THEME: REDOX REACTIONS

TOPIC 16: INDUSTRIAL PROCESSES

Competency: The learner appreciates the principles behind some industrial processes and the importance of the products formed.

By the end of this topic, the learner should be able to;

a) *know about some of the main industries that produce useful chemicals, such as the oil industry for our organic chemicals, the production of metals, the acid industry, the alkali industry, the fertiliser industry and the cement industry (k, u)*
b) *understand the processes for obtaining useful chemicals from rocks (k, u)*
c) *understand the processes involved in extracting and purifying metals, with particular reference to processes used in Uganda (k, u)*
d) *understand the importance of nitrates as fertilisers in food production and know how they are produced from the nitrogen in the air(k, u)*
e) *outline four industrial processes that make use of natural resources obtained in Uganda*
f) *recognise the importance of industrial processes in utilising natural resources to make useful chemicals, and appreciate that industrial processes have social benefits and cause problems of pollution and environmental destruction. (u, s)*
g) *describe some of the dangers to the community arising from these industrial processes and the steps that may be taken to minimise these dangers (u)*
h) *understand the process in the manufacture of lime and cement(u)*
i) *understand the production of alkali and chlorine by the electrolysis of salt solution (u)*
j) *evaluate uses of synthetic polymers(u)*

Introduction:

One of the main purposes of chemistry is to make the best use of the limited raw materials that occur naturally. ***Industrial processes involve chemical, physical and mechanical processes that aid the manufacture different products usually carried out on a large scale.*** These processes are carried out basing on particular principles. Therefore in this topic, you will appreciate the principles behind some industrial processes and the importance of the products formed.

Main industries that produce useful chemicals

These include;

- oil industry for our organic chemicals.
- Metal processing industry (production of metals).
- Acid industry.
- Alkali industry.
- Fertilizer industry.
- Cement and lime industry etc.

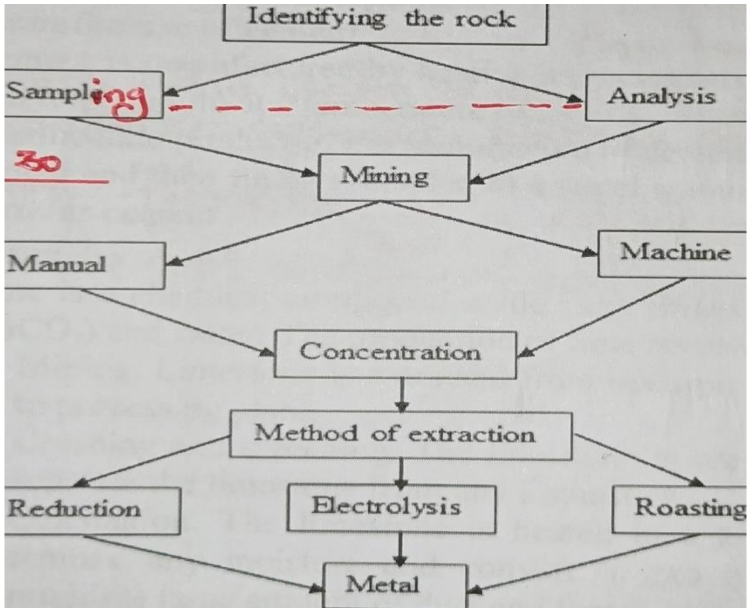
Assignment:

List some common products and identify which of the main chemical industries in Uganda were involved in their production

Processes for obtaining useful chemicals from rocks

Rocks contain useful chemicals such as mineral elements which can be extracted and used. These mineral elements are contained in ores which are found in rocks e.g. haematite is an ore of iron, copper pyrite is an ore of copper.

The flow chart below summarises the processes of obtaining useful chemicals from rocks.



Extraction and purification of metals in Uganda

<u>Extraction and purification of iron</u>

The chief ores from which iron can be extracted are;

- haematite (iron(III) oxide,Fe_2O_3)
- magnetite (Fe_3O_3)
- siderite or spathic iron (iron(II) carbonate)

The **ores** are crushed and **roasted in air to drive off water**, spathic iron loses carbon dioxide and forms **iron(III) oxide**.

$$FeCO_3(s) \rightarrow FeO(s) + CO_2(g);\ \ 4FeO(s) + O_2(g) \rightarrow 2Fe_2O_3(s)$$

The **roasted ore** is mixed with **coke** and **limestone** and dropped into the **blast furnace. Hot air at 800 ^{0}C** is blown into the bottom of the furnace, the following reactions occur;

The **coke burns in the air forming carbon dioxide** and producing temperatures up to 1700 ^{0}C.

$$C(s) + O_2(g) \rightarrow CO_2(g) + heat$$

Higher up the furnace, the **carbon dioxide is reduced by unburnt hot coke to carbon monoxide.**

$$CO_2(g) + C(s) \rightarrow 2CO(g)$$

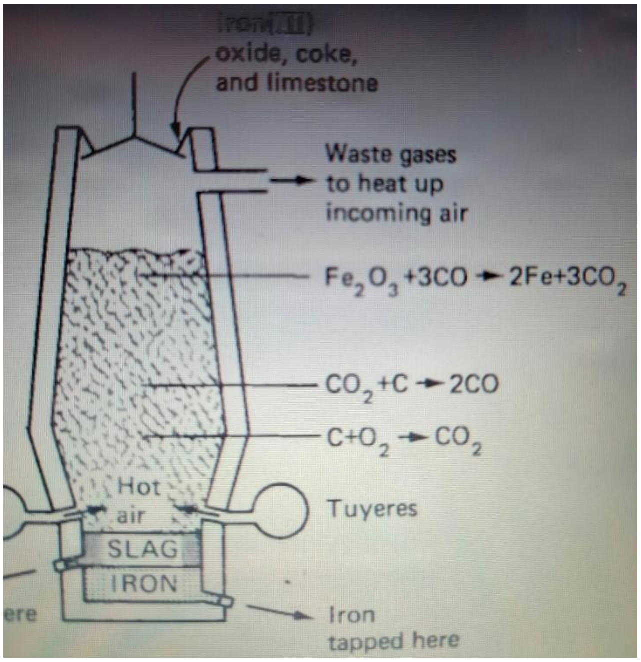
The **carbon monoxide formed reduces the iron oxides (haematite, magnetite) to molten iron.**

The **limestone is decomposed by the heat in the furnace to calcium oxide,** this then **combines with sand (silica) present as an impurity in the iron ore to form a slag of calcium silicate.**

Both **molten iron and slag run to the bottom of the blast furnace** and are **tapped off separately from time to time**. **The molten iron is allowed to solidify in moulds in wet sand** and the **product formed is called pig iron or cast iron.**

The cast iron is **impure** and **heating it with haematite (iron(III) oxide) in a furnace** gives **wrought iron** which is the **purest form of iron.**

Blast furnace



Task:

1. What are the main ores from which iron is extracted?
2. What raw materials are required during the extraction of iron?
3. Sand is one of the impurities found in iron ores. How is this impurity removed?
4. How is pure iron obtained from impure iron?

Side effects of the production process

- The un reacted carbon dioxide can escape into the atmosphere causing global warming, mitigated by recycling the carbon dioxide.
- Emission of heat from the furnace causing rise of temperature of the surrounding environment, which affects the people, mitigated by installing heat absorbers around the furnace.
- Emission of poisonous gases leading to air pollution that may cause suffocation hence illness or death, mitigated by treatment of these gases before emission to the atmosphere

Social benefits

- Source of employment opportunities, hence improved income and therefore better standards of living.
- Increased government revenue through taxes hence improvement of infrastructure such as roads, schools, health facilities leading development of the society.
- Provision of market for goods of the community members, hence generating income, leading to better lives.

Extraction and purification of copper

Copper is extracted mainly from sulphide ores such as **copper pyrite, $CuFeS_2$.**

The ore (copper pyrite, $CuFeS_2$) is **first concentrated by froth flotation.** During the process, the ore (copper pyrite) is crushed into a fine powder and added to water containing a frothing agent in a **concentration tank**, the mixture then **agitated by blowing air**. **Copper bearing particles collect in the froth and are skimmed off**, the concentrate may contain up to 25 % of copper.

The **concentrated ore** is then **roasted in air** to obtain copper(I) sulphide, iron(II) oxide and sulphur dioxide i.e.

copper pyrites + oxygen → copper(I) sulphide + iron(II) oxide + sulphur dioxide

$$[2CuFeS_2(s) + 4O_2(g) \rightarrow Cu_2S(s) + 2FeO(s) + 3SO_2(g)]$$

The **product of the roasting is heated in a reverberatory furnace with sand (silica).** Iron(II) oxide **reacts with silica** to form **iron(II) silicate as a slag, the slag is poured off.**

Iron(II) oxide + silica → iron(II) silicate(slag)

The copper(I) sulphide is further **heated in a regulated supply of air** to form **blister copper (impure copper)**.

$$(Cu_2S(s) + O_2(g) \rightarrow 2Cu(s) + SO_2(g))$$

The **impure copper is then refined (purified) by electrolysis** using **acidified copper(II) sulphate solution** as an electrolyte in an **electrolytic cell.** The **anode is made of impure copper** and the **cathode is made of pure copper**. During the process, the **impure copper anode dissolves in the electrolytic solution**, **forming copper(II) ions** which then **migrate to the cathode, gain electrons and are discharged as pure copper.**

Reaction at the anode: $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$

Reaction at the cathode: $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

The pure copper is then packed and transported for sell.

Dangers/side effects of the process of production and the mitigations.

- Release of sulphur dioxide causes air pollution resulting into acid rains that affect plant growth and also causes global warming, mitigated by treatment of the gas or installing catalytic converters in the exhaust pipes.
- Exposure to copper fumes or dust can cause poisoning leading to cancer and even death, mitigated by personal protective equipment.

Social benefits of the production process

- Source of employment opportunities, hence improved income and therefore better standards of living.
- Increased government revenue through taxes hence improvement of infrastructure such as roads, schools, health facilities leading development of the society.
- Provision of market for goods of the community members, hence generating income, leading to better lives.

Extraction and purification of aluminium

Aluminium is extracted by electrolysis of its oxide (aluminium oxide) which occurs as **hydrated aluminium oxide (bauxite,$Al_2O_3.2H_2O$)**

Raw materials;

- Bauxite ($Al_2O_3.2H_2O$).
- Concentrated sodium hydroxide solution (NaOH).

Process of production

The process involves purification of bauxite followed by electrolysis of pure aluminium oxide.

Purification of bauxite;

The **bauxite ore** which **contains impurities (silica, iron oxides, titanium(IV) oxide)** is first **roasted in air to drive off any water in the ore, any iron(II) oxide present is converted to iron(III) oxide.**

The ore is then **crushed into a fine powder** and **heated in autoclaves (tank) with concentrated sodium hydroxide solution**, **aluminium oxide dissolves** forming a solution of sodium aluminate(III), **some silica also dissolves as sodium silicate** while **iron(III) oxide and titanium(IV) oxide remain undissolved**, the **undissolved impurities are filtered off.**

Carbon dioxide is bubbled through the filtrate to **precipitate aluminium hydroxide** leaving the sodium silicate in solution.

The **aluminium hydroxide is filtered off, washed, dried and heated strongly to obtain pure aluminium oxide which is then electrolysed.**

$$[2Al(OH)_3(s) \rightarrow Al_2O_3(s) + 3H_2O(l)]$$

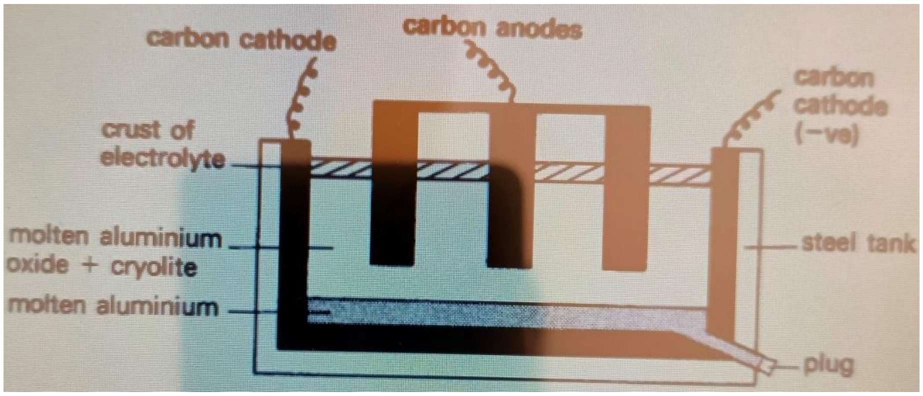
Electrolysis of pure aluminium oxide

The **pure aluminium oxide is dissolved in a molten mixture of cryolite and calcium fluoride**, then **electrolysed** at 850^{0}C in a **steel tank lined with carbon cathode**, **carbon anodes dip into the electrolyte**. **Aluminium ions move to the cathode, gain electrons and form aluminium** i.e.

$$\mathbf{Al^{3+}(l) + 3e^- \rightarrow Al(l)}$$

The aluminium formed then collects on the flow of the cell and is tapped off.

Steel container used for electrolysis



Side effects and mitigations

- Water pollution, mining operations and aluminium processing plants release toxic chemicals into water sources contaminating the water which harms aquatic animals as well as people.

Social benefits

- Source of employment opportunities, hence improved income and therefore better standards of living.
- Increased government revenue through taxes hence improvement of infrastructure such as roads, schools, health facilities leading development of the society.
- Provision of market for goods of the community members, hence generating income, leading to better lives.

FERTILIZER INDUSTRY

The production of fertilisers improves the production of farm produce for farmers in less fertile areas. There are two types of fertilisers;

1. Organic fertilisers derived from plant animal waste e.g. cow dung, chicken droppings, etc.
2. Synthetic or inorganic fertilizer made by man in industries, they contain one or more of the major elements required by plants for good growth. Examples are ammonium nitrate, ammonium sulphate, urea etc.

Importance of nitrates as fertilisers in food production.

Nitrogen is the main constituent of air and essential for living organisms. Plants require nitrogen to grow and animals obtain the nitrogen by feeding on plants. However, nitrogen gas must first be converted into nitrates that can be used by plants and animals as sources of nitrogen.

Nitrogen is primarily absorbed through fine roots as ammonium nitrate. Nitrogen is used in the manufacture of ammonia and fertilisers mainly ammonium fertlilisers such as urea, ammonium nitrate and ammonium sulphate.

Task

1. What is the importance of nitrogen?

2. What is the importance of nitrates as fertilisers in food production?

Production of nitrates as fertilisers (i.e. ammonium nitrate) from the nitrogen in the air

Raw materials are;

- Nitrogen
- Hydrogen
- Nitric acid

Process of production

Nitrogen gas from **fractional distillation of liquid air** and **hydrogen gas** from **natural gas** are **mixed in a volume ratio of 1:3 respectively** in a **reactor vessel.** The mixture is then passed over **finely-divided iron catalyst** at a **temperature of about 500 ^{0}C** and **pressure of 200 atmospheres**, a reaction occurs forming **ammonia gas.**

Nitrogen + Hydrogen ↔ Ammonia

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$$N_2(g) + 3H_2(g) \leftrightarrow 2NH_3(g) + \text{Heat}$$

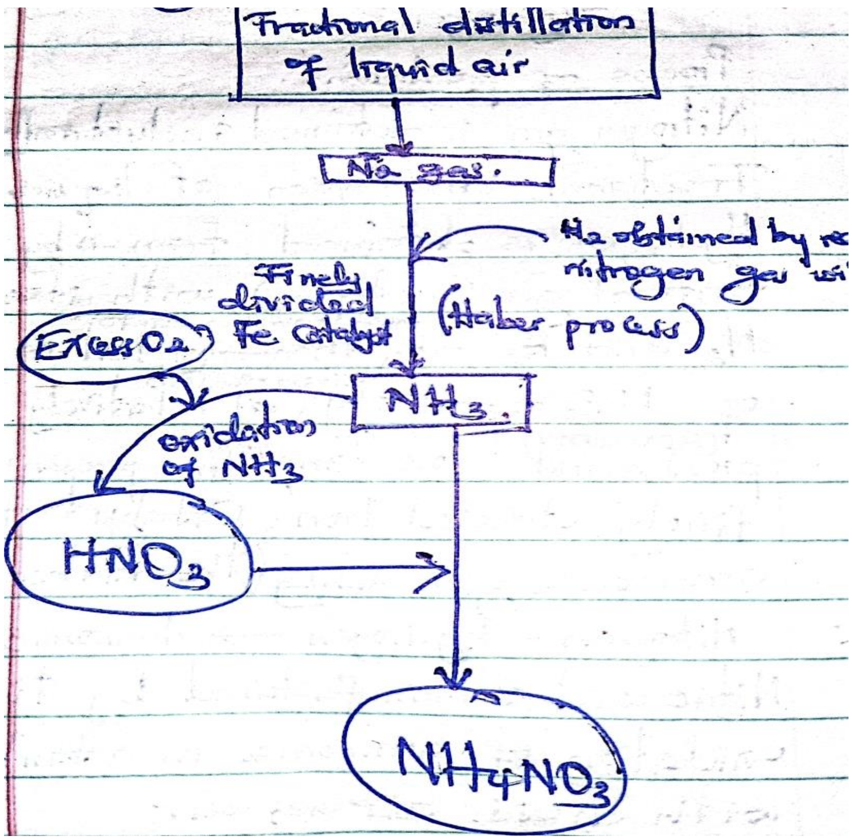
The ammonia formed is **either dissolved in water or liquefied** then packed for storage.

Nitric acid is manufactured by the **oxidation of ammonia in a tank filled with excess air**, the nitric acid **(concentrated)** is then **reacted with aqueous ammonia** in a **tank** to obtain **ammonium nitrate** fertiliser.

(Ammonia + nitric acid → ammonium nitrate)

The ammonium nitrate is **further concentrated and converted to solid form** then packed for storage.

Flow diagram



Other ammonium fertilisers (urea and ammonium sulphate) can be manufactured from ammonia as follows;

Urea

Ammonia is **reacted with carbon dioxide** at **high pressure** in a **tank** to form **urea** and water.

Ammonia + carbon dioxide → urea + water

The urea formed is **concentrated and converted to solid form** then packed for storage.

Ammonium sulphate

Sulphuric acid is obtained industrially through the contact process.

Ammonia is then **reacted with sulphuric acid** in a **tank** forming **ammonium sulphate.**

(ammonia + sulphuric acid → ammonium sulphate)

The ammonium sulphate is **further concentrated and converted to solid form** then packed for storage.

Dangers/side effects of the process of production (manufacture of fertilisers) and the control measures that should be taken to mitigate them

1. Pollution of water bodies due to release of industrial waste
2. Emission of ammonia, nitrogen oxides and sulphur oxides can pollute the air, causing respiratory problems and environmental issues, mitigated by installing catalytic converters to convert them to less toxic substances.

Social benefits:

- Source of employment opportunities, hence improved income and therefore better standards of living.
- Increased government revenue through taxes hence improvement of infrastructure such as roads, schools, health facilities leading development of the society.
- Provision of market for goods of the community members, hence generating income, leading to better lives.

Industrial processes that make use of natural resources obtained in Uganda

Several industrial processes make use of natural resources as raw materials for manufacturing various products. These processes include;

- Manufacture of lime and cement.
- Manufacture of chlorine and sodium hydroxide.
- Extraction and purification of metals.
- Manufacture of ammonia and ammonium fertilisers etc.

Task:

For each industrial process above;

a) Explain the process.
b) Identify the social benefits.
c) Identify some of the dangers to the community arising from the industrial process.
d) Identify steps taken to minimize the above dangers.

The manufacture of lime and cement (the lime and cement industry)

Cement and lime are of great importance in most societies. These materials are useful in the construction of houses, roads and other infrastructure.

Manufacture of cement

Cement is a mixture of calcium silicates and aluminates made by strongly heating limestone and clay.

Raw materials are;

- Limestone
- clay
- gypsum

Process of production

The **limestone** obtained from the quarry is **mixed with clay** in the correct proportions and crushed into a fine powder. The fine powder is mixed with little water and allowed to flow as sludge down a **slopping, rotating cylinder** where it is **strongly heated** at about 1500 ^{0}C.

Limestone decomposes to calcium oxide and carbon dioxide. The **calcium oxide formed reacts with silica and aluminium oxide from the clay** to give a mixture of calcium silicates and aluminates, called **clinker.** The resulting clinker is allowed to cool then **ground with a small amount of gypsum** to **form cement as a fine powder**.

Cement is then packed in bags ready for use.

Side effects of the process of production

- Carbon dioxide emissions to the atmosphere can cause global warming, this is mitigated by recycling of carbon dioxide.
- Inhalation of air contaminated with cement dust causes respiratory diseases, mitigated by wearing personal protective equipment.
- Effluent discharge from the cement plant can contaminate water bodies, affecting aquatic life and quality of water, mitigated by treatment of waste water through sedimentation and filtration before discharge / recycling the water with in the plant.

Social benefits

- Source of employment opportunities, hence improved income and therefore better standards of living.
- Increased government revenue through taxes hence improvement of infrastructure such as roads, schools, health facilities leading development of the society.
- Provision of market for goods of the community members, hence generating income, leading to better lives.

Manufacture of lime

Lime can exist in two forms that is, **hydrated lime** and **quick lime**

Raw materials are limestone and water

Process of production

Limestone is crushed into small pieces, then fed into the **lime kiln** where it is strongly heated to high temperatures of about 900 ^{0}C. The high temperature causes **limestone to decompose to quick lime (calcium oxide)** and carbon dioxide.

The quick lime formed is removed from the base of the lime kiln and cooled; cold water is then added to this quick lime to obtain **slaked lime (calcium hydroxide).**

The slaked lime is then passed through various purification processes to remove impurities and excess water. The final lime product is then packed in bags ready for use.

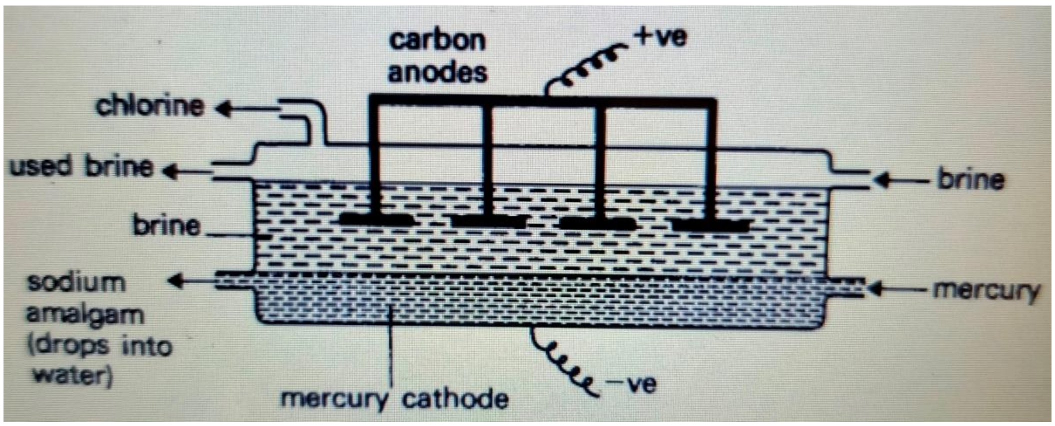
Side effects of the process of production

- Carbon dioxide emissions to the atmosphere can cause global warming, this is mitigated by recycling of carbon dioxide.

Alkali industry

Production of alkali (sodium hydroxide) and chlorine by the electrolysis of salt solution

Mercury cathode cell



The raw material used is **brine (concentrated sodium chloride solution)**

Process of production

Chlorine and sodium hydroxide are manufactured by the electrolysis of brine (concentrated sodium hydroxide solution) using **graphite anode** and **mercury cathode** in a **mercury cathode cell.**

The ions present in the electrolytic solution (concentrated sodium hydroxide solution) are sodium ions(Na^+), chloride ions(Cl^-), hydroxide ions(OH^-) and hydrogen ions(H^+). These ions migrate to oppositely charged electrodes.

The chloride ions and hydroxide ions migrate to the anode, the chloride ions being in high concentration than the hydroxide ions are preferentially discharged by electron loss, forming chlorine gas.

$$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$$

The chlorine formed is then collected and stored in tightly closed tanks.

For the production of sodium hydroxide:

The sodium ions and hydrogen ions migrate to the mercury cathode, sodium ions are discharged by electron gain in preference to hydrogen ions because hydrogen ions cannot easily discharge on a mercury surface.

$$Na^+(aq) + e^- \rightarrow Na(s)$$

Sodium and mercury react to form sodium amalgam. The sodium amalgam is then dissolved in water to obtain sodium hydroxide.

The sodium hydroxide solution is evaporated to dryness to obtain solid pellets of sodium hydroxide.

NB: *the production of sodium hydroxide by electrolysis of brine requires water as one of the raw materials.*

Side effects of the process of production

- Inhalation of chlorine can cause death as it is a poisonous gas, mitigated by wearing protective gears.
- Contact with sodium hydroxide causes severe burns to the eyes, skin, digestive system resulting into permanent damage of the body organs and even death, mitigated by wearing personal protective gears.

Social benefits:

- Source of employment opportunities, hence improved income and therefore better standards of living.
- Increased government revenue through taxes hence improvement of infrastructure such as roads, schools, health facilities leading development of the society.

- Provision of market for goods of the community members, hence generating income, leading to better lives.

Polymers (part already covered in s.3)

The term polymer (Gr. Poly, many; meros, parts) describes a very large molecule made by linking together many small molecules (at least several hundreds of them). The small molecules are called monomers and the overall process is called polymerization.

Polymers can be classified into two;

- Natural polymers
- Synthetic polymers

Natural polymers are made by natural processes. Examples are; starch, cellulose, proteins, sugars, fats and oils, silk, natural rubber, wool, cotton etc.

Wool and silk are natural protein fibres, used for making clothes.

Cellulose is a polymer made from glucose units, its present in cotton and wood. Cotton is used for making clothes while wood is used for making papers and furniture.

Synthetic polymers are manufactured in industries. **Most (if not all) synthetic polymers are plastic in nature.** Plastics are solid compounds capable of being moulded and are primarily derived from petroleum.

Examples of synthetic polymers are; polythene, polyester, polystyrene, polytetrafluoroethene (Teflon), nylon, polyvinyl chloride (PVC), Perspex, vulcanized rubber, bakelite, Kevlar etc.

Uses of synthetic polymers

Assignment:

Research on the properties and uses of the following synthetic polymers (plastics).

Properties and uses of polythene

Properties and uses of polyester

Properties and uses of polystyrene

Properties and uses of polytetrafluoroethene (Teflon)

Properties and uses of nylon

Properties and uses of polyvinyl chloride

Properties and uses of Perspex

Properties and uses of vulcanized rubber

Properties and uses of bakelite

Properties and uses of kevlar

Methods of disposal of synthetic polymers

- Incineration: involves burning plastics in the absence of air.
- Recycling; involves melting the wasted plastics and remoulding them into new products.
- Re-use; some waste plastics can be re-used e.g. plastic water bottles can be used to water plants.

Environmental effects of non-biodegradable synthetic polymers

- Non-biodegradable synthetic polymers remain unchanged in the environment for a long time thus causing environmental pollution.
- When they are burnt, they produce toxic gases that cause air pollution.

Uses of biodegradable polymers

- Can be used in food packaging, garbage bags and wrappers.
- Can be used for making disposable cups.