Mastering Chemistry

- Book 2B
- Topic 5 Redox Reactions,
  Chemical Cells and Electrolysis

Content

Continued on next page

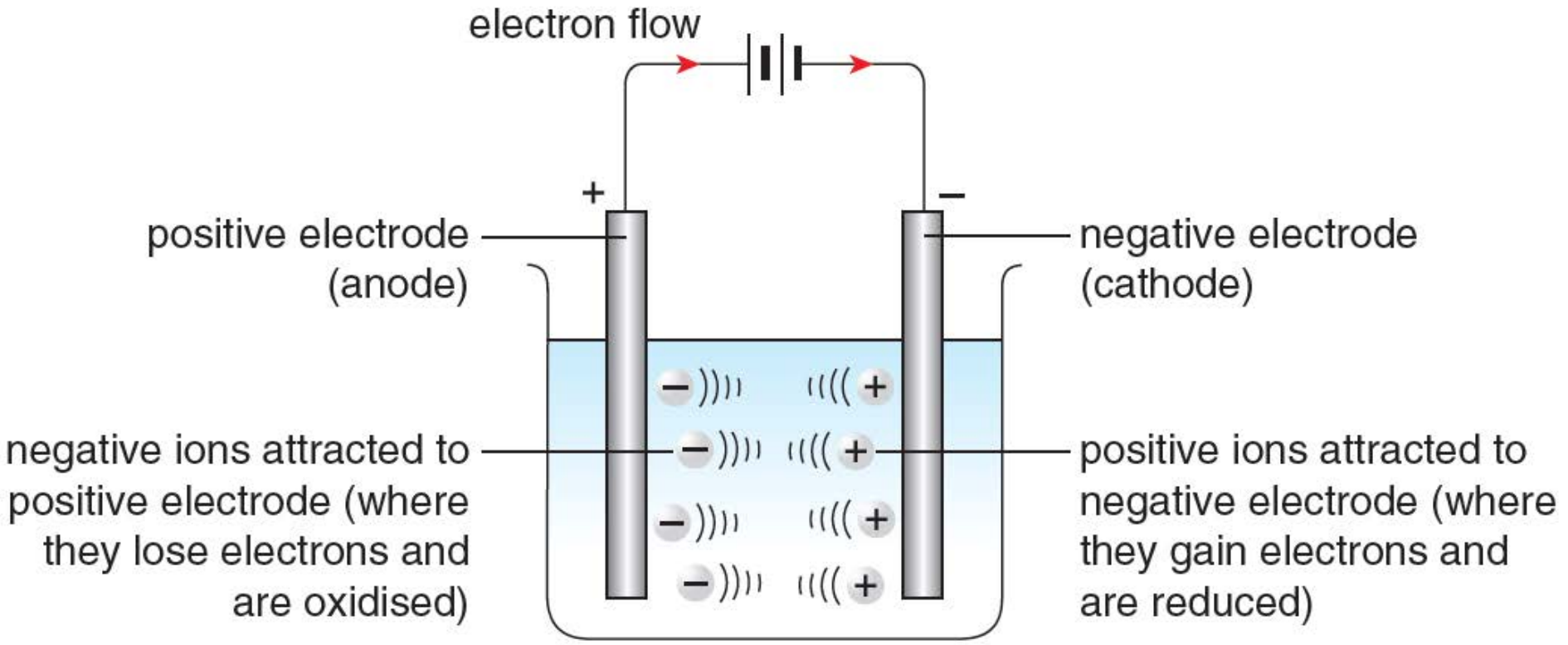
Content

22.1 What is electrolysis? (p.130)

- Substances can be classified into three groups according to how they conduct electricity — conductors, electrolytes and non-conductors.
- Electrolytes are substances which conduct electricity in molten state or aqueous solution, and are decomposed during the conduction.
- The process of decomposing an electrolyte with an electric current is called **electrolysis (電解)**. The apparatus in which electrolysis is carried out is known as an **electrolytic cell (電解池)**.
- The electric current enters and leaves the electrolyte through electrodes, which are usually made of carbon or metal.

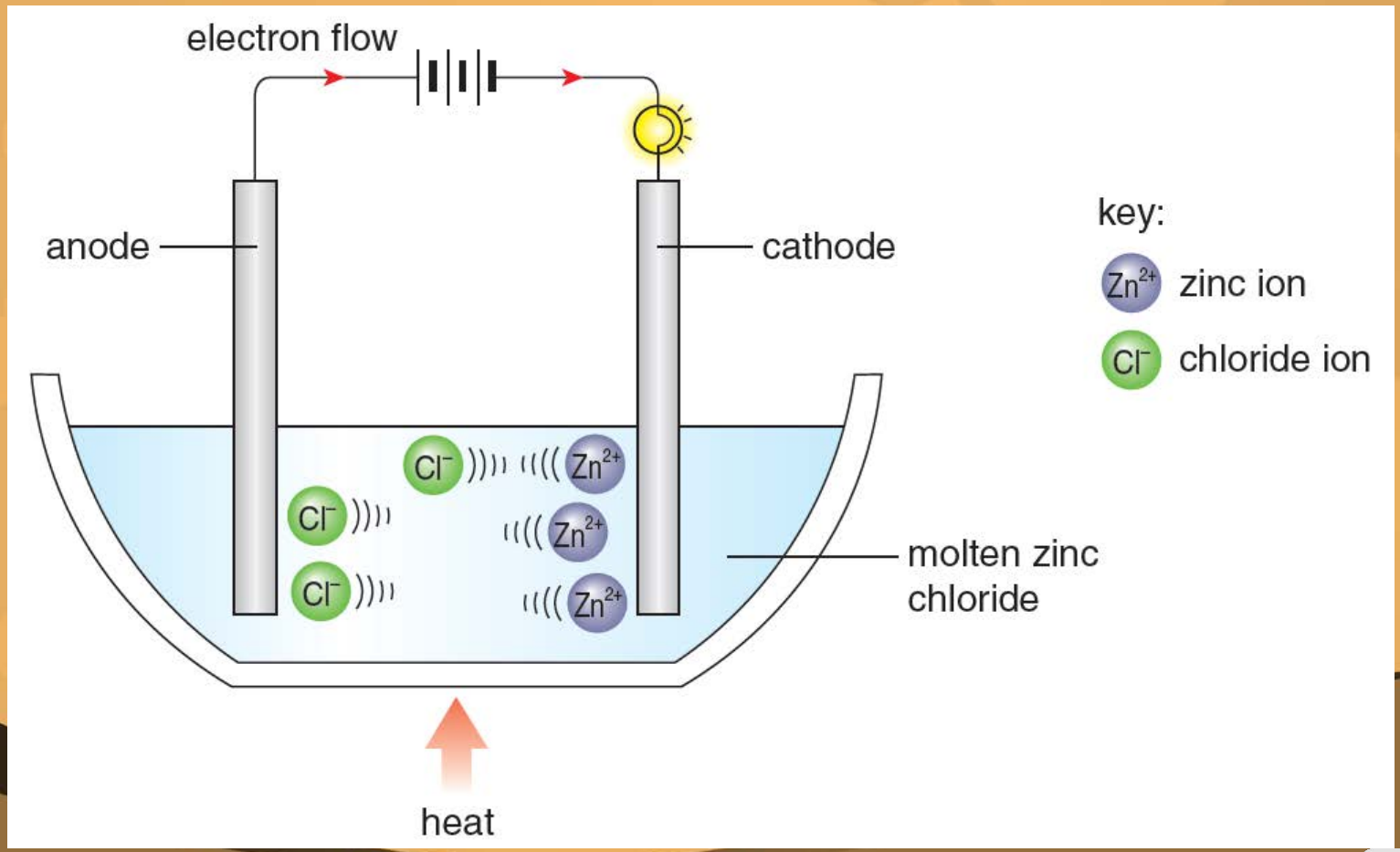
22.1 What is electrolysis? (p.130)

- The experimental set-up for electrolysis is shown below:



22.2 Electrolysis of molten zinc chloride (p.131)

- The experimental set-up for the electrolysis of molten zinc chloride is shown below:



22.2 Electrolysis of molten zinc chloride (p.131)

- Electrolysing molten zinc chloride breaks it down to make zinc and chlorine.
- Zinc ions are attracted to the cathode where they gain electrons and turn into zinc atoms.

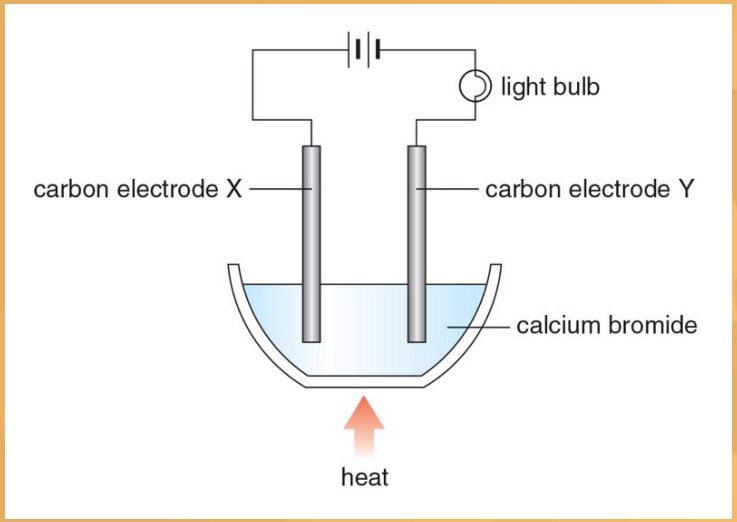
  $Zn^{2+}(l) + 2e^- \longrightarrow Zn(s)$
- Chloride ions are attracted to the anode where they lose electrons to form chlorine atoms and the chlorine atoms join together to form chlorine molecules.

  $2Cl^-(l) \longrightarrow Cl_2(g) + 2e^-$

22.2 Electrolysis of molten zinc chloride (p.131)

Practice 22.1

Consider the experimental set-up shown below.



When the calcium bromide becomes molten, the bulb lights up.

a) What will be observed at electrode X? Write the half equation for the change that occurs.

Reddish brown fumes

$2Br^-(aq) \longrightarrow Br_2(aq) + 2e^-$

22.2 Electrolysis of molten zinc chloride (p.131)

Practice 22.1

b) Write the half equation for the change that occurs at electrode Y.

$Ca^{2+}(l) + 2e^- \longrightarrow Ca(s)$

c) Decide whether electrode X or electrode Y is the anode. Explain your answer.

Electrode X is the anode as oxidation occurs here.

d) State ONE potential hazard when carrying out the experiment.

Bromine gas is toxic.

22.3 Comparing a chemical cell and an electrolytic cell (p.132)

- A chemical cell converts chemical energy to electrical energy while an electrolytic cell converts electrical energy to chemical energy.
- Ions flow in the electrolytes of both electrolytic and chemical cells while electrons only flow in the external circuit of these cells.

22.3 Comparing a chemical cell and an electrolytic cell (p.132)

- The table below summarises the differences between a chemical cell and an electrolytic cell.

A chemical cell	An electrolytic cell
It uses a redox reaction to produce a voltage.	It uses electricity to carry out a redox reaction.
The cathode is the positive electrode while the anode is the negative electrode (during discharge).	The cathode is the negative electrode while the anode is the positive electrode.
Oxidation occurs at the anode (the negative electrode).	Oxidation occurs at the anode (the positive electrode).
Reduction occurs at the cathode (the positive electrode).	Reduction occurs at the cathode (the negative electrode).
Electrons are supplied by the chemical species being oxidised; they move from the anode to the cathode in the external circuit.	The external d.c. supply supplies the electrons; electrons enter through the cathode and come out through the anode.

22.4 Electrolysis of aqueous solutions (p.133)

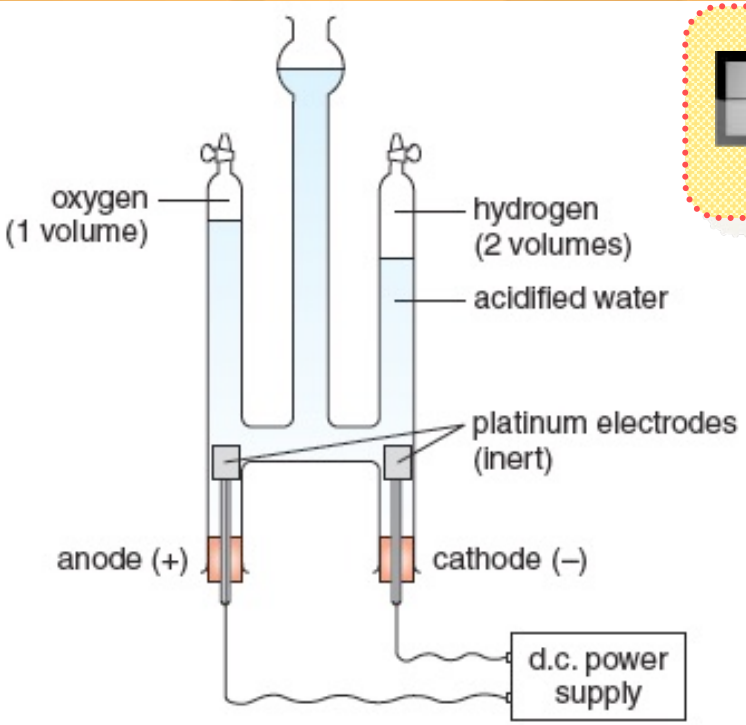
- Aqueous solutions of electrolytes contain more than one type of cation and more than one type of anion.
- For example, an aqueous solution of sodium chloride contains $Na^+(aq)$, $Cl^-(aq)$, $H^+(aq)$ and $OH^-(aq)$ ions. The $H^+(aq)$ and $OH^-(aq)$ ions arise from the dissociation of water:

$$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$$

22.4 Electrolysis of aqueous solutions (p.133)

Electrolysis of acidified water using platinum electrodes

- Pure water is a very poor conductor of electricity because there are so few ions in it. So the electrolysis of water is usually carried out on water to which a small amount of sulphuric acid has been added (acidified water).



3 Investigating the chemical changes in electrolysis *Ref.*

A Hoffman voltameter used to electrolyse acidified water

22.4 Electrolysis of aqueous solutions (p.133)

- When an electric current flows through the acidified water, gases are produced at the two electrodes and they are collected in the side arms of the apparatus.
  Acidified water contains the following ions:
  from water $H^+(aq)$, $OH^-(aq)$
  from sulphuric acid $H^+(aq)$, $SO_4^{2-}(aq)$

- $H^+(aq)$ ions are attracted to the cathode while the $OH^-(aq)$ ions and $SO_4^{2-}(aq)$ ions are attracted to the anode.

22.4 Electrolysis of aqueous solutions (p.133)

At the cathode

- The gas collected above the cathode burns with a 'pop' sound, showing that it is hydrogen gas. The gas is produced because the $H^+(aq)$ ions are discharged at the cathode.

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

At the anode

- The gas collected above the anode relights a glowing splint, showing that it is oxygen gas. This gas is produced because the $OH^-(aq)$ ions are **preferentially discharged (優先放電)** at the anode.

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

22.4 Electrolysis of aqueous solutions (p.133)

- When four electrons are lost from $OH^-(aq)$ ions at the anode, one oxygen molecule is formed, but when four electrons are gained by $H^+(aq)$ ions at the cathode, two hydrogen molecules are formed.
- Electrons must be lost from the anode at the same rate at which they are gained at the cathode, so two hydrogen molecules are formed for every oxygen molecule formed. Notice that volume of hydrogen : volume of oxygen is also 2 : 1.
  The overall reaction is:

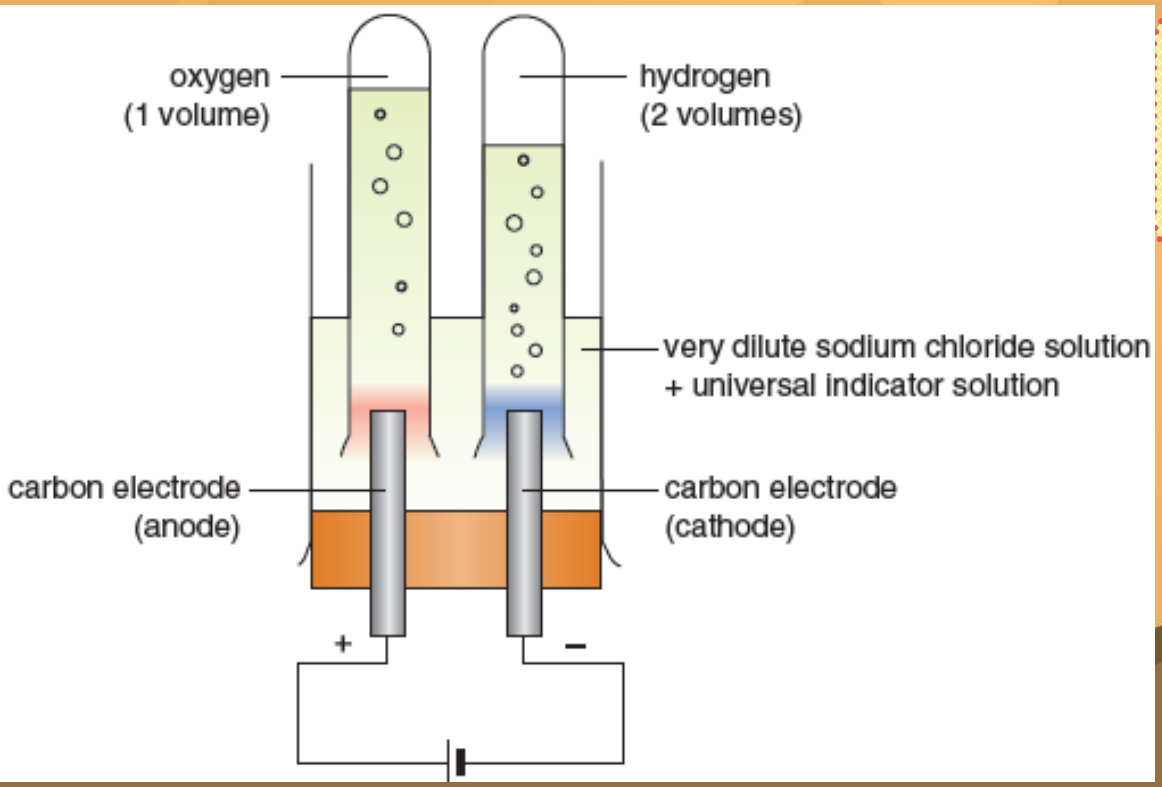
$$2H_2O(l) \longrightarrow 2H_2(g) + O_2(g)$$

- As the electrolysis proceeds, water molecules dissociate to replace the ions that have been discharged. Thus, although the quantity of sulphuric acid is unchanged, its concentration increases as the water is consumed.

22.4 Electrolysis of aqueous solutions (p.133)

Electrolysis of very dilute sodium chloride solution using carbon electrodes

- The figure below shows the electrolytic cell for the electrolysis of very dilute sodium chloride solution (0.1 mol dm^{-3}) with a few drops of universal indicator solution added.



Electrolysis of very dilute sodium chloride solution using carbon electrodes *Ref.*

22.4 Electrolysis of aqueous solutions (p.133)

- When an electric current flows through the solution, gases are produced at the two electrodes.
  Very dilute sodium chloride solution contains the following ions:

from sodium chloride	$Na^+(aq)$, $Cl^-(aq)$
from water	$H^+(aq)$, $OH^-(aq)$

- The $Na^+(aq)$ ions and $H^+(aq)$ ions are attracted to the cathode while the $Cl^-(aq)$ ions and $OH^-(aq)$ ions are attracted to the anode.

22.4 Electrolysis of aqueous solutions (p.133)

At the cathode

- Hydrogen gas is collected above the cathode. This is because $H^+(aq)$ ions are preferentially discharged at the cathode.

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

- As the electrolysis proceeds, water molecules dissociate to replace the $H^+(aq)$ ions discharged. Thus, there is a build-up of $OH^-(aq)$ ions near to the cathode. The solution there becomes alkaline and the universal indicator solution turns blue.

22.4 Electrolysis of aqueous solutions (p.133)

At the anode

- Oxygen gas is collected above the anode. This is beacuse $OH^-(aq)$ ions are preferentially discharged at the anode.

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

- As the electrolysis proceeds, water molecules dissociate to replace the $OH^-(aq)$ ions discharged. Thus, there is a build-up of $H^+(aq)$ ions near to the anode. The solution there becomes acidic and the universal indicator solution turns red.
  Equation for the overall reaction is:

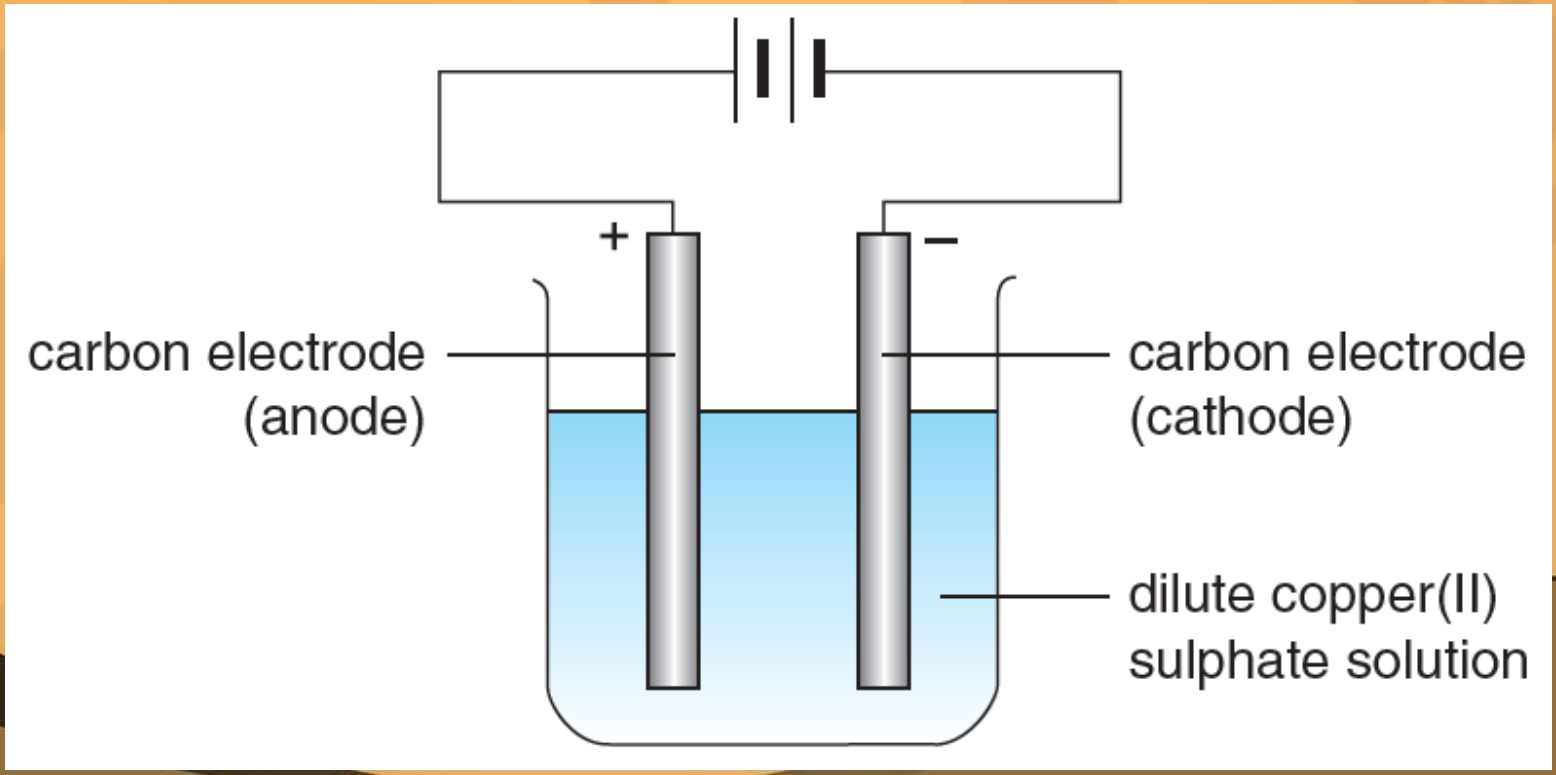
  $$2H_2O(l) \longrightarrow 2H_2(g) + O_2(g)$$

- The concentration of the sodium chloride solution increases as water is consumed in the electrolysis.

22.4 Electrolysis of aqueous solutions (p.133)

Electrolysis of dilute copper(II) sulphate solution using carbon electrodes

- The figure below shows the electrolytic cell for the electrolysis of dilute copper(II) sulphate solution using carbon electrodes.

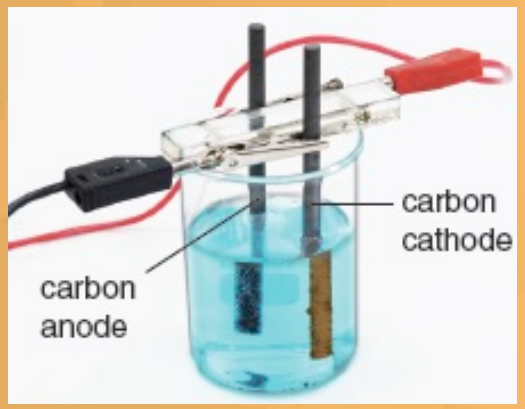


22.4 Electrolysis of aqueous solutions (p.133)

- When an electric current flows through the solution, the cathode becomes coated with a reddish brown solid and a colourless gas is produced at the anode. The blue colour of the solution fades gradually.

Dilute copper(II) sulphate solution contains the following ions:

from copper(II) sulphate	$Cu^{2+}(aq)$, $SO_4^{2-}(aq)$
from water	$H^+(aq)$, $OH^-(aq)$



Observable changes during the electrolysis of dilute copper(II) sulphate solution using carbon electrodes

- The $Cu^{2+}(aq)$ ions and $H^+(aq)$ ions are attracted to the cathode while the $SO_4^{2-}(aq)$ ions and $OH^-(aq)$ ions are attracted to the anode.

22.4 Electrolysis of aqueous solutions (p.133)

At the cathode

- The reddish brown deposit on the cathode is copper. $Cu^{2+}(aq)$ ions are preferentially discharged here.

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

At the anode

- Oxygen gas is formed at the anode. $OH^-(aq)$ ions are preferentially discharged here.

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

Equation for the overall reaction is:

$$2Cu^{2+}(aq) + 4OH^-(aq) \longrightarrow 2Cu(s) + O_2(g) + 2H_2O(l)$$

22.4 Electrolysis of aqueous solutions (p.133)

- The blue colour of the solution is due to the presence of $Cu^{2+}(aq)$ ions. The colour of the solution becomes paler as the $Cu^{2+}(aq)$ ions are removed from the solution by reduction at the cathode.
- $Cu^{2+}(aq)$ ions and $OH^{-}(aq)$ ions are consumed in the electrolysis. $H^{+}(aq)$ ions and $SO_4^{2-}(aq)$ ions remain in the solution. Thus, the solution eventually becomes sulphuric acid.

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

- Which ions are preferentially discharged during the electrolysis of aqueous solutions depends on a number of factors, one of which is the position of ions in the electrochemical series.
- The table below summarises the products of electrolysis of some aqueous solutions.

Aqueous solution	Material of electrodes	Ions attracted to cathode	Ions preferentially discharged at cathode	Product at cathode	Ions attracted to anode	Ions preferentially discharged at anode	Product at anode
Acidified water	platinum	$H^+(aq)$	$H^+(aq)$	$H_2(g)$	$OH^-(aq)$ $SO_4^{2-}(aq)$	$OH^-(aq)$	$O_2(g)$
Very dilute sodium chloride solution	carbon	$Na^+(aq)$ $H^+(aq)$	$H^+(aq)$	$H_2(g)$	$Cl^-(aq)$ $OH^-(aq)$	$OH^-(aq)$	$O_2(g)$
Dilute copper(II) sulphate solution	carbon	$Cu^{2+}(aq)$ $H^+(aq)$	$Cu^{2+}(aq)$	$Cu(s)$	$SO_4^{2-}(aq)$ $OH^-(aq)$	$OH^-(aq)$	$O_2(g)$

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

Cations discharged at cathode

- The figure below shows the relative positions of sodium ion, hydrogen ion and copper(II) ion in the electrochemical series.

Investigating factors affecting the order of discharge of ions during electrolysis – position of ions in the electrochemical series ***Ref.***

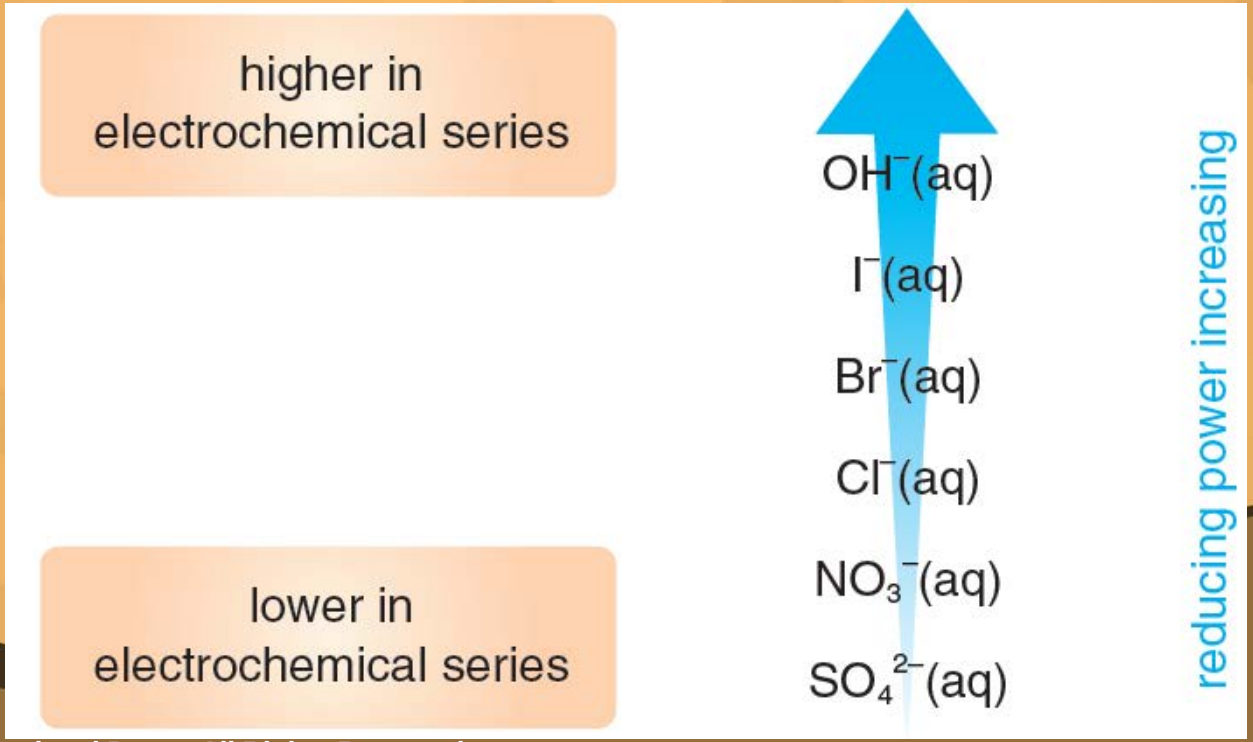
22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

- Since discharge at the cathode involves reduction, ions that accept electrons readily will be reduced first. Thus, stronger oxidising agents will be preferentially discharged compared to weaker oxidising agents.
- $H^+(aq)$ ion is a stronger oxidising agent than $Na^+(aq)$ ion. Hence $H^+(aq)$ ions are discharged (reduced) at the cathode in preference to $Na^+(aq)$ ions during the electrolysis of very dilute sodium chloride solution.
- $Cu^{2+}(aq)$ ion is a stronger oxidising agent than $H^+(aq)$ ion. Hence $Cu^{2+}(aq)$ ions are discharged (reduced) at the cathode in preference to $H^+(aq)$ ions during the electrolysis of dilute copper(II) sulphate solution.

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

Anions discharged at anode

- The figure below shows the relative positions of hydroxide ion, halide ions, nitrate ion and sulphate ion in the electrochemical series.



22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

- Since discharge at the anode involves oxidation, ions that lose electrons readily will be oxidised first. Thus, stronger reducing agents will be preferentially discharged compared to weaker reducing agents.
- $OH^-(aq)$ ion is a stronger reducing agent than $SO_4^{2-}(aq)$ ion and $Cl^-(aq)$ ion. Hence $OH^-(aq)$ ions are discharged (oxidised) at the anode in preference to $SO_4^{2-}(aq)$ ions and $Cl^-(aq)$ ions.

Electrolysing tin(II) chloride solution *Ref.*

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

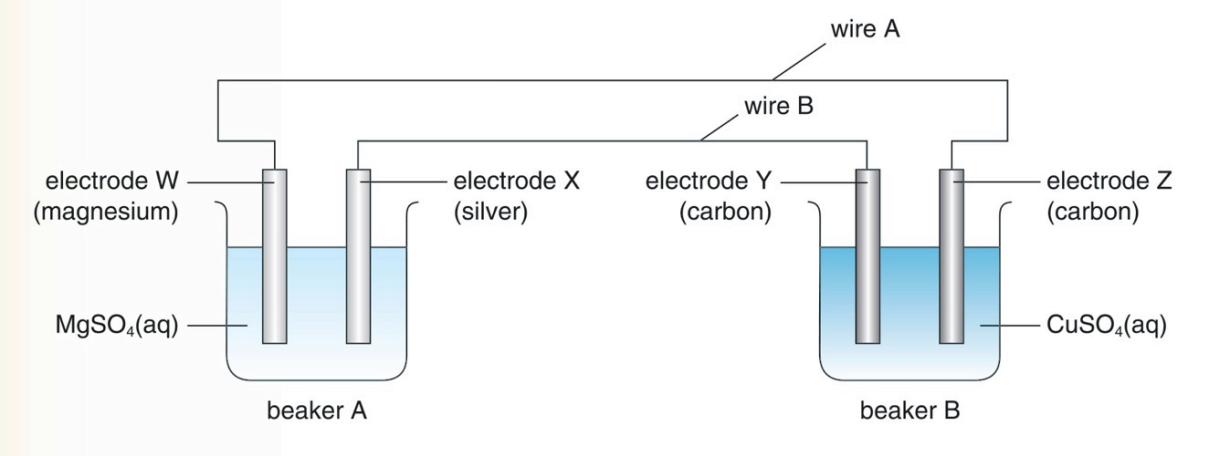
When inert electrodes are used during the electrolysis of very dilute aqueous solutions:

- **metals or hydrogen are formed at the cathode while non-metals (apart from hydrogen) are formed at the anode.**
- **cations lower in the electrochemical series will be discharged first at the cathode;**
- **anions higher in the electrochemical series will be discharged first at the anode.**

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

Q (Example 22.1)

Consider the following set-up consisting of a chemical cell joined to an electrolytic cell:



a) What is the direction of electron flow in wire A (from electrode W to electrode Z or from electrode Z to electrode W)?

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

Q (Example 22.1) (continued)

b) State an expected observation at each electrode. Write a half equation for the expected change that occurs at each electrode.

c) Complete the following table by filling in “anode” and “cathode” to describe the electrodes.

Electrode	Anode / cathode
W	
X	
Y	
Z	

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

Q (Example 22.1) (continued)

A

a) From electrode W to electrode Z

b)

Electrode	Observation	Half equation
W	becomes thinner gradually	$Mg(s) \longrightarrow Mg^{2+}(aq) + 2e^-$
X	colourless bubbles are given off	$2H^+(aq) + 2e^- \longrightarrow H_2(g)$
Y	colourless bubbles are given off	$4OH^-(aq) \longrightarrow 2H_2O(l) + O_2(g) + 4e^-$
Z	a reddish brown deposit	$Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$

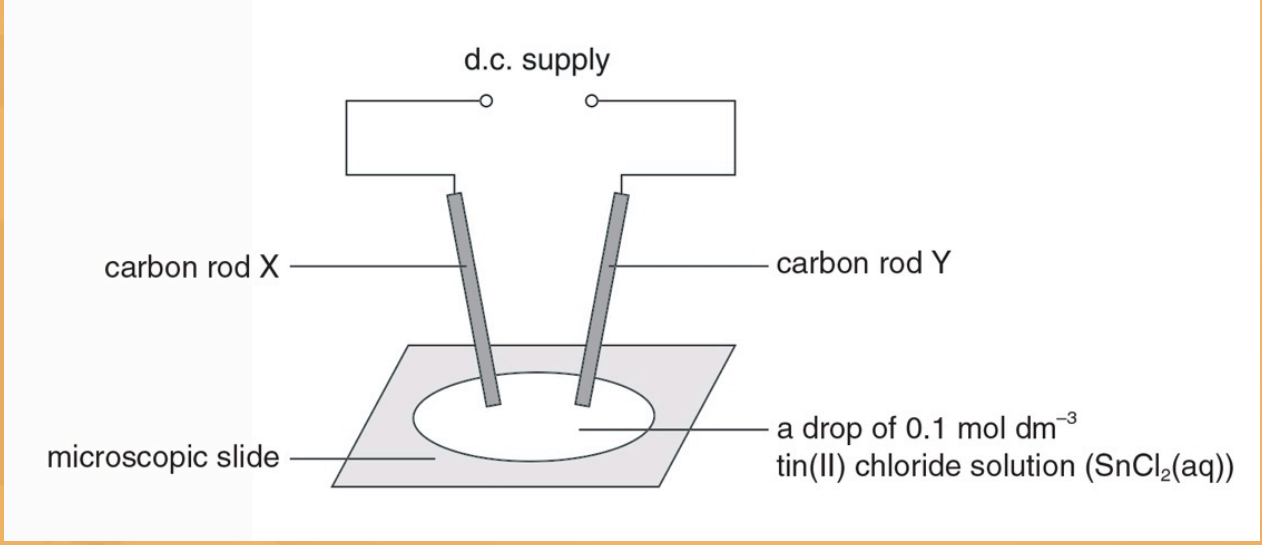
c)

Electrode	Anode / cathode
W	anode
X	cathode
Y	anode
Z	cathode

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

Q (Example 22.2)

A student used the set-up shown below to conduct a microscale experiment on electrolysis.



a) A silvery solid was found on carbon rod X after some time.
   i) What was the silvery solid found on carbon rod X?
   ii) Write the half equation for the formation of the silvery solid.

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

Q (Example 22.2) (continued)

b) A colourless gas was liberated at carbon rod Y.
   i) What was the gas?
   ii) Explain the formation of the gas with the help of a half equation.

c) Explain whether carbon rod X or Y is the anode.

d) Suggest TWO advantages of carrying out experiments in microscale.

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

Q (Example 22.2) (continued)

A

a) i) Tin

ii) $Sn^{2+}(aq) + 2e^- \longrightarrow Sn(s)$

b) i) Oxygen

ii) $OH^-(aq)$ ions and $Cl^-(aq)$ ions are attracted to carbon rod Y. $OH^-(aq)$ ion is a stronger reducing agent than $Cl^-(aq)$ ion. Hence $OH^-(aq)$ ions are preferentially discharged at carbon rod Y to give oxygen.

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

c) Carbon rod Y

Oxidation occurred here.

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

Q (Example 22.2) (continued)

A

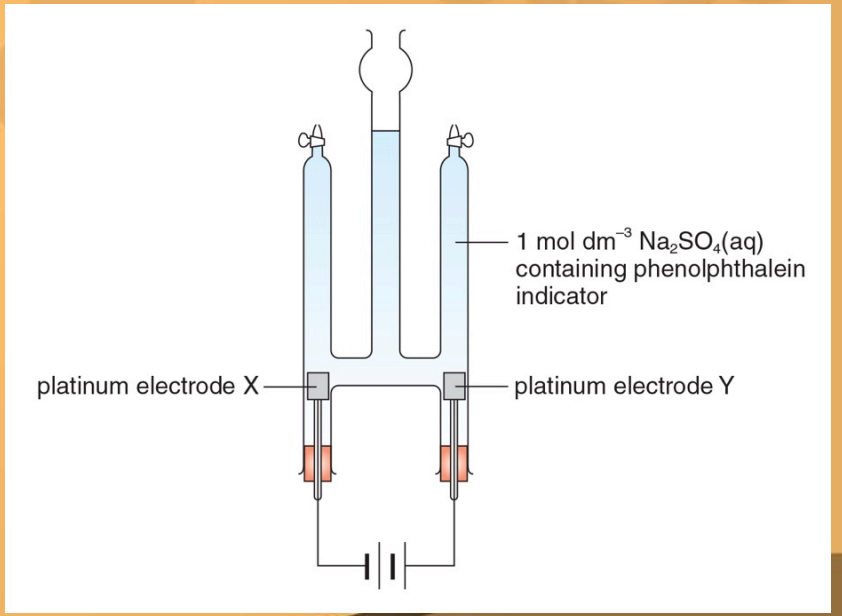
d) Any two of the following:

- Less chemicals are used.
- Less harmful to the environment.
- Less dangerous.
- Easier to handle.
- Save money.
- Save time.

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

Practice 22.2

1 The diagram below shows a set-up for the electrolysis of a colourless solution of 1 mol dm^{-3} $Na_2SO_4(aq)$ containing phenolphthalein indicator.



a) List ALL the ions that exist in the solution.

From sodium sulphate $Na^+(aq)$, $SO_4^{2-}(aq)$
From water $H^+(aq)$, $OH^-(aq)$

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

Practice 22.2 (continued)

b) State, with explanation, the expected observation(s) around each electrode.

At electrode X

$H^+(aq)$ ions and $Na^+(aq)$ ions are attracted to electrode X.
$H^+(aq)$ ion is a stronger oxidising agent than $Na^+(aq)$ ion.
Hence $H^+(aq)$ ions are preferentially discharged at electrode X to give colourless hydrogen gas.

At electrode Y

$OH^-(aq)$ ions and $SO_4^{2-}(aq)$ ions are attracted to electrode Y.
$OH^-(aq)$ ion is a stronger reducing agent than $SO_4^{2-}(aq)$ ion.
Hence $OH^-(aq)$ ions are preferentially discharged at electrode Y to give colourless oxygen gas.

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

Practice 22.2 (continued)

c) Write a half equation for the expected change at each electrode.

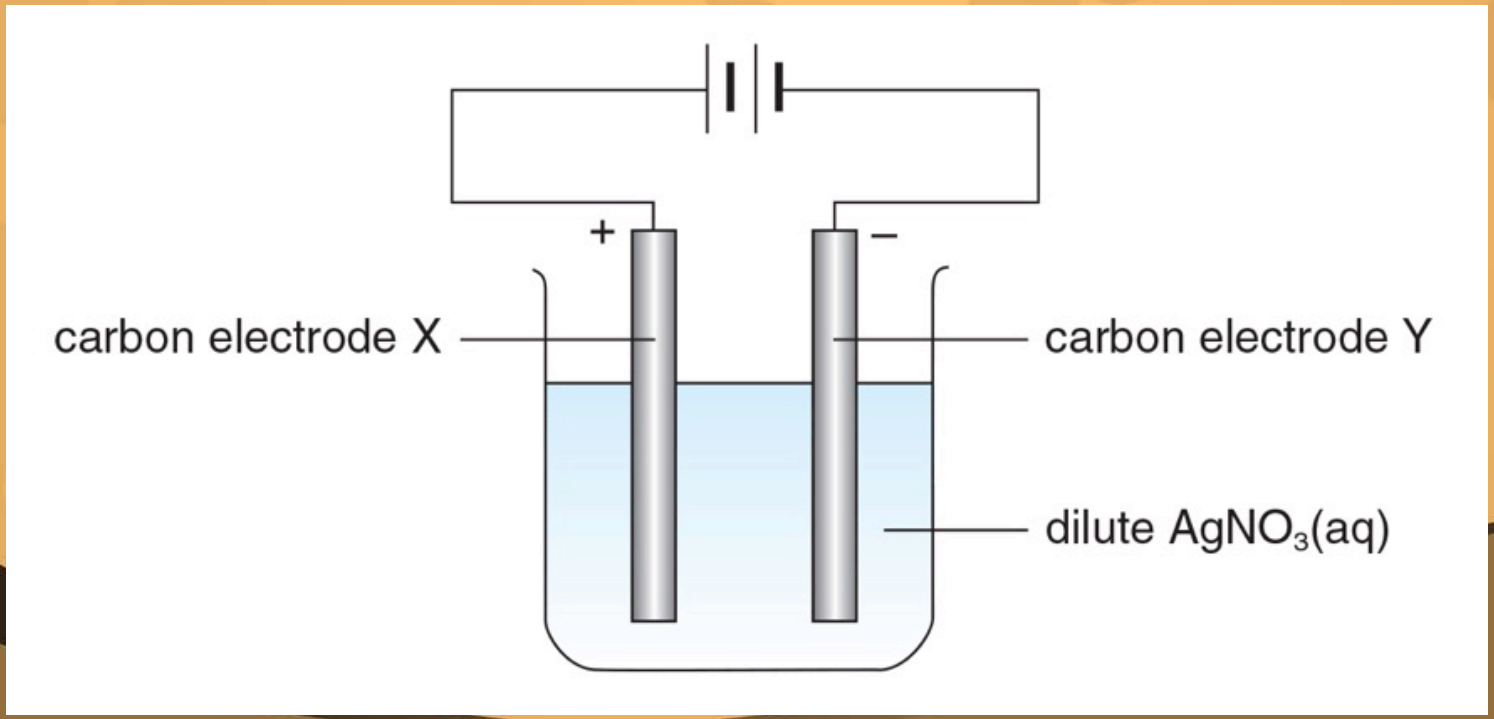
Electrode X: $2H^+(aq) + 2e^- \longrightarrow H_2(g)$

Electrode Y: $4OH^-(aq) \longrightarrow O_2(g) + 2H_2O(l) + 4e^-$

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

Practice 22.2 (continued)

2 The diagram below shows the experimental set-up used in the electrolysis of dilute silver nitrate solution.



22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

Practice 22.2 (continued)

a) State, with explanation, the expected observation(s) at each electrode.

At electrode X

$OH^-(aq)$ ions and $NO_3^-(aq)$ ions are attracted to electrode X.
$OH^-(aq)$ ion is a stronger reducing agent than $NO^{3-}(aq)$ ion.
Hence $OH^-(aq)$ ions are preferentially discharged at electrode X to give colourless oxygen gas.

At electrode Y

$H^+(aq)$ ions and $Ag^+(aq)$ ions are attracted to electrode Y.
$Ag^+(aq)$ ion is a stronger oxidising agent than $H^+(aq)$ ion.
Hence $Ag^+(aq)$ ions are preferentially discharged at electrode Y to give a silvery deposit of silver.

22.5 Position of ions in the electrochemical series and the preferential discharge of ions (p.138)

Practice 22.2 (continued)

b) Write a half equation for the expected change at each electrode.

Electrode X:

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

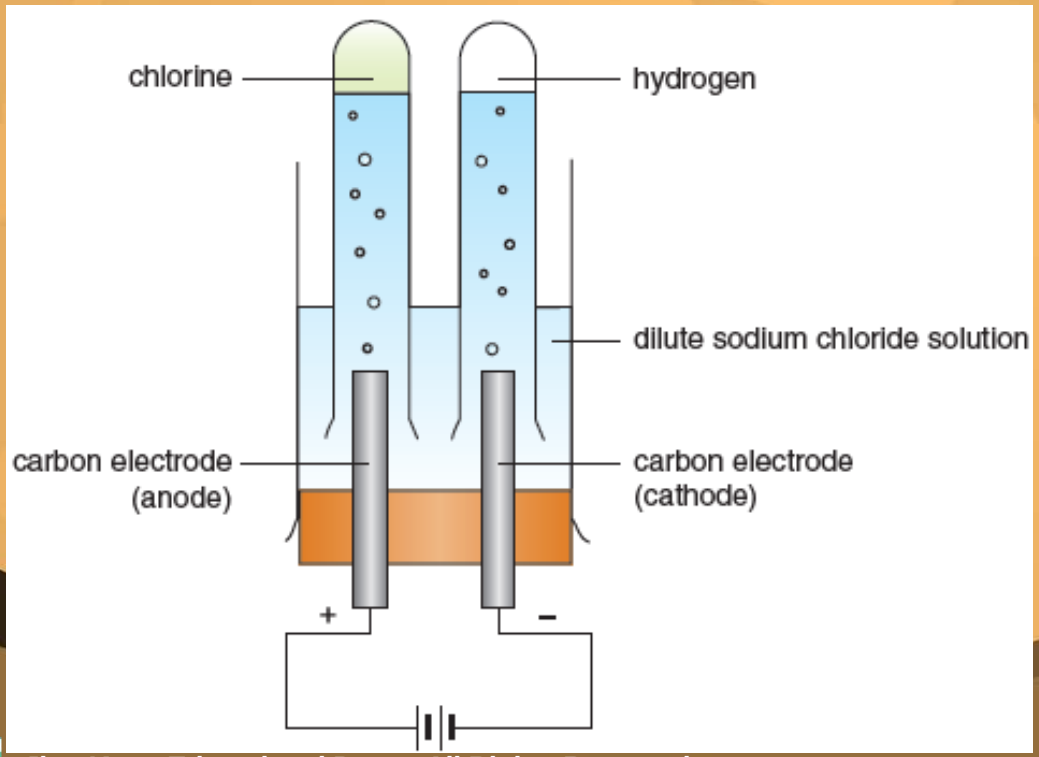
Electrode Y:

$Ag^+(aq) + e^- \longrightarrow Ag(s)$

22.6 Concentration of ions in solution and the preferential discharge of ions (p.144)

Electrolysis of dilute sodium chloride solution using carbon electrodes

- The figure below shows the electrolytic cell for the electrolysis of dilute sodium chloride solution (2 mol dm^{-3}).



Investigating factors affecting the order of discharge of ions during electrolysis – effect of concentration of ions in the solution ***Ref.***

22.6 Concentration of ions in solution and the preferential discharge of ions (p.144)

- When an electric current flows through the solution, gases are produced at the two electrodes.
  Dilute sodium chloride solution contains the following ions:
  from sodium chloride $Na^+(aq)$, $Cl^-(aq)$
  from water $H^+(aq)$, $OH^-(aq)$
- The $Na^+(aq)$ ions and $H^+(aq)$ ions are attracted to the cathode while the $Cl^-(aq)$ ions and $OH^-(aq)$ are attracted to the anode.

22.6 Concentration of ions in solution and the preferential discharge of ions (p.144)

At the cathode

- Hydrogen gas is collected above the cathode. This is because H+(aq) ions are preferentially discharged at the cathode.

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

At the anode

- A greenish yellow gas, chlorine, is collected above the anode. This is because $Cl^-(aq)$ ions are preferentially discharged at the anode.

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

Electrolysis of concentrated sodium chloride solution using carbon electrodes *Ref.*

22.6 Concentration of ions in solution and the preferential discharge of ions (p.144)

- $OH^-(aq)$ ion is a stronger reducing agent than $Cl^-(aq)$ ion. If a solution of sodium chloride of very low concentration is electrolysed, $OH^-(aq)$ ions would be preferentially discharged at the anode. However, at higher concentraions of sodium chloride, the discharge of $Cl^-(aq)$ ions becomes more favourable.
  Equation for the overall reaction is:
  $2H^+(aq) + 2Cl^-(aq) \longrightarrow H_2(g) + Cl_2(g)$
- The $Na^+(aq)$ ions and $H^+(aq)$ ions are attracted to the cathode while the $Cl^-(aq)$ ions and $OH^-(aq)$ are attracted to the anode.

22.6 Concentration of ions in solution and the preferential discharge of ions (p.144)

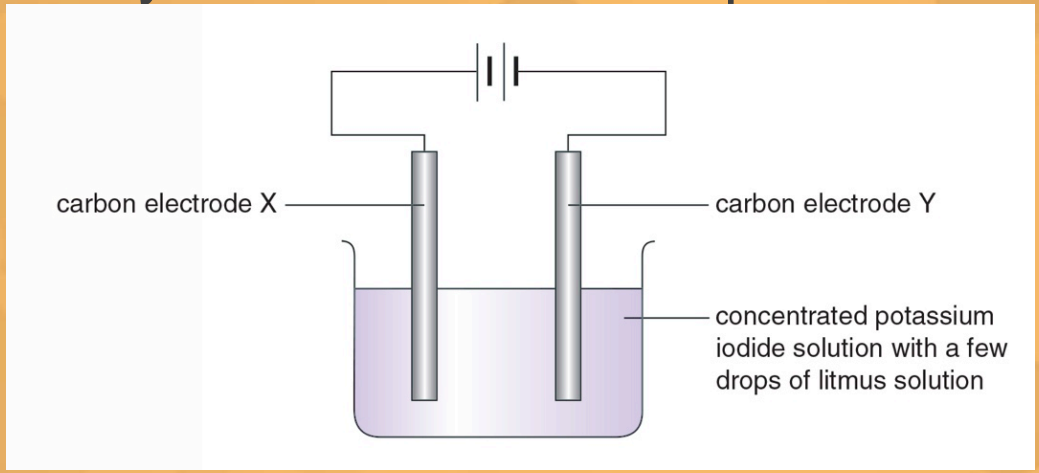
- The table below summarises the products of electrolysing sodium chloride solutions of different concentrations using carbon electrodes.

Sodium chloride solution	Product at		Change in solution
	anode	cathode	
Very dilute	oxygen	hydrogen	becomes more concentrated
Dilute	chlorine	hydrogen	becomes sodium hydroxide solution

22.6 Concentration of ions in solution and the preferential discharge of ions (p.144)

Q (Example 22.3)

The diagram below shows the experimental set-up used in the electrolysis of concentrated potassium iodide solution.



a) List ALL the ions that exist in the solution.

b) State and explain the expected observation around the solution near carbon electrode X during the electrolysis.

c) State and explain the expected observation around the solution near carbon electrode Y during the electrolysis.

22.6 Concentration of ions in solution and the preferential discharge of ions (p.144)

Q (Example 22.3) (continued)

A

a) $K^+(aq)$ ions, $I^-(aq)$ ions, $H^+(aq)$ ions, $OH^-(aq)$ ions

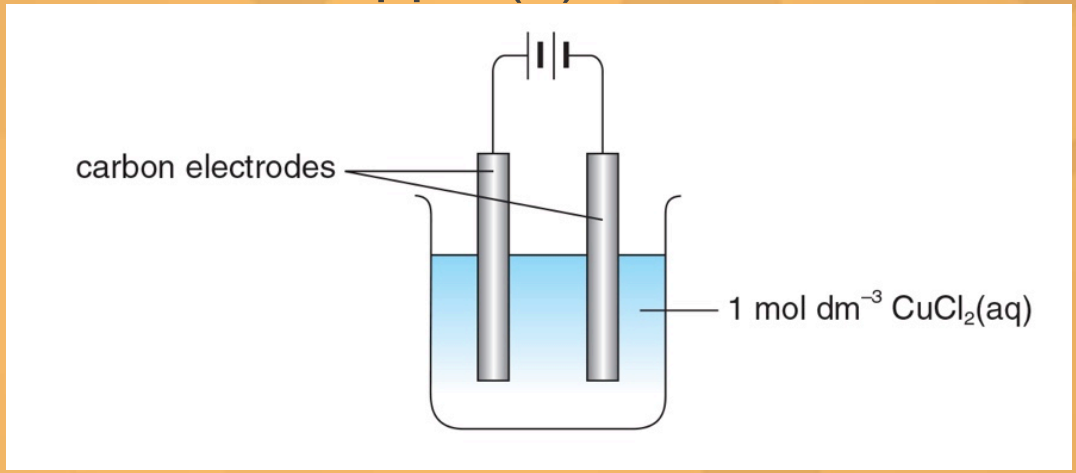
b) A brown colour is observed.
The $I^-(aq)$ ions and $OH^-(aq)$ ions are attracted to electrode X.
The concentration of $I^-(aq)$ ions in the solutions is much higher than that of $OH^-(aq)$ ions. Thus, $I^-(aq)$ ions are preferentially discharged to give iodine which dissolves in KI(aq) to give brown $I_3^-(aq)$ ions.

c) A blue colour is observed.
The $K^+(aq)$ ions and $H^+(aq)$ ions are attracted to electrode Y.
$H^+(aq)$ ion is a stronger oxidising agent than $K^+(aq)$ ion.
Thus, $H^+(aq)$ ions are preferentially discharged.
Water molecules dissociate continuously to replace the $H^+(aq)$ ions discharged. Thus, there is a build-up of $OH^-(aq)$ ions.
The litmus solution turns blue under alkaline conditions.

22.6 Concentration of ions in solution and the preferential discharge of ions (p.144)

Practice 22.3

The diagram below shows the experimental set-up used in the electrolysis of 1 mol dm^{-3} copper(II) chloride solution.



a) List ALL the ions that exist in the solution.

From copper(II) chloride $Cu^{2+}(aq)$, $Cl^-(aq)$

From water $H^+(aq)$, $OH^-(aq)$

22.6 Concentration of ions in solution and the preferential discharge of ions (p.144)

Practice 22.3 (continued)

b) State, with explanation, the expected observation(s) at each electrode.

At the cathode

$H^+(aq)$ ions and $Cu^{2+}(aq)$ ions are attracted to the cathode. $Cu^{2+}(aq)$ ion is a stronger oxidising agent than $H^+(aq)$ ion. Hence $Cu^{2+}(aq)$ ions are preferentially discharged at the cathode to give a reddish brown deposit of copper.

At the anode

$Cl^-(aq)$ ions and $OH^-(aq)$ ions are attracted to the anode. $OH^-(aq)$ ion is a stronger reducing agent than $Cl^-(aq)$ ion. However, at higher concentrations of chloride, the discharge of $Cl^-(aq)$ ions becomes more favourable. A greenish yellow gas forms.

22.6 Concentration of ions in solution and the preferential discharge of ions (p.144)

Practice 22.3 (continued)

c) Write a half equation for the expected change at each electrode.

At the cathode: $Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$

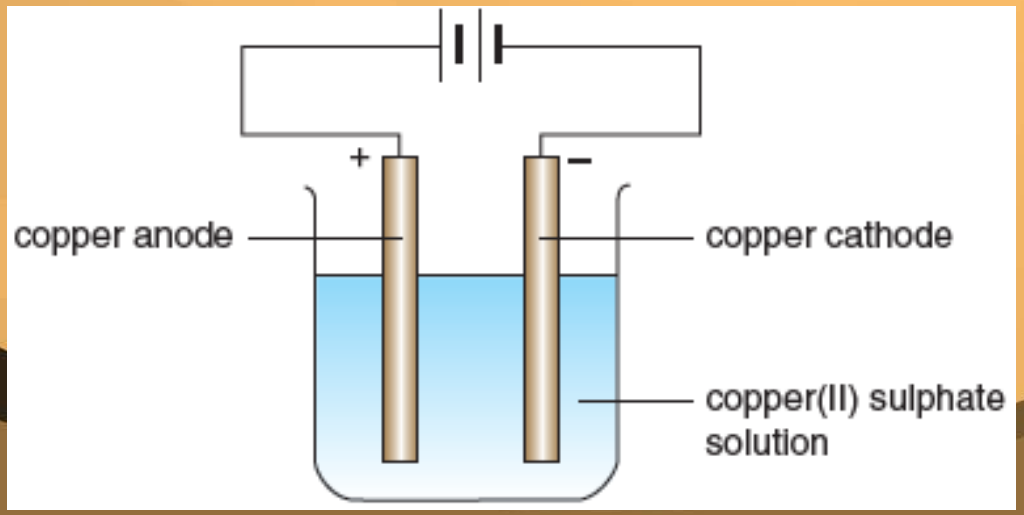
At the anode: $2Cl^-(aq) \longrightarrow Cl_2(g) + 2e^-$

22.7 The nature of the electrodes and the preferential discharge of ions (p.148)

- The material form which the electrodes are made also affects which ions are preferentially discharged during the electrolysis of aqueous solutions.

Electrolysis of dilute copper(II) sulphate solution using copper electrodes

- The figure below shows the electrolytic cell for the electrolysis of dilute copper(II) sulphate solution using copper electrodes.



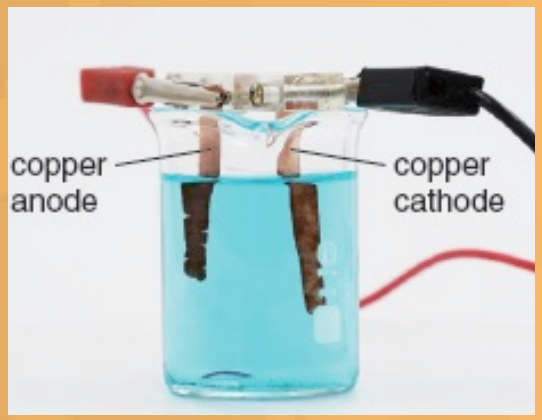
Investigating factors affecting the order of discharge of ions during electrolysis – effect of the nature of electrodes *Ref.*

22.7 The nature of the electrodes and the preferential discharge of ions (p.148)

- When an electric current flows through the solution, the cathode becomes coated with a reddish brown solid and the anode becomes thinner. The solution remains the same colour.

Dilute copper(II) sulphate solution contains the following ions:

from copper(II) sulphate	$Cu^{2+}(aq)$, $SO_4^{2-}(aq)$
from water	$H^+(aq)$, $OH^-(aq)$



Observable changes during electrolysis of dilute copper(II) sulphate solution using copper electrodes

- The $Cu^{2+}(aq)$ ions and $H^+(aq)$ ions are attracted to the cathode while the $SO_4^{2-}(aq)$ ions and $OH^-(aq)$ ions are attracted to the anode.

22.7 The nature of the electrodes and the preferential discharge of ions (p.148)

At the cathode

- The change at the cathode is exactly the same as when using carbon electrodes. $Cu^{2+}(aq)$ ions are preferentially discharged here.

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

At the anode

- The change at the anode is different from using carbon electrodes. No oxygen is given off.

22.7 The nature of the electrodes and the preferential discharge of ions (p.148)

- Copper is a stronger reducing agent than $OH^-(aq)$ ion and $SO_4^{2-}(aq)$ ion. Thus, the oxidation of copper is more favourable. The copper anode dissolves to form $Cu^{2+}(aq)$ ions.

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

- The net process is a transfer of copper from the anode to the cathode. If pure copper electrodes are used, the mass of copper lost from the anode is equal to the mass of copper deposited on the cathode.

- The net overall concentration of $Cu^{2+}(aq)$ ions in the electrolyte does not change and the blue colour of the solution remains the same.

22.7 The nature of the electrodes and the preferential discharge of ions (p.148)

- The table below summarises the products of electrolysing dilute copper(II) sulphate solutions using different electrodes.

Material of		Product at		Change in solution
anode	cathode	anode	cathode	
carbon	carbon	oxygen	copper	becomes sulphuric acid
copper	copper	copper(II) ions	copper	remains the same

22.7 The nature of the electrodes and the preferential discharge of ions (p.148)

Which ions are preferentially discharged during the electrolysis of aqueous solutions depends on a number of factors, including:

- **the position of ions in the electrochemical series;**
- **the concentration of ions in the solution;**
- **the material from which the electrodes are made.**

22.7 The nature of the electrodes and the preferential discharge of ions (p.148)

Practice 22.4

1 mol dm^{-3} hydrochloric acid is electrolysed using a copper anode and a carbon cathode.

a) List ALL the ions that exist in the solution.

From hydrochloric acid $H^+(aq)$, $Cl^-(aq)$

From water $H^+(aq)$, $OH^-(aq)$

b) State, with explanation, the expected observation(s) at each electrode.

At the copper anode

$Cl^-(aq)$ ions and $OH^-(aq)$ ions are attracted to the anode.

Copper is a stronger reducing agent than $Cl^-(aq)$ ion and $OH^-(aq)$ ion. Thus, the oxidation of copper is more favourable. The copper anode dissolves to form $Cu^{2+}(aq)$ ions.

The anode dissolves and the solution turns blue.

At the carbon cathode

$H^+(aq)$ ions are attracted to the cathode. $H^+(aq)$ ions are discharged at the cathode to give colourless hydrogen gas.

22.7 The nature of the electrodes and the preferential discharge of ions (p.148)

Practice 22.4 (continued)

c) Write a half equation for the expected change at each electrode.

At the copper anode: $Cu(s) \longrightarrow Cu^{2+}(aq) + 2e^-$

At the carbon cathode: $2H^+(aq) + 2e^- \longrightarrow H_2(g)$

22.8 Electroplating (p.150)

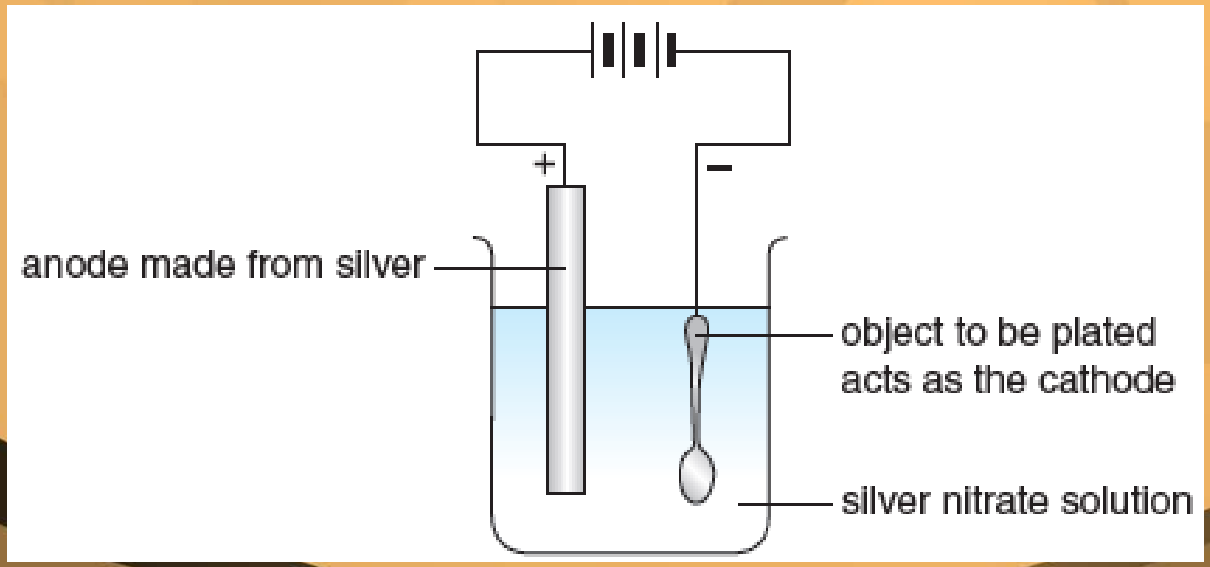
Electroplating with nickel *Ref.*

- **Electroplating (電鍍)** is the process of coating an object with a thin layer of a metal using electrolysis.
- Metals are electroplated to improve their appearance or to prevent corrosion. The most commonly used metals for electroplating are copper, chromium, silver and tin.
- For example, steel car bumpers are coated with chromium. Steel cans are coated with tin to make 'tin' cans for food. Cheap copper or nickel jewellery is often coated with silver.

Chromium-plated steel car Bumpers (left); silver-plated jewellery (right)

22.8 Electroplating (p.150)

- The figure below shows an electrolytic cell used to perform silver plating:
  - the cathode is the object to be coated;
  - the anode is a piece of silver;
  - the electrolyte is a solution containing ions of the coating metal, such as silver nitrate solution.



Electroplating *Ref.*

22.8 Electroplating (p.150)

At the anode

- The silver anode dissolves, forming silver ions in solution.

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

At the cathode

- Silver ions receive electrons, forming a coat of silver on the spoon.

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

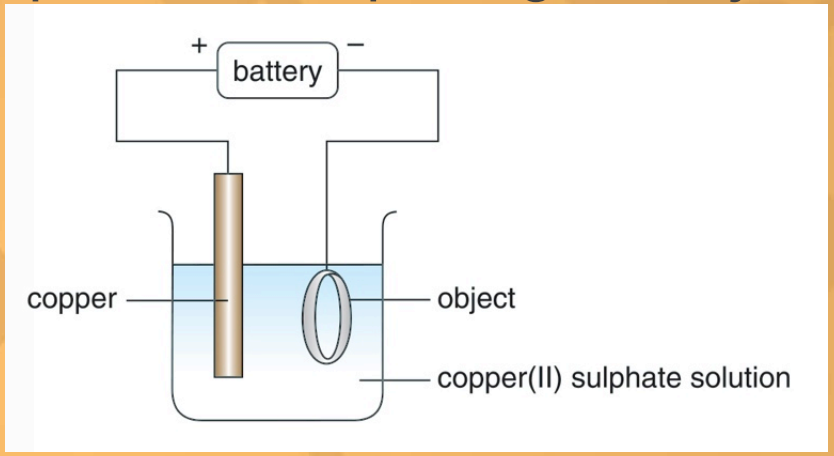
22.8 Electroplating (p.150)

- In order to obtain a good coating of metal during electroplating:
  - the object to be plated must be clean and free of grease;
  - the object should be rotated to give an even coating;
  - the current must not be too large or the 'coating' will form too rapidly and flake off;
  - the temperature and concentration of the electrolyte must be carefully controlled, otherwise the 'coating' will be deposited too rapidly or too slowly.

22.8 Electroplating (p.150)

Q (Example 22.4)

Consider the experiment set-up for electroplating an object shown in the diagram below.



a) i) Explain why copper(II) ions are preferentially discharged at the object.

ii) Write the half equation for the change that occurs.

b) State the observable change, if any, in the copper(II) sulphate solution during the electroplating process. Explain your answer.

22.8 Electroplating (p.150)

Q (Example 22.4) (continued)

c) It is known that 3.96×10^{22} electrons have passed through the external circuit during the electroplating process. What is the mass of copper that would theoretically be plated on the object?
(Relative atomic mass: Cu = 63.5; Avogradro constant = 6.02×10^{23} mol^{-1})

22.8 Electroplating (p.150)

Q (Example 22.4) (continued)

A

a) i) $Cu^{2+}(aq)$ ion is a stronger oxidising agent than hydrogen ion. Hence $Cu^{2+}(aq)$ ions are preferentially discharged to form a coat of copper on the object.

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

b) There is no observable change in the copper(II) sulphate solution.

The copper anode dissolves to form $Cu^{2+}(aq)$ ions. A deposit of copper is formed on the object. The net process is a transfer of copper from the anode to the object. The overall concentration of $Cu^{2+}(aq)$ ions in the solution does not change.

22.8 Electroplating (p.150)

Q (Example 22.4) (continued)

A

c) Number of mole of electrons involved = $\frac{3.96 \times 10^{22}}{6.02 \times 10^{23} \text{ mol}^{-1}}$

$= 0.0658 \text{ mol}$

The following half equation represents the reaction that occurs at the object:

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

Number of mole of copper plated = $\frac{0.0658}{2}$ mol

$= 0.0329 \text{ mol}$

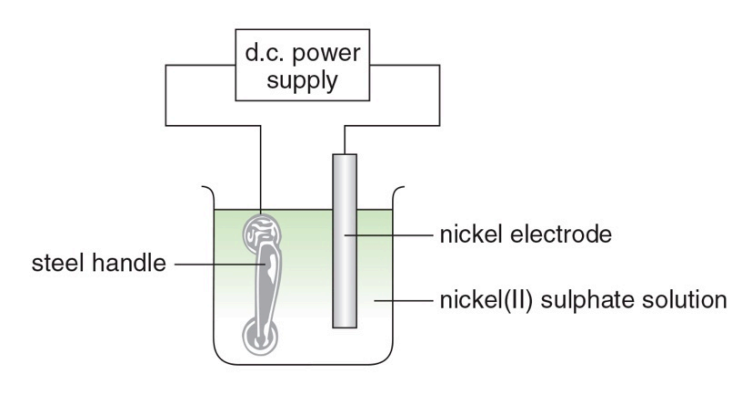
Mass of copper plated = $0.0329 \text{ mol} \times 63.5 \text{ g mol}^{-1}$

$= 2.09 \text{ g}$

22.8 Electroplating (p.150)

Practice 22.5

1 The diagram below shows the experimental set-up for electroplating a steel handle with nickel.



a) Decide whether the nickel electrode is the anode or the cathode.

Anode

b) What will be observed at the steel handle? Write the half equation for the change that occurs.

A thin layer of shiny metal will form on the steel handle.

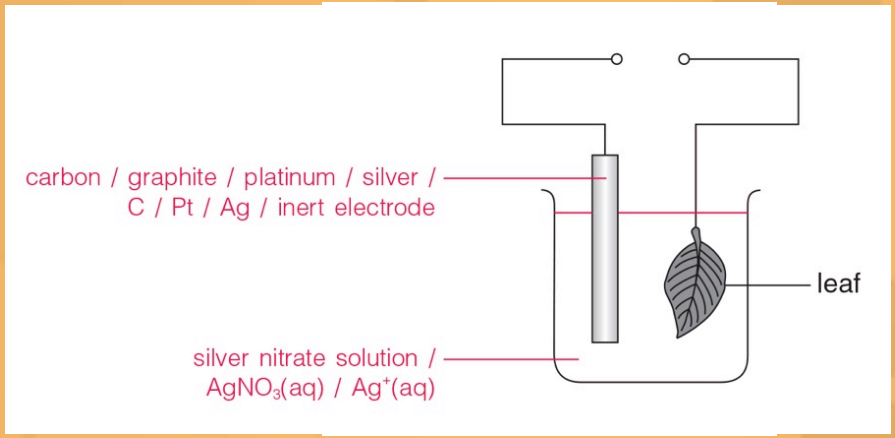
$Ni^{2+}(aq) + 2e^- \longrightarrow Ni(s)$

22.8 Electroplating (p.150)

Practice 22.5 (continued)

2 A small leaf was to be made into a piece of jewellery by plating it with silver. The leaf was first covered in graphite paste.

a) The diagram below shows an incomplete set-up. Add suitable drawings and labels to the diagram for electroplating of silver onto the leaf.



b) Why was the leaf first covered with graphite paste?

To make the leaf a conductor of electricity for the plating process.

c) Write the half equation for the change that occurred at the leaf.

$Ag^+(aq) + e^- \longrightarrow Ag(s)$

22.9 Environmental impact of the electroplating industry (p.154)

- The electroplating process involves pretreatment (e.g. cleaning and degreasing), plating and post plating treatment (e.g. rinsing with water).
  Major pollutants from the electroplating industry include:
  • acids and alkalis;
  • heavy metal ions;
  • cyanides.
- Discharge of untreated electroplating effluents affects water life and causes contamination of water courses and ground water.

Discharge of effluents from an electroplating factory causes contamination of water courses

22.9 Environmental impact of the electroplating industry (p.154)

Controlling pollution from the electroplating industry

- Making changes in work practices can stop pollutants being discharged into the environment. Some examples are listed below:
  - Design better rinsing systems to achieve reduction in water usage.
  - Replace cyanides, which have been key components of plating solutions for years, by less toxic compounds.
  - Recover metals, such as nickel and copper, by treating waste solutions.
  - Reuse plating bath solutions and rinse water.

22.9 Environmental impact of the electroplating industry (p.154)

Treating effluents before discharge

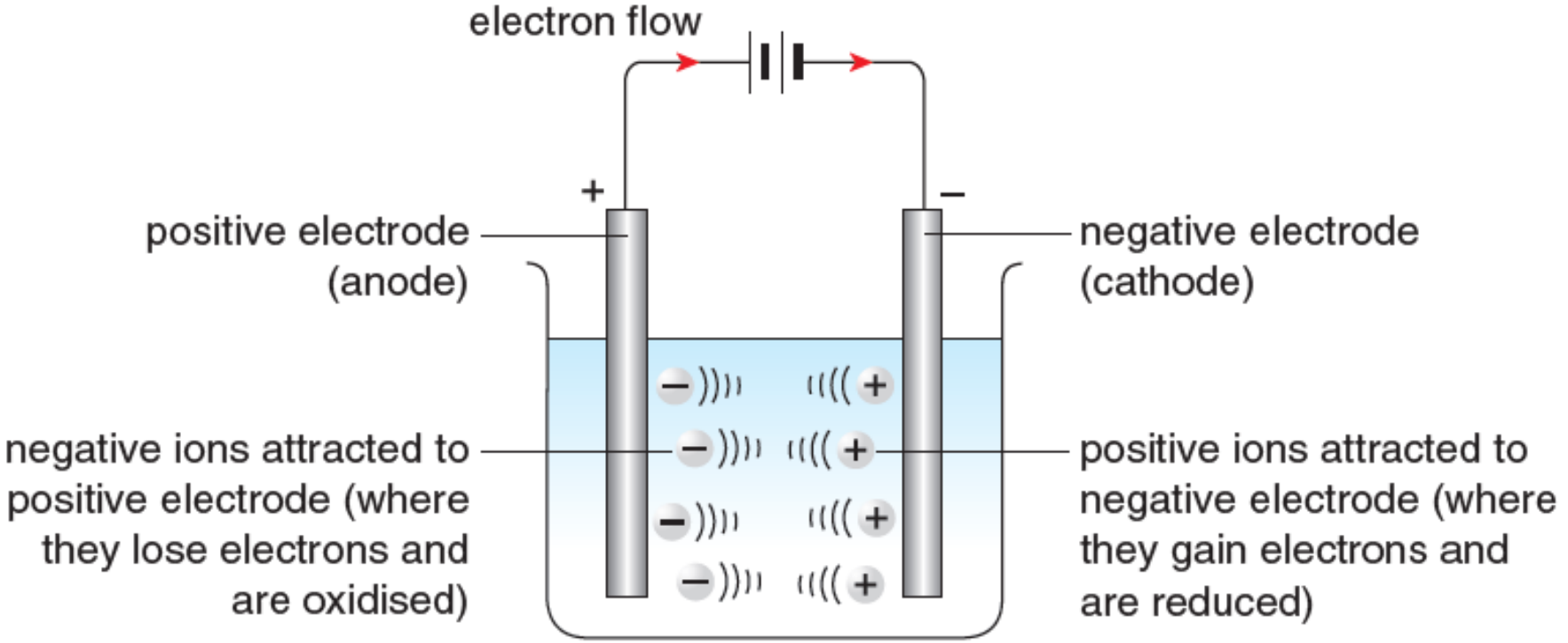
- Adjust the pH of effluents to around neutral (e.g. by adding slaked lime or sulphuric acid).
- Remove heavy metal ions by precipitation using sodium hydroxide solution.
- Remove chromium(VI) ions, which are highly toxic to humans, by a two-step process — first reduce these ions to less toxic chromium(III) ions using a reducing agent (e.g. sodium sulphite), then add sodium hydroxide solution to precipitate the ions as chromium(III) hydroxide.

Key terms (p.155)

electrolysis	電解	preferentially discharged	優先放電
electrolytic cell	電解池	electroplating	電鍍

Summary (p.156)

1 Electrolysis is a process of decomposing an electrolyte with an electric current.



Summary (p.156)

2 The following table summarises the differences between a chemical cell and an electrolytic cell:

A chemical cell	An electrolytic cell
It uses a redox reaction to produce a voltage.	It uses electricity to carry out a redox reaction.
The cathode is the positive electrode while the anode is the negative electrode (during discharge).	The cathode is the negative electrode while the anode is the positive electrode.
Oxidation occurs at the anode (the negative electrode).	Oxidation occurs at the anode (the positive electrode).
Reduction occurs at the cathode (the positive electrode).	Reduction occurs at the cathode (the negative electrode).
Electrons are supplied by the chemical species being oxidised; they move from the anode to the cathode in the external circuit.	The external d.c. supply supplies the electrons; electrons enter through the cathode and come out through the anode.

Summary (p.156)

3 When inert electrodes are used during the electrolysis of very dilute aqueous solutions:
- metals or hydrogen are formed at the cathode while non-metals (apart from hydrogen) are formed at the anode.
- cations lower in the electrochemical series will be discharged first at the cathode;
- anions higher in the electrochemical series will be discharged first at the anode.

4 Which ions are preferentially dicharged during the electrolysis of aqueous solutions depends on a number of factors, including:
- the position of ions in the electrochemical series;
- the concentration of ions in the solution;
- the material from which the electrodes are made.

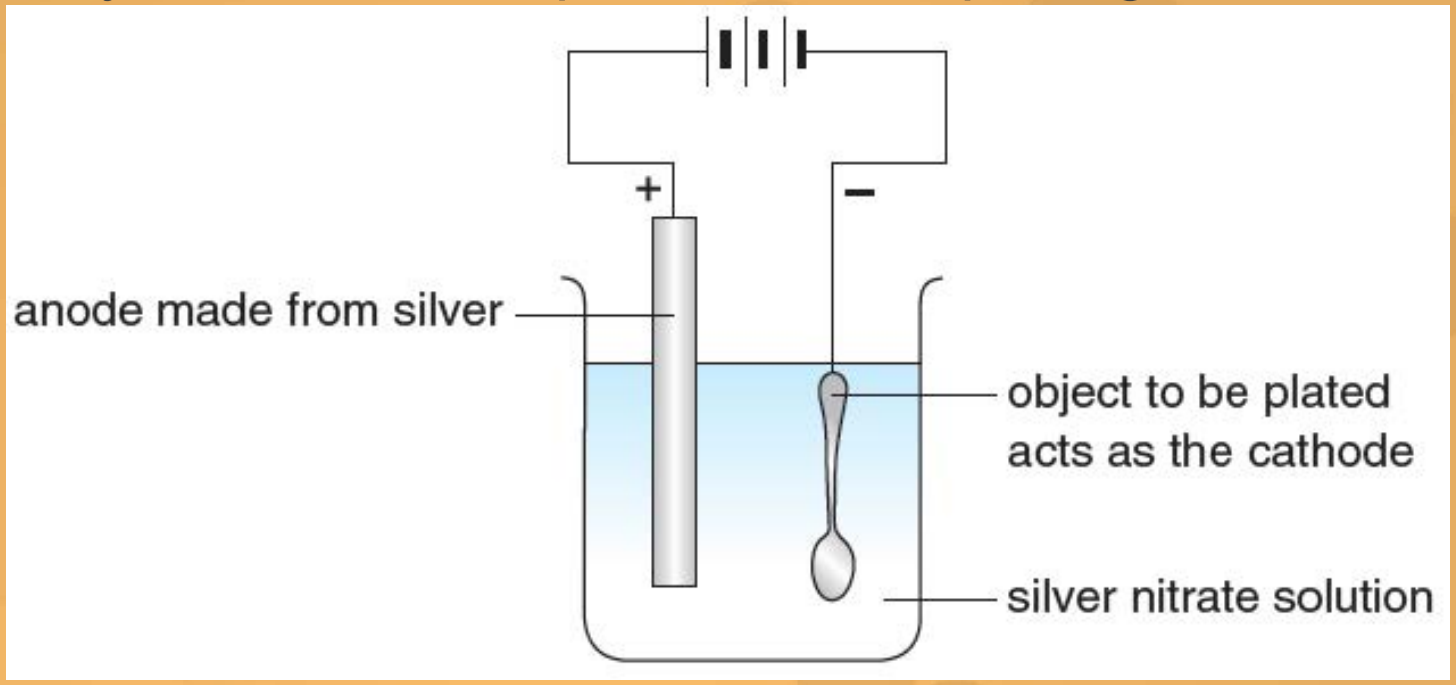
Summary (p.156)

5 The following table summarises the products of electrolyzing a molten liquid and some aqueous solutions.

Substance		Material of electrode		Product at		Change in electrolyte
		anode	cathode	anode	cathode	
Molten liquid	zinc chloride	carbon	carbon	chlorine gas	zinc	—
Aqueous solution	acidified water	platinum	platinum	oxygen gas	hydrogen gas	becomes more concentrated
	very dilute sodium chloride	carbon	carbon	oxygen gas	hydrogen gas	becomes more concentrated
	dilute sodium chloride	carbon	carbon	chlorine gas	hydrogen gas	becomes sodium hydroxide solution
	dilute copper(II) sulphate	carbon	carbon	oxygen gas	copper	becomes sulphuric acid
		copper	copper	copper(II) ions	copper	remains the same

Summary (p.156)

6 An electrolytic cell used to perform silver plating is shown below:



- the cathode is the object to be coated;
- the anode is a piece of silver;
- the electrolyte is a solution containing ions of the coating metal, such as silver nitrate solution.

Summary (p.156)

7 Methods to control pollution from the electroplating industry include:

a) design better rinsing systems;

b) replace cyanides by less toxic compounds;

c) recover metal by treating waste solutions;

d) reuse plating bath solution and rinse water; and

e) treat effluents before discharge.

Unit Exercise (p.158)

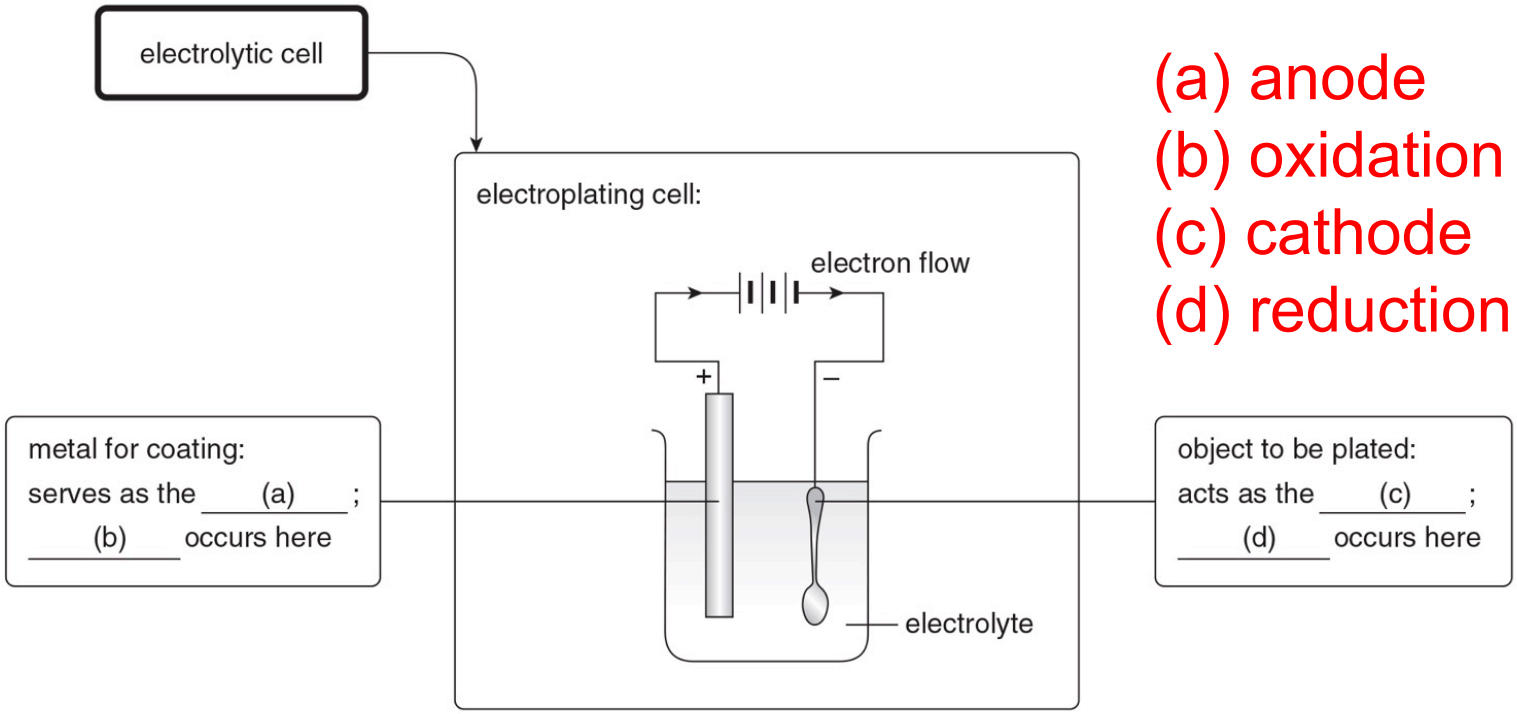
Note: Questions are rated according to ascending level of difficulty (from 1 to 5):

 **question targeted at level 3 and above;**
 **question targeted at level 4 and above;**
 **question targeted at level 5.**
‘ * ’ indicates 1 mark is given for effective communication.

Unit Exercise (p.158)

PART I KNOWLEDGE AND UNDERSTANDING

1 Complete the following concept map.



(a) anode
(b) oxidation
(c) cathode
(d) reduction

Unit Exercise (p.158)

PART II MULTIPLE CHOICE QUESTIONS

2 Which of the following statements is correct when molten magnesium chloride is electrolysed?

A Magnesium ions move to the anode and become oxidised.
B Magnesium ions move to the cathode and become reduced.
C Chloride ions move to the anode and become reduced.
D Chloride ions move to the cathode and become oxidised.

Answer: B

Unit Exercise (p.158)

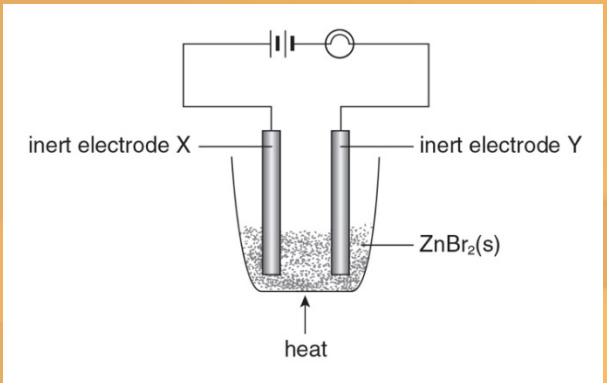
3 Which of the following combinations describes the polarity of the anodes in a chemical cell and an electrolytic cell?

	Chemical cell	Electrolytic cell
A	negative	negative
B	negative	positive
C	positive	negative
D	positive	positive

Answer: B

Unit Exercise (p.158)

4 Consider the experimental set-up shown below:



Explanation:
Zinc ions are attracted to electrode Y and discharged.
$Zn^{2+}(l) + 2e^- \longrightarrow Zn(s)$
Reduction occurs at electrode Y.

$ZnBr_2(s)$ is heated until it becomes molten.
Which of the following statements about the experiment is INCORRECT?

Answer: C

A The bulb lights up.
B A reddish brown gas is evolved at electrode X.
C Oxidation occurs at electrode Y.
D The experiment should be carried out inside a fume cupboard.

Unit Exercise (p.158)

5 Potassium peroxodisulphate ($K_2S_2O_8$) can be obtained from the electrolysis of a saturated solution of potassium hydrogensulphate ($KHSO_4$).

Which of the following correctly describes the oxidation number of sulphur in $KHSO_4$, and the electrode at which $K_2S_2O_8$ is produced during the electrolysis?

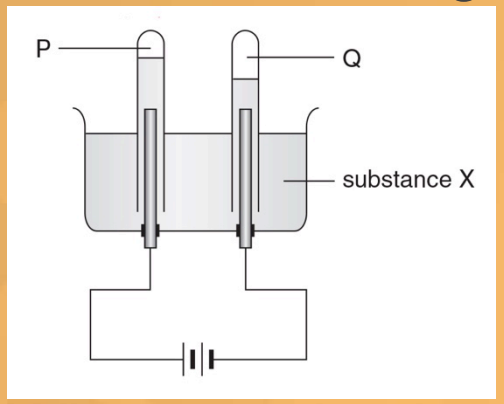
	Solution	Observation
A	+6	anode
B	+6	cathode
C	+4	anode
D	+4	cathode

Answer: A

(HKDSE, Paper 1A, 2013, 17)

Unit Exercise (p.158)

6 When substance X is electrolysed using carbon electrodes, the amounts of gases P and Q formed is shown below.



What could substance X be?

A Concentrated magnesium chloride solution
B Dilute copper(II) sulphate solution
C Dilute sulphuric acid
D Concentrated hydrochloric acid

Answer: C

Unit Exercise (p.158)

6 (continued)

Explanation:

Solution	Product at anode	Product at cathode
Concentrated magnesium chloride solution	chlorine gas	hydrogen gas
Dilute copper(II) sulphate solution	oxygen gas	copper
Dilute sulphuric acid	oxygen gas	hydrogen gas
Concentrated hydrochloric acid	chlorine gas	hydrogen gas

During the electrolysis of dilute sulphuric acid, the overall reaction is:

$2H_2O(l) \longrightarrow O_2(g) + 2H_2(g)$

Volume of oxygen gas : volume of hydrogen gas is 1 : 2, as shown in the diagram.

Unit Exercise (p.158)

7 Consider the electrolysis of copper(II) sulphate solution using carbon electrodes.
Which of the following statements about the copper(II) sulphate solution is INCORRECT?

A The blue colour of the solution becomes less intense gradually.
B The solution becomes acidic.
C The amount of hydrogen ions in the solution decreases.
D The amount of sulphate ions in the solution remains unchanged.

Answer: C

Unit Exercise (p.158)

7 (continued)

Explanation:

Option A — A reddish brown deposit of copper forms on the cathode. $Cu^{2+}(aq)$ ions are preferentially discharged here.

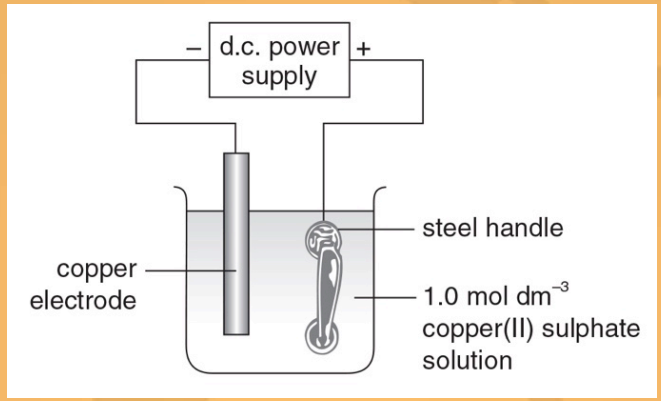
$Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$

The blue colour of the solution is due to the presence of $Cu^{2+}(aq)$ ions. The colour of the solution becomes less intense as the $Cu^{2+}(aq)$ ions are removed from the solution by reduction at the cathode.

Options B, C and D — $Cu^{2+}(aq)$ ions and $OH^-(aq)$ ions are consumed in the electrolysis. $H^+(aq)$ ions and $SO_4^{2-}(aq)$ ions remain in the solution. Thus, the solution eventually becomes sulphuric acid.

Unit Exercise (p.158)

8 The diagram below shows an experimental set-up a student used to copper-plate a steel handle. However, the experiment was unsuccessful.



Which of the following changes is necessary to plate the steel handle with copper?

A Increase the concentration of the copper(II) sulphate solution.

B Use iron(II) sulphate solution as the electrolyte.

C Increase the current.

D Make the steel handle the cathode.

Answer: D

Unit Exercise (p.158)

9 A copper(II) sulphate solution is electrolysed for 30 minutes using carbon electrodes. 0.010 mole of copper is deposited on one of the electrodes. Which of the following statements is correct?

A 0.020 mole of oxygen is produced at the cathode.
B 0.010 mole of oxygen is produced at the anode.
C 0.010 mole of oxygen is produced at the cathode.
D 0.0050 mole of oxygen is produced at the anode.

Explanation:
Equation for the overall reaction is:
$2Cu^{2+}(aq) + 4OH^{-}(aq) \longrightarrow 2Cu(s) + O_2(g) + 2H_2O(l)$
Thus, 0.0050 mole of oxygen is produced when 0.010 mole of copper is deposited.

Answer: D

Unit Exercise (p.158)

10 Which of the following statements is correct for the electrolysis of copper(II) sulphate solution using copper electrodes?

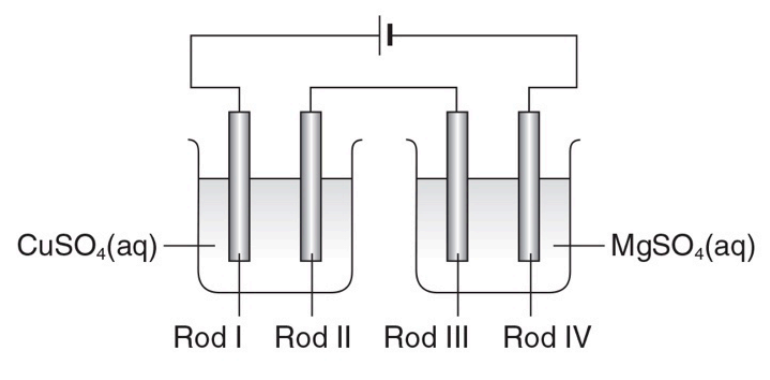
A Copper(II) ions move towards the cathode.
B Oxygen is produced at the cathode.
C The anode gains in mass due to deposition of copper.
D The blue colour of the copper(II) sulphate solution fades.

Explanation:
During the electrolysis of copper(II) sulphate solution using copper electrodes, the net process is a transfer of copper from the anode to the cathode.

Answer: A

Unit Exercise (p.158)

11 The diagram below shows the set-up used is an electroplating experiment involving four iron rods:



On which of the following iron rods would a metal be plated?

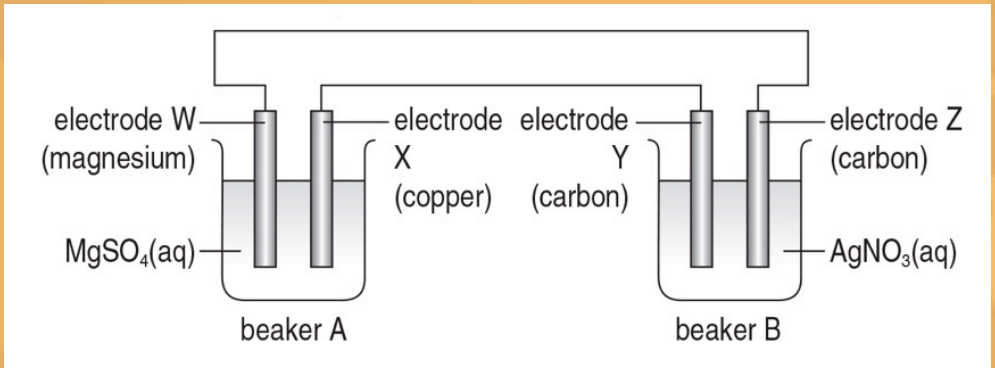
A Rod I
B Rod II
C Rod III
D Rod IV

Answer: B

(HKDSE, Paper 1A, 2016, 12)

Unit Exercise (p.158)

12 The diagram below shows a set-up in which electrons are flowing through the electric wires. Moreover, one of the electrodes in beaker A is forming ions.



Answer: A

Which of the following statements about the set-up is correct?

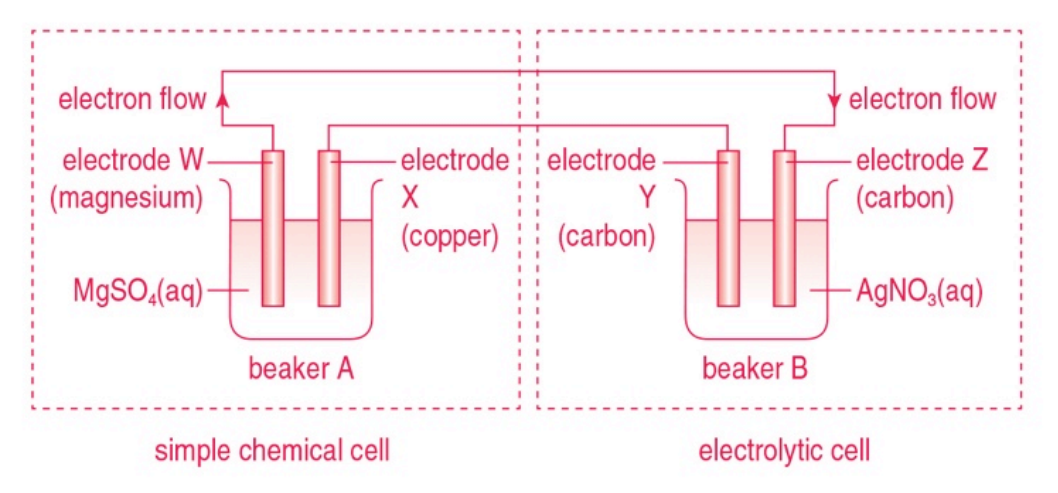
A Electrode W becomes thinner gradually.
B A layer of brown metal deposits on electrode X gradually.
C A layer of silvery metal deposits on electrode Y gradually.
D Colourless gas bubbles are given off from electrode Z.

Unit Exercise (p.158)

12 (continued)

Explanation:

The set-up consists of a simple chemical cell connected to an electrolytic cell.



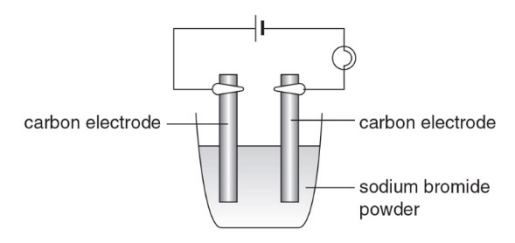
Electrode W (magnesium) loses electrons and forms ions.

$Mg(s) \longrightarrow Mg^{2+}(aq) + 2e^-$

Thus, electrode W becomes thinner gradually.

Unit Exercise (p.158)

13 The diagram below shows the set-up of an experiment:
Which of the following methods may light up the light bulb?



Which of the following methods may light up the light bulb?

(1) Heating the sodium bromide powder until molten
(2) Adding deionised water to the sodium bromide powder
(3) Replacing the sodium bromide powder with bromine liquid

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

Answer: A

(HKDSE, Paper 1A, 2014, 20)

Unit Exercise (p.158)

14 Which of the following statements about the electrolysis of concentrated copper(II) chloride solution using carbon electrodes are correct?

(1) Electrons are transferred from the cathode to the copper(II) ions.
(2) Chloride ions are attracted to the anode.
(3) Hydrogen ions transfer electrons to the cathode.

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

Explanation:
(1) and (3) $H^+(aq)$ ions and $Cu^{2+}(aq)$ ions are attracted to the cathode.
$Cu^{2+}(aq)$ ion is a stronger oxidising agent than $H^+(aq)$ ion.
Hence $Cu^{2+}(aq)$ ions are preferentially discharged at the cathode.
$Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$

Answer: A

Unit Exercise (p.158)

15 Using carbon as electrodes, which of the following solutions would give hydrogen upon electrolysis?

(1) 1 mol dm^{-3} calcium chloride solution
(2) 1 mol dm^{-3} potassium sulphate solution
(3) 1 mol dm^{-3} silver nitrate solution

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

Explanation:

Solution	Product at anode	Product at cathode
(1) 1 mol dm^{-3} calcium chloride solution	chlorine	hydrogen
(2) 1 mol dm^{-3} potassium sulphate solution	oxygen	hydrogen
(3) 1 mol dm^{-3} silver nitrate solution	oxygen	silver

Answer: A

Unit Exercise (p.158)

PART III STRUCTURED QUESTIONS

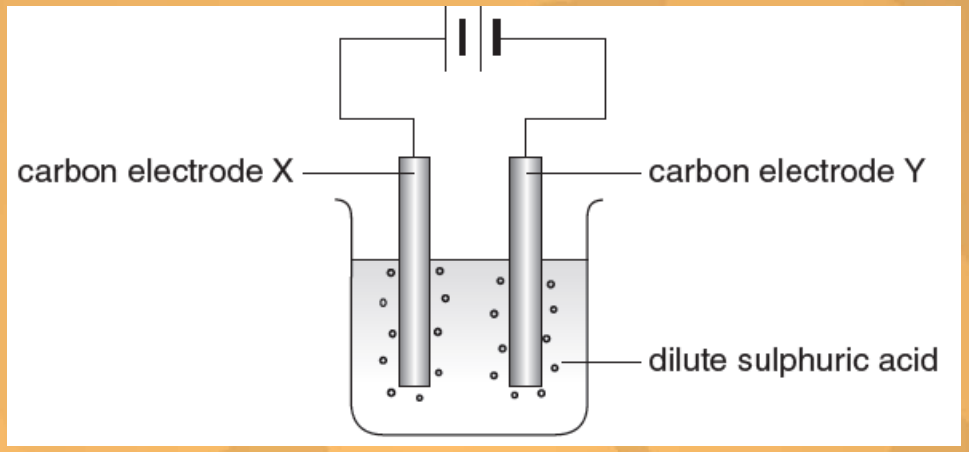
16 Several solutions are electrolysed using inert electrodes.

Complete the table for the product at each electrode and the substance left in the electrolytic cell at the end of the electrolysis.

Solution	Product at anode	Product at cathode	Substance left at the end of electrolysis
Dilute copper(II) sulphate solution	oxygen gas (1)	copper (1)	sulphuric acid
Dilute magnesium nitrate solution	oxygen gas (1)	hydrogen gas (1)	becomes more concentrated (1)
Concentrated potassium chloride solution	chlorine gas (1)	hydrogen gas (1)	potassium hydroxide solution (1)
Dilute silver nitrate solution	oxygen gas (1)	silver (1)	nitric acid (1)

Unit Exercise (p.158)

17 The diagram below shows the electrolysis of dilute sulphuric acid.



a) i) Write the half equation for the change that occurs at electrode X?

$4OH^-(aq) \longrightarrow O_2(g) + 2H_2O(l) + 4e^-$ (1)

ii) Is this change oxidation or reduction? Explain how you can tell from the half equation in (i).

The change is an oxidation as electrons are lost. (1)

Unit Exercise (p.158)

17 (continued)

b) i) Write the half equation for the change that occurs at electrode Y?

$2H^+(aq) + 2e^- \longrightarrow H_2(g)$ (1)

ii) Is this change oxidation or reduction? Explain how you can tell from the half equation in (i).

The change is a reduction as electrons are gained. (1)

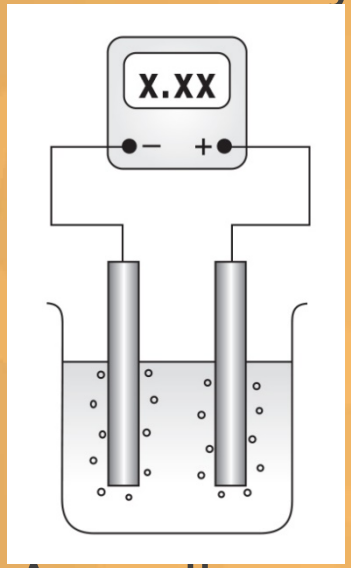
c) What change would occur to the concentration of dilute sulphuric acid as the electrolysis proceeds? Explain.

As the electrolysis proceeds, watermoleculesdissociate to replace the ions that have been discharged. Thus, although the quantity of sulphuric acid is unchanged, its concentration increases as water is consumed. (1)

Unit Exercise (p.158)

17 (continued)

d) After some time, the power supply is removed and immediately replaced by a multimeter.

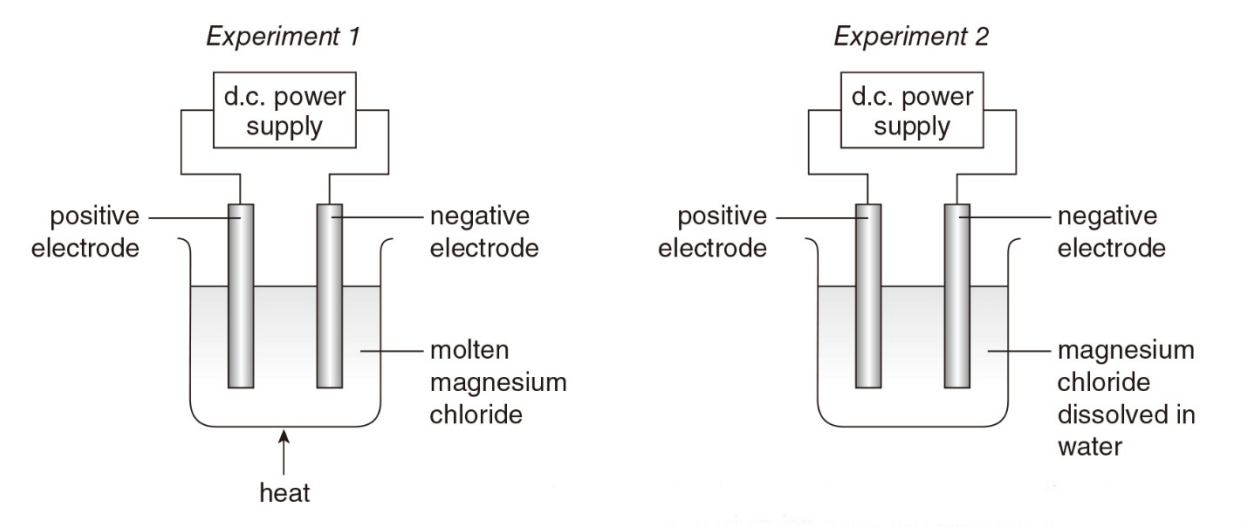


This is a chemical cell. (1)
Hydrogen reacts with oxygen.
This reaction produces flow of electrons / changes chemical energy to electrical energy.

A reading on the multimeter shows that electrical energy is being produced. Suggest an explanation for how this energy is produced.

Unit Exercise (p.158)

18 This question is about magnesium and magnesium chloride.
Magnesium chloride can be electrolysed.
The following figure shows two experiments for electrolyzing magnesium chloride.



a) Explain why magnesium chloride must be molten or dissolved in water to be electrolysed.

The ions become mobile and move to the electrodes. / The ions become mobile and can carry charges. (1)

Unit Exercise (p.158)

18 (continued)

b) Explain how magnesium is produced at the negative electrode in *Experiment 1*.

Magnesium ions are attracted to the negative electrode. Each magnesium ion gains two electrons to form a magnesium atom. (1)

c) In *Experiment 2* a gas is produced at the negative electrode. Name the gas produced at the negative electrode.

Hydrogen (1)

Unit Exercise (p.158)

18 (continued)

d) Suggest why magnesium is NOT produced at the negative electrode in *Experiment 2*.

$H^+(aq)$ ion is a stronger oxidising agent than $Mg^{2+}(aq)$ ion. (1)

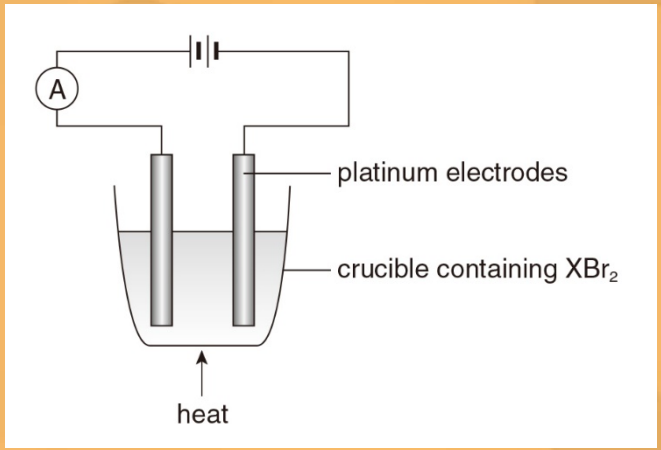
e) Complete and balance the half equation for the reaction at the positive electrode.

$$\underline{2}\ Cl^- \longrightarrow Cl_2 + \underline{2e^-}. \quad (1)$$

(AQA GCSE (Higher Tier), Additional Science Chemistry, Unit 2, Jun. 2016, 5(b))

Unit Exercise (p.158)

19 A teacher demonstrated the process of electrolysis of a molten salt using an unknown metal salt, XBr_2. The set-up used was shown below.



a) For electricity to flow, XBr_2 must be molten. Give a reason for this.

The ions in molten XBr_2 are mobile and move to the electrodes. / The ions in molten XBr_2 are mobile and can carry charges. (1)

Unit Exercise (p.158)

19 (continued)

b) Write the half equation for the change that occurs at the anode.

$2Br^-(l) \longrightarrow Br_2(l \text{ or } g) + 2e^-$ (1)

c) It was known that 1.65×10^{22} electrons had passed through the external circuit during the process. 2.84 g of metal X was produced.

Unit Exercise (p.158)

19 (continued)

c) i) Determine the number of moles of metal X that was produced.
(Avogadro constant = 6.02×10^{23} mol^{-1})

Number of moles of electrons = $\frac{1.65 \times 10^{22}}{6.02 \times 10^{23}}$ mol

= 0.0274 mol

The half equation for the change that occurs at the cathode is: $X^{2+}(l) + 2e^- \longrightarrow X(s)$

$\therefore$ number of moles of X produced = $\frac{0.0274}{2}$ mol

= 0.0137 mol (1)

Unit Exercise (p.158)

19 (continued)

c) ii) Identify metal X. (Refer to the Periodic Table.)

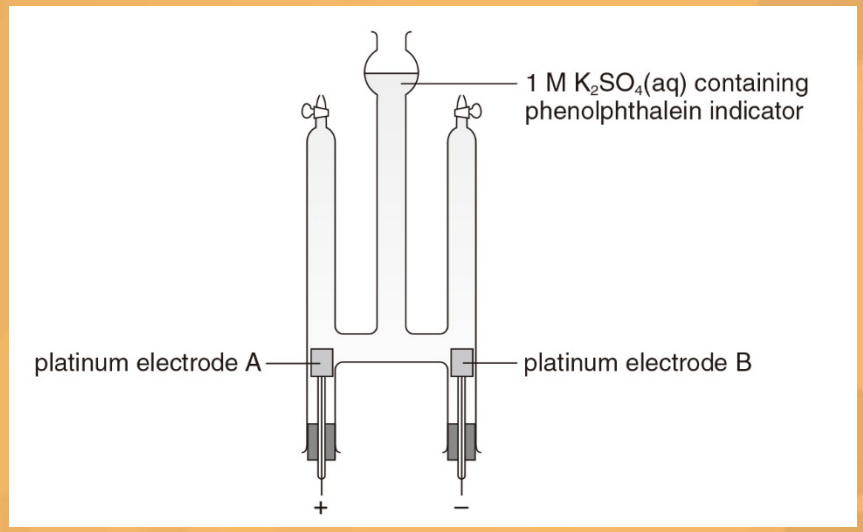
$$\text{Molar mass of X} = \frac{2.84\ \text{g}}{0.0137\ \text{mol}}$$

$$= 207.3\ \text{g mol}^{-1}\ (1)$$

X is lead. (1)

Unit Exercise (p.158)

20 The diagram below shows a set-up for the electrolysis of a colourless solution of 1 M K_2SO_4(aq) containing phenolphthalein indicator.



a) State, with explanation, the expected observation around the following electrodes during the electrolysis:
   i) Electrode A
   ii) Electrode B

Unit Exercise (p.158)

20 (continued)

b) Write the equation of the overall reaction in the electrolysis.

c) Explain whether there are any changes in the expected observation around the following electrodes during the electrolysis if the 1 M $K_2SO_4(aq)$ is replaced with 1 M $H_2SO_4(aq)$:

i) Electrode A

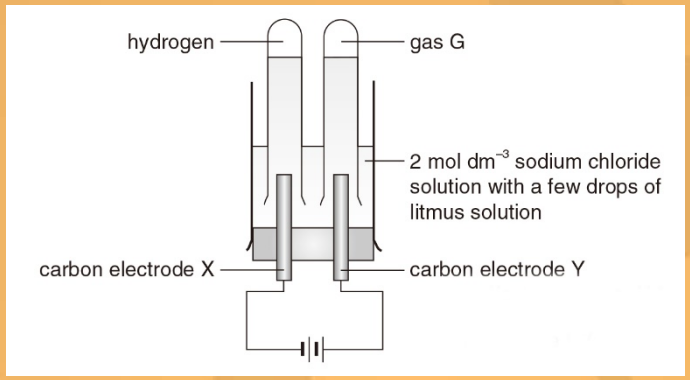
ii) Electrode B

(HKDSE, Paper 1B, 2017, 4)

Answers for the questions of the public examinations in Hong Kong are not provided (if applicable).

Unit Exercise (p.158)

21 2 mol dm^{-3} sodium chloride solution with a few drops of litmus solution was electrolysed using carbon electrodes in the cell shown below.



a) Hydrogen was collected above electrode X and the litmus solution around the electrode turned blue.
Write the half equation for the formation of hydrogen and explain why the litmus solution formed blue.

$2H^+(aq) + 2e^- \longrightarrow H_2(g)$ (1)

As the electrolysis proceeds, water molecules dissociate to replace the $H^+(aq)$ ions discharged. Thus, there is a build- up of $OH^-(aq)$ ions near to electrode X. The solution there becomes alkaline and the litmus solution turns blue. (1)

Unit Exercise (p.158)

21 (continued)

b) The litmus solution around electrode Y turned colourless.

i) Identify gas G and write the half equation for its formation.

Chlorine gas

$2Cl^-(aq) \longrightarrow Cl_2(g) + 2e^-$ (1)

ii) Gas G is toxic.

Suggest a safety precaution that should be taken when gas G is formed in a reaction.

Use a fume cupboard / a well ventilated laboratory. (1)

Unit Exercise (p.158)

22 Copper can be extracted by the electrolysis of an aqueous solution. Suggest why the electrolysis of an aqueous solution CANNOT be used to extract aluminium.

$H^+(aq)$ ion is a stronger oxidising agent than $Al^{3+}(aq)$ ion. (1)
Hence $H^+(aq)$ ions are discharged at the cathode in preference to $Al^{3+}(aq)$ ions during the electrolysis of an aqueous solution containing $Al^{3+}(aq)$ ions. (1)

Unit Exercise (p.158)

23 Concentrated sodium chloride solution can be

- electrolysed to produce useful substances:
- chlorine;
- hydrogen;
- sodium hydroxide solution.

a) Write half equations for changes that occur at the electrodes.

Effervescence occurred. (1)

The gas turned limewater milky.(1)

b) State why sodium hydroxide is a product of the process.

$H^+(aq)$ ions and Cl^- ions are consumed in the electrolysis. $Na^+(aq)$ ions and $OH^-(aq)$ ions remained in the solution. Eventually, the solution becomes sodium hydroxide solution. (1)

Unit Exercise (p.158)

24 When dilute nickel(II) nitrate solution is electrolysed, the product at one electrode is nickel.

a) Write the half equation for the formation of nickel.

$Ni^{2+}(aq) + 2e^- \longrightarrow Ni(s)$ (1)

b) Explain whether nickel is formed at the anode or cathode.

Nickel is formed at the cathode as reduction occurs here. (1)

c) i) State, with explanation, the expected observation(s) at the other electrode.

$OH^-(aq)$ ions and $NO_3^-(aq)$ ions are attracted to the other electrode. $OH^-(aq)$ ion is a stronger reducing agent than $NO_3^-(aq)$ ion. (1) Hence $OH^-(aq)$ ions are preferentially discharged at this electrode to give colourless oxygen gas. (1)

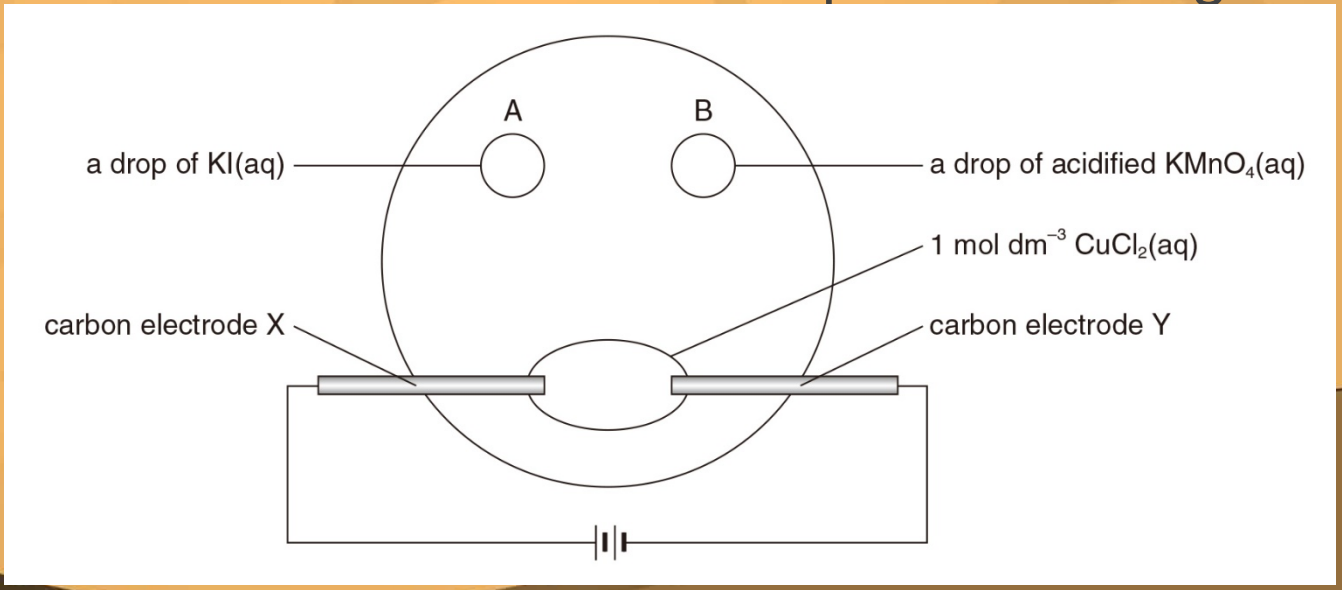
ii) Write the half equation for the expected change at this electrode.

$4OH^-(aq) \longrightarrow O_2(g) + 2H_2O(l) + 4e^-$ (1)

Unit Exercise (p.158)

25 The diagram below shows the set-up used in performing a microscale electrolysis of 1 mol dm^{-3} copper(II) chloride solution.

1 mol dm^{-3} copper(II) chloride solution was placed between two carbon electrodes in a petri dish. The dish was covered with its lid and a current was passed through the solution.



Unit Exercise (p.158)

25 (continued)

a) State, with explanation, the expected observation(s) at each electrode.

At electrode X

The $Cl^-(aq)$ ions and $OH^-(aq)$ ions are attracted to electrode X.

The concentration of $Cl^-(aq)$ ions in the solution is much higher than that of $OH^-(aq)$ ions. (1)

Thus, $Cl^-(aq)$ ions are preferentially discharged to give greenish yellow chlorine gas. (1)

At electrode Y

$H^+(aq)$ ions and $Cu^{2+}(aq)$ ions are attracted to electrode Y.

$Cu^{2+}(aq)$ ion is a stronger oxidising agent than $H^+(aq)$ ion. (1)

Hence $Cu^{2+}(aq)$ ions are preferentially discharged at electrode Y to give a reddish brown deposit of copper. (1)

Unit Exercise (p.158)

25 (continued)

b) Write a half equation for the expected change at each electrode.

At electrode X: $2Cl^-(aq) \longrightarrow Cl_2(g) + 2e^-$ (1)

At electrode Y: $Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$ (1)

c) State the expected observations at positions A and B. In each case, write an ionic equation if a reaction occurred.

Position A: The solution changed from colourless to brown / yellow. (1)

$Cl_2(g) + 2I^-(aq) \longrightarrow 2Cl^-(aq) + I_2(aq)$ (1)

Position B: No observable change. (1)

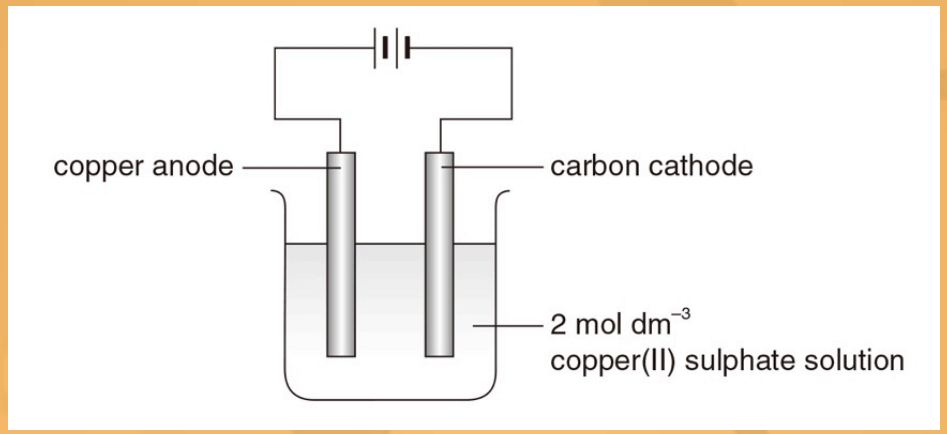
d) Suggest ONE advantage of microscale experiments.

Any one of the following:

- Less chemicals are used. (1)
- Less harmful to the environment. (1)
- Less dangerous. (1)
- Easier to handle. (1)
- Save money. (1)
- Save time. (1)

Unit Exercise (p.158)

26 The electrolysis of 2 mol dm^{-3} copper(II) sulphate solution was carried out using the set-up shown below.



a) List ALL the ions that exist in the solution.

From copper(II) sulphate $Cu^{2+}(aq)$, $SO_4^{2-}(aq)$

From water $H^+(aq)$, $OH^-(aq)$ (1)

Unit Exercise (p.158)

26 (continued)

b) State, with explanation, the expected observation(s) at each electrode.

At the carbon cathode

$H^+(aq)$ ions and $Cu^{2+}(aq)$ ions are attracted to the cathode.

$Cu^{2+}(aq)$ ion is a stronger oxidising agent than $H^+(aq)$ ion. (1)

Hence $Cu^{2+}(aq)$ ions are preferentially discharged at the cathode to give a reddish brown deposit of copper. (1)

At the copper anode

$OH^-(aq)$ ions and $SO_4^{2-}(aq)$ ions are attracted to the anode.

Copper is a stronger reducing agent than $OH^-(aq)$ ion and $SO_4^{2-}(aq)$ ion. (1)

Thus, the oxidation of copper is more favourable. The copper anode dissolves to form $Cu^{2+}(aq)$ ions. (1)

Unit Exercise (p.158)

26 (continued)

c) Write a half equation for the expected change at each electrode.

At the cathode: $Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$ (1)

At the anode: $Cu(s) \longrightarrow Cu^{2+}(aq) + 2e^-$ (1)

d) The blue colour of the copper(II) sulphate solution remained the same intensity throughout the electrolysis. Explain why.

The net process is a transfer of copper from the anode to the cathode.

The overall concentration of $Cu^{2+}(aq)$ ions in the electrolyte does not change and the blue colour of the solution remains the same. (1)

Unit Exercise (p.158)

26 (continued)

e) Would there be any change in observation if the carbon cathode was replaced by a copper cathode? Explain.

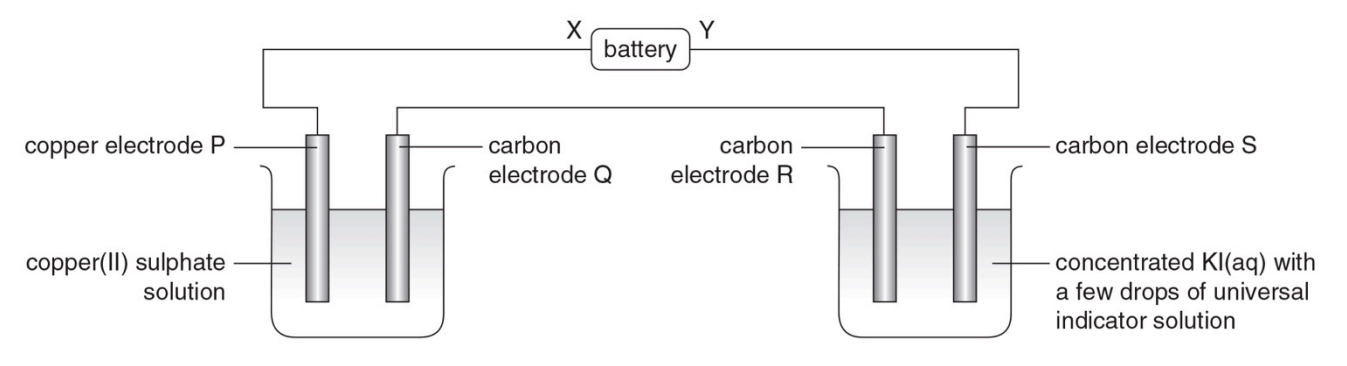
Accept both 'yes' and 'no' answers.

'No': The copper cathode would not lose electrons to give $Cu^{2+}(aq)$ ions. (1)

'Yes': Copper and carbon have different electrical conductivities. The current in the external circuit would change. (1)

Unit Exercise (p.158)

27 Consider the experimental set-up shown below.



A current had passed through the set-up for a period of time. The solution near carbon electrode R gradually turned blue.

a) Explain the observation at electrode R.

$H^+(aq)$ ions are discharged at electrode R to give hydrogen. (1)
As the electrolysis proceeds, water molecules dissociate to replace the $H^+(aq)$ ions discharged. Thus, there is a build-up of $OH^-(aq)$ ions near to electrode R. The solution there becomes alkaline and the universal indicator solution turns blue. (1)

Unit Exercise (p.158)

27 (continued)

b) State and explain the expected observation around carbon electrode S.

A brown colour would be observed.
$I^-(aq)$ ions and $OH^-(aq)$ ions are attracted to electrode S. (1)
The concentration of $I^-(aq)$ ions in the solution is much higher than that of $OH^-(aq)$ ions. (1)
Thus, $I^-(aq)$ ions are preferentially discharged to give iodine which dissolves in KI(aq) to give brown $I_3^-(aq)$ ions. (1)

c) State whether X or Y is the positive electrode of the battery.

Y is the positive electrode. (1)

Unit Exercise (p.158)

27 (continued)

d) Complete the following table by filling in 'anode' or 'cathode' to describe the electrodes.

Electrode	P	Q	R	S	
Anode / cathode	cathode	anode	cathode	anode	(1)

e) State and explain the expected observations at electrodes P and Q.

At electrode P

$H^+(aq)$ ions and $Cu^{2+}(aq)$ ions are attracted to electrode P.

$Cu^{2+}(aq)$ ion is a stronger oxidising agent than $H^+(aq)$ ion. (1)

Hence $Cu^{2+}(aq)$ ions are preferentially discharged at electrode P to give a reddish brown deposit of copper. (1)

At electrode Q

$OH^-(aq)$ ions and $SO_4^{2-}(aq)$ ions are attracted to electrode Q.

$OH^-(aq)$ ion is a stronger reducing agent than $SO_4^{2-}(aq)$ ion. (1)

Hence $OH^-(aq)$ ions are preferentially discharged at electrode Q to give colourless oxygen gas. (1)

Unit Exercise (p.158)

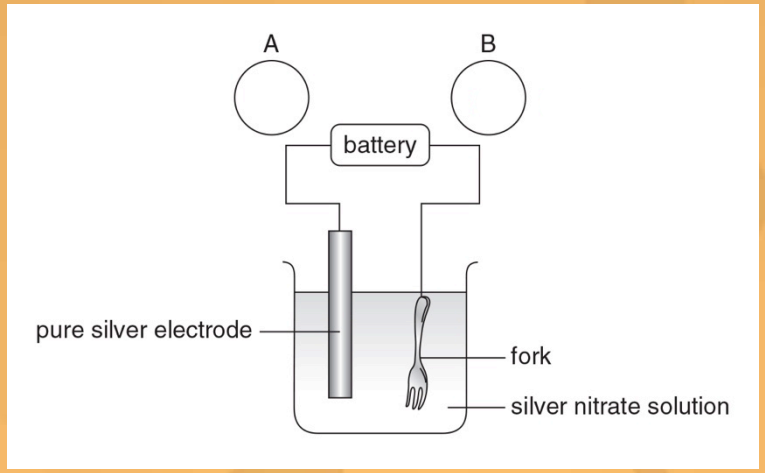
27 (continued)

f) What change would occur in the copper(II) sulphate solution after electrolysis? Explain your answer.

$Cu^{2+}(aq)$ ions and $OH^-(aq)$ ions are consumed in the electrolysis. $H^+(aq)$ ions and $SO_4^{2-}(aq)$ ions remain in the solution. Thus, the solution eventually becomes sulphuric acid. (1)

Unit Exercise (p.158)

28 Cutlery can be plated with silver using the set-up shown below.



a) i) What is the meaning of the term 'electroplating'?

Electroplating is the process of coating an object with a thin layer of a metal using electrolysis. (1)

ii) Give TWO advantages of electroplating.

To improve appearance. (1)

To prevent corrosion. (1)

Unit Exercise (p.158)

28 (continued)

b) On the diagram above, indicate the polarities (+ or –) of the battery in circles A and B.

A: +; B: –

c) State, with explanation, the expected observation at each electrode.

The silver electrode dissolves, forming silver ions. (1)

Silver ions receive electrons, forming a coat of silver on the fork. (1)

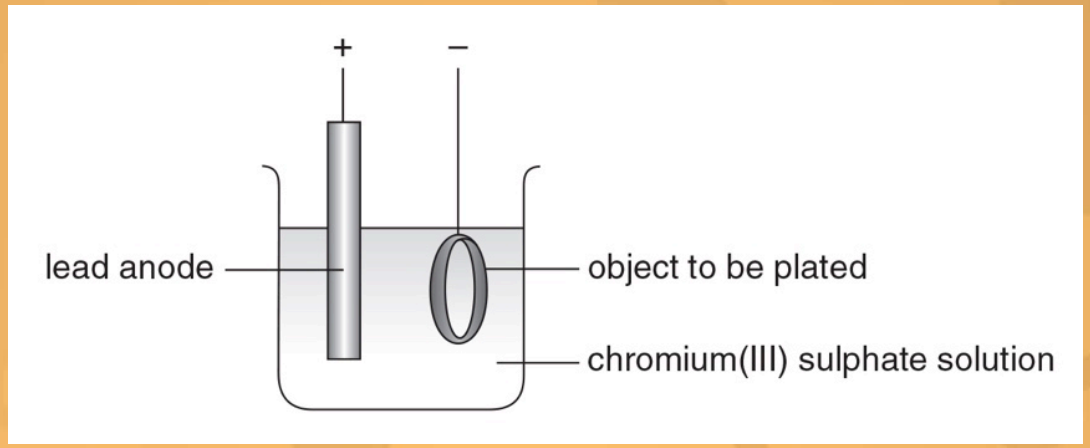
d) Write a half equation for the expected change at each electrode.

At the silver electrode: $Ag(s) \longrightarrow Ag^+(aq) + e^-$ (1)

At the fork: $Ag^+(aq) + e^- \longrightarrow Ag(s)$ (1)

Unit Exercise (p.158)

29 An object is plated with chromium by using the experimental set-up shown below.



a) Write the half equation for the change that occurs at the object.

$Cr^{3+}(aq) + 3e^- \longrightarrow Cr(s)$ (1)

Unit Exercise (p.158)

29 (continued)

b) It is known that 2.71×10^{22} electrons have passed through the external circuit during the process. What is the mass of chromium that would theoretically be plated on the object? (Relative atomic mass: Cr = 52.0; Avogadro constant = 6.02×10^{23} mol^{-1})

Number of moles of electrons = $\frac{2.71 \times 10^{22}}{6.02 \times 10^{23}}$ mol

= 0.0450 mol

Number of moles of Cr plated on object = $\frac{0.0450}{3}$ mol

= 0.0150 mol (1)

Mass of Cr plated on object = 0.0150 mol x 52.0 g mol^{-1}

= 0.780 g (1)

Unit Exercise (p.158)

29 (continued)

c) Wastewater from a chromium-plating factory contains chromium(III) ions. Suggest how these metal ions can be removed from the water before the water is discharged into a river.

Add NaOH(aq) / KOH(aq) / a hydroxide / an alkali to form chromium(III) hydroxide. (1)

Remove the precipitate by filtration. (1)

Topic Exercise (p.169)

Note: Questions are rated according to ascending level of difficulty (from 1 to 5):

 **question targeted at level 3 and above;**
 **question targeted at level 4 and above;**
 **question targeted at level 5.**
‘ * ’ indicates 1 mark is given for effective communication.

Topic Exercise (p.169)

PART I MULTIPLE CHOLCE QUESTIONS

1 The oxidation number of chromium changes as CrO_4^{2-} is converted to $Cr(OH)_3$. How many electrons are gained or lost by the chromium during the change?

A 1 electron lost
B 1 electron gained
C 3 electrons lost
D 3 electrons gained

Explanation:
The half equation for the conversion of CrO_4^{2-} to $Cr(OH)_3$ is:

$$CrO_4^{2-} + 4H_2O(l) + 3e^- \longrightarrow Cr(OH)_3 + 5OH^-$$

Answer: D

Topic Exercise (p.169)

2 Which of the following is NOT a redox reaction?

A $2Mg + SO_2 \longrightarrow 2MgO + S$

B $CaCO_3 + SiO_2 \longrightarrow CaSiO_3 + CO_2$

C $Cu_2O + H_2SO_4 \longrightarrow CuSO_4 + Cu + H_2O$

D $3CuS + 8HNO_3 \longrightarrow 3CuSO_4 + 8NO + 4H_2O$

(HKDSE, Paper 1A, 2018, 12)

Answer: B

Topic Exercise (p.169)

3 Consider the following experiments:

Beaker I Copper(II) sulphate solution is added to sodium chloride solution.

Beaker II Acidified potassium dichromate solution is added to potassium iodide solution.

Beaker III Sulphur dioxide gas is bubbled through iron(III) sulphate solution.

In which beakers will a reaction occur?

A Beaker I only

B Beaker II only

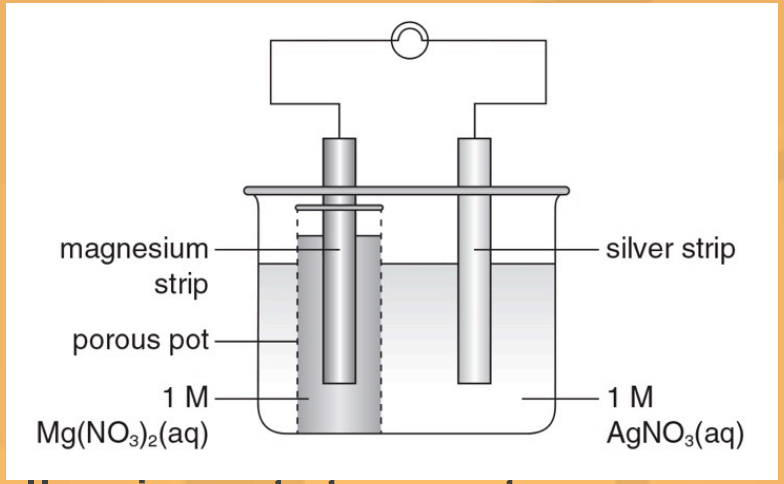
C Beakers I and II only

D Beakers II and III only

Answer: D

Topic Exercise (p.169)

4 The diagram below shows a set-up with the bulb lights up:



Answer: B

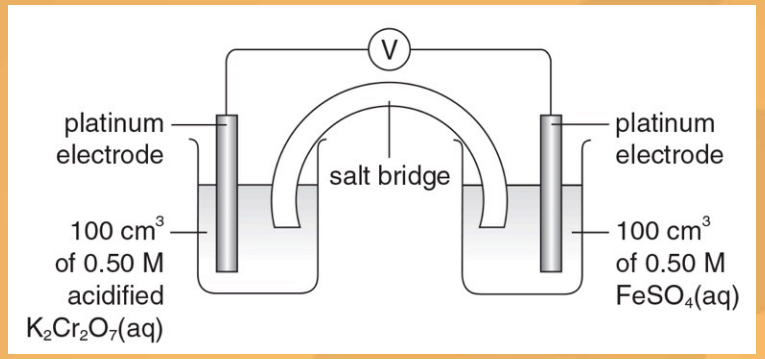
Which of the following statements concerning the set-up is correct?

A Silver ions migrate towards the porous pot.
B The mass of the magnesium strip decreases.
C Heat energy is converted into electrical energy.
D Hydrogen ions are discharged on the silver strip.

(HKDSE, Paper 1A, 2017, 4)

Topic Exercise (p.169)

5 Consider the following set-up at the start of an experiment:



After a period of time, the concentration of $K_2Cr_2O_7$(aq) drops to 0.47 M. What is the concentration of $FeSO_4$(aq) at that time?

A 0.53 M
B 0.47 M
C 0.41 M
D 0.32 M

Answer: D

(HKDSE, Paper 1A, 2015, 16)

Topic Exercise (p.169)

6 The following equation shows the reaction when a lead acid battery is discharging:

$$Pb(s) + PbO_2(s) + 2H_2SO_4(aq) \longrightarrow 2PbSO_4(s) + 2H_2O(l)$$

Which of the following half equations shows the change at the negative electrode when an external power source is used to recharge a flat lead acid battery?

A $PbO_2(s) + 3H^+(aq) + HSO_4^-(aq) + 2e^- \longrightarrow PbSO_4(s) + 2H_2O(l)$

B $PbSO_4(s) + 2H_2O(l) \longrightarrow PbO_2(s) + 3H^+(aq) + HSO_4^-(aq) + 2e^-$

C $Pb(s) + HSO_4^-(aq) \longrightarrow PbSO_4(s) + H^+(aq) + 2e^-$

D $PbSO_4(s) + H^+(aq) + 2e^- \longrightarrow Pb(s) + HSO_4^-(aq)$

Answer: D

Topic Exercise (p.169)

6 (continued)

Explanation:

The following reaction occurs during recharging:

$2PbSO_4(s) + 2H_2O(l) \longrightarrow Pb(s) + PbO_2(s) + 2H_2SO_4(aq)$

Positive electrode:

$PbSO_4(s) + 2H2O(l) \longrightarrow PbO_2(s) + 3H^+(aq) + HSO_4^-(aq) + 2e^-$

Negative electrode:

$PbSO_4(s) + H^+(aq) + 2e^- \longrightarrow Pb(s) + HSO_4^-(aq)$

Topic Exercise (p.169)

7 Which of the following statements is true for both chemical cells and electrolytic cells?

A Oxidation occurs at the positive electrode in both cells.
B Reduction occurs at the cathode in both cells.
C Anions migrate to the cathode in both cells.
D The anode is the positive electrode in both cells.

Explanation:
Option A — Oxidation occurs at the negative electrode in a chemical cell.
Option C — Anions migrate to the anode in an electrolytic cell.
Option D — The anode is the negative electrode in a chemical cell.

Answer: B

Topic Exercise (p.169)

8 An aqueous solution containing a mixture of 1.0 mol dm^{-3} NaI(aq) and 1.0 mol dm^{-3} $CuCl_2(aq)$ was electrolysed using carbon electrodes.

Which of the following changes will occur at the anode?

A $2I^-(aq) \longrightarrow I_2(aq) + 2e^-$

B $2Cl^-(aq) \longrightarrow Cl_2(aq) + 2e^-$

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

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

Answer: A

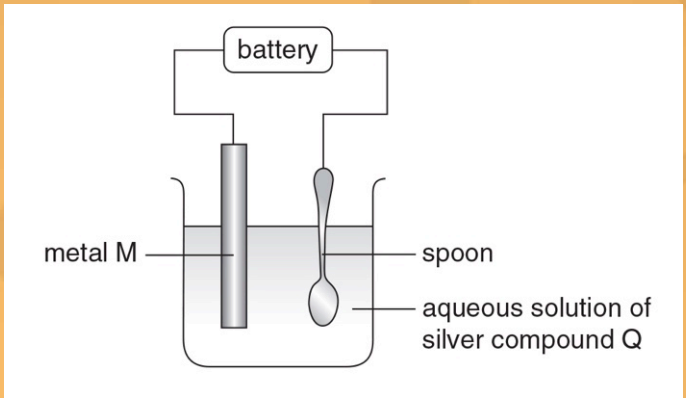
Explanation:

$I^-(aq)$ ions, $Cl^-(aq)$ ions and $OH^-(aq)$ ions are attracted to the anode.

$I^-(aq)$ ion is a stronger reducing agent than $Cl^-(aq)$ ion, and its concentration is much higher than that of $OH^-(aq)$ ion. Thus, $I^-(aq)$ ions are preferentially discharged.

Topic Exercise (p.169)

9 The diagram below shows a set-up in which silver is being plated on a spoon:



Which of the following statements concerning the above set-up is correct?

A M must be silver.

B Q can be silver chloride.

C The spoon is connected to the negative pole of the battery.

D Electrons flow from metal M to the spoon through the solution.

Answer: C

(HKDSE, Paper 1A, 2014, 11)

Topic Exercise (p.169)

10 When the yellow liquid NCl_3 is stirred into sodium hydroxide solution, the reaction that occurs can be represented by the equation below.

$2NCl_3(l) + 6NaOH(aq) \longrightarrow N_2(g) + 3NaCl(aq) + 3NaOCl(aq) + 3H_2O(l)$

Which of the following statements about the reaction is / are correct?

(1) Sodium ions are reduced.
(2) A bleaching solution remains after the reaction.
(3) The final mixture gives a white precipitate with silver nitrate solution.

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

Explanation:
(2) NaOCl(aq) is a bleaching solution.

Answer: D

Topic Exercise (p.169)

11 Which of the following statements concerning the reaction of concentrated nitric acid with copper is / are correct?

(1) Concentrated nitric acid acts as a reducing agent.
(2) A brown gas is formed.
(3) One mole of $NO_3^-(aq)$ ions requires one mole of electrons for reduction.

Answer: D

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

Explanation:
(1) Concentrated nitric acid acts as an oxidising agent.
(3) The half equation for the reduction of concentrated nitric acid is shown below.

$$NO_3^-(aq) + 2H^+(aq) + e^- \longrightarrow NO_2(g) + H_2O(l)$$

Thus, one mole of $NO_3^-(aq)$ ions requires one mole of electrons for reduction.

Topic Exercise (p.169)

12 An aqueous solution of potassium iodide turns yellow with time due to the following reaction:

$4KI(aq) + 2CO_2(g) + O_2(g) \longrightarrow 2K_2CO_3(aq) + 2I_2(aq)$

Which of the following statements concerning the above reaction is / are correct?

(1) KI(aq) is oxidised by $O_2(g)$.
(2) KI(aq) is oxidised by $CO_2(g)$.
(3) The yellow colour is due to the $K_2CO_3(aq)$ formed.

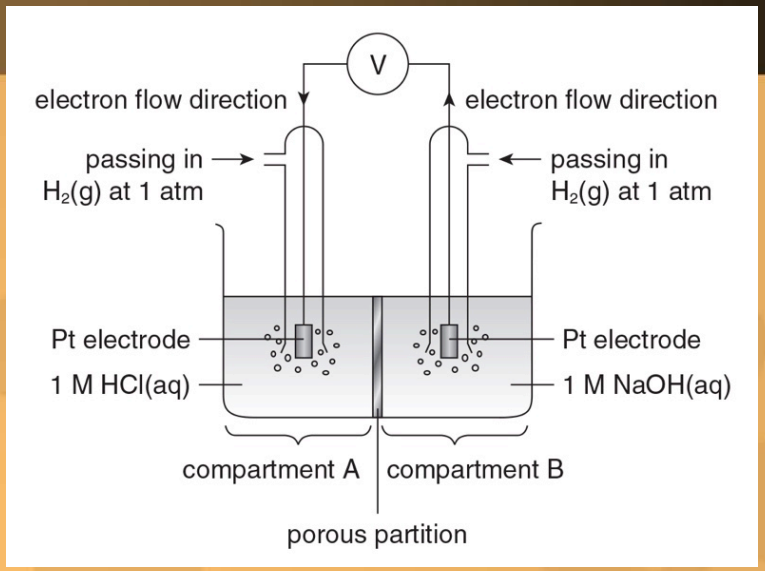
A (1) only
B (2) only
C (1) and (3) only
D (2) and (3) only

Answer: A

(HKDSE, Paper 1A, 2015, 17)

Topic Exercise (p.169)

13 Consider the following chemical cell:



Which of the following statements are correct?

(1) The pH of the solution in compartment A decreases gradually.
(2) Hydrogen gas in compartment B acts as a reducing agent.
(3) The equation for the overall reaction is:

$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$

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

Answer: C

(HKDSE, Paper 1A, 2018, 23)

Topic Exercise (p.169)

Directions:
Each question (Questions 14–15) consists of two separate statements. Decide whether each of the two statements is true or false; if both are true, then decide whether or not the second statement is a correct explanation of the first statement. Then select one option from A to D according to the following table :

A	Both statements are true and the 2nd statement is a correct explanation of the 1st statement.
B	Both statements are true but the 2nd statement is NOT a correct explanation of the 1st statement.
C	The 1st statement is false but the 2nd statement is true.
D	Both statements are false.

Topic Exercise (p.169)

14 1st statement

Aqueous chlorine can react with KBr(aq).

2nd statement

The reducing power of $Br^-(aq)$ ion is stronger than that of $Cl^-(aq)$ ion.

Answer: A

Topic Exercise (p.169)

15 1st statement

During anodisation, the aluminium oxide on the surface of aluminium is reduced to metal.

2nd statement

The corrosion resistance of aluminium can be enhanced by anodisation.

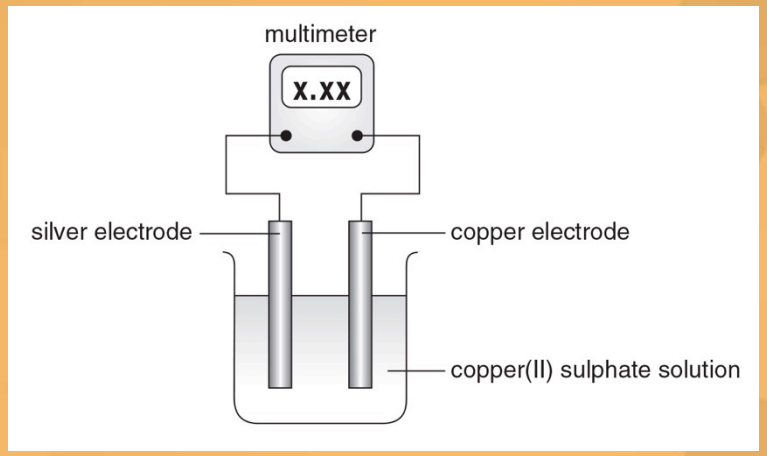
Answer: C

(HKDSE, Paper 1A, 2016, 23)

Topic Exercise (p.169)

PART II STRUCTURED QUESTIONS

16 Electrons have flowed through the external circuit of the chemical cell for some time.



a) Identify the direction of electron flow in the external circuit. From copper electrode to silver electrode (1)

b) Explain whether the copper electrode or silver electrode is the anode.

The copper electrode is the anode as oxidation occurs here. (1)

Topic Exercise (p.169)

16 (continued)

c) What will happen to the colour intensity of the copper(II) sulphate solution after the cell has operated for some time? Explain your answer.

The copper electrode dissolves, forming copper(II) ions. (1)
Copper(II) ions receive electrons from the silver electrode, forming a deposit of copper. (1)
The overall concentration of $Cu^{2+}(aq)$ ions in the electrolyte does not change and the blue colour of the solution remains the same. (1)

Topic Exercise (p.169)

*17 You are provided with common laboratory apparatus, and strips of copper, magnesium and zinc. Outline how you would perform a fair comparison in studying the relative tendency of forming ions of the three metals.

You have to state the additional chemical reagent(s) required.

Procedure

- Set up two chemical cells using the metal couples: (1)
  - magnesium and copper couple
  - zinc and copper couple
- Use lemon juice / sodium chloride solution / copper(II) sulphate solution as the electrolyte. (1)
  (Chemical cells built using magnesium half cell, copper half cell and zinc half cell are also acceptable.)
- Connect the copper electrode of each chemical cell to the positive terminal of a multimeter. Record the voltage of each cell. (1)
- Compare the voltages of the two chemical cells. The chemical cell built by using magnesium and copper couple has a higher voltage than that built by using zinc and copper. Thus, the tendencies of the metals to form ions are in the order of:
  magnesium > zinc > copper (1)

Conditions for performing a fair comparison

Any one of the following:

- Metal strips of the same length (1)
- Electrolyte of the same concentration (1)

Communication mark (1)

Topic Exercise (p.169)

18 Many crude oils contain sulphur as hydrogen sulphide. During refining, hydrogen sulphide is converted into sulphur via two reactions.

a) The first reaction involves the conversion of hydrogen sulphide into sulphur dioxide.

(1)

Balance the above equation.

Topic Exercise (p.169)

18 (continued)

b) The sulphur dioxide formed is then reacted with the remaining hydrogen sulphide, producing sulphur and water.

$$2H_2S(g) + SO_2(g) \longrightarrow 3S(s) + 2H_2O(l)$$

Identify the oxidising agent and reducing agent in the process. Explain your answer in terms of changes in oxidation numbers.

SO_2 is the oxidising agent, because the oxidation number of S decreases from +4 to 0. (1)

H_2S is the reducing agent, because the oxidation number of S increases from –2 to 0. (1)

Topic Exercise (p.169)

19 Chlorine can be used to extract bromine from seawater. In this process, chlorine gas is bubbled through a solution containing bromide ions.

a) Write the ionic equation for the reaction between chlorine and bromide ions.

$Cl_2(g) + 2Br^-(aq) \longrightarrow 2Cl^-(aq) + Br_2(aq)$ (1)

b) Give ONE observation that will be made during this reaction.

The colourless solution turns yellow / orange / brown. (1)

c) Bromide ion behaves as a reducing agent in the reaction. In terms of electrons, state the meaning of the term 'reducing agent'.

As an electron donor (1)

Topic Exercise (p.169)

20 For each of the following experiments, state the expected observation(s), and write the chemical equation(s) for the reaction(s) involved.

a) Adding potassium iodide solution to iron(III) sulphate solution until in excess

The yellow-brown iron(III) sulphate solution turns brown. (1)

$2Fe^{3+}(aq) + 2I^{-}(aq) \longrightarrow 2Fe^{2+}(aq) + I_2(aq)$ (1)

b) Bubbling sulphur dioxide into aqueous iodine until in excess

Brown aqueous iodine turns colourless. (1)

$SO_3^{2-}(aq) + I_2(aq) + H_2O(l)$

$\longrightarrow SO_4^{2-}(aq) + 2I^{-}(aq) + 2H^{+}(aq)$ (1)

Topic Exercise (p.169)

20 (continued)

c) Adding dilute nitric acid to copper

Copper dissolves. (1)

A blue solution forms. (1)

A colourless gas is given off. This gas gives a brown gas when mixed with air. (1)

$3Cu(s) + 2NO_3^-(aq) + 8H^+(aq) \longrightarrow 3Cu^{2+}(aq) + 2NO(g) + 4H_2O(l)$ (1)

d) Adding concentrated sulphuric acid to solid sodium bromide

Steamy fumes and brown fumes are given off. Colourless sulphur dioxide is also formed. (1)

$NaBr(s) + H_2SO_4(l) \longrightarrow NaHSO_4(s) + HBr(g)$ (1)

$2HBr(g) + H_2SO_4(l) \longrightarrow Br_2(g) + SO_2(g) + 2H_2O(l)$ (1)

Topic Exercise (p.169)

21 Chlorine is used in water treatment. When chlorine is added to cold water it reacts according to the equation below.

oxidation number of Cl

$$\underset{0}{Cl_2(aq)} + H_2O(l) \longrightarrow \underset{-1}{HCl(aq)} + \underset{+1}{HOCl(aq)}$$

a) By giving appropriate oxidation numbers, explain why this is a disproportionation reaction.

Chlorine is both oxidised and reduced. Thus, this is a disproportionation reaction. (1)

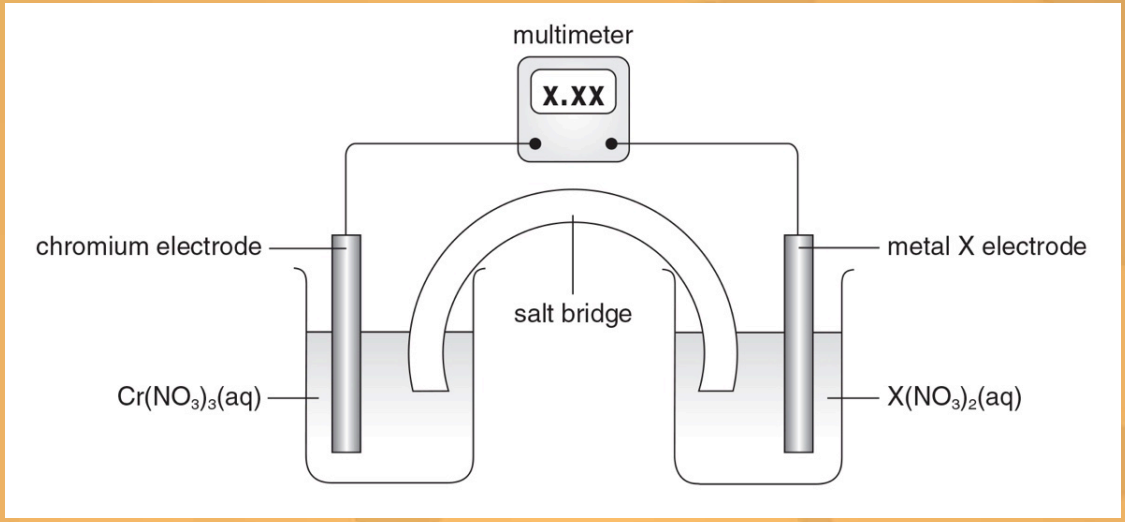
b) Chlorine is used in water treatment.
State ONE benefit and ONE risk of chlorine in water treatment.

Benefit: Kill bacteria (1)

Risk: Toxic / Form chlorinated hydrocarbons / Form carcinogens / Form toxic compounds (1)

Topic Exercise (p.169)

22 A student built a chemical cell as shown below.



The equation for overall reaction in the chemical cell was:

$2Cr(s) + 3X^{2+}(aq) \longrightarrow 2Cr^{3+}(aq) + 3X(s)$

a) Which metal was the cathode? Explain your answer.

Metal X electrode is the cathode as reduction occurs here. (1)

Topic Exercise (p.169)

22 (continued)

b) Identify the direction of electron flow in the external circuit.

From chromium to metal X (1)

c) Suggest whether the multimeter gave a positive or negative reading.

A positive reading (1)

Topic Exercise (p.169)

22 (continued)

d) After the chemical cell had operated for a period of time, the metal X electrode gained 2.38 g in mass while the chromium electrode lost 1.30 g in mass.

i) Determine the number of moles of X produced. (Relative atomic mass: Cr = 52.0)

$$\text{Number of moles of Cr} = \frac{1.30\ \text{g}}{52.0\ \text{g mol}^{-1}}$$

$$= 0.0250\ \text{mol}$$

$$\text{Number of moles of X produced} = \frac{3}{2} \times 0.0250\ \text{mol}$$

$$= 0.0375\ \text{mol}\ (1)$$

Topic Exercise (p.169)

22 (continued)

d) ii) Identify metal X. (Refer to the Periodic Table.)

$$\text{Molar mass of X} = \frac{2.38\ \text{g}}{0.0375\ \text{mol}}$$

$$= 63.5\ \text{g mol}^{-1} \quad (1)$$

Copper (1)

Topic Exercise (p.169)

23 The simplified half reactions in a secondary lithium ion cell during discharge are shown below.

Electrode A $Li^+(s) + MnO_2(s) + e^- \longrightarrow LiMnO_2(s)$

Electrode B $Li(s) \longrightarrow Li^+(s) + e^-$

a) During discharge, what is the polarity of electrode B?

Negative (1)

b) Write the equation for the overall reaction that occurs when this lithium cell is being recharged.

$LiMnO_2(s) \longrightarrow Li(s) + MnO_2(s)$ (1)

c) In a lithium ion cell, lithium metal must not be in contact with water.

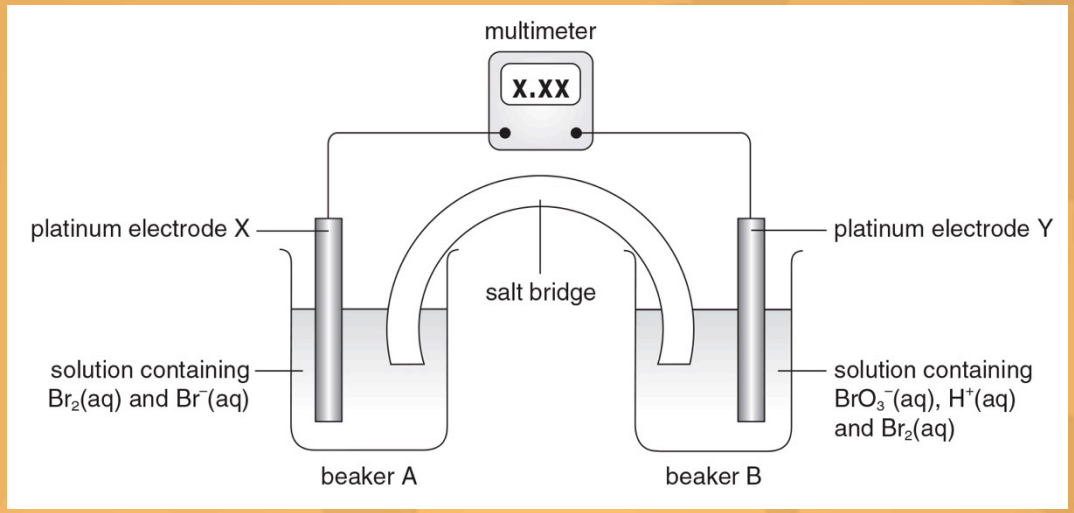
Explain why and justify your answer with the use of an appropriate equation.

Lithium reacts readily with water. (1)

$2Li(s) + 2H_2O(l) \longrightarrow H_2(g) + 2LiOH(aq)$ (1)

Topic Exercise (p.169)

24 A chemical cell using platinum electrodes X and Y is shown below.



The relative positions of $Br_2(aq)$ and $BrO_3^-(aq)$ in the electrochemical series are shown below.

higher in electrochemical series	$Br_2(aq) + 2e^- \longrightarrow 2Br^-(aq)$
lower in electrochemical series	$2BrO_3^-(aq) + 12H^+(aq) + 10e^- \longrightarrow Br_2(aq) + 6H_2O(l)$

Topic Exercise (p.169)

24 (continued)

a) i) State the expected observation in beaker A.

The yellow colour becomes more intense. (1)

ii) Write the half equation for the expected change.

$2Br^-(aq) \longrightarrow Br_2(aq) + 2e^-$ (1)

b) Write the equation for the overall cell reaction.

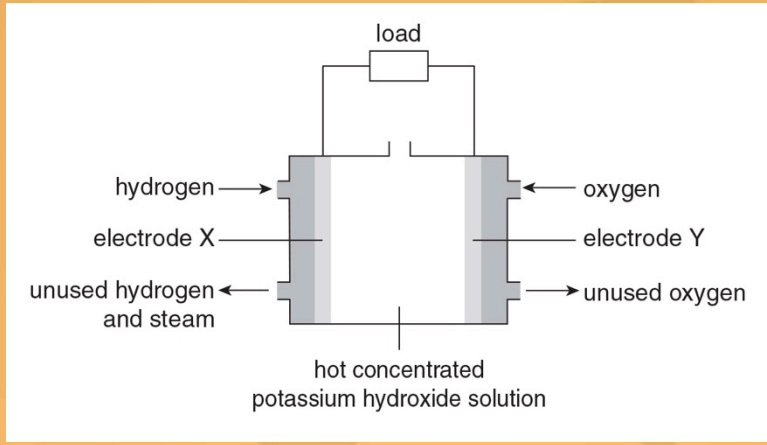
$2BrO_3^-(aq) + 10Br^-(aq) + 12H^+(aq) \longrightarrow 6Br_2(aq) + 6H_2O(l)$ (1)

c) Identify the direction of electron flow in the external circuit.

From electrode X to electrode Y (1)

Topic Exercise (p.169)

25 A simplified diagram of a hydrogen-oxygen fuel cell is shown below.



a) Suggest ONE way in which a fuel cell differs from other chemical cells.

Any one of the following:

- Fuel cells require a continuous supply of reactants, whereas in a chemical cell they are stored in the cell. (1)
- Some products are removed from fuel cells. (1)
- Fuel cell electrodes are porous. (1)

Topic Exercise (p.169)

25 (continued)

b) i) Which electrode, X or Y, is the anode?

Electrode X (1)

ii) Write the half equation for the change that occurs at the anode.

$H_2(g) + 2OH^-(aq) \longrightarrow 2H_2O(l) + 2e^-$ (1)

c) i) Which electrode, X or Y, is the cathode?

Electrode Y (1)

ii) Write the half equation for the change that occurs at the cathode.

$O_2(g) + 2H_2O(aq) + 4e^- \longrightarrow 4OH^-(aq)$ (1)

Topic Exercise (p.169)

25 (continued)

d) Identify the direction of electron flow in the external circuit.
From electrode X to electrode Y in the external circuit. (1)

e) Write the equation for the overall cell reaction.
$2H_2(g) + O_2(g) \longrightarrow 2H_2O(l)$ (1)

f) Suggest TWO major advantages of the fuel cell.

Any two of the following:

- Fuel cells do not emit air pollutants. (1)
- Fuel cells have high efficiency of energy conversion. (1)
- Fuel cells can operate continuously if the flow of hydrogen and oxygen can be maintained (they do not run down or require charging). (1)

Topic Exercise (p.169)

25 (continued)

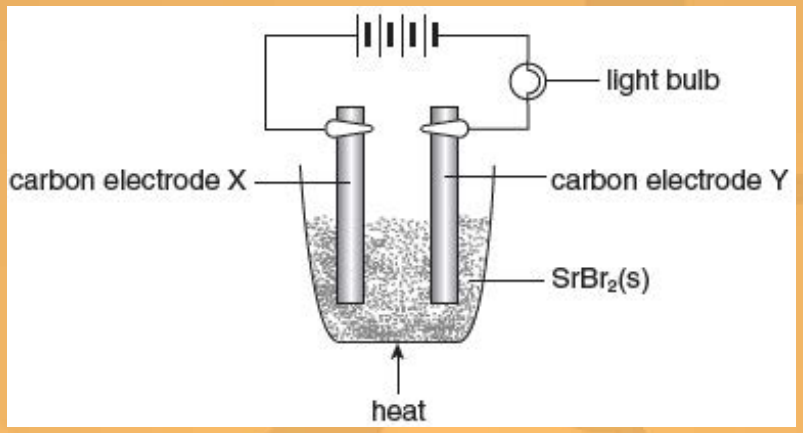
g) Suggest ONE disadvantage of using a hydrogen-oxygen fuel cell compared with a rechargeable battery when providing electrical energy for a motor vehicle.

Any one of the following:

- It is difficult to transport hydrogen. (1)
- Leakage of hydrogen may occur. (1)
- Hydrogen is flammable / explosive. (1)
- Fuel cell is expensive. (1)
- Fuel cell requires regular re-filling. (1)
- Fuel cell requires continual supply of H_2 and O_2. (1)
- Hydrogen is made from fossil fuels / natural gas. (1)
- Hydrogen is made by electrolysis. (1)

Topic Exercise (p.169)

26 Consider the experimental set-up shown below:



a) In the above experiment, the bulb lights up when the $SrBr_2(s)$ becomes molten.
(Atomic number of Sr = 38)
i) State the observation at carbon electrode X.
ii) Write a half equation for the change that occurs at carbon electrode Y.

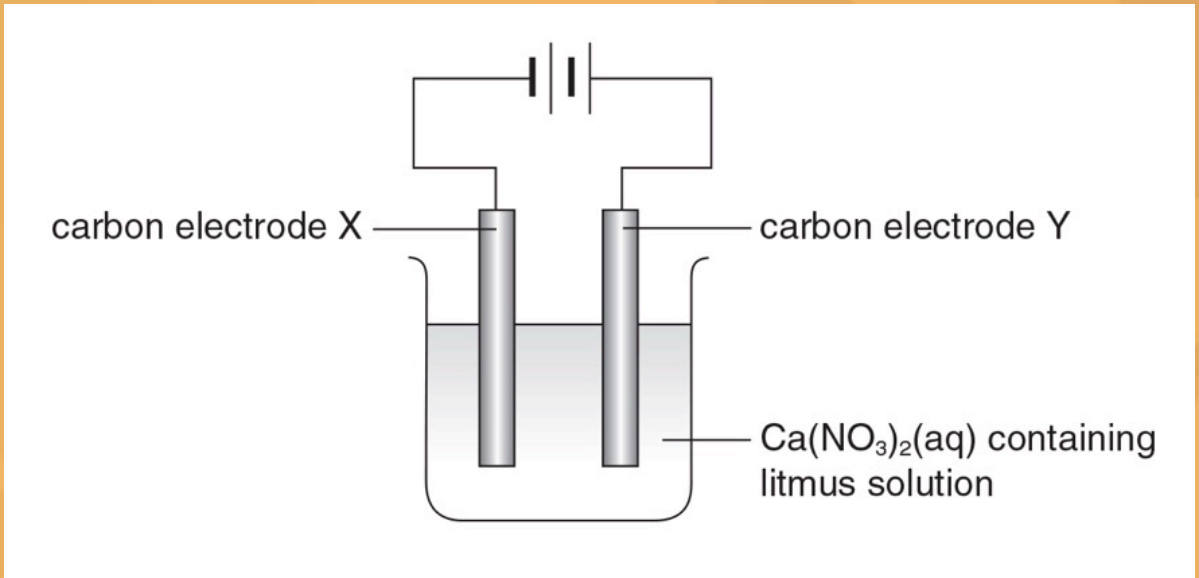
b) Explain why the experiment should be performed in a fume cupboard.

Answers for the questions of the public examinations in Hong Kong are not provided (if applicable).

(HKDSE, Paper 1B, 2016, 8(a)–(b))

Topic Exercise (p.169)

27 A dilute calcium nitrate solution containing some litmus solution was electrolysed using carbon electrodes.



a) Explain why calcium is NOT formed in the process.

H^+(aq) ion is a stronger oxidising agent than Ca^{2+}(aq) ion. (1)
Thus, Ca^{2+}(aq) ion is NOT reduced as easily as H^+(aq) ion.

Topic Exercise (p.169)

27 (continued)

b) State, with explanation, the expected observations around each electrode.

At electrode X

$H^+(aq)$ ions are preferentially discharged to give colourless hydrogen gas. (1)
As the electrolysis proceeds, water molecules dissociate to replace the $H^+(aq)$ ions discharged. Thus, there is a build-up of $OH^-(aq)$ ions near to electrode X. The solution there becomes alkaline and the litmus solution turns blue. (1)

At electrode Y

$OH^-(aq)$ ions are preferentially discharged to give colourless oxygen gas. (1)
As the electrolysis proceeds, water molecules dissociate to replace the $OH^-(aq)$ ions discharged. Thus, there is a build-up of $H^+(aq)$ ions near to electrode Y. The solution there becomes acidic and the litmus solution turns red. (1)

Topic Exercise (p.169)

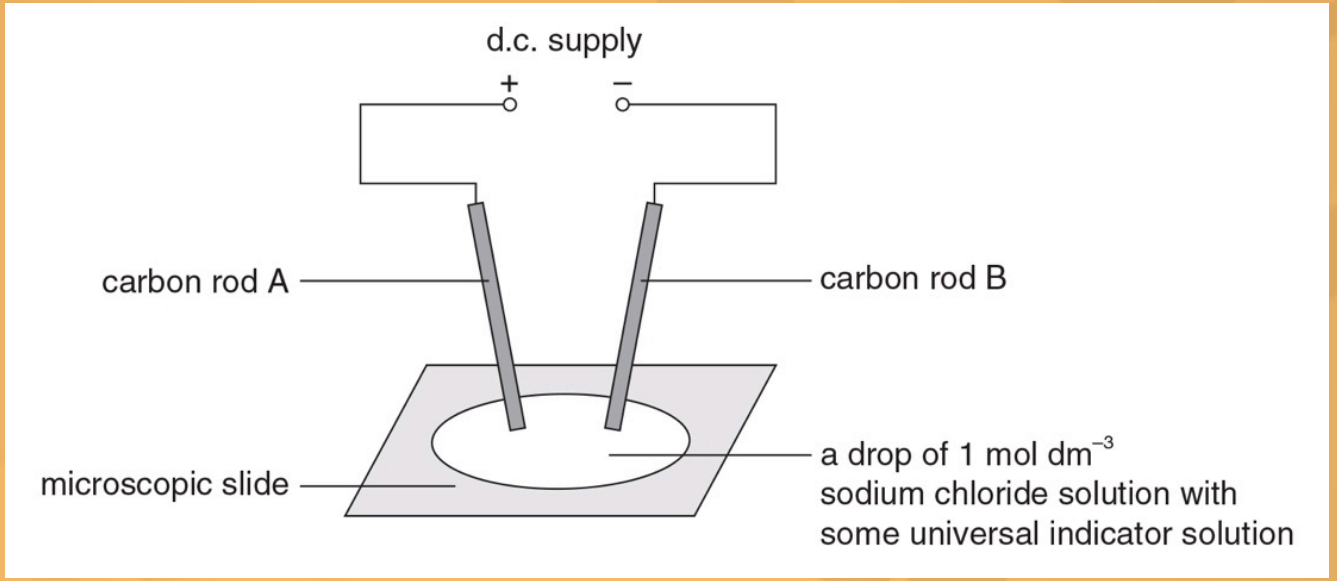
27 (continued)

c) What change would occur in the calcium nitrate solution after electrolysis? Explain your answer.

The concentration of the calcium nitrate solution increases as water is consumed in the electrolysis. (1)

Topic Exercise (p.169)

28 A student used the set-up shown below to conduct a microscale experiment on electrolysis.



a) A gas was liberated at carbon rod A.

i) What was the gas?

Chlorine (1)

Topic Exercise (p.169)

28 (continued)

a) ii) Explain the formation of the gas with the help of a half equation.

$Cl^-(aq)$ ions and $OH^-(aq)$ ions are attracted to carbon rod A.

The concentration of $Cl^-(aq)$ ions in the solution is much higher than that of hydroxide ions. Thus, $Cl^-(aq)$ ions are preferentially discharged at carbon rod A to give chlorine gas. (1)

$2Cl^-(aq) \longrightarrow Cl_2(g) + 2e^-$ (1)

Topic Exercise (p.169)

28 (continued)

b) The initial colour of the drop shown above was green. State the colour change of the liquid around carbon rod B after a current was passed through the circuit for some time. Explain your answer with the help of a half equation.

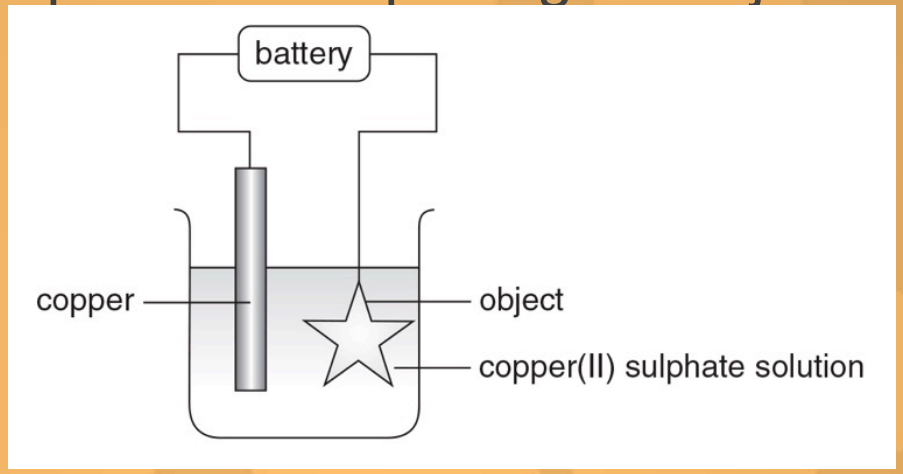
$Na^+(aq)$ ions and $H^+(aq)$ ions are attracted to carbon rod B. $H^+(aq)$ ion is a stronger oxidising agent than $Na^+(aq)$ ion. Thus, $H^+(aq)$ ions are preferentially discharged at carbon rod B. (1)

$2H^+(aq) + 2e^- \longrightarrow H_2(g)$ (1)

As the electrolysis proceeds, water molecules dissociate to replace the $H^+(aq)$ ions discharged. Thus, there is a build-up of $OH^-(aq)$ ions near to carbon rod B. The solution there becomes alkaline and the universal indicator solution turns blue. (1)

Topic Exercise (p.169)

29 Refer to the set-up for electroplating an object shown in the diagram below.



a) Explain why oily dirts on the object should be removed before electroplating.

b) Copper(II) sulphate is an electrolyte. What is meant by the term 'electrolyte'?

c) List ALL the ions existing in the solution.

d) Explain why copper(II) ions are preferentially discharged during the electroplating process.

Topic Exercise (p.169)

29 (continued)

e) Write the half equation of the change that occurs at the anode.

f) State the observable change, if any, in the solution during the electroplating process.

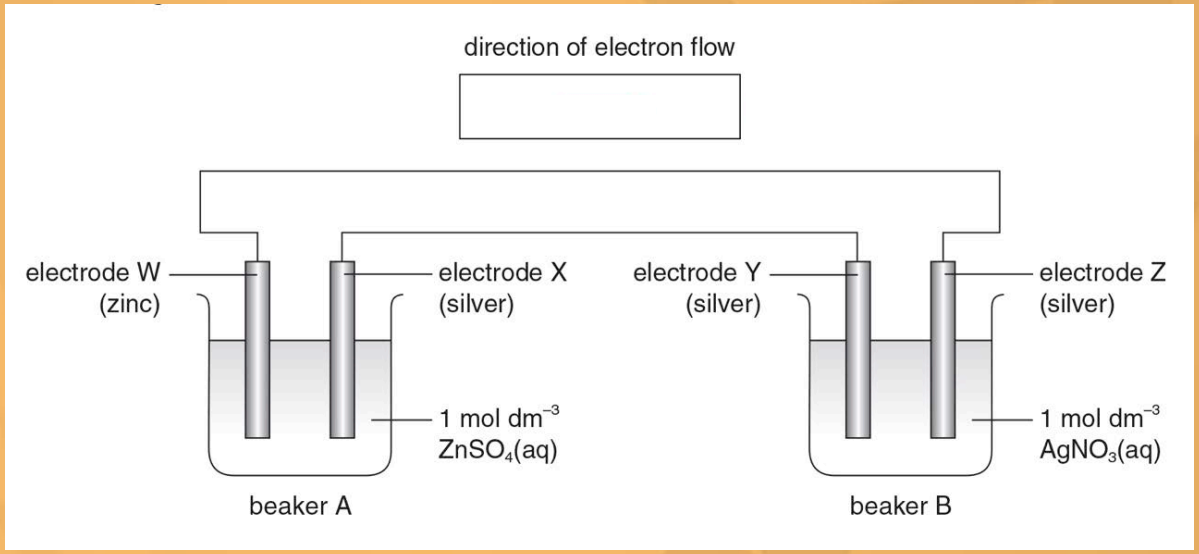
g) It is known that 2.28×10^{22} electrons have passed through the external circuit during the electroplating process. Calculate the mass of copper that would theoretically be plated on the object.
(Relative atomic mass: Cu = 63.5;
Avogadro's constant = 6.02×10^{23} mol^{-1})

Answers for the questions of the public examinations in Hong Kong are not provided (if applicable).

(HKDSE, Paper 1B, 2015, 7)

Topic Exercise (p.169)

30 The diagram below shows a set-up in which electrons are flowing through the conducting wires. Electrode W in beaker A is forming ions.



a) i) State the expected observation at each electrode in beaker A.

Electrode W becomes thinner gradually. (1)
A colourless gas given off from electrode X. (1)

Topic Exercise (p.169)

30 (continued)

a) ii) Write a half equation for the expected change at each electrode.

Electrode W: $Zn(s) \longrightarrow Zn^{2+}(aq) + 2e^{-}$ (1)

Electrode X: $2H^{+}(aq) + 2e^{-} \longrightarrow H_2(g)$ (1)

b) In the box provided on the diagram, use an arrow ($\longrightarrow$ or $\longleftarrow$) to indicate the direction of electron flow in the upper wire. $\longrightarrow$ (1)

c) i) State the expected observation at each electrode in beaker B.

Electrode Y dissolves, forming silver ions. (1)

Silver ions receive electrons from electrode Z, forming a silvery deposit of silver. (1)

Topic Exercise (p.169)

30 (continued)

c) ii) Write a half equation for the expected change at each electrode.

Electrode Y: $Ag(s) \longrightarrow Ag^+(aq) + e^-$ (1)

Electrode Z: $Ag^+(aq) + e^- \longrightarrow Ag(s)$ (1)

d) Complete the following table by filling in 'anode' or 'cathode' to describe the electrodes.

Electrode	X	Z
Anode / cathode	cathode	cathode

(1)