CARBON AND ITS COMPOUNDS (9 Periods)

Carbon is an element in period 2 and group IV of the periodic table. Pure carbon is found in the form of diamond (South Africa) and impure carbon as graphite (Sri Lanka). It occurs in most naturally occurring substances like coal, mineral oils, calcium carbonate as (chalk, limestone or marble), organic matter, in air as carbon dioxide gas and so on.

Allotropic forms of carbon

Carbon is allotropic because it is capable of existing in different structural forms without changing its state. **Allotrope:** Is one of the physical forms of an element. **Allotropes:** Are different structural forms of an element in the same physical state. **Allotropy**: Is the existence of an element in different structural forms but in the same physical state.

The allotropic forms of carbon are;

i. Graphite
ii. Diamond
iii. Amorphous carbon

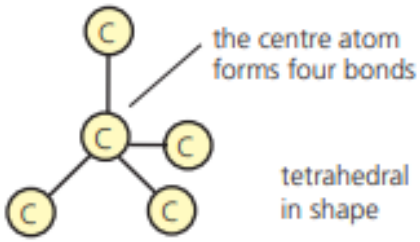
Diamond and graphite are the pure crystalline forms of carbon and are therefore called polymorphs (substances that can exist in more than one crystalline form). Amorphous carbon is an impure form of carbon e.g. wood charcoal, sugar charcoal, animal charcoal, lampblack, soot and coal.

DIAMOND

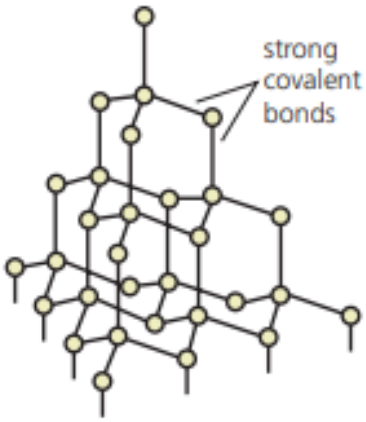
The structure of diamond

Diamond has a tetrahedral structure in which one carbon atom is bonded to four other carbon atoms by strong covalent bonds. The valency electrons are all used up in forming covalent bonds and are therefore localized. This structure is extended throughout the substance in three dimensions.

Single unit of diamond



Extended unit of diamond



Properties of diamond

- It is a very hard and non-volatile solid.
- It has a very high melting (3930^{o}C)
- It sparkles/ glitters.
- It does not conduct electricity since all the valency electrons are used in bonding.
- It is a colourless and transparent solid.
- It has a high density of 3.5g/cm^{3} because of its close packing.
- Resistant to reactions with chemicals like acids, alkalis and fluorine.

Uses of diamond

i. Diamond is used for drilling rocks and making glass cutters because it is very hard.

ii. Diamond can be used as an insulator because it does not conduct electricity.

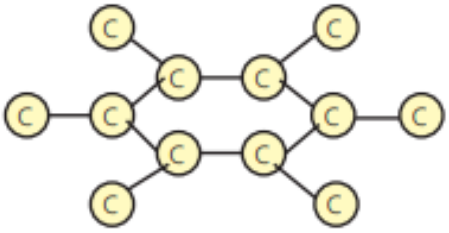
iii. Diamond is used for making jewellery like necklaces, ear rings, bungles, watches etc because is sparkles/ glitters.

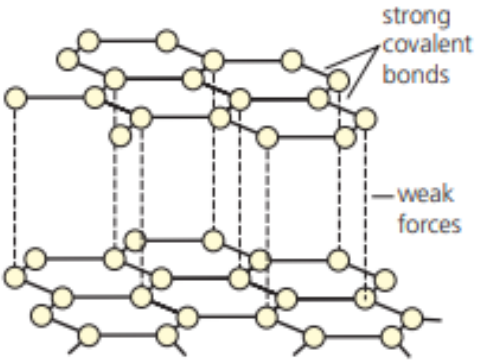
GRAPHITE

The structure of graphite

In graphite, one carbon atom is covalently bonded to three other carbon atoms in hexagonal rings. Each unit extends forming parallel planes. The planes form layers which lie above one

another and they are held together by the weak van der waal's forces of attraction and so layers can slide over each other.





NOTE: Since each carbon atom uses three out of the four valency electrons, one valency electron is left to move freely. The free mobile electron at each carbon atom enables graphite to conduct electricity.

Properties of graphite

- Graphite is soft and greasy.
- Graphite is slippery.
- It has a melting point of 2300 ^{o}C
- Graphite is black in colour or dark grey and opaque.
- Graphite conducts electricity.
- It has a density of 2.3 g/cm^{3}.

Uses of graphite

i. It is used in the manufacture of electrodes because it conducts electricity.

ii. It is used in the manufacture of pencils because it is soft.

iii. It is used as a lubricant in machines because it is soft and greasy.

iv. Used as a protective coat of iron thus reducing rusting.

AMORPHOUS CARBON

This form of carbon is obtained by heating carbon compounds in limited supply of air. Examples of amorphous carbon include;

1. Wood charcoal. This is obtained by heating wood in limited supply of air. It is used for domestic and industrial heating (source of fuel). It is light, porous and used to absorb poisonous gases like ammonia, chlorine and so on.
2. Lamp charcoal (lampblack). This is obtained by heating oils' in limited supply of air. It is used in the manufacture of shoe polish, carbon papers, printing ink, duplicating ink, dyes/ pigments and as a filler of rubber used to make tyres.

$$CH_4\,(g) + O_2\,(g) \longrightarrow \underset{\text{Soot}}{C\,(s)} + 2\,H_2O\,(l)$$

3. Animal charcoal. This is obtained by heating hard animal remains e.g. bones, teeth in limited supply of air. Animal charcoal is used as a bleaching agent in the manufacture of sugar.
4. Sugar charcoal. This is obtained by removing the elements of water from sucrose using concentrated sulphuric acid (dehydration) or heating sugar in absence of air.

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

   The carbon obtained in this case is very pure. Sugar charcoal is used in appliances where carbon of high purity is needed e.g. in the calibration of mass spectrometers.
5. Coal. It exists as readily combustible black rock containing mainly carbon and other elements like sulphur, oxygen, hydrogen etc. Types of coal include; peat coal, lignite coal, sub-bituminous coal, bituminous coal and anthracite coal. They are generally used as fuels.
6. Coke. Is a solid material left out when coal is heated in a limited supply of air (oxygen).

NOTE: Other elements that exhibit allotropy include the following.

i. **Oxygen**; Allotropes: ordinary oxygen and ozone.
ii. **Sulphur;** Allotropes: monoclinic sulphur, rhombic sulphur and amorphous sulphur.
iii. **Tin**; Allotropes: grey tin and white tin.
iv. **Phosphorus**; Allotropes: Red phosphorus and white phosphorus.

CHEMICAL PROPERTIES OF CARBON

1. Combustion of carbon. Carbon burns in excess oxygen to produce carbon dioxide gas.

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

   However if oxygen is in limited supply, carbon monoxide gas is formed.

   $2C(s) + O_2(g) \longrightarrow 2CO(g)$

   The combustion temperature of diamond (900^oC), graphite (700^oC) and amorphous carbon (500^oC) depends on the strength of the bonds in the different forms of carbon.

2. Carbon is used as **a reducing agent**, it reduces heated metal oxides from zinc and below in the reactivity series to corresponding metals and carbon dioxide gas. **However, if the metal oxide is not in excess, carbon monoxide gas is formed.** In these reactions both oxidation and reduction takes place and this technique is used in extraction of metals.

   Examples

   a) Equation:

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

   Observation: A black solid turns brown.

   Explanation: Carbon reduces copper (II) oxide to copper while it is oxidised to carbon dioxide gas.

   b) Equation:

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

   Observation: A yellow solid turns shiny grey.

   Explanation: Carbon reduces lead (II) oxide to lead while it is oxidised to carbon dioxide gas.

   c) Equation:

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

   Observation: A white solid turns grey.

   Explanation: Carbon reduces zinc oxide to zinc while it is oxidised to carbon dioxide gas.

   d) Equation:

   $2Fe_2O_3(s) + 3C(s) \longrightarrow 4Fe(s) + 3CO_2(g)$

Observation: Reddish- brown solid turns grey.

Explanation: Carbon reduces iron (III) oxide to iron while it is oxidised to carbon dioxide gas.

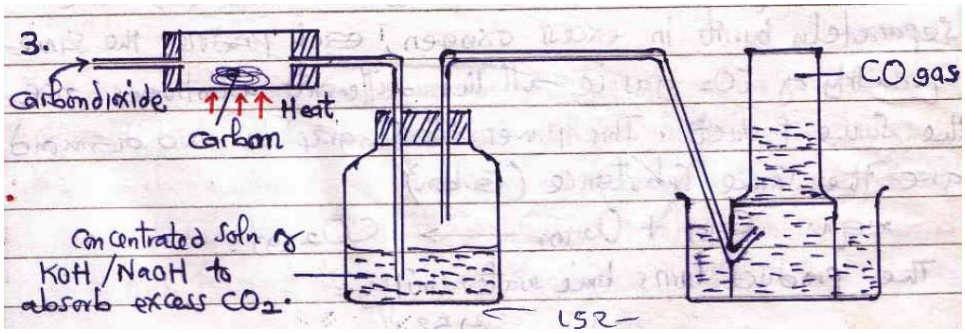
e) Equation:

$$Fe_3O_4\ (s) + 2\ C\ (s) \longrightarrow 3\ Fe\ (s) + 2\ CO_2\ (g)$$

Observation: Blue-black solid turns grey.

Explanation: Carbon reduces triiron tetraoxide to iron while it is oxidised to carbon dioxide gas.

3. Diagram



Carbon when heated reduces carbon dioxide gas to carbon monoxide gas which is a colourless that burns with a blue flame.

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

4. If air is passed through heated carbon, producer gas (a mixture of nitrogen and carbon monoxide gas) is produced which is used as a fuel. Producer gas is produced as follows.

i. Carbon reacts with oxygen to produce carbon dioxide gas.

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

ii. Carbon dioxide gas produced together with carbon dioxide gas in air; react with carbon to produce carbon monoxide gas.

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

iii. Nitrogen gas which did not react together with the formed carbon monoxide gas constitutes producer gas.

5. Heated carbon reduces steam to water gas (a mixture of carbon monoxide and hydrogen gas) which produces more heat than producer gas since both gases can burn in air.

$$C\,(s) + H_2O\,(g) \longrightarrow CO\,(g) + H_2\,(g)$$

6. Reaction with acids.

   Carbon reacts with hot concentrated sulphuric and nitric acid which are oxidizing agents capable of oxidizing carbon to carbon dioxide gas. Sulphuric acid reduces to sulphur dioxide gas while nitric acid reduces to nitrogen dioxide gas.

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

$$C\,(s) + 4\,HNO_3\,(l) \longrightarrow CO_2\,(g) + 2\,H_2O\,(l) + 4\,NO_2\,(g)$$

Proof for allotropy of carbon

When equal masses of graphite and diamond are separately burnt in oxygen, each produces the same quantity/ volume of carbon dioxide gas. Therefore, both graphite and diamond are made up of carbon since they give the same product.

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

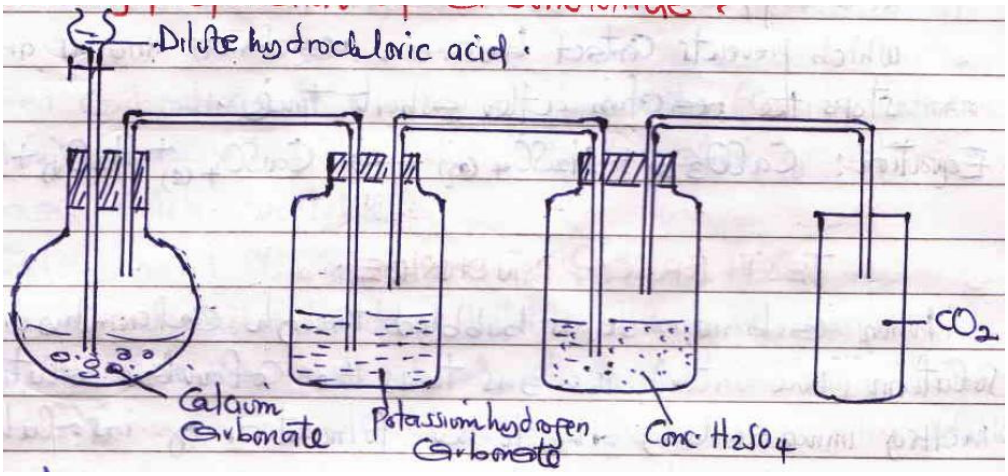
The carbon dioxide gas produced turns lime water milky.

CARBON DIOXIDE GAS

Carbon dioxide gas also known as carbon (IV) oxide occurs naturally in air and is 0.03% by volume of air. It is also found in mines, mineral springs and drinking water.

Laboratory preparation of carbon dioxide gas

Set-up



Procedure

Calcium carbonate powder is placed into a conical flask because it is a solid. Dilute hydrochloric acid is added from the tap funnel because it is a liquid to the calcium carbonate in a flask fitted with a delivery tube. Carbon dioxide gas is produced according to the equation.

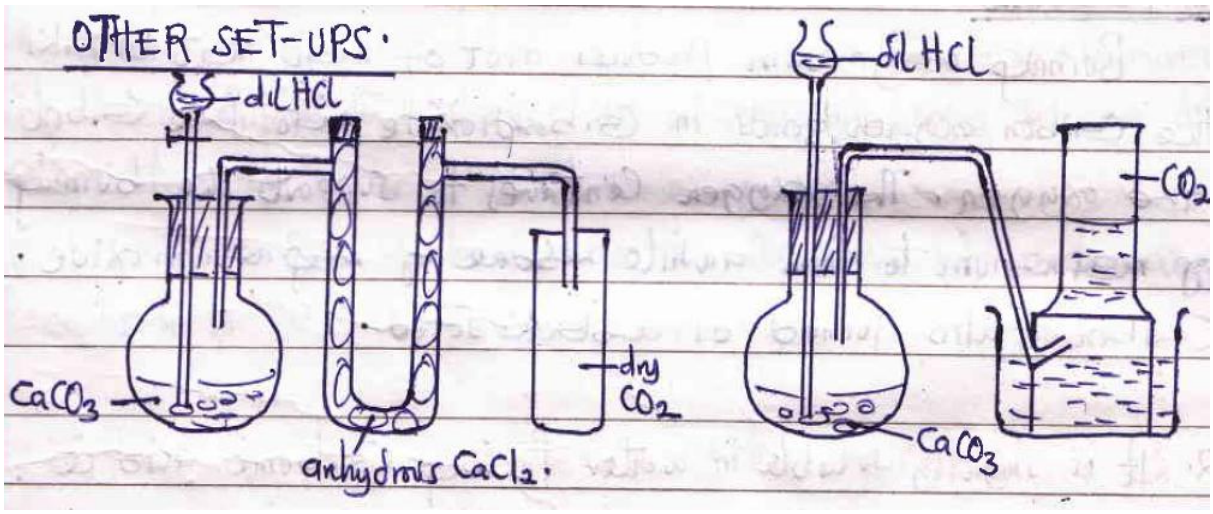
$$CaCO_3\,(s) + 2\,HCl\,(aq) \longrightarrow CaCl_2\,(aq) + H_2O\,(l) + CO_2\,(g)$$

The gas is bubbled through a wash bottle containing potassium hydrogen carbonate solution to remove traces of hydrogen chloride gas, and then through another wash bottle containing concentrated sulphuric acid for drying because the acid is hygroscopic and does not react with the gas. The gas is finally collected by down ward delivery because it is denser than air.

NOTE

1. Instead of passing the gas through a wash bottle containing concentrated sulphuric acid to dry, carbon dioxide gas could also be passed through a U-tube containing anhydrous calcium chloride.
2. Carbon dioxide gas can also be collected over water if it's not required dry since it is slightly soluble in water.

Set-ups



Note: Dilute sulphuric acid is not suitable for laboratory preparation of carbon dioxide gas in the presence of calcium carbonate because it reacts with calcium carbonate forming a coating/ passive layer which is insoluble calcium sulphate which prevents contact between reactants and as a result stops the reaction after a short time.

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

Test for carbon dioxide gas

When carbon dioxide gas is bubbled through calcium hydroxide solution (lime water), the colourless solution immediately turns milky due to the formation of insoluble calcium carbonate.

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

PHYSICAL PROPERTIES OF CARBON DIOXIDE GAS

i. It is a colourless gas.
ii. It has a very faint smell.
iii. It has a sharp pleasant taste.
iv. It is denser than air.
v. It is slightly soluble in water.

CHEMICAL PROPERTIES OF CARBON DIOXIDE GAS

1. Carbon dioxide gas does not support combustion but it can burn under drastic conditions. When burning magnesium is lowered into a jar of carbon dioxide gas, it burns with a spluttering flame forming a white solid and a black solid.

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

   Explanation

   Burning magnesium produces a lot of heat that decomposes carbon dioxide gas into free carbon and oxygen. The oxygen continues to support the burning of magnesium to form a white residue of magnesium oxide and carbon is formed as a black solid.

2. It is slightly soluble in water forming weak carbonic acid which turns blue litmus paper red.

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

3. It oxidises carbon to carbon monoxide gas.

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

4. Carbon dioxide gas reacts with sodium hydroxide solution or potassium hydroxide solution to form sodium carbonate or potassium carbonate solution and water (colourless solution)

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

   When excess carbon dioxide gas is bubbled through the resultant mixture, sodium hydrogen carbonate or potassium hydrogen carbonate is formed as a white precipitate.

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

5. When carbon dioxide gas is bubbled into lime water (calcium hydroxide solution) it turns milky due to the formation of insoluble calcium carbonate.

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

   When excess carbon dioxide gas is bubbled through the resultant mixture, the white precipitate dissolves to form a colourless solution due to the formation of calcium hydrogen carbonate which is soluble.

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

Uses of carbon dioxide gas

a) Because of its pleasant taste, carbon dioxide gas is used in the manufacture of soft drinks e.g. coke, pepsi etc.

b) It is used as a refrigerating agent.

c) It is used in the ammonia soda or Solvay process to produce sodium carbonate and sodium hydrogen carbonate which are used in bakeries.

d) It is used by plants to make food during photosynthesis.

e) It is used in fire extinguishers to put out fire. Carbon dioxide gas being denser than air forms a layer around the burning material. It covers the fire and starves it off oxygen hence the fire is put out.

f) Pieces of solid carbondioxide are sometimes dropped into clouds to cool them to form rain.

Extinguishing fire outbreak in the environment

The major elements of a fire/ a blaze include; **oxygen, fuel and heat.** This is known as the ‘**’fire triangle’’**. When one of the three elements is removed, the triangle no longer stands and the fire will die. To effectively fight a fire, one must know the type of fire at hand (i.e. caused by wood, flammable liquids, electricity or metals like sodium). Most fires are fought using fire extinguishers. *A typical fire extinguisher is the high pressure fire extinguisher which is operated by pressing the trigger and carbondioxide gas is released onto the fire, covers it, starving it off oxygen hence putting out fire/ killing fire.*

Fire outbreak is also fought using **a fire blanket**. Afire blanket is a wool or synthetic blanket specifically treated with fire retardants. Just like fire extinguishers, it deprives the fire off oxygen. **A sand bucket** can also be used to put out fire.

CARBON MONOXIDE GAS

Carbon monoxide is a gas produced by burning carbon or carbon compounds in a limited supply of oxygen.

$$2\,C\,(s) + O_2\,(g) \longrightarrow 2\,CO\,(g)$$

Other sources of carbon monoxide gas include coal fire/ charcoal fire, power stations, exhaust fumes, producer gas and water gas. In most cases these occur when fuels burn in limited oxygen.

Physical properties of carbon monoxide gas

i. It is a colourless gas.
ii. It is tasteless.
iii. It odourless/ has no smell.
iv. It is less dense than air.
v. It is insoluble in water.
vi. It has no effect on litmus paper.
vii. It is a poisonous gas.

Chemical properties of carbon monoxide gas

1. It burns quietly in air with a blue flame forming carbon dioxide gas. This reaction distinguishes carbon monoxide gas from carbon dioxide gas which does not burn.

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

2. Carbon monoxide gas is a powerful reducing agent. It reduces heated metallic oxides of zinc and below in the reactivity series to form corresponding metal and carbon dioxide gas.

   Example

   Copper (II) oxide reacts with carbon monoxide gas to form copper and carbon dioxide gas

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

   Observation: The black solid turns to a brown solid.

   Explanation: Carbon monoxide gas reduces copper (II) oxide to copper and it is oxidised to carbon dioxide gas.

   Conditions: Heat is required (copper (II) oxide must be heated) and carbon monoxide gas should be dry.

   Other similar reactions

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

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

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

$$Fe_3O_4\ (s) + 4\ CO\ (g) \longrightarrow 3\ Fe\ (s) + 4\ CO_2\ (g)$$

Test for carbon monoxide gas

It is a colourless gas which burns in air with a blue flame to form a colourless gas (carbon dioxide gas) which turns lime water milky.

Uses of carbon monoxide gas

- Used in extraction of less reactive metals.
- Used as fuel in form of producer gas and water gas.
- Manufacture of other fuels like petrol.

CARBONATES AND HYDROGEN CARBONATES

Carbonates and hydrogen carbonates are salts of carbonic acid. Carbonates are formed when all the ionisable hydrogen ions of carbonic acid are replaced by a metal or ammonium ion. While hydrogen carbonates are formed when part of the ionisable hydrogen ions of carbonic acid are replaced by a metal or ammonium ion.

Some of the examples of carbonates and hydrogen carbonates

Carbonates			**Hydrogen carbonates**		
Name	**Formula**	**Colour**	**Name**	**Formula**	**Colour**
Potassium carbonate	K_2CO_3	White solid	Potassium hydrogen carbonate	$KHCO_3$	White solid

Sodium carbonate	Na_2CO_3	White solid	Sodium hydrogen carbonate	$NaHCO_3$	White solid
Calcium carbonate	$CaCO_3$	White solid	Ammonium hydrogen carbonate	NH_4HCO_3	White solid
Magnesium carbonate	$MgCO_3$	White solid	Calcium hydrogen carbonate	$Ca(HCO_3)_2$	Colourless solution
Zinc carbonate	$ZnCO_3$	White solid	Magnesium hydrogen carbonate	$Mg(HCO_3)_2$	Colourless solution
Lead(II) carbonate	$PbCO_3$	White solid			
Ammonium carbonate	$(NH_4)_2CO_3$				
Iron(II) carbonate	$FeCO_3$	Green solid			
Copper(II) carbonate	$CuCO_3$	Green solid			

NB: Aluminium carbonate and iron (III) carbonate do not exist. This is because their aqueous solutions undergo hydrolysis producing hydrogen ions which make the solutions acid. The hydrogen ions then react with the carbonate ions liberating carbon dioxide gas.

EFFECT OF HEAT ON CARBONATES

1. The carbonates of potassium and sodium are stable and do not decompose on heating. Therefore the white solids remain white.

   When hydrated sodium carbonate crystals (sodium carbonate decahydrate) are heated, sodium carbonate and water are formed.

   $$Na_2CO_3.\ 10H_2O\ (s) \longrightarrow Na_2CO_3\ (s) + 10H_2O\ (l)$$

   Observation: Shinny crystals turn into a white powder and a colourless liquid is formed on the cooler parts of the test-tube.

   Explanation: The shinny hydrated crystals lose their water of crystallisation on heating forming sodium carbonate which is a white powder.

2. When ammonium carbonate is heated, it decomposes to form ammonia gas, carbon dioxide gas and water.

   $$(NH_4)_2CO_3\ (s) \longrightarrow 2\ NH_3\ (g) + CO_2\ (g) + H_2O\ (l)$$

   Observation: A white solid sublimes on heating and a colourless liquid is formed on the cooler parts of the test-tube.

3. The carbonates of magnesium, calcium, zinc, lead, iron and copper decompose to form metal oxides and carbon dioxide gas.

a) Copper (II) carbonate decomposes on heating to form copper (II) oxide and carbon dioxide gas.

$$CuCO_3\ (s) \longrightarrow CuO\ (s) + CO_2\ (g)$$

Observation: A green powder turns black.

b) Iron (II) carbonate decomposes on heating to produce iron (II) oxide and carbon dioxide gas.

$$FeCO_3\ (s) \longrightarrow FeO\ (s) + CO_2\ (g)$$

Observation: A green powder turns black.

c) Zinc carbonate decomposes on heating to produce zinc oxide and carbon dioxide gas.

$$ZnCO_3\ (s) \longrightarrow ZnO\ (s) + CO_2\ (g)$$

Observation: A white powder forms a residue which is yellow when hot and turns white on cooling.

d) Lead (II) carbonate decomposes on heating to produce lead (II) oxide and carbon dioxide gas.

$$PbCO_3\ (s) \longrightarrow PbO\ (s) + CO_2\ (g)$$

Observation: A white solid forms a residue which turns reddish- brown on heating and yellow on cooling.

e) Calcium carbonate and magnesium carbonate decomposes on heating forming respective metal oxides and carbon dioxide gas.

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

Observation: A white solid forms a white residue on heating or white solid remains white.

NB: In all the above cases, a colourless gas (carbon dioxide gas) which turns damp blue litmus paper red and lime water milky is given off.

EFFECT OF HEAT ON HYDROGEN CARBONATES

Hydrogen carbonates decompose on heating forming a carbonate (a salt), water and carbon dioxide gas.

$$2\ KHCO_3\ (s) \longrightarrow K_2CO_3\ (s) + H_2O\ (l) + CO_2\ (g)$$

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

$$2\ NH_4HCO_3\ (s) \longrightarrow (NH_4)_2CO_3\ (s) + H_2O\ (l) + CO_2\ (g)$$

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

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

On further heating, both potassium carbonate and sodium carbonate do not decompose on heating. However, calcium carbonate, magnesium carbonate and ammonium carbonate further decompose as previously discussed.

ACTION OF DILUTE MINERAL ACIDS ON CARBONATES AND HYDROGEN CARBONATES

When dilute nitric acid, hydrochloric acid or sulphuric acid is added to a carbonate or hydrogen carbonate, a salt, water and carbon dioxide gas is formed.

$$HCO_3^-\ (aq/\ s) + H^+\ (aq) \longrightarrow H_2O\ (l) + CO_2\ (g)$$

$$CO_3^{2-}\ (aq/\ s) + 2\ H^+\ (aq) \longrightarrow H_2O\ (l) + CO_2\ (g)$$

a) When a dilute mineral acid is added to zinc carbonate, magnesium carbonate, calcium carbonate, calcium hydrogen carbonate, lead (II) carbonate, sodium carbonate, potassium hydrogen carbonate and potassium carbonate.

Observation: A white solid dissolves with effervescence of a colourless gas forming a colourless solution.

$$MgCO_3\,(s) + 2\,HNO_3\,(aq) \longrightarrow Mg(NO_3)_2\,(aq) + H_2O\,(l) + CO_2\,(g)$$

$$KHCO_3\,(s) + HCl\,(aq) \longrightarrow KCl\,(aq) + H_2O\,(l) + CO_2\,(g)$$

$$Na_2CO_3\,(s) + 2\,HCl\,(aq) \longrightarrow 2\,NaCl\,(aq) + H_2O\,(l) + CO_2\,(g)$$

$$ZnCO_3\,(s) + H_2SO_4\,(aq) \longrightarrow ZnSO_4\,(aq) + H_2O\,(l) + CO_2\,(g)$$

Note: Dilute sulphuric acid reacts with calcium carbonate or calcium hydrogen carbonate. However the reaction stops after a short time due to formation of insoluble calcium sulphate which forms a coating on calcium carbonate thus preventing further reaction.

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

Lead (II) carbonate only reacts with dilute nitric acid since it also forms insoluble salts with dilute sulphuric and hydrochloric acid. However, the lead (II) chloride salt formed with dilute hydrochloric acid dissolves on heating forming a colourless solution.

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

b) Copper (II) carbonate

A green solid dissolves with effervescence of a colourless gas forming a blue solution.

$$CuCO_3\,(s) + 2\,HNO_3\,(aq) \longrightarrow Cu(NO_3)_2\,(aq) + H_2O\,(l) + CO_2\,(g)$$

$$CuCO_3\,(s) + 2\,HCl\,(aq) \longrightarrow CuCl_2\,(aq) + H_2O\,(l) + CO_2\,(g)$$

c) Iron (II) carbonate

The green solid dissolves with effervescence of a colourless gas forming a green solution.

$$FeCO_3\,(s) + 2\,HNO_3\,(aq) \longrightarrow Fe(NO_3)_2\,(aq) + H_2O\,(l) + CO_2\,(g)$$

SOLUBILITY OF CARBONATES

All carbonates are insoluble except sodium carbonate, ammonium carbonate and potassium carbonate. For hydrogen carbonates, only sodium hydrogen carbonate and potassium hydrogen carbonate are sparingly soluble in water but the rest of the hydrogen carbonates are soluble in water.

Laboratory preparation of insoluble carbonates (i.e. Magnesium carbonate)

To warm magnesium sulphate solution in a beaker, add sodium carbonate solution until when precipitation stops. Magnesium carbonate is produced according to the following equation.

$$MgSO_4\,(s) + Na_2CO_3\,(aq) \longrightarrow MgCO_3\,(s) + Na_2SO_4\,(aq)$$

The mixture is filtered, and the residue washed with distilled water to remove any soluble impurities and finally dried by pressing between filter papers.

Laboratory preparation of soluble carbonates (i.e. sodium carbonate, Soda ash)

Excess carbondioxide gas is bubbled through a concentrated solution of sodium hydroxide.

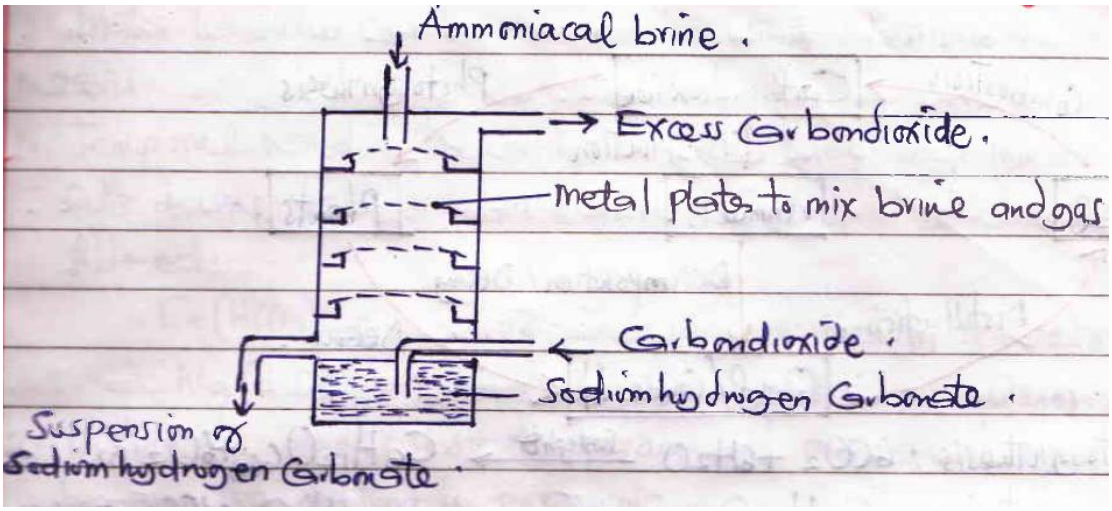
$$2\,NaOH\,(aq) + CO_2\,(g) \longrightarrow Na_2CO_3\,(aq) + H_2O\,(l)$$

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

Some water is evaporated off to form a standard solution of sodium hydrogen carbonate. The solution is then cooled until a white precipitate of sodium hydrogen carbonate forms. The solid sodium hydrogen carbonate is filtered off and dried between filter papers. The solid is then put in a hard glass test tube and heated strongly until there is no further change to form sodium carbonate.

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

MANUFACTURE OF SODIUM CARBONATE (SOLVAY PROCESS)



The major raw materials for the Solvay process include sodium chloride and calcium carbonate (limestone). The limestone is decomposed on heating to produce carbon dioxide gas.

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

A mixture of concentrated sodium chloride and ammonia (ammoniacal brine) goes slowly down the Solvay tower as carbon dioxide gas is passed upwards. The ammonia reacts with carbon dioxide gas to form ammonium hydrogen carbonate.

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

The ammonium hydrogen carbonate immediately reacts with brine to form slightly soluble sodium hydrogen carbonate and ammonium chloride.

$$NH_4HCO_3\ (aq) + NaCl\ (aq) \longrightarrow NaHCO_3\ (s) + NH_4Cl\ (aq)$$

The sodium hydrogen carbonate is filtered off, washed to remove ammonium compound and then dried. It is the decomposed by heating strongly to form sodium carbonate.

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

NB: All the by-products of the Solvay process are re-used except calcium chloride

USES OF SOME CARBONATES AND HYDROGEN CARBONATES

a) Uses of sodium carbonate

- Used in softening hard water for domestic purposes
- Used in the manufacture of glass (by mixing it with sand and calcium carbonate).

- Used in preparation of soap and detergent

b) Uses of sodium hydrogen carbonate

- Manufacture of sodium carbonate
- Making baking powder

c) Uses of calcium carbonate

- Used for making cement.
- Removal of impurities during extraction of iron.
- It is used in road construction.

TESTING FOR CO_3^{2-} AND HCO_3^-

1. Add dilute hydrochloric acid or dilute sulphuric acid to a solution or a solid of CO_3^{2-} or HCO_3^-.

Observation: Effervescence of a colourless gas that turns lime water milky.

$$CO_3^{2-}(aq) + 2H^+(aq) \longrightarrow H_2O(l) + CO_2(g)$$

$$HCO_3^-(aq) + H^+(aq) \longrightarrow H_2O(l) + CO_2(g)$$

2. Add magnesium sulphate or magnesium chloride solution to a solution containing (*This test is used to distinguish between a carbonate, CO_3^{2-} and a hydrogen carbonate, HCO_3^-)*

   i. A carbonate ion, CO_3^{2-}.

   $$Mg^{2+}(aq) + CO_3^{2-}(aq) \longrightarrow MgCO_3(s)$$

   Observation: A white precipitate is formed.

   ii. Hydrogen carbonate ion, HCO_3^-.

   $$Mg^{2+}(aq) + 2HCO_3^-(aq) \longrightarrow Mg(HCO_3)_2(aq)$$

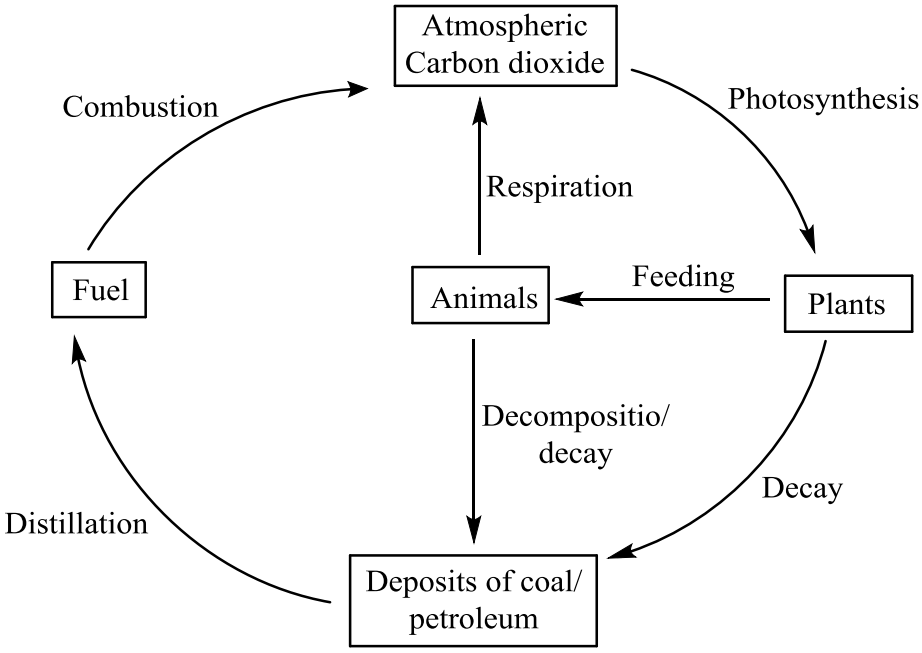
   Observation: No observable change.

   NB: On heating a white precipitate is formed due to formation of insoluble magnesium carbonate on decomposition of magnesium hydrogen carbonate solution.

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

THE CARBON CYCLE

The carbon cycle describes processes that maintain the percentage of carbondioxide gas (0.03%) in the atmosphere.



Equilibrium of the atmosphere via the oxygen and carbon dioxide gas cycles

Carbondioxide gas is removed from the atmosphere by green plants to synthesize glucose in the presence of sunlight trapped in the chlorophyll. In the process, oxygen gas is released into the atmosphere. This process is known as **photosynthesis.**

$$6\ CO_2\ (g) + 6\ H_2O\ (l) \xrightarrow{\text{Sunlight}} C_6H_{12}O_6\ (aq) + 6\ O_2\ (g)$$

At the same time, carbon dioxide gas is returned back into the atmosphere through respiration by both plants and animals. Glucose produced from photosynthesis is transported to all plant cells or

animal cells where respiration takes place in the presence of oxygen gas obtained from the atmosphere. Animals get glucose for respiration when they feed on plants.

$$C_6H_{12}O_6\,(aq) + 6\,O_2\,(g) \longrightarrow 6\,H_2O\,(l) + 6\,CO_2\,(g) + \text{Energy}$$

These processes (photosynthesis and respiration), therefore maintains the balance between the concentrations of carbon dioxide gas and oxygen gas in the atmosphere.

EFFECT OF CARBON DIOXIDE AND CARBON MONOXIDE GAS

Environmental effect of carbon monoxide gas

Carbon monoxide gas is a poisonous and its symptoms in humans include; headache, dizziness and tiredness. Once carbon monoxide gas is inhaled into the body, it binds to haemoglobin in the red blood cells to form a bright red substance called carboxy-haemoglobin which prevents it from carrying and supplying oxygen gas to all parts of the body. This may result into death of humans.

Environmental effect of carbon dioxide gas

i. Carbon dioxide gas dissolved in rain water to form weak carbonic acid (acid rain).

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

When the acid rain goes into rivers, lakes and streams, it may kill some animals and causes death of plants and forests. Furthermore, it corrodes metals and outer coats of buildings made up of calcium carbonate.

ii. Increase of carbon dioxide gas in the atmosphere also increases the green house effect and hence leading to global warming due to the depletion of the ozone layer