Chemistry & Energy

Chapter 8

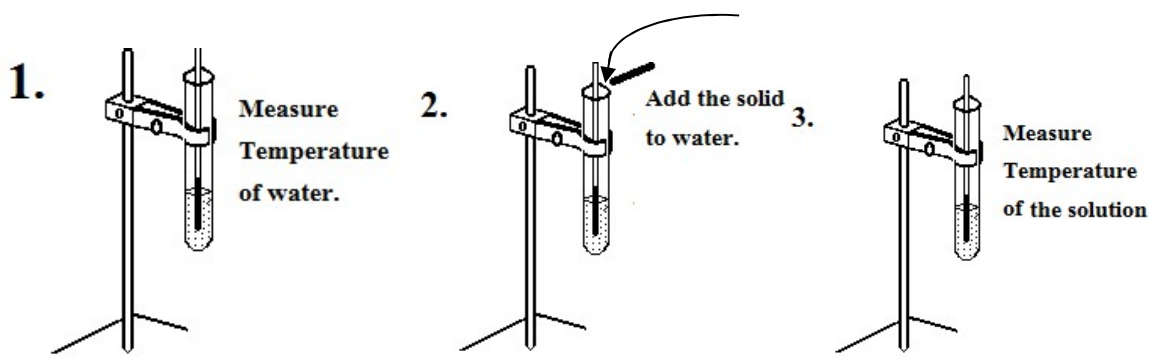
Introduction

Any chemical reaction is accompanied by/with heat change.

The heat change may occur in two ways- they are Exothermic and Endothermic reactions.

An endothermic reaction is one which absorbs energy (heat)causing a temperature drop in the surroundings.

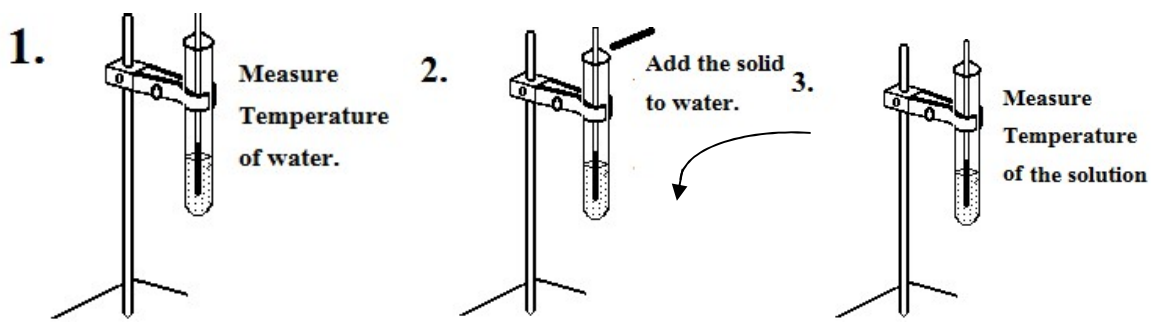
In an experiment, an amount of water is taken in a test tube and its temperature is measured with a thermometer. An amount of solid NH_4Cl is added to it and the temperature is measured again. The second temperature reading is lower than the previous one. This experiment proves that the reaction is endothermic.



An exothermic reaction is one.....

In an experiment, ...an amount of solid CaO is .....

[Do yourself]



Q1. Describe an experiment to show that KNO_3 dissolves in water endothermically.

Q2. Describe an experiment to show that ethanol burns exothermically.

Q3. Describe an experiment to show that zinc displaces copper from $CuSO_4$ exothermically.

Enthalpy of reaction and ΔH notation:

'H' stands for 'heat' and the 'ΔH' represents the heat/enthalpy change in a chemical reaction.

The units of 'ΔH' are **kJ mol^{-1}**

Its value is positive for an endothermic reaction and negative for an exothermic reaction.

Example: $H_2 + \frac{1}{2}O_2 \longrightarrow H_2O$ $\Delta H = -242$ kJmol^{-1} [3]

This means that when

1 mole of hydrogen is burnt completely in air 242 kJ heat is given out to the surroundings.

Example 2:

$N_2 + O_2 \longrightarrow 2NO$ $\Delta H = +187$ kJmol^{-1}

This means

when.....of nitrogen is reacted with oxygen.....kJ heat is.....from the surroundings causing.....in the surroundings.

What causes the heat to change?:

Chemical reactions involve breaking of old bonds in the reactants and making of new bonds in the products.

Bonds of **reactants** are broken by absorbing **heat energy** from the surroundings, whereas for forming new bonds in **products** heat is released to the surroundings.

Thus a chemical reaction involves both energy absorption, E_{in} and energy release, E_{out}.

However, the amounts of energy absorbed and released are **not** equal.

Heat energy released $\neq$ heat energy absorbed

In a chemical reaction if,

i.e. Heat energy released, E_{out} < heat energy absorbed, E_{in} = endothermic (ΔH= +Ve)

i.e. Heat energy released, E_{out}> heat energy absorbed, E_{in} = exothermic (ΔH= –Ve)

Q. Explain why enthalpy changes in any chemical reaction. [3]

Bond dissociation energy or bond enthalpy:

The term '**bond enthalpy**' is used to describe the amount of energy needed to break 1 mole of a particular bond; this is also the amount of energy released when the same chemical bond is formed.

The units of bond dissociation energy are $kJmol^{-1}$.

Some bond enthalpies are given in the table below.

Bond	Average Bond enthalpy (kJ mol^{-1})
C=C	612
C—C	348
Cl—Cl	243
H —Cl	431
C—Br	276
Br—Br	193
H ——Br	364
C—H	413
C=O	745
C—O	360
O=O	496
O-O	146
O—H	460
H—H	436

[Not to memorize]

Calculating enthalpy of reaction, ΔH, using bond enthalpy:

Step 1: Calculate the total amount of energy absorbed, E_{in}, to break all the bonds in the reactants.

Step 2: Calculate the total amount of energy released, E_{out}, to make all the bonds in the products.

Step 3: Calculate the enthalpy change in the reaction as,

Enthalpy of reaction = total amount of energy absorbed— total amount of energy released.

i.e.$\Delta H = E_{in} - E_{out}$

For example,

Burning of hydrogen gas in oxygen is an exothermic process.

$$H_2 + \frac{1}{2}O_2 \longrightarrow H_2O(g) + \text{heat}$$

$$H - H + \frac{1}{2}O = O \longrightarrow (H - O - H) + \text{heat}$$

In this reaction, bonds in hydrogen and oxygen molecules are broken by absorbing heat energy from the surroundings.

Thus energy taken in, E_{in} $= E(H-H) + \frac{1}{2} E(O=O)$

$= 436 + \frac{1}{2} \times 496$

$= 684$ kJ

And bonds of water molecule are formed by releasing heat energy to the surroundings.

Thus energy given out, E_{out} $= 2E(O-H)$

$=(2 \times 460)$

$= 920$ kJ

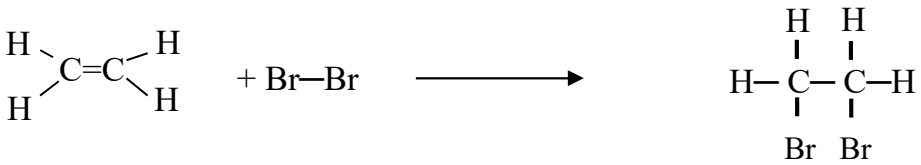
So, total energy change, ΔH_R $= E_{in} - E_{out}$

$= +684 - 920$

$= -236$ kJmol^{-1}

As heat is released, the reaction is exothermic.

Q1. The equation for the addition of bromine to ethene is represented by:



Calculate:

(i) the total amount of energy required to break all the bonds in reactant molecules.

(ii) the total amount of energy released when all the new bonds are formed in the product molecule.

(iii) the enthalpy change, ΔH_R for the reaction.

(iv) what does the sign with the value of enthalpy changes indicates about the reaction?

Answer:

(i) Thus energy taken in, E_{in} = [yourself]

$= 2457$ kJ

(ii) Thus energy given out , E_{out} =

$= 2552$ kJ [yourself]

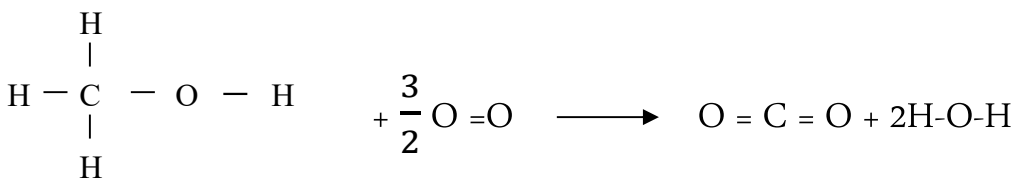
(iii) So, total energy change, ΔH $= E_{in} - E_{out}$

$= 2457 - 2552$

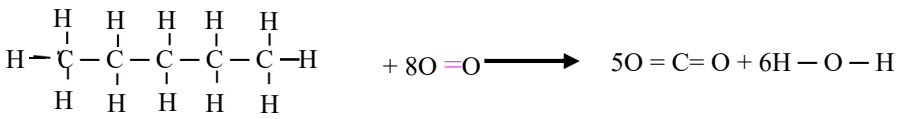
$= -95$ kJmol^{-1}

(iv) Exothermic reaction

Q 2. When methanol is burnt in air, the reaction can be represented by the following equation:



Q 3.The following equation represents complete combustion of pentane.



Complete the following tables and hence calculate the enthalpy of combustion of pentane.

Table 1: Energy taken in to break the bonds:

Bond	Number of the bonds	Bond dissociation energy/kJmol^{-1}	Energy taken in/ kJ
C — C	……	346	……
C—H	12	413	4956
O=O	……	497	……
Total energy taken in			……10….6

Table 2: Energy given out when new bonds are formed:

Bond	Number of the bonds	Bond dissociation energy/kJmol^{-1}	Energy given out/ kJ
C=O	……	745	……
H—O	……	463	5556
Total energy given out			……13…6

Electrolysis:

Definitions:

"Electrolysis" is a process to **split a compound** into simpler substances by **passing of electricity** through its **aqueous solution or liquid** (molten) state."

Electrolyte:

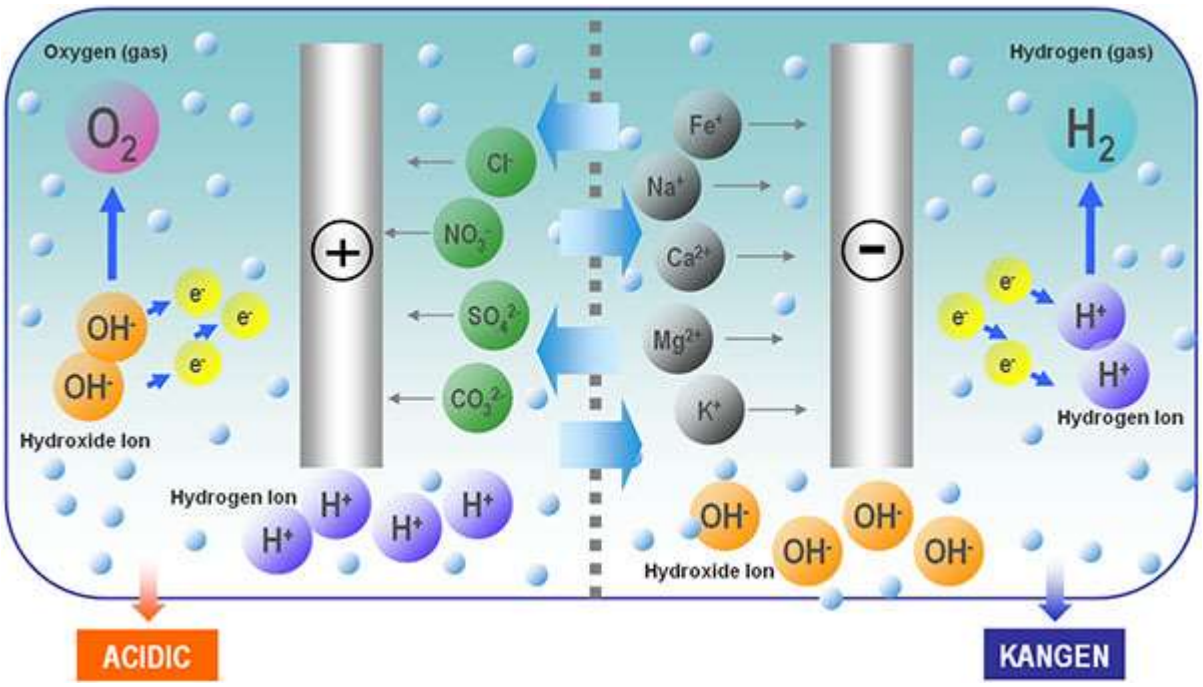
An **aqueous solution or a molten/liquid** substance which splits into simpler substances by an electric current.

Electrodes:

The electrical leads dipping into the electrolyte to pass electric current are known as electrodes.

The anode is connected to the positive terminal and the cathode is connected to the negative terminal of a cell/battery.
Oxidation (OIL) occurs at **anode** and reduction (RIG) occurs at the **cathode**.

1. Video Link: https://www.youtube.com/watch?v=yVCPtFOdH1I&t=125s



When an electric current is passed through the electrolyte, the positive ions move to the negative electrode (cathode) and the negative ions move to the positive electrode (anode).

When the ions reach the electrodes, they often lose their charge by gaining or losing electrons and turn into atoms.

This may result in one of the followings:

- the atoms may coat the surface of the electrode - this is particularly true for metal atoms on cathode.
- the atoms may pair up to form diatomic molecules such as H_2, O_2, Cl_2, Br_2 or I_2 ; which are often released as a gas or dissolve in the solution around the electrode;
- they may react with the electrode, wearing it away-this particularly happens at high temperature.

There are three very simple rules to apply:

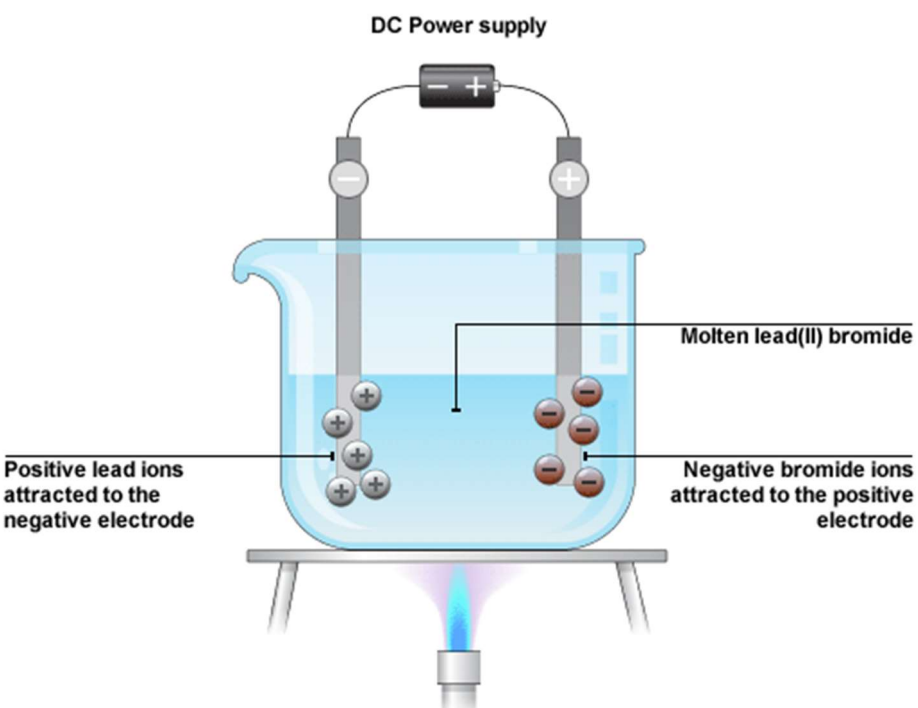
- metals and hydrogen all carry positive charges, non-metals carry negative charges;
- the number of charges carried by an ion is the same as its valency;
- aqueous solutions always contain H^+ and OH^-, e.g., an aqueous solution of sodium chloride contains the following ions: Na^+, OH^-, Cl^-, H^+.

Examples of electrolysis:

Lead (II) bromide is an example of a salt which is easily melted.

In the molten liquid there are lead ions, Pb^{2+}, and bromide ions, Br^-.

$PbBr_2 \longrightarrow Pb^{2+} + 2Br^-$



The lead ions, being positively charged, are attracted to the negative electrode.

The equation for the reaction at the **cathode**,

$Pb^{2+} + 2e^- \longrightarrow Pb$

The electrons given by Br^- ions at the **anode** flows through the electric wire to the cathode.

The equation for the reaction at the anode,

$2Br^- \longrightarrow Br_2 + 2e^-$

Observations

(i) A small bead of molten (shiny grey liquid) lead gradually appears near the cathode and

(ii) an effervescence of red-brown gas (bromine) is seen near the anode.

Exercise: Fill in the blanks

The following table shows electrolysis of some molten ionic compounds with graphite electrodes:

Electrolyte	Ions in electrolyte	Reaction at anode	Reaction at cathode	Observations
AgBr(l)	Ag^+ and Br^-	$2Br^- \longrightarrow Br_2 + 2e^-$	$Ag^+ + e^- \longrightarrow Ag$	1. black cathode turns silver 2. effervesces of gas at anode 3. brown fume over the anode
CuO (l)	Cu^{2+} and O^{2-}			
AuCl (l)	Au^+ and Cl^-			

Q. Molten electrolytes containing the following ions were electrolysed separately with graphite electrodes.

F^-, K^+, Ca^{2+}, O^{2-}, S^{2-}, Mg^{2+}, Al^{3+}, H^+, I^- and N^{3-}

Write the equations for the reactions at the anode and cathode during the electrolysis.

[halogens, oxygen, nitrogen are diatomic, but metals & sulfur are not]

Ans:

Reactions at anode:	Reactions at cathode:

Electrochemical series:

It is the series of ions depending on their tendency to gain or lose electrons. It stands for both cations and anions separately.

For cations, electrochemical series is based on the tendency of gaining electrons.

It is just opposite to the reactivity series of metals as the cation of a less reactive metal gains electrons more readily than the cation of a more reactive metal.

Au^{+}, Cu^{2+}, H^{+},..... Ca^{2+}, Na^{+}, K^{+}

For anions, Electrochemical series of anions is based on the tendency of losing electrons.

OH^{-}, X^{-}, NO_3^{-}, SO_4^{2-} [here X is halogens]

NOTE: If an aqueous solution contains both OH^{-} and Cl^{-} ions, OH^{-} ions are prior to lose electrons. But if the concentration of Cl^{-} ions is much greater than that of OH^{-} ions (e.g in saturated NaCl or brine solution), Cl^{-} ions will lose electrons before the OH^{-}.
But If a solution contains both Na^{+} and H^{+} ions, at their any concentration, H^{+} ions will gain electrons before the Na^{+} ions as the difference in tendency of gaining electrons of the ions is very high.

2. Video Link: https://www.youtube.com/watch?v=1k62zJp25dg&t=57s

Electrolysis of sodium Chloride:

3.Video Link: https://www.youtube.com/watch?v=BsXzbej9DFI&t=522s

Fill the table after your watch the video above:

Electrolyte	Molten sodium chloride	Very dilute sodium chloride	Concentrated/saturated sodium chloride/ /brine
Ions in the electrolyte		Na^+, Cl^-, H^+, and OH^-	
reaction at cathode	$Na^+ + e^- \longrightarrow Na$	$2H^+ + 2e^- \longrightarrow H_2$	
reaction at anode		$4OH^-(aq) \longrightarrow$ $2H_2O(l) + O_2(g) + 4e$	
Observations	✵ ✵ ✵	✵ Effervescence of gas at both the electrodes. ✵ Greater effervescence near cathode.	
Products	Chlorine and sodium metal	Oxygen and hydrogen gas	Chlorine, hydrogen and sodium hydroxide

Q. Explain why:

(i) Electrolysis of dilute $NaCl_{(aq)}$ solution becomes concentrated gradually.

(ii) Electrolysis of concentrated $NaCl_{(aq)}$ solution becomes alkaline gradually.

OR electrolyte with few drops of methyl orange indicator turns yellow.

Q. Give the formulae of the ions present in concentrated hydrochloric acid.

Compare the products of the electrolysis of hydrochloric acid and brine solution.

Comprehensive Questions

Electrolysis of Sodium Chloride

Total marks 10

Name of the student:

.....

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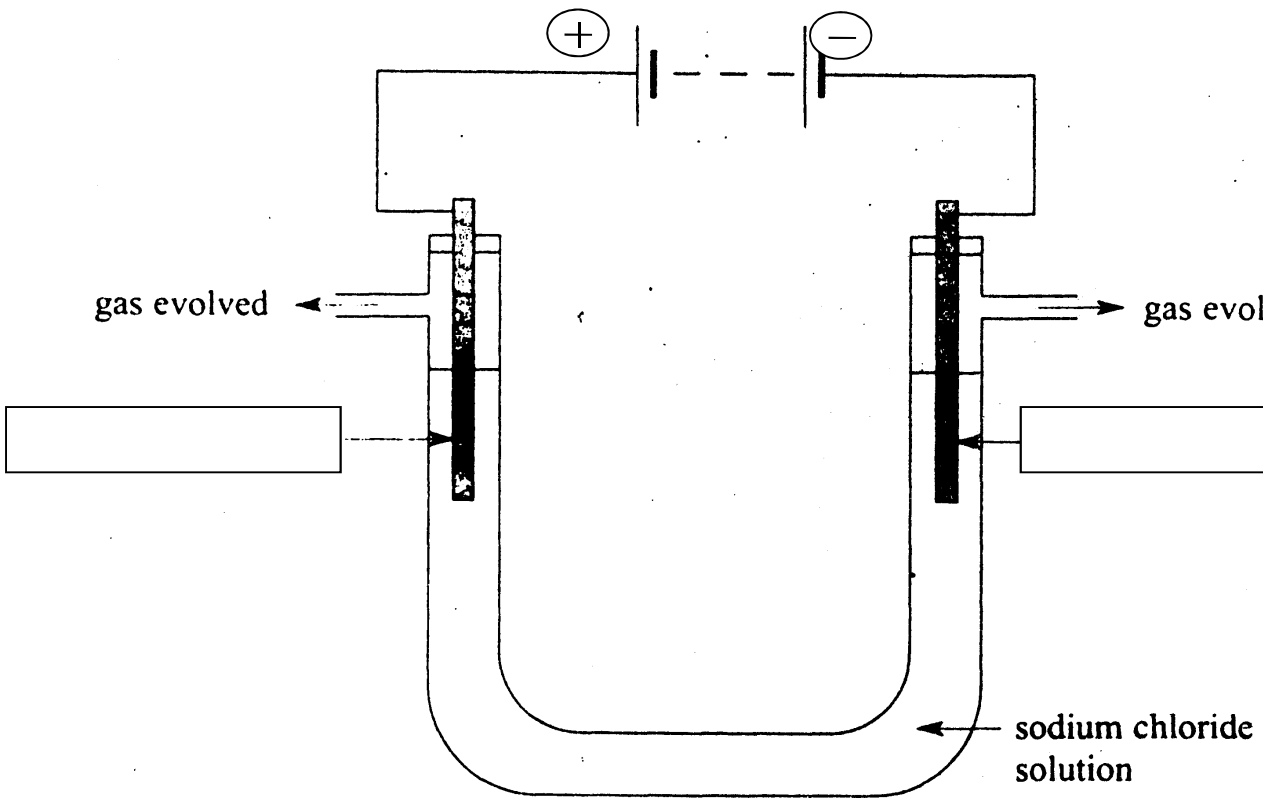
1. The electrolysis of **concentrated aqueous** sodium chloride was carried out using the following apparatus.



(a) The electrodes are made of graphite. Label the type of electrodes on the diagram above.

[1]

(b) Give the formulae of **ALL the ion**s present in aqueous sodium chloride.

.....

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[2]

(c) Chlorine is produced at the positive electrode.

(i) Name the gas evolved at the negative electrode.

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.....[1]

(ii) Write an equation for the reaction to produce chlorine.

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[1]

(iii) What do you expect to see during the electrolysis.

Observation 1:

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.....

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Observation 2:

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[2]

(d) Explain why the neutral aqueous solution turns alkaline during the electrolysis.

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[2]

(e) How will the reaction at anode be different when the electrolysis carried out using **dilute** aqueous solution.

.....

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[1]

Total 10 marks for the question

Electrolysis of water:

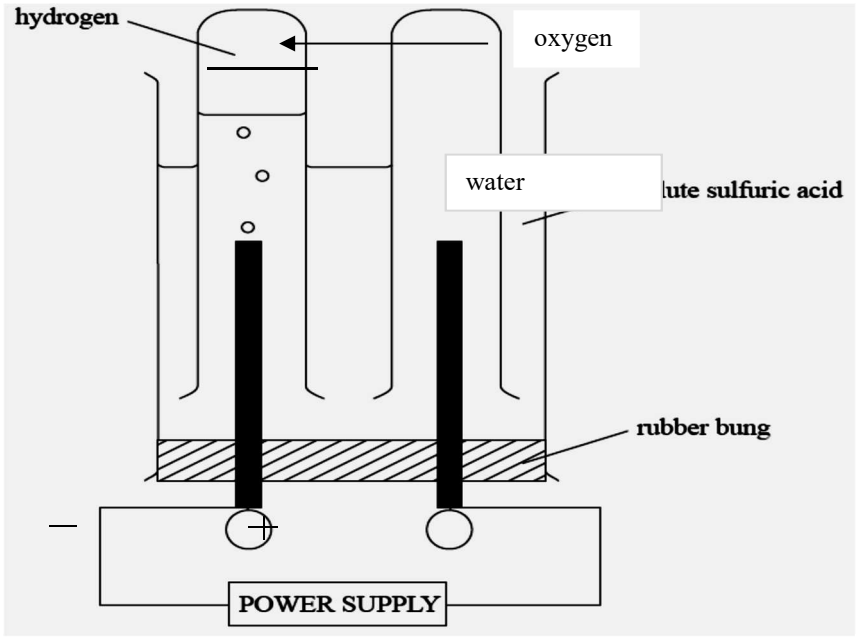
Water is a covalent substance, but it ionizes very slightly to give a small amount of ions.

$$H_2O \leftrightarrows H^+ + OH^-$$

[Sometimes few drops of sulfuric acid are added to water to increase the amount of ions in order to increase rate of the electrolysis]

Simply two carbon rods (or platinum electrodes) connected to a battery are dipped into the liquid.

A current will flow and bubbles of gas (effervescence) will be seen at both the electrodes, oxygen at the anode and hydrogen at the cathode. If you collect the gasses, you will see that there is twice as much hydrogen as oxygen.



The H^+ moves towards the cathode where it forms hydrogen:

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

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

1 mol of oxygen is produced at anode with the loss of 4 moles of electrons, which are received by hydrogen ions at cathode to form 2 moles of hydrogen gas.

So, the volume of hydrogen gas produced is nearly double than that of the oxygen gas.

Electrolysis of aqueous copper (II) sulfate solution using inert electrodes (graphite):

Aqueous copper (II) sulfate is a pale blue solution containing following ions:

$$Cu^{2+},\ SO_4^{2-},\ H^+ \text{ and } OH^-$$

Reaction at cathode : $Cu^{2+} + 2e^- \rightarrow Cu$ Reaction at anode : $4OH^- \rightarrow 2H_2O + O_2 + 4e^-$

Observations:

- Effervescence near anode
- Black cathode turns pink brown
- Blue solution fades away

NOTE:

- If the current is reversed for the same time, the brown electrode turns black again.
- After electrolysis, the electrolyte becomes acidic (will turn blue litmus red), as OH^- ions are removed from the solution leaving the H^+ ions.

Products:

Copper metal at cathode and Oxygen gas at anode

Sulfuric acid in remaining solution (as by-product) .

[So, if a small piece of blue litmus paper is introduced into the column, it would turn red.]

Comprehensive Exercise

Total marks 10

Name of the student:

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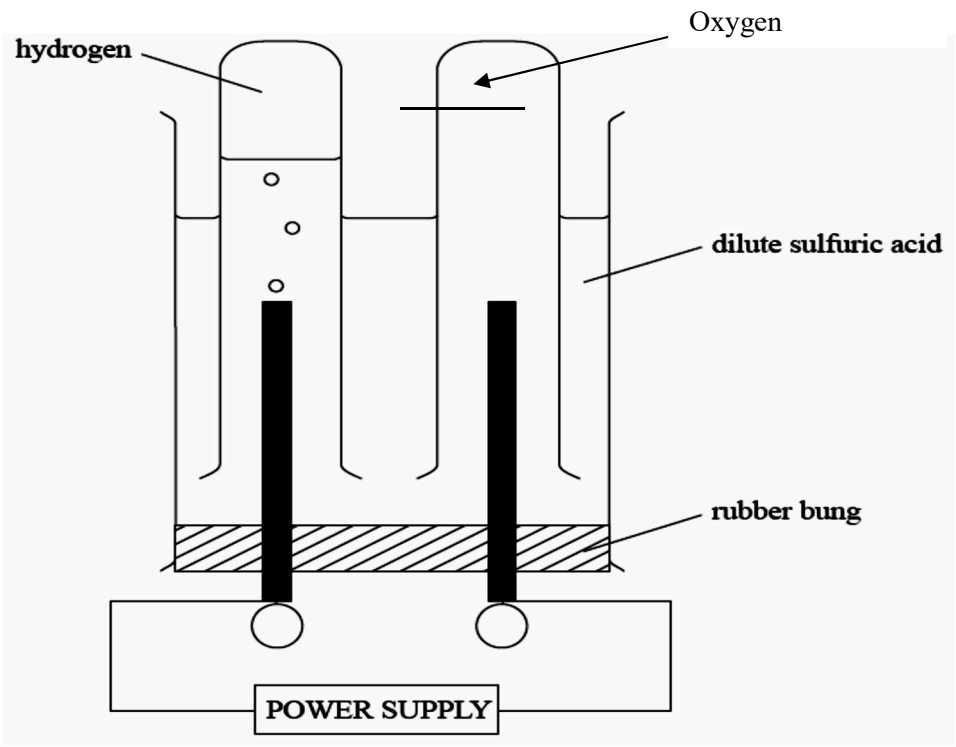
1. The diagram shows apparatus that can be used to electrolyze water.



(a)(i) **Label** the electrodes in the diagram by writing the symbols " + " and " – " in the circles.

[1]

(ii) Write the formulae of **all** the ions present in the electrolyte.

.....

[1]

(iii) Write the equations for the reactions that occur in the electrolysis.

Reaction at cathode: .....

[1]

Reaction at anode: .....

[1]

(b) The volume of gas collected after a few minutes is shown on the diagram.

The overall equation for the reaction to produce hydrogen and oxygen is: $2H_2O \longrightarrow 2H_2 + O_2$

Use the equation to Explain why the volume of hydrogen gas is nearly double than that of oxygen.

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[2]

(c) (i) Aqueous copper (II) sulfate is neutral. After the electrolysis for few minutes, the solution turns acidic.

Considering the ions present in the solution explain why the solution turns acidic.

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[2]

(ii) State two observations during the electrolysis of aqueous copper (II) sulfate.

Observation 1:

.....

Observation 2:

.....

Total 10 marks

Electroplating

Electroplating is the electrical precipitation of a metal on another substance by electrolysis.

Electroplating on a substance is done

(i) to give improved appearance

(ii) to give greater resistance to corrosion

Electroplating with zinc on any other metal is known as **galvanizing**.

Electrochemical Cells:

4. Video Link:

https://www.youtube.com/watch?v=oQrWsYm48lM