

Electrolysis

This is the decomposition of an ionic compound in molten or solution form into its constituent elements by electricity.

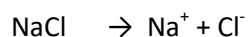
Note that

1. An electrolyte is an ionic substance that conducts electricity in solid or molten form.
2. Solid electrolyte do not conduct electricity because the ions cannot move because they are held together by strong ionic bonds.

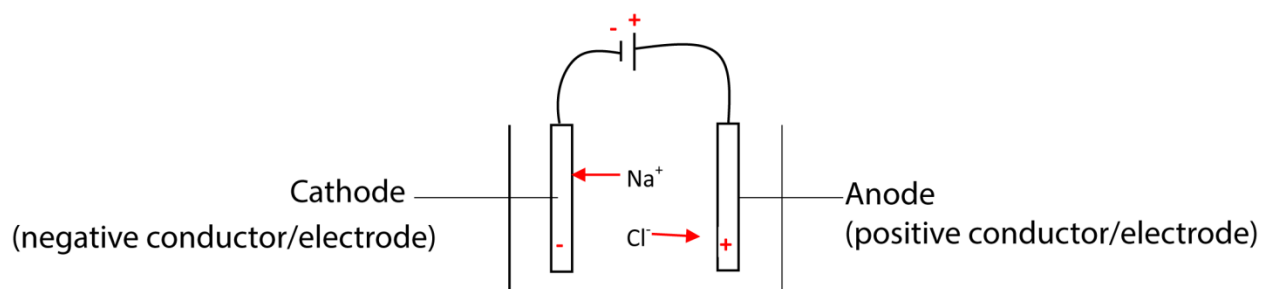
Mechanism of electrolysis

Consider electrolysis of molten sodium

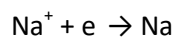
In molten form sodium chloride ionizes as follows



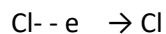
In an electrolytic cell, unlike charges attract; Na^+ migrate to the cathode while Cl^- migrate to the anode.



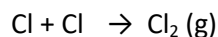
At the cathode, Na^+ ion acquires an electron to become sodium atom.



At the anode the Cl^- loses an electron to form a Cl atom



The chlorine atoms combine to form chlorine gas.

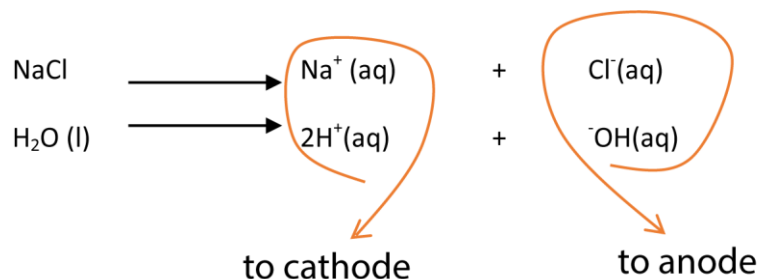


Ultimately, sodium chloride in molten form is decomposed by electrolysis to sodium metal and chlorine gas.

Selective discharge

Consider electrolysis of sodium chloride solution

Both sodium chloride and water ionize to form ions



The positively charged ion migrate to the cathode while negatively charged ions migrate to the anode.

Factors that decide the ion to be eliminated or discharged first.

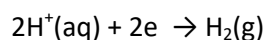
(i) **Position in electro-chemical series:**

Series for cations (**high to low**) K⁺, Ca²⁺, Na⁺, Mg²⁺, Al³⁺, [C], Zn²⁺, Fe²⁺, Pb²⁺, Cu²⁺, Ag⁺

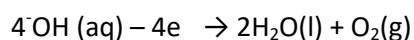
Series for anions (**high to low**) SO₄²⁻, NO₃⁻, Cl⁻, Br⁻, I⁻, OH⁻

The ion lower in electro-chemical series is discharged first. Consequently, during electrolysis of dilute sodium chloride, H⁺ which is low in the reactivity series than Na⁺ is discharged at the cathode whereas, OH⁻ ions are discharged at the anode.

At the cathode



At the anode

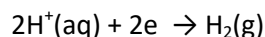


(ii) **Concentration:**

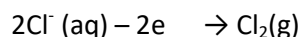
When Cl⁻, Br⁻ or I⁻ are concentrated, then they will be discharged with respect to OH⁻.

In this case electrolysis of concentrated sodium chloride solution liberates chlorine at the anode and hydrogen gas at the cathode (concentration does not affect Na⁺)

At the cathode



At the anode

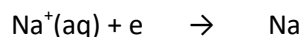


(iii) **Nature of electrode**

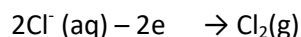
(a) When mercury cathode is used Na⁺ is discharged with preference to H⁺.

Therefore, electrolysis concentrated sodium chloride using mercury cathode liberates Na at the cathode and chlorine gas at the anode (due to high concentration of Cl⁻).

At the cathode



At the anode



Application of electrolysis

1. Industrial preparation of gases; Cl_2 , H_2 and O_2 .
2. Extraction of metal: metals above carbon in the reactivity series are almost all extracted by electrolysis.

Example Extraction of sodium.

Ore: molten NaCl

Anode: iron cylinder is cheap and has a melting point above the melting point of NaCl .

Cathode: carbon because it does not react with chloride.

Calcium chloride added to the mixture to

- lower the melting point of sodium chloride from 800°C to 600°C ,
- reduce solubility of sodium in molten sodium chloride,
- Lower the corrosive vapor of sodium chloride.

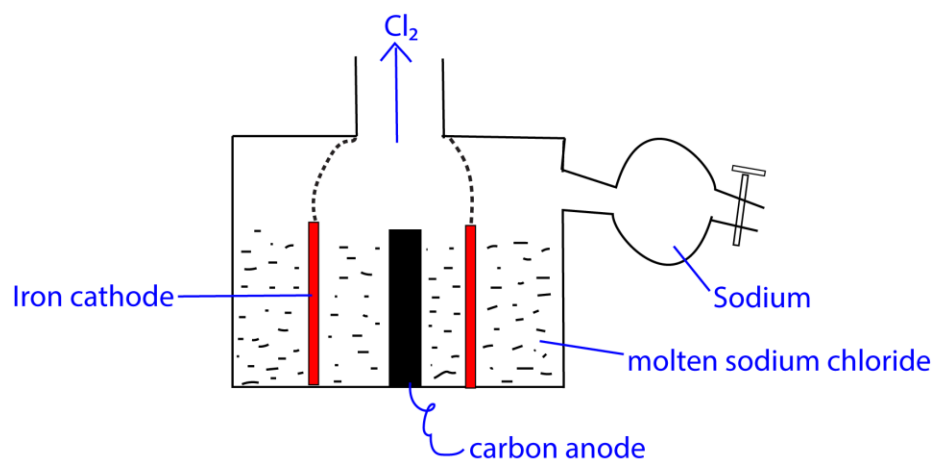
Sodium is collected in dry nitrogen to protecting it from reacting with air.

At the cathode
 $\text{Na}^+ + \text{e}^- \rightarrow \text{Na}$

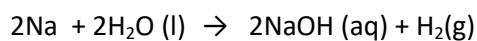
At the anode
 $2\text{Cl}^- - 2\text{e}^- \rightarrow \text{Cl}_2(\text{g})$

Setup

The setup is such chlorine produced in a different compartment not react with sodium



When sodium amalgam is dropped in water, sodium reacts to form sodium hydroxide and hydrogen gas.



Sodium hydroxide is concentrated to form pellets.

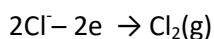
1. Preparation of sodium hydroxide

By electrolysis of concentrated solution of sodium chloride using carbon anode and mercury cathode. At the anode chlorine is liberated and at mercury cathode Na^+ instead of H^+ is discharged and dissolved in mercury to form mercury amalgam.

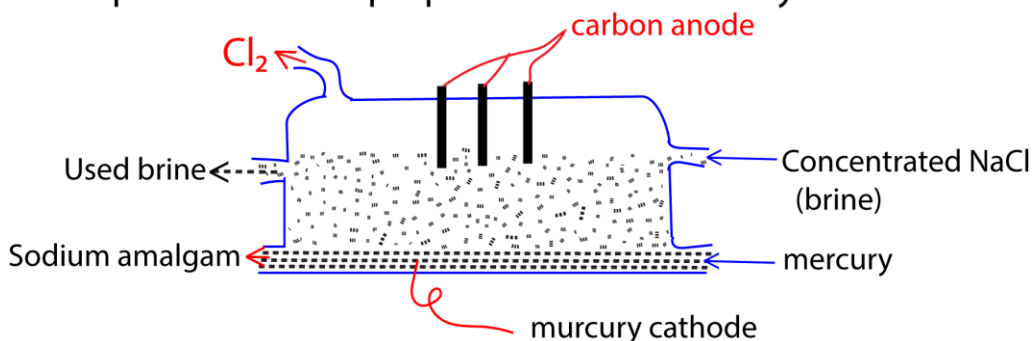
At the cathode



At the anode



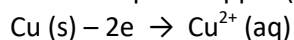
Set up for industrial preparation of sodium hydroxide



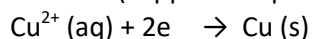
This process is disadvantageous because it releases poisonous mercury into the environment

2. Purification of copper

Anode: impure copper (dissolves)



Cathode (copper is deposited)



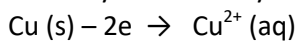
Electrolyte: copper sulphate solution

Copper migrated from the anode to the cathode.

Faraday's Laws of electrolysis

1. The mass of a substance liberated at an electrode is proportional to the quantity of electricity used.
The quantity of electricity Q in coulombs = It
(I = current of electricity in amperes, t = time in second)
2. The moles of electricity required to liberate one mole of an element is proportion to the charge on its ions. (1mol of electricity = 1Faraday = $1F = 96500 \text{ C}$)
Example
Calculate the mass of copper liberated by a current of 1A for 1hour . ($\text{Cu} = 63.5$)

Quantity of electricity $Q = It = 1 \times (1 \times 60 \times 60) = 3600\text{C}$



It implies that $(96500 \times 2)\text{C}$ is required to liberate 63.5g of copper

Therefore, 3600C will liberate $\frac{63.5 \times 3600}{2 \times 96500} = 1.18\text{g}$

Daniels' or electromotive cell

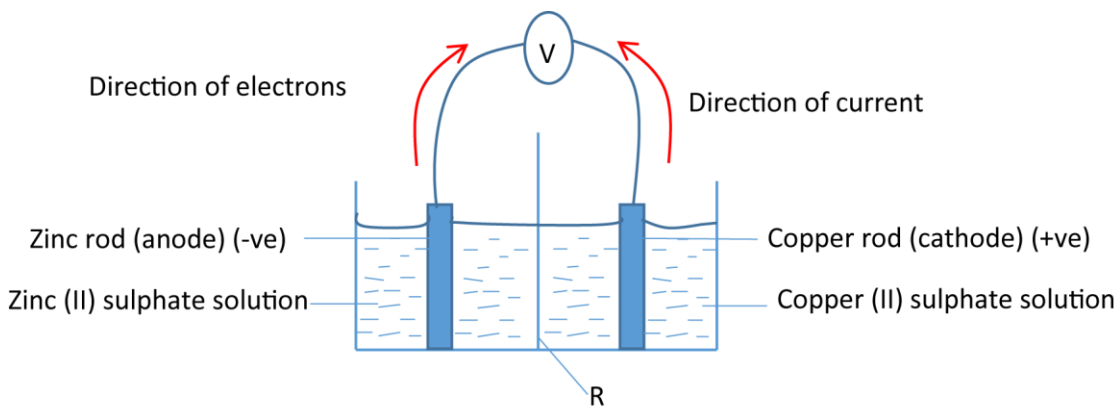
This is a cell that produce electric current

It consists of two metal rods connect to each other via a voltmeter and each dipped in a solution of respective metal ions. The solution separated from each other by a porous wall or a salt bridge.

Note that

- The metal dipped into a solution of its metal ions constitute a half cell.
- The half-cell for most reactive element is place to the left of that of the least reactive element.
- The half-cell on the left constitutes the anode where oxidation occurs while that on the right is the cathode where reduction occurs
- In external wire electrons move from the anode to the cathode while current move in opposite direction from the cathode to the anode
- The porous partition or salt bridge serves to complete the circuit.

An example of electromotive cell made of copper and zinc is shown below



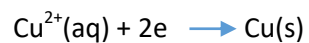
The cell consists of a zinc rod dipped in zinc sulphate and a copper rod dipped in copper sulphate solution, the solutions separated by a porous wall, and the rods connect by a wires to a voltmeter.

Zinc half-cell a constitutes the anode while copper while copper half-cell constitutes the cathode

Reaction equation on zinc electrode (anode): oxidation occurs



Reaction equation on Copper electrode (cathode): reduction occurs



Overall equation



In otherwise, electron from ionization of zinc reduce copper ions to copper.

Cell notation: $\text{Zn}(\text{s})/\text{Zn}^{2+}(\text{aq}) // \text{Cu}^{2+}(\text{aq}) / \text{Cu}$

Differences between electrolytic cell and emf cell

Electrolytic cell

Use emf

Use single electrolytes

Anode is the positive electrode

Cathode is the negative electrode

Emf/Daniel's cell

Generate emf

Uses two electrolytes

Anode is a negative electrode

Cathode is the positive electrode

Exercise

Section A

For questions 1 to 9 circle the most correct optional

- Which one of the following substances is used as the anode during the extraction of sodium from sodium chloride?
A. Iron
B. Graphite
C. Mercury
D. Platinum
- Which one of the following equations represent the reaction that takes place at the cathode during electrolysis of dilute copper (II) chloride solution?
A. $4\text{OH}^-(\text{aq}) \longrightarrow 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g}) + 4\text{e}^-$
B. $2\text{Cl}^-(\text{aq}) \longrightarrow \text{Cl}_2(\text{g}) + 2\text{e}^-$
C. $2\text{H}^+(\text{aq}) \longrightarrow \text{H}_2(\text{g})$
D. $\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \longrightarrow \text{Cu}(\text{s})$

- Some physical properties of substance P, Q, R and S are shown below

Substance	Melting point ($^{\circ}\text{C}$)	Boiling point ($^{\circ}\text{C}$)	Conduction of electricity	
			solid	Liquid/molten
P	High	High	poor	Poor
Q	High	High	Good	Good
R	High	High	Poor	Good
S	low	low	Poor	Poor

Which of the substances is a metal?

- P
 - Q
 - R
 - S
- Which one of the following is formed during the electrolysis of concentrated sodium chloride using mercury cathode?
A. Sodium
B. Oxygen
C. Hydrogen
D. Sodium hydroxide
 - Which one of the following pairs of substances consist of strong electrolyte only?
A. Potassium hydroxide and dilute ethanoic acid
B. Sodium hydroxide solution and dilute sulphuric acid
C. Sodium hydroxide solution and carbonic acid
D. Aqueous ammonia and dilute ethanoic acid
 - Which of the following substances is a strong electrolyte?
A. Aqueous ethanoic acid
B. Ammonia solution
C. Aqueous carbonic acid

D. Aqueous potassium iodide

7. The compound which does not form an electrolyte when dissolved in water is
- A. Potassium chloride
 - B. Hydrogen chloride
 - C. Ethanol
 - D. Ethanoic acid
8. Which one of the following metals is extracted by electrolysis?
- A. Zinc
 - B. Lead
 - C. Sodium
 - D. Copper
9. During electrolysis of dilute sodium chloride, the carbon anode decrease in size because carbon react with
- A. Chlorine
 - B. Oxygen
 - C. Sodium
 - D. Sodium hydroxide

Each of the questions 10 to 14 consist of an assertion (statement) on the left hand side and a reason on the right hand side.

Select

- A. If both assertion and reason are true statements and the reason is a correct explanation of the assertion.
- B. If both assertion and reason are true statements and the reason is **not** a correct explanation of the assertion
- C. If the assertion is true but the reason is not correct statement.
- D. If the assertion is not correct but the reason is a correct statement.

Instruction summarized

Assertion	
A. True	True and a correct explanation
B. True	True but not a correct explanation
C. True	Incorrect
D. Incorrect	Correct

- | | | |
|--|---------|---|
| 10. Aqueous solution of hydrogen gas conducts electricity | because | Hydrogen chloride gas is a covalent compound |
| 11. During the electrolysis of concentrated sodium chloride solution, chlorine is liberated at anode | because | The chloride ions is higher the hydroxide ion in the electrochemical series |

- | | | |
|---|---------|--|
| 12. During the manufacture of chlorine by electrolysis of brine, the cathode is made of mercury | because | Chlorine gas is soluble in water |
| 13. Electrolysis of brine using carbon electrodes, chlorine is liberated at the anode | because | Chlorine is lower than hydroxide ions in electrochemical series |
| 14. In electrolysis of dilute sulphuric acid, OH^- (aq) is discharged in preference to SO_4^{2-} (aq) | because | SO_4^{2-} (a) ion carries more charge than OH^- (aq) |

In each of the questions 15 to 19 one or more of the answers given may be correct. Read each questions carefully and then indicate the correct answer according to the following

- A. If 1, 2, 3, only are correct
 - B. If 1 and 3 only are correct
 - C. If 2 and 4 only are correct
 - D. If 4 only is correct
15. Which of the following is/are true about electroplating of iron with silver?
1. Silver nitrate solution is used as electrolyte
 2. Silver is made the anode
 3. Iron is made the cathode
 4. Iron (II) sulphate is used as electrolyte
16. During electroplating of iron with copper, the
1. Cathode is made of iron
 2. Anode is made of copper
 3. Electrolyte is iron (II) sulphate solution
 4. Electrolyte is copper (II) sulphate solution
17. Which factor(s) determine the ions to be discharged at an electrode during electrolysis?
1. The nature of electrode
 2. The amount of current used
 3. The position of ion in the activity series
 4. The charge on ion
18. Which of the following when electrolyzed between platinum electrodes will produce water and hydrogen?
1. Acidified water
 2. Sodium chloride solution
 3. Copper (II) chloride solution
 4. Sodium nitrate
19. During electrolysis of dilute hydrochloric acid using carbon electrodes.
1. Oxygen is given off at the anode
 2. Chlorine is given off at the anode
 3. Hydrogen is given off at the cathode
 4. The pH of the acid decreases.

SECTION B

Answer question 20 in the spaces provided

20. Dilute sulphuric acid was electrolyzed using carbon electrodes.

- (a) State what was observed at the
 - (i) Anode (1mark)
 - (ii) Cathode (1mark)
- (b) Write an equation for the reaction at the anode (2marks)
- (c) Dilute copper (II) was electrolyzed using copper electrodes. State what was observed at the anode (1mark)

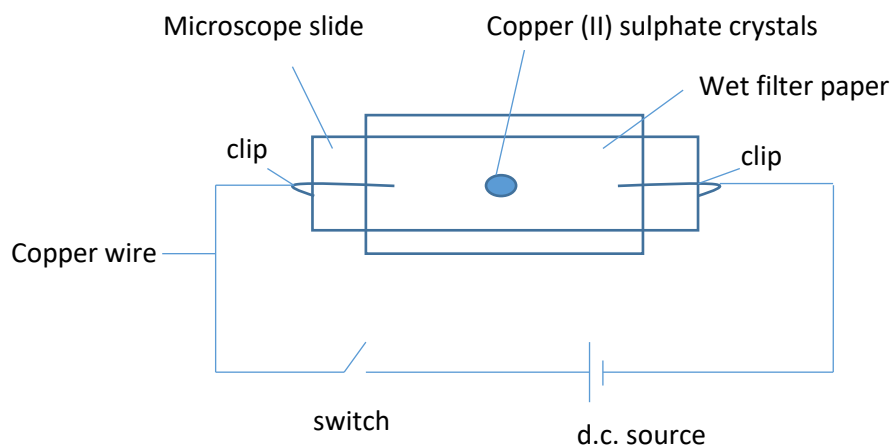
Section C

Answer on the answer sheets provides

21. (a) Both copper wire and copper (II) sulphate conduct electric current.

Name the particles which conduct electricity current in

- (i) Copper wire
 - (ii) Aqueous copper (II) ions
- (b) The set up apparatus in the diagram below was used to find out what happens when an electrolyte is connected to a source of electric current.



State what was observed

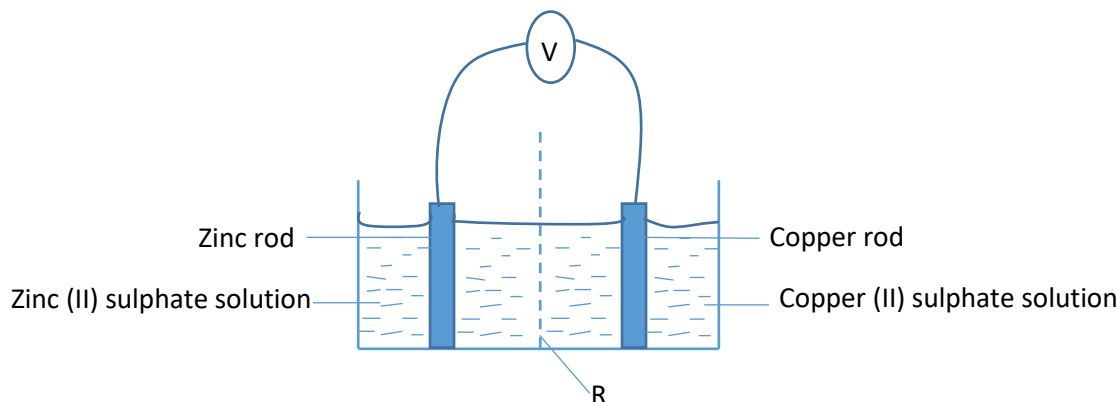
- (i) When the switch was closed
 - (ii) If copper sulphate crystal was replaced with potassium manganate (VII) crystal and the switch closed once again.
- (c) (i) Give a reason for the observation you have made in (b)(i) and (ii)
(ii) State any general conclusion that can be drawn following the reason you have given in (c)(i).

22. An aqueous solution of potassium iodide was electrolyzed between carbon electrode
- (a) State what was observed at the anode
 - (b) (i) Name the product formed at the anode
(ii) Describe the test that can be carried out to identify the product at the cathode
 - (c) Litmus paper was dropped into the solution around the cathode at the end of the experiment.
 - (i) State what was observed
 - (ii) Give a reason for your answer in (c)(i).
 - (d) Draw a labelled diagram of a setup of an apparatus that can be used to prepare oxygen by electrolysis of water.
23. (a) State two factors that can determine the product formed at an electrode during electrolysis
- (b) Explain why aqueous solution of copper (II) chloride conducts electric current whereas solid copper (II) chloride does not.
 - (c) a dilute solution of copper (II) chloride was electrolyzed using graphite electrodes
 - (i) state what was observed at the cathode and write equation for the reaction that took place.
 - (ii) Name the substance that was produced at the anode.
 - (iii) Explain how the product you have named in (c)(ii) above is formed at the anode and write equation to illustrate your answer.
 - (d) The electrolysis of copper (II) chloride was repeated using copper electrodes. State what was observed at the anode and briefly explain your answer.
24. (a) An aqueous solution of copper (II) sulphate was electrolyzed between graphite electrode.
- (i) state what was observed at the cathode
 - (ii) write equation for the reaction that took place at the anode.
- (b) The solution that remained after electrolysis in (a) was tested with litmus solution
- (i) state what was observed
 - (ii) Give a reason for your answer in (b)(i)
- (c) The electrolysis in (a) was repeated using copper electrode that had been weighed before the experiment. State the change in mass of the electrode that took place after electrolysis.
25. Acidified water was electrolyzed using platinum electrode
- (a) Write an equation for the reaction that took place at then
 - (i) anode (1½ marks)
 - (ii) cathode (1½ marks)
 - (b) Name one other substance that can be used as electrode in the electrolysis of acidified water. (1marks)

26. (a) (i) using an example state the difference between an electrolyte and an electrode. (04marks)

(ii) Explain why aqueous solution of sodium chloride conducts electricity whereas solid sodium chloride does not. (02mark)

(b) The diagram below shows a set-up of an electrochemical cell which can be used to compare the reactivity of zinc and copper.



(i) Identify the rod that is positively charged (01)

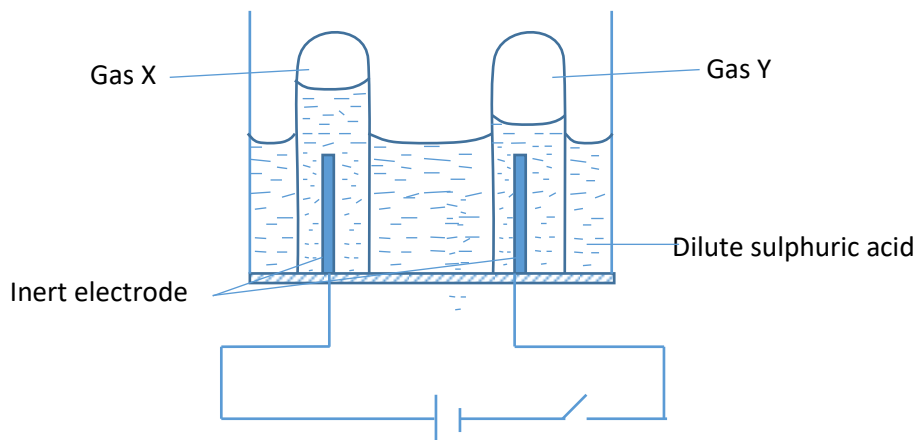
(ii) Identify R and state its purpose (1 ½ mark)

(iii) Write equation for the reaction taking place at the copper and zinc rods (03 marks)

(iv) Write equation for the overall reaction in the cell. (1 ½ marks)

(v) State what would happen if zinc metal is dropped in a solution containing copper (II) ions (02)

27. The diagram below shows an electrolytic cell in which electrolysis of dilute sulphuric acid occurs



(i) Name the gases X and Y that are evolved during electrolysis (02marks)

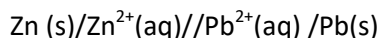
(ii) Give equation for the reaction occurring at the anode. (02marks)

(iii) Indicate the direction of electrons in the circuit. (01mark)

(iv) Calculate the volume of gas X produced when the current of one ampere flows for 10 minutes through the electrolyte. [1 faraday = 9.6×10^4 coulombs, 1 mole of a gas occupies $2.4 \times 10^4 \text{ cm}^3$ at room temperature and pressure]

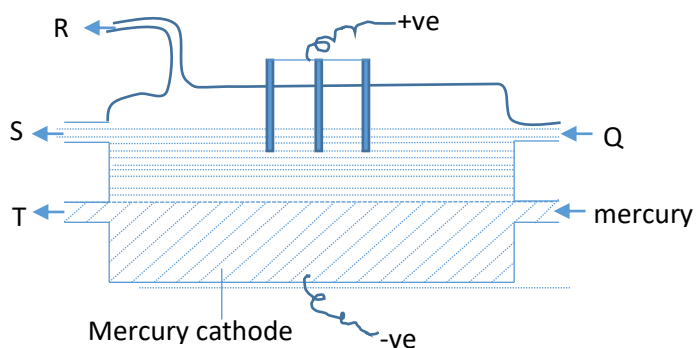
- (v) State two industrial application of electrolysis other than manufacture of sodium hydroxide
- (b) sodium hydroxide can be manufactured using a mercury cell. How would the manufacturing process affect the environment? (3 ½ marks)

28. A notation for electromotive cell is given below



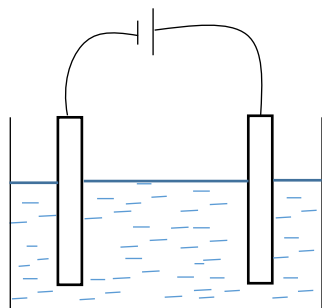
- (a) Name two substance that can be used as electrolytes (2marks)
- (b) State which of the electrode is the anode
- (c) Write equation for the reaction at
- (i) The anode
- (ii) The cathode
- (d) Write the overall equation for the cell reaction

29. During the manufacture of sodium hydroxide, concentrated sodium chloride solution (brine) is electrolyzed using a mercury cathode as shown in the diagram below



- (a) Name the substance used as the anode
- (b) Name the substance
- (i) Taken in at Q
- (ii) Taken out through R, S, T.
- (c) Name one other substance formed during the manufacture of sodium hydroxide
- (d) Describe briefly how solid sodium hydroxide can be obtained from the products of electrolysis.

30. The diagram below shows an arrangement of apparatus used for purification of copper



- (a) Name the substance used as
 - (i) Anode
 - (ii) Cathode
 - (iii) Electrolyte
- (b) Write equation for the reaction that took place at
 - (i) Anode
 - (ii) cathode

31. (a) Draw a diagram of A Daniel Cell consisting of a zinc rod dipped in zinc sulphate and a copper rod dipped in copper sulphate solution, the solutions separated by a porous wall, and the rods connect by a wires to a voltmeter

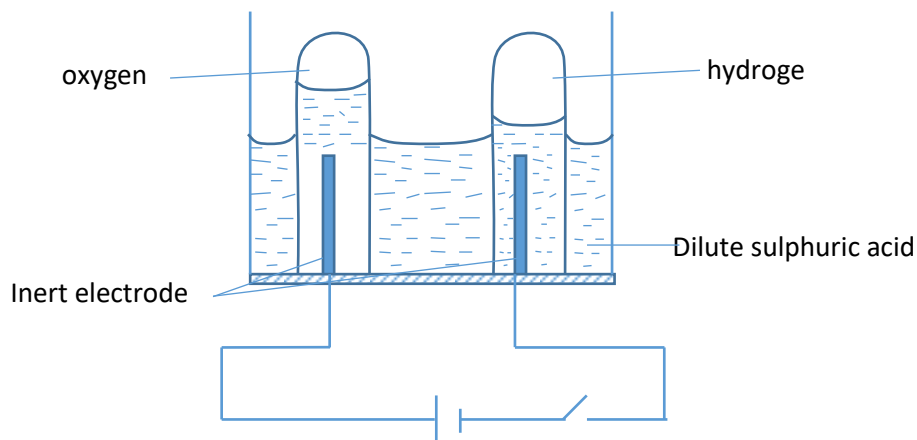
(b) Indicate

- (i) the charges on each electrode
 - (ii) the direction of electron at each electrode
- (c) (i) write equation for reaction at each electrode
- (ii) an equation for the overall reaction

Answers

1	B	5	B	9	B	13	C	17	B
2	A	6	D	10	D	14	B	18	D
3	B	7	C	11	B	15	A	19	B
4	A	8	C	12	C	16	C	20	

- 20 (a) (i) Colorless gas
(ii) colorless gas
(b) $4\text{OH}^-(\text{aq}) - 4\text{e}^- \longrightarrow 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$
(c) Anode decrease in size
- 21 (a) (i) Electrons
(ii) Ions
(b) (i) Blue color moves towards the cathode
(ii) Purple color moves towards the anode
(c) (i) Blue Cu^{2+} migrate to the cathode
(d) During electrolysis cations migrate to the cathode whereas anions migrate to the anode
22. (a) Brown color
(b) (i) Iodine
(ii) A blue color forms when a drop of iodine solution is added
(c) (i) Color of litmus turns blue
(ii) Removal of hydrogen ion and iodide ion leaves an alkaline solution of KOH
(d)



- 23 (a) - Position in the reactivity series
- Concentration
- Nature of electrode
- (b) In aqueous solution copper (II) chloride ions are free to move whereas in solid state ions do not move
- (c) (i) Brown coat formed on graphite
 $\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \longrightarrow \text{Cu}(\text{s})$
(copper ions are lower than hydrogen ions in reactivity series)
(ii) oxygen

- (iii) OH^- ions are lower than Cl^- in the reactivity series and is preferentially discharged
 $4\text{OH}^- (\text{aq}) - 4\text{e} \longrightarrow 2\text{H}_2\text{O} (\text{l}) + \text{O}_2 (\text{g})$
- (d) The anode decrease in size due to oxidation
 $\text{Cu}(\text{s}) - 2\text{e} \longrightarrow \text{Cu}^{2+} (\text{aq})$
- 24 (a) (i) Brown coat formed on graphite
 $\text{Cu}^{2+} (\text{aq}) + 2\text{e} \longrightarrow \text{Cu}(\text{s})$
 (copper ions are lower than hydrogen ions in reactivity series)
- (b) (i) Turned litmus solution red
 (ii) Removal of copper ions from solution leaves acid H^+
- (c) The anode decrease in size due to oxidation
 $\text{Cu}(\text{s}) - 2\text{e} \longrightarrow \text{Cu}^{2+} (\text{aq})$
 The cathode increase in size due to deposition
 $\text{Cu}^{2+} (\text{aq}) + 2\text{e} \longrightarrow \text{Cu}(\text{s})$
- 25 (a) (i) Anode : $4\text{OH}^- (\text{aq}) - 4\text{e} \longrightarrow 2\text{H}_2\text{O} (\text{l}) + \text{O}_2 (\text{g})$
 (ii) Cathode: $2\text{H}^+ (\text{aq}) + 2\text{e} \longrightarrow \text{H}_2 (\text{g})$
- (b) Graphite
- 26 (a) (i) An electrolyte is an ionic compound that conducts electricity in solution or molten form while electrodes are conductors dissolved in electrolytic solution
 (ii) Aqueous sodium chloride conducts electricity because it has free moving ions whereas solid sodium chloride has ions that do not move.
- (b) (i) Copper rod
 (ii) R is porous partition that allows exchange of charges without mixing the solutions or completes the circuit
 (iii) At zinc rod
 $\text{Zn} - 2\text{e} \longrightarrow \text{Zn}^{2+} (\text{aq})$
 Copper rod
 $\text{Cu}^{2+} (\text{aq}) + 2\text{e} \longrightarrow \text{Cu}(\text{s})$
- (iv) $\text{Zn} (\text{s}) + \text{Cu}^{2+} (\text{aq}) \longrightarrow \text{Zn}^{2+} (\text{aq}) + \text{Cu}(\text{s})$
27. (a) (i) X = oxygen and Y = hydrogen
 (ii) $4\text{OH}^- (\text{aq}) - 4\text{e} \longrightarrow 2\text{H}_2\text{O} (\text{l}) + \text{O}_2 (\text{g})$
 (iii) From anode to cathode
 (iv) $Q = it = (1 \times 10 \times 60) = 600\text{C}$
- (96000 x 4) produce 24000cm^3 of oxygen
 600C produce $\frac{24000 \times 600}{96000 \times 4}$
 $= 37.5 \text{ cm}^3$
- (v) Electroplating
 Extraction of metals
 Purification of copper
- (b) Mercury when released in the environment is very poisonous, it accumulates through food chains
- 28 (a) Zinc sulphate and copper sulphate

- (b) The anode is zinc
- (c) (i) $\text{Zn (s)} - 2\text{e}^- \rightarrow \text{Zn}^{2+}(\text{aq})$
(ii) $\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Cu(s)}$
(iv) $\text{Zn (s)} + \text{Cu}^{2+}(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{Cu(s)}$
29. (a) Carbon
(b) (i) Brine/concentrated sodium chloride solution
(ii) R – chloride
S- used brine
T- sodium amalgam
(c) hydrogen
(d) Sodium amalgam is dissolved in water. Sodium reacts with water to form sodium hydroxide and hydrogen
 $2\text{Na (s)} + 2\text{H}_2\text{O(l)} \rightarrow 2\text{NaOH(aq)} + \text{H}_2(\text{g})$
Sodium hydroxide solution is concentrated by evaporation to form pellets.
30. (a) (i) Anode is impure copper sulphate
(ii) Cathode is pure copper sulphate
(b) (i) $\text{Cu (s)} - 2\text{e}^- \rightarrow \text{Cu}^{2+}(\text{aq})$
(ii) $\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Cu(s)}$

End

Supplementary questions

31. Which one of the following processes does not involve electrolysis?
- Extraction of iron
 - Extraction of copper
 - Manufacture of sodium hydroxide
 - Manufacture of chlorine