CHAPTER 6

ELECTROCHEMISTRY

State three uses of electrolysis.

Name the process used in the treatment of wastewater by applying electrolysis.

Give one example of a fruit and one example of a plant part which can be used to build a chemical cell that produces electrical energy.

Let's study

- Electrolytic cell
- Chemical cell

Science Bulletin

Success stories in the field of electric automobiles such as electric cars are closely related to the technological development and advancement of battery.

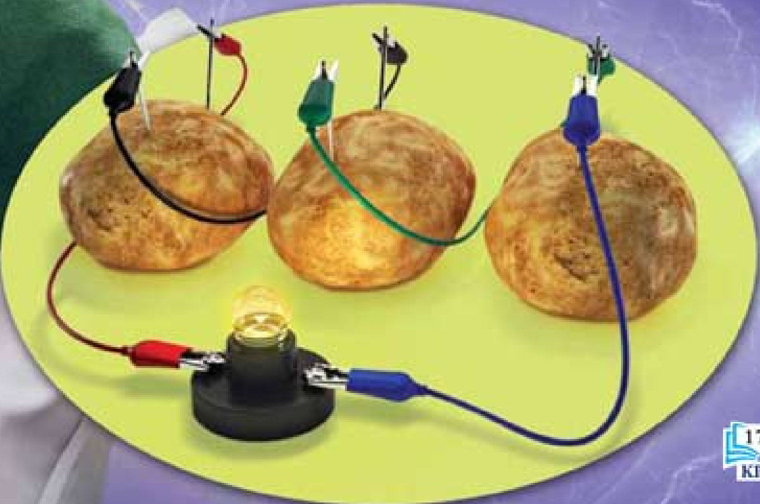
The properties of superior car batteries include, their ability to produce and store a lot of energy, rapid rate of charging, durable, light and can be safely used at high or low temperatures without exploding. What are the advantages of the battery fitted to electric cars?

Charging the electric car battery

Lithium-ion batteries in an electric car

Keywords

- Electrochemical cell
- Electrolytic cell
- Chemical cell
- Electrolysis
- Anode
- Cathode
- Anion
- Cation
- Electrode
- Electrolyte
- Non-electrolyte
- Ionic compound
- Electrochemical series
- Type of electrode
- Metal extraction
- Purification of metal
- Electroplating
- Electrocoagulation



6.1 Electrolytic Cell

Electrochemistry is a study in chemistry of the relationship between **electrical** and **chemical** phenomena like those occurring in two types of **electrochemical cells** as follows:

(a) **Electrolytic cell**
In an electrolytic cell, electric current flows through an electrolyte to produce a chemical reaction. Electrical energy is converted to chemical energy through **electrolysis**.

(b) **Chemical cell** (voltaic cell or galvanic cell)
In a chemical cell, chemical changes that occur in the cell produce an electric current. Chemical energy is converted to electrical energy in the cell.

Electrolysis

In Form 2, you studied about electrolysis that is used to determine the composition of elements in water molecules using an **electrolytic cell** (Figure 6.1).

Electrolysis is the decomposition of a compound in the molten or aqueous state into its constituent elements when electric current flows through it. What are the decomposed compound and constituent elements produced in the electrolysis process (Figure 6.1)?

An electrolytic cell is made up of:
- an **electrical source** such as battery
- an **anode** which is the electrode connected to the positive terminal of an electrical source
- a **cathode** which is the electrode connected to the negative terminal of an electrical source
- an **electrolyte** which contains positive ions (cations) and negative ions (anions) (Figure 6.2)

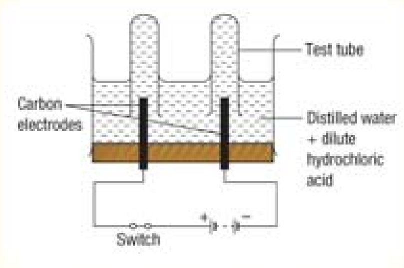


Figure 6.1 Electrolytic cell

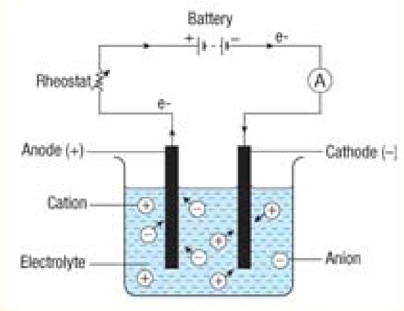


Figure 6.2 Electrolytic cell

Electrical Source

The function of the **electrical source** in an electrolytic cell is to produce electric current to carry out electrolysis. Electrolysis cannot take place if there is no electric current flowing through the electrolyte.

Electrode

Electrode is the electric conductor that is connected to the battery and enables electric current to enter or leave the electrolyte during electrolysis. The electrode connected to the positive terminal of the electrical source is known as the **anode** while the electrode connected to the negative terminal of the electrical source is known as the **cathode**.

Electrolyte

Substances in the molten or aqueous state which allow electric current to flow through them and undergo chemical changes are known as **electrolytes**. Substances which do not allow electric current to flow through them in the molten or aqueous state are known as **non-electrolytes**.

Table 6.1 Examples of electrolyte and non-electrolyte

Examples of electrolyte	Examples of non-electrolyte
• Molten lead(II) bromide, $PbBr_2$ • Molten sodium chloride, $NaCl$ • Sodium hydroxide solution, $NaOH$ • Copper(II) sulphate solution, $CuSO_4$	• Naphthalene, $C_{10}H_8$ • Acetamide, CH_3CONH_2 • Glucose solution, $C_6H_{12}O_6$ • Ethanol, C_2H_5OH

Electrolytes are ionic compounds in the molten or aqueous state which consist of positive ions, **cations** and negative ions, **anions**. For example, sodium chloride is an electrolyte which is an ionic compound made up of sodium ions, Na^+ (positively charged ions) and chloride ions, Cl^- (negatively charged ions).

$$NaCl \longrightarrow Na^+ + Cl^-$$

Activity 6.1

21st Century Skills
• TPS

To draw and label the structures of an electrolytic cell

Instructions

1. Carry out this activity individually.
2. Draw and label the electrolytic cell in Figure 6.1. The parts that need to be labelled include:
   (a) anode
   (b) cathode
   (c) electrolyte
3. Present the drawing of the labelled electrolytic cell to the class.

6.1.1

Electrolysis Process

During the electrolysis process,

- positively charged ions (cations) move to the cathode (negative electrode)
- negatively charged ions (anions) move to the anode (positive electrode)

For example, during the electrolysis of molten lead(II) bromide, $PbBr_2$, positively charged lead(II) ions, Pb^{2+}, move to the negatively charged cathode while negatively charged bromide ions, Br^-, move to the positively charged anode (Figure 6.3).

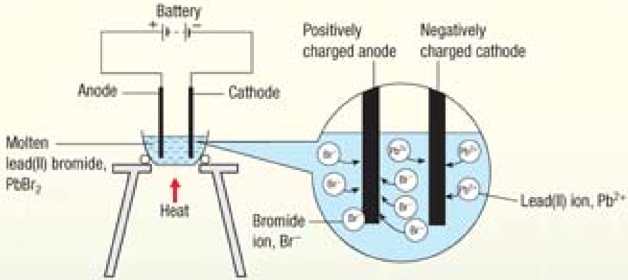


Figure 6.3 Movement of ions towards electrodes during the electrolysis of molten lead(II) bromide, $PbBr_2$

Electrolytes in the solid state cannot conduct electricity because there are no free-moving ions to conduct the electricity.

Experiment 6.1

Aim: To study the electrolysis of ionic compounds in solid, molten and aqueous states

Problem statement: Can ionic compounds in solid, molten and aqueous states be electrolysed?

Hypotheses:
1. Ionic compounds in molten and aqueous states can be electrolysed.
2. Ionic compounds in solid state cannot be electrolysed.

Variables:
(a) manipulated : State of ionic compound, namely solid, molten or aqueous
(b) responding : Condition of light bulb
(c) constant : Type of electrode

Materials: Solid lead(II) bromide, $PbBr_2$ and 0.1 mol dm^{-3} copper(II) sulphate solution, $CuSO_4$

Apparatus: Battery, carbon electrodes, connecting wires with crocodile clips, crucible, tripod stand, pipe clay triangle, Bunsen burner, switch, beaker, light bulb, electrolytic cell, spatula and test tubes

Procedure:

A Electrolysis of ionic compound in solid and molten states

Teacher's demonstration (carried out in a fume chamber)

CAUTION!
Bromine gas is poisonous. Do not inhale the bromine gas.

1. Put solid lead(II) bromide powder, $PbBr_2$, into a dry crucible until it is half-full.
2. Place the crucible on a pipe clay triangle atop a tripod stand (Figure 6.4).
3. Complete the circuit by connecting the carbon electrodes, switch, battery and light bulb with connecting wires and crocodile clips.
4. Turn on the switch. Observe and record the changes that happen to the light bulb.
5. Heat the solid lead(II) bromide, $PbBr_2$, until it melts (Figure 6.5).
6. Repeat steps 3 and 4.

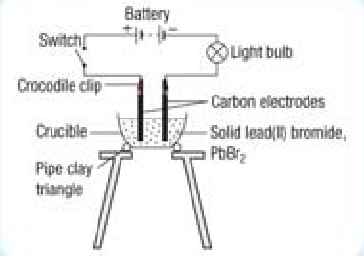


Figure 6.4 Electrolysis of solid lead(II) bromide, $PbBr_2$

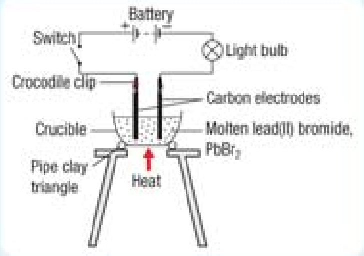


Figure 6.5 Electrolysis of molten lead(II) bromide, $PbBr_2$

B Electrolysis of ionic compound in aqueous state

1. Prepare the apparatus set-up with an electrolytic cell half-filled with 0.1 mol dm^{-3} copper(II) sulphate solution, $CuSO_4$, and two test tubes filled completely with 0.1 mol dm^{-3} copper(II) sulphate solution, $CuSO_4$ (Figure 6.6).

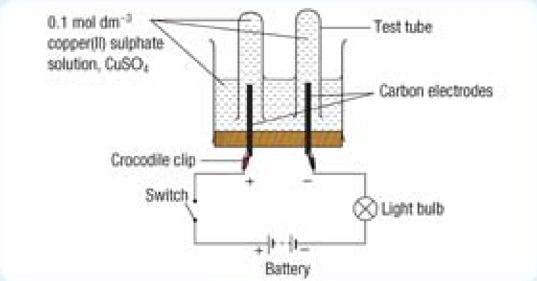


Figure 6.6

2. Turn on the switch for 5 minutes. Observe and record the changes that happen to the light bulb.

6.1.2

Observation:

Material	Condition of light bulb	Inference
Solid lead(II) bromide, $PbBr_2$		
Molten lead(II) bromide, $PbBr_2$		
0.1 mol dm^{-3} copper(II) sulphate solution, $CuSO_4$		

Conclusion:

Are the hypotheses accepted? What is the conclusion for this experiment?

Questions:

1. Why should the electrolysis of molten lead(II) bromide, $PbBr_2$, be carried out in a fume chamber?
2. What is the purpose of connecting a light bulb to the electrolytic cell?
3. Why does electrolysis not occur in ionic compounds that are in the solid state?

Factors Affecting the Products in Electrolysis

Three factors which affect the selection of ions to be discharged at the electrodes in the electrolysis of aqueous solutions are:

- **position of ions in the electrochemical series**
- **concentration of electrolyte**
- **types of electrode**

Science Info

When a positive ion is discharged, the ion will receive one or more electrons, become neutral, and form an atom or a molecule. When a negative ion is discharged, the ion will donate one or more electrons, become neutral, and form an atom or a molecule.

Position of Ions in the Electrochemical Series

In the electrochemical series, metals are arranged according to the tendency of their atom to donate electron(s). The higher the position of a metal in the electrochemical series, the easier it is for the metal to donate electron(s). Figure 6.7 shows the arrangement of ions in the electrochemical series according to their tendency to be discharged.

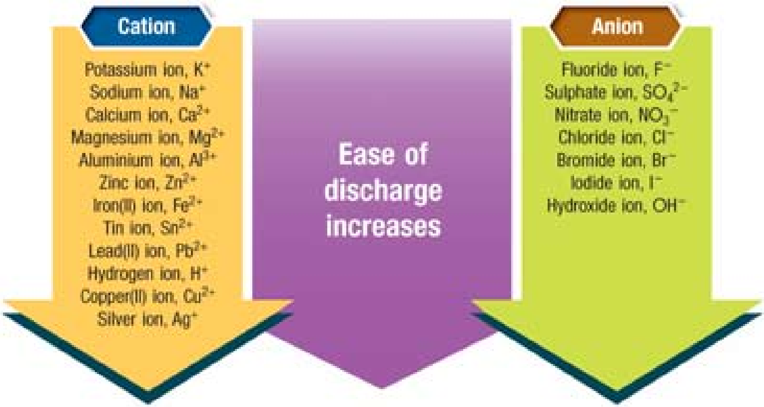


Figure 6.7 Arrangement of ions in the electrochemical series according to their tendency to be discharged

Ions at the bottom of the electrochemical series have higher tendencies to be discharged.

Example 1

Electrolysis of sodium sulphate solution

(a) Ions present in a sodium sulphate solution during electrolysis are sodium ions, sulphate ions, hydrogen ions and hydroxide ions

(b) **Cathode (negative electrode)**
   (i) Attracts positive ions, namely sodium ions and hydrogen ions
   (ii) Hydrogen ions are selected to be discharged because the hydrogen ion is less electropositive compared to the sodium ion
   (iii) Hydrogen gas is produced at the cathode

(c) **Anode (positive electrode)**
   (i) Attracts negative ions, namely sulphate ions and hydroxide ions
   (ii) Hydroxide ions are selected to be discharged because the hydroxide ion is less electronegative compared to the sulphate ion
   (iii) Oxygen gas is produced at the anode

6.1.3

Example 2

Electrolysis of copper(II) sulphate solution

(a) Ions present in a copper(II) sulphate solution during electrolysis are copper(II) ions, sulphate ions, hydrogen ions and hydroxide ions.

(b) **Cathode (negative electrode)**
  (i) Attracts positive ions, namely copper(II) ions and hydrogen ions
  (ii) Copper(II) ions are selected to be discharged because the copper(II) ion is less electropositive compared to the hydrogen ion
  (iii) Copper is deposited at the cathode

(c) **Anode (positive electrode)**
  (i) Attracts negative ions, namely sulphate ions and hydroxide ions
  (ii) Hydroxide ions are selected to be discharged because the hydroxide ion is less electronegative compared to the sulphate ion
  (iii) Oxygen gas is produced at the anode

Experiment 6.2

Aim: To study the effect of the position of ions in the electrochemical series on the tendency of the ion to be discharged at the electrode

Problem statement: How does the position of ions in the electrochemical series affect the tendency of the ion to be discharged at the electrode?

Hypothesis: The lower the position of an ion in the electrochemical series, the easier it is for the ion to be discharged.

Variables:
(a) manipulated : Position of ion in the electrochemical series
(b) responding : Product at electrode
(c) constant : Concentration of electrolyte and type of electrode

Materials: 0.5 mol dm^{-3} magnesium nitrate solution, $Mg(NO_3)_2$, 0.5 mol dm^{-3} sodium sulphate solution, Na_2SO_4 and wooden splinter

Apparatus: Battery, carbon electrodes, connecting wires with crocodile clips, electrolytic cell, ammeter, test tubes and switch

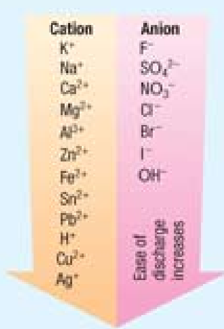


Figure 6.8 Arrangement of ions in the electrochemical series according to their tendency to be discharged

Procedure:

1. Prepare the apparatus set-up with an electrolytic cell half-filled with 0.5 mol dm^{-3} magnesium nitrate solution, $Mg(NO_3)_2$.
2. Fill completely two test tubes with 0.5 mol dm^{-3} magnesium nitrate solution, $Mg(NO_3)_2$, and invert both test tubes in the electrolytic cell (Figure 6.9).
3. Turn on the switch. Observe and record the changes that occur at the anode and cathode.
4. Turn off the switch when the test tube is almost full with gas released from the electrode.
5. Test the gas released using a glowing wooden splinter and a burning wooden splinter.
6. Observe and record the results.
7. Repeat steps 1 to 6 by replacing magnesium nitrate solution, $Mg(NO_3)_2$, with sodium sulphate solution, Na_2SO_4.

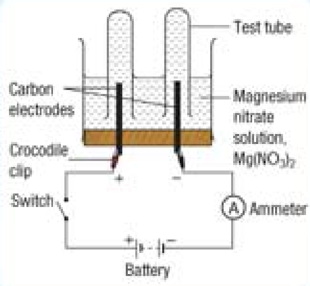


Figure 6.9

Science Info

Glowing wooden splinter test (test for oxygen gas)
- Insert a glowing wooden splinter into the test tube containing the gas.
- If the glowing wooden splinter ignites, the gas in the test tube is oxygen.

Burning wooden splinter test (test for hydrogen gas)
- Bring a burning wooden splinter close to the mouth of the test tube containing the gas.
- If the gas explodes with a 'pop' sound, the gas in the test tube is hydrogen.

Observation:

Electrolyte	Test for gas released at	
	anode	cathode
Magnesium nitrate solution, $Mg(NO_3)_2$	Glowing wooden splinter test: .... Burning wooden splinter test:	Glowing wooden splinter test: .... Burning wooden splinter test: ....
Sodium sulphate solution, Na_2SO_4	Glowing wooden splinter test: .... Burning wooden splinter test:	Glowing wooden splinter test: .... Burning wooden splinter test: ....

Conclusion:

Is the hypothesis accepted? What is the conclusion for this experiment?

Questions:

1. Name the ions in the following solutions:
   (a) magnesium nitrate solution, $Mg(NO_3)_2$
   (b) sodium sulphate solution, Na_2SO_4
2. Based on your observations in Experiment 6.2, name the gas produced at the anode and cathode for each electrolyte in the table below.

Electrolyte	Product formed at	
	anode	cathode
Magnesium nitrate solution, $Mg(NO_3)_2$		
Sodium sulphate solution, Na_2SO_4		

3. Name the ion selected to be discharged at the anode and cathode for each electrolyte in the table below.

Electrolyte	Ion selected to be discharged at	
	anode	cathode
Magnesium nitrate solution, $Mg(NO_3)_2$		
Sodium sulphate solution, Na_2SO_4		

Concentration of Electrolyte

The concentration of ions in an electrolyte also affects the selection of ion to be discharged. Negative ions which are more concentrated in an electrolyte are more likely to be discharged at the anode. However, the selection of positive ions to be discharged at the cathode is still influenced by the position of the positive ions in the electrochemical series.

Example

Electrolysis of concentrated sodium chloride solution and dilute sodium chloride solution

(a) Ions present in a concentrated or dilute sodium chloride solution during electrolysis are sodium ions, chloride ions, hydrogen ions and hydroxide ions.

(b) **Cathode (negative electrode)**
   (i) Attracts positive ions, namely sodium ions and hydrogen ions
   (ii) Hydrogen ions are selected to be discharged because the hydrogen ion is less electropositive compared to the sodium ion
   (iii) Hydrogen gas is produced at the cathode

(c) **Anode (positive electrode)**
   (i) Attracts negative ions, namely chloride ions and hydroxide ions
   (ii) The negative ion discharged at the anode is influenced by the concentration of the negative ion in the electrolyte as follows:

- the concentration of chloride ion is higher than the concentration of hydroxide ion in a concentrated sodium chloride solution such as 1.0 mol dm^{-3} sodium chloride solution, therefore the chloride ion will be selected to be discharged even though the position of the chloride ion is higher than the hydroxide ion in the electrochemical series. Chlorine gas is produced at the anode.
- the concentration of chloride ion is lower than the concentration of hydroxide ion in a dilute sodium chloride solution such as 0.0001 mol dm^{-3} sodium chloride solution, therefore the hydroxide ion will be selected to be discharged because it is less electronegative compared to the chloride ion. Oxygen gas is produced at the anode.

Experiment 6.3

Aim: To study the effect of concentration of ions in electrolytes on the selection of ion to be discharged at the anode

CAUTION!
Chlorine gas is poisonous.

Problem statement: How does the concentration of hydrochloric acid, HCl, influence the selection of ion to be discharged at the anode?

Hypothesis: Ions of a higher concentration will be selected to be discharged at the anode

Variables:
(a) manipulated : Concentration of ion in electrolyte
(b) responding : Product at anode
(c) constant : Type of electrode

Materials: 1.0 mol dm^{-3} hydrochloric acid, HCl, 0.0001 mol dm^{-3} hydrochloric acid, HCl and wooden splinter

Apparatus: Battery, carbon electrodes, connecting wires with crocodile clips, electrolytic cell, ammeter, test tubes, litmus paper and switch

Procedure:
1. Prepare the apparatus set-up with an electrolytic cell half-filled with 1.0 mol dm^{-3} hydrochloric acid, HCl.
2. Fill completely two test tubes with 1.0 mol dm^{-3} hydrochloric acid, HCl, and invert both test tubes in the electrolytic cell (Figure 6.10).
3. Turn on the switch. Observe and record the changes which occur at the anode.
4. Turn off the switch when the test tube is almost filled with gas released from the anode.

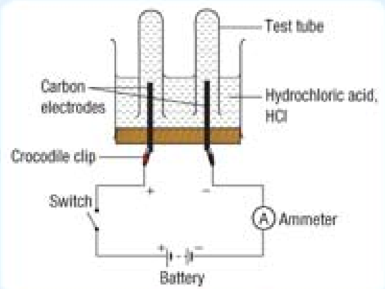


Figure 6.10

5. Test any gas released using a glowing wooden splinter, and moist blue and red litmus papers.
6. Observe and record the results of the gas tests.
7. Repeat steps 1 to 6 by replacing 1.0 mol dm^{-3} hydrochloric acid, HCl, with 0.0001 mol dm^{-3} hydrochloric acid, HCl.

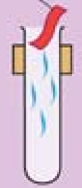
Science Info

Moist blue litmus paper test

- Place a piece of moist blue litmus paper close to the mouth of the test tube containing the gas.
- If the moist blue litmus paper turns red, the gas in the test tube is acidic.
- If the colour of the moist blue litmus paper bleaches, the gas in the test tube is halogen gas.
- If the moist blue litmus paper does not change colour, the gas in the test tube is alkaline or neutral.

Moist red litmus paper test

- Place a piece of moist red litmus paper close to the mouth of the test tube containing the gas.
- If the moist red litmus paper turns blue, the gas in the test tube is alkaline.
- If the moist red litmus paper does not change colour, the gas in the test tube is acidic or neutral.



Observation:

Electrolyte	Test for gas produced at the anode
1.0 mol dm^{-3} hydrochloric acid, HCl	Glowing wooden splinter test: .... Moist blue litmus paper test: .... Moist red litmus paper test: ....
0.0001 mol dm^{-3} hydrochloric acid, HCl	Glowing wooden splinter test: .... Moist blue litmus paper test: .... Moist red litmus paper test: ....

Conclusion:

Is the hypothesis accepted? What is the conclusion for this experiment?

Questions:

1. What is the difference in the concentration of chloride ion, Cl^-, between 1.0 mol dm^{-3} hydrochloric acid, HCl and 0.0001 mol dm^{-3} hydrochloric acid, HCl?
2. Based on your observations in Experiment 6.3, name the product formed at the anode of each of the following electrolytes:
   (a) 1.0 mol dm^{-3} hydrochloric acid, HCl
   (b) 0.0001 mol dm^{-3} hydrochloric acid, HCl
3. Name the ion selected to be discharged at the anode of each of the following electrolytes:
   (a) 1.0 mol dm^{-3} hydrochloric acid, HCl
   (b) 0.0001 mol dm^{-3} hydrochloric acid, HCl

Types of Electrode

The **type of electrode** used also affects the selection of ion to be discharged as follows:

(a) If the metal used as the anode is the **same** as the metal ion in the electrolyte, then
- at the anode, the metal atoms will ionise to form positive ions that dissolve into the electrolyte
- at the cathode, the metal ions will discharge to form atoms of the metal which are then deposited at the cathode
- the concentration of metal ions in the electrolyte does not change because the rate of metal atoms ionised to form metal ions at the anode is the same as the rate of metal ions discharged to form metal atoms which are then deposited at the cathode

(b) If the type of substance used as the anode is **not the same** as the type of metal ion in the electrolyte, then
- the atoms of the anode do not dissolve in the electrolyte. Negative ions in the electrolyte are discharged at the anode
- at the cathode, the less electropositive ion will be selected to be discharged

Example

Electrolysis of silver nitrate solution using:

- **Silver electrode**
  (a) Ions present in a silver nitrate solution during electrolysis are silver ions, nitrate ions, hydrogen ions and hydroxide ions.
  (b) **Cathode (negative electrode)**
    (i) Attracts positive ions, namely silver ions and hydrogen ions
    (ii) Silver ions are selected to be discharged because the silver ion is less electropositive compared to the hydrogen ion
    (iii) Silver is deposited at the cathode
  (c) **Anode (positive electrode)**
    (i) Forms silver ions when silver atoms at the anode ionise. Nitrate ions and hydroxide ions are not discharged
    (ii) The silver electrode dissolves in the electrolyte
  (d) The concentration of silver ions in the electrolyte does not change because the rate of silver atoms ionised to form silver ions at the anode is the same as the rate of silver ions discharged to form silver atoms which are deposited at the cathode.

- **Carbon electrode**
  (a) Ions present in a silver nitrate solution during electrolysis are silver ions, nitrate ions, hydrogen ions and hydroxide ions.

(b) **Cathode (negative electrode)**
   (i) Attracts positive ions, namely silver ions and hydrogen ions
   (ii) Silver ions are selected to be discharged because the silver ion is less electropositive compared to the hydrogen ion
   (iii) Silver is deposited at the cathode

(c) **Anode (positive electrode)**
   (i) Attracts negative ions, namely nitrate ions and hydroxide ions
   (ii) Hydroxide ions are selected to be discharged because the hydroxide ion is less electronegative compared to the nitrate ion
   (iii) Oxygen gas is produced at the anode

(d) The concentration of silver ions in the electrolyte decreases because the silver ions from the electrolyte are discharged to become silver atoms and deposited at the cathode.

Experiment 6.4

Aim: To study the effect of the type of electrode on the selection of ion to be discharged at the electrode

Problem statement: How does the type of electrode affect the selection of ion to be discharged at the anode?

Hypotheses:
1. If carbon electrodes are used during the electrolysis of copper(II) sulphate solution, $CuSO_4$, then the hydroxide ion, OH^-, is selected to be discharged at the anode.
2. If copper electrodes are used during the electrolysis of copper(II) sulphate solution, $CuSO_4$, then the copper(II) ion, Cu^{2+}, is formed at the anode.

Variables:
(a) manipulated : Type of electrode (carbon or copper)
(b) responding : Product of electrolysis at the anode
(c) constant : Type and concentration of electrolyte

Materials: 0.1 mol dm^{-3} copper(II) sulphate solution, $CuSO_4$ and wooden splinter

Apparatus: Battery, carbon electrodes, copper electrodes, connecting wires with crocodile clips, electrolytic cell, ammeter, test tubes and switch

Procedure:
1. Prepare the apparatus set-up with an electrolytic cell half-filled with 0.1 mol dm^{-3} copper(II) sulphate solution, $CuSO_4$.
2. Fill completely a test tube with 0.1 mol dm^{-3} copper(II) sulphate solution, $CuSO_4$ and then invert the test tube at the anode (Figure 6.11).

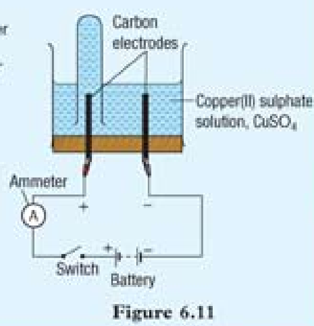


Figure 6.11

3. Turn on the switch for 15 minutes. Observe and record the changes that occur at the anode.
4. Test any gas released using a glowing wooden splinter.
5. Observe and record the result of the gas test.
6. Repeat steps 1 to 4 by replacing the carbon electrodes with copper electrodes.

Observation:

Type of electrode	Glowing wooden splinter test at anode
Carbon electrode	
Copper electrode	

Conclusion:

Are the hypotheses accepted? What is the conclusion for this experiment?

Questions:

1. Name the ions present in the electrolyte during electrolysis.
2. Name the ions selected to be discharged or the ions produced at the anode for the following types of electrodes:
   (a) carbon electrode
   (b) copper electrode

Application of Electrolysis in Industries

Examples of applications of electrolysis in industries include:

(a) **Extraction of metals**
In Form 3, you have studied the position of metals in the reactivity series of metal and methods of metal extraction from their ores. Metals like potassium, sodium, calcium, magnesium and aluminium are extracted from their molten ores or salts through electrolysis.

(b) **Purification of metals**
In the purification of metal, the impure metal is used as the anode while the pure metal is used as the cathode. During electrolysis, the metal at the anode will dissolve into the electrolyte to form ions. These ions will move to the cathode to be discharged and deposited at the cathode as pure metal.

(c) **Electroplating of metals**
In the process of electroplating a metal, gold, platinum and silver are electroplated on other metals to make the metal look more attractive and to withstand corrosion.

(d) **Wastewater treatment using electrocoagulation**
Electrocoagulation is an innovative technique to treat wastewater (Figure 6.12). Electrocoagulation applies two processes, namely electrolysis and coagulation.

- **Electrolysis**
  1. At the anode, a metal electrode such as aluminium ionises in the electrolyte to produce positively charged aluminium ions, Al^{3+}.
  2. At the cathode, hydrogen ions, H^+ are selected to be discharged to form hydrogen gas. Hydrogen gas bubbles are released from the cathode and rise to the water surface.

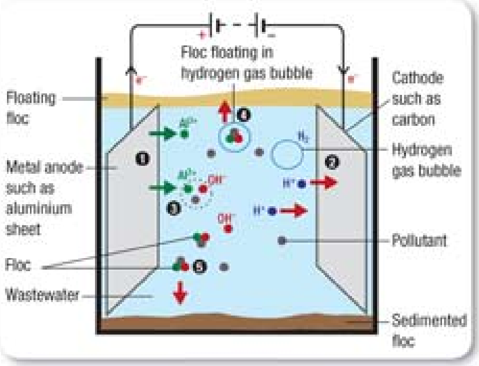


Figure 6.12 Electrocoagulation

- **Coagulation**
  3. Coagulation occurs when aluminium ions, Al^{3+}, hydroxide ions, OH^- and pollutants in the wastewater combine to produce coagulants known as floc.
  4. Floc, trapped in hydrogen gas bubbles released from the cathode, are brought up to the water surface.
  5. The remaining flocs sinks and accumulates at the base.

Formative Practice 6.1

1. Draw and label the structures of an electrolytic cell.
2. Describe the movement of ions to electrodes during electrolysis.
3. Give **four** examples of applications of electrolysis in industries.

6.2 Chemical Cell

A **simple chemical cell** is made up of two different metals immersed in an electrolyte and connected to an external circuit with connecting wires (Figure 6.13).

Observe the simple chemical cell which is made up of magnesium and copper electrodes in Figure 6.14 and the electrochemical series in Figure 6.15.

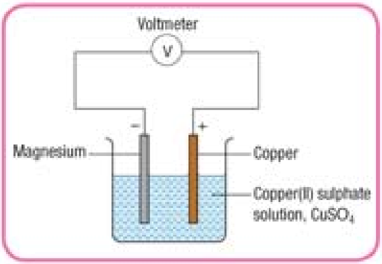


Figure 6.13 Example of a simple chemical cell

6.1.4 6.2.1

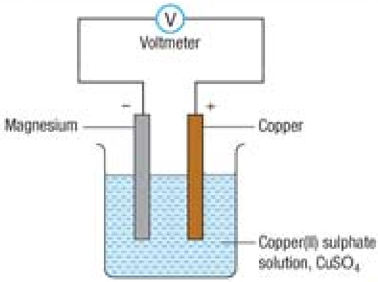


Figure 6.14 Simple chemical cell

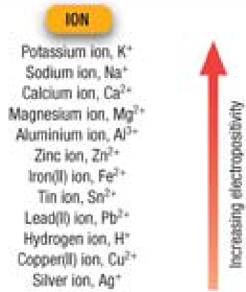


Figure 6.15 Electrochemical series showing arrangement of ions in order of electropositivity

By referring to the simple chemical cell in Figure 6.14, magnesium becomes the negative terminal and copper becomes the positive terminal. This is because magnesium is more electropositive than copper (Figure 6.15). Magnesium is more likely to donate electrons compared to copper.

- Magnesium which donates electrons forms magnesium ions and dissolves in the electrolyte (copper(II) sulphate solution).
- Magnesium acts as the negative terminal of the chemical cell.
- The released electrons will flow through the external circuit from magnesium to copper which acts as the positive terminal of the chemical cell.

- Electrons from magnesium are received by the copper(II) ion from the electrolyte and not by the hydrogen ion because the copper(II) ion is less electropositive than the hydrogen ion.
- Solid copper is formed and deposited on the copper strip.
- Copper acts as the positive terminal of the chemical cell.

- The flow of electrons from the negative terminal to the positive terminal through the external circuit will produce electrical energy.
- Conversion of energy which occurs in the chemical cell is from chemical energy to electrical energy.

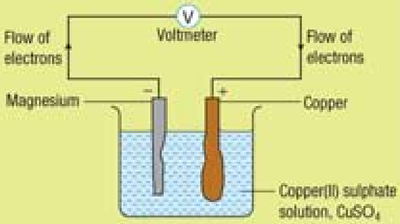


Figure 6.16 Chemical reactions in a chemical cell with different metal electrodes

6.2.1

Activity 6.2

21st Century Skills
- TPS
- Inquiry-based activity

To build a simple chemical cell

Materials

Sandpaper, two magnesium ribbons, two copper strips and 1.0 mol dm^{-3} sodium chloride solution, NaCl

Apparatus

Measuring cylinder, beaker, connecting wires with crocodile clips and voltmeter

Instructions

1. Clean two magnesium ribbons and two copper strips with sandpaper.
2. Measure and pour 150 cm^3 of 1.0 mol dm^{-3} sodium chloride solution, NaCl into a clean beaker using a measuring cylinder.
3. Immerse a magnesium ribbon and a copper strip into the sodium chloride solution, NaCl, in the beaker.
4. Connect the magnesium ribbon, copper strip and voltmeter with connecting wires (Figure 6.17).
5. Turn on the switch. Observe and record the voltmeter reading.
6. Repeat steps 1 to 5 by replacing the magnesium ribbon and copper strip with a pair of magnesium ribbons and a pair of copper strips.

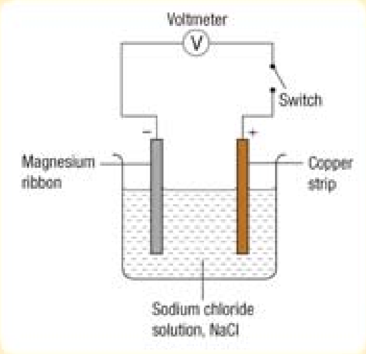


Figure 6.17 Simple chemical cell

Result

Pair of metals	Voltmeter reading (V)
Magnesium – copper	
Magnesium – magnesium	
Copper – copper	

Application of Chemical Cell Concept in Generating Electrical Energy from a Variety of Sources

Can fruits or other parts of a plant and seawater be used to generate electrical energy? Let us carry out Activity 6.3 to generate ideas on how the concept of chemical cell can be applied to generate electrical energy from a variety of sources.

6.2.1 6.2.2

Activity 6.3

To generate electrical energy from fruits or other plant parts and seawater

21st Century Skills
- TPS, STEM
- STEM project-based activity

Instructions

1. Carry out this activity in groups to generate ideas on how the concept of chemical cell can be applied to generate electrical energy from a variety of sources. Study the following statement:

    > The generation of electrical energy can be obtained from a variety of sources. For example, a simple chemical cell is a device which can convert chemical energy into electrical energy.

2. Plan and carry out a project based on the STEM approach. Build a simple chemical cell which can convert chemical energy into electrical energy from various sources such as fruits or other plant parts and seawater.
3. Gather and discuss information or ways to construct a simple chemical cell from fruits or other plant parts and seawater from the following websites:

    Related websites
    (a) Electrical energy produced from fruits
    http://buku-teks.com/sc5195a

    (b) Electrical energy produced from vegetables
    http://buku-teks.com/sc5195b

4. Present your simple chemical cell design to the class.

Formative Practice 6.2

1. What is a simple chemical cell?
2. Draw and label a simple chemical cell.
3. How does the position of an ion in the electrochemical series determine the positive terminal and the negative terminal in a simple chemical cell?

6.2.2

Summary

- **Electrochemistry**
  - Study in the field of chemistry on the relationship between chemical and electrical phenomena
    - **Electrolytic cell**
      - Anode, cathode, anion, cation, electrolyte and electrical source
        - Electrical energy to chemical energy
          - Electrolysis
            - Products of electrolysis
              - affected by factors
                - Position of ions in the electrochemical series, concentration of electrolyte and types of electrode
            - Applications in industries
              - Extraction of metal, purification of metal, electroplating of metal, treatment of wastewater through electrocoagulation
    - **Chemical cell**
      - Electrolyte and two different types of metals
        - Chemical energy to electrical energy
          - Chemical changes that occur in cell
            - at
              - Metal rod, electrolyte

Self-Reflection

After studying this chapter, you are able to:

6.1 Electrolytic Cell

- ☐ Understand electrolysis.
- ☐ Carry out experiments to study electrolysis of ionic compounds in various conditions.
- ☐ Carry out experiments to study the factors affecting the products in electrolysis.
- ☐ Communicate about the application of electrolysis in industries.

6.2 Chemical Cell

- ☐ Explain the energy change in a simple chemical cell.
- ☐ Generate ideas on the application of the chemical cell concept in generating electricity from a variety of sources.

Summative Practice 6

Quiz
http://buku-teks.com/sc5197

Answer the following questions:

1. Figure 1 shows an apparatus set-up to study the electrolysis of an aqueous copper(II) sulphate solution, $CuSO_4$ using different electrodes as shown in electrolytic cell P and electrolytic cell Q.

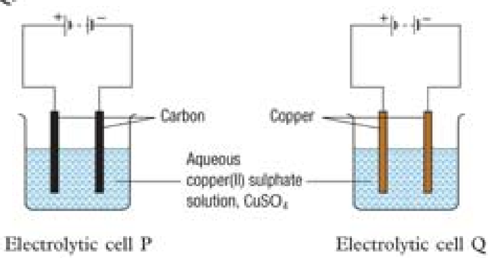


Figure 1

(a) State the meaning of electrolysis.

(b) State all the ions present in the aqueous copper(II) sulphate solution.

(c) Name the ions discharged at the anode and cathode for the following electrolytic cells:

(i) electrolytic cell P
at anode:
at cathode:

(ii) electrolytic cell Q
at anode:
at cathode:

(d) Name **one** example of the application of electrolysis in industries which applies the electrolysis concept of electrolytic cell Q.

2. Figure 2 shows an apparatus set-up to study the electrolysis of aqueous sodium nitrate solution, $NaNO_3$, using carbon electrodes labelled P and Q.

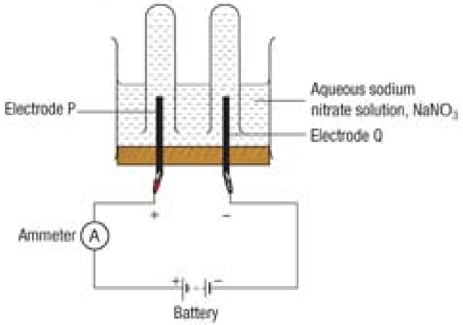


Figure 2

(a) (i) State all the cations present in the electrolyte.
(ii) State all the anions present in the electrolyte.

(b) Which electrode acts as the anode?

(c) Name the ion chosen to be discharged at:
(i) electrode P:
(ii) electrode Q:

(d) Explain your answer in 2(c)(ii) based on the selection of ion to be discharged.

3. Rohani found a rusted iron nail. Using your knowledge of electrolysis, describe a simple way to prevent the rusting of the iron nail.

Enrichment Practice

4. You are given three potatoes, three iron nails, three copper rods, light bulb and connecting wires with crocodile clips. Using these materials, design a simple chemical cell with the following features:

(a) simple chemical cell that can light up a light bulb with maximum brightness.
(b) simple chemical cell that can last the longest when lighting up a light bulb.