By the end of the topic, students should be able to:

Explain why molten ionic compounds conduct electricity but solid ionic compounds do not.

State in which direction
- Anions and cations move during electrolysis
- Electrons move in the wires joined to the electrodes in electrolysis.

State the ions present, name the products and give the electrodes reactions in the electrolysis of
- Molten sodium chloride using inert electrodes.
- Concentrated aqueous sodium chloride, using inert electrodes.
- Dilute sulphuric acid using inert electrode.
- Aqueous copper(II) sulphate using carbon electrodes
- Aqueous copper (II) sulphate using copper electrode

Predict the likely products of the electrolysis of a molten compound or of an aqueous solution.
Explain what happen in refining copper.

Describe electroplating (e.g. copper plating)

Describe the extraction of aluminium by electrolysis.

*Please tick in the box if you can do the above.*

**ELECTROLYTES**

- Electrolytes are ionic compounds that conduct electricity. The electrolyte can be either a molten ionic compound or an aqueous solution of an ionic compound.

- Electrolytes conduct electricity because they contain positive and negative ions that can move freely throughout the liquid.

  ⇒ Solid ionic compounds do not conduct electricity. Why?

---

- When an electric current flows through an electrolyte, the compound is decomposed in a chemical reaction. This is called **electrolysis**.

**TERMS USED IN ELECTROLYSIS**

<table>
<thead>
<tr>
<th>term</th>
<th>meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>electrodes</td>
<td>the solid electrical contacts that are immersed in the electrolyte, through which current flows to and from the battery</td>
</tr>
<tr>
<td>anode</td>
<td>positive electrode</td>
</tr>
<tr>
<td>cathode</td>
<td>negative electrode</td>
</tr>
<tr>
<td>anion</td>
<td>negative ion that is attracted to the positive anode</td>
</tr>
<tr>
<td>cation</td>
<td>positive ion that is attracted to the negative cathode</td>
</tr>
</tbody>
</table>
| discharge     | remove charge from an ion when it arrives at an electrode:  
  • positive ions gain electrons to form neutral atoms  
  • negative ions lose electrons to form neutral atoms |
| inert electrodes | unreactive electrodes that do not change during electrolysis, carbon and platinum are common inert electrodes |
The diagram below shows the flow of electrons to and from the battery in an electrolytic cell.

ELECTROLYSIS OF MOLTEN IONIC COMPOUNDS

- When a molten ionic compound is electrolysed,
  - the positive cations go to the ___________ and are discharge by ___________ electrons to become _________________.
  - the negative anions go to the ___________ and are discharge by ___________ electrons to become neutral _________________.
  - the ionic compound is decomposed into its _________________.

例 1: Electrolysis of molten potassium iodide.
  a) What ions are present? _______________
  b) Which one will move towards the cathode? _______________.
  c) Which one will move towards the anode? _______________.
  d) Write the anode half equation.
Electrolysis of molten sodium chloride

a) What ions are present? _______________

b) Which one will move towards the cathode? ______________.

c) Which one will move towards the anode? ________________.

d) Write the anode half equation.

________________________________________

e) Write the cathode half equation.

_______________________________________

f) Write the overall redox reaction.

_______________________________________

⇒ Why is it important to keep on heating the crucible throughout the electrolysis?

________________________________________________________________________

⇒ When these ions react this is called “discharging the ions”. Why?

________________________________________________________________________

😊 Please proceed to do exercise from:
ELECTROLYSIS OF AQUEOUS SOLUTIONS

• There are 2 major differences here. The temperature is room temperature and there is water in the reaction. A small number of water molecules ionise

\[ \text{H}_2\text{O}(l) \rightarrow \text{H}^+(aq) + \text{OH}^-(aq) \]

• So all aqueous solutions have small concentration of H\(^+\) and OH\(^-\) ions.

• In electrolysis, when more than one type of cation or anion is present in a solution, only ONE cation and one anion are preferentially discharged. This is called **selective discharge** of ions.

• How do you decide which ion is discharged? It depends on three factors
  - The position of the metal (producing the cation) in the reactivity series.
  - The relative ease of discharge of an anion.
  - The concentration of the anion in the electrolyte.

😊 The ease of discharge of cations and anions is shown below.

Electrolysis of dilute sodium chloride solution
In dilute NaCl (aq) – what cations are present? _______________________
- what anions are present? ________________________

Using the reactivity series of metal and the relative ease of discharge of anion:
- Which cation is reduced? ________________________________
- Which anion is oxidised? ________________________________

- Write the anode half equation. __________________________
- Write the cathode half equation. __________________________
- Write the overall redox reaction. __________________________

Please proceed to do exercise from:
WORKSHEET 2

ELECTROLYSIS WITH REACTIVE ELECTRODES

Electrodes can be inert. These do not react, they are just conductors of electricity to transfer electrons. E.g. platinum and graphite (carbon)

Other electrodes can be reactive and be oxidized and are made from most of the other metals. These electrodes are oxidised before anions.
Dilute CuSO₄ solution with copper electrodes.

a) Which ions are present in the solution? ____________________________
b) Which ion will react at the cathode? ______________________________
c) Which ion will react at the anode? ________________________________
d) Write the oxidation half equation. ________________________________
e) Write the reduction half equation. ________________________________
f) Write the overall equation for electrolysis in the cell.

😊 Please proceed to do exercise from:
WORKSHEET 3

SUMMARY
INDUSTRIAL APPLICATION OF ELECTROLYSIS

1) Electroplating
Electroplating is coating an object with a metal by electrolysis.

The object is the cathode. The metal to be plated is the anode. The electrolyte is a solution of the metal ions to be plated.

During electroplating, metal from the anode dissolves in the electrolyte as metal ions. These ions go to the cathode where they are discharged onto the object as a layer of metal.

An example of electroplating copper is shown in the diagram below.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Use</th>
<th>Reason for use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silver</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2) **Purifying (Refining) of metals**

- Similar to plating but the impure metal is the anode so it is oxidised and then reduced to a pure metal.

- This electrolysis is used to refine copper (see diagram)
Write the anode half equation.

Write the cathode half equation.

Write the overall redox reaction.

3) Extraction of metals from their ores

- Metals can be extracted from their ores by electrolysis. Electricity is expensive, so electrolysis is only used to extract very reactive metals such as sodium, calcium and aluminium.

- These metals, ‘high up’ in the reactivity series, cannot be extracted by other methods.

- Pure $\text{Al}_2\text{O}_3$ is extracted from bauxite. $\text{Al}_2\text{O}_3$ has a very high melting point ($>2000^\circ\text{C}$) so it is added to molten cryolite ($\text{Na}_3\text{AlF}_6$) which dissolves the $\text{Al}_2\text{O}_3$ at about $950^\circ\text{C}$. The mixture is now electrolysed using carbon electrodes.

Why is it an advantage to use a lower melting point to extract Al?
Recycling of Aluminium

- Aluminium is recycled because it saves the cost of extracting new metal from aluminium ore. About 90% of the cost of aluminium is due to the expenses of electrolysis.

ELECTRIC CELLS

- A simple electric cell consists of two different metals in an electrolyte. An example is shown in the diagram. The metals are zinc and copper, and the electrolyte is aqueous sodium chloride.

- The more reactive metal (higher up in the reactivity series) is the negative electrode. It becomes negative because the electrode dissolves in the electrolyte leaving electrons on the electrode:

\[ \text{Zn} \rightarrow \text{Zn}^{2+} + 2e^- \]

- Electrons go from the negative electrode through the wire to the positive electrode.
• The less reactive metal (lower down in the reactivity series) is the positive electrode. It becomes positive because positive ions in the electrolyte take electrons from the electrode and are discharged.

• For example, if the electrolyte is NaCl (aq), hydrogen ions from the solution are discharged:

\[2H^+ + 2e^- \rightarrow H_2\]

• The further apart in the reactivity series the two metals are, the bigger is the voltage.

USES OF ELECTRIC CELLS

• Electric cells are also known as batteries. Batteries are used in small flashlights and cars because

a) They can be carried about without attached electrical cables.

b) They can be used outdoors where there is no mains electricity available.

© Please proceed to do exercise from: Chemistry Insights, Pg 354, Questions, Question 1-2 WORKSHEET 4
WORKSHEET 1

Answer the following questions about electrolysis using the following electrolytes.

1) PbBr₂ (l)
   a) What ions are present?
   b) Which one will move towards the cathode?
   c) Which one will move towards the anode?
   d) Write the anode half equation.
   e) Write the cathode half equation.
   f) Write the overall redox reaction.

2) Al₂O₃ (l)
   a) What ions are present?
   b) Which one will move towards the cathode?
   c) Which one will move towards the anode?
   d) Write the anode half equation.
   e) Write the cathode half equation.
   f) Write the overall redox reaction.

3) CaCl₂ (l)
   a) What ions are present?
   b) Which one will move towards the cathode?
   c) Which one will move towards the anode?
   d) Write the anode half equation.
   e) Write the cathode half equation.
   f) Write the overall redox reaction.

4) LiI (l)
   a) What ions are present?
   b) Which one will move towards the cathode?
   c) Which one will move towards the anode?
   d) Write the anode half equation.
   e) Write the cathode half equation.
   f) Write the overall redox reaction.
WORKSHEET 2

Electrolysis of Concentrated Aqueous Sodium Chloride

In dilute NaCl (aq) –what cations are present? ________________

- what anions are present? ________________

Using the reactivity series of metal and the relative ease of discharge of anion:

- Which cation is reduced? ________________

- Which anion is oxidised? ________________

- Write the anode half equation.

- Write the cathode half equation.

- Write the overall redox reaction.

Electrolysis of Dilute Sulphuric Acid

In dilute H₂SO₄ (aq) –what cations are present? ________________

- what anions are present? ________________

Using the reactivity series of metal and the relative ease of discharge of anion:

- Which cation is reduced? ________________

- Which anion is oxidised? ________________

- Write the anode half equation.

- Write the cathode half equation.

- Write the overall redox reaction.

Electrolysis of Aqueous Copper (II) Sulphate

Prepared by Kartini Ishak
In dilute CuSO₄ (aq) – what cations are present? _______________________
- what anions are present? ________________________

Using the reactivity series of metal and the relative ease of discharge of anion:
- Which cation is reduced? _____________________________
- Which anion is oxidised? _____________________________

- Write the anode half equation. _____________________________

- Write the cathode half equation. _____________________________

- Write the overall redox reaction. _____________________________

WORKSHEET 3

Dilute CuCl₂ solution with copper electrodes.
a) Which ions are present in the solution? _____________________________
b) Which ion will react at the cathode? _____________________________
c) Which ion will react at the anode? _____________________________
d) Write the oxidation half equation. _____________________________
e) Write the reduction half equation. _____________________________
f) Write the overall equation for electrolysis in the cell. _____________________________

Dilute NaCl solution with zinc electrodes.
a) Which ions are present in the solution? _____________________________
b) Which ion will react at the cathode? _____________________________
c) Which ion will react at the anode? _____________________________
d) Write the oxidation half equation. _____________________________
e) Write the reduction half equation. _____________________________
f) Write the overall equation for electrolysis in the cell. _____________________________
Multiple Choice Questions

1. Solid lead(II) bromide cannot be electrolysed but molten lead(II) bromide can be electrolysed. What is the reason for this difference?
   A. Solid lead(II) bromide does not contain ions.
   B. The ions can move in molten lead(II) bromide but not in the solid.
   C. All the ionic bonds are broken in molten lead(II) bromide.
   D. Electrodes can be put into molten lead(II) bromide but not into solid.

2. Which change does not take place when dilute sulphuric acid is electrolysed with platinum electrodes?
   A. Hydrogen gas is produced.
   B. The concentration of the acid increases.
   C. The solution loses water.
   D. Sulphate ions are discharged.

3. An object is electroplated with copper. Which statement about the process is correct?
   A. The concentration of the copper ions in the electrolyte decreases.
   B. Copper is used as the cathode.
   C. Copper ions gain electrons from the object being electroplated.
   D. Oxygen is evolved at the anode.

4. Which one of the following elements requires the largest number of electrons for one mole of atoms to be discharged during electrolysis?
   A. aluminium
   B. calcium
   C. copper
   D. magnesium

5. A solid layer of element E is formed on the cathode when aqueous solution of ions of E is electrolysed. Which statement about element E is correct?
   A. Ions of E lose electrons at the cathode.
   B. Element E forms a non-metal.
   C. Element E forms positive ions.
   D. Element E must be below hydrogen in the reactivity series.

6. The following three solutions were electrolysed using inset electrodes:
   solution X: dilute sulphuric acid
   solution Y: aqueous sodium acid
   solution Z: dilute hydrochloric acid
   Which solution would produce hydrogen gas at the cathode?
   A. solution X and Z
   B. solution Z only
   C. solution Y and Z only
   D. solution X, Y and Z

7. What are the most likely products at the electrodes when a dilute solution of potassium sulphate (K₂SO₄) is electrolysed using inset electrodes?

<table>
<thead>
<tr>
<th>Cathode</th>
<th>Anode</th>
</tr>
</thead>
<tbody>
<tr>
<td>potassium</td>
<td>oxygen</td>
</tr>
<tr>
<td>hydrogen</td>
<td>sulphur</td>
</tr>
<tr>
<td>oxygen</td>
<td>hydrogen</td>
</tr>
</tbody>
</table>
8. In the electrolysis of electrolyte Q, the following products were observed:
   A. At the cathode: a brown solid
   B. At the anode: a pale yellow-green gas that bleached damp litmus paper. Which one of the following could be Q?
   A. dilute hydrochloric acid
   B. molten lead(II) bromide
   C. dilute copper(II) chloride
   D. dilute copper(II) bromide

9. Which statement is correct about the electrolysis of concentrated aqueous sodium chloride using inert electrodes?
   A. Chlorine is produced at the anode.
   B. Sodium is produced at the anode.
   C. Chlorine is produced at the cathode.
   D. Sodium is produced at the cathode.

10. The diagram shows a method for the extraction of aluminium from its ore.

![Diagram showing the extraction of aluminium from its ore.]

What are substances X and Z in the diagram?
A. aluminium oxide  B. steel  C. aluminium chloride  D. carbon

11. A liquid Y does not conduct electricity. When a few drops of sulphuric acid are added to the liquid, bubble of hydrogen and oxygen gases are produced at the electrodes. What could be liquid Y?
   A. aqueous sodium chloride
   B. concentrated hydrochloric acid
   C. aqueous copper(II) sulphate
   D. water

12. In the refining of copper, using the impure copper as the anode and pure copper as the cathode, the anode was found to decrease in mass by 40 kg and the cathode was found to increase in mass by 36 kg. What was the percentage purity of the impure copper anode?
   A. 4%  B. 36%  C. 72%  D. 90%

**Short Answer Questions**

1. Complete the table for the electrolysis experiments.

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Anode (+)</th>
<th>Product at Anode</th>
<th>Cathode (-)</th>
<th>Product at Cathode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrated aqueous copper(II) sulphate</td>
<td>carbon</td>
<td>carbon</td>
<td>copper</td>
<td></td>
</tr>
<tr>
<td>Concentrated aqueous sodium chloride</td>
<td>platinum</td>
<td>chlorine</td>
<td>platinum</td>
<td></td>
</tr>
<tr>
<td>Molten potassium chloride</td>
<td>carbon</td>
<td>carbon</td>
<td>carbon</td>
<td></td>
</tr>
</tbody>
</table>

2. (a) An electric current was passed through dilute sulphuric acid. The electrode reactions are given below.
   Reaction at cathode: 
   \[2H^+(aq) + 2e^- \rightarrow H_2(g)\]
   Reaction at anode: 
   \[4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-\]
   (i) Give the formula of the other ion that is present in dilute sulphuric acid.
   (ii) Explain why the volume of gas formed at the cathode in the experiment is twice as large as that formed at the anode. [3]

(b) Predict the products that will be obtained at the anode (+) and at the cathode (-) when an electric current is passed through the following:
   (i) molten lead(II) iodide, using carbon electrodes;
   (ii) aqueous potassium sulphate, using platinum electrodes. [4]

(c) Give one use of electroplating. [1]

3. (a) The diagram shows the electrolysis of aqueous copper(II) sulphate using copper electrodes.

![Diagram showing the electrolysis of aqueous copper(II) sulphate using copper electrodes.]

(i) Give the formulae of four ions that are present in the solution.
(ii) Explain why the concentration of aqueous copper(II) sulphate does not change during the electrolysis.
(iii) State two changes you would observe if the electrolysis were repeated using a carbon anode. [6]

(b) Aqueous sodium hydroxide can be electrolysed in the laboratory using inert electrodes.
(i) Predict the products at the anode and cathode.
(ii) Explain why solid sodium hydroxide cannot be electrolysed. [3]