CARBON

AND SOME OF ITS COMPOUNDS

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Organizer

(20 Lessons)

Objectives

By the end of this chapter, the learner should be able to:

(a) Define the terms allotropy and allotropes.

(b) State and explain some physical and chemical properties of carbon.

(c) Describe the laboratory preparation of carbon (IV) and carbon (II) oxides

(d) State and explain the physical and chemical properties of carbon (IV) and carbon (II) oxide
(e) State the uses of carbon, carbon (IV) and carbon (II) oxides.
(f) Describe the chemical properties of carbonates and hydrogen carbonates.
(g) Describe the extraction and manufacture of sodium carbonate.
(h) State the effects of carbon (IV) and carbon (II) oxides on the environment.

CARBON

AND SOME OF ITS COMPOUNDS

Carbon is the first element in group (IV) of the periodic table. It has an electron arrangement of 2.4. It forms covalent bonds in most of its compounds.

It occurs in the **pure state** as **diamond and graphite,** and in the impure state as **amorphous carbon.** It also occurs in the **combined state** in compounds such as **carbonates, mineral oils, organic matter, and carbon (IV) oxide.**

Carbon and its allotropes

Allotropy is the existence of an element in more than one form, in the same physical state. The different forms are called **allotropes**.

Carbon has two naturally occurring allotropes, **diamond** and **graphite**.

Carbon can be manipulated using energy such as laser beams to form other allotropes known as fullerenes or 'buckyballs'.

Diamond

This is one of the stable allotropes of carbon. It is a colourless, transparent shiny crystalline solid.

In diamond, carbon **uses all the four valence electrons to form covalent bonds**. Since it uses all the four electrons in the outermost energy level for bonding, it **does NOT conduct both electricity and heat.**

Diamond has a density of 3.51 g/cm^3. The **high density is due to continuous close packing of carbon atoms.**

Diamond has a high melting point (3700°C). The **high melting point is due to the strong covalent bonds.**

Diamond is one of the hardest naturally occurring substances. **The hardness is due to the uniformity of covalent bonds between the atoms throughout the structure.**

Diamond has a giant atomic structure in which each carbon atom is bonded to four other carbon atoms arranged in a regular tetrahedron shape. The whole structure of diamond extends in all directions forming a rigid mass of atoms.

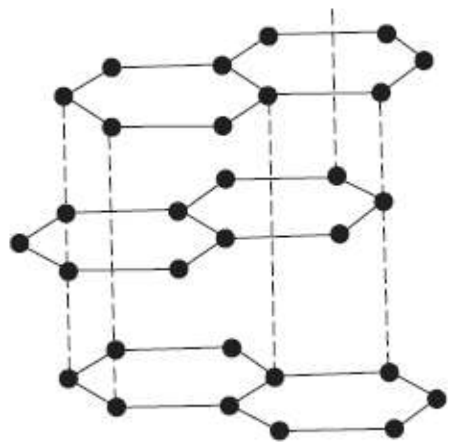
Diamond is found in some parts of India, South Africa and in Tanzania where it is mined. It is used as a **jewel** because of its **shiny appearance when polished.** It is used in **glass cutters and drill bits** because **of its hardness.**

Graphite

This is another stable allotrope of carbon. It is a **black, soft, slippery crystalline solid.** Graphite is made up of **hexagonally arranged carbon atoms bonded together in layers** where each atom is bonded to **three carbon atoms**. The layers are held together by **van der Waals forces.**

Graphite has a density of 2.3g/cm^3. The **low density is due to the spaces between the layers**. It is **soft and slippery** because the **layers in the structure can slide over each other due to the weak van der Waals forces**.

In graphite, each carbon atom uses only three electrons in the outer energy level to form covalent bonds with other carbon atoms. **One electron** in the outer energy level of each atom is **not used in bonding**. It is **delocalised hence graphite conducts heat and electricity.**



Both melting point (3500°C) and boiling point (4800°C) of graphite are **high because of the strong covalent bonds between the atoms in its layers.** Graphite has a giant atomic structure in which layers are held together by van der Waals forces.

The **high melting point** and **its slippery nature** makes graphite a **good lubricant in moving machine parts where a lot of heat is produced**.

The high melting point also makes graphite useful in **making moulds for casting metals**. It has **delocalised** electrons within its structure hence is used as an **electrode**.

Graphite is **mixed with clay to make pencil 'leads' becaus**e the carbon layers **can slide over each other.** Graphite is found in South Africa, Brazil, Sweden, Germany and U.S.A.

Fullerenes

Fullerenes are **synthetic allotropes of carbon**. They are found in different shapes such as spherical, tubular or elliptical. The best known fullerene is the **spherical C_{60} molecule** which consists of hexagonally arranged carbon atoms similar to the panels of some soccer balls.

Amorphous Carbon

This is an **impure form of carbon**. Examples are **charcoal, soot, coke and coal**. They contain small amounts of graphite. They **do not conduct electricity or heat, because of the irregular arrangement of graphite crystals in their structure.**

Amorphous carbon especially charcoal has the ability to **adsorb gases and liquids**. It is therefore used in **gas masks**.

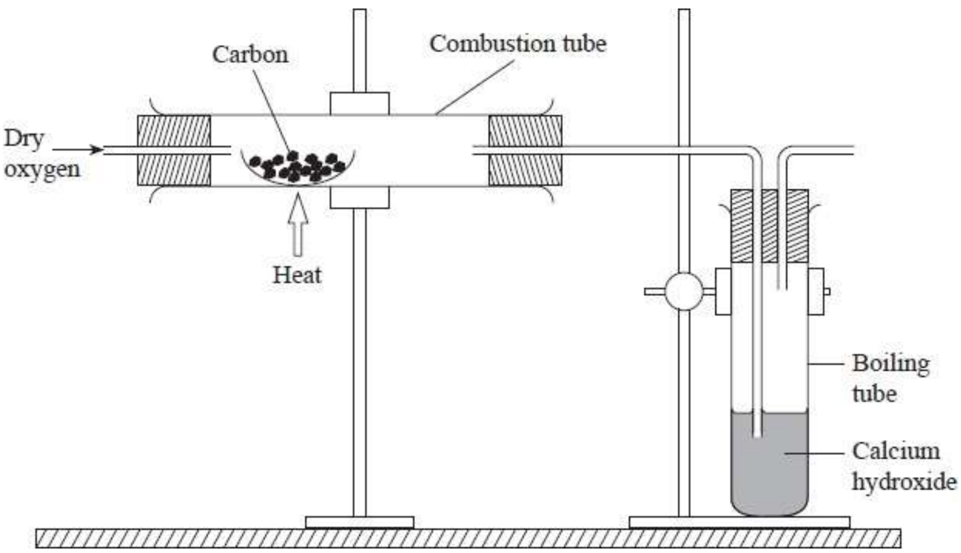
Charcoal is used to **adsorb colored impurities in sugar refining industries.**

Carbon black is mixed with rubber in the manufacture of **tyres as a filler to improve tensile strength and reduce wear and tear. It also gives tyres the black appearance.**

Chemical Properties of Carbon

Burning in air

When carbon is heated, it glows red. A colourless gas is produced which reacts with calcium hydroxide to form a white precipitate. The red glow shows that the reaction produces heat. The white precipitate shows that the gas produced is carbon (IV) oxide.



When pure carbon is used in this experiment there is no residue in the combustion tube.

Carbon + oxygen ⟶ carbon (IV) oxide

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

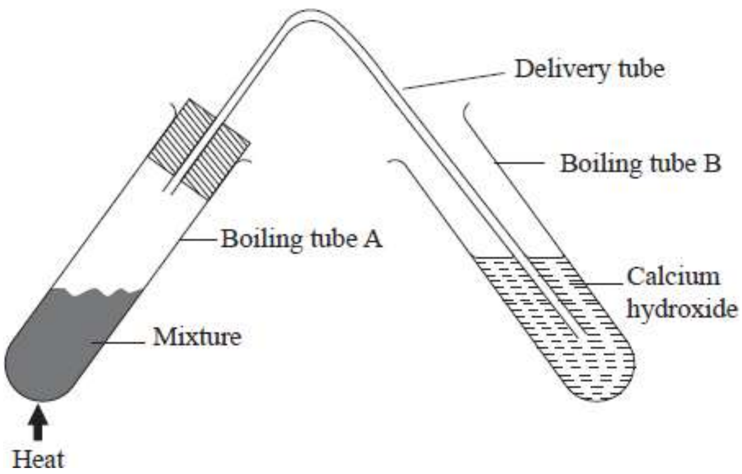
Carbon (IV) oxide + Calcium hydroxide ⟶ Calcium carbonate + water

$$CO_2(g) + Ca(OH)_2(aq) \longrightarrow \underset{(white)}{CaCO_3(s)} + H_2O(l)$$

All forms of carbon burn in oxygen to produce carbon (IV) oxide. However, the **temperature at which they burn varies from one allotrope to another.**

Reducing property of carbon.

Place a small amount of copper (II) oxide and powdered charcoal in a test tube and mix well. Set up the apparatus as shown and heat.



Effect of heating carbon with some metal oxides

When a mixture of copper (II) oxide and carbon is heated the black mixture turns into a brown powder. A colourless gas produced forms a white precipitate with calcium hydroxide. The brown powder is copper metal and the colourless gas is carbon (IV) oxide.

Copper (II) oxide + Carbon $\longrightarrow$ Copper + Carbon (IV) oxide

$$2CuO(s) + C(s) \longrightarrow 2Cu(s) + CO_2(g)$$

(black) (black) (brown) (colourless)

Similarly, carbon removes combined oxygen from zinc oxide, lead (II) oxide and iron (III) oxide.

$$2PbO(s) + C(s) \longrightarrow 2Pb(s) + CO_2(g)$$

(yellow) *(black)* *(grey)* *(colourless)*

Lead (II) oxide + Carbon $\longrightarrow$ Lead + Carbon (IV) oxide

$$2ZnO(s) + C(s) \longrightarrow 2Zn(s) + CO_2(g)$$

(white) *(black)* *(grey)* *(colourless)*

Zinc oxide + Carbon $\longrightarrow$ Zinc + Carbon (IV) oxide

Iron (III) oxide + Carbon $\longrightarrow$ Iron + Carbon (IV) oxide

$$2FeO(s) + C(s) \longrightarrow 2Fe(s) + CO_2(g)$$
(brown) (black) (grey) (colourless)

Carbon has the ability to **remove combined oxygen from some metals**. In these reactions, carbon is **oxidised** to **carbon (IV) oxide** and the metal oxides are **reduced to metals**.

In terms of competition for combined oxygen, carbon can be placed in the reactivity series of metals between Aluminium and Zinc. Thus, it **reduces the oxides of all the metals below it in the reactivity series**. Therefore, carbon is a **reducing agent**.

Potassium	K
Sodium	Na
Calcium	Ca
Magnesium	Mg
Aluminium	Al
Carbon	**C**
Zinc	Zn
Iron	fe
Tin	Sn
Lead	Pb
Hydrogen	**H**
Copper	Cu
Silver	Ag
Gold	Au
Platinum	Pt

The reactivity series of metals showing the position of carbon and hydrogen.

The **reducing property** of carbon is used in the **extraction of metals from their oxides.**

At temperatures of about 1200°C, carbon reduces steam to hydrogen gas. Carbon is in turn oxidised to carbon (II) oxide. A mixture of the two gases is called **water gas**.

Carbon + Steam ⟶ Carbon (II) oxide + Hydrogen

Reaction of Carbon with concentrated nitric (V) acid and sulphuric acids

Carbon **reduces** hot concentrated **nitric acid to brown nitrogen (IV) oxide gas and water**. Carbon is in turn **oxidized to carbon (IV) oxide gas**.

Hot **concentrated sulphuric acid** is **reduced to sulphur (IV) oxide** and **water** while **carbon is oxidized to carbon (IV) oxide** gas. Both sulphur (IV) oxide and carbon (IV) oxide react with calcium hydroxide to form a white precipitate of calcium sulphite and calcium carbonate respectively.

Carbon + Conc. Nitric (V) acid ⟶ Nitrous (IV) oxide + Carbon (IV) oxide + water

$$C(s) + 4HNO_3(l) \longrightarrow \underset{(brown)}{4NO_2(g)} + CO_2(g) + 2HO_2(l)$$

Carbon + Conc. Sulphuric (VI) acid ⟶ Sulphur (IV) oxide + carbon (IV) oxide + water

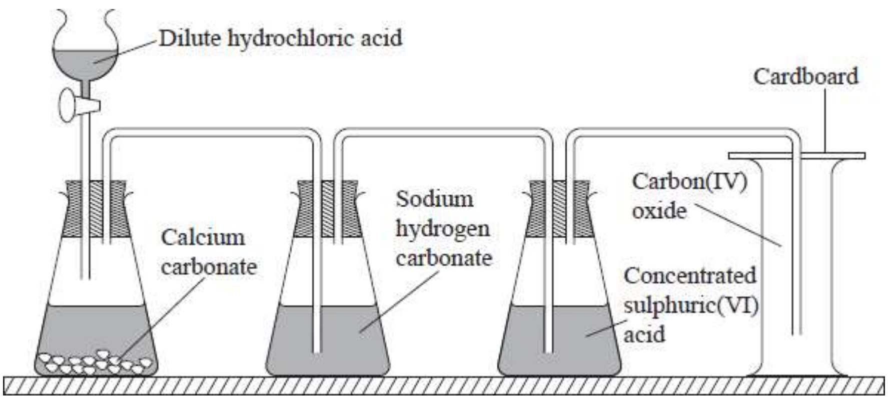
$$C(s) + 2H_2SO_4(l) \longrightarrow 2SO_2(g) + CO_2(g) + 2H_2O(l)$$

The two hot concentrated acids react with carbon because they are strong oxidizing agents.

Carbon (IV) oxide (CO_2)

This is the most stable oxide of carbon. In carbon (IV) oxide, the carbon atom forms strong covalent bonds with two oxygen atoms. Carbon (IV) oxide is a **molecular substance.** The gas accounts for 0.03% of the volume of air. However, it occurs in some regions at a higher concentration due to various activities such as volcanic action. In Kenya, these regions are: Esageri near Eldama Ravine and Kerita in Kimabu where commercial tapping of the gas is done.

Preparation of Carbon (IV) oxide



Carbon (IV) oxide is prepared by reacting calcium carbonate with dilute hydrochloric acid.

Questions

1. **What is observed in the conical flask containing the reactants?**

When dilute hydrochloric acid is added to calcium carbonate, a **vigorous effervescence occurs releasing carbon (IV) oxide gas**.

2. Write an equation for the reaction that occurs between calcium carbonate and dilute hydrochloric acid.

Calcium carbonate + Dil. hydrochloric acid ⟶ Calcium chloride + Carbon (IV) oxide + Water

$$CaCO_3(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$

3. Explain the purpose of sodium hydrogen carbonate in this set-up.

The gas is passed through **sodium hydrogen carbonate or water** to remove traces of hydrochloric acid fumes in the gas.

4. Explain why the gas is passed through concentrated suphuric acid.

When required **dry**, the gas is passed through **concentrated sulphuric (VI) a**cid which acts as a drying agent.

4. **Suggest an alternative to concentrated sulphuric (VI) acid**.

Anhydrous calcium chloride can be used in place of concentrated sulphuric (VI) acid as a **drying agent**.

6. Which other reactants can be used to prepare carbon(IV) oxide? Is there an exception?

A**ny other carbonate can be used** with a **suitable acid**.

Dilute sulphuric (VI) acid **SHOULD NOT BE** reacted with **calcium carbonate, barium carbonate and lead carbonate**. This is because **insoluble sulphates** produced form a **coating on the carbonates and prevent further reaction**. For the same reasoned dilute hydrochloric acid is not reacted with lead carbonate.

Properties of carbon (IV) oxide

Carbon (IV) oxide is a colourless, odourless gas. It is denser than air and neither burns nor supports combustion. It is an acidic gas and dissolves in water to form weak carbonic acid. As a test for the gas, It forms a white precipitate with calcium hydroxide.

Questions

1. Explain why carbon (IV) oxide is collected by downward delivery.

The gas is **denser than air and this explains why it is collected by down ward delivery.**

1. What deductions can be made about the properties of carbon (IV) oxide gas from the following tests?

(a) Bubbling the gas through water containing the universal indicator.

The gas is acidic, and turns the universal indicator solution **red**.

(b) Inverting separate gas jars of carbon (IV) dioxide in troughs of water and sodium hydroxide solution.

Carbon (IV) oxide gas slightly **dissolves in water** to form **carbonic acid**, a **weak acid**.

$$\text{Carbon (IV) oxide} + \text{Water} \longrightarrow \text{Carbonic acid}$$

$$CO_2(g)\ \text{oxide} + H_2O(g) \longrightarrow H_2CO_3(g)$$

Carbon (IV) oxide gas is **acidic** and **readily reacts with sodium hydroxide** solution to form sodium carbonate.

$$\text{Sodium hydroxide} + \text{Carbon (IV) oxide} \longrightarrow \text{Sodium carbonate} + \text{Water}$$

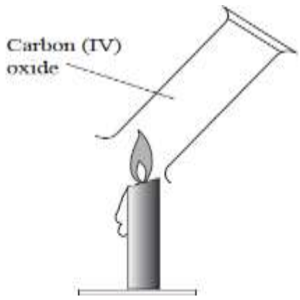
$$2NaOH(aq) + CO_2(g) \longrightarrow Na_2CO_3(aq) + H_2O(l)$$

If the gas is in **excess**, a further reaction occurs that leads to the formation of **sodium hydrogen carbonate.**

$$\text{Sodium carbonate} + \text{Water} + \text{Carbon (IV) oxide} \longrightarrow \text{Sodium hydrogen carbonate}$$

$$Na_2CO_3(aq) + H_2O(l) + CO_2(g) \longrightarrow 2NaHCO_3(aq)$$

(c)Inverting a gas jar full of carbon (IV) oxide over a candle flame as shown below.



Carbon (IV) oxide **neither burns nor supports combustion. This is why the gas puts off a burning candle.**

2. Explain using equations, the change observed when carbon (IV) oxide is bubbled through limewater until there is no further change.

When Carbon (IV) oxide is bubbled through calcium hydroxide for a short while, a white precipitate is formed. The white precipitate is due to the formation of the insoluble calcium carbonate. ***This is the confirmatory test for carbon (IV) oxide*****.**

$$\text{Calcium hydroxide} + \text{Carbon (IV) oxide} \longrightarrow \text{Calcium carbonate} + \text{Water}$$

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

When the gas is passed through the mixture for a while the **white precipitate dissolves to form a colourless solution of calcium hydrogen carbonate.**

$$\text{Calcium carbonate} + \text{Water} + \text{Calcium (IV) oxide} \longrightarrow \text{Calcium hydrogen carbonate}$$

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

4. **Write chemical equations for the reactions that take place when:**

(a) **Magnesium is burnt in carbon (IV) oxide gas.**

Although the gas does not support combustion, **burning magnesium continues to burn in it to produce a white powder of magnesium oxide and black specks of carbon. The burning magnesium produces a lot of heat that decomposes carbon (IV) oxide to carbon and oxygen.**

Magnesium + Carbon (IV) oxide ⟶ Magnesium oxide + Carbon

$$2Mg(s) + CO_2(g) \longrightarrow 2MgO(s) + C(s)$$

The addition of dilute nitric (V) acid dissolves magnesium oxide leaving black specks of carbon.

(b) **Carbon (IV) oxide is reacted with sodium hydroxide solution for a few seconds**.

$$2NaOH(aq) + CO_2(g) \longrightarrow Na_2CO_3(aq) + H_2O(l)$$

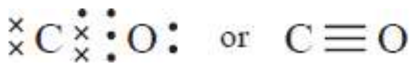
Uses of Carbon (IV) oxide gas

1. Carbon (IV) oxide gas is used as a refrigerating agent for perishable goods. This is because **solid carbon (IV) oxide sublimes when heated, leaving no residue.**
2. Carbon (IV) oxide is used to **extinguish fires** because it is **non-flammable** and has a **higher density than air** therefore it forms a 'blanket' on fire cutting off oxygen supply.
3. It is used in the manufacture of sodium carbonate in the **Solvay process**.
4. Carbon (IV) oxide is dissolved in water to make aerated drinks to add taste, it is also used to make baking powder.

Review Questions: Carbon (IV) oxide

Carbon (II) Oxide

This is another oxide of carbon in which a carbon atom forms three covalent bonds with one



oxygen atom. It is a molecular substance.

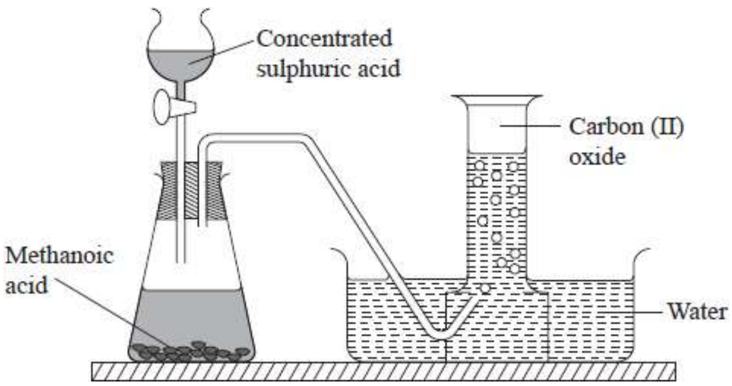
Structure of Carbon (II) oxide

The dot (·) and cross (×) diagram shows the three covalent bonds in a carbon (II) oxide molecule one of which is **a dative bond**.

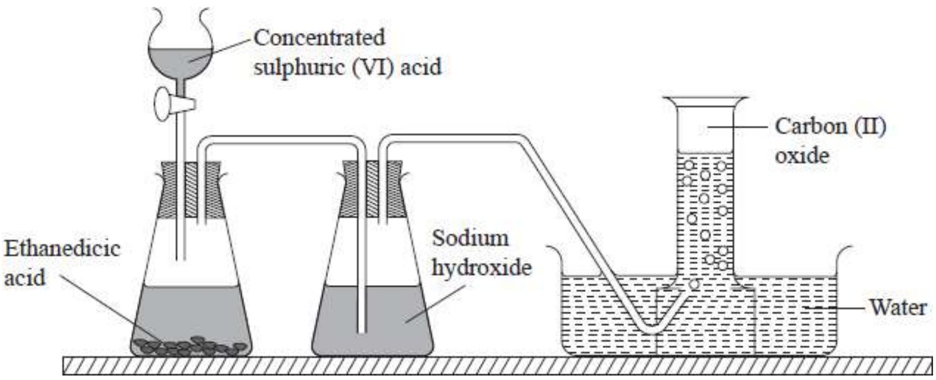
Preparation of carbon (II) oxide

Carbon (II) oxide may be prepared by dehydrating methanoic acid using concentrated sulphuric (VI) acid.

$$\text{Methanoic acid} \xrightarrow[\text{(Conc. } H_2SO_4)]{\text{Conc. sulphuric acid}} \text{Carbon (II) oxide + Water}$$



$$HCOOH(s) \longrightarrow CO(g) + H_2O(l)$$



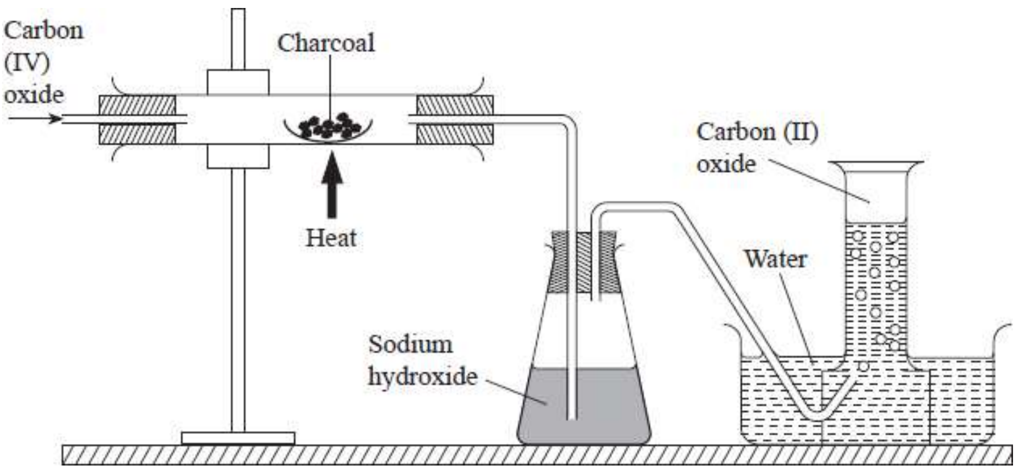
Ethanedioic acid (oxalic acid) may be used in place of methanoic acid as shown below.

$$\text{Ethanedioic acid} \xrightarrow{Conc.\ H_2SO_4} \text{Carbon (II) oxide + Carbon (IV) oxide + water}$$

$$H_2C_2O_4(s) \xrightarrow{Conc.\ H_2SO_4} CO(g) + CO_2(g) + H_2O(l)$$

The gaseous mixture should be passed through a concentrated solution of sodium hydroxide to remove the carbon (IV) oxide, CO_2. The gas may also be prepared by passing Carbon (IV) oxide over heated charcoal as shown in the set up below.

$$\text{Carbon (IV) oxide + Carbon} \longrightarrow \text{Carbon (II) oxide}$$



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

Properties of carbon (II) oxide

Physical properties of Carbon (II) oxide

Carbon (II) oxide gas is colourless, odourless and slightly less dense than air.

It has a low boiling point of -111°C. The low boiling point is because of the weak forces of attraction between the molecules.

The gas is slightly soluble in water. The solution formed is neutral.

The gas is extremely poisonous. It combines with haemoglobin in the blood to form a stable compound known as **carboxy-haemoglobin**. The carboxy-haemoglobin formed prevents formation of oxyhaemoglobin leading to suffocation.

Chemical properties of Carbon (II) oxide

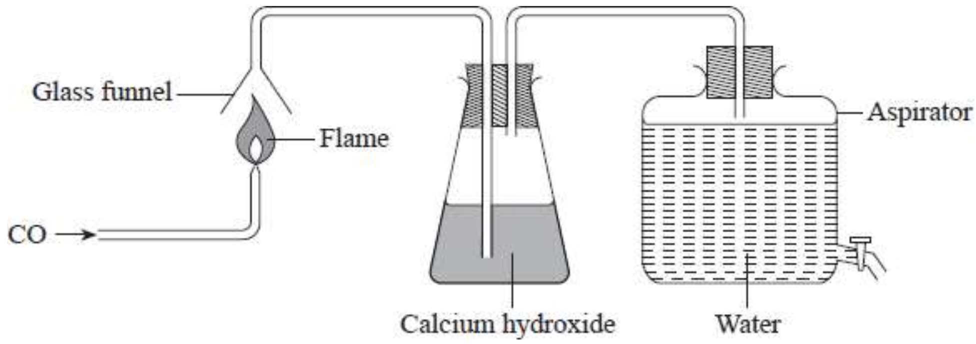
Combustion.

Carbon (II) oxide burns in air with a blue flame to form Carbon (IV) oxide

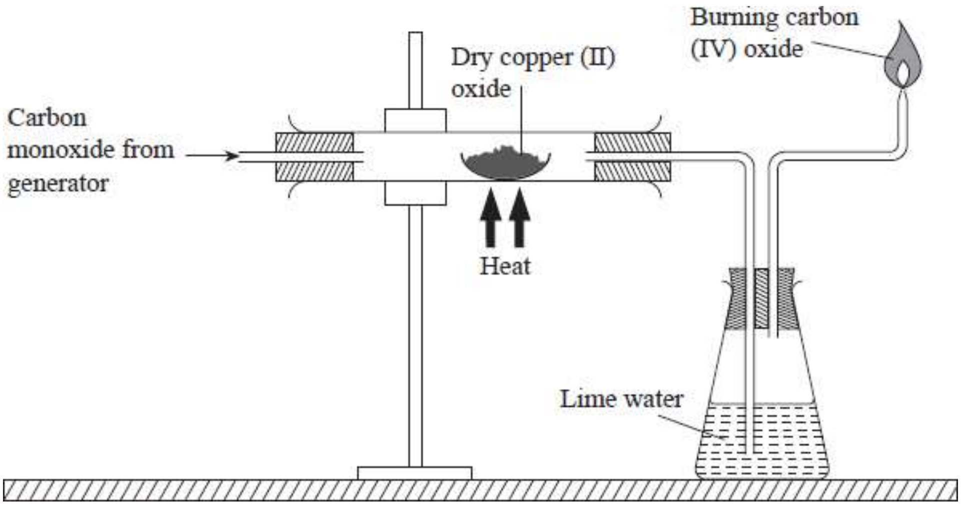
Carbon (II) oxide + Oxygen ⟶ Carbon (IV) oxide

$$2CO(g) + O_2(g) \longrightarrow 2CO_2(g)$$

The set up below is for the combustion of Carbon (II) oxide.



Reduction property.



The following set up that may be used to show the effect of Carbon (II) oxide on hot metallic oxides

Carbon (II) oxide gas readily removes combined oxygen from metals low in the reactivity series such as copper, lead and iron. It is inturn oxidized to carbon (II) oxide. **Therefore carbon (II) oxide is a reducing agent.**

Copper (II) oxide + Carbon (II) oxide ⟶ Copper + Carbon (IV) oxide

$$CuO(s) + CO(g) \longrightarrow Cu(s) + CO_2(g)$$

Zinc (II) Oxide + Carbon (II) oxide ⟶ Zinc + Carbon (IV) oxide

$$ZnO(s) + CO(g) \longrightarrow Zn(s) + CO_2(g)$$

Lead (II) oxide + Carbon (II) oxide ⟶ Lead + Carbon (IV) oxide

$$PbO(s) + CO(g) \longrightarrow Pb(s) + CO_2(g)$$

Iron (III) oxide + Carbon (II) oxide ⟶ Iron + Carbon (IV) oxide

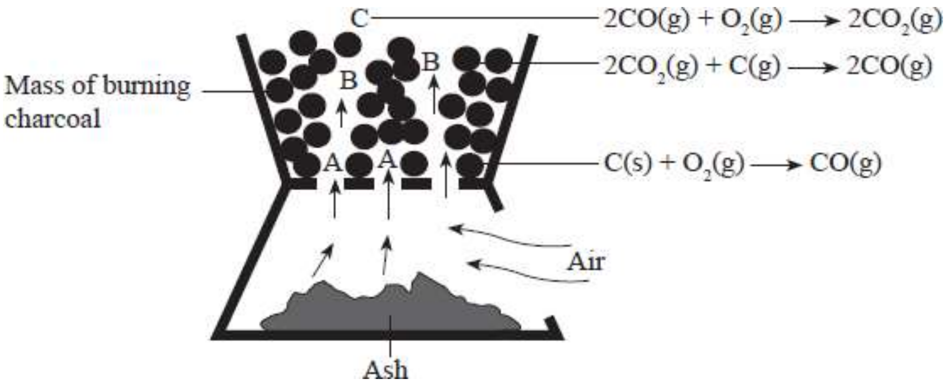
$$Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(s) + CO_2(g)$$

The **reducing property of carbon (II) oxide** makes the gas useful in the **extraction of some metals from their oxides.**

Other Sources of Carbon (II) oxide

Carbon (II) oxide is encountered almost in every day situations through combustion of charcoal and fossil fuels such as kerosene, diesel, petrol and coal.

When charcoal burns in a charcoal stove (jiko) three reactions occur in the various regions



after five as shown below.

Region A: Region a in this region **plenty of air** enters the jiko allowing **complete combustion** of carbon to carbon (IV) oxide.

Carbon + Oxygen ⟶ Carbon (IV) oxide

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

Region B: The carbon (IV) oxide produced in region 'A' rises up to region 'B' where it is reduced.

Carbon (IV) oxide + Carbon ⟶ Carbon (II) oxide

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

Region C: Here, there is **enough oxygen** therefore carbon (II) oxide produced in region B burns to form carbon (IV) oxide.

Carbon (II) oxide + Oxygen ⟶ Carbon (IV) oxide

$$2CO(g) + O_2(g) \longrightarrow 2CO_2(g)$$

In case of insufficient air, some carbon (II) oxide produced in region B is released into the atmosphere. This is common in **poorly ventilated rooms.**

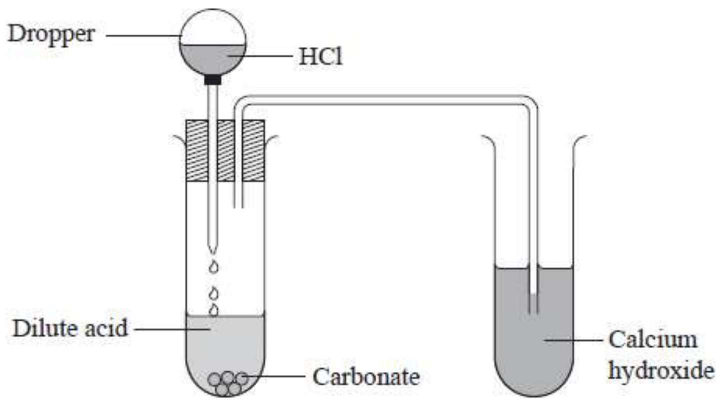
Review Questions: Carbon (II) oxide

Carbonates

Carbonates are salts of metal ions or ammonium ions with carbonate ions. The carbonate ions are indirectly obtained from carbonic acid (H_2CO_3) formed when carbon (IV) oxide is dissolved in water. Carbonates occur naturally in rocks as limestone ($CaCO_3$), malachite ($CuCO_3.Cu(OH)_2$ and dolomite, $CaCO_3.MgCO_3$. In Kenya, dolomite is mined in Kariandusi near Gilgil.

Hydrogencarbonates are salts derived from carbonic acid formed by the partial displacement of hydrogen by a metal or ammonium radical. Hydrogencarbonates of sodium, potassium and ammonium exist as solids at room temperature, where as those of calcium and magnesium only exist in solution. The hydrogen carbonates of other metals do not exist.

Reaction of carbonates and hydrogen carbonates with dilute acids



All carbonates give off carbon (IV) oxide when reacted with acids. For example:
Calcium carbonate + Dil. Hydrochloric acid ⟶ Calcium chloride + Carbon (IV) oxide + Water

$$CaCO_3(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$

Zinc carbonate + Dil. Hydrochloric acid ⟶ Zinc chloride + Carbon (IV) oxide + Water

$$ZnCO_3(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + CO_2(g) + H_2O(l)$$

Sodium hydrogen carbonate + Dil. Hydrocloric acid ⟶ Sodium chloride + Water + Carbon (IV) oxide

$$NaHCO_3 + HCl(aq) \longrightarrow NaCl(aq) + H_2O(g) + CO_3(g)$$

Lead carbonate + Dil. Nitric acid ⟶ Lead + Carbon (IV) oxide + Water

$$PbCO_3(s) + 2HNO_3(aq) \longrightarrow Pb(NO_3)_2(aq) + CO_2(g) + H_2O(l)$$

Sodium carbonate + Dil. Sulphuric (VI) acid ⟶ Sodium sulphate + carbon (IV) oxide + Water

$$NaCO_3(s) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + CO_2(g) + H_2O(l)$$

The reaction between **calcium** carbonate or **lead** carbonate with dilute sulphuric acid **does not go to completion. This is due to the formation of insoluble calcium sulphate and lead sulphate respectively.** The insoluble sulphates form a **coating on the carbonate and prevent further reaction**.

The reaction between **lead carbonate and hydrochloric acid** also does not go to completion because of the formation of the **insoluble lead chloride**.

Calcium carbonate + Dil. Sulphuric (VI) acid ⟶ Calcium sulphate + Carbon (IV) oxide + Water

$$CaCO_3(s) + H_2SO_4(aq) \longrightarrow CaSO_4(s) + CO_2(g) + H_2O(l)$$

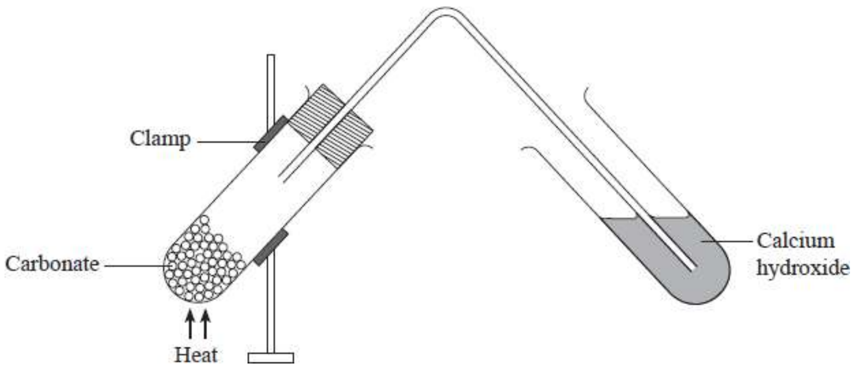
Lead carbonate + Dil. Sulphuric (VI) acid ⟶ Lead sulphate + Carbon (IV) oxide + Water

$$PbCO_3(s) + H_2SO_4(aq) \longrightarrow PbSO_4(s) + CO_2(g) + H_2O(l)$$

Lead carbonate + Dil. Hydrochloric acid ⟶ Lead chloride + Carbon (IV) oxide + Water

$$PbCO_3(s) + 2HCl(aq) \longrightarrow PbCl_2(s) + CO_2 + H_2O$$

Action of Heat on Carbonate and Hydrogen Carbonates



All carbonates **except** the carbonates of potassium and sodium decompose when heated to produce a metal oxide and carbon (IV) oxide. The ease of decomposition **depends on the position of the metal in the reactivity series. Those lower in the reactivity series are easily decomposed**.

$$\text{Copper carbonate} \xrightarrow{heat} \text{Copper (II) oxide} + \text{Carbon (IV) oxide}$$

$$\underset{(green)}{CuCO_3(s)} \xrightarrow{heat} \underset{(black)}{CuO(s)} + CO_2(g)$$

$$\text{Lead carbonate} \xrightarrow{heat} \text{Lead (II) oxide} + \text{Carbon (IV) oxide}$$

$$\underset{(green)}{PbCO_3(s)e} \xrightarrow{heat} PbO(s) + CO_2(g)$$

(red when hot)
(yellow when cold)

$$\text{Zinc carbonate} \xrightarrow{heat} \text{Zinc (II) oxide} + \text{Carbon (IV) oxide}$$

$$ZnCO_3(s) \xrightarrow{heat} ZnO(s) + CO_2(g)$$

$$\text{Calcium carbonate} \xrightarrow{heat} \text{Calcium Oxide} + \text{Carbon (IV) oxide}$$

$$CaCO_3(s) \xrightarrow{heat} CaO(s) + CO_2(g)$$

Ammonium carbonate decomposes when heated to produce **ammonia, carbon (IV) oxide**

$$\text{Ammonium carbonate} \xrightarrow{heat} \text{Ammonia} + \text{Carbon (IV) oxide} + \text{Water}$$

$$(NH)_2CO_3(s) \xrightarrow{heat} 2NH_3(g) + CO_2(g + H_2O(l)$$

and water.

Hydrogen carbonates decompose on heating to produce a **carbonate, carbon (IV) oxide and water.**

$$\text{Sodium hydrogen carbonate} \xrightarrow{heat} \text{Sodium carbonate} + \text{Carbon (IV) oxide} + \text{Water}$$

$$2NaHCO_3(s) \xrightarrow{heat} Na_2CO_3(s) + CO_2(g) + H_2O(l)$$

$$\text{Potassium hydrogen carbonate} \xrightarrow{heat} \text{Potassium carbonate} + \text{Carbon (IV) oxide} + \text{Water}$$

$$2KHCO_3(s) \xrightarrow{heat} K_2CO_3(s) + CO_2(g) + H_2O(l)$$

$$\text{Calcium hydrogen carbonate} \xrightarrow{heat} \text{Calcium carbonate} + \text{Carbon (IV) oxide} + \text{Water}$$

$$Ca(HCO_3)_2(aq) \xrightarrow{heat} CaCO_3(s) + CO_2(g) + H_2O(l)$$

The calcium carbonate is further decomposed by heat to produce an oxide and hydrogen carbonate.

$$\text{Calcium carbonate} \longrightarrow \text{Calcium oxide} + \text{Carbon (IV) oxide}$$

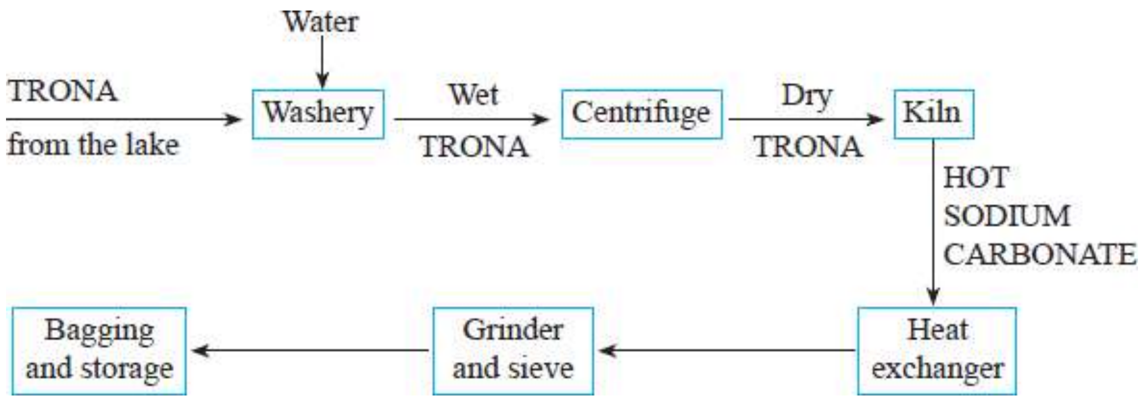
$$CaCO_3(s) \longrightarrow CaO(s) + CO_2(g)$$

Large scale production of Sodium Carbonate and Sodium Hydrogen Carbonate

Sodium carbonate is an important raw material in the glass and paper industries. It is also used in water treatment plants. This important raw material is obtained in two ways extraction from trona and preparation by Solvay process.

Extraction from Trona

Trona is a **double salt** containing **sodium carbonate, sodium hydrogen carbonate and water of crystallisation**, **$Na_2CO_3.NaHCO_3.H_2O$,** found in some lakes in the Rift valley. These lakes have only in-lets but no out-lets. Lake Magadi in Kenya is a good example.



The flow chart below shows the steps in the extration of trona from salty water.

Steps in the manufacture of sodium carbonate

Lake Magadi contains large amounts of solid trona and small amounts of sodium chloride. Trona is dug by bucket dredges and taken to the washery where it is washed in water to remove mud and small rocks. The wet trona is then centrifuged to remove water and to purify it further. The dry trona is then heated to about 300°C in a kiln to decompose the sodium carbonate.

After removal of the trona from the lake, a solution rich in sodium chloride remains. The solution is pumped into shallow basins where evaporation takes place until the percentage of sodium chloride is 14%. The solution is then transfered to another basin for crystalisation.

During the day when the temperature is about 40°C trona crystalises and is removed. During the night when the temperature is about 21°C sodium chloride crystalises and is removed.

$$2Na_2CO_3.NaHCO_3.2H_2O(s) \xrightarrow{heat} Na_2CO_3.NaHCO_3(s) + 2H_2O(l)$$

$$2Na_2CO_3.NaHCO_3(s) \xrightarrow{heat} 3Na_2CO_3(s) + CO_2(g) + H_2O(l)$$

The sodium carbonate obtained is cooled, ground,, sieved and bagged ready for storage and transportation to the consumers.

The Solvay Process

In places where trona is not available, sodium carbonate and sodium hydrogen carbonate are manufactured by the Solvay process.

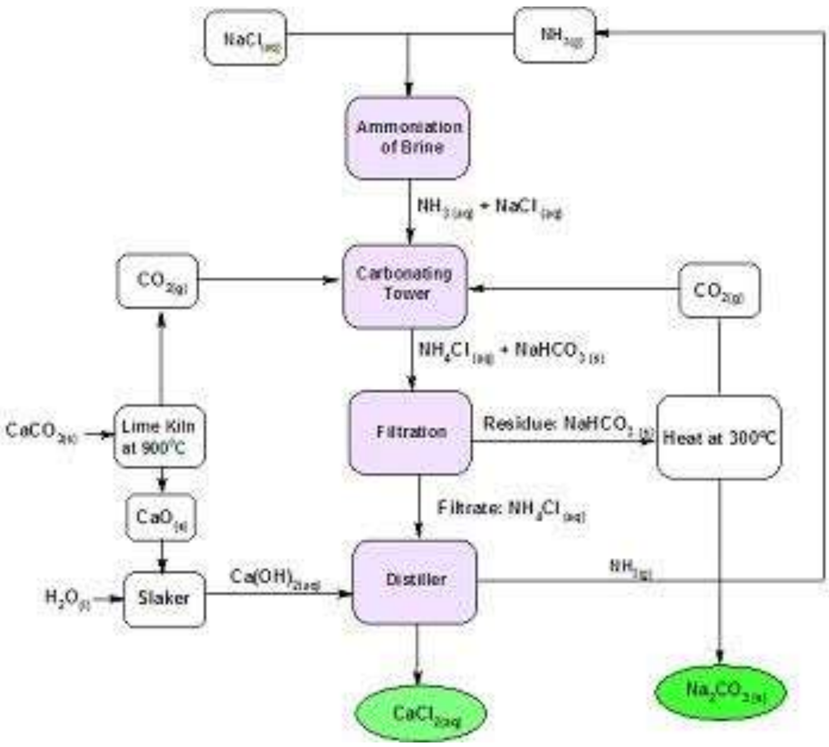
Raw Materials

1. **Sodium chloride (brine)**-obtained from sea salt by evaporating the water to obtain crystals.
2. **Calcium carbonate and coke**-Sources of CO2 when heated and roasted respectively.

$$CaCO_3(s) \longrightarrow CaO(s) + CO_2(g) \text{ (thermal decomposition)}$$

$$C(s) + O_2(g) \longrightarrow CO_2(g) \text{ (roasting)}$$

3. **Ammonia**-Obtained from the Haber process.



Ammonia is dissolved in **brine** in the Solvay tower to produce **ammoniacal brine**. A lot of **heat is produced** in the process. The amount of heat produced is controlled by **regulating the flow of brine into the Solvay tower.**

The ammoniacal brine is then **pumped into the carbonator from the top** where it **trickles down the carbonator while carbon (IV) oxide** from the kiln is **pumped from the base**. The carbonator has to be cooled regularly to reduce the amount of heat produced in it.

Sodium hydrogen carbonate being **less soluble** than **ammonium chloride at low temperatures,** forms crystals in the lower cooled part of the carbonator. The reactions that take place in the carbonator are as follows:

Ammonia + Carbon (IV) oxide + Water $\longrightarrow$ Ammonium hydrogen carbonate

$$NH_3(g) + CO_2(g) + H_2O(l) \longrightarrow NH_4HCO_3(aq)$$

Ammonium hydrogen carbonate + Sodium chloride $\longrightarrow$ Sodium hydrogen carbonate + Ammonium chloride

$$NH_4HCO_3(aq) + NaCl(aq) \longrightarrow NaHCO_3(s) + NHC_4(aq)$$

The reaction in the carbonator can be summarized by the equation below:

Ammonia + Carbon (IV) oxide + Sodium chloride + Water ⟶ Sodium hydrogen carbonate + Ammonium chloride

$$NH_3(g) + CO_2(g) + NaCl(aq) + H_2O(l) \longrightarrow NaHCO_3(s) + NH_4Cl(aq)$$

Sodium hydrogen carbonate is separated from ammonium chloride by **filtration**. Sodium hydrogen carbonate is **dried and decomposed by heat at 300ºC** to produce **sodium carbonate.**

Sodium hydrogen carbonate $\xrightarrow{heat}$ Sodium carbonate + Carbon (IV) oxide + Water

$$2NaHCO_3(s) \xrightarrow{heat} Na_2CO_3(s) + CO_2(g) + H_2O(l)$$

The **calcium oxide** produced in the limestone kiln is **slaked (combined) with water** and **mixed with the filtrate ammonium chloride** to produce **ammonia gas, water and calcium chloride.**

Calcium oxide + Water ⟶ Calcium hydroxide

$$CaO(s) + H_2O(l) \longrightarrow Ca(OH)_2(s)$$

Calcium hydrogen carbonate + Ammonium chloride ⟶ Ca lcium chloride + Water + Ammonia

$$Ca(OH)_2(s) + 2NH_4Cl(aq) \longrightarrow CaCl_2(s) + 2H_2O(l) + 2NH_3(g)$$

The Solvay process is one of the best examples of an **<u>efficient industrial chemical process,</u>** because pollution problems are considerably reduced. The **carbon (IV) oxide and ammonia gases** produced are **recycled** to minimise costs.

The **water** produced is also **recycled** to minimise **thermal effects on the water source** near the plant. The process **does not involve large consumption of energy** because the **coke burned in the kiln supplies the necessary heat in the process.**

In brief:

1. Only by-product which is not recycled is calcium chloride
2. Recyclable substances - NH_3, H_2O, CO_2 (this explains why this is an efficient process).
3. Sodium carbonate is used in water softening, glass making, paper industry and making of sodium silicate. The sodium silicate is used in the making of detergents.

4. Sodium hydrogen carbonate is used in the making of health drinks and as baking powder in the food

5. Calcium chloride is used as a drying agent in the school laboratory preparation of gases., In the Downs cell (process for extraction of Sodium) to lower the melting point of rock salt, used as a food additive, food preservative, and used for de-icing roads in winter

6. The best site for the Solvay process plant should be close to a river or large source of water to cool down the carbonator.

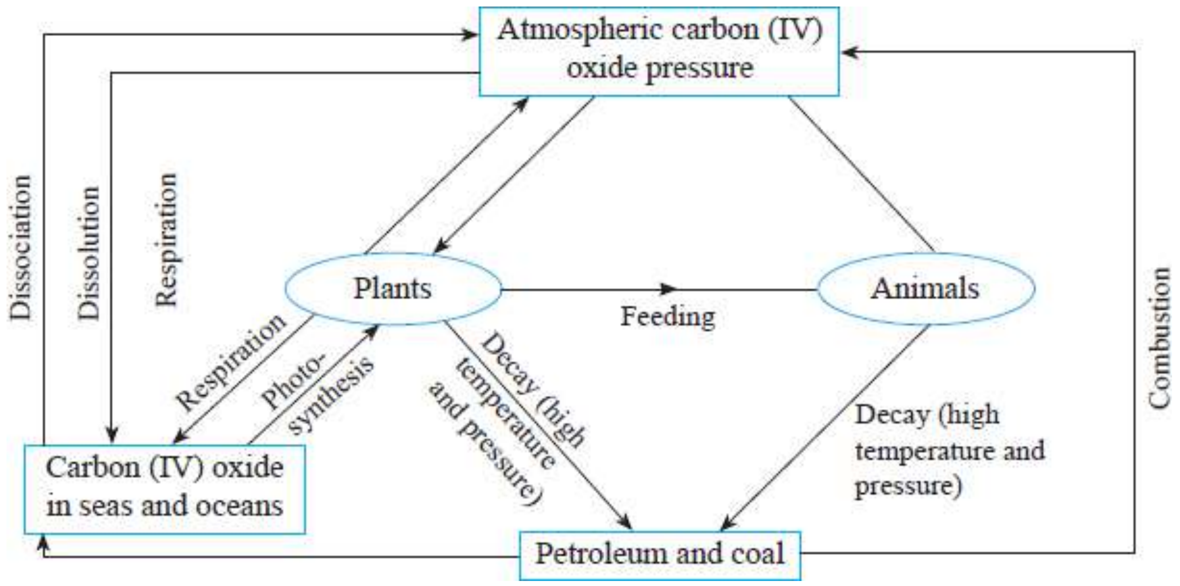
Effects of Carbon (IV) oxide and Carbon (II) oxide on the Environment

The level of carbon (IV) oxide in the atmosphere is increasing due to the use of fossil fuels such as petrol, diesel, natural gas and coal. This increase is causing global warming due to the green house effect. Some of the effects of global warming include melting of polar ice caps which leads to the rise in the sea water levels and erratic weather patterns.

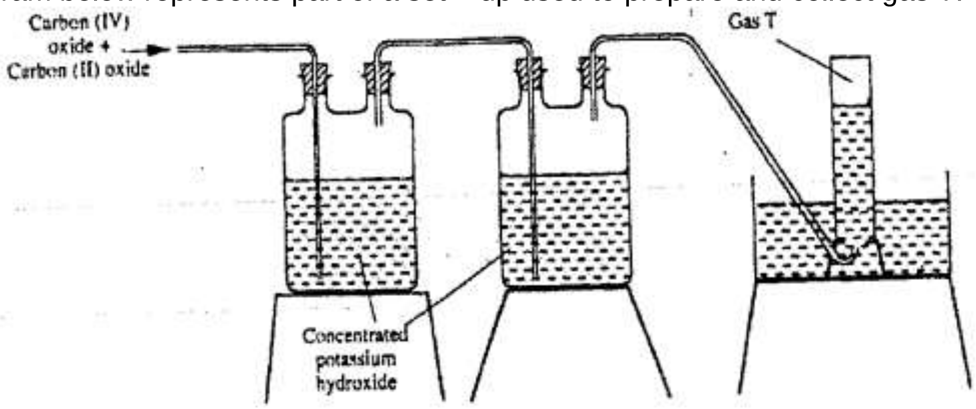
Vehicle exhaust fumes make-up more than 60% of all the carbon (II) oxide emitted into the atmosphere. Carbon (II) oxide emissions are highest during cold weather. This is because low temperatures make combustion less complete. Carbon (II) oxide can cause death through suffocation. Luckily, carbon (II) oxide is quickly removed from the atmosphere by micro-organisms in the soil.

The Carbon Cycle

The way in which carbon compounds circulate in nature constitutes the carbon cycle which is shown below. The processes that release carbon (IV) oxide to the atmosphere include combustion of fuels, respiration in both animals and plants, fermentation, decomposition of carbonates and hydrogencarbonates. Those processes that remove carbon (IV) oxide in the atmosphere include photosynthesis in plants, dissolving of carbon (IV) oxide in seas and oceans. The amount of carbon (IV) oxide in the atmosphere has remained fairly constant at 0.03% owing to the delicate balance between the processes that absorb the gas and those that evolve it. Lately, the balance is being interfered with by human activity leading to an increase in the level of carbon (IV) oxide in the atmosphere thus causing global warming since carbon (IV) oxide has a greenhouse effect.

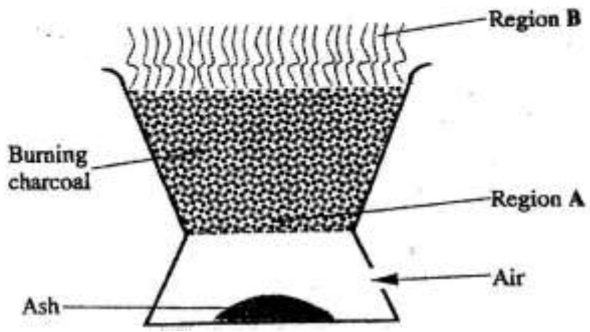


1. 2006 P1 Q22.
The diagram below represents part of a set – up used to prepare and collect gas T.



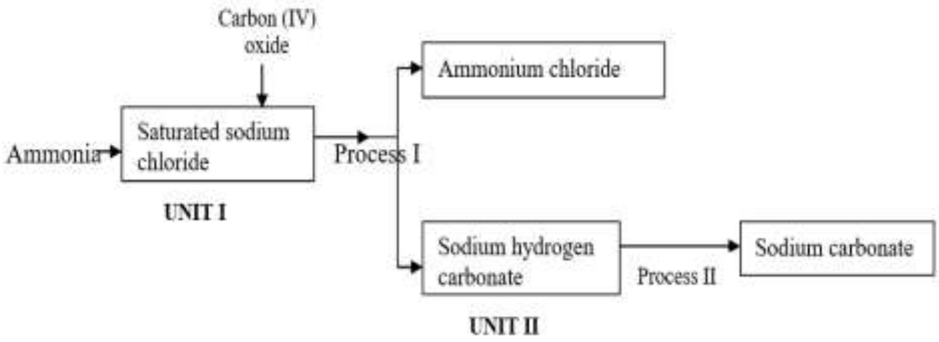
(a) Name two reagents that are reacted to produce both carbon (IV) oxide and carbon(II) oxide.
(1 mark)
(b) Write the equation for the reaction which takes place in the wash bottles. (1 mark)
(c) Give a reason why carbon (II) oxide is not easily detected. (1 mark)

2. 2007 P1 Q1.
The diagram below shows a "Jiko" when in use. Study it and answer the questions that follow.



(a) Identify the gas formed at region A. (1 mark)
(b) State and explain the observation made at region B. (2 marks)

3. 2009 P2 Q4.
(a) The schematic diagram shows part of the Solvay process used for the manufacture of sodium carbonate.



(i) Explain how the sodium chloride required for this process is obtained from sea water.
(2marks)

(ii) Two main reactions take place in UNIT I . The first one is the formation of ammonium hydrogen carbonate.
I. Write an equation for this reaction (1 mark)
II. Write an equation for the second reaction (1 mark)

(iii) State how the following are carried out:
I. Process I (1 mark)
II. Process II (1 mark)

(iv) In an experiment to determine the percentage purity of the sample of sodium carbonate produced in the Solvay process, 2.15 g of the sample reacted completely with 40.0cm^3 of 0.5 M sulphuric acid.
I. Calculate the number of moles of sodium carbonate that reacted. (1 mark)

II. Determine the percentage of sodium carbonate in the sample.
(Na= 23.0, C= 12.0, O = 16.0) (2 marks)

(b) Name two industrial uses of sodium carbonate. (2 marks)

4. 2010 P1 Q15.
Carbon (II) oxide is described as a “silent killer”
(a) State one physical property of carbon (II) oxide that makes it a “silent killer” (1 mark)

(b) State and explain one chemical property that makes carbon (II) oxide poisonous to human beings (2 marks)

5. 2011 P1 Q11.
Exhaust fumes of some cars contain carbon(II)oxide and other gases.

(a) Explain how carbon (II) oxide is formed in the internal combustion engines. (1 mark)

(b) Name two gases other than carbon (II) oxide that are contained in exhaust fumes and are pollutants. (2 marks)

6. 2011 P1 Q21.
Graphite is one of the allotropes of carbon.
(a) Name one other element which exhibits allotropy. (1 mark)

(b) Explain why graphite is used in the making of pencil leads. (2 marks)

7. 2012 P1 Q1 ,2016 P1 Q25
Charcoal is a fuel that is commonly used for cooking. When it burns it forms two oxides.
(a) Name the two oxides. (2 marks)
(b) State one use of any of the two oxides. (1 mark)

8. 2013 P1 Q19.
(a) Diamond and graphite are allotropes of carbon. What is meant by an allotrope? (1 mark)

(b) Explain why graphite can be used as a lubricant while diamond cannot. (1 mark)

9. 2015 P1 Q27.
(a) Describe how carbon (IV) oxide can be distinguished from Carbon (II) Oxide using calcium hydroxide solution. (2 marks)

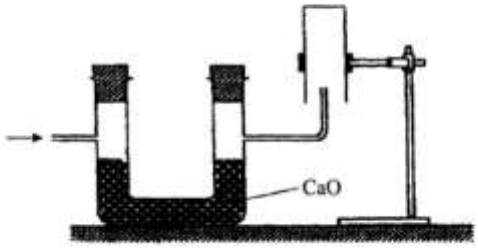
(b) What is the role of carbon (IV) oxide in fire extinguishing? (1 mark)

10. 2015 P2 Q1. (a)
(i) Carbon (IV) oxide is present in soft drinks. State two roles of carbon (IV) oxide in soft drinks. (1 mark)

(ii) Explain the observation made when a bottle containing a soft drink is opened. (2 marks)

(iii) Carbon (IV) oxide dissolves slightly in water to give an acidic solution. Give the formula of the acid. (1 mark)

11. 2016 P1 Q22.
The set up below was used to collect a dry sample of a gas



Give two reasons why the set up cannot be used to collect carbon (IV) oxide gas. (2 marks)

12. 2018 P1 Q2.

(a) Explain why it is not advisable to prepare a sample of carbon(IV) oxide using barium carbonate and dilute sulphuric(VI) acid. (2 marks)

(b) State a method that can be used to collect dry carbon(IV) oxide gas. Give a reason. (1 mark)

13. 2018 P2 Q6.

(a) In Kenya, sodium carbonate is extracted from trona at Lake Magadi.

(i) Give the formula of trona. (1 mark)

(ii) Name the process of extracting sodium carbonate from trona. (2 marks)

(b) The flow chart in **Figure 5** summarises the steps involved in the production of sodium carbonate. Use it to answer the questions that follow.

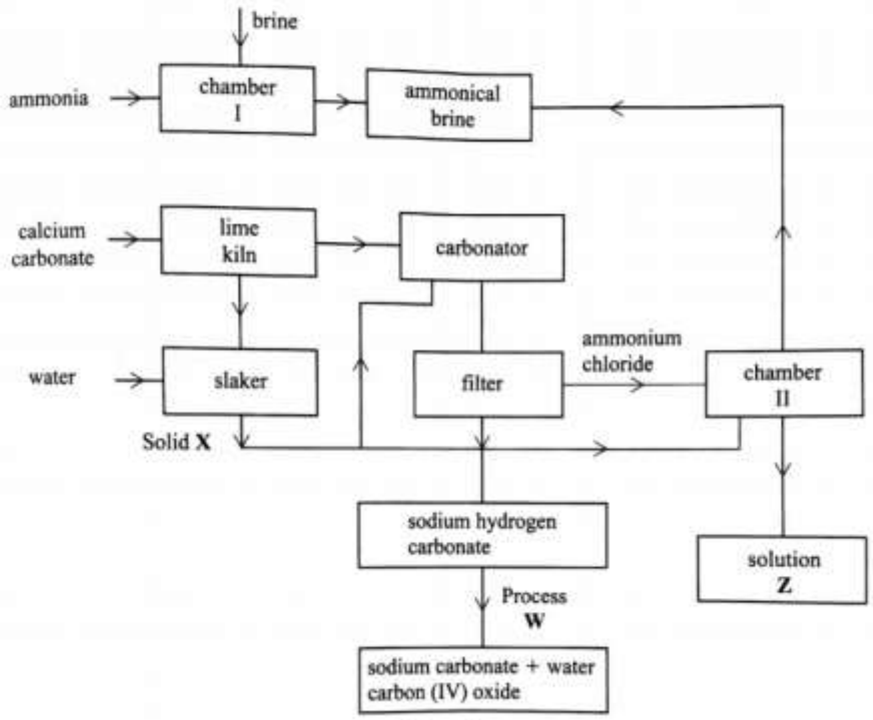


Figure 5

(i) Name the process illustrated in **Figure 5**. (1 mark)

(ii) Identify the starting raw materials required in the production of sodium carbonate.

(2 marks)

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

(2 marks)

(iv) Name two substances that are recycled. (2 marks)

(v) Identify:

Solid X; .... (1 mark)

Process W .... (1 mark)

(vi) Write an equation for the reaction that produces solution Z.

(1 mark)

(vii) Apart from softening hard water, state two other uses of sodium carbonate.

(2 marks)

14. 2019 P1 Q20.

During laboratory preparation of carbon (IV) oxide gas, substance **L** in a conical flask.

(a) Identify substance L. (1 mark)

(b) Write an equation that produces carbon (IV) oxide. (1 mark)

(c) State the observations made when the gas produced WHS bubbled through calcium hydroxide solution for a long time.

(1 mark)