APPLIED CHEMISTRY (12 periods)

WATER

Water is the commonest liquid on earth and is a compound of the elements hydrogen and oxygen with the formula H_2O. The major **sources of water** include; rain, rivers, lakes, seas, springs, oceans, boreholes and so on. Natural water is not pure because it contains dissolved solids, dissolved gases and suspended solids particles. It is then purified for different uses.

USES OF WATER

a) Domestic uses of water

- Used for drinking
- Used for washing
- Used for bathing
- Used for cooking
- Used when cleaning i.e. mopping

b) Industrial/ large scale uses of water

- For generating hydroelectric powder
- It is used as a solvent/ raw material in the manufacture of beverages (i.e. sodas and beers), ethanol, nitric acid, sulphuric acid and so on.
- Used in irrigation of plants
- Used as a cooling agent in machines.

CAUSES OF WATER POLLUTION

Water pollution refers to contamination of water sources with undesirable substances which may be toxic to living organisms. The sources of water pollution include the following and majorly result from domestic and industrial activities.

i. Use of fertilizers. Fertilizers are usually used in agriculture to improve on the crop yields and are discharged into water bodies through run off. They are rich in plant nutrients and once leached into water bodies, they cause eutrophication (supporting group of plant life).

ii. Discharge of soluble toxic fumes into the water bodies like sulphur dioxide fumes, oxides of nitrogen and so on which make water acidic hence affecting living organisms.

iii. Dumping of garbage near water bodies or into the water bodies hence polluting water bodies.

iv. Discharge of hot water into the water bodies from power stations. This increases the temperatures within the water bodies hence affecting the living organisms.

v. Discharge of oil spills into water bodies from oil tankers during loading or accidents and from oil factories.

vi. Discharge of untreated sewage from domestic and industrial sources into the water bodies. Such water may cause diseases like cholera, typhoid and so on.

HARD AND SOFT WATER

Soft water is a type of water which easily forms lather with soap. Rain water is a good example of soft water and it is good for washing since it does not contain dissolved salts.

Hard water is the type of water which does not easily form lather with soap. This is caused due to the presence of dissolved magnesium ions and calcium ions in water.

Causes of hard water

Hard water is caused due to the presence of dissolved magnesium or calcium ions in water in the form of magnesium hydrogen carbonate, calcium hydrogen carbonate, magnesium sulphate and calcium sulphate. These ions combine with the stearate ions from the soap solution forming insoluble magnesium stearate or calcium stearate (scum)

TYPES OF HARD WATER

There are two types of hard water.

1. **Temporary hard water.**
   This is the type of hard water which can be made soft by boiling the water. It is caused by the presence of dissolved **magnesium hydrogen carbonate,** $\boldsymbol{Mg(HCO_3)_2}$ or **calcium hydrogen carbonate**, $\boldsymbol{Ca(HCO_3)_2}$in water.

Temporary hard water is formed when rain water dissolves in carbondioxide gas from air forming weak carbonic acid.

$$CO_2\,(g) + H_2O\,(l) \rightleftharpoons H_2CO_3\,(aq)$$

When this water containing carbonic acid comes into contact with a rock containing limestone (calcium carbonate/ magnesium carbonate) it dissolves some of it forming corresponding hydrogen carbonate.

$$CaCO_3\,(s) + H_2CO_3\,(aq) \longrightarrow Ca(HCO_3)_2\,(aq)$$

$$MgCO_3\,(s) + H_2CO_3\,(aq) \longrightarrow Mg(HCO_3)_2\,(aq)$$

This runs to rivers, wells and lakes causing temporary hardness in water.

2. Permanent hardness of water

This is the type of hard water which does not become soft on boiling the water. It is caused due to the presence of dissolved **calcium sulphate, $CaSO_4$** or **magnesium sulphate, $MgSO_4$** in water which do not decompose on heating.

REMOVAL OF WATER HARDNESS

Water hardness can be removed by using physical and chemical means.

a) Methods of removing only temporary hardness

1. Boiling the water. The soluble calcium hydrogen carbonate or magnesium hydrogen carbonate decompose on heating to form insoluble calcium carbonate or magnesium carbonate respectively, which is then filtered off.

$$Ca(HCO_3)_2\,(aq) \longrightarrow CaCO_3\,(s) + H_2O\,(l) + CO_2\,(g)$$

$$Mg(HCO_3)_2\,(aq) \longrightarrow MgCO_3\,(s) + H_2O\,(l) + CO_2\,(g)$$

2. Addition of aqueous ammonia solution. The soluble calcium hydrogen carbonate or magnesium hydrogen carbonate is converted to insoluble calcium carbonate or magnesium carbonate respectively, which is filtered off.

$$Ca(HCO_3)_2\,(aq) + 2\,NH_3\,(aq) \longrightarrow CaCO_3\,(s) + (NH_4)_2CO_3\,(aq)$$

$$Mg(HCO_3)_2\,(aq) + 2\,NH_3\,(aq) \longrightarrow MgCO_3\,(s) + (NH_4)_2CO_3\,(aq)$$

3. Addition of calcium hydroxide solution. The soluble calcium hydrogen carbonate is converted to insoluble calcium carbonate which is filtered off. The amount added must be controlled because excess of the solution will make the water hard again.

$$Ca(HCO_3)_2\ (aq) + Ca(OH)_2\ (aq) \longrightarrow 2\ CaCO_3\ (s) + 2\ H_2O\ (l)$$

$$Mg(HCO_3)_2\ (aq) + Ca(OH)_2\ (aq) \longrightarrow CaCO_3\ (s) + MgCO_3\ (s) + 2\ H_2O\ (l)$$

b) Methods of removing both temporary and permanent hardness

1. Distillation. This involves evaporating the water leaving the dissolved salts behind. This method is expensive.

2. Addition of sodium carbonate solution or washing soda. It converts the soluble salts into insoluble salts which are filtered off.

$$Ca(HCO_3)_2\ (aq) + Na_2CO_3\ (aq) \longrightarrow CaCO_3\ (s) + 2\ NaHCO_3\ (s)$$

$$CaSO_4\ (aq) + Na_2CO_3\ (aq) \longrightarrow CaCO_3\ (s) + Na_2SO_4\ (aq)$$

3. Ion exchange (use of permutit): It involves the use of zeolites and resins. Zeolites/ resins are complex organic polymers that produce de-ionised water. They remove hardness by precipitating magnesium ions or calcium ions in water forming insoluble compounds which are filtered off.

$$Na_2Z\ (aq) + CaSO_4\ (aq) \longrightarrow Na_2SO_4\ (aq) + CaZ\ (s)$$

$$Ca(HCO_3)_2\ (aq) + Na_2Z\ (aq) \longrightarrow NaHCO_3\ (s) + CaZ\ (s)$$

Advantages of hard water

- It provides calcium and magnesium ions to the body which is good for formation of strong teeth and bones as well as in formation of strong egg shells.
- It does not affect lead pipes. Hard water forms a coating of lead(II) carbonate and sulphate inside lead water pipes. This prevents further reaction between the water and lead unlike soft water which dissolves the lead that is poisonous to the body.
- Hard water is used for brewing beer because of its pleasant taste.

Disadvantages of hard water

- It wastes soap since one needs a lot of soap to form lather while washing.
- Soap reacts with hard water to form scum which leaves dirty marks on clothes.

$$Ca^{2+}(aq) + 2\,St^{-}(aq) \longrightarrow CaSt_2(s)$$

- Hard water forms fur in kettles and sauce pans. This layer of fur is a bad conductor of heat and so wastes fuel.
- Hard water forms boiler scales which are poor conductors of heat and so wastes fuel. This narrows the boiler pipes which may be blocked causing a rise in steam pressure that may burst the pipes.

How to differentiate between hard water and soft water

Separately add a known volume of soap solution to equal volumes of samples of hard water and soft water. **Observation:** Soft water easily forms lather with soap solution whereas hard water does not form lather with soap.

PURIFICATION OF WATER

The process of removing pollutants from water involves the following stages.

a) **Filtration:** Dirty/ impure water is passed through the screen to trap any big particles. It is then passed through coarse sand or clean gravels to filter out larger insoluble particles. The sand also contains grown microbes which removes some of the bacteria.
b) **Sedimentation:** After filtration, the water obtained is not pure enough since it contains very tiny particles that must be removed. This is done by adding powdered potash alum (potassium aluminium sulphate) to the water which coagulates/ precipitates out the impurities which are further removed by filtration through the fine sand.
c) **Chlorination and fluoridation:** To the clear water obtained after sedimentation is added a recommended amount of chlorine so as to kill the harmful bacteria. In some plants a fluoride compound is also added so as to fight tooth decay.

d) P^H adjustment

Addition of chlorine to the water lowers its P^H. Therefore, sodium carbonate is added to the water so as to correct its P^H.

SEWAGE

Sewage is the product formed when domestic and industrial waste matter enters the water. It contains some organisms which can cause diseases like typhoid and cholera when ingested by humans. Therefore, sewage must be treated before getting into water bodies.

Treatment of domestic sewage

In the primary stages/ treatment, sewage is passed through the screens to remove large solid particles like wood, grass, metals and plastics. It is then passed into a chamber where sand, gravels and silt are made to settle out of the suspension. The effluent from the primary stage is brought into contact with oxygen and aerobic micro-organisms, which breaks down much of the organic matter to harmless substances like water and carbon dioxide gas. Chlorine is then added to the resultant effluent so as to reduce the content of bacteria. This is the secondary treatment. The effluent is then returned to water bodies.

BIOGAS

Biogas is a mixture of gases produced by action of bacteria on animal and plant wastes in the absence of air (oxygen). Biogas **mainly contains methane** with small amounts of ammonia gas, carbon monoxide gas and hydrogen sulphide gas.

NB: Biomass is a mass of naturally grown plants and animal material that can provide energy. Examples of such materials include; wood, food, plant and animal wastes as well as agricultural wastes. Biomass is an important source of biogas and ethanol.

Raw materials used in the production of biogas

The raw materials include; urine, cow dung, human waste, plant wastes (water hyacinth), sludge from sewage treatment and so on.

Manufacture of biogas

The wastes are put in a container (generator/ digester), mixed with some little water and then covered to prevent oxygen from getting into contact with the mixture. The container and the contents are maintained at room temperature ($25^oC - 30^oC$). The bacteria then digest the rotten material to biogas by anaerobic decomposition.

NOTE:

- The quality of biogas produced depends on the materials fed into the digester.
- The residue formed (sludge) is used as fertilizers because of its high nitrogen content.

Advantages of biogas production

i. Biogas is easy and cheap to produce.
ii. It saves forests which would be destroyed for the production of fire wood and charcoal.
iii. The bi-product can be used as a fertilizer since they are rich in nitrogen.
iv. It reduces on the pollution problem since the organic wastes are used up in the process.
v. Improves on sewage management since the sewage waste materials can be converted into biogas.
vi. It reduces on the spread of water hyacinth since it is harvested for use as a raw material.

Disadvantages of biogas production

i. It produces other gases like hydrogen sulphide and ammonia that are poisonous and can cause eye irritations.
ii. It produces pollutants when burnt such as sulphur dioxide gas.
iii. Dry fermented manure forms very fine particles which may cause some nosal problems.

EXTRACTION OF METALS

Metals are found combined with other elements in the earth's crust known as ores. **An ore** is a naturally occurring mineral from which a metal and other certain elements can be extracted. During extraction, more than one element can be extracted from an ore.

General methods of extraction of metals

1. **Electrolysis.** It is used for extraction of metals higher in electrochemical series (very reactive metals) by electrolysis of their molten ores. Examples include; potassium, sodium, calcium, magnesium and aluminium.
2. **Chemical reduction.** This method is suitable for extraction of moderately reactive metals like zinc, iron and lead. Their ores are first roasted in air to form metal oxides which are later reduced using carbon or carbon monoxide gas.
3. **Thermal decomposition.** it is used for extraction of metals lower in the electrochemical series like carbon, silver, mercury and gold

Summary

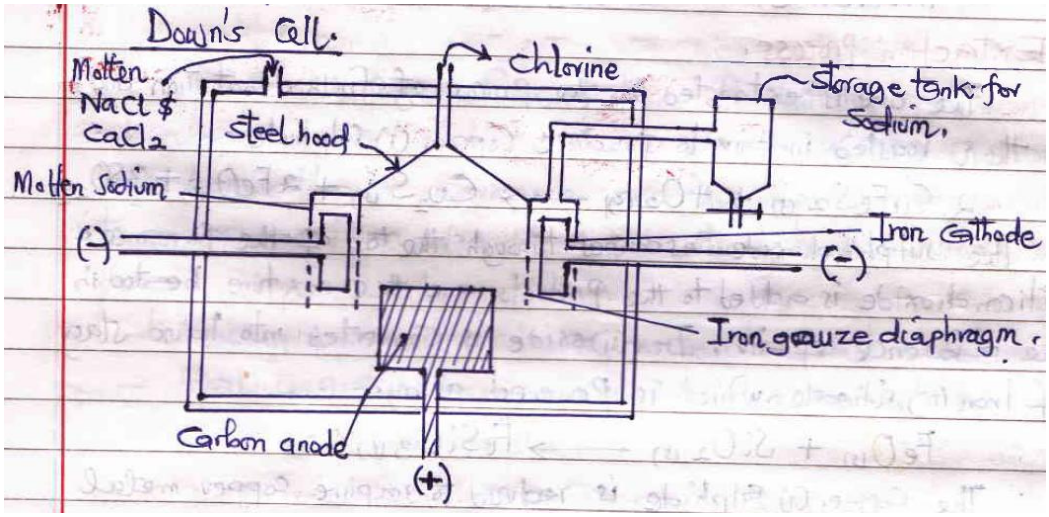
Metal	Method of extraction
Potassium, *Sodium*, *Calcium*, *Magnesium*, *Aluminium*	Metals above carbon are extracted from their molten ores by electrolysis.
Carbon	
Zinc, *Iron*, *Lead*	Metals below carbon are extracted from their ores by reduction using carbon.
Copper, *Silver*, *Mercury*, *Gold*	Copper can be extracted by thermal decomposition of the sulphide in the presence of oxygen.

EXTRACTION OF SODIUM

Sodium occurs in a number of compounds which include; sodium carbonate, sodium nitrate, sodium chloride etc.

Extraction process

Sodium is extracted by electrolysis of molten sodium chloride by the Down's cell.



Sodium metal is extracted by electrolysis of molten sodium chloride to which calcium chloride is added to lower its melting point from 800^{o}C to about 600^{o}C so as to lower the costs of maintaining the molten ore at high temperatures. The Down cell consists of an iron cathode and carbon anode separated from each other using steel gauze to prevent the violent reaction of sodium and chlorine which could reform sodium chloride. Chlorine gas produced as the by-product at the anode is collected in a cylinder. Molten sodium collects in the inverted trough, placed over the cathode, rises up the pipe, and is tapped off and collected under dry nitrogen to prevent sodium from reacting.

Equation at the

a) Anode:

$$2\,Cl^{-}(aq) - 2e \longrightarrow Cl_2(g)$$

b) Cathode:

$$Na^{+}(aq) + e \longrightarrow Na(s)$$

Uses of sodium metal

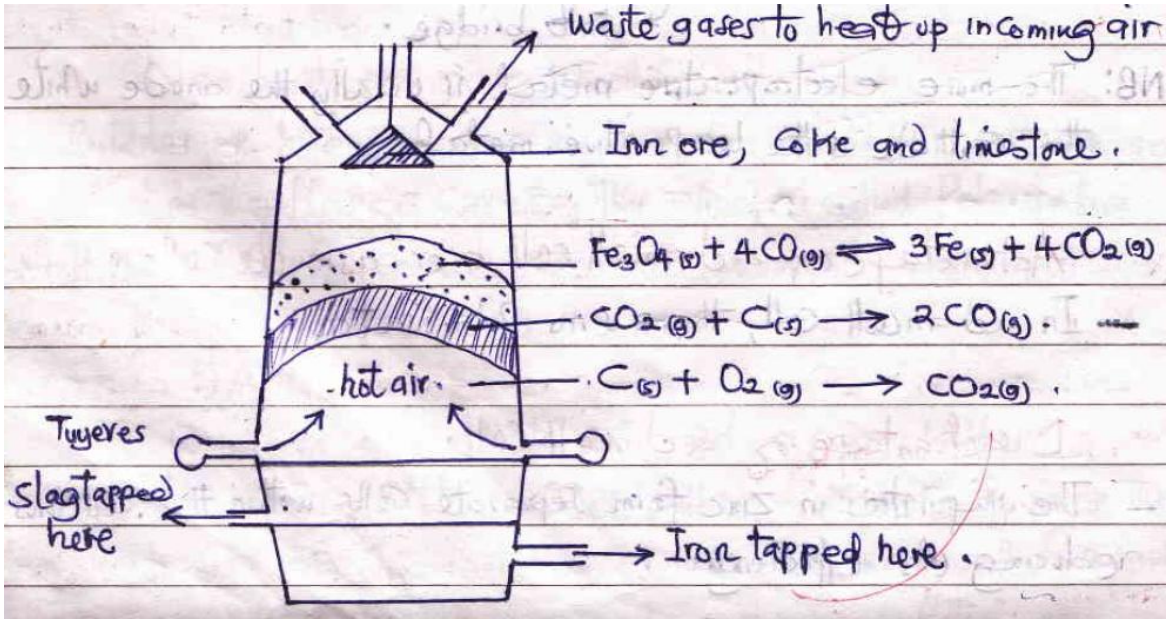
i. Used in the manufacture of sodium cyanide used in the extraction of gold.
ii. Used in the manufacture of sodium peroxide used in the preparation of hydrogen peroxide.
iii. Used as a coolant in nuclear reactions.
iv. Used in sodium vapour lamps for street lighting. The lamps have a characteristic orange glow.
v. Used in the manufacture of anti-knock compounds e.g. tetraethyl lead which slows down the combustion process of a mixture of petrol and air.

EXTRACTION OF IRON

The main ores of iron include;

i. Haematite (impure iron (III) oxide), Fe_2O_3.
ii. Magnetite (tri iron tetra oxide), Fe_3O_4.
iii. Spathic iron ore/ siderite (iron (II) carbonate), $FeCO_3$.

Process of extraction



The ore is first roasted in air to dry off the water and the carbonate decomposes to form iron (III) oxide and carbondioxide gas.

$$4\ FeCO_3\ (s) + O_2\ (g) \longrightarrow 2\ Fe_2O_3\ (s) + 4\ CO_2\ (g)$$

The roasted ore is mixed with coke and limestone and fed into the blast furnace from the top. Hot air at 1900^{o}C is blown into the furnace from the bottom through the tubes called tuyeres. The hot air reacts with the coke to form carbon dioxide gas and heat.

$$C\ (s) + O_2\ (g) \longrightarrow CO_2\ (g)$$

As the carbon dioxide gas rises up the furnace where there is little supply of oxygen, it gets in contact with hot coke and it is reduced to carbon monoxide gas. This process is endothermic and the temperature of the furnace drops to 1100^{o}C.

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

Carbon monoxide gas produced then reduces the iron ore into molten iron. This process is also an endothermic process and the temperature of the furnace drops further to 700^{o}C.

$$Fe_2O_3\ (s) + 3\ CO\ (g) \rightleftharpoons 2\ Fe\ (l) + 3\ CO_2\ (g)$$

At this stage, there is need to use excess carbon monoxide gas to reduce all the oxides completely. The limestone decomposes to produce calcium oxide and more carbon dioxide gas.

$$CaCO_3\ (s) \longrightarrow CaO\ (s) + CO_2\ (g)$$

The calcium oxide combines with sand (silicon dioxide) which is present as an impurity to form a liquid slag (calcium silicate).

$$CaO\ (s) + SiO_2\ (s) \longrightarrow CaSiO_3\ (l)$$

NOTE:

- The liquid slag floats on top of the iron since it less dense than iron from where it is tapped off. It also prevents the oxidation of iron by carbon.

- The major use of limestone is to remove the impurities which are removed off as liquid slag.

Cast iron (pig iron)

This is an impure form of iron with about 4% carbon and small quantities of silicon, phosphorus and sulphur. Cast iron is brittle and cannot be welded. *It is used for making cookers, stoves, iron boxes, engine blocks, bases of Bunsen burners and hot water pipes.*

Wrought iron

This is the purest form of iron. It contains 99% iron with about 0.25% carbon. It is made by heating cast iron with hematite in a furnace and the impurities are converted into gaseous oxides. Wrought iron is strong and malleable. ***Wrought iron is used for*** *making iron nails, chains, horse shoes and iron sheets, farm machines and magnets and making alloys e.g. steel.*

STEEL

This is the general name for alloys of iron. The types of steel include;

Type of steel	**Property**	**Composition**	**Uses**
Manganese steel	Very tough	13% manganese	Making rock breaking machinery and railway cross over.
Stainless steel	Does not rust	20% chromium 10% nickel	Used for making cutlery, surgical instruments, car bumpers etc.
High speed steel (Tungsten steel)	Very hard and less brittle	5% chromium 18% tungsten	Making edges of high speed cutting tools.
Mild steel		99.5% iron 0.5% carbon	Car bodies, large structures.
Hard steel		99% iron 1% carbon	Cutting tools, razor blades

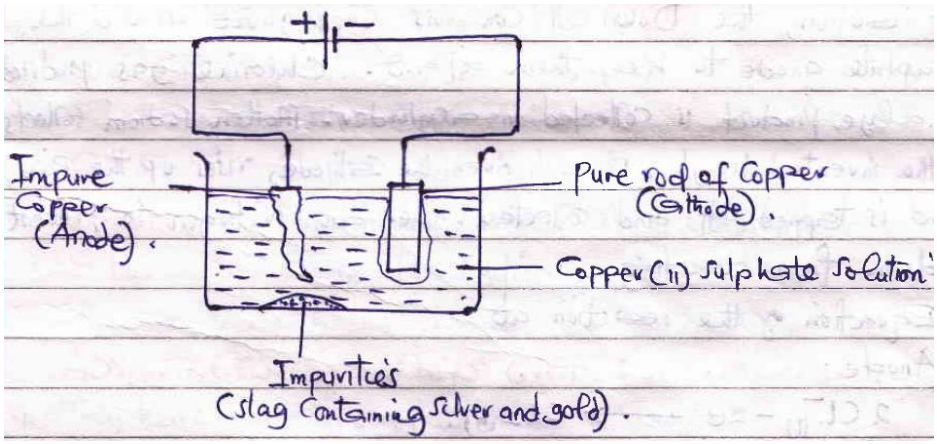
EXTRACTION OF COPPER

The principle ores of copper include;

i. Copper pyrites, $CuFeS_2$.
ii. Cuprites, Cu_2O.
iii. Copper (I) sulphide, Cu_2S.
iv. Malachite, $CuCO_3$. $Cu(OH)_2$.

Purification of copper

The impure copper is purified by electrolysis of copper (II) sulphate solution using the impure rod as the anode and a strip of pure copper as the cathode.



During electrolysis, impure copper anode dissolves, and the copper (II) ions are reduced and deposited at the cathode as pure copper. The reactions are;

At the anode:

$$Cu\ (s)\ -\ 2e \longrightarrow Cu^{2+}\ (aq)$$

Observation: It decreases in size.

At the cathode:

$$Cu^{2+}\ (aq)\ +\ 2e \longrightarrow Cu\ (s)$$

Observation: A reddish- brown solid is deposited.

Uses of copper

i. Making ornaments because it is not easily attacked by air.
ii. Making alloys e.g. brass, bronze, duralumin etc.
iii. Pure copper can be shaped into wires and rods used for electrical conduction.

ALLOYS

An alloy is the uniform mixture of two or more metals or a mixture of a metal with a non metal. The table below shows some common alloys, their composition and uses.

Alloy	**Composition**	**Uses**
Brass	Copper and zinc	Making ornaments, buttons and screws.
Bronze	Copper and tin	Making ornaments.
German silver	Copper, nickel and zinc	Making silver coins
Duralumin	Aluminium with small amounts of magnesium, manganese and copper	Used for making aircraft and bicycle parts.
Solder	Tin and lead	Used for joining metals
Steel	**Refer to extraction of iron**	

Summary

BCZ: Better Conn Zainah

BCT: Brother Come Tomorrow

DAMC: Don't Allow Michael Marry Christine

STL: Some Tea Lydia

GCNZ: George Can Not Zoom

Advantages of alloys over pure metals

i. They have a better appearance.
ii. Alloys are less malleable and ductile.

MANUFACTURE OF SUGAR

Sugar is a form of carbohydrates. Sugar canes contain 15% by mass sucrose.

Procedure

Sugarcanes are crushed and the juice squeezed out. The sugar cane juice is diluted with water and to it is added lime (calcium oxide) to precipitate the impurities such as proteins and organic acids. The impurities are filtered off and the resulting solution is evaporated to form a thick brown liquid. The thick liquid is distilled to form sugar crystals suspended in a brown liquid called molasses. The mixture is centrifuged and washed to separate the sugar crystals from molasses. The brown colour in the sugar is removed by filtering the sugar through animal charcoal.

NB: Molasses also contain sugar and so they are used as animal feeds, fertilizers and for brewing.

Properties of sugar

1. It is a white crystalline solid in its pure form.
2. It dissolves readily in water but it is slightly soluble in ethanol.
3. It is insoluble in organic solvents.
4. It decomposes on heating to form a dark brown liquid called **caramel**. The caramel when mixed with little vinegar can be used in the manufacture of sweets.
5. When concentrated sulphuric acid is added to sugar crystals, *the white solid swells forming a black solid and a colourless vapour is given off.*

$$C_{12}H_{22}O_{11}\ (s) \xrightarrow{\text{Conc. } H_2SO_4} 12\ C\ (s) + 11\ H_2O\ (l)$$

Uses of sugar

i. Used form making sweets and cakes.
ii. Used for coating tablets to make them sweet.
iii. Used in the manufacture of syrups and oral dehydration salts.
iv. For sweetening foods.
v. It is a source of glucose and fructose.