ELECTROCHEMISTRY

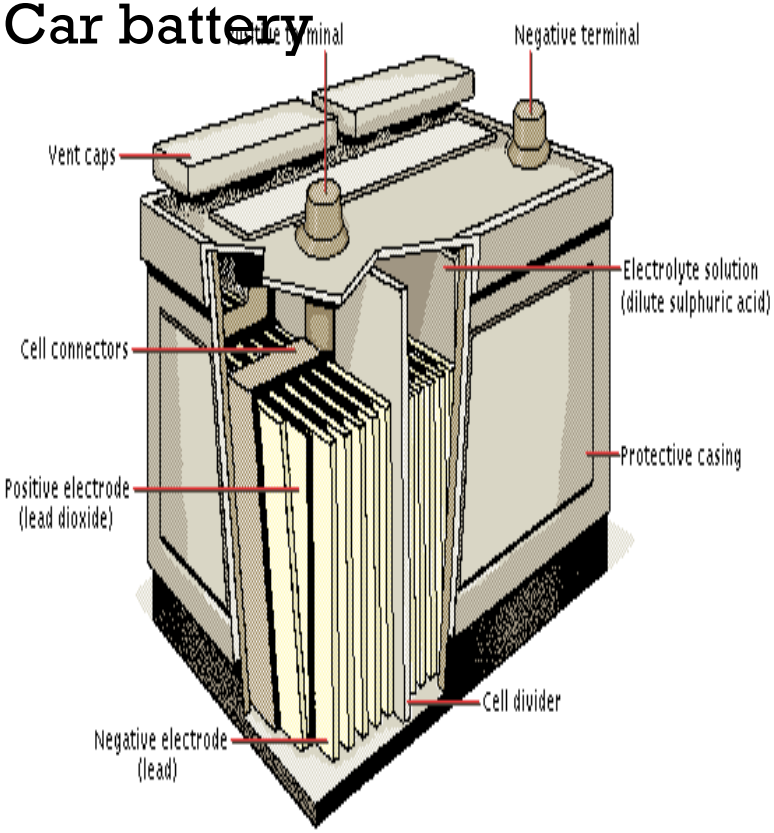
THE ELECTROLYTIC CELLS

DEFINITION

- Electrochemistry is the branch of chemistry that deals with interrelationship of electrical currents and chemical reactions

ELECTROCHEMISTRY IN EVERYDAY LIFE

Car battery



IN CALCULATORS

- Calculators

TWO TYPES OF CELLS IN ELECTROCHEMISTRY

GALVANIC (VOLTAIC) CELLS

- Has two compartments
- Has salt bridge
- Does not have a battery
- Anode is negative and cathode is positive
- Chemical energy is converted to electrical energy
- Redox reaction is spontaneous: E^{Θ}_{cell} is positive

ELECTROLYTIC CELLS

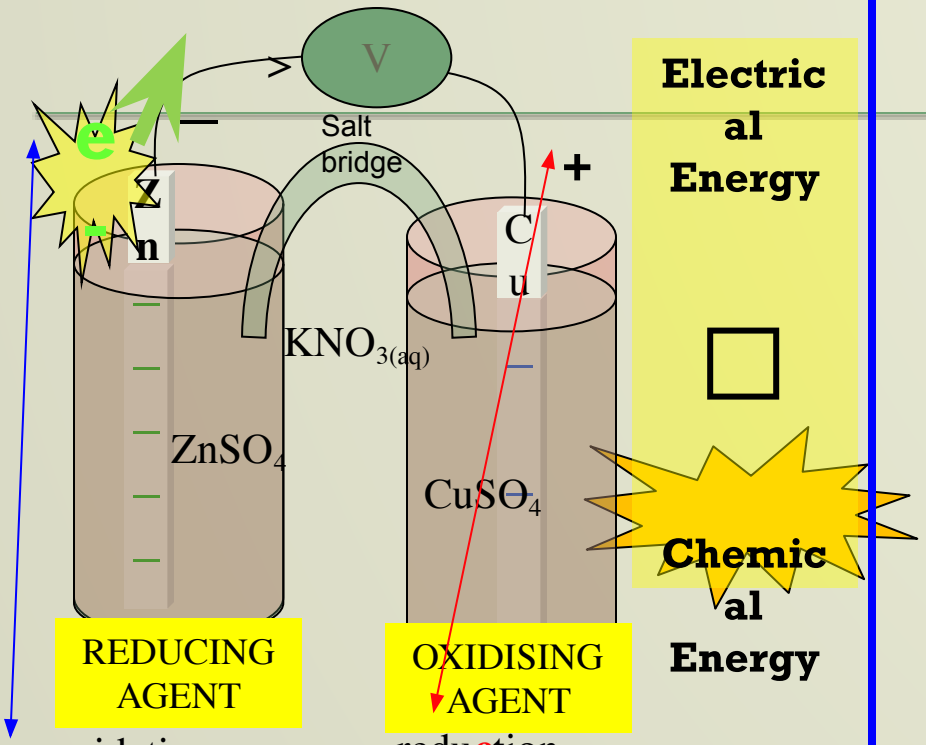
- Has only one compartment
- Does not have a salt bridge
- Has a battery
- Anode is positive and cathode is negative
- Electrical energy is converted to chemical energy
- Redox reaction is not spontaneous: E^{Θ}_{cell} is negative

SMILARITIES OF GALVANIC AND ELECTROLYTIC CELLS

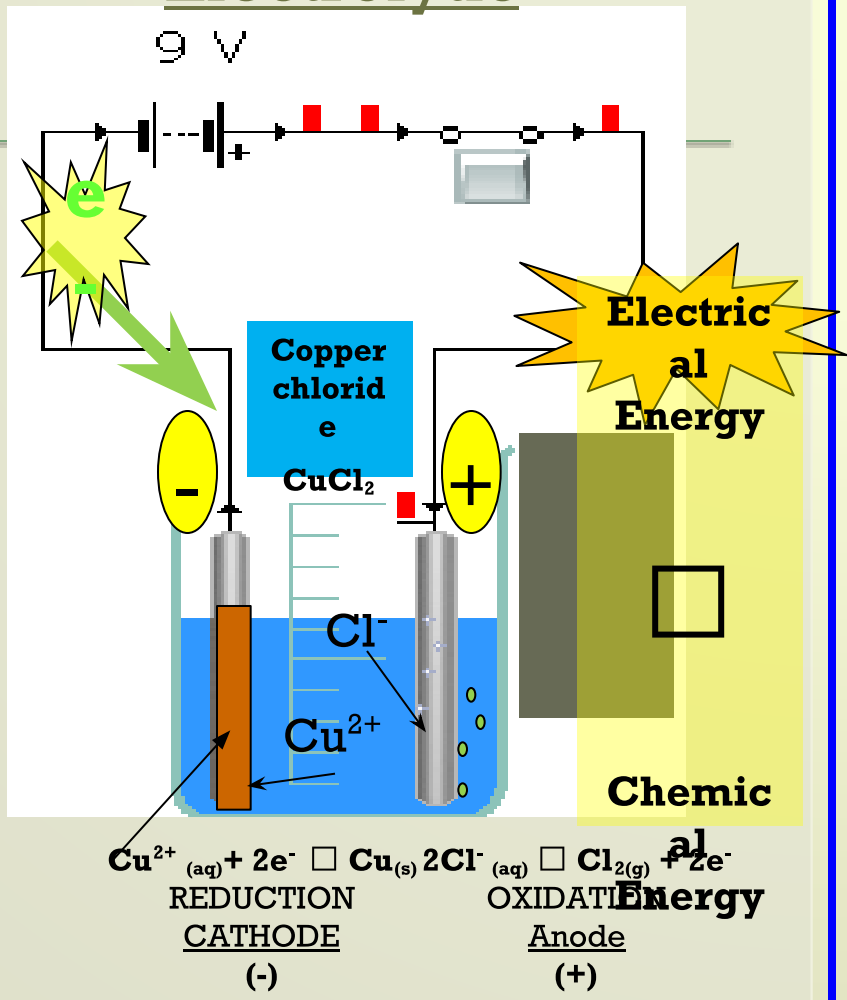
- In both cells redox reaction takes place
- Oxidation takes place at the anode and reduction at cathode in both cells
- Negative ions from solution are attracted to the anode while positive ion are attracted to the cathode
- Electrons flow in the external circuit from anode to cathode in both cells

Electrochemical Cells

Voltaic (Galvanic) vs Electrolytic



Chemical Energy → Electrical Energy



Electrical Energy → Chemical Energy

TERMINOLOGY

- Oxidation: loss of electrons
- Reduction: gaining of electrons
- Oxidising agent:
- Reducing agent:
- Anode: electrode where oxidation occurs
- Cathode: electrode where reduction takes place
- Electrolyte:
- Electrolysis: breaking down of chemical compound with the help of electric current

GENERAL VIEW OF ELECTROLYTIC CELL

- ELECTROLYTC CELL
  - Two carbon electrodes are connected to DC- from battery
  - Form of carbon used is graphite- unreactive
  - Electrons flow from negative terminal of battery to positive terminal

ELETROLYTIC CELL (CONT…)

- THE CATHODE
- Cathode is the negative electrode of electrolytic cell
- This is because it is connected to the negative terminal of the battery
- Positive ions are attracted to the cathode, where they accept electrons
- Therefore reduction takes place at the cathode

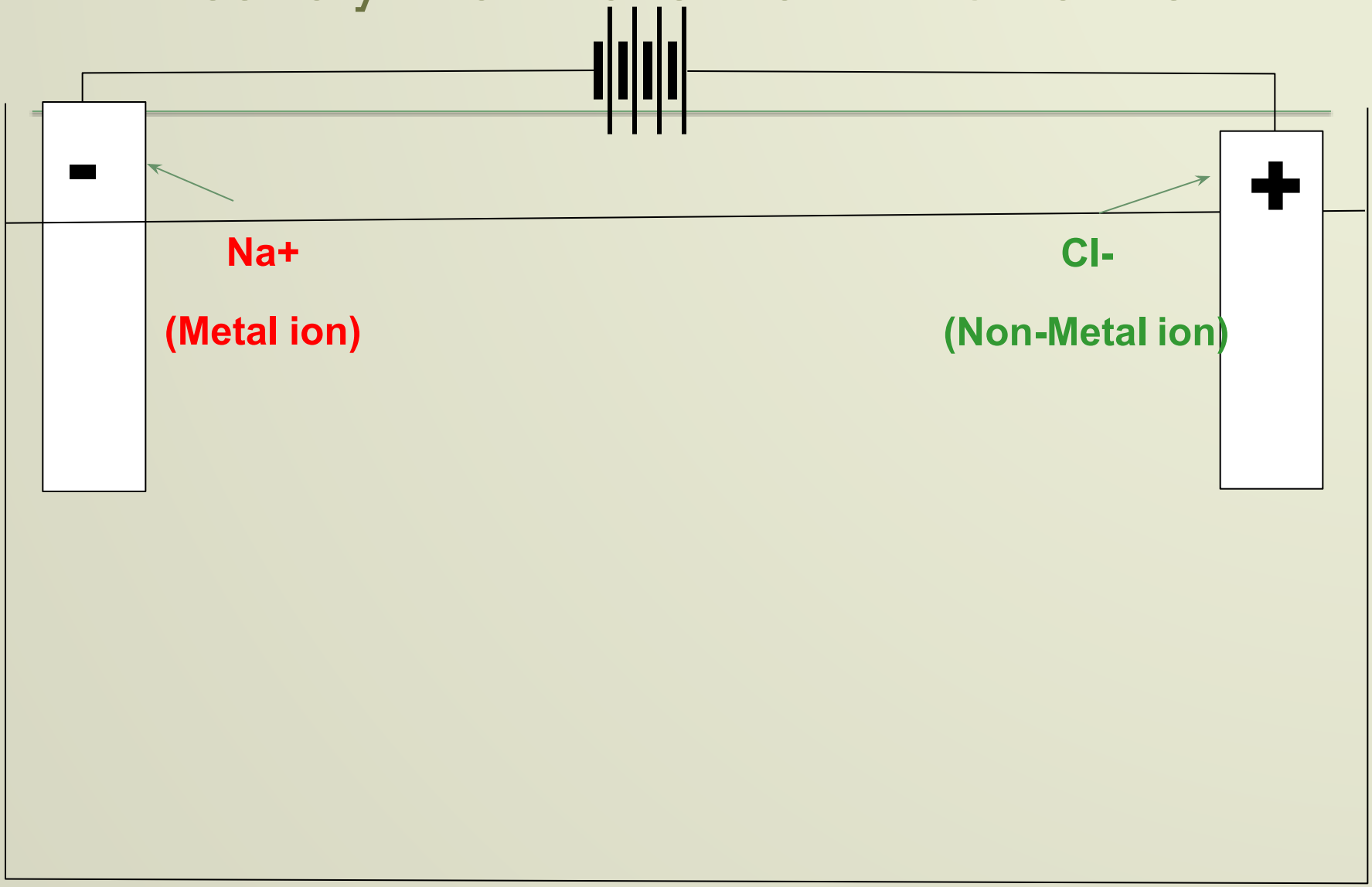
THE ANODE

- Anode is the positive electrode of electrolytic cell – connected to positive terminal of the battery
- Electrons from negative ions are transferred to the cathode
- Electrons are given off & oxidation takes place

ELETROLYTIC CELLS (CONT…)

- Electrons are released from the anode (+) and are accepted at the cathode (-).
- Process of electrolysis takes place, i.e electrical energy (provided by the battery) is converted to chemical energy –this is accompanied by decomposition of electrolyte

Electrolysis of molten sodium Chloride



ELETROLYSIS OF MOLTEN SODIUM CHLORIDE

- AT CATHODE
- Na^+ ions are attracted to negative electrode
- Na^+ ions accept electrons to form sodium atoms
- This process is called reduction
- Half reaction :

$Na^+ + e^- \rightarrow Na$

- AT ANODE
- Cl^- ions are attracted to positive electrode
- Cl^- ions donate electrons to the anode
- Chloride ions lose electrons to form chlorine atoms – which combine to form a chlorine molecule
- Half reaction:

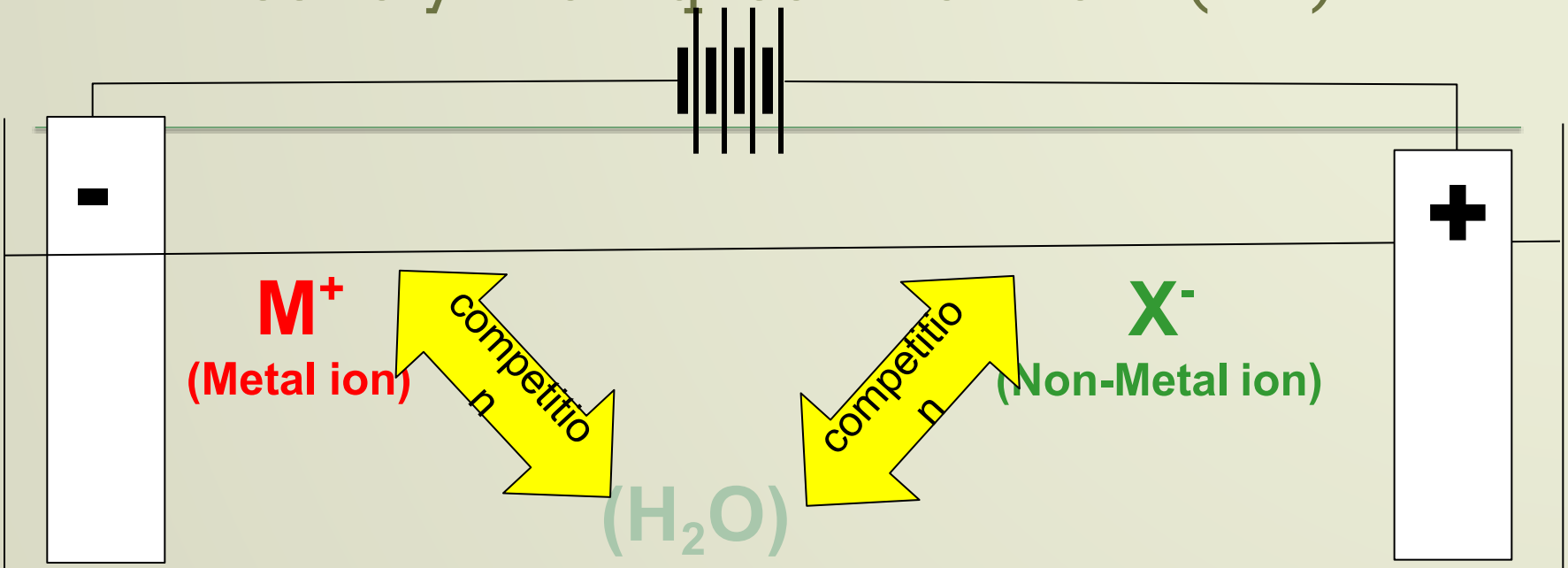
$2Cl^- \rightarrow Cl_2 + 2e^-$

ELECTROLYSIS OF MOLTEN SODIUM CHLORIDE (CONT…)

- $Na^+ + e^- \rightarrow Na$ (reduction half reaction)
- $2Cl^- \rightarrow Cl_2 + 2e^-$ (oxidation half reaction)
- Nett reaction: $2\ Na^+ + 2Cl^- \rightarrow 2Na + Cl_2$

ELETROLYSIS OF ACQUEOUS SODIUM CHLORIDE SOLUTION

Electrolysis of aqueous solutions (MX)



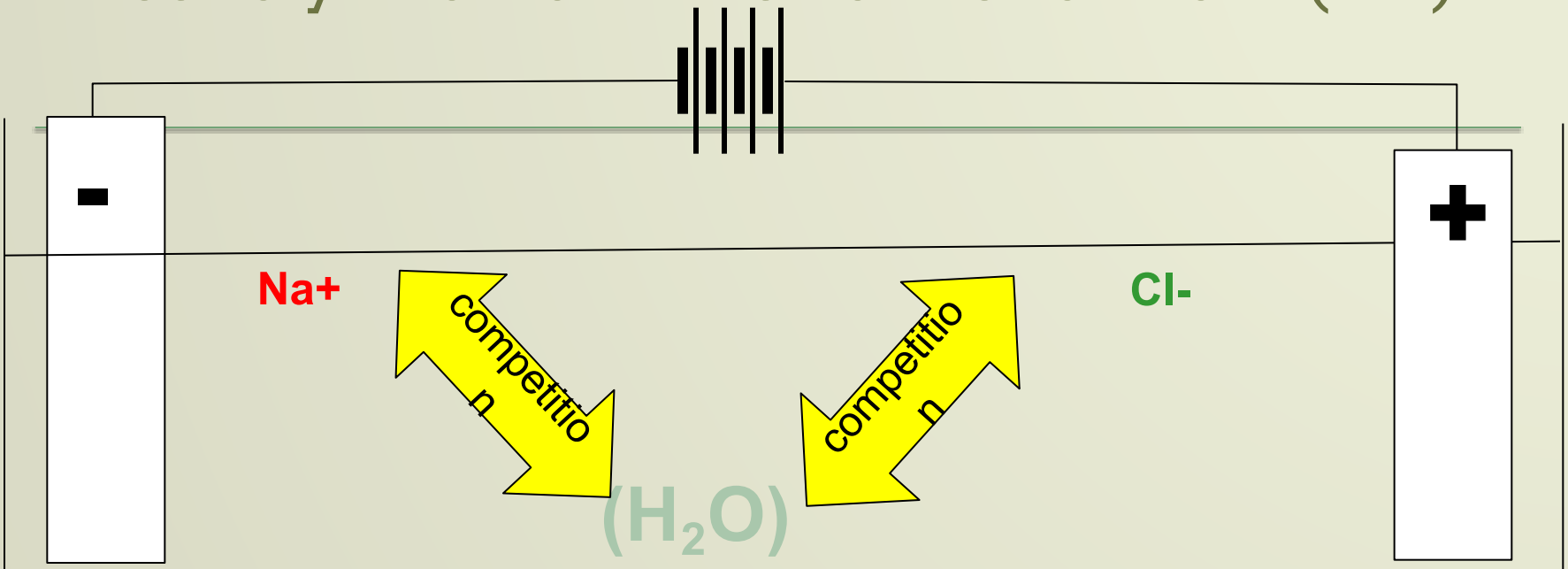
If the metal is **more positive** than hydrogen, its ions will be **reduced**.

$M^+ + e \rightarrow M$

If **halide ions** (X^-) are present (**more positive** than OH^-) ions then the halide ions (X^-) are oxidised.

$X^- \rightarrow X_2 + 2e^-$

Electrolysis of sodium chloride solutions (MX)



If the $^{Na+}$ **ion** is **more positive** than hydrogen, its ions will be **reduced**.

$$Na^+ + e \rightarrow Na$$

If **halide ions** (Cl^-) present are **more positive** than **OH^-** ions then the halide ions (Cl^-) are oxidised.

$$Cl^- \rightarrow Cl_2 + 2e^-$$

COMPETING REACTING SPECIES

POSSIBLE REDUCTION HALF REACTION

$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$

$E_{reduction} = -0.83V$

$Na^+ + e^- \rightarrow Na$

$E_{reduction} = -2.71V$

Water is more positive than Na^+ ions

POSSIBLE OXIDATION HALF REACTIONS

- $2H_2O + 2e- \rightarrow O_2 + 4H^+ + 4e-$

  $E_{oxidation} = + 1,23V$
- $2Cl^- \rightarrow Cl_2 + 2e^-$

$E_{oxidation} = + 1,36V$

Cl^- ions are more positive than water

- Redution half reaction at cathode:
- Water will be reduced since it is more positive than Na ion. (reduction of H2O requres less energy than Na ion- that is according to std reduction potentials)
- Therefore at cathode $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
- at anode $2Cl^- \rightarrow Cl_2 + 2e^-$ (since Cl- ions are more positive than H_2O.
- Nett reaction: $2H_2O + 2Cl^- \rightarrow Cl_2 + H_2 + 2OH^-$

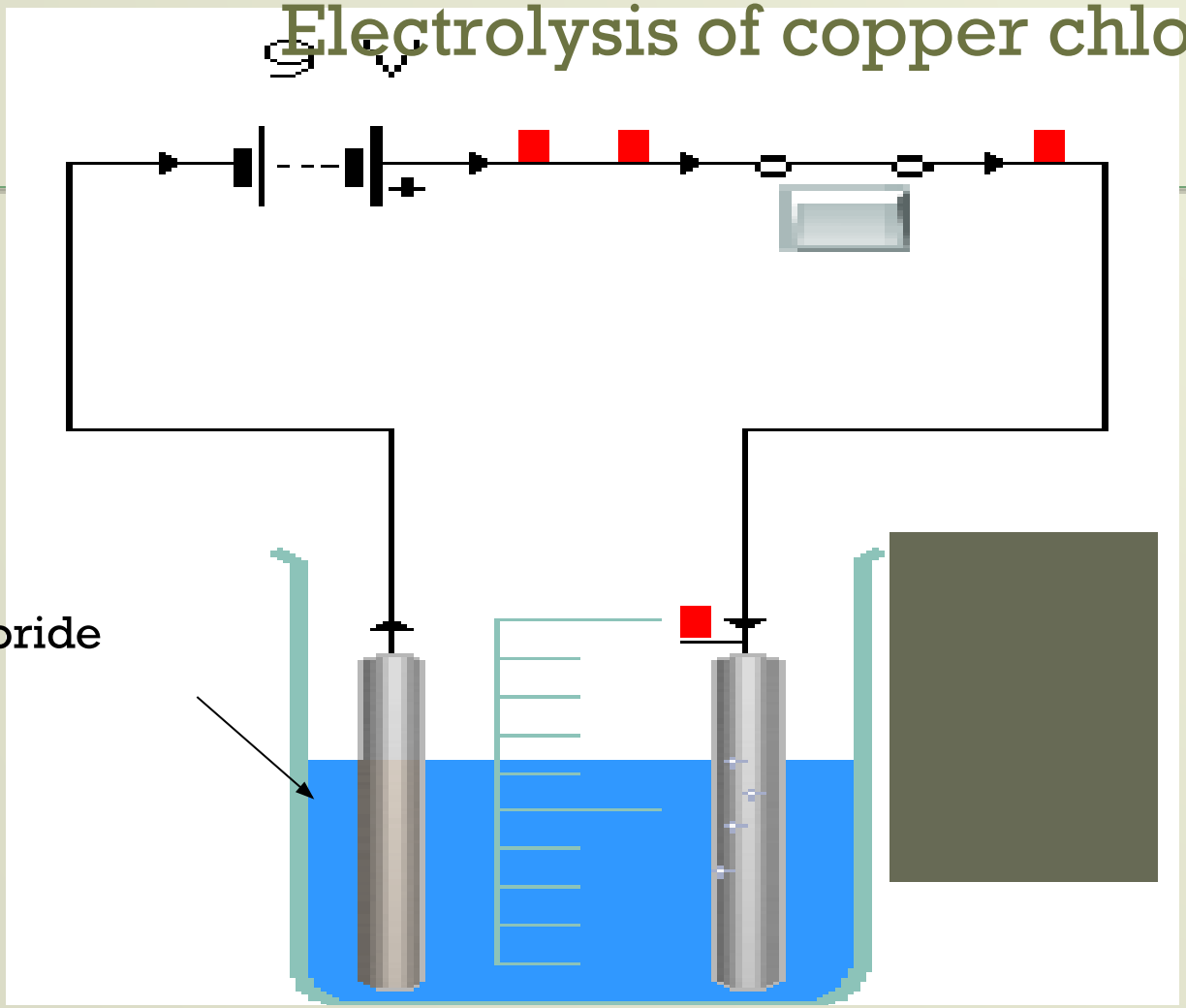
APPLICATION OF ELECTROLYSIS

The process of Electrolysis plays an important role in the industry

It is used in :

- Electroplating of metals
- Extraction of metals such as aluminium
- Purification of metals such as copper
- Decomposition of solutions such as copper chloride

Electrolysis of copper chloride



- Electrolytic cell: Converts…

ELETROLYSIS OF COPPER CHLORIDE

CATHODE

- **Positive copper ions move to cathode (negative electrode) where they take up electrons & form solid Cu which forms reddish brown deposit on cathode**
- **CATHODE HALF REACTION:**

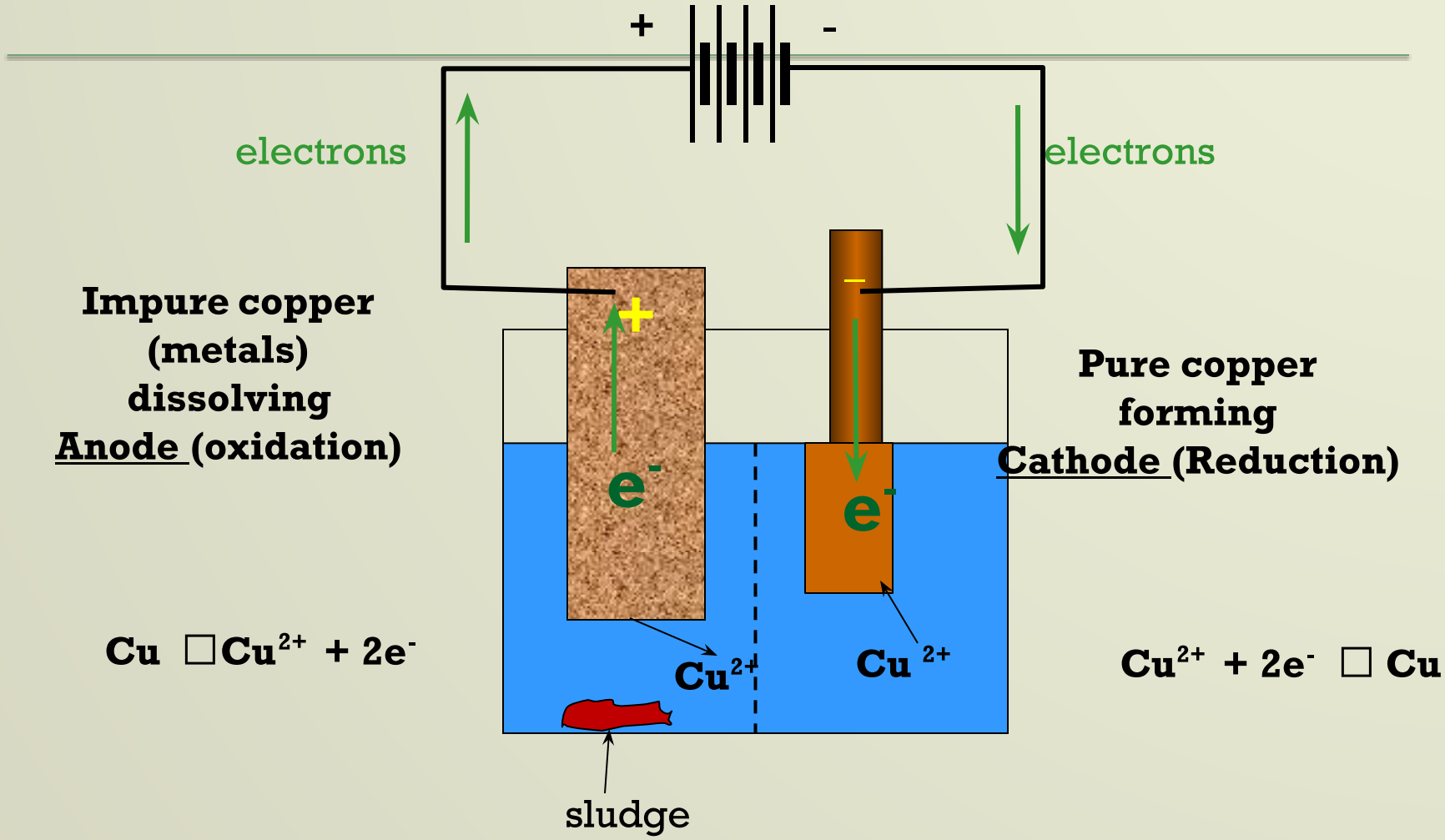
$Cu^{2+}(aq) + 2e^- \rightarrow Cu.$

ANODE

- **negative chloride ions move to anode (positive electrode) where they give off electrons to form chlorine gas**
- **ANODE HALF REACTION**
- **$2Cl^- \rightarrow Cl_2(g) + 2e^-$**

PURIFICATION OF COPPER

Purifying Copper



$Cu \rightarrow Cu^{2+} + 2e^-$

$Cu^{2+} + 2e^- \rightarrow Cu$

- Identify the anode cathode etc

PURIFICATION OF COPPER

- **Copper obtained from its ore is not pure and it needs to be purified. The SLIDE above shows the typical diagram illustrating how copper is purified**
- **Anode composed of impure copper**
- **Cathode is a bar of pure copper**
- **Two electrodes are placed in copper (II) sulphate solution**

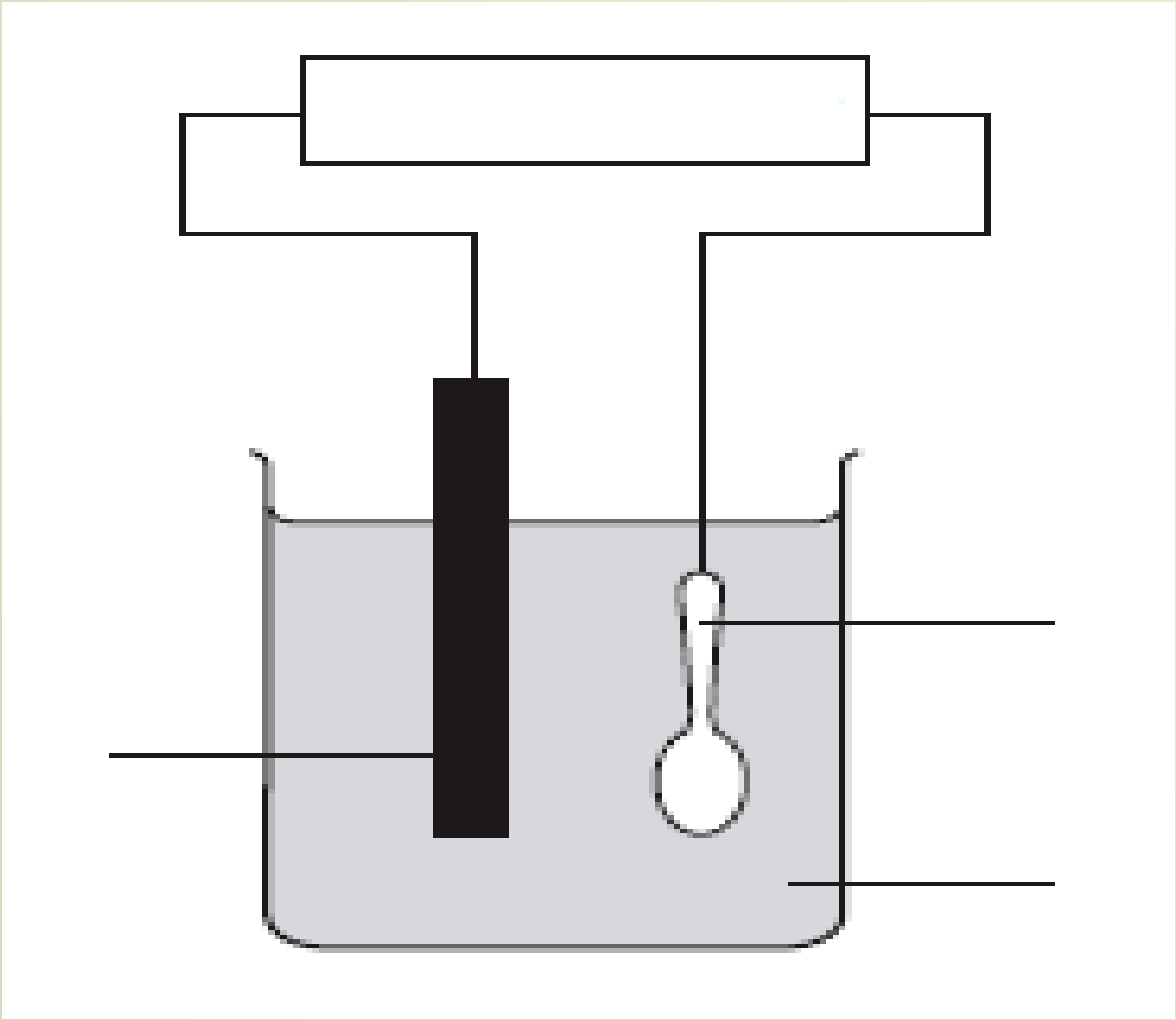
Purification of copper (cont…)

- **Oxidation takes plce at anode: $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$**
- **Reduction takes place at cathode: $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$**
- **For eacg Cu2+ in that deposit on cathode, another goes into solution at anode.**
- **Concentration of solution therefore remains constant**
- **Pure copper cathode increases while impure copper decreases in size**
- **Impurities that stay behind at the anode form residue below the anode**
- **What happen to impurities?: (1)any metal impurities less rective than copper (below copper in the redox table) such as silver and gold will form part of residue as metal atoms. The sludge may therefore contain very valuable metals.**
- **(2) metals that are more reactive than copper (which are above Cu in the table) such as zinc, will form ions at anode and go into the solution. These ions will not be reduced unless their concentration is too high. As time proceeds, concentration of zinc ions in solution increases and that of Cu^{2+} decreases.**
- **$CuSO_4$ solution must therefore be purified regularly**

ELETROPLATING OF METALS

- **During the process of electroplating one metal is covered with layer of another metal.**
- **The aim of electroplating is to protect against corrosion**
- **Electroplating with zinc is called galvanization- it is mainly used to protect steel**
- **Other examples include chromium, silver and gold**
- **Chromium is used in motor spares and silver is used in cutlery**

EECTROPLATING WITH SILVER

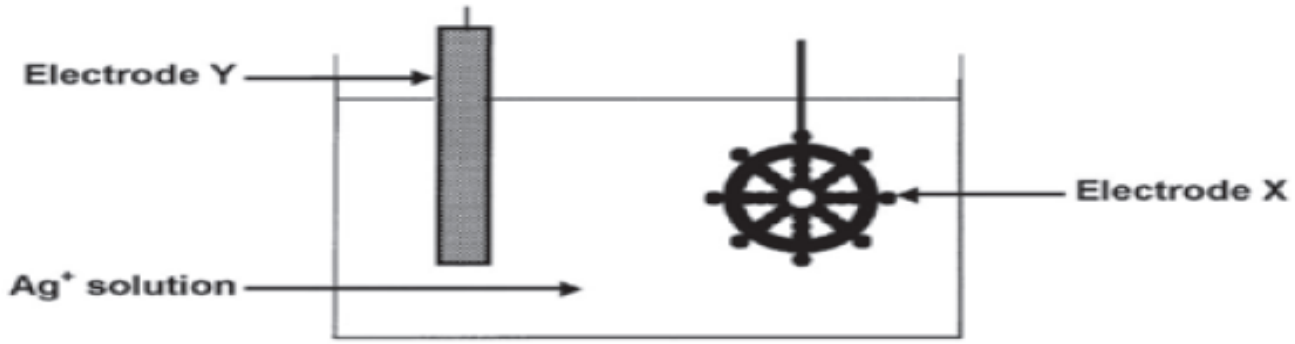


ELECTROPLATING WITH SILVER

- Oxidation & reduction occur simultaneously
- Positive silver ions in solution is attracted to negative cathode and reduced to solid silver
- $Ag^{+}+e- \rightarrow Ag$ (reduction half reaction)
- The opposite occurs at anode. Silver atoms from anode are oxidised to form silver ions
- $Ag \rightarrow Ag^{+}+e-$
- NB: with electroplating, the same metal that is oxidised is reduced

QUESTIONS

An attractive silver appearance can be created by electroplating artefacts (objects) made from cheaper metals, such as nickel, with silver. The simplified diagram here represents an arrangement that can be used to electroplate a nickel artefact with silver.



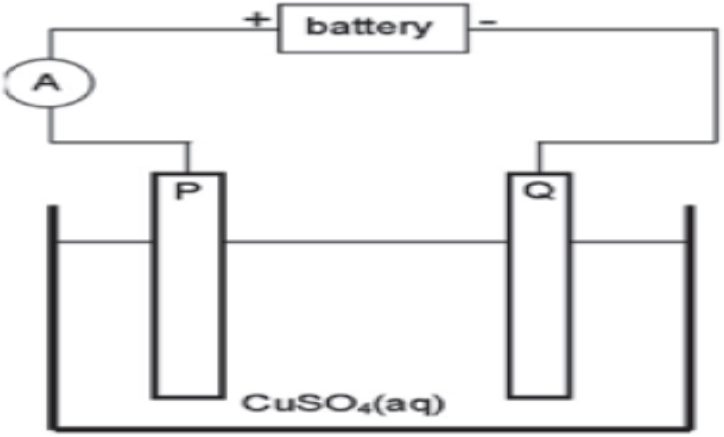
1. Which electrode (cathode or anode) does the nickel artefact represent?
2. Name the metal represented by electrode Y.
3. Write down the half-reaction responsible for the change that occurs at the surface of the artefact.
4. Give a reason why the concentration of the electrolyte remains constant during electroplating.
5. In industry some plastic articles are sometimes electroplated. Explain why plastic must be coated with graphite before electroplating.
6. Give a reason why, from a business point of view, it is not advisable to plate platinum with silver.

SOLUTIONS

1. Cathode
2. Silver
3. $Ag^+ + e^- \rightarrow Ag$
4. The rate of oxidation of silver at the anode is equal to the rate of reduction of silver ions at the cathode.
5. Plastic is a non-conductor. It must be covered with a conducting layer so that it can act as the cathode. Graphite is a conductor.
6. Platinum is expensive and is more durable than other metals. You would normally electroplate a cheap metal with an expensive, durable metal and not the other way round.

QUESTION ON PURIFICATION OF COPPER

Impure copper can be purified by the process of electrolysis. The simplified diagram represents an electrolytic cell used to purify copper.



1. Define the term electrolysis.
2. Which electrode, P or Q, consists of the impure copper? Explain how you arrived at your answer.
3. Write down the half-reactions that take place at electrodes P and Q.
4. During purification, metals such as silver and platinum form sludge at the bottom of the container. Refer to the relative strengths of reducing agents to explain why these two metals do not form ions during the purification process.
5. Explain why the concentration of the copper (II) sulphate solution remains constant. Assume that the only impurities in the copper are silver and platinum.
6. Why is the sludge of economic importance?

SOLUTION

1. Electrolysis is a process during which electrical energy is converted to chemical energy. It is the process in which electricity is used to bring about a chemical change / decompose / break compounds into components.
2. P: P is the positive electrode / anode. The impure Cu is oxidised at the positive electrode / anode.
3. P: Anode: $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$ oxidation
   impure
   Q: Cathode: $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ reduction
   pure
4. Platinum and silver are both weaker reducing agents than copper and will not be oxidised to form ions.
5. The rate at which copper is oxidised (at the anode) is equal to the rate at which copper ions are reduced (at the cathode).
6. Silver and platinum are valuable and expensive metals and can therefore be sold at a profit.

QUESTIONS ON PURIFICATION OF COPPER (CONT …)

1. Refer to the diagram in the worked example above. One of the electrodes consists of impure copper and the other one of pure copper.

   1. What type of power source is used to drive the reaction in this cell? Write down only AC or DC. (1)

   2. Give a reason why the copper(II) sulphate is dissolved in water before it is used in this cell. (1)

   When an electric current passes through the solution, electrode **P** becomes coated with copper.

   3. Is electrode **P** the cathode or the anode? Support your answer by writing the half-reaction that takes place at electrode **P**. (2)

   4. Write down the half-reaction that takes place at electrode **Q**. (2)

   It is found that the impure copper plate contains platinum. The platinum forms a residue at the bottom of the container during electrolysis.

   5. Refer to the relative strengths of reducing agents to explain why platinum forms a residue at the bottom of the container. (2)

   6. How will the concentration of the copper(II) sulphate solution change during electrolysis? Write down only INCREASES, DECREASES or REMAINS THE SAME. (3)

   [11]

SOLUTIONS

1. DC ✓ (1)
2. Free ions needed to conduct electricity ✓ (1)
3. Cathode. ✓ $Cu^{2+} + 2e^- \rightarrow Cu$ ✓ (2)
4. $Cu \rightarrow Cu^{2+} + 2e^-$ ✓ ✓ (2)
5. Pt is a weaker reducing agent than Cu ✓and will not be oxidised ✓ (2)

   OR

   Cu is a stronger reducing agent than Pt and will be oxidised
6. Remains the same.✓ The rate at which Cu is oxidised at the anode ✓ equals the rate at which $Cu^{2+}(aq)$ is reduced at the cathode ✓ (3)

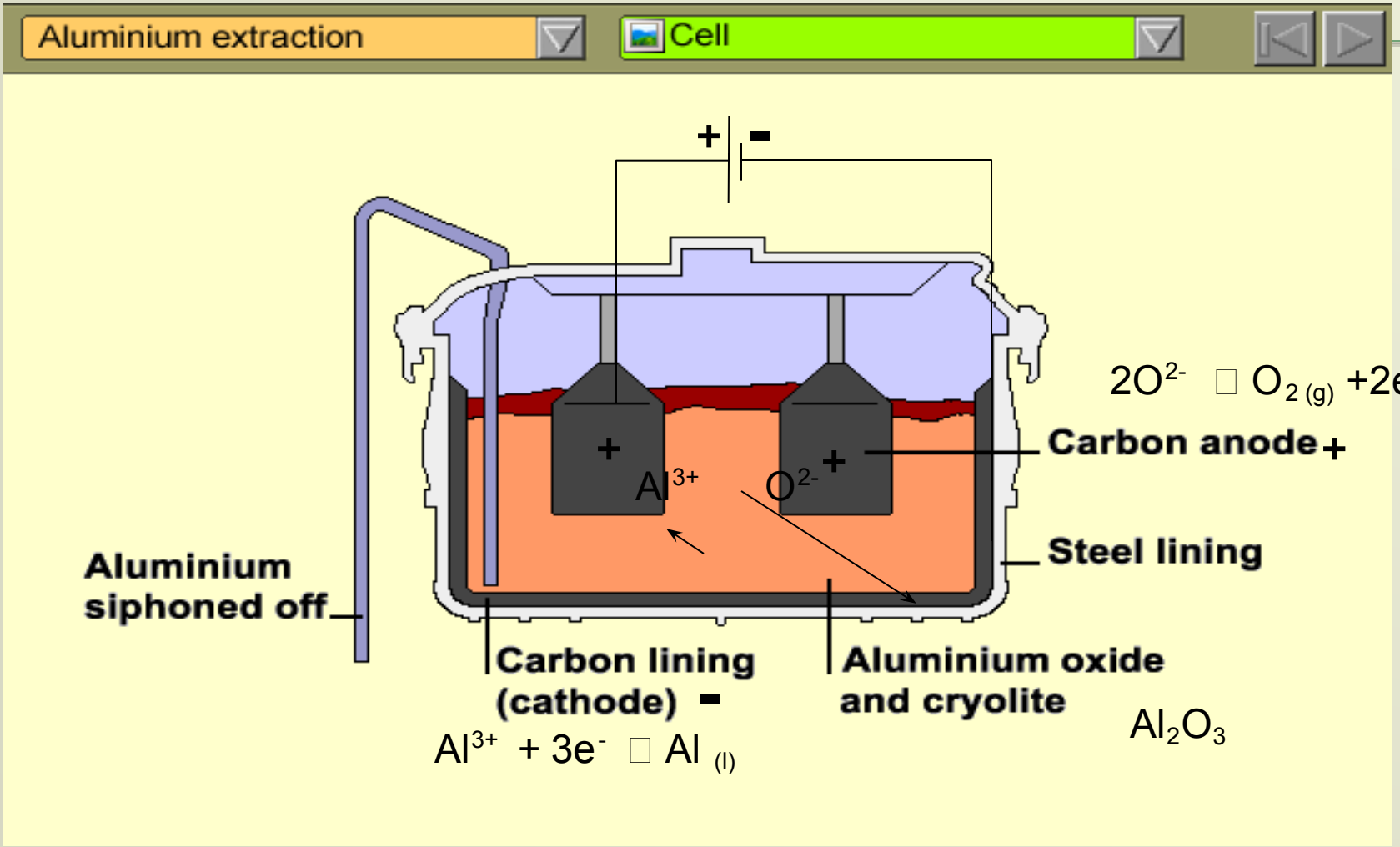
[11]

EXTRACTION OR RECOVERY OF ALUMINIUM

- **Aluminium is one of the most abundant metals on earth, yet it is expensive –**
- **largely because of the amount of electricity needed to extract it.**
- **• has the following properties: a low density; the ability to resist**
- **corrosion; is very ductile; can be rolled out in thin layers; is**
- **lightweight and is a good electrical conductor.**
- **It is very expensive to extract aluminium from its ore. That is why the metal, although is plenty on earth but very expensive.**
- **This is attributed to the amount of electricity used during the process of electrolysis**
- **Aluminium ore is called bauxite**
- **Bauxite contains aluminium oxide, water, iron oxide and other impurities**
- **After purification the dry ore consists of aluminium oxide (Al_2O_3) – Alumina, from which aluminium is extracted**

ELECTROLYSIS OF ALUMINA

Extraction of Aluminium



EXTRACTION OF ALUMINIUM (CONT…)

- **Extraction of aluminium is done through the process of electrolysis.**
- **Aluminium oxide is first melted**
- **Melting point of aluminium is 2000°C.**
- **To save the costs, it is first dissolved in cryolite (Na_3AlF_6)- melts only at 900°C**
- **As a results mixture of alumina and cryolite can be electrolysed at around 950°C. and this requires very low potential difference.**
- **Electrolysis of this mixture is performed in steel container**
- **Both anode and cathode are made from graphite**
- **Carbon lining inside steel container forms the cathode**
- **During electrolysis of aluminium-cryolite mixture, aluminium forms at the cathode**
- **$Al^{3+}(aq) + 3e- \rightarrow Al(s)$**
- **Oxidation at carbon electrode forms oxygen**
- **$2O^{2-}(aq) + 4e- \rightarrow O_2(g)$**

EXTRACTION OF ALUMINIUM (CONT…)

- **Aluminium is denser than aluminium oxide-cryolite mixture, and therefore sinks to the bottom where it can be drained as pure liquid metal**
- **Complete cell reaction:**
- **$2Al_2O_3(l) \rightarrow 4Al(l) + 3O_2(g)$**
- **As Al forms and is drained new aluminium oxide is added from the top.**
- **Hot oxygen forming at the anode reacts with carbon electrodes to form carbon dioxide: $C(s) + O_2(g) \rightarrow CO_2(g)$.**
- **Consequently carbon anode is slowly burnt away and has to be replaced regularly**
- **This contributes to the cost of the process**

ECOLOGICAL & ENVIRONMENTAL IMPACT OF RECOVERY OF ALUMINIUM

The ecological impact of Aℓ extraction: Loss of landscape due to

- the size of the chemical plant needed; disposal of red mud (iron (III)oxide) formed during extraction of aluminium oxide from bauxite, into rivers and lagoons and into ground water.
- • Environmental impact of Aℓ extraction: Carbon dioxide from the burning of the anodes contributes to the greenhouse effect, causing global warming.

Fluorine and its compounds lost from the cryolite during the electrolysis process are poisonous.

Chemicals in the red mud dams drain into the soil and contaminate groundwater.

- Pollution caused by power generation (for electrolytic process) using coal fired plants leads to acid rain and adds to the greenhouse effect.
- Noise pollution from the extraction plant.

QUESTIONS ON EXTRACTION OF ALUMINIUM

1. In an aluminium smelter, aluminium metal is extracted from bauxite, a hydrated aluminium oxide, via an electrolytic process.
1.1 Write down the energy conversion that takes place in an electrolytic cell. (2)
1.2 Write down the equation for the half reaction responsible for the formation of aluminium metal in a smelter. (2)
1.3 Explain in terms of the relative strength of oxidizing agents why the electrolytic production of aluminum requires more electrical energy than that of iron or copper. (2)
1.4 Name TWO advantages that the use of aluminium has over that of iron. (2)
2. A huge aluminium smelter is planned for Coega in the Eastern Cape. When operational, it will consume 1350 MW of electricity, or 4% of the nation's total electrical energy. It is estimated that 5200 jobs will be created at the peak of construction. About 1000 workers will be employed on a full-time permanent basis, and between 200 and 300 full-time subcontractors will also be directly associated with the smelter.
(Source: www.engineeringnews.co.za; www.groundwork.org.za).

QUESTIONS (CONT…)

2.1 Taking the present South African socio-economic
realities into account, give ONE reason why the aluminium
smelter should:
(a) Not be built (1)
(b) Be built (1)
2.2 Give ONE reason why environmental activists oppose the
construction of the smelter. (1)
[11]

ANSWERS

1.1	Electrical energy ⟶ chemical energy ✓ ✓	(2)
1.2	$A\ell^{3+} + 3e^- \longrightarrow A\ell$ ✓ ✓	(2)
1.3	Aluminium has a lower reduction potential (–1,66 V) ✓/ Weaker oxidizing agent compared to that of iron (–0,44 V) [and copper (+0,34 V)]. The aluminium ions therefore require a large amount of energy to be reduced/ will reduce more difficultly than iron (and copper). ✓	(2)
1.4	It is much lighter for the same strength (or stronger for the same mass). ✓ It is corrosion free.✓	(2)
2.1	(a) It will consume huge amount of electricity. ✓/ Will cause power failures ✓ (any 2)	(1)
	(b) It will create jobs ✓/Create foreign investment. ✓ Contribute to GDP ✓ (any 3)	(1)
2.2	The production of the large amount of electricity used ✓ enhances the greenhouse effect (or climate change) ✓ **OR** The process is responsible for toxic fluoride waste **OR** pollution. (any one)	(1)
		[11]

THE CHLORALKALI INDUSTRY

- **This is one of the world's largest electrochemical industries**
- **It is energy intensive process and one of the largest consumers of electricity**
- **Chlor-alkali plants produce two main product: $Cl_2(g)$ and sodium hydroxide**
- **Chlorine & NaOH are among top ten chemicals produced in the world**
- **Both used for manufacturing of wide range of products used in everyday life**
- **Hydrogen is also a by-product from the process**

THE CHLORALKALI INDUSTRY

The chlor-alkali industry products can be produced by using a:

- • membrane cell
- • mercury cell
- • diaphragm cell

THE CHLORALAKALI INDUSTRY

	Membrane Cell	Diaphragm Cell	Mercury Cell
Purity and yield of $C\ell_2$ (g) produced	• Produces relatively pure $C\ell_2$(g) that is mixed with very small amount of O_2(g).	• Produces $C\ell_2$(g) that is mixed with O_2(g) so the product is less pure.	• Low yield of $C\ell_2$(g) and of NaOH(aq).
Purity of NaOH (aq) produced	• High	• Medium • NaOH (aq) is mixed with NaCℓ (aq)	• Low
Energy consumption (Affects costs)	• Lowest	• Relatively low	• Very high
Environmental impact	• Lowest • Non-toxic, reusable components - low setup costs. • Lowest energy consumption therefore small carbon footprint.	• High • Diaphragm is made from asbestos.	• Highest • Mercury reacts with the NaCℓ (aq) and leaches into the groundwater.
Health risks	• No potential health risks / environmental risks due to components. • H_2(g) is explosive and $C\ell_2$(g) is poisonous.	• Diaphragm is made from asbestos – health risk for workers – asbestosis and cancer. • H_2(g) is explosive and $C\ell_2$(g) is poisonous.	• Mercury is toxic. • Risks due to contamination of groundwater. (Fish, animals and humans use the water. • H_2(g) is explosive and $C\ell_2$(g) is poisonous.

USES OF PRODUCTS OF CHLOR-ALKALI INDUSTRY

1 Chlorine.

- For manufacture of PVC
- Paints and colourants
- Bleaching agents
- Manufacture of insecticides
- Dry-cleaning solvents
- Disinfectant in drinking water
- Disinfectant in swimming pools
- Manufacture of hydrochloric acid

Sodium hydroxide

- Manufacturing of soaps
- Cleaning agents
- Textile manufacturing
- Paper
- Extraction of aluminium
- Food industry
- Treatment of waste water

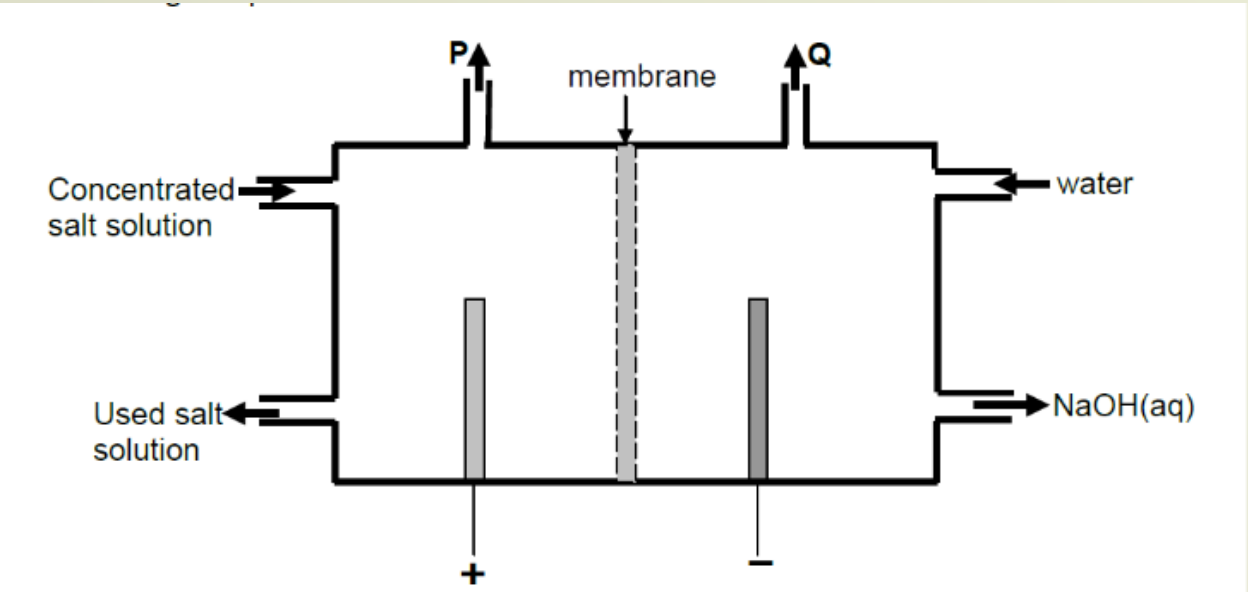
Hydrogen

- Manufacturing of margarine
- HCl
- Rocket fuel
- Preparation of hydrogen peroxide
- Preparation of ammonia
-

ELECTROLYTIC CELLS IN CHLORALKALI INDUSTRY

- There are three types of cells used in the industry, namely the mercury cell, diaphragm cell and the membrane cell.
- The two cells, mercury cells and diaphragm cells have been discontinued because of their environmental problems

THE MEMBRANE CELL



THE MEMBRANE CELL

- **It uses special type of plastic as a membrane to separate anode and cathode**
- **It is the ion-exchange membrane that allows only positive ions to pass through**
- **Graphite anode is used and cathode is made from stainless steel**
- **Saturated sodium chloride enters the anode compartment where chloride ions are oxidized to chlorine gas**
- **Water in cathode compartment undergoes reduction to form hydrogen gas and hydroxide ions**
- **Positive sodium ions move through the membrane from anode to cathode compartment**
- **Sodium hydroxide and hydroxide ions forM**

MEMBRANE CELL

Reactions taking place in the cell

- **Anode: $2Cl^-(aq) \rightarrow Cl_2 + 2e^-$**
- **Cathode: $2H_2O + 2e^- \rightarrow 2OH^- + H_2$**
- **Cell reaction: $2Cl^-(aq) + 2H_2O \rightarrow Cl_2 + 2OH^- + H_2$**
- **complete cell reaction: $2NaCl + 2H_2O \rightarrow Cl_2 + NaOH + H_2$**

MEMBRANE CELL

Advantages of membrane cell

- **No environmental problems associated with the cell**
- **Membrane is effective in keeping products separate**
- **Pure products are produced**
- **Less energy is needed to operate the cell**

SUMMARY OF PRODUCTS

REACTANTS			
• Sodium chloride solution, $NaC\ell(aq)$ • Produced by evaporation from sea water, salt lakes			
PRODUCTS			
	Chlorine gas $C\ell_2(g)$	**Hydrogen gas** $H_2(g)$	**Sodium hydroxide (caustic soda)** **NaOH(aq)**
PROPERTIES & PRECAUTIONS	• Yellow-green gas • Poisonous: Do not inhale.	• Colourless gas • Explosive: No open flames or electronic sparks nearby.	• Colourless solution • Highly corrosive • Prevent leaching into the ground • Prevent skin and eye contact.
USES	Reactant for production of: • hydrochloric acid, $HC\ell(aq)$; • extraction of Cu, Au, Ti; • paint; • PVC plastics; • insecticides and weed killers; • bleaching agents. Used to: • disinfect water.	Reactant for production of: • hydrochloric acid, $HC\ell(aq)$; • ammonia, $NH_3(g)$, • $H_2O_2(g)$ (hydrogen peroxide); • nylon; • rocket fuel; • margarine from plant oils (hydrogenation of unsaturated hydrocarbons).	Reactant for production of: • soap and bleaching agents; • paper; • textiles; • oven cleaners. Used to: • treat waste water (sewage water).

EXAMPLE

1. Chlorine is produced industrially by electrolysis in an electrolytic cell and can be represented as follows:

$2NaC\ell(aq)$	+	$2H_2O(\ell)$	$\longrightarrow$	$H_2(g)$	+	$C\ell_2(g)$	+	$2NaOH(aq)$

I	$2H_2O$	+	$2e^-$	$\longrightarrow$	H_2	+	$2OH^-$
II	$C\ell_2$	+	$2e^-$	$\longrightarrow$	$2C\ell^-$		
III	$2C\ell^-$			$\longrightarrow$	$C\ell_2$	+	$2e^-$
IV	H_2	+	$2OH^-$	$\longrightarrow$	$2H_2O$	+	$2e^-$

The correct statement(s) is/are:
A I and III
B I only
C II and IV
D III only

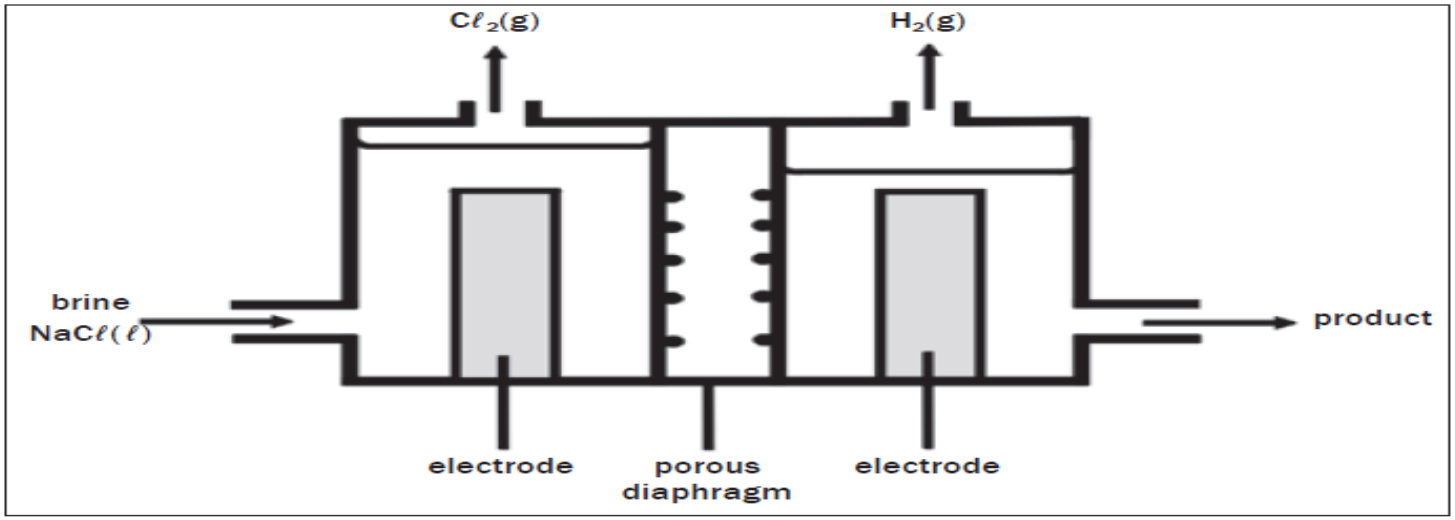
2. Chlorine is a poisonous gas commonly used as a bleaching agent. Chlorine is produced in industry by _____.

Solutions

1. A
2. Electrolysis of brine

THE MEMBRANE CELL

The electrolysis of saturated sodium chloride can be illustrated as follows: Hydrogen and chlorine bubble off at the electrodes.



1. Give an equation to show how chlorine bubbles are formed at the electrode. (2)
2. At which electrode are the chlorine bubbles formed? (1)
3. At which electrode does hydrogen gas form? (1)
4. What is the name of the product which leaves the cell? (1)
5. Give TWO applications of the product formed in 2.4. (2)
6. What purpose does the porous diaphragm serve? (2)
7. The chlorine gas produced, dissolves in water to form chlorine water. Write down a balanced equation for the reaction that takes place. (2)

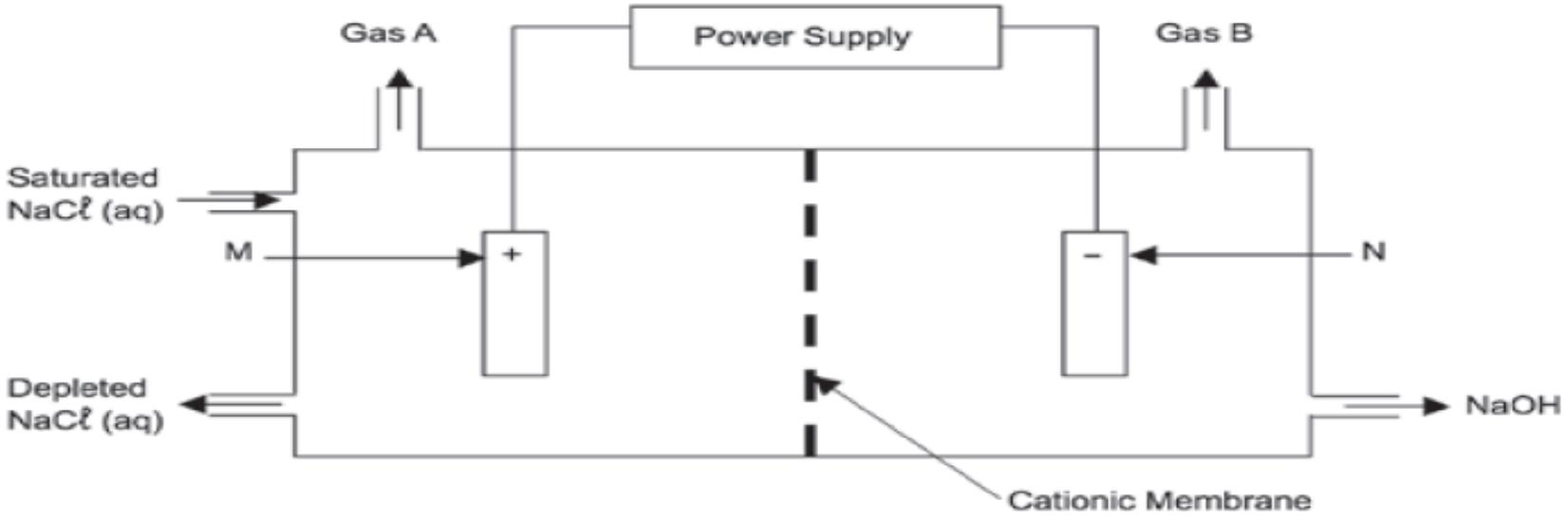
[11]

MEMBRANE CELL

- Solutions
- 1. 2Cℓ–(aq) → Cℓ2(g
- 3
-) + 2e–3 (2)
- 2. Anode 3 (1)
- 3. Cathode 3 (1)
- 4. Sodium hydroxide 3 (1)
- 5. Making soap and detergents3 ; paper3 ; rayon and other fibre3 s;
- dyeing textiles 3 (any 2) (2)
- 6. Stops chlorine passing through; helps to separate sodium
- hydroxide from NaCℓ(aq). 3 3 (2)
- 7. Cℓ2 + H2O → HCℓ + HOCℓ (2)
- 3 3
- [11]

MEMBRANE CELL

The diagram below shows a type of **membrane cell** used in the chlor-alkali industry.



1. Name the gases A and B
2. Why is the membrane called a cationic membrane?
3. Write down the half-reaction that takes place at electrode N.
4. Apart from its use in household products, name ONE industrial use of chlorine.
5. Explain why this electrolytic process cannot be done in one large container without a membrane.

THE MEMBRANE CELL

Solutions

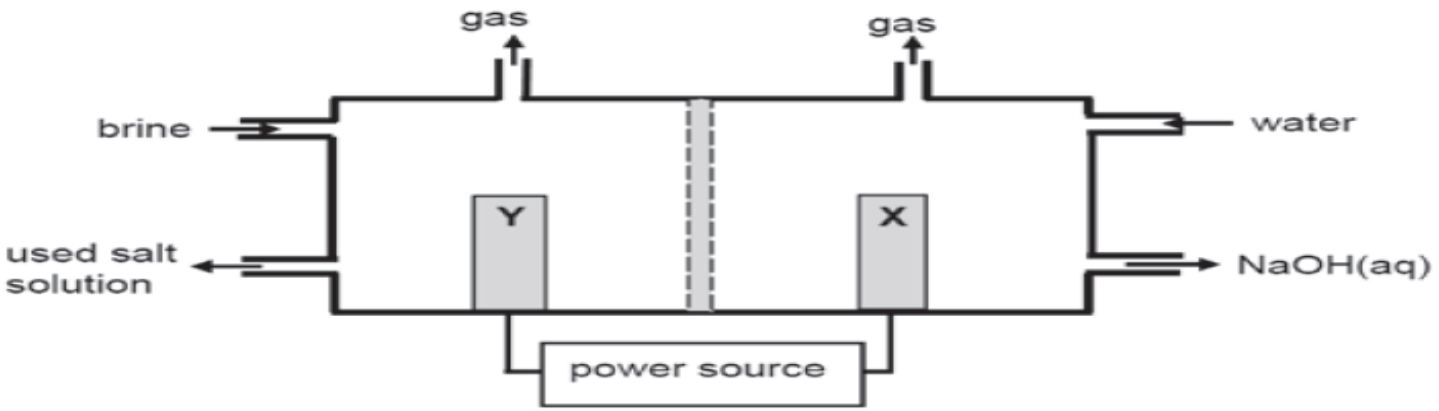
1. A: Chlorine

   B: Hydrogen
2. Allows only the positive ions (cations) to pass through it.
3. $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
4. Manufacture of PVC, paper, drugs, etc

   Disinfectant for water
5. In a single pot the chlorine will react with water to form chlorine water/or the chlorine will react with the OH^- ions to form bleach OR the products formed will be contaminated

THE MEMBRANE CELL

The simplified diagram of a cell used in the chlor-alkali industry is shown below.



1. Write down the CHEMICAL FORMULA of brine. (1)
2. At which electrode, **X or Y** is chlorine gas formed? (1)
3. Write down a half-reaction that explains the formation of hydrogen gas at one of the electrodes. (4)
4. The purity of the sodium hydroxide produced in the chlor-alkali industry depends on the extent to which it is separated from the chlorine gas produced by this cell. Briefly describe how chlorine gas and sodium hydroxide are prevented from mixing in this cell. (2)
5. Apart from the advantages and disadvantages of products produced, write down for this process:
   - 5.1 ONE positive impact on humans. (1)
   - 5.2 ONE negative impact on humans (1)

[10]

MEMBRANE CELL

Solutions

1. $NaC\ell$ (aq) ✓ (1)
2. Y ✓ (1)
3. $2H_2O$ ✓ + $2e^-$ ✓ → H_2 ✓ + $2OH^-$ ✓ (4)
4. The membrane prevents chloride ions from moving to the cathode ✓, only allows positive ions through. ✓ (2)

5.1 Job creation resulting in more people having a better life. ✓ (1)

5.2 Uses huge amounts of electricity ✓ resulting in load shedding.

OR

Chemical plant uses a lot of space that could have been used for housing/gardens, etc. ✓ (any one) (1)

[10]