Class: Senior three

UNIT 3: SULPHUR AND ITS INORGANIC COMPOUNDS

Key unit competency

After studying this unit, student will be able to relate the properties of sulphur and its compounds to their uses, describe how some compounds of sulphur are prepared and discuss the related environmental issues.

Learning objectives

By the end of this unit, I should be able to:

- Recall the occurrence, extraction, properties and uses of sulphur.
- Prepare, test and collect sulphur dioxide gas and explain the impact of sulphur oxides on the environment.
- Describe the industrial preparation of sulphuric acid by the contact process.
- Develop skills in observation in preparing sulphur dioxide gas and testing for the presence of sulphates and sulphites in given solutions.
- Protect natural resources.
- Develop self confidence in discussions and presentation of research findings.
- Develop a culture of working in a team during research and discussions.
- Respect procedures during experiments.

Study the chart below carefully. What is the chart about?

Mind teaser

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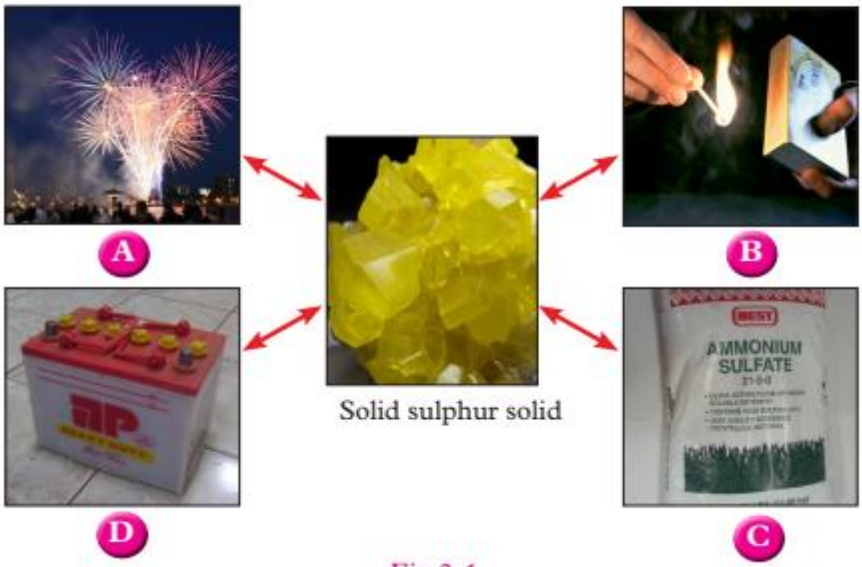


Fig 3.1

Try to identify the properties or uses of sulphur and its compounds associated with the pictures above. Which other ways do we use sulphur in our daily lives?

INTRODUCTION

In senior one, you learnt that sulphur is a non-metal located in groupVI and period 3 of the Periodic Table. It is a **bright yellow** non–metallic element which has been known since ancient times. One of the many compounds of sulphur is sulphuric acid. This acid is very important in Chemistry. For example, it is a major component of car batteries. It is also used to make fertilisers such as ammonium sulphate. Other Sulphur compounds include sulphates, sulphites and gases like hydrogen sulphide, Sulphur dioxide and sulphur trioxide.

3.1 Occurrence, extraction, properties and uses of Sulphur

Occurrence

Sulphur occurs naturally in volcanic regions or regions where volcanoes were formerly active. As a free element sulphur is found occurring about 150 m underground inTexas and Louisiana in USA and Sicily in Italy. Sulphur also occurs as underground deposits in Japan.

Sulphur can occur as a "free" element or combined in compounds such as:

• Hydrogen sulphide found in petroleum, coal gas and natural gas.

• Metal sulphides, for example, zinc blende (ZnS), iron pyrites (FeS_2), copper pyrites ($CuFeS_2$), galena (PbS) etc.

• Metal sulphates, for example gypsum ($CaSO_4.\ 2H_2O$).

Extraction of Sulphur

Sulphur is normally extracted from its underground deposits by **Frasch process**, developed by American Herman Frasch. The sulphur deposits usually occur at about 150 metres below the ground level in beds of about 30 metres diameter. These deposits lie beneath layers of clay, sand and limestone. It is therefore not easy to extract it using ordinary mining methods. The basic principle behind Frasch process is melting the underground Sulphur and then pumping it to the earth's surface. **Three concentric pipes** of different diameters are drilled through into sulphur beds. Super-heated water at 170°C and a pressure of 10 atmospheres is pumped down the outermost pipe to melt the sulphur deposits.The melting point of sulphur is 113°C.
Hot compressed air at pressure of 15 atmospheres is pumped down the innermost pipe.This changes the molten sulphur into a froth which is then forced up through the middle pipe and collects in large containers where it solidifies to yellow solid sulphur.The sulphur obtained this way is usually over 99.8% pure.

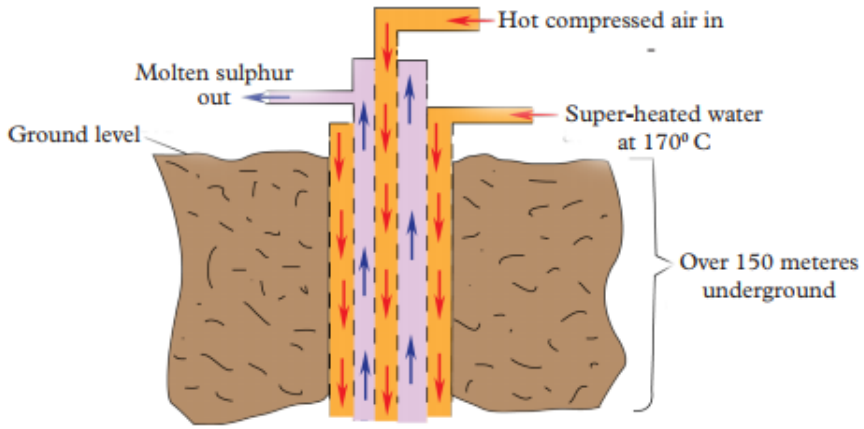


Fig 3.2: Extraction of sulphur by Frasch process

Other methods used to extract Sulphur

Sulphur can also be extracted from crude oil gases. Crude oil gases include hydrogen sulphide (H_2S), carbon dioxide (CO_2) and methane (CH_4).This gaseous mixture is passed through an alkaline solution. Since hydrogen sulphide and carbon dioxide are acidic gases, they are absorbed by the alkaline solution and can be regenerated by heating the solution. The hydrogen sulphide produced is later oxidised to sulphur by air. The hydrogen sulphide is oxidised in the presence of aluminium oxide catalyst as shown in the equation below.This is called the **Claus process**.

$$2H_2S(g) + O_2(g) \xrightarrow{Al_2O_3} 2S(s) + 2H_2O(g)$$

Sulphur can also be produced during the extraction of metals from metal sulphides like zinc blende. When the ore is roasted in air it forms zinc and sulphur dioxide.The sulphur dioxide is reduced by reacting it with hydrogen sulphide to give sulphur.

$$2ZnS(s) + 3O_2(g) \longrightarrow 2ZnO(s) + 2SO_2(g)$$
$$SO_2(g) + 2H_2S(g) \longrightarrow 3S(s) + 2H_2O(g)$$

3.2 Properties and uses of Sulphur

Physical properties of Sulphur

1. It is a bright yellow solid substance at room temperatures.
2. Sulphur is soluble in organic solvents such as carbon disulphide and benzene but it is insoluble in polar solvents like water.
3. It melts at 113°C and boils at 444°C.

Chemical properties of Sulphur

1. Sulphur burns easily with a blue flame in the presence of air to give fumes which turn wet blue litmus paper red.The gas formed is sulphur dioxide. Sulphur dioxide dissolves in water to form sulphurous acid (H_2SO_3).

$$S(s) + O_2(g) \longrightarrow SO_2(g)$$
$$SO_2(g) + H_2O(l) \longrightarrow H_2SO_3(aq)$$

2. Sulphur combines with metals directly and easily to form the corresponding metal sulphides. For example, when a mixture of iron and sulphur is heated, it produces a red hot glow and iron (II) sulphide salt is formed.This reaction is exothermic and once it starts, the glow continues even after heat is withdrawn.

$$Cu(s) + S(s) \xrightarrow{heat} CuS(s)$$

3. When heated with concentrated sulphuric acid, sulphur is oxidised to sulphur dioxide which turns wet blue litmus paper red.

$$S(s) + 2H_2SO_4(l) \longrightarrow 3SO_2(g) + 2H_2O(l)$$

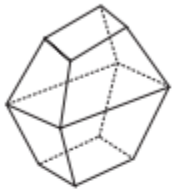
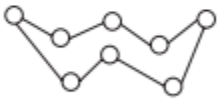
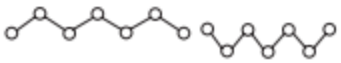
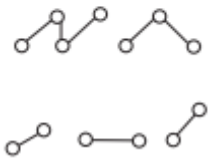
4. Hot concentrated nitric acid oxidises sulphur to sulphuric acid while the acid itself is reduced to brown nitrogen dioxide gas.This is a slow reaction.

   $$S(s) + 6HNO_3(aq) \longrightarrow H_2SO_4(aq) + 6NO_2(g) + 2H_2O(l)$$

   Note: These experiments should be done in the fume cupboard since both SO_2 and NO_2 are poisonous.

5. When heated, sulphur undergoes several changes as shown in the following table 3.1

Table 3.1: Changes that take place in sulphur when heated at different temperatures

Temperature(°C)	Physical change	Explanation
113	Sulphur melts to give a mobile amber coloured liquid; further increase in temperatures makes the liquid to darken.	Intermolecular forces are broken by heat. 
180	The liquid becomes viscous. Colour changes gradually from red to black.	The S_8 rings that forms sulphur molecules open up forming long chains. These chains entangle making them viscous. 
250	Liquid becomes very thick and viscous and cannot flow.	The rings of 8 atoms open up as the molten sulphur is heated more strongly. The long chain entangle and make liquid sulphur viscous. 
Above 250	Colour becomes brighter again and the liquid becomes mobile again.	Short units escape from liquid as gas (sulphur vapour). 

Uses of Sulphur

1) It is used in the manufacture of sulphuric acid.
2) To vulcanise (harden) rubber; ordinary rubber is soft and elastic. However, when heated with sulphur, rubber becomes hard and tough making it suitable for use in making tyres.
3) Manufacture of matches, fireworks and gun powder.The explosive head of a match stick contains sulphur among other substances.
4) Used as a fungicide. Powdered sulphur is usually mixed with petroleum jelly and the mixture used as a skin ointment to treat fungal diseases in animals and plants.
5) Used in the production of important chemicals such as carbon sulphide (CS_2) and calcium hydrogen sulphite $Ca(HSO_3)_2$. Calcium hydrogen sulphite is used during the manufacture of paper to bleach wood pulp.
6) Making sulphur dyes which are used for dyeing cotton and artificial hair.
7) Making of sulphur drugs. Some antimalarial drugs contain sulphur.
8) Manufacture of sodium thiosulphate used in photography.

Fig 3.4: Products made of sulphur

3.3 Inorganic compounds of sulphur and their properties *Sulphur dioxide*

Sulphur dioxide is prepared in a fume cupboard or in the open air because it is poisonous. When a mixture of sodium sulphite and dilute hydrochloric acid is warmed, effervescence occurs producing a colourless gas. The gas is sulphur dioxide.

$$Na_2SO_3\,(aq) + 2HCl(aq) \longrightarrow 2NaCl(aq) + SO_2(g) + H_2O(l)$$

The gas is passed through concentrated sulphuric acid to dry it. It is then collected by downward delivery since it is denser than air. Sulphur dioxide gas may also be prepared in the laboratory by heating a mixture of copper turnings with concentrated sulphuric acid using the following set up.

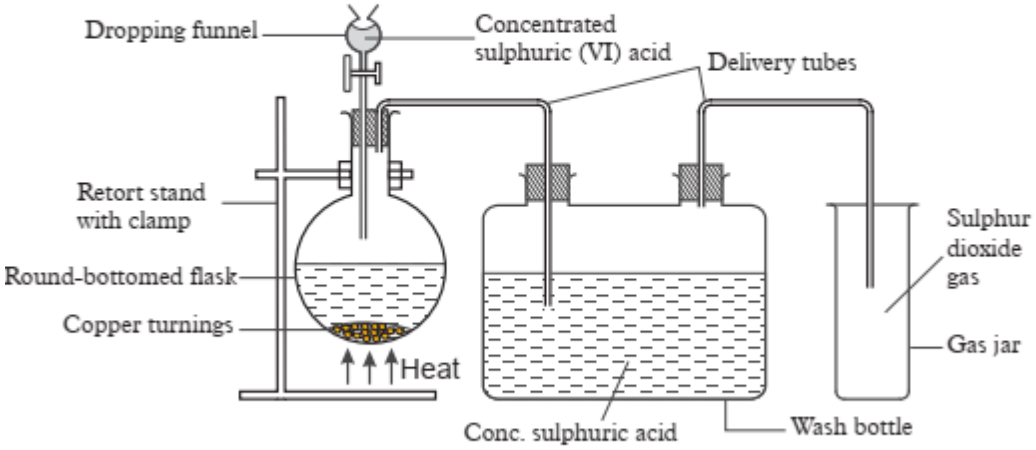


Fig 3.7: Preparation of sulphur dioxide gas using concentrated sulphuric acid and copper turnings

When the reaction mixture in the flask gets hot, effervescence occurs and a colorless gas is collected by downward delivery. The equation for the reaction is as follows.

$$Cu\,(s) + 2H_2SO_4(l) \longrightarrow CuSO_4(aq) + SO_2(g) + 2H_2O(l)$$

When the gas jar is full of the gas, the moist potassium dichromate paper placed at the mouth of the gas jar turns from orange to green.

Properties of sulphur dioxide

Physical properties

- It is a colourless gas.
- It has a pungent choking smell.
- It is very soluble in water.This explains why water rushed into the gas jar in procedure 4 above.
- It is denser than air. This explains why it is collected by downward delivery.

Chemical properties

1. Reaction with water

Sulphur dioxide reacts with water to form sulphurous acid. This is a weak acid that partially dissociates to yield few hydrogen and sulphide ions.The presence of

hydrogen ions explains why a solution of the gas turns blue litmus paper red.

$$H_2O\ (l) + SO_2\ (g) \rightleftharpoons H_2SO_3(aq) \rightleftharpoons 2H^+(aq) + SO_3^{2-}(aq)$$

2. Reaction with alkalis

When sulphur dioxide is passed through sodium hydroxide solution, neutralisation reaction occurs. With excess alkali, sodium sulphite is formed as shown in the following equation.

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When sulphur dioxide is passed through sodium hydroxide solution, neutralisation reaction occurs. With excess alkali, sodium sulphite is formed as shown in the following equation.

$$2NaOH\ (g) + SO_2\ (g) \longrightarrow Na_2SO_3\ (aq) + H_2O(l)$$

With excess sulphur dioxide, sodium hydrogen sulphite is formed as shown in the equations below.

$$NaOH\ (aq) + SO_2\ (g) \longrightarrow Na_2SO_3(aq) + H_2O\ (l)$$

$$Na_2SO_3(aq) + H_2O\ (l) + SO_2\ (g) \longrightarrow 2NaHSO_3(aq)$$

These solutions have bleaching properties.

3. Bleaching action

Flower petals and wet litmus papers when placed in a gas jar of sulphur dioxide, they become bleached. However, dry litmus papers are not bleached. This is because sulphur dioxide gas must first dissolves in water to form sulphurous acid. It is this acid that thus reduces the dye in petals and wet litmus papers by removing the oxygen atom from them. The dye is thus said to be bleached.

$$H_2O(l) + SO_2(g) \rightleftharpoons H_2SO_3(aq) \rightleftharpoons SO_3^{2-}(aq) + 2H^+(aq)$$

$$SO_3^{2-}(aq) + \underset{\text{Coloured}}{\text{dye}} \longrightarrow SO_4^{2-}(aq) + \underset{\text{Colourless}}{\text{(Dye-O)}}$$

Since this type of bleaching occurs by removal of an oxygen atom from a substance, it is called bleaching by reduction. Sulphur dioxide can only bleach in presence of water.

The colour of the dye can be restored if the dye is exposed to environmental oxygen in the presence of sunlight.That is why old newspapers that had been bleached by reduction turn yellow/brown on exposure to air and sunlight after a long time.

Note: Bleaching means removing coloured materials from substances or removing colour.

Laboratory test for sulphur dioxide gas

Sulphur dioxide decolourises an acidified solution of potassium permanganate.The gas also changes the colour of potassium dichromate from orange to green. A solution of iron (III) chloride changes from brown to green.

The three reagents potassium manganate (VII), potassium dichromate (VI) and iron (IIII) chloride are used to test for sulphur dioxide gas. The above colour changes and the bleaching action of sulphur dioxide are used to identify the gas.

Uses of sulphur dioxide

1. It is an intermediate in the manufacture of sulphuric acid.
2. Used as a preservative in jam and fruit juices.
3. Used in fumigation to remove sources of infection from a house or room.
4. Used to make calcium hydrogen sulphite, $Ca(HSO_3)_2$ that is used to bleach wood pulp in the manufacture of paper.
5. Liquid sulphur dioxide is used in refrigerators as a refrigerant.
6. It is used for bleaching wool, straw, silk and sponges.These cannot be bleached using chlorine as they react with it.

Self-evaluation Test

1) Write balanced chemical equations that show the two methods of preparing sulphur dioxide in the laboratory.
2) Blue litmus paper placed in a solution of sulphur dioxide turns red and then colourless. Explain.
3) Describe an experiment you can carry out in the laboratory to establish that a gas is sulphur dioxide.

3.4 Industrial preparation of sulphuric acid

The amount of sulphuric acid consumed by a country in tonnes can be used as a measure of the level of industrialisation of that country. This is so because sulphuric acid is a very important industrial chemical. The industrial process of making sulphuric acid in large scale is known as the **contact process**. The major raw materials for the contact process are sulphur or sulphide ore, air and water. The process takes place in the following stages:

Stage I: Production of sulphur dioxide

Sulphur dioxide is produced by either burning sulphur or by burning sulphur containing ores such as iron pyrites, (FeS_2), zinc blende, (ZnS) or galena, (PbS) Sulphur dioxide may also be produced by burning hydrogen sulphide from crude oil.The following equations show methods of obtaining sulphur dioxide.

a) Burning sulphur from Frasch process in air.

$$S(s) + O_2(g) \longrightarrow SO_2(g)$$

b) Roasting sulphide ores in air during the extraction of metals.

$$2ZnS(s) + 3O_2(g) \longrightarrow 2ZnO(s) + 2SO_2(g)$$
$$4FeS_2(s) + 11O_2(g) \longrightarrow 2Fe_2O_3(s) + 8SO_2(g)$$
$$2PbS(s) + 3O_2(g) \longrightarrow 2PbO(s) + 2SO_2(g)$$

c) Burning hydrogen sulphide from crude oil in air.

$$2H_2S(g) + 3O_2(g) \longrightarrow 2SO_2(g) + 2H_2O(g)$$

Stage II: Oxidation of sulphur dioxide to sulphur trioxide

The sulphur dioxide produced in stage 1 is mixed with air and passed through a dust precipitator (purification chamber). Here dust particles and other impurities are removed then the gases dried. This is achieved through electrostatic precipitation. Purification is important to remove impurities that could otherwise render the catalyst useless (poison the catalyst). The purified gases are then heated to a temperature of (450 – 500)°C and compressed over heated Vanadium (V) oxide catalyst. Under these conditions, sulphur dioxide is oxidised to sulphur trioxide. The equation for the reaction is:

$$2SO_2(g) + O_2(g) \underset{450°C-500°C}{\overset{V_2O_5}{\rightleftharpoons}} 2SO_3(g) + \text{heat}$$

This reaction is exothermic and the temperature rises to about 600°C. Under these optimum conditions, there is 98% yield of sulphur trioxide. The Vanadium (V) oxide catalyst is spread on silica gel to increase the surface area for the reaction. Platinum catalyst can be used in place of Vanadium (V) oxide but it has a disadvantage of being easily susceptible to poisoning and is also expensive.

The gases coming from the catalyst chamber are at high temperatures due to the exothermic nature of the reaction. They are therefore taken back to the heat exchanger for cooling as they pre-heat the incoming mixture of sulphur dioxide and air. Once the reaction has begun, the heat released is used to maintain the operating temperatures. Any sulphur dioxide that is not converted to sulphur dioxide should not be allowed to escape into the atmosphere as this would cause pollution. It is therefore reacted with calcium hydroxide in the chimneys forming salt and water.

Calcium hydroxide + sulphur dioxide ⟶ calcium sulphite + water

$$Ca(OH)_2(s) + SO_2(g) \longrightarrow CaSO_3(s) + H_2O(l)$$

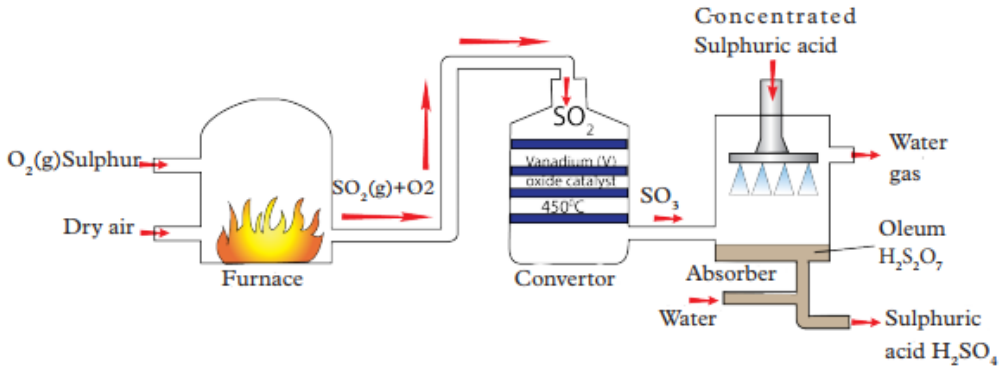


Fig 3.8: The Contact process

Stage III: Production of oleum

The cooled gases are passed to the absorption tower, packed with ceramic rings through which concentrated sulphuric acid flows. The sulphur trioxide reacts with concentrated sulphuric acid forming oleum (fuming sulphuric acid). Oleum is an oily liquid.

$$H_2SO_4\,(l) + SO_3(g) \longrightarrow \underset{\text{Oleum}}{H_2S_2O_7(l)}$$

Sulphur trioxide is not dissolved directly in water to form sulphuric acid. This is because if dissolved in water directly, the reaction will produce a lot of heat as it is highly exothermic. The heat produced boils the acid forming a mist of tiny droplets acid sprays which are dangerous and condense slowly.

Stage IV: Dilution of Oleum to form sulphuric acid

Oleum produced in stage III is mixed with a carefully calculated quantity of water to give concentrated sulphuric acid. The acid obtained from this process is about 98% pure.

$$H_2S_2O_7(l) + H_2O\,(l) \longrightarrow 2H_2SO_4(l)$$

3.5 Properties of concentrated and dilute sulphuric acid

1. *Properties of concentrated sulphuric acid*

Concentrated sulphuric acid converts sugar crystals to yellow, brown and finally to a black mass of substance. Blue copper (II) sulphate crystals in the acid turns into a white powder. On the other hand, brown copper turnings disappear in the acid forming a blue solution. When a piece of paper and a piece of cloth are placed in the acid, they get charred and torn into small pieces. When concentrated sulphuric acid is placed in an open place for sometime its level in the container rises up.

Physical properties of sulphuric acid

1) It is a colourless, odourless oily liquid.
2) It has a density of 1.84 g/cm3.
3) It dissolves in water with evolution of large amounts of heat, that is, why when added to water in the boiling tube, the boiling tube becomes hot.
4) It freezes at 10°C and boils at 338°C.

Note: When diluting the acid, always add the acid into water and never water into the acid and stir continuously. If water is added to the acid, a lot of heat is produced causing the solution to boil very violently, splashing the acid out of the container.

Chemical properties of concentrated sulphuric acid

i) It is hygroscopic

Concentrated sulphuric acid absorbs water from the atmosphere. That is why the level of water in the beaker in procedure (3) of activity 3.4 rose after 48 hours. This property makes concentrated sulphuric acid a suitable drying agent for gases which do not react with it.

ii) It is a dehydrating agent

It is capable of removing combined water from substances. This explains the changes that occurred to sugar crystals in procedure (4) of activity 3.4. The black mass formed is carbon. The equation for the reaction that took place is:

$$C_{12}H_{22}O_{11}(s) \longrightarrow 12C(s) + 11\,H_2O(g)$$

Concentrated sulphuric acid as well removes water from hydrated copper (II) sulphate converting it to a white powder of anhydrous copper (II) sulphate.

$$\underset{\text{Blue crystals}}{CuSO_4.5H_2O(s)} \xrightarrow{\text{conc.}H_2SO_4} \underset{\text{White powder}}{CuSO_4(s)} + 5H_2O\,(l)$$

Similarly concentrated sulphuric acid removes water from wood converting it into a black mass of carbon.

Note: Dehydration is the removal of chemically combined water or elements of water from a compound. A substance capable of removing chemically combined water or elements of water is called a **dehydrating agent**.

iii) It is corrosive

Concentrated sulphuric acid should not come into contact with skin or cloth as it will corrode them. The same happens to paper when put into the acid.

iv) It is an oxidising agent

Hot concentrated sulphuric acid acts as an oxidising agent. It oxidises almost all metals with the exception of those that are very low in the reactivity series such as gold and platinum. The following equations shows the effect of concentrated sulphuric acid with metals.

i $\underset{\text{(Brown)}}{Cu(s)} + 2H_2SO_4(l) \longrightarrow \underset{\text{(blue)}}{CuSO_4(aq)} + SO_2(g) + 2H_2O(l)$

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

ii. $Mg(s) + 2H_2SO_4(l) \longrightarrow MgSO_4(aq) + SO_2(g) + 2H_2O(l)$

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

iii. $Zn(s) + 2H_2SO_4(l) \longrightarrow ZnSO_4(aq) + SO_2(g) + 2H_2O(l)$

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

As seen from the above equations, the metals lose two electrons to form corresponding metal ions. This is oxidation. Concentrated sulphuric acid accepts the electrons lost and reduced into sulphur dioxide and water. This is reduction.

$$2H_2SO_4(l) + 2e^- \longrightarrow SO_4^{2-}(aq) + SO_2(g) + 2H_2O(l)$$

Note: Oxidation is the loss of electrons while reduction is the gain of electrons

(b)Properties of dilute sulphuric acid

Blue litmus paper in dilute sulphuric acid turns red. Phenolphthalein indicator in a mixture of sulphuric acid and sodium hydroxide turns pink. Copper (II) oxide reacts with the acid forming a blue solution. When either sodium carbonate or sodium hydrogen carbonate reacts with dilute sulphuric acid, effervescence is seen due to production of a gas. The gas forms a white precipitate with lime water.

Physical properties of dilute sulphuric acid

• It is colourless and odourless.

Chemical properties of dilute sulphuric acid

i. Reaction with metals

Dilute sulphuric acid reacts with metals to form salt and hydrogen gas. However, metals like copper, silver and gold do not react with dilute sulphuric acid. They cannot displace hydrogen from the acid. Reaction of dilute sulphuric acid with some metals are shown below.

$Mg(s) + H_2SO_4(aq) \longrightarrow MgSO_4(aq) + H_2(g)$

$Zn(s) + H_2SO_4(aq) \longrightarrow ZnSO_4(aq) + H_2(g)$

$Fe(s) + H_2SO_4(aq) \longrightarrow FeSO_4(aq) + H_2(g)$

ii. Reaction with oxides and hydroxides

Dilute sulphuric acid reacts with hydroxides to form salt and water. This is a neutralisation reaction. Phenolphthalein indicator turns pink in a neutral solution. This is shown in the following reactions.

$H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + H_2O(l)$

$H_2SO_4(aq) + 2KOH(aq) \longrightarrow K_2SO_4(aq) + H_2O(l)$

Dilute sulphuric acid also neutralises metal oxides to form salt and water. It reacts with copper (II) oxide forming a blue solution of copper (II) sulphate as shown in the following equation.

$H_2SO_4(aq) + CuO(s) \longrightarrow CuSO_4(aq) + H_2O(l)$

iii. Reaction with carbonates and hydrogen carbonates

Dilute sulphuric acid reacts with metal carbonates and hydrogen carbonates to form salt, water and carbon dioxide. The carbon dioxide produced forms a white precipitate with lime water. The following equations show the reactions that take place when the acid reacts with sodium carbonate and sodium hydrogen carbonate respectively.

$Na_2CO_3(s) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + CO_2(g) + H_2O(l)$

$2NaHCO_3(aq) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + 2CO_2(g) + 2H_2O(l)$

Note: When the carbonates of lead, calcium and barium are added to dilute sulphuric acid, the reaction starts soon stops. This is because the sulphates formed are insoluble; they coat the rest of the metal carbonate preventing further contact between it and the acid hence the reaction stops.

Uses of sulphuric acid

Laboratory preparation of sulphates

There are three ways of preparing sulphates in the laboratory.

1) By neutralising dilute sulphuric acid with an alkali.

$2NaOH(aq) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$

The solution is evaporated to concentrate it and when it slowly cools, sodium

sulphate crystals form. Ammonium sulphate and aluminium sulphate can also be prepared using a similar reaction method.

2. By the action of concentrated or dilute sulphuric acid on an appropriate metal as shown by the equations below.

$$Cu(s) + 2H_2SO_4(l) \longrightarrow CuSO_4(aq) + 2SO_2(g) + 2H_2O(l)$$
$$Zn(s) + H_2SO_4(aq) \longrightarrow ZnSO_4(aq) + H_2(g)$$

Filtration is done and the filtrate evaporated then cooled slowly to form crystals of the salt.

3. By double decomposition.

This method is suitable for preparing insoluble sulphates.The reaction equation below show how this happens.

$$Na_2SO_4(aq) + Pb(NO_3)_2(aq) \longrightarrow 2NaNO_3(aq) + PbSO_4(s)$$

$$Na_2SO_4(aq) + Ca(NO_3)_2(aq) \longrightarrow 2NaNO_3(aq) + CaSO_4(s)$$

After filtration, the residue is washed with distilled water and dried.

3.6 Test for sulphates and sulphites

When a few drops of barium nitrate is added to a solution containing sulphite or sulphate ions, a white precipitate forms. On addition of dilute nitric acid, the precipitate formed with sulphite ions dissolves while that formed with sulphate ions persist.

Solutions containing sulphite and sulphate ions form white precipitate when barium nitrate or barium chloride solutions are added.

$$Ba^{2+}(aq) + SO_3^{2-}(aq) \longrightarrow \underset{\text{White precipitate}}{BaSO_3(s)}$$
$$Ba^{2+}(aq) + SO_4^{2-}(aq) \longrightarrow \underset{\text{White precipitate}}{BaSO_4(s)}$$

To differentiate between sulphite and sulphate ions, dilute nitric acid or dilute hydrochloric acid is added to the test tube containing the white precipitate. If the salt is a sulphate, the white precipitate persists. However, if the salt is a sulphite the precipitate dissolves giving off sulphur dioxide and a colourless solution is formed.

$$BaSO_3(s) + 2HNO_3(aq) \longrightarrow Ba(NO_3)_2(aq) + SO_2(g) + H_2O(l)$$
$$BaSO_3(s) + 2HCl(aq) \longrightarrow BaCl_2(aq) + SO_2(g) + H_2O(l)$$

The identity of the sulphur dioxide gas may be confirmed by testing with a paper dipped in acidified potassium dichromate (VI) solution which changes colour from orange to green.

3.7 Environmental issues related to sulphur oxides

Steps to reduce pollution by sulphur oxides

1) Unreacted sulphur dioxide and sulphur trioxide are recycled into the catalyst chamber in the Contact process.

2) Unreacted sulphur dioxide during Contact process undergoes scrubbing in the chimney.
3) Always use sulphur free fossil fuels.
4) Abide by the laws set up by the government to reduce the amount of sulphur oxides released to the atmosphere.

My environment, my life!

Always remember to protect the environment while undertaking any activity whether commercial or not. Preserve the environment for future generation.

3.8 Unit Summary

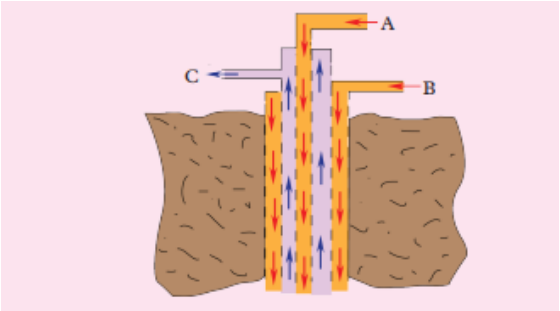
- Sulphur occurs naturally as a free element or in combined form as hydrogen sulphide, metal sulphide or metal sulphates.
- Extraction of sulphur is done by the Frasch process. Claus process can also be used.
- Sulphur does not dissolve in water but dissolves in organic solvents like carbon disulphide.
- In the laboratory, sulphur dioxide is prepared by the action of dilute hydrochloric acid on sodium sulphite or heating a mixture of copper turnings and concentrated sulphuric acid.
- Sulphur dioxide is a colourless, poisonous, acidic gas with a choking smell. It is very soluble in water and denser than air.
- Sulphuric acid is industrially prepared by the Contact process.The main raw materials for this process are sulphur or an ore of sulphur, water and air.
- Concentrated sulphuric acid has oxidizing, dehydrating, corrosive and hygroscopic properties. Dilute sulphuric acid on the other hand has all the acidic properties of a strong mineral acid.
- Sulphites and sulphates are identified by reacting them with barium nitrate or barium chloride solution. A white precipitate of barium sulphite dissolves in dilute hydrochloric acid or dilute nitric acid but the barium sulphate precipitate persists in either of the dilute acids.
- Oxides of sulphur should not be allowed into the atmosphere as they are a major cause of environmental pollution.

Unit Test

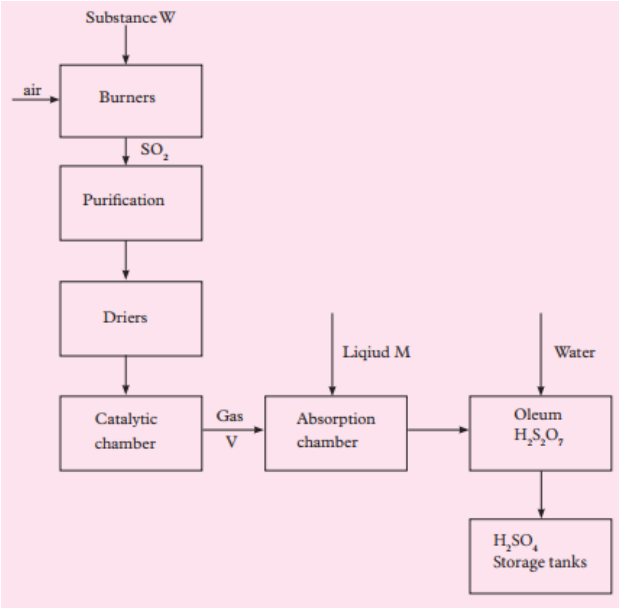
Test your competency by answering the following questions

1) Extraction of sulphur is carried out by the _____ process while industrial preparation of sulphuric acid is done by the _____ process.
2) Kampire and Gasimba wanted to prepare dilute sulphuric acid using concentrated sulphuric acid and distilled water.
   (a) What procedure should they follow?
   (b) Why should they follow the procedure you have mentioned in 1(a) above?

3) Sulphuric acid can be used for all of the following except ——————.
   A. Manufacture of fertiliser
   B. Making car tyres
   C. Dehydrating sugar
   D. Used in car batteries
4) Write **true** or **false** for each of the following statements.
   a) Dilute sulphuric acid is a dehydrating agent. _____
   b) Metals react with concentrated sulphuric acid to form salts and hydrogen gas. _____
   c) Sulphur dioxide bleaches by reduction. _____
   d) Sulphur dioxide is an alkaline gas _____
5) The figure below shows the process used to extract sulphur.



   a) Name the substance that passes through pipes A, B and C.
   b) What is the role of the substances that pass though pipes A and B?
6) _____ is the catalyst used in the contact process.
7) Powdered sulphur was placed in deflagrating spoon and heated in a Bunsen burner flame until the sulphur started to burn.
   a) What is observed as the sulphur burns?
   b) Write an equation for the reaction in 7(a) above.
   c) What problem does this reaction pose to the environment?
8) tudy the flowchart below showing manufacture process of sulphuric acid.



a) Identify (i) Substance W
(ii) Gas V
(iii) Liquid M

b) State the conditions necessary for the formation of Gas V.

c) How would you control pollution that may come as a result of the above process?

9) You have been requested to give a speech on the environmental impact of sulphur compounds and ways of protecting the environment from pollution by sulphur compounds. Prepare the speech you would give.

10) In an experiment, 2.5g of sulphur was obtained by reacting hydrogen sulphide and chlorine as shown by the equation below.

$$H_2S(g) + Cl_2(g) \longrightarrow S(s) + 2HCl(g)$$

a) Which of the reactants acts as a reducing agent in the above reaction.

b) State the effects of hydrogen sulphide on the environment.

11) Powdered sulphur was placed in deflagrating spoon and heated in a Bunsen flame until the sulphur started to burn.

a) What was seen when the sulphur burns.

b) Write an equation for the reaction in 11(a) above.

c) When the product formed in 11(b) is dissolved in water, name the solution that is formed and write the equation for the reaction.

d) If a few drops of litmus solution was added to the solution in 11(c) above, what would be the colour of the litmus solution?

e) Write an equation for the reaction that will occur between the solution formed in 11(c) above and sodium hydroxide solution.

12) a) Suggest ways through which air pollution can be reduced.

(b) To what extent is acid rain a problem in Rwanda?

(c) Acid rain is an international problem. Justify the statement.

(d) Should governments of different countries be doing something about the problem? Discuss.

Facilitator: MICOMYIZA Faustin
Phone: 0781147047(WatsApp)