

Topic 24 – Electrolysis

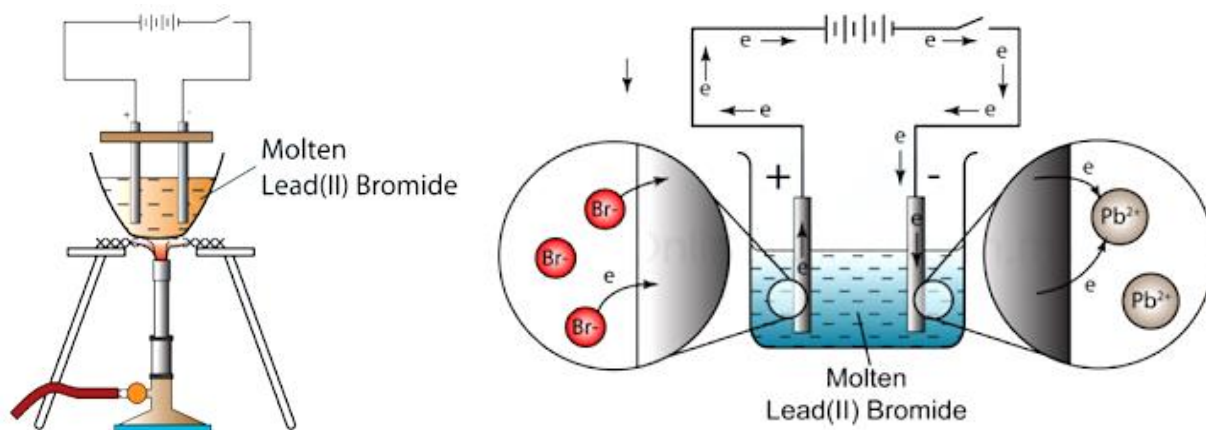
Subject content

- (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 (see also 9.2)
 - (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

Definitions

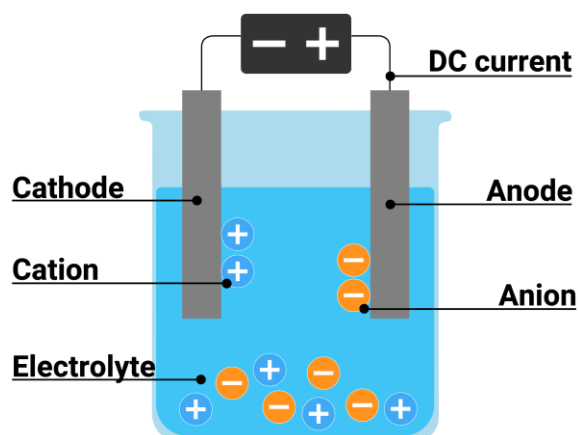
| Term | Definition |
|------------------------|---|
| Electrolysis | Chemical decomposition of compound brought about by flow of electric current through aqueous / molten compound |
| Electrolyte | Compound, when molten / dissolved in aqueous solution, conducts electric current and is decomposed |
| Non-electrolyte | Compound, when molten / dissolved in aqueous solution, cannot conduct electric current or be decomposed by it |
| Cation | Positively charged ion |
| Anion | Negatively charged ion |
| Electrode | Metal or graphite rod by which current enters / leaves electrolyte |
| Anode | Positive electrode that attracts anions in electrolyte Connected to positive terminal of battery in electrolytic cell |
| Cathode | Negative electrode that attracts cations in electrolyte Connected to negative terminal of battery in electrolytic cell |

24.1 Electrolysis of Molten Ionic Compound



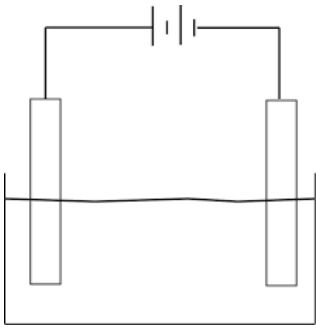

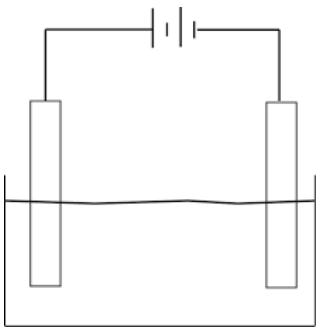


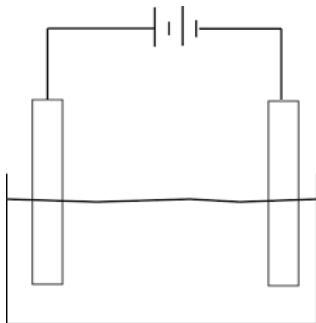
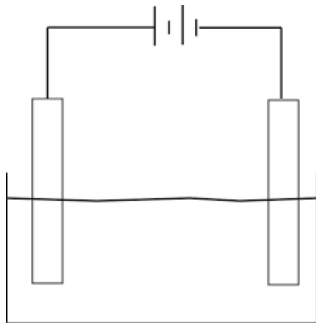
| Cathode (–) | Anode (+) |
|--|---|
| Attract cation (+) | Attract anion (–) |
| <u>Reduction</u> (cation gain $e^- \rightarrow$ metal/hydrogen) | <u>Oxidation</u> (anion lose $e^- \rightarrow$ non-metal) |
| $Pb^{2+} (l) + 2 e^- \rightarrow \underline{Pb} (l)$ [silver liquid] | $2 Br^- (l) \rightarrow \underline{Br_2} (g)$ [reddish-brown gas] + $2 e^-$ |
| $PbBr_2 (l) \rightarrow Pb (l) + Br_2 (g)$ | |

24.2 Electrolysis of Aqueous Ionic Compound

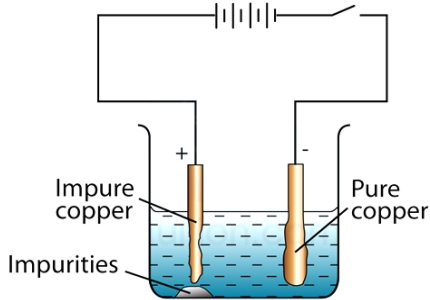
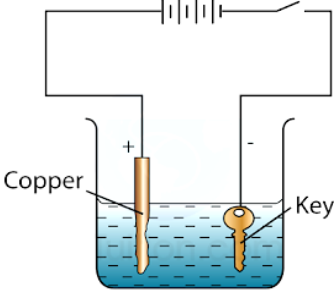


Selective discharge of ions

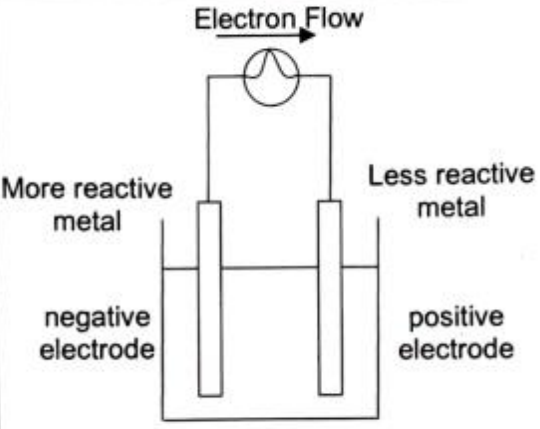
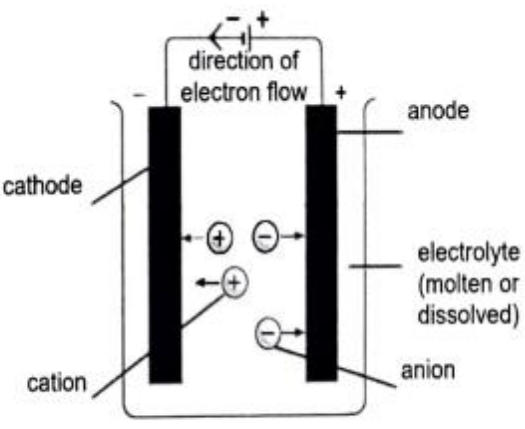
| Factor | Description | Cathode | Anode | Figure | | | | | | | | | | | | | | | | | | | | | | | | | | |
|--|---|--|---|--|----------------|---|----------------|------------------|-------------------------------|-----------------|------------------------------|------------------|-----------------|------------------|-----------------|------------------|----------------|------------------|-----------------|------------------|--|----------------|--|------------------|--|-----------------|--|---|---|--|
| 1. Relative positions of ions in electro - chemical series | <ul style="list-style-type: none">Ions discharged in preference to those above itElectrochemical series: <table><tr><td><u>Cation</u></td><td></td><td><u>Anion</u></td></tr><tr><td>K⁺</td><td rowspan="11"></td><td>F⁻</td></tr><tr><td>Ca²⁺</td><td>SO₄²⁻</td></tr><tr><td>Na⁺</td><td>NO₃⁻</td></tr><tr><td>Mg²⁺</td><td>Cl⁻</td></tr><tr><td>Al³⁺</td><td>Br⁻</td></tr><tr><td>Zn²⁺</td><td>I⁻</td></tr><tr><td>Fe²⁺</td><td>OH⁻</td></tr><tr><td>Pb²⁺</td><td></td></tr><tr><td>H⁺</td><td></td></tr><tr><td>Cu²⁺</td><td></td></tr><tr><td>Ag⁺</td><td></td></tr></table> <p>Ease of discharge increase</p> | <u>Cation</u> | | <u>Anion</u> | K ⁺ |  | F ⁻ | Ca ²⁺ | SO ₄ ²⁻ | Na ⁺ | NO ₃ ⁻ | Mg ²⁺ | Cl ⁻ | Al ³⁺ | Br ⁻ | Zn ²⁺ | I ⁻ | Fe ²⁺ | OH ⁻ | Pb ²⁺ | | H ⁺ | | Cu ²⁺ | | Ag ⁺ | | $2 \text{H}^+(\text{aq}) + 2 \text{e}^- \rightarrow \text{H}_2(\text{g})$ | $4 \text{OH}^-(\text{aq}) \rightarrow 2 \text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g}) + 4 \text{e}^-$ | Dilute sodium chloride solution  |
| | | <u>Cation</u> | | <u>Anion</u> | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | K ⁺ |  | F ⁻ | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ca ²⁺ | SO ₄ ²⁻ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Na ⁺ | NO ₃ ⁻ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mg ²⁺ | Cl ⁻ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Al ³⁺ | Br ⁻ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Zn ²⁺ | I ⁻ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fe ²⁺ | OH ⁻ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Pb ²⁺ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H ⁺ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cu ²⁺ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ag ⁺ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <ul style="list-style-type: none">Na⁺ and H⁺H⁺ preferentially discharged: gain e⁻ more readily → H₂Universal Indicator: green → violet<ul style="list-style-type: none">H⁺ dischargedSol → alkaline (H⁺ conc ↓) | <ul style="list-style-type: none">Cl⁻ and OH⁻OH⁻ preferentially discharged: lose e⁻ more readily → O₂Universal Indicator: green → red<ul style="list-style-type: none">OH⁻ dischargedSol → acidic (OH⁻ conc ↓) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| $2 \text{H}_2\text{O}(\text{l}) \rightarrow 2 \text{H}_2(\text{g}) + \text{O}_2(\text{g})$ [electrolysis of water] | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2. Relative concentration of ions in solutions | <ul style="list-style-type: none">Increase in conc of ion <u>tends to</u> promote dischargeInfluence is secondary: effective only when rival ions closely positioned | $2 \text{H}^+(\text{aq}) + 2 \text{e}^- \rightarrow \text{H}_2(\text{g})$ | $2 \text{Cl}^-(\text{aq}) \rightarrow \text{Cl}_2(\text{g}) + 2 \text{e}^-$ | Concentrated sodium chloride solution  | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | <ul style="list-style-type: none">Na⁺ and H⁺H⁺ preferentially discharged: gain e⁻ more readily → H₂Universal Indicator: green → violet<ul style="list-style-type: none">H⁺ dischargedSol → alkaline (H⁺ conc ↓) | <ul style="list-style-type: none">Cl⁻ and OH⁻Cl⁻ preferentially discharged (high conc): lose e⁻ more readily → Cl₂Universal Indicator: green → red → colourless<ul style="list-style-type: none">Cl₂ turn indicator red → bleach | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | $2 \text{H}^+(\text{aq}) + 2 \text{Cl}^-(\text{aq}) \rightarrow \text{H}_2(\text{g}) + \text{Cl}_2(\text{g})$ $2 \text{H}_2\text{O}(\text{l}) + 2 \text{NaCl}(\text{aq}) \rightarrow \text{H}_2(\text{g}) + \text{Cl}_2(\text{g}) + 2 \text{NaOH}(\text{aq})$ | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| | | | | |
|-------------------------|---|--|--|--|
| 3. Nature of electrodes | <ul style="list-style-type: none">Inert electrode: X take part in electrolytic reaction (e.g. platinum, graphite) | $\text{Cu}^{2+}(\text{aq}) + 2 \text{e}^{-} \rightarrow \text{Cu}(\text{s})$ | $4 \text{OH}^{-}(\text{aq}) \rightarrow 2 \text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g}) + 4 \text{e}^{-}$ | Graphite electrodes  |
| | | <ul style="list-style-type: none">Cu^{2+} and H^{+}<u>Cu</u>²⁺ preferentially discharged: gain e^{-} more readily $\rightarrow \text{Cu}$ | <ul style="list-style-type: none">SO_4^{2-} and OH^{-}<u>OH</u>⁻ preferentially discharged: lose e^{-} more readily $\rightarrow \text{O}_2$ | |
| | | $2 \text{CuSO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2 \text{Cu}(\text{s}) + \text{O}_2(\text{g}) + 2 \text{H}_2\text{SO}_4(\text{aq})$ <div style="display: flex; justify-content: space-around; width: 100%;">[blue][colourless]</div> | | |
| | | $\text{Cu}^{2+}(\text{aq}) + 2 \text{e}^{-} \rightarrow \text{Cu}(\text{s})$ | $\text{Cu}(\text{s}) \rightarrow \text{Cu}^{2+}(\text{aq}) + 2 \text{e}^{-}$ | Copper electrodes  |
| | | <ul style="list-style-type: none">Cu^{2+} and H^{+}<u>Cu</u>²⁺ preferentially discharged: gain e^{-} more readily $\rightarrow \text{Cu}$ | <ul style="list-style-type: none">SO_4^{2-} and OH^{-}Copper X inert electrode \rightarrow lose e^{-} more readily<u>Cu</u> anode dissolve $\rightarrow \text{Cu}^{2+}$ enter sol | |
| | | Solution remains blue <ul style="list-style-type: none">1 Cu^{2+} ion discharged at cathode \Leftrightarrow 1 Cu^{2+} ion formed at anodeconc of Cu^{2+} remains same | | |

24.3 Applications of Electrolysis

| Aspect | | Purification of metals | Electroplating |
|-------------|-------------|--|---|
| Description | | <ul style="list-style-type: none"> Use non-inert electrodes → refine (purify) metals | <ul style="list-style-type: none"> Coat surface of conducting material with metal Aim <ol style="list-style-type: none"> improve appearance of metal prevent metal from corroding Control thickness of plating <ul style="list-style-type: none"> magnitude of current time duration |
| Components | cathode | pure metal | object to be plated |
| | anode | impure metal | metal for plating object |
| | electrolyte | solution of compound of anode | solution of compound of anode |
| Figure | |  |  |
| | | Anode: $\text{Cu} \rightarrow \text{Cu}^{2+} + 2\text{e}^-$ Cathode: $\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$ | Anode: $\text{Cu} \rightarrow \text{Cu}^{2+} + 2\text{e}^-$ Cathode: $\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$ |

Differences b/w simple cell and electrolytic cell

| | <i>Simple cell</i> | <i>Electrolytic cell</i> |
|--|---|---|
| Diagram |  <p>More reactive metal</p> <p>Less reactive metal</p> <p>negative electrode</p> <p>positive electrode</p> <p>Electron Flow</p> <p>light bulb or voltmeter present</p> |  <p>direction of electron flow</p> <p>cathode</p> <p>anode</p> <p>electrolyte (molten or dissolved)</p> <p>cation</p> <p>anion</p> <p>No light bulb or voltmeter present</p> |
| Battery present? | No Battery | Battery required |
| Electricity supply? | Generated by the cell | Supplied to the cell by battery |
| Energy conversion | Chemical → Electrical | Electrical → Chemical |
| Types of electrode Reaction at each electrode Electron flow | <p>Electrode polarity depends on reactivity of electrodes.</p> <p>More reactive metal electrode:</p> <ul style="list-style-type: none"> ⇒ <u>Oxidation</u> of metal occurs ⇒ Electrode becomes <u>negative</u> ⇒ Electrons flow to the <u>positive</u> electrode through the external wire <p>Less reactive metal electrode:</p> <ul style="list-style-type: none"> ⇒ is the positive electrode ⇒ cations in electrolyte gain electrons from the electrode ⇒ cations are reduced | <p>Electrode polarity depends on the connection to battery.</p> <p>Positive electrode (anode):</p> <ul style="list-style-type: none"> ⇒ <u>Anions</u> in the electrolyte are attracted to the anode ⇒ <u>Oxidation</u> of anions occurs <p>Negative electrode (cathode):</p> <ul style="list-style-type: none"> ⇒ <u>Cations</u> in the electrolyte are attracted to the cathode ⇒ <u>Reduction</u> of cations occurs <p>Electrons flow from the <u>positive</u> electrode to the <u>negative</u> electrode through the external wire.</p> |
| Applications | batteries, fuel cell | purification of metals, electroplating |

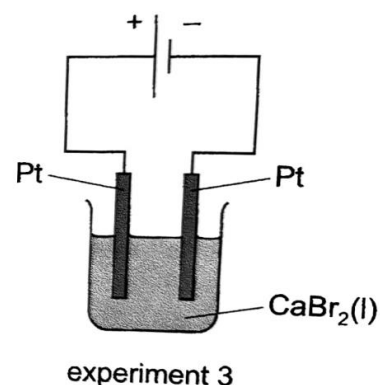
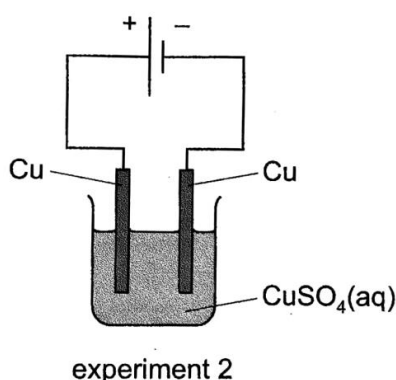
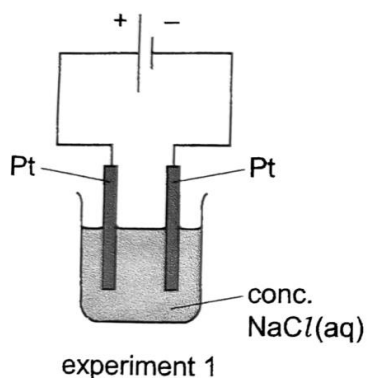
Typical questions**Multiple choice questions**

- 1 A concentrated aqueous solution containing each of the following ions – Cl^- , SO_4^{2-} , Na^+ , Cu^{2+} – is electrolysed using platinum electrodes.

Which row shows the ions that discharge first at the two electrodes? (2021 P1 Q13)

| | at positive electrode | at negative electrode |
|----------|-----------------------|-----------------------|
| A | Cl^- | Cu^{2+} |
| B | Cl^- | Na^+ |
| C | SO_4^{2-} | Cu^{2+} |
| D | SO_4^{2-} | Na^+ |

- 2 Three different compounds are electrolysed.



Which experiments produce a gas at the negative electrode?

(2020 P1 Q12)

- A** 1 only
B 2 only
C 1 and 3
D 2 and 3

- 3 Four different conditions under which sodium chloride is electrolysed using inert electrodes are listed.

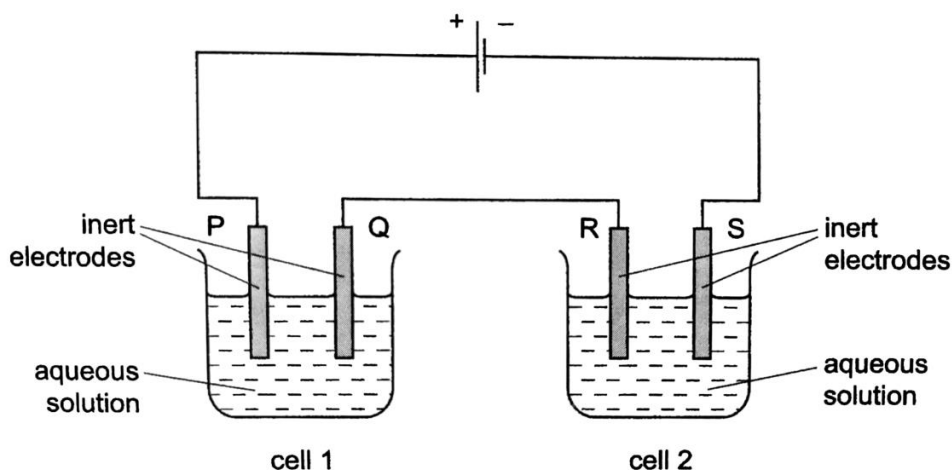
1. concentrated aqueous sodium chloride
2. dilute aqueous sodium chloride
3. molten sodium chloride
4. solid sodium chloride

Under which conditions is a green gas formed?

(2019 P1 Q13)

- A** 1 and 2
B 1 and 3
C 3 and 4
D 3 only

- 4 In the diagram, each cell contains an aqueous solution of a single salt. All four electrodes are platinum.



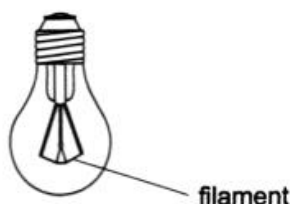
Electrodes Q and S increase in mass during the electrolysis but no gas is given off at Q or S. The increase in mass of Q is greater than the increase in mass of S.

Which statement must be correct?

(2018 P1 Q13 / 2015 P1 Q17)

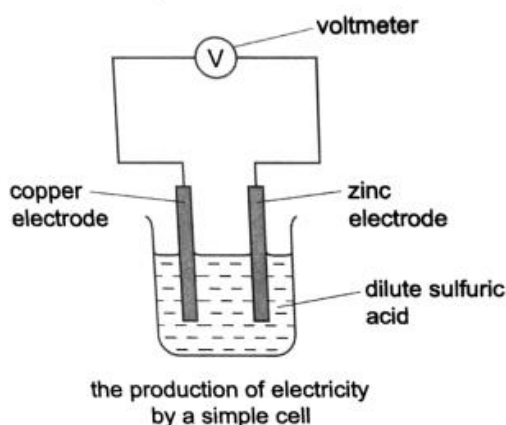
- A The cation in cell 1 is the same as in cell 2 but the solution in cell 1 is more concentrated than in cell 2.
 - B The cation of the solution in cell 1 is different from the cation of the solution in cell 2.**
 - C The current flowing in cell 1 is greater than the current flowing in cell 2.
 - D The loss of mass of electrode P is less than the loss of mass of electrode R.
- 5 Processes 1, 2 and 3 each involve the movement of charged particles.

process 1

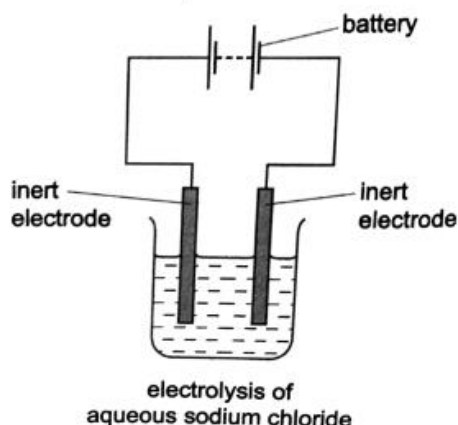


conduction of electricity through the metal filament of a light bulb

process 2



process 3



Which processes involve the movement of ions?

(2016 P1 Q10 / 2012 P1 Q21)

- A process 1 only
- B process 2 only
- C processes 1 and 2
- D processes 2 and 3

6 In an electrolysis experiment, the same amount of charge deposited 16 g of copper and 6 g of titanium. The charge on the copper ion was 2+.

What was the charge on the titanium ion?

(2014 P1 Q12)

- A 1+
- B 2+
- C 3+
- D 4+

7 Inert electrodes are used in the electrolysis of an aqueous solution containing both copper(II) sulfate and magnesium sulfate.

What will be produced at the negative electrode?

(2014 P1 Q14)

- A copper
- B hydrogen
- C magnesium
- D oxygen

8 In the electrolysis of molten sodium chloride, 46 g of sodium is formed at the cathode. How many moles of chlorine gas are formed at the anode?

(2013 P1 Q9)

- A 0.5 mol
- B 1.0 mol
- C 2.0 mol
- D 4.0 mol

9 In which electrolyte would a carbon cathode (negative electrode) increase in mass during electrolysis?

(2012 P1 Q13)

- A aqueous copper(II) sulfate
- B concentrated hydrochloric acid
- C concentrated aqueous sodium chloride
- D dilute sulfuric acid

Structured questions

1 The table below shows information about some electrolysis experiments.

| experiment | negative electrode | positive electrode | electrolyte | substance formed at negative electrode | substance formed at positive electrode |
|------------|--------------------|--------------------|--------------------------------------|--|--|
| 1 | carbon | carbon | dilute aqueous sodium chloride | <u>hydrogen</u> | <u>oxygen</u> |
| 2 | carbon | carbon | concentrated aqueous sodium chloride | <u>hydrogen</u> | <u>chlorine</u> |
| 3 | silver | silver | dilute aqueous copper(II) sulfate | copper | oxygen |
| 4 | copper | copper | dilute aqueous copper(II) sulfate | <u>copper</u> | <u>copper(II) ions</u> |

(2021 P2 A3)

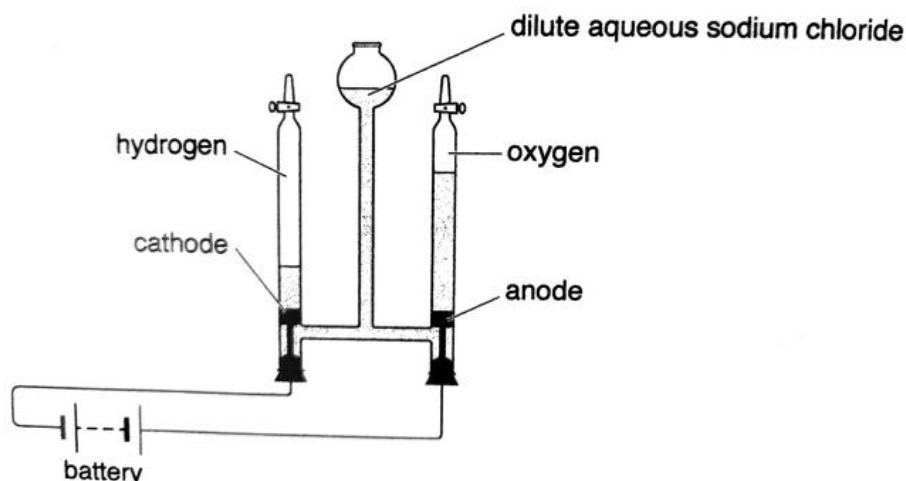
- (a) Complete the table above by filling in the missing information. [2]
- (b) Use examples from the table to explain the difference between an inert electrode and an electrode that is not inert. [2]
- When an inert electrode such as carbon is used at the positive electrode (e.g. Expt. 1 and 2), ions from the solution will be preferentially discharged to form substance such as oxygen or a halogen (chlorine).
 - When an electrode that is not inert such as copper is used at the positive electrode (e.g. Expt. 4), substance formed will be the metal ions (Cu^{2+} ions) due to oxidation of the copper metal.
- (c) For experiment 3, [1]
- (i) Describe the change that would be **seen** at the negative electrode. [1]
- Reddish-brown solid will be deposited on the negative silver electrode.
- (ii) Write an ionic equation for the reaction at the positive electrode. [1]
- $4 \text{OH}^-(\text{aq}) \rightarrow 2 \text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g}) + 4 \text{e}^-$
- (iii) Describe and explain the colour change of the solution. [2]
- Blue colour of the dilute aqueous copper(II) sulfate solution gradually fades as copper(II) ions are being discharged to form copper metal.

- 2 The table shows information about the electrolysis of some substances. Complete the table by filling in the missing information.

[3]
(2018 P2 A2)

| substance | electrodes used | product of reaction at positive electrode | product of reaction at negative electrode |
|--|-----------------|---|---|
| concentrated aqueous copper(II) chloride | carbon | <u>chlorine</u> | copper |
| dilute aqueous copper(II) sulfate | copper | copper(II) ions | <u>copper</u> |
| <u>molten sodium chloride</u> | platinum | chlorine | sodium |

- 3 Dilute aqueous sodium chloride forms hydrogen and oxygen during electrolysis.

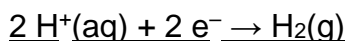


(2015 P2 A5)

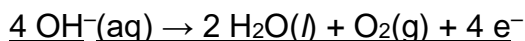
- (a) Write ionic equations for the reactions at the cathode and anode.

[2]

Cathode:



Anode:



- (b) The gases are collected and their volumes are measured. In theory, the ratio of hydrogen to oxygen should be 2 : 1. Oxygen is more soluble than hydrogen in water. This changes the ratio of gases that are collected.

- (i) Why is the theoretical ratio of hydrogen to oxygen 2 : 1?

[2]

For every 4 moles of electrons transferred, 2 volumes of H₂ gas and 1 volume of O₂ gas are formed.

The overall reaction is $2 \text{H}_2\text{O}(l) \rightarrow 2 \text{H}_2(g) + \text{O}_2(g)$

- (ii) Explain how and why the solubility of oxygen affects the ratio of hydrogen to oxygen that is collected. [2]

Some of the oxygen produced would dissolve in the solution, resulting in a smaller than expected volume of oxygen being collected. Hence, the ratio of hydrogen to oxygen collected would be greater than 2:1.

- (iii) The difference from the expected ratio is greater when the electrolysis starts but less noticeable after the electrolysis has been running for some time. Suggest why this happens. [1]

At the start of electrolysis, the concentration of dissolved oxygen in the solution is low. After the electrolysis has been running for some time, the solution becomes saturated with dissolved oxygen, and oxygen produced is less likely to dissolve in the solution.

- (c) What happens to the concentration of sodium chloride during the electrolysis? Explain your reasoning. [1]

H⁺ and OH⁻ ions are being discharged, leaving behind Na⁺ and Cl⁻ ions and the concentration of sodium chloride increases. Hence, the concentration of sodium chloride increases as the volume of water decreases.

- (d) The same apparatus can be used to electrolyse concentrated aqueous sodium chloride. Give one similarity and one difference between the products of the electrolysis of dilute and concentrated aqueous sodium chloride. [2]

Hydrogen is collected at the cathode for both electrolytes.

Oxygen is collected at the anode for electrolysis of dilute aqueous sodium chloride while chlorine is collected from electrolysis of concentrated aqueous sodium chloride.

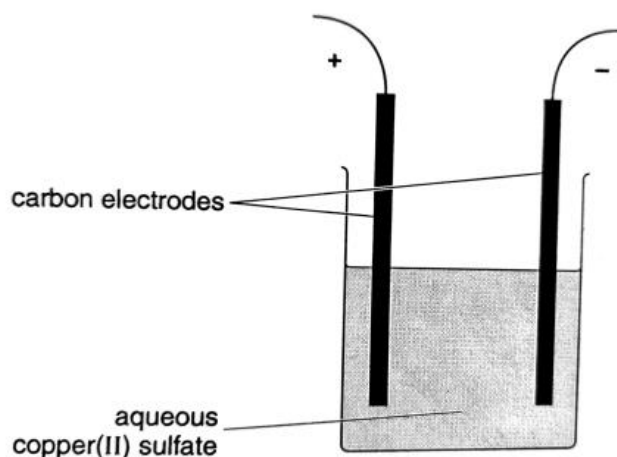
- (e) Platinum metal electrodes are used. Why is platinum a suitable material for use as an electrode? [1]

Platinum is an unreactive metal.

It is not a good electrical conductor and is not easily corroded by gases.

Therefore, it is suitable for use as an inert electrode.

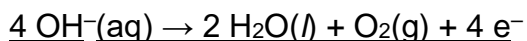
- 4 A student investigates the amount of copper that forms on the negative electrode during the electrolysis of aqueous copper(II) sulfate.
The student uses this apparatus.



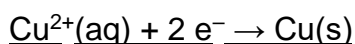
(2014 P1 A5)

- (a) Write equations for the reactions that happen at each electrode during the electrolysis. Include state symbols. [3]

Positive electrode:



Negative electrode:



- (b) The student measures the mass of the negative electrode at the start.
He allows the electrolysis to continue for 10 minutes.
He dries the electrode, reweighs it and then replaces the electrode to allow the electrolysis to continue for a further 10 minutes.
He repeats this process until the mass of the electrode does not change.
The table below shows his results.

| total time / min | mass of electrode / g |
|---------------------|--------------------------|
|---------------------|--------------------------|

| | |
|----|------|
| 0 | 3.50 |
| 10 | 3.91 |
| 20 | 4.15 |
| 30 | 4.78 |
| 40 | 5.21 |
| 50 | 5.61 |
| 60 | 6.10 |
| 70 | 6.10 |
| 80 | 6.10 |

- (i) What **general pattern** is shown by the results? [1]

The mass of the electrode increases as the total time for electrolysis increases.

- (ii) The student makes an error in recording one of the mass readings. Which result is most likely to be an error? Explain your reasoning. [2]

At the total time of 20 mins, mass of 4.15 g is most likely an error.

The mass increases by about 0.4 g for every 10 mins increase in total time, so at a total time of 20 g, the mass should be about 4.3 g.

- (iii) Suggest why the mass does not change after 60 minutes. [1]

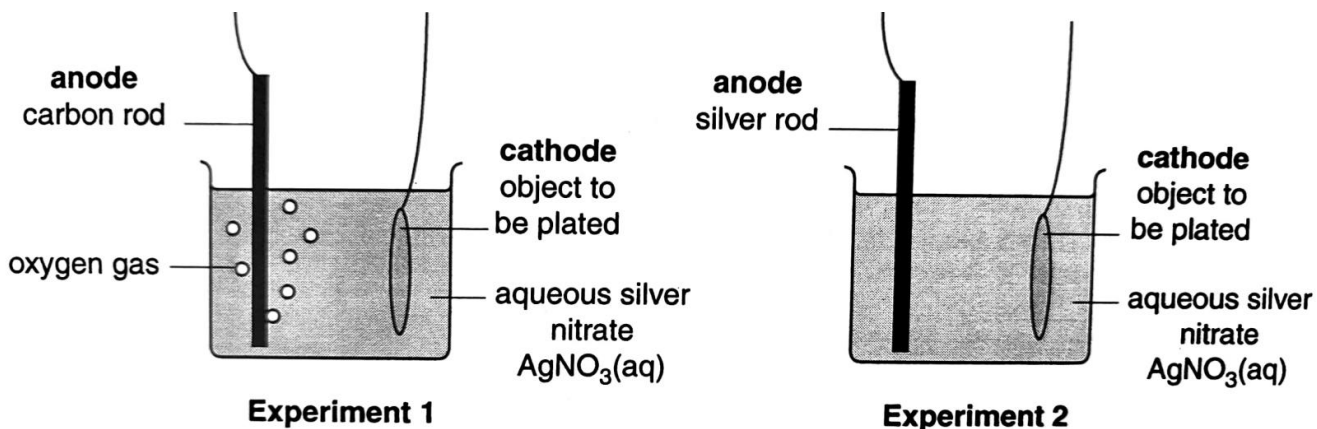
All the Cu^{2+} ions in the electrolyte have been discharged.

- (c) The student repeats the experiment. This time he uses copper electrodes. How would you expect his results for this experiment to differ from his first experiment? Explain your reasoning. [3]

The mass of the negative electrode will continue to increase after 60 mins.

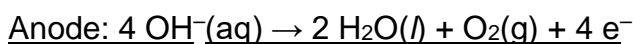
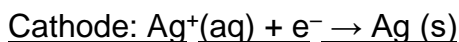
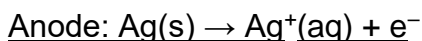
The copper anode ionises (and becomes smaller), $\text{Cu(s)} \rightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{e}^-$. This replaces the number of Cu^{2+} ions discharged at the cathode. The Cu^{2+} ions that are discharged at the cathode come mainly from the copper anode.

5 A student sets up two different experiments for electroplating an object with silver.



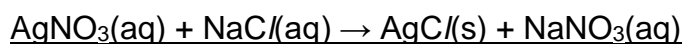
(2013 P2 B8)

- (a) Write equations, with state symbols, to show the reactions that happen at the anode and cathode during each experiment.

Experiment 1:**Experiment 2:**

- (b) At the beginning of each experiment, the student removes a sample of the electrolyte, aqueous silver nitrate, and puts it into a test tube. The student then adds a few drops of aqueous sodium chloride to the sample.
- (i) Describe and explain what the student sees. Include an equation in your answer. [2]

A white precipitate of silver chloride is formed.



- (ii) After some time, the student observes that no more silver is being deposited on the object in experiment 1 but more silver is still being deposited on the object in experiment 2. Suggest a reason for this observation and describe how he could use aqueous sodium chloride to find out if his reasoning is correct. [2]

Experiment 1:

No more silver is deposited on the object because all the silver ions from the electrolyte of silver nitrate have been discharged. This can be verified upon taking a sample of the electrolyte and testing with sodium chloride, no precipitate is formed.

Experiment 2:

The electrolyte will still form a white precipitate when tested with sodium chloride because the silver ions discharged at the cathode are continuously being replaced by the silver anode which ionised into silver ions.

- (c) If an iron object is placed in a beaker of aqueous silver nitrate, a silver coating forms on the iron. If a gold object is placed in aqueous silver nitrate, no reaction happens. Explain why. [1]

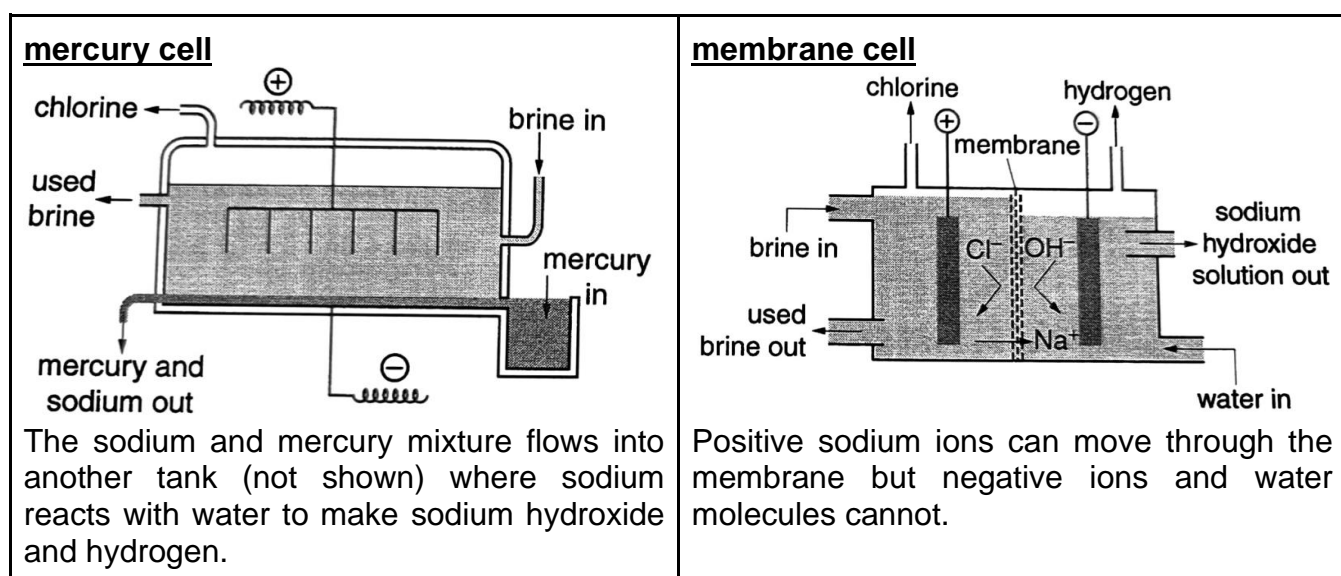
Iron is more reactive than silver, so it displaces silver from aqueous silver nitrate.

Gold is less reactive than silver, so it does not displace silver from aqueous silver nitrate, hence no reaction occurs.

6 Read the information about the industrial electrolysis of brine.

Industrial Electrolysis of Brine

Brine is a saturated solution of sodium chloride, containing about 25% by mass of sodium chloride. Electrolysis of brine produces chlorine, hydrogen and sodium hydroxide. Industrial electrolysis of brine used to be carried out in **mercury cells** but is now carried out in **membrane cells**. The diagrams show how these cells work.



The membrane cell was a major breakthrough when it was developed because it allows sodium hydroxide and chlorine to be produced in the same cell. Without the membrane, the sodium

hydroxide would not be pure because it would contain chloride ions. One other problem that the membrane cell solves is that it keeps the chlorine gas and hydroxide ions separate. Chlorine and hydroxide ions react together – this would reduce the amount of chlorine made and create more impurities in the sodium hydroxide.

The table shows some information about the two types of cells.

| | mercury | membrane |
|--|--|-----------------------|
| overall energy consumption (kWh per tonne of chlorine) 1 tonne = 1 000 000 g | 3360 | 2750 |
| purity of sodium hydroxide produced | high purity | high purity |
| concentration of sodium hydroxide produced | 50% concentration | 35% concentration |
| other points | mercury is toxic and must be removed from used brine | low maintenance costs |

(2012 P2 B7)

(a) In the membrane cell, it is important that negative ions do not pass through the membrane. Explain why. [3]

- If chlorine ions can pass through the membrane, the sodium hydroxide will not be pure as there would be sodium chloride present.
- It would also decrease the yield of chlorine gas produced since hydroxide ions would react with it and create more impurities in the sodium hydroxide.

(b) It is an advantage that negative ions do not pass through the membrane. Describe the **other** advantages of using the membrane cell instead of the mercury cell. [2]

- The membrane cell consumes less energy so less fuel is needed and cost of production is lower.
- Unlike the mercury cell, there is no toxic waste to be handled in the membrane cell. Hence, the cost of maintaining the membrane cell is cheaper.

(c) Give one disadvantage of using the membrane cell instead of the mercury cell. [1]

A lower concentration of sodium hydroxide is produced by the membrane cell.

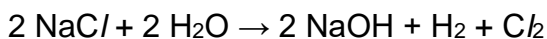
(d) Calculate the energy consumption of the membrane cell **per mole** of chlorine gas produced. [2]

Energy required to produce 1 tonne of $C_2(g) = 2750 \text{ kWh}$

Energy required to produce 1 g of $C_2(g) = \frac{2750}{1\,000\,000} \text{ kWh}$

Energy required to produce 1 mol of $C_2(g) = \frac{2750}{1\,000\,000} \times 71 = \underline{\underline{0.195 \text{ kWh}}}$ (3 s.f.)

- (e) Write an equation for the overall reaction that happens in the membrane cell. [1]



- (f) Calculate the maximum mass of sodium hydroxide that can be produced from 1 tonne of saturated brine. [3]

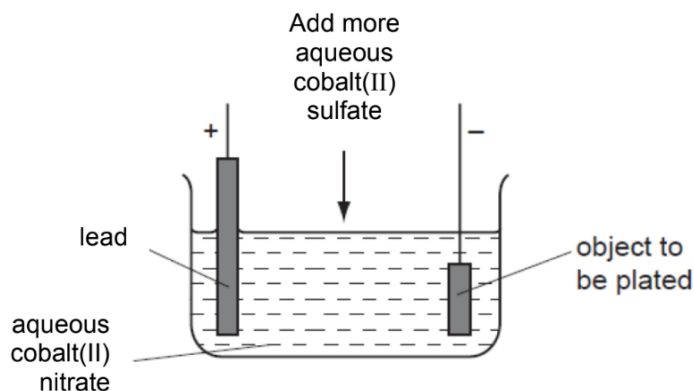
Since brine contains only about 25% by mass of NaCl,
1 tonne of brine contains 0.25 tonne = 250 000 g of NaCl

No. of moles of NaCl = $250000/58.5 = 4273.5 \text{ mol}$

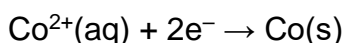
No. of moles of NaOH = $1/1 \times 4273.5 = 4273.5 \text{ mol}$

Mass of NaOH = $4273.5 \times 40 = 170\,940 \text{ g} = \underline{\underline{0.171 \text{ tonne}}}$ (3 s.f.)

- 7 Cobalt is used to electroplate steel objects.
The diagram shows how this could be done.

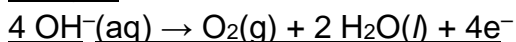


- (a) Write the ionic half equation to show the reaction at the cathode.



- (b) A colourless gas is formed at the anode.
Name this gas and explain how it is formed. Include an equation in your answer.

Oxygen



The hydroxide ion loses electrons to form oxygen gas and water.

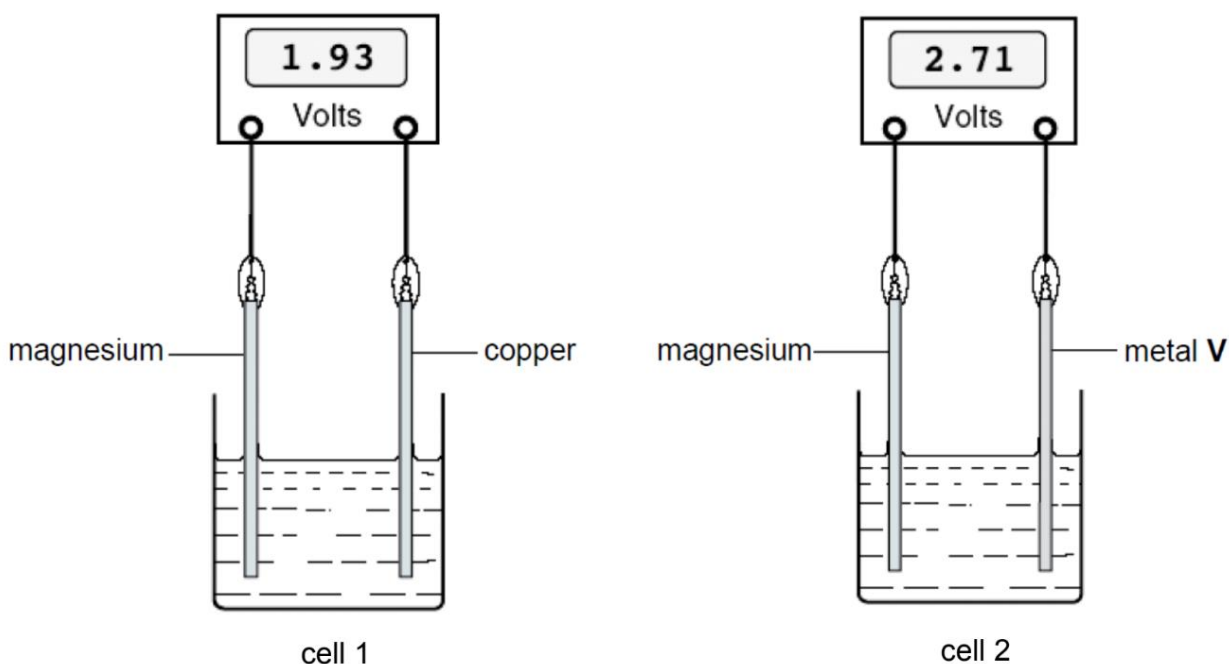
- (c) Explain why aqueous cobalt(II) sulfate is added during the electroplating process.

Suggest and explain another method besides adding cobalt(II) sulfate during the electroplating process.

During electroplating, cobalt(II) ions in the electrolyte are reduced at the negative electrode and they will be used up/depleted over time.

Replace the lead electrode with cobalt electrode. The cobalt electrode will be oxidised to produce cobalt(II) ions that replace the cobalt(II) ions in the electrolyte.

- 8 The diagram shows two electrical cells in which magnesium ribbon is used as one of the electrodes. In both cells, magnesium is the more reactive metal.

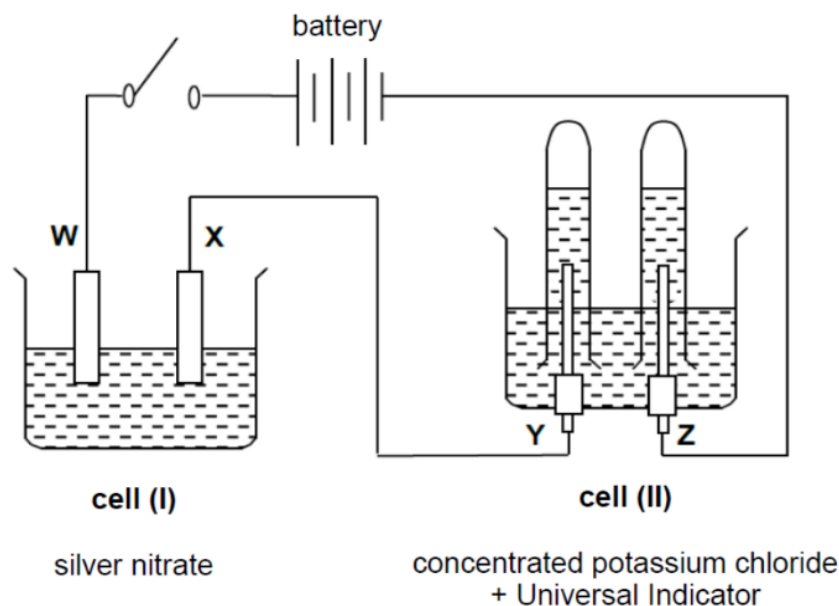


- (a) Use the information in the diagram to deduce how the reactivity of metal V compares with that of copper. Explain your answer.

Metal V is less reactive than copper.

The larger voltage produced in cell 2 indicates that the difference in reactivity between copper and metal V is greater.

- (b) A student set up an electric circuit as shown below.



Electrodes W and X are made of copper while electrodes Y and Z are made of carbon. The switch is closed and some changes are observed.

- electrode W becomes smaller in size;
- a layer of silvery solid is formed on electrode X.

Write ionic equations for the reactions that occur at electrode W and X in cell (I).

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

Electrode X: $\text{Ag}^{+}(\text{aq}) + \text{e}^{-} \rightarrow \text{Ag(s)}$

- (c) A student predicted the loss in mass of electrode W is equal to the mass of the silvery solid deposited on electrode X.

Do you agree with the student? Explain your answer.

No. The same number of moles of electrons will flow through the wire.

The overall equation in cell (I): $\text{Cu(s)} + 2\text{Ag}^{+}(\text{aq}) \rightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{Ag(s)}$

From the overall equation, 2 mol of Ag^{+} is discharged for every 1 mol of Cu oxidised. This implies that $2 \times 108 = 216$ g of Ag is deposited for every $1 \times 64 = 64$ g of loss in the mass of electrode W.

- (d) Describe the colour change of the Universal Indicator around electrode Z during electrolysis of the concentrated potassium chloride solution in cell (II).

Universal Indicator turns from green to blue / purple.

- (e) Explain your observation in (d).

H⁺ ions are preferentially discharged as compared to K⁺ ions.

This causes the concentration of H⁺ ions to decrease. Hence, the concentration of H⁺ ions becomes lower than the concentration of OH⁻ ions. The solution around electrode Z becomes alkaline.

OR

H⁺ ions are preferentially discharged as compared to K⁺ ions.

This causes the concentration of H⁺ ions to decrease and aqueous potassium hydroxide KOH is formed as a by-product around electrode Z. Hence, the solution around electrode Z becomes alkaline.