mg is replaced by Zn?

(b) What if the electrolyte was dilute $H_2SO_4(aq)$?

(c) What happens if both electrodes are Magnesium?

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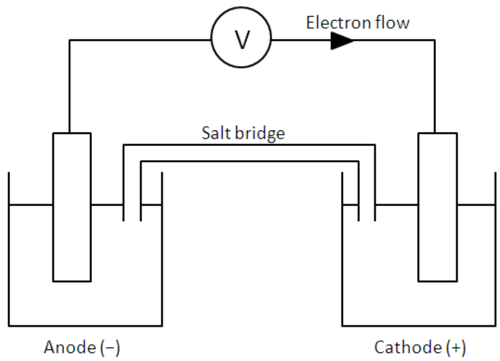
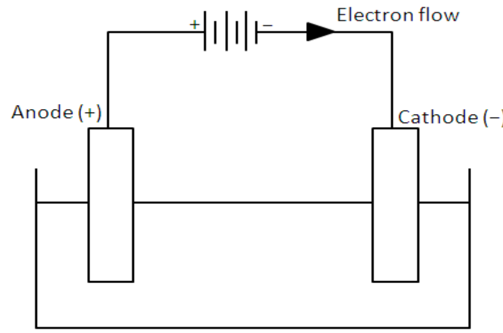
Electrolytic Cell VS Simple Cell

	Electrochemical cell (simple)	Electrolytic cell
Diagram	 Light Bulb or Voltmeter Present	 No Light Bulb or Voltmeter Present
Battery	No Battery	Battery required
E.m.f.	Generated by the cell	Is supplied to the cell by battery
Energy conversion	Chemical → Electrical	Electrical → Chemical
Cathode	Reduction occurs Positive (+)	Reduction occurs Negative (−) [due to connection to battery]
Anode	Oxidation occurs Negative (−)	Oxidation occurs Positive (+) [due to connection to battery]
Electron flow	From anode to cathode (determine by the redox processes)	From anode to cathode (determine by the polarity of battery)

Electrolysis

Electrolysis

(a) describe electrolysis as the conduction of electricity by an ionic compound (an electrolyte), when molten or dissolved in water, leading to the decomposition of the electrolyte

(b) describe electrolysis as evidence for the existence of ions which are held in a lattice when solid but which are free to move when molten or in solution

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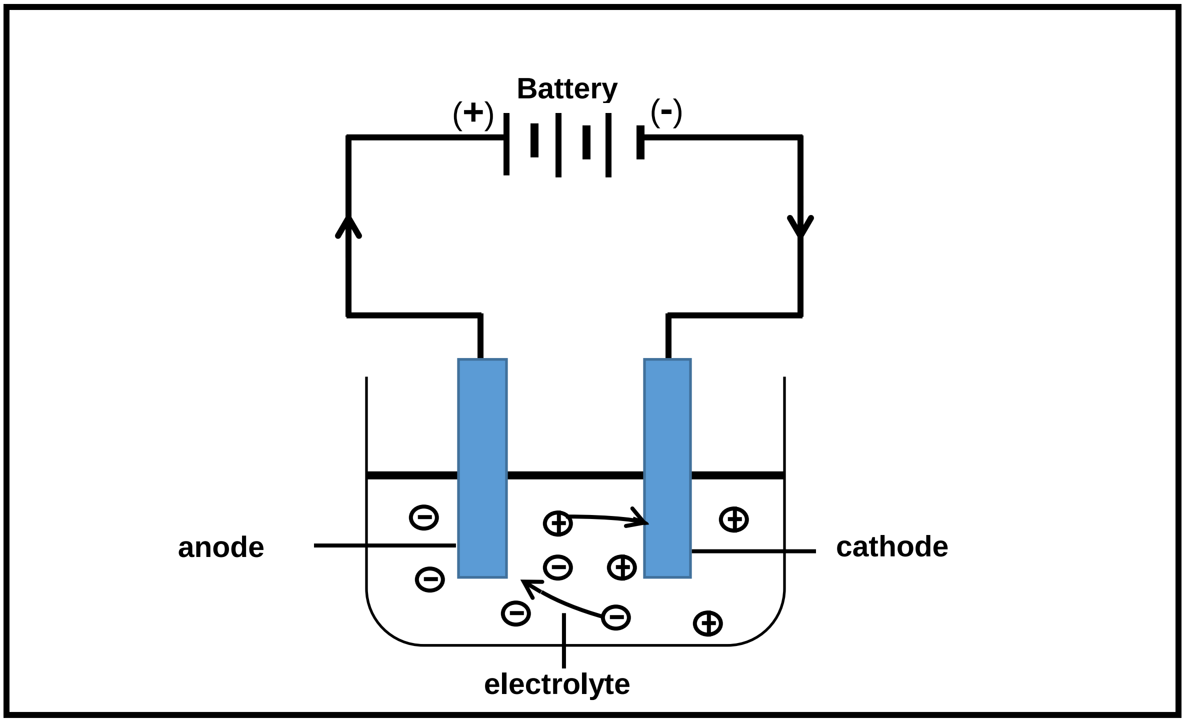

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3 Electrolytes

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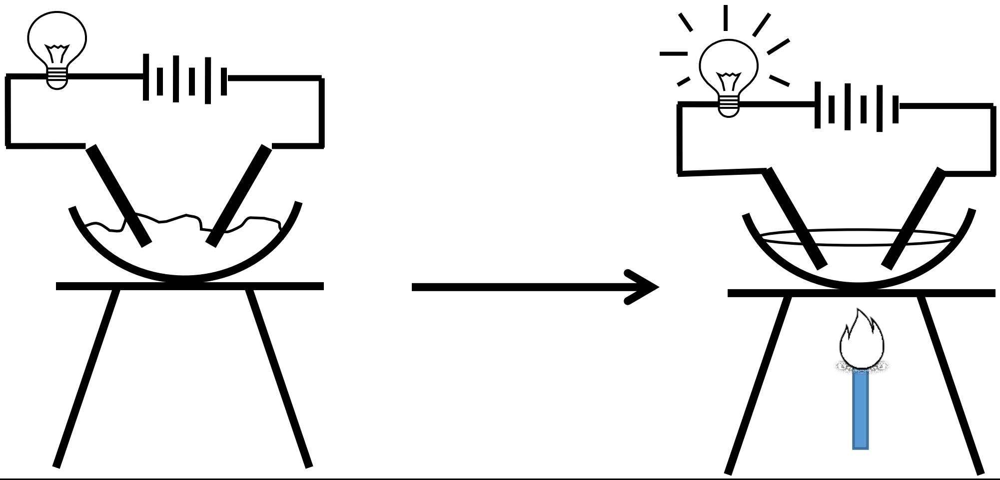
E.g. Comparison of using solid and molten NaC*l* for electrolysis.



Solid NaC*l*	Molten NaC*l*
Observation: Light bulb does not light up.	**Observation:** Light bulb lights up.
Reason: Ions are not free and mobile to carry electric current though the solid NaC*l*.	**Reason:** Ions are free and mobile to carry electric current though the molten NaC*l*.
Principle: When in solid state, ions are in fixed position in the lattice structure.	**Principle:** When molten, ionic bonds are broken and ions are free and mobile.

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4. Electrolysis of Molten Ionic Compounds

Molten ionic compounds are usually **binary**. This means **contains only two elements**, a metal cation (e.g. Na^+) and a non-metal anion (e.g. Cl^-)

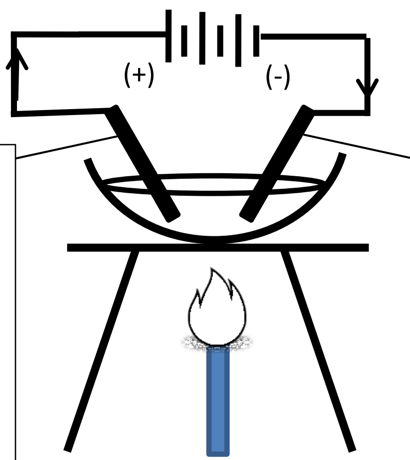
When such binary compounds, e.g. NaC*l* undergoes electrolysis, a metal (Na) and a non metal (Cl_2) are produced.

4.1 *The electrolysis of molten NaC*l* ♡

Carbon anode

- Attracts negative ions (Cl^-)
- Cl^- ions are discharged via the process of oxidation:

$2Cl^-\ (aq) \rightarrow Cl_2\ (g) + 2e$



Carbon cathode

- Attracts positive ions (Na^+)
- Na^+ ions are discharged via the process of reduction:

$Na^+\ (aq) + e \rightarrow Na\ (l)$

4.2 *Use of carbon electrodes

Chlorine formed at the carbon anode is highly reactive. Hence, the choice of electrode is important. Carbon is inert (does not react easily with other chemicals), so its use as an electrode can prevent further reaction with the chlorine formed at the anode.

Concept Test

2 Molten lithium chloride is electrolysed using carbon electrodes.

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5. Electrolysis of Aqueous solutions of Ionic Compounds

In an aqueous solution of ionic compounds, it is important to recognise the presence of water in the solution. As such, apart from the metal cation and non-metal anion, there is also the presence of H^+ and OH^- (both coming from water).

E.g. In an aqueous solution of NaC*l*, the following ions are present: Na^+, Cl^-, H^+, OH^-

Since there are 2 cations and 2 anions competing to be discharged at the electrodes, selective discharge of ions will occur such that only one cation and one anion will be discharged, the others will remain as ions in the solution.

Selective discharge depends on 3 factors:

4. Selective discharge of cations
5. Selective discharge of anions
6. Anion concentration

5.1 Selective discharge of cations

Reactivity	Elements	Cations	Ease of discharge
most reactive	Potassium	K^+	**most difficult**
↑	Sodium	Na^+	↓
	Calcium	Ca^{2+}	
	Magnesium	Mg^{2+}	
	Zinc	Zn^{2+}	
	Iron	Fe^{2+}	
	Lead	Pb^{2+}	
	Hydrogen	H^+	
	Copper	Cu^{2+}	
least reactive	silver	Ag^+	**easiest**

E.g. Given an aqueous/ dilute solution of sodium chloride, the cations present are:

- Na^+ (from NaC*l*)
- H^+ (from H_2O)

With reference to table 5.1, the ease of discharge of hydrogen ions is much easier than sodium; hence, hydrogen ions will be discharged:

Reduction half-equation at cathode: $2H^+ (aq) + e^- \rightarrow H_2 (g)$

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5.2 Selective discharge of anions

anions	Ease of discharge
SO_4^{2-}	**most difficult**
NO_3^-	↓
Cl^-	↓
Br^-	↓
I^-	↓
OH^-	**easiest**

E.g. Given an aqueous/ dilute solution of sodium chloride, the anions present are:

- Cl^- (from Na*Cl*)
- OH^- (from H_2O)

With reference to table 5.2, the ease of discharge of hydroxide ions is much easier than chloride; hence, hydroxide ions will be discharged:

Oxidation half-equation at anode: $4OH^-$ (aq) → $2H_2O$ (*l*) + O_2 (g) + $4e^-$

5.3 Selective discharge of anions due to effect of concentration

Generally, the selective discharge of anions follows table 5.2 above. However, in the case when one anion is present in larger concentration compared to the other, the more concentrated anion will be discharged.

E.g. Given concentrated sodium chloride, the anions present are:

- Cl^- (from concentrated Na*Cl*) ~present in large amount
- OH^- (from H_2O) ~present in smaller amount

Although the ease of discharge of hydroxide ions is easier than chloride ions, chloride is preferably discharged because of higher concentration.

Oxidation half-equation at anode: $2\ Cl^-$ (aq) → Cl_2 (g) + $2e^-$

***Note: This is true for anions only!**

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Station 1: water	
Draw a well-labelled diagram of the electrolysis of water in the space below. Show clearly the apparatus used, electron flow, and movement of ions	[2]
What did you observe from the setup? Bubbles are seen at both electrodes.	[2]
Explain the chemistry behind what you observed.	[4]
My refined explanation. In water, H+ and OH- ions are present. During electrolysis, H+ ions are attracted to the negatively charged cathode while OH- ions are attracted to the positively charged anode. At cathode, H+ ions undergo reduction by gaining electrons to form hydrogen gas, $2H^+ + 2e^- \rightarrow H_2$ that is responsible for the bubbles observed at cathode. On the other hand, at anode, OH- ions undergo oxidation by losing electrons to form water and oxygen gas, $4OH^- \rightarrow 2H_2O + O_2 + 4e^-$ that is responsible for the bubbles observed at anode.	

Station 2: dilute aqueous copper (II) sulfate

Draw a well-labelled diagram of the electrolysis of copper(II) sulfate in the space below. [2]
Show clearly the apparatus used, electron flow, and movement of ions

What did you observe from the setup? [2]

Reddish-brown solid is formed at cathode. Bubbles are seen at anode. The blue colour fades.

Explain the chemistry behind what you observed. [4]

My refined explanation.

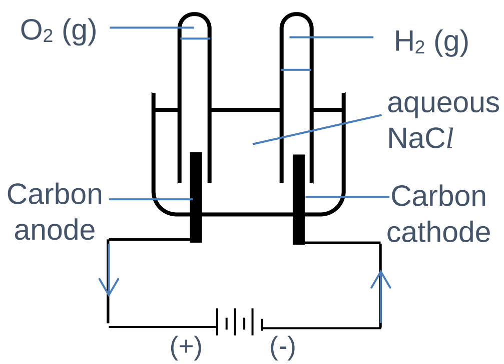
In CuSO4(aq), there are Cu2+, SO4 2-, H+, OH- ions present. During electrolysis, Cu2+ and H+ ions move towards cathode while OH- and SO4 2- move towards anode. Cu2+ is lower than H+ in the reactivity series so Cu2+ ions are discharged and reduced by gaining electrons, Cu2+ +2e- -> Cu, to form copper solid that is observed at cathode and because CU2+ ions are continuously discharged / removed from electrolyte, the blue colour fades. On the other hand, OH- is lower Than SO4 2- in the reactivity series, so OH- ions are discharged and oxidised by losing e- 4OH- -> 2H2O +O2 +4e-, to form oxygen n gas that is responsible for the bubbles at cathode.

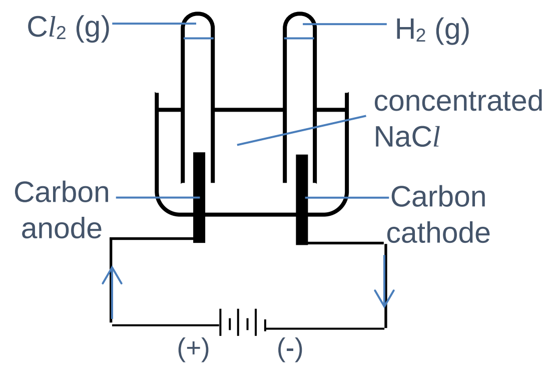
Station 3: concentrated aqueous sodium chloride
Draw a well-labelled diagram of the electrolysis of concentrated sodium chloride in the space below. Show clearly the apparatus used, electron flow, and movement of ions. [2]
What did you observe from the setup? [2] ____ ____ ____
Explain the chemistry behind what you observed. [4] ____ ____ ____ ____ ____ ____
My refined explanation. ____ ____ ____ ____ ____ ____

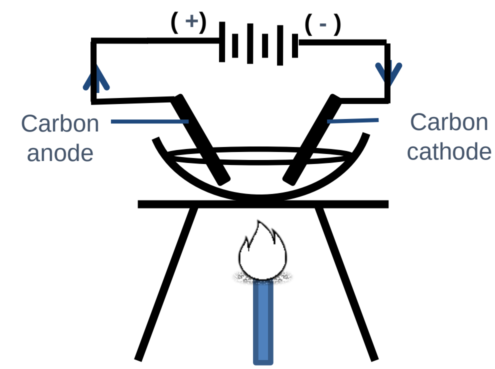
Station 4: dilute aqueous sodium chloride
Draw a well-labelled diagram of the electrolysis of dilute sodium chloride in the space below. Show clearly the apparatus used, electron flow, and movement of ions. [2]
What did you observe from the setup? [2] __________ __________ __________
Explain the chemistry behind what you observed. [4] __________ __________ __________ __________ __________ __________
My refined explanation. __________ __________ __________ __________ __________ __________

Concept Test

The diagrams for the electrolysis of sodium chloride are shown below. Complete the information in the table.
Fill in: direction of electron flow; charge on the battery; carbon anode, carbon cathode; identity of the electrolyte; level of gas collected in each test tube

<table>
<tr><th>Aqueous solution/ dilute sodium chloride</th><th>Concentrated sodium chloride</th><th>Molten sodium chloride</th></tr>
<tr><td>


</td><td>


</td><td>


</td></tr>
<tr><td><u>At cathode</u>
Cations present: hydrogen ions and sodium ions
Reaction: reduction
Selective discharge of cation: hydrogen ions
Half-equation: $2H^+(aq) + 2e^- \rightarrow H_2(g)$</td><td><u>At cathode</u>
Cations present: hydrogen ions and sodium ions
Reaction: reduction
Selective discharge of cation: hydrogen ions
Half-equation: $2H^+(aq) + 2e^- \rightarrow H_2(g)$</td><td><u>At cathode</u>
Cations present: sodium ions only
Reaction: reduction
Selective discharge of cation: sodium ions
Half-equation: $Na^+(aq) + e^- \rightarrow Na(l)$</td></tr>
<tr><td><u>At anode</u>
Anions present: hydroxide ions and chloride ions
Reaction: oxidation
Selective discharge of anion: hydroxide ions
Half-equation: $4OH^-(aq) \rightarrow 2H_2O(l) + O_2(g) + 4e^-$</td><td><u>At anode</u>
Anions present: hydroxide ions and chloride ions
Reaction: oxidation
Selective discharge of anion: chloride ions
Half-equation: $2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$</td><td><u>At anode</u>
Anions present: chloride ions only
Reaction: oxidation
selective discharge of anion: chloride ions
Half-equation: $2Cl^-$ (aq) $\rightarrow Cl_2(g) + 2e^-$</td></tr>
<tr><td><u>Overall</u>: $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$
As water decompose, the NaCl concentration increases.</td><td><u>Overall</u>: $2H^+(aq) + 2Cl^-(aq) \rightarrow H_2(g) + Cl_2(g)$
The remaining sodium and hydroxide ions forms sodium hydroxide, making the resulting electrolyte alkaline.</td><td><u>Overall</u>: $2NaCl(l) \rightarrow 2Na(l) + Cl_2(g)$</td></tr>
</table>

Exercise

Caroline was trying an electrolysis experiment using graphite electrodes. For the electrolyte, she dissolved a little sodium sulphate into water and added a few drops of universal pH indicator, turning the solution green. When the electrolysis began, the solution turned red around one electrode, and blue-violet around the other electrode.

Draw a well-labelled diagram to illustrate the experiment and explain why the red and blue-violet colouration around the electrodes was observed.

Diagram: [2]
Explanation: [4]

6 Electrolysis of copper (II) sulfate solution using INERT electrodes

When copper(II) sulfate undergoes electrolysis using an inert electrode, e.g. platinum, a reddish-brown deposit is found at the cathode and bubbling is observed at the anode.

With an aid of a diagram, explain the observations above.

At anode:

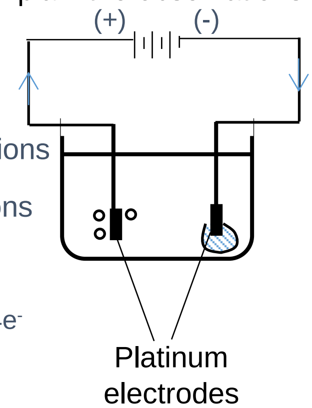
Ions present: SO_4^{2-} and OH^- ions

Selective discharge of OH^- ions

Equation:

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

SO_4^{2-} ions remain in solution



At cathode:

Ions present: Cu^{2+} ions and H^+ ions

Selective discharge of Cu^{2+} ions

Equation:

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

H^+ ions remain in solution

Oxygen is produced at the anode, accounting for the bubbling of gas observed.

The reddish-brown deposit found at the cathode is the copper metal formed from the selective discharge of Cu^{2+} ions.

Notice that both sulfate ions and hydrogen ions are left in the solution:

$SO_4^{2-}(aq) + H^+(aq) \rightarrow$ **H_2SO_4 (aq)** ← **Acidic**

The resulting electrolyte becomes acidic.

Concept Test

Predict the substances produced at the anode and cathode when a solution of potassium sulfate is electrolysed using platinum electrode.

Write ionic equations that occur at the electrodes.

Anode: OH^- preferentially discharged (oxidised); O_2 (g) produced at anode.

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

Cathode: H+ preferentially discharged (reduced); H_2 (g) produced at cathode.

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

Hence, write an equation for the overall reaction.

Overall equation: $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$

Describe what happens to the resulting electrolyte.

Resulting electrolyte is more concentrated with potassium sulfate.

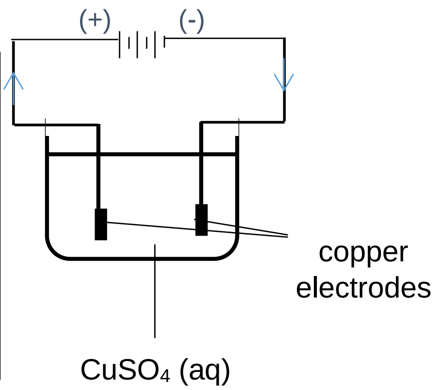
7 Electrolysis of copper (II) sulfate solution using <u>reactive</u> electrodes

When copper(II) sulfate is electrolysed using reactive copper electrodes, the reactive copper electrode is preferentially discharged at the anode.

At Anode (oxidation occurs)

Since copper is a reactive electrode, it will be preferentially discharged (oxidised).

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



At cathode (reduction occurs)

Although copper is a reactive electrode, it does NOT discharge here as the copper metal is already at its lowest oxidation state.

Hence, between Cu^{2+} and H^{+} ions present in the electrolyte, Cu^{2+} is preferentially discharged.

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

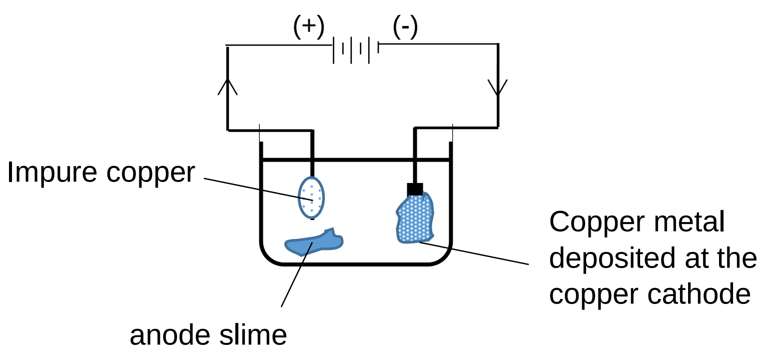
Observation:

The copper electrode at the anode becomes smaller as the copper metal is oxidised to Cu^{2+}. These Cu^{2+} ions together with those originally present in the electrolyte were discharged at the cathode.

Hence, the copper electrode at the cathode will become bigger.

7.1 Purification of impure copper

The above method is commonly used in the purification of impure copper where the anode is replaced with the impure copper. As such, as the copper at the anode is discharged to form Cu^{2+} (aq) ions, the impurities (e.g. silver, platinum) fall to the bottom forming "anode slime".



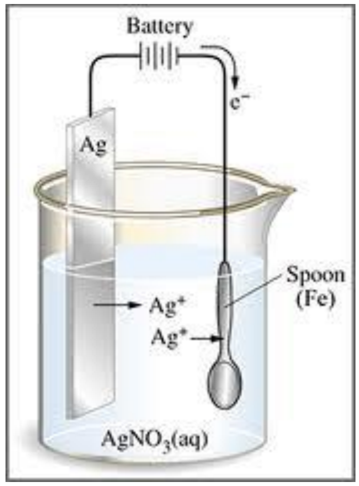
7.2 Electroplating

Electroplating is the process of coating a metal object with another metal by transferring the metal electrode at the anode onto the metal object at the cathode.

At anode

Silver is a reactive electrode and is discharged:

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



At cathode

Silver ions are deposited onto the spoon:

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

*You'll need to know and be able to identify the 2 industrial application of electrolysis (see 7.1 and 7.2)

8 Simple Cells

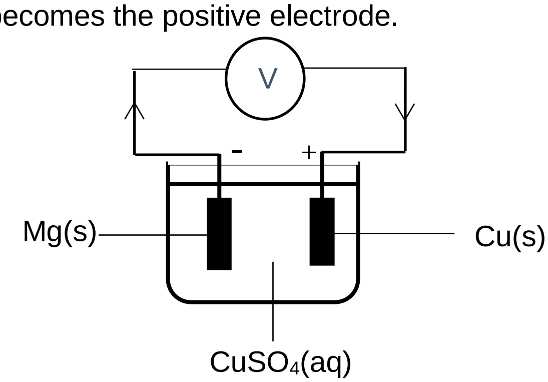
A simple cell also known as an electric cell, is one that converts chemical energy into electrical energy.

A simple cell is established when 2 different metals electrodes are placed into the same electrolyte, causing a chemical reaction to occur and hence producing a voltage/ potential difference between the metal electrodes.

The further apart the 2 metals are in the reactivity series, the greater the voltage produced.

In a simple cell, the more reactive metal becomes the negative electrode and the less reactive metal becomes the positive electrode.

Example:



Since **magnesium is more reactive**, the **magnesium metal plate takes the negative electrode where oxidation occurs:**

Oxidation: $Mg(s) \rightarrow Mg^{2}(aq) + 2e^{-}$

The copper electrode is therefore playing the role of the positive electrode where reduction occurs. Possible ions present for reduction includes Mg^{2+}, Cu^{2+} and H^{+}. Cu^{2+} ions are preferentially discharged, forming more copper metal that is deposited onto the copper metal electrode.

Reduction: $Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s)$

Observation: The magnesium electrode reduces in size; the copper electrode increases in size.

Overall equation: $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

Concept Test

With reference to the above example of a simple cell, answer the following:

(d) What happens to the voltage if Mg is replaced by Zn?

The voltage will decrease as Zn is less reactive than Mg.

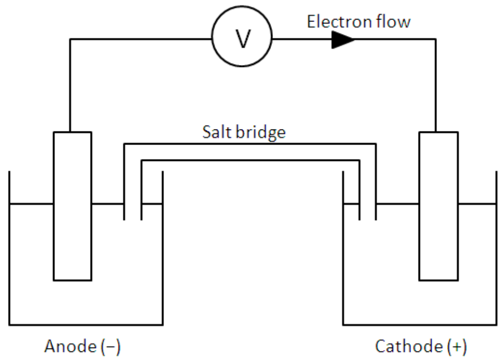
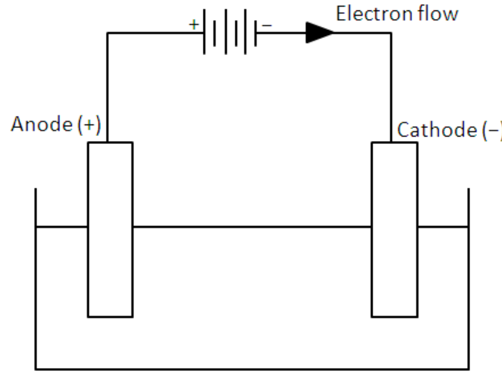
(e) What if the electrolyte was dilute $H_2SO_4(aq)$?

H^{+} will be preferentially discharged at the copper electrode, bubbling of gas will be observed. Hydrogen gas is produced.

(f) What happens if both electrodes are Magnesium?

No current will flow.

My Learning Space

	Electrochemical cell (simple)	Electrolytic cell
Diagram	 Light Bulb or Voltmeter Present	 No Light Bulb or Voltmeter Present
Battery	No Battery	Battery required
E.m.f.	Generated by the cell	Is supplied to the cell by battery
Energy conversion	Chemical → Electrical	Electrical → Chemical
Cathode	Reduction occurs Positive (+)	Reduction occurs Negative (−) [due to connection to battery]
Anode	Oxidation occurs Negative (−)	Oxidation occurs Positive (+) [due to connection to battery]
Electron flow	From anode to cathode (determine by the redox processes)	From anode to cathode (determine by the polarity of battery)