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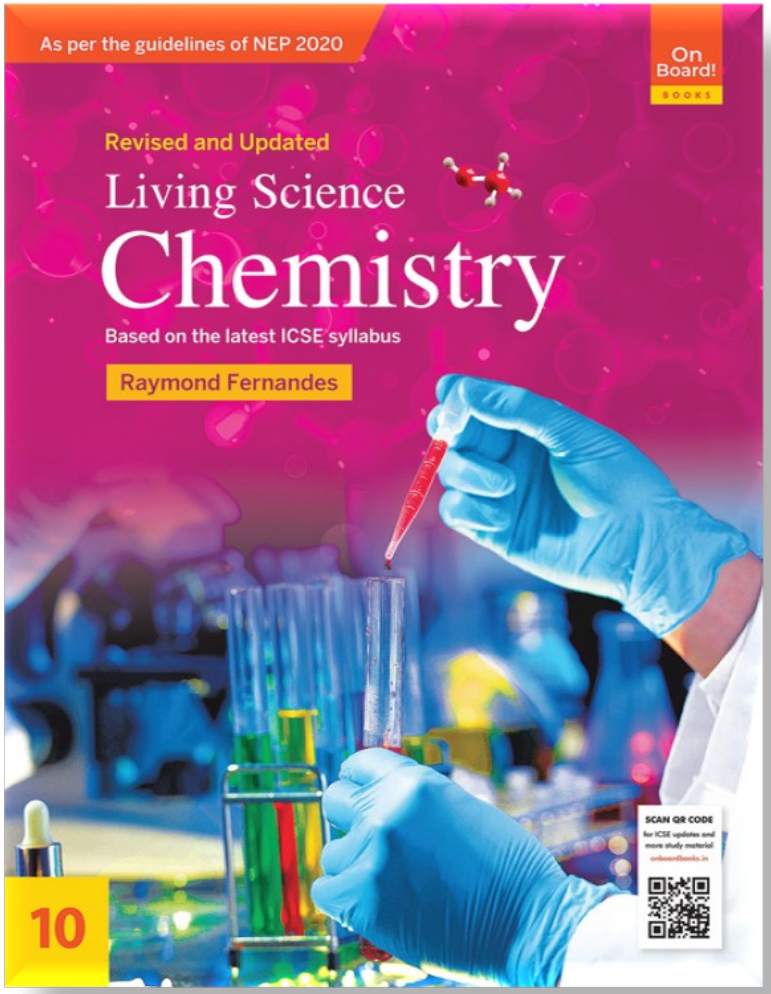
ICSE
Living Science
Chemistry

Class 10

Chapter-11 Study of Compounds- Sulphuric Acid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Living Science
Chemistry
Based on the latest ICSE syllabus
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LEARNING OBJECTIVES

Sulphuric Acid

- Occurrence
- Important characteristics
- Preparation
- Industrial methods for preparation
- Physical properties
- Chemical properties
- Tests
- Uses

Why is Sulphuric Acid called king of chemicals and oil of vitriol?

Of all acids, sulphuric acid is the most important one. It is used directly or indirectly in all industries. Hence it is called “king of chemicals”. It is also called oil of vitriol because it was first prepared by the dry distillation of green vitriol ($FeSO_4 \cdot 7H_2O$) and obtained as an oily viscous liquid.

$$2FeSO_4 \cdot 7H_2O \longrightarrow Fe_2O_3 + SO_2 + SO_3 + 14H_2O$$

The sulphur trioxide dissolves in water forming sulphuric acid.

$$SO_3 + H_2O \longrightarrow H_2SO_4$$

Important Characteristics of Sulphuric Acid

Molecular formula: H_2SO_4

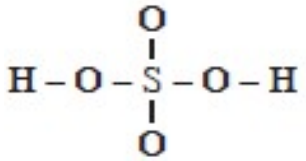
Molecular mass: 98 u

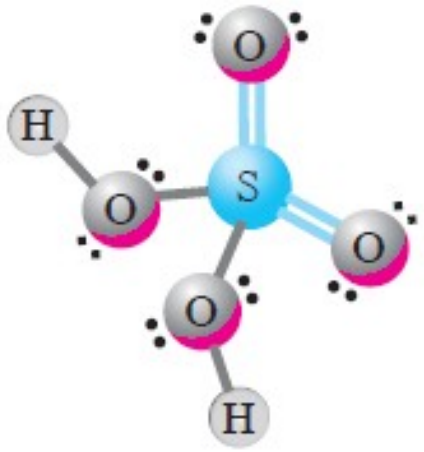
Nature: Oily, viscous, hygroscopic and acidic

Solubility: Soluble in water

Specific gravity: 1.85 (of the pure acid)

Common name: Oil of vitriol





Structure: The sulphuric acid molecule consists of one sulphur atom bonded to two oxygen atoms by double bonds and to two more by single bonds. The single bonded oxygen atoms are then bonded to hydrogen atoms.

Occurrence of sulphuric acid

Sulphuric acid is a constituent of acid rain. It is formed by the atmospheric oxidation of sulphur dioxide in the presence of moisture. It is also formed near sulphur beds and is present in minute traces in hot springs. In the combined form it is present as metallic sulphates like barytes (barium sulphate, $BaSO_4$), gypsum ($CaSO_4 \cdot 2H_2O$), aluminium sulphate, $Al_2(SO_4)_3$.

Preparation of sulphuric acid

1. From sulphur

When sulphur is warmed with concentrated nitric acid, it forms sulphuric acid as a byproduct.

$$S + 6HNO_3 \longrightarrow H_2SO_4 + 2H_2O + 6NO_2$$

2. From sulphur dioxide

Sulphur dioxide can be converted to sulphuric acid in many ways:

a. By oxidizing moist sulphur dioxide

$$2SO_2 + 2H_2O + O_2 \rightarrow 2H_2SO_4$$

b. By passing sulphur dioxide through chlorine water or bromine water

$$SO_2 + 2H_2O + Cl_2 \rightarrow H_2SO_4 + 2HCl$$

$$SO_2 + 2H_2O + Br_2 \rightarrow H_2SO_4 + 2HBr$$

c. By combining sulphur dioxide directly with hydrogen peroxide.

$$H_2O_2 + SO_2 \longrightarrow H_2SO_4$$

3. From sulphuryl chloride

Sulphuryl chloride on hydrolysis forms sulphuric acid.

$$SO_2Cl_2 + 2H_2O \longrightarrow H_2SO_4 + 2HCl$$

4. From sulphur trioxide

When sulphur trioxide reacts with water, it forms sulphuric acid. This reaction is highly exothermic and very dangerous because the heat of reaction vaporises the sulphuric acid forming a dense fog.

$$SO_3 + H_2O \longrightarrow H_2SO_4$$

5. From hydrated sulphates

Heating hydrated metallic sulphates in the absence of air also forms sulphuric acid.

$$Al_2(SO_4)_3 \cdot 3H_2O \longrightarrow Al_2O_3 + 3H_2SO_4$$

Industrial methods for the preparation of sulphuric acid

Industrially, the main method for the preparation of sulphuric acid is the Contact process.

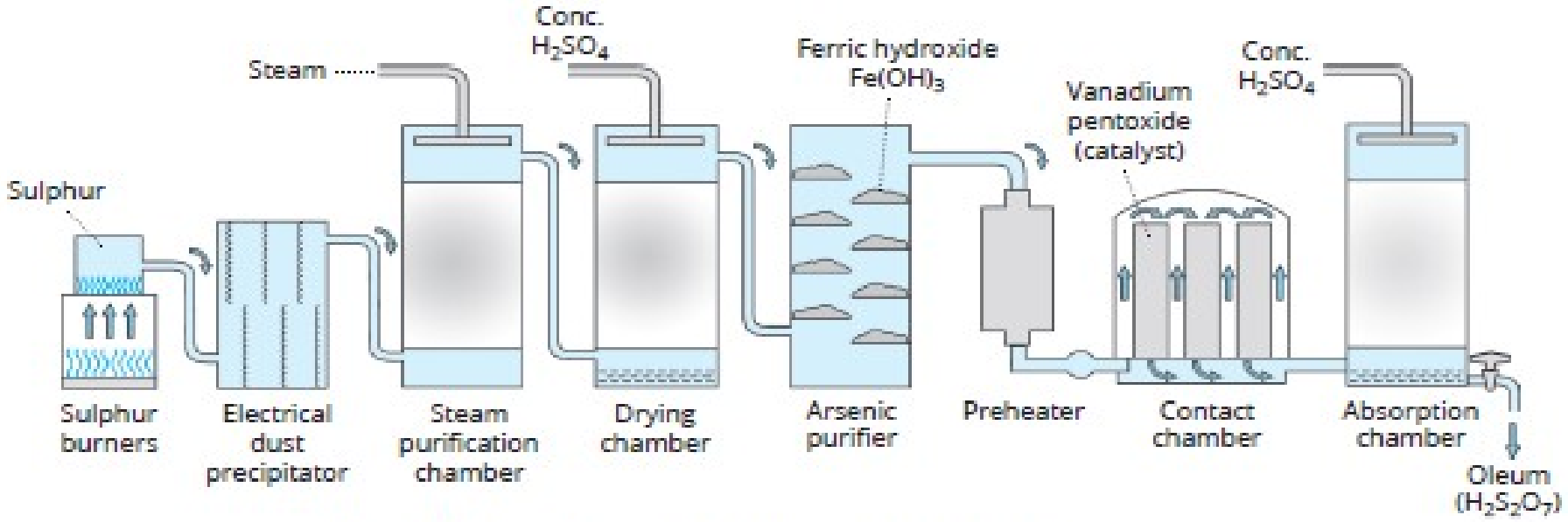
The Contact process

This process is based upon the reversible combination of sulphur dioxide and oxygen to form sulphur trioxide.

The Contact process for manufacturing sulphuric acid has main five stages :

Stage 1: Production of sulphur dioxide

Sulphur dioxide is obtained by burning sulphur or by roasting iron pyrites in excess supply of oxygen.



Here, sulphur burns with a characteristic pale blue flame.

$$S + O_2 \longrightarrow SO_2$$

$$4FeS_2 + 11O_2 \longrightarrow 2Fe_2O_3 + 8SO_2$$

Stage 2: Purification of sulphur dioxide

Purification of the gaseous mixture is essential to remove the arsenical compounds and other compounds that may poison the catalyst in the next stage. In order to remove impurities, the gaseous mixture of sulphur dioxide and oxygen is passed through a series of converters:

a. Electrostatic precipitator: Most of the fly ash and dust particles in a gaseous mixture are attracted by the electric charge and are removed.

b. Scrubber: The gaseous mixture is then passed through the water scrubber which removes the remaining dust particles and fly ash.

c. Washing tower: Water is sprayed to remove any other solid particles from the gaseous mixture after cooling it.

d. Drying chamber: The gaseous mixture is then dried by passing it through drying chamber where concentrated sulphuric acid, a dehydrating agent, is sprayed to remove water from SO_2 and O_2 mixture.

e. Arsenic purifier: The arsenic oxide is present in the gaseous mixture as an impurity, which can be removed by passing the gas over ferric hydroxide.

$$As_2O_3 + 2Fe(OH)_3 \longrightarrow 2FeAsO_3 + 3H_2O$$

Now, the gaseous mixture is completely free of impurities as tested by passing the gas through tyndall or dark box, wherein no scattering of light takes place.

Stage 3: Catalytic oxidation of sulphur dioxide

Dried and purified sulphur dioxide containing excess of oxygen is passed through series of converters where the catalyst, vanadium pentoxide, is stored on shelves in a way which exposes the maximum possible surface area to the reacting gases. The gaseous mixture of sulphur dioxide and oxygen on passing through these preheated catalytic converters forms sulphur trioxide.

$$2SO_2 + O_2 \rightleftharpoons 2SO_3 + \text{heat}$$

V_2O_5 is preferred over platinum as a catalyst since it is less susceptible to poisoning by impurities like arsenic. It is much cheaper than platinum. The catalyst is heated only at the initial stage. The oxidation of sulphur dioxide is exothermic and the temperature required for the reaction is maintained without external heating by using heat exchangers

Stage 4: Absorption of sulphur trioxide

After passing through converters, sulphur trioxide is cooled and passed into an absorption tower where it is absorbed in concentrated sulphuric acid to form oleum ($H_2S_2O_7$). Sulphur trioxide is not absorbed into sulphuric acid directly as the reaction is exothermic.

$$SO_3 + H_2SO_4 \longrightarrow H_2S_2O_7$$

Stage 5: Diluting oleum

Oleum is diluted by adding a calculated amount of water to obtain H_2SO_4 of the desired strength.

$$H_2S_2O_7 + H_2O \longrightarrow 2H_2SO_4$$

Favourable conditions for catalytic conversion of sulphur dioxide (SO_2) to sulphur trioxide (SO_3)

1. **Temperature**: The temperature should be maintained between 450 °C and 500 °C for catalytic conversion of sulphur dioxide to sulphur trioxide. If the temperature is above 500 °C (or high), sulphur trioxide may decompose to give sulphur dioxide and oxygen. However, the low temperature slows down the rate of reaction.

2. **Pressure**: An optimum pressure of about 1–2 atmospheres is required. This is because high pressure may give a higher yield of sulphur trioxide but would damage or corrode the lead pipes and acid-resisting towers containing gases as these gases are acidic in nature.

3. **Excess of oxygen**: Presence of excess amounts of oxygen increases the production of sulphur trioxide.

4. **Catalyst**: A suitable catalyst vanadium pentoxide is used for the conversion of sulphur dioxide to sulphur trioxide. Platinum is not preferred because it is quite expensive and easily poisoned by arsenic impurities.

Physical properties of sulphuric acid

1. **Physical appearance:** Sulphuric acid is a colourless, odourless and oily liquid.
2. **Taste:** It has a slight sour taste.
3. **Nature:** Concentrated sulphuric acid is highly corrosive and hygroscopic in nature. When exposed to air, it absorbs moisture and increases in volume. So, it should be kept in stoppered bottles.
4. **Solubility:** It is heavier than water and soluble in it in all proportions.
5. **Boiling point:** It boils at 338 °C and forms a constant boiling mixture at 338 °C. As sulphuric acid forms a constant boiling mixture, it cannot be concentrated by boiling or distillation beyond a certain concentration. Hence, aqueous solution of sulphuric acid gives out vapours of both acid and water on boiling.
6. **Melting point:** It freezes to colourless crystals at 10.4 °C.

What happens when sulphuric acid is dissolved in water ?

If equal volume of acid and water is mixed at ordinary temperature, the solution attains a temperature of 120 °C. Therefore, water must not be added to the concentrated acid as it is a highly exothermic reaction which can cause splashing of the acid. This can result in severe burn injuries. Hence, the acid should be diluted by pouring it slowly into the water with continuous stirring. The acid being denser will sink to the bottom and the heat evolved is distributed uniformly.

Chemical properties of sulphuric acid

Properties of dilute sulphuric acid

Dilute sulphuric acid behaves like a typical acid and shows the following reactions:

Pure sulphuric acid does not show any ionization and hence, does not show any acidic properties. But when it is dissolved in water, it ionizes and hence, shows acidic properties.

Being dibasic, it ionizes in two steps:

$$H_2SO_4 + H_2O \rightleftharpoons H_3O^+ + HSO_4^-$$

$$HSO_4^- + H_2O \rightleftharpoons H_3O^+ + SO_4^{2-}$$

Note: Pure sulphuric acid is a poor conductor of electricity. But when water is added to pure sulphuric acid, it becomes a very good conductor and behaves like a strong electrolyte.

2. Action on indicators

The hydronium ion formed when sulphuric acid is dissolved in water is responsible for the colour changes in indicators.

a. **Litmus paper:** From blue to red

b. **Methyl orange:** From orange to red

c. **Phenolphthalein:** Phenolphthalein solution stays colourless. But alkaline phenolphthalein changes from pink to colourless.

3. With active metals

Sulphuric acid reacts with active metals to liberate hydrogen gas.

$$Zn + H_2SO_4 \longrightarrow ZnSO_4 + H_2\uparrow$$

$$Fe + H_2SO_4 \longrightarrow FeSO_4 + H_2\uparrow$$

Hydrogen gas when tested burns with a pale blue flame and produces a pop sound.

Note: Highly active metals like potassium, calcium and sodium react so violently with sulphuric acid that the hydrogen produced in the reaction catches fire.

4. With oxides and hydroxides of metals

Sulphuric acid neutralizes oxides and hydroxides of metals to form their corresponding salts and water.

$$2NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$$

$$Zn(OH)_2 + H_2SO_4 \longrightarrow ZnSO_4 + 2H_2O$$

5. With carbonates and bicarbonates

Sulphuric acid reacts with metal carbonates and bicarbonates to liberate carbon dioxide.

$$CaCO_3 + H_2SO_4 \longrightarrow CaSO_4 + H_2O + CO_2\uparrow$$

$$K_2CO_3 + H_2SO_4 \longrightarrow K_2SO_4 + H_2O + CO_2\uparrow$$

6. With sulphides

Sulphuric acid reacts with metallic sulphides to form hydrogen sulphide.

$$FeS + H_2SO_4 \longrightarrow FeSO_4 + H_2S$$

7. With sulphites and bisulphites: Sulphuric acid reacts with metallic sulphites and bisulphites to liberate sulphur dioxide.

$$K_2SO_3 + H_2SO_4 \longrightarrow K_2SO_4 + H_2O + SO_2$$

$$ZnSO_3 + H_2SO_4 \longrightarrow ZnSO_4 + H_2O + SO_2$$

$$Na_2SO_3 + H_2SO_4 \longrightarrow Na_2SO_4 + H_2O + SO_2$$

$$2NaHSO_3 + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O + 2SO_2$$

8. With bleaching powder

Dilute sulphuric acid reacts with bleaching powder to liberate chlorine.

$$CaOCl_2 + H_2SO_4 \longrightarrow CaSO_4 + H_2O + Cl_2$$

9. With soluble salts of lead, barium and calcium

Sulphuric acid reacts with soluble salts of lead, barium and calcium to form their insoluble sulphates.

$$Pb(NO_3)_2 + H_2SO_4 \longrightarrow \underset{\text{(white ppt.)}}{PbSO_4\downarrow} + 2HNO_3$$

$$BaCl_2 + H_2SO_4 \longrightarrow \underset{\text{(white ppt.)}}{BaSO_4\downarrow} + 2HCl$$

$$CaCl_2 + H_2SO_4 \longrightarrow \underset{\text{(white ppt.)}}{CaSO_4\downarrow} + 2HCl$$

For more reaction examples, please see p. 203-204 of the textbook.

Properties of concentrated sulphuric acid

Concentrated sulphuric acid shows entirely different properties from dilute sulphuric acid.

1. As a dehydrating agent

Concentrated sulphuric acid is a powerful dehydrating agent. It removes water from organic compounds and also water of crystallization from hydrated salts.

a. Dehydration of copper sulphate crystals: It dehydrates blue crystalline hydrated copper sulphate (blue vitriol) and turns it into white amorphous copper sulphate powder.

$$CuSO_4 \cdot 5H_2O \xrightarrow[\text{concentrated}]{H_2SO_4} CuSO_4 + 5H_2O$$

b. Dehydration of sugar: It dehydrates white crystalline sugar and turns it into black spongy carbon.

$$C_{12}H_{22}O_{11} \xrightarrow[\text{concentrated}]{H_2SO_4} 12C + 11H_2O$$

c. Dehydration of organic acids: It dehydrates formic acid and oxalic acid to form carbon monoxide and a mixture of carbon monoxide and carbon dioxide, respectively.

$$HCOOH \xrightarrow[\text{concentrated}]{H_2SO_4} CO + H_2O$$

$$\begin{matrix} COOH \\ | \\ COOH \end{matrix} \xrightarrow[\text{concentrated}]{H_2SO_4} CO + CO_2 + H_2O$$

Properties of concentrated sulphuric acid

2. As a non-volatile acid

Concentrated sulphuric acid has a high boiling point and is therefore called a non-volatile acid. Hence, when salts of more volatile acids are heated with sulphuric acid, it displaces the acids from the salts.

$$KCl + H_2SO_4 \longrightarrow KHSO_4 + HCl$$

$$NaCl + H_2SO_4 \longrightarrow NaHSO_4 + HCl$$

3. As an oxidizing agent

Concentrated sulphuric acid when heated undergoes decomposition giving out nascent oxygen that oxidizes the substances. On the other hand, sulphuric acid itself gets reduced to sulphur dioxide.

$$H_2SO_4 \rightarrow H_2O + SO_2 + [O]$$

Concentrated sulphuric acid oxidizes strong reducing agents like hydrogen iodide and hydrogen sulphide.

a. With non-metals

$$C + 2H_2SO_4 \longrightarrow 2SO_2 + 2H_2O + CO_2$$

$$S + 2H_2SO_4 \longrightarrow 3SO_2 + 2H_2O$$

b. With metals

$$Cu + 2H_2SO_4 \longrightarrow CuSO_4 + 2H_2O + SO_2$$

$$Zn + 2H_2SO_4 \longrightarrow ZnSO_4 + 2H_2O + SO_2$$

c. With reducing agents

Hydrogen sulphide gets oxidized to sulphur.

$$H_2S + H_2SO_4 \longrightarrow SO_2 + 2H_2O + S$$

Tests for sulphuric acid

1. Dilute sulphuric acid gives a white precipitate of barium sulphate (BaSO4) when added to barium chloride solution which is insoluble in dilute HCl or HNO_3. Concentrated sulphuric acid has no effect on $BaCl_2$ solution.

$$BaCl_2 + H_2SO_4(dil.) \longrightarrow 2HCl + BaSO4 \downarrow$$

(white ppt.)

2. Concentrated sulphuric acid when heated with copper gives SO_2 gas which turns acidified potassium dichromate solution green.

$$Cu + 2H_2SO_4(conc.) \longrightarrow CuSO_4 + 2H_2O + SO_2\uparrow$$

3. Concentrated sulphuric acid when heated with sodium chloride gives hydrogen chloride gas which forms dense white fumes with a rod dipped in ammonia solution.

$$NaCl + H_2SO_4(conc.) \longrightarrow NaHSO_4 + HCl \uparrow$$

$$NH_3 + HCl \longrightarrow NH_4Cl \uparrow$$

white dense fumes

Uses of sulphuric acid

1. It is used in lead storage batteries as H_2SO_4 undergoes electrolysis.
2. It is used in the manufacture of dyes, drugs and disinfectants.
3. It is used in the manufacture of explosives like nitroglycerine.

4. It is used in the manufacture of chemicals like HCl, HNO_3, H_3PO_4 and artificial fibres like rayon and nylon.
5. It is used in the manufacture of fertilizers like ammonium sulphate $(NH_4)_2SO_4$, ammonium phosphate, etc.
6. It is used for electrolytic refining of metals.
7. It is used for pickling, i.e. cleaning of metal surfaces by the removal of metallic impurities (oxides and carbonates) before electroplating.
8. In laboratory, it used as a drying agent for gases such as N_2, O_2, Cl_2, SO_2 and HCl.

Note:

- Concentrated sulphuric acid cannot be used to dry H_2S and NH_3 as they react with the acid.
- Drying agents only cause a physical change in the compound. There is no alteration in the composition of the compound.
- Dehydrating agents cause a chemical change by changing the composition of a compound.

Sulphuric acid is hygroscopic in nature. It readily absorbs water vapour from the atmosphere. Therefore, it is used as a good dehydrating agent and kept in airtight bottles to prevent it from getting diluted.

SUMMARY

1. Sulphuric acid was first obtained as an oily viscous liquid from the distillation of green vitriol (i.e. ferrous sulphate), therefore, it is known as oil of vitriol.
2. **Preparation of sulphuric acid**

$$S + 6HNO_3 \longrightarrow H_2SO_4 + 2H_2O + 6NO_2$$

$$2SO_2 + 2H_2O + O_2 \longrightarrow 2H_2SO_4$$

$$SO_2 + 2H_2O + Cl_2 \longrightarrow H_2SO_4 + 2HCl$$

$$SO_2 + 2H_2O + Br_2 \longrightarrow H_2SO_4 + 2HBr$$

$$H_2O_2 + SO_2 \longrightarrow H_2SO_4$$

$$SO_3 + H_2O \longrightarrow H_2SO_4$$

$$SO_2Cl_2 + 2H_2O \longrightarrow H_2SO_4 + 2HCl$$

$$Al_2(SO_4)_3{\cdot}3H_2O \longrightarrow Al_2O_3 + 3H_2SO_4$$

3. **The Contact process**

Stage 1: $S + O_2 \longrightarrow SO_2$

$$4FeS_2 + 11O_2 \longrightarrow 2Fe_2O_3 + 8SO_2$$

Stage 2: Removal of dust, flyash and arsenic impurities. If not removed, these impurities will poison the catalyst used.

Stage 3: $2SO_2 + O_2 \underset{V_2O_5}{\rightleftharpoons} 2SO_3 + \text{heat}$

Stage 4: $SO_3 + H_2SO_4 \longrightarrow H_2S_2O_7$

Stage 5: $H_2S_2O_7 + H_2O \longrightarrow 2H_2SO_4$

SO_3 is not directly dissolved in water as the reaction being exothermic results in the formation of dense fog of H_2SO_4 which is difficult to condense.

Favourable conditions:

a. Temperature: 450–500 °C
b. Pressure: 1–2 atmosphere
c. Excess of oxygen: to increase the production of sulphur trioxide

4. While diluting the acid, concentrated sulphuric acid should be added slowly to a given amount of water with continuous stirring.
5. Sulphuric acid being hygroscopic liquid readily absorbs water from the atmosphere.

6. Reactions of dilute sulphuric acid

- With active metals

$$Zn + H_2SO_4 \longrightarrow ZnSO_4 + H_2$$

$$Fe + H_2SO_4 \longrightarrow FeSO_4 + H_2$$

- With oxides and hydroxides of metals

$$KOH + H_2SO_4 \longrightarrow KHSO_4 + H_2O$$

$$2NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$$

$$Zn(OH)_2 + H_2SO_4 \longrightarrow ZnSO_4 + 2H_2O$$

- With carbonates and bicarbonates

$$CaCO_3 + H_2SO_4 \longrightarrow CaSO_4 + H_2O + CO_2$$

$$K_2CO_3 + H_2SO_4 \longrightarrow K_2SO_4 + H_2O + CO_2$$

$$Na_2CO_3 + H_2SO_4 \longrightarrow Na_2SO_4 + H_2O + CO_2$$

$$KHCO_3 + H_2SO_4 \longrightarrow KHSO_4 + H_2O + CO_2$$

$$NaHCO_3 + H_2SO_4 \longrightarrow NaHSO_4 + H_2O + CO_2$$

$$CuCO_3 + H_2SO_4 \longrightarrow CuSO_4 + H_2O + CO_2$$

- With sulphites and bisulphites

$$K_2SO_3 + H_2SO_4 \longrightarrow K_2SO_4 + H_2O + SO_2$$

$$ZnSO_3 + H_2SO_4 \longrightarrow ZnSO_4 + H_2O + SO_2$$

$$Na_2SO_3 + H_2SO_4 \longrightarrow Na_2SO_4 + H_2O + SO_2$$

$$2NaHSO_3 + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O + 2SO_2$$

- With sulphides

$$FeS + H_2SO_4 \longrightarrow FeSO_4 + H_2S$$

- With bleaching powder

$$CaOCl_2 + H_2SO_4 \longrightarrow CaSO_4 + H_2O + Cl_2$$

- With soluble salts of lead, barium and calcium

$$Pb(NO_3)_2 + H_2SO_4 \longrightarrow \underset{\text{white ppt.}}{PbSO_4\downarrow} + 2HNO_3$$

$$BaCl_2 + H_2SO_4 \longrightarrow \underset{\text{white ppt.}}{BaSO_4\downarrow} + 2HCl$$

$$CaCl_2 + H_2SO_4 \longrightarrow \underset{\text{white ppt.}}{CaSO_4\downarrow} + 2HCl$$

7. Reactions of concentrated sulphuric acid

- As a dehydrating agent

$$CuSO_4{\cdot}5H_2O \xrightarrow[\text{concentrated}]{H_2SO_4} CuSO_4 + 5H_2O$$

$$C_{12}H_{22}O_{11} \xrightarrow[\text{concentrated}]{H_2SO_4} 12C + 11H_2O$$

$$HCOOH \xrightarrow[\text{concentrated}]{H_2SO_4} CO + H_2O$$

$$\begin{matrix}COOH\\|\\COOH\end{matrix} \xrightarrow[\text{concentrated}]{H_2SO_4} CO + CO_2 + H_2O$$

$$C_2H_5OH \xrightarrow[\text{concentrated}]{H_2SO_4} C_2H_4 + H_2O$$

- As a less volatile acid

$$NaCl + H_2SO_4 \longrightarrow NaHSO_4 + HCl$$

$$NaNO_3 + H_2SO_4 \longrightarrow NaHSO_4 + HNO_3$$

- As an oxidizing agent

$$C + 2H_2SO_4 \longrightarrow 2SO_2 + 2H_2O + CO_2$$

$$S + 2H_2SO_4 \longrightarrow 3SO_2 + 2H_2O$$

$$Cu + 2H_2SO_4 \longrightarrow CuSO_4 + 2H_2O + SO_2$$

$$Zn + 2H_2SO_4 \longrightarrow ZnSO_4 + 2H_2O + SO_2$$

$$H_2S + H_2SO_4 \longrightarrow SO_2 + 2H_2O + S$$

$$2HI + H_2SO_4 \longrightarrow I_2 + 2H_2O + SO_2$$

THANK YOU