13 SOME COMPOUNDS OF NON-METALS

Which is the most abundant element in the atmosphere?

* From where do plants get nitrogen which is essential for their growth?

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* You know the compounds and chemical fertilizers that contain nitrogen. What are the other elements present in them? List them.

You have studied that ammonia is the main raw material used in the manufacture of chemical fertilizers. Shall we try to make ammonia gas?

Take some ammonium chloride (NH_4Cl) in a test tube and heat it. Do you sense a peculiar smell? (Don't try to smell the gas directly. You can get it by waving with your palm).

* Introduce a wet red litmus paper into the gas. What change have you observed?

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* What indication does this change give about the property of the gas?

Ammonia gas

- Colour

- Odour

- Nature : acidic/basic

Introduce a glass rod dipped in concentrated hydrochloric acid at the mouth of the test tube.

Note down your observation in the science diary.

What might have happened here?

Aren't the dense white fumes produced those of ammonium chloride?

$$NH_3 + HCl \rightarrow NH_4Cl$$

Can't we use this experiment for the detection of ammonia?

Now introduce a glass rod dipped in ammonia solution at the mouth of the test tube.

★ What is the observation?

★ What can be the reason for the formation of dense white fumes of NH_4Cl when a glass rod dipped in ammonia solution is introduced?

★ Which may be the substances (gases) produced when ammonium chloride is heated?

★ Can you write down the equation for the reaction?

$NH_4Cl \xrightarrow{heat}$ ..... + ...

Let's understand the method of preparation of ammonia in the laboratory

Ammonia is prepared in the laboratory by heating a mixture of ammonium chloride and calcium hydroxide [$Ca(OH)_2$]. The arrangement is shown (Fig 13.1).

Write down the equation for the reaction.

$2\ NH_4Cl + Ca(OH)_2 \rightarrow CaCl_2 + 2H_2O + ...$

Some substances can absorb moisture to make materials dry. They are known as drying agents. During the preparation of gases like hydrogen chloride, sulphur dioxide etc., water vapour is also formed along with the gas. These water molecules which are not chemically combined with the molecules of the gas can be absorbed using drying agents.

Quicklime (CaO), silica gel, concentrated sulphuric acid etc. are used for this in appropriate instances.

Analyse the picture and find out the following.

★ What is done to make ammonia gas dry?

★ Which substance is used as the drying agent?

★ Notice the method for collecting ammonia in the gas jar. Is the density

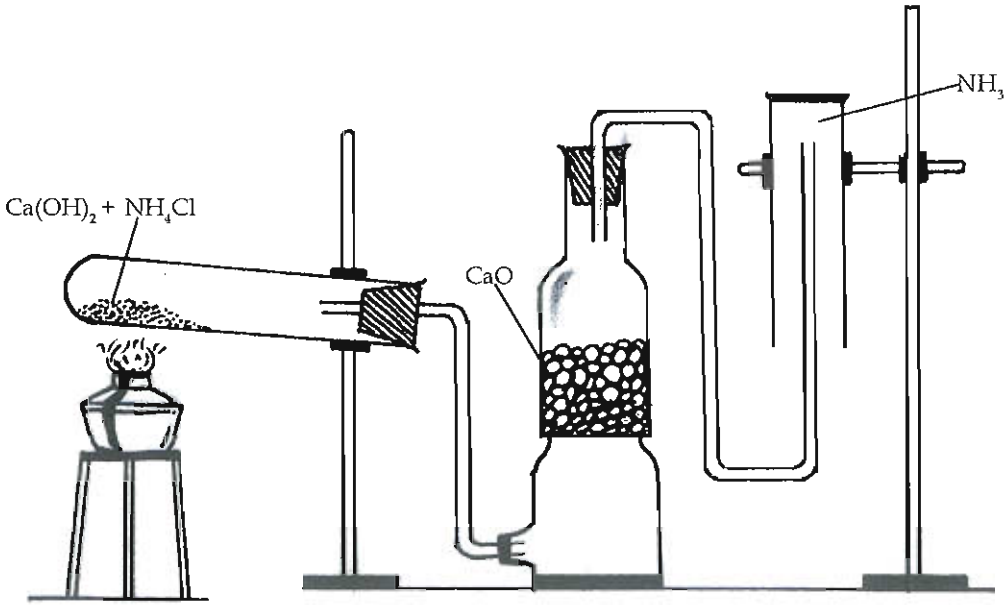


Fig. 13.1

of ammonia greater or lesser than that of air?

- -

★ Instead of calcium oxide, can we use concentrated sulphuric acid, another drying agent? Think about this in relation to the basic nature of ammonia.

Note down your conclusions in the science diary.

Solubility of ammonia in water

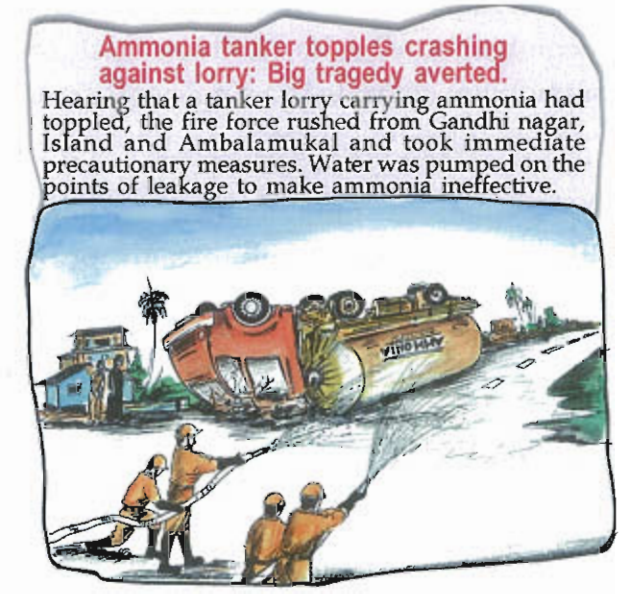


Fig. 13.2

★ What can be the reason for pumping water in this situation?

★ What is the chemistry behind this?

Let us try to find it by doing a simple experiment. Arrange the equipment as shown in Fig. 13.3 and do the experiment.

Collect ammonia gas in an RB flask. Close the flask with a cork containing a jet tube and an injection syringe as shown in the figure.

Using the syringe, introduce a few drops of water into the flask. Close the mouth of the jet tube with your finger. Shake the flask well and as shown in the figure, dip the end of the jet tube into water containing some phenolphthalein in the beaker. What do you observe?

- -

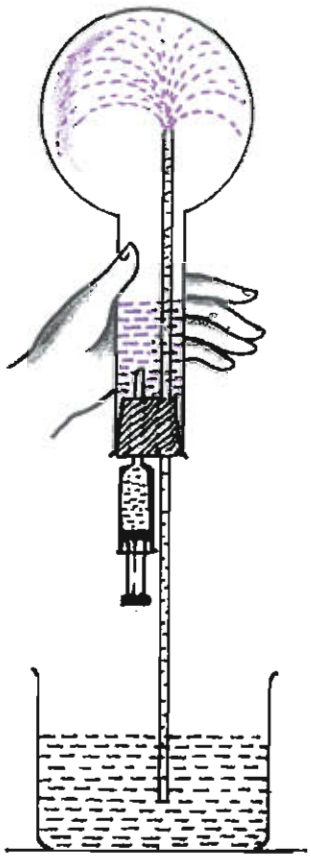


Fig. 13.3

★ How may the pressure inside the flask have become so low as to enable the water to rush into the flask? Can you explain?

★ What is your inference about the solubility of ammonia in water?

- -

See the chemical equation for the reaction.

$NH_3 + H_2O \rightarrow NH_4OH$ (ammonium hydroxide)

★ What is the colour of the solution collected in the flask?

★ What may be the reason for the colour change of water containing

phenolphthalein when it enters the flask?

The concentrated solution of ammonium hydroxide obtained by dissolving ammonia in water is called liquor ammonia.

Ammonia gas can be easily liquefied by applying pressure. It is called liquid ammonia. This is used as a refrigerant.

Reversible reactions and Irreversible reactions

We have already understood that ammonium chloride on heating gives ammonia and hydrogen chloride.

★ What did you see when a glass rod dipped in hydrochloric acid was shown over ammonia gas? Can you explain the reason?

Let us try an activity

Take a glass tube. At one end of the tube place some cotton soaked with concentrated hydrochloric acid and at the other end, cotton soaked with ammonia solution. Close the two ends of the tube tightly with cork. Now observe the changes taking place inside the tube.

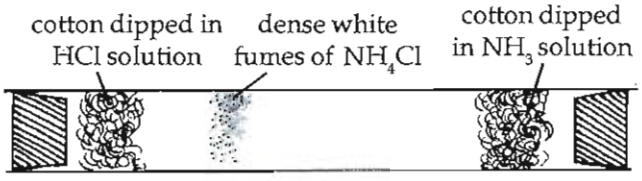


Fig. 13.4

★ What may be the reason for the formation of dense white fumes ?

Write down the equation for the formation of ammonium chloride by the reaction between ammonia and hydrogen chloride.

$$NH_3 + HCl \rightarrow .....$$

★ You can also write the equation for the decomposition of ammonium chloride, can't you?

$$NH_4Cl \rightarrow ..... + ...$$

Let us represent the decomposition of ammonium chloride when heated and the recombination of the products back to ammonium chloride in a single equation.

$$NH_4Cl \rightleftharpoons NH_3 + HCl$$

The symbol '$\rightleftharpoons$' indicates that reactions take place simultaneously in both directions.

In the reactions mentioned above, what change happened to the reactants? And to the products? Do both the reactions take place simultaneously?

Reactions which take place simultaneously in both directions under the same set of conditions are called reversible reactions.

In reversible reactions, the reaction in which the reactants are converted to the products is called the forward reaction and that in which the products are converted back to the reactants is called the backward reaction.

See more examples of reversible reactions given.

$$N_2 + O_2 \rightleftharpoons 2NO$$
$$CaCO_3 \rightleftharpoons CaO + CO_2$$
$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$
$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

You might have seen the reaction in which magnesium burns in air to form magnesium oxide. Here, will the product change to the reactants again?

$$2Mg + O_2 \rightarrow 2MgO$$

See the chemical equation given below.

$$NaOH + HCl \rightarrow NaCl + H_2O$$

Will the products of this reaction, sodium chloride and water, react to give NaOH and HCl? Test it by mixing some common salt with water.

Chemical changes in which the reactants react to form products and under the same conditions, the products are not converted to the reactants are called irreversible reactions.

More examples:

$$NaCl + AgNO_3 \rightarrow NaNO_3 + AgCl$$

$$Zn + 2HCl \rightarrow ZnCl_2 + H_2$$

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

Industrial production of ammonia

We have already familiarized ourselves with the laboratory method of preparation of ammonia. Ammonia is produced on a large scale by the reaction between nitrogen and hydrogen under high pressure and optimum temperature in the presence of a suitable catalyst. This method is known as Haber process.

The different stages of production of ammonia through Haber process are given in the flow chart.

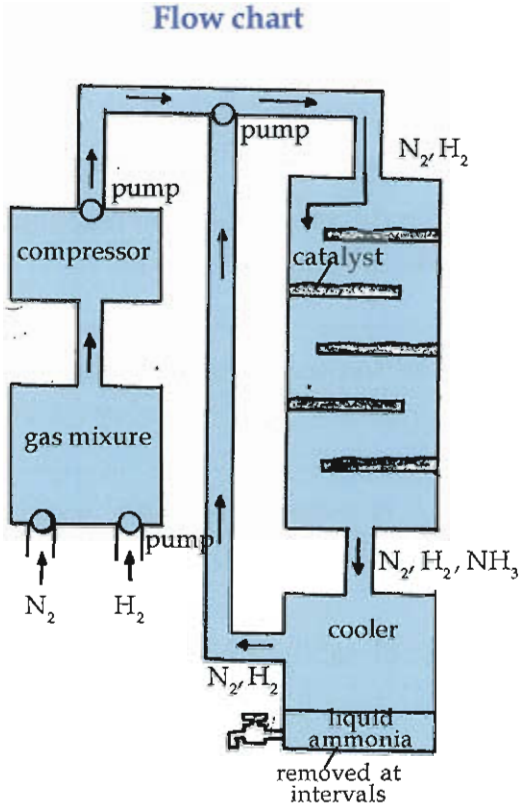


Fig. 13.5

See the equation given for this chemical reaction. This is a reversible reaction.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) + \text{heat}$$

★ With how many moles of hydrogen does one mole of nitrogen react?

- -

★ How many moles of ammonia are to be obtained as the product?

- -

But, as this reaction is reversible, the N_2 and H_2 taken are not completely converted to ammonia. Isn't it necessary to produce maximum NH_3 to make the manufacturing process profitable?

Aren't reactants only present when the reaction begins? At that time what is the amount of the product?

(more / less / zero) ✓ the correct one.

In which direction does the reaction take place at that time?

- -

★ What is your guess about the speed of the reaction? Will it be slow or fast?

- -

★ What change occurs to the amount of the reactants when time passes?

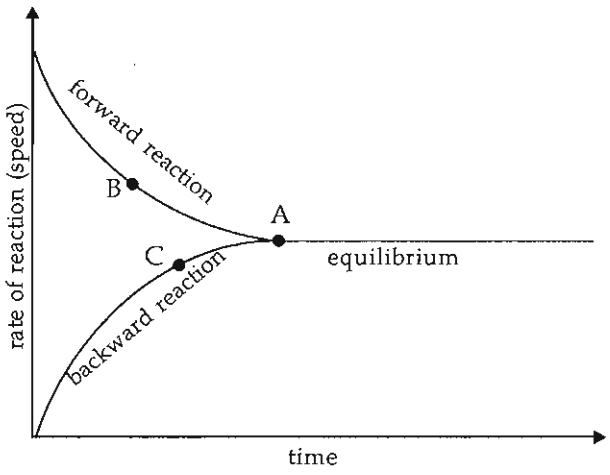
- -

★ What about the amount of the product?

- -

In accordance with this what will be the change in the rates of the forward and backward reactions?

Analyse the graph given below and record your inferences in the science diary.



★ As time passes the rate of the forward reaction .....

★ Rate of the backward reaction.....

★ Will there be a situation when the rate of the forward reaction becomes equal to that of the backward reaction?

- -

★ Which point in the graph indicates this?

- -

The state at which the rate of the forward reaction becomes equal to that of the backward reaction is called the state of equilibrium.

At this stage the speed at which the reactants are converted to the products will be same as the speed at which the products are converted back to the reactants.

★ In a system at equilibrium, will there be any change in the concentration of the reactants with time?

- -

★ What about the concentration of the products?

- -

★ What may be the reason?

- -

Won't there be both reactants and products present in a system at equilibrium?

Let us do an experiment.

Take solutions of ferric nitrate, potassium thiocyanate and potassium nitrate.

Note the colour of each solution and record it in your science diary.

Take some dilute ferric nitrate [$Fe(NO_3)_3$] solution in a test tube, add a few drops of potassium thiocyanate (KCNS) solution and shake well.

★ What is the observation?

- -

See the equation given for this chemical reaction.

ferric nitrate + potassium thiocyanate $\rightleftharpoons$ ferric thiocyanate (blood red colour) + potassium nitrate

$Fe(NO_3)_3 + 3KCNS \rightleftharpoons Fe(CNS)_3 + 3KNO_3$

Keep the solution still for a while. Does the red colour intensify? Hasn't it attained a state from which the intensity of the colour does not change further? Dilute the solution and observe for some time. Now take equal portions of this solution in three test tubes. Keep one as the reference solution.

Add some ferric nitrate solution to the second test tube.

★ What is observed?

★ The formation of which substance is indicated by this?

Ferric thiocyanate is formed due to the presence of the reactant, KCNS, remaining in the solution, isn't it?

Add a few drops of potassium thiocyanate solution to the third test tube.

★ What is observed? What may be the reason?

★ The presence of which reactant is indicated by this?

Doesn't this show that along with the products, the reactants also exist in each of the solutions? Even then the colour of the reference solution does not change, which shows that the system is in the state of equilibrium.

Aren't more products formed when more of any of the reactants is added to the second and third test tubes having this system in the state of equilibrium?

★ Which reaction that took place at a faster rate resulted in this? Is it the forward reaction or the backward reaction?

★ What change occurs in the concentration of the products when the concentration of the reactant is increased in a system at equilibrium?

★ What may be the reason for this?

★ Which reaction will become faster if the concentration of the product is increased?

★ And if the concentration of the product is decreased?

In all the systems at equilibrium, both reactants and products co-exist. When more $Fe(NO_3)_3$ is added, a change occurs in the existing equilibrium. To reduce this effect, the KCNS present in the solution converts the added $Fe(NO_3)_3$ to the products, thus deepening the red colour. Similarly, when more KCNS is added, it reacts with the $Fe(NO_3)_3$ present in the solution to form the products, which again deepens the colour. That is, if the concentration of any one of the reactants is increased in a system at equilibrium, the forward reaction becomes faster resulting in the formation of more products.

Like the change in concentration, the change in pressure and the change in temperature are also factors that affect the equilibrium state.

The effect of these factors on the equilibrium state was predicted by the scientist Le Chatelier.

Le Chatelier's Principle

If a change in concentration, pressure or temperature is brought about in a system at equilibrium, the system will readjust by itself so as to cancel the effect of the change, thus attaining a new equilibrium state. This is Le Chatelier's principle.

Let us see how Le Chatelier's principle can be utilized in the industrial production of ammonia.

1. Effect of concentration

In the manufacture of ammonia, if we increase the concentration of any one or all the reactants at the equilibrium state, the speed of the forward reaction will increase and more ammonia will be formed. If the concentration of the product is increased the speed of the backward reaction will increase. If there is a decrease in the concentration of the product the speed of the forward reaction increases according to Le Chatelier's principle. Accordingly, if the ammonia formed is removed continuously from the system, forward reaction will become faster and more ammonia will be formed. Now you might have understood why ammonia is liquefied and removed frequently as shown in the flowchart of the industrial production of ammonia. Aren't N_2 and H_2 also continuously admitted into the system for the same purpose?

2. Effect of pressure

We have already understood that pressure has a marked effect only on gases. In the manufacture of ammonia let us see the effect of changing the pressure.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$
$$1\ mol \quad 3\ mol \quad 2\ mol$$

★ What is the total number of the reactant molecules in the equation?

- -

★ What about that of the products?

- -

Forward reaction: 4 mol of reactant molecules → 2 mol of product molecules.

NH_3 can be taken as the reactant in the backward reaction. What are the products?

Backward reaction: 2 mol of reactant molecules → 4 mol of product molecules.

According to Le Chatelier's principle, if pressure is increased in a system at equilibrium, the system will try to regain equilibrium by reducing pressure.

When does the pressure of a gas decrease in a closed vessel? Is it when the number of molecules increases or when it decreases?

★ If so, what is the way to decrease pressure? Should the number of molecules be increased or decreased?

- -

★ In the manufacture of ammonia, in which direction should the reaction take place to decrease the number of molecules?

- -

★ If this reaction takes place with more speed, will the amount of product increase or decrease?

- -

★ What if the pressure is decreased?

- -

Haven't you understood that in the manufacture of ammonia, if the pressure

is increased, the reaction which causes a decrease in the number of molecules, i.e., the reaction giving more NH_3, will take place faster to give more products? Hence a high pressure of 150 - 300 atm is used in Haber process.

3. Effect of temperature

We know that a transfer of energy occurs during chemical reactions. Reactions in which energy is absorbed are endothermic reactions and reactions in which energy is released are exothermic reactions.

✶ In a reversible reaction, if the forward reaction is endothermic, the backward reaction will be exothermic. What if the forward reaction is exothermic?

In the manufacture of ammonia the forward reaction is exothermic.

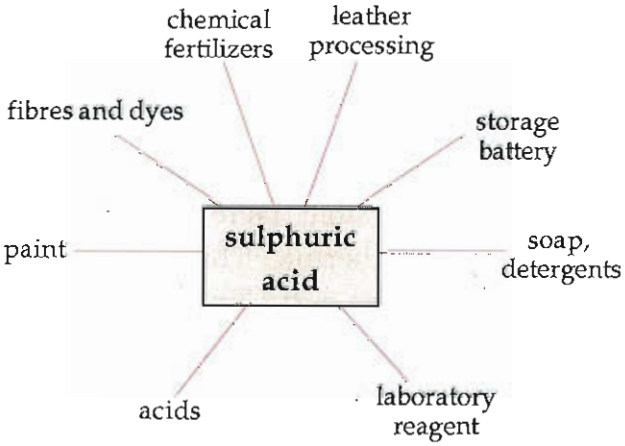
If we increase the temperature of the system at equilibrium, the system will try to decrease it by favouring the endothermic reaction. As a result, ammonia decomposes to N_2 and H_2. Therefore, according to Le Chatelier's principle, to get more ammonia temperature should be decreased. But at low temperature both the forward and backward reactions become extremely slow and the system takes a very long time to attain equilibrium. Hence for the industrial production of ammonia, 500 °C is taken as the optimum temperature.

Effect of catalyst on reversible reactions

You have studied about catalysts. For the formation of NH_3, spongy iron (Fe) acts as a positive catalyst. In a reversible reaction, the catalyst increases the velocities of both the forward and backward reactions equally, and hence the equilibrium state is attained faster.

Sulphuric acid (H_2SO_4)

Sulphuric acid is the chemical that is most widely used in industries and in laboratories. Sulphuric acid is known as the king of chemicals. See the use of sulphuric acid in various fields.



Method of manufacture

What might be the product obtained by burning sulphur in air? Write down the equation.

$$S + O_2 \rightarrow .....$$

The Sulphur dioxide (SO_2) thus obtained is oxidized to prepare sulphur trioxide (SO_3). See the equation for this reaction.

$$2SO_2 + O_2 \underset{1-2 \text{ atm pressure } 450^\circ C}{\overset{V_2O_5}{\rightleftharpoons}} 2SO_3 + \text{heat}$$

Sulphuric acid can be obtained by dissolving SO_3 in water. But since the dissolution of SO_3 in water is highly exothermic, the sulphuric acid that is formed first vapourises to form a smog which hinders further dissolution. Hence

this method is not used for the preparation of sulphuric acid. Instead, sulphur trioxide is dissolved in 98% sulphuric acid solution to get oleum ($H_2S_2O_7$) and sulphuric acid of any concentration can be prepared by adding required quantity of water to oleum.

$SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$ (oleum)

$H_2S_2O_7 + ... \rightarrow 2H_2SO_4$

This industrial method of preparation of sulphuric acid is known as Contact process.

Among the chemical reactions taking place in Contact process, a very important reaction is the oxidation of SO_2. We have seen that this reaction in which SO_3 is formed is reversible. Here the forward reaction is exothermic. This reaction is carried out at the optimum temperature of 450 ^{0}C. Even though a high pressure will give a better yield of SO_3, only a pressure of 1-2 atm is commonly used. As SO_3 is highly corrosive, it may weaken the walls of the reaction chamber at high pressure. This may lead to an explosion and hence high pressure is not employed.

Vanadium pentoxide (V_2O_5) is used as the catalyst in Contact process.

Physical properties

Take concentrated sulphuric acid available in the laboratory and find out its colour and solubility in water with the help of your teacher.

Take some water in a test tube and add a few drops of concentrated H_2SO_4.

★ Touch the bottom of the test tube. What do you feel?

- -

★ Why is it that when concentrated sulphuric acid is diluted, instead of adding water to acid, acid is added to water in small quantities with constant stirring?

- -

- -

The reaction between acid and water is exothermic. Hence when concentrated acids are diluted, slowly add the required quantity of acid in a thin stream, to water with continuous stirring. Never add water into concentrated acid.

Chemical properties

Affinity towards water

Take some sugar in a dry test tube and add a few drops of concentrated H_2SO_4.

★ What is your observation?

- -

The molecular formula of cane sugar is $C_{12}H_{22}O_{11}$.

★ Which are the elements present in it?

★ Which is the substance obtained after adding concentrated H_2SO_4?

Examine the H:O ratio in the molecules of sugar. It can be presumed that in this reaction, concentrated H_2SO_4 absorbs 11 water molecules from each molecule of cane sugar.

★ Take some powdered copper sulphate (blue vitriol) in a china dish and heat it. What change has occurred? What may be the reason?

- -

★ To the white powder obtained, add some water. What is the observation?

- -

Take some blue vitriol ($CuSO_4.5H_2O$) in a watch glass and add a few drops of concentrated sulphuric acid to it.

★ What is observed?

★ What has happened?

Discuss the reason and note it down in the science diary.

As concentrated sulphuric acid absorbs the water of crystallization from blue crystalline copper sulphate, it is converted into white anhydrous copper sulphate ($CuSO_4$). Dehydration is the process of removing the chemically combined water from substances. Haven't you understood the dehydrating property of concentrated H_2SO_4?

Concentrated H_2SO_4 is used for drying gases like sulphur dioxide (SO_2) and hydrogen chloride (HCl) during their laboratory preparation. Thus concentrated H_2SO_4 can also be used as a drying agent.

Reaction with salts

Take some dilute sulphuric acid in a test tube. Add a little sodium carbonate to it. Pass the gas produced through clear limewater taken in another test tube.

★ What change has occurred?

From the observation, can't you guess the gas produced?

See the equation given for the reaction that has taken place.

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

Aren't you convinced that CO_2 gas will be produced when sulphuric acid reacts with carbonates?

Examine the equations given below for the reactions of concentrated sulphuric acid with salts like sodium nitrate and sodium chloride. Which are the acids formed?

$$NaNO_3 + H_2SO_4 \rightarrow NaHSO_4 + HNO_3$$

$$NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$$

From the equations it can be understood that concentrated H_2SO_4 reacts with nitrates to give HNO_3 and with chlorides to give HCl.

These reactions are made use of to prepare nitric acid and hydrochloric acid in the laboratory.

Test to detect sulphates

Take a small quantity of aqueous solution of sodium sulphate (Na_2SO_4) in a test tube. Add three or four drops of barium chloride ($BaCl_2$) solution into it.

★ What is the change that takes place?

See the chemical equation for the reaction.

$$Na_2SO_4 + BaCl_2 \rightarrow BaSO_4 + 2NaCl$$

★ You know that NaCl is soluble in water. Then which is the substance that forms the white precipitate?

As barium carbonate also forms a white precipitate, to confirm the presence of sulphate, it is to be tested by adding concentrated hydrochloric acid to it.

Add concentrated HCl to the white precipitate obtained. $BaSO_4$ is a compound which is insoluble in hydrochloric acid. Therefore, if there is no change for the precipitate on adding HCl, the presence of sulphate can be confirmed.

If the precipitate is that of carbonate it will dissolve in HCl.

Test to detect chlorides

Take a small quantity of sodium chloride solution in a test tube and add a few drops of silver nitrate solution into it.

★ What is observed?

- -

See the chemical equation.

$$NaCl + AgNO_3 \rightarrow \underset{\text{(white curdy precipitate)}}{AgCl} + NaNO_3$$

To the white curdy precipitate obtained in the above reaction, add a few drops of ammonium hydroxide solution.

★ What is observed?

- -

If the white precipitate dissolves on adding NH_4OH, it can be confirmed that the given salt is a chloride.

Test to detect nitrates

Take a small quantity of the aqueous solution of a nitrate in a test tube. Add an equal volume of freshly prepared ferrous sulphate ($FeSO_4$) solution to it. Shake well. Then pour concentrated H_2SO_4 through the sides of the test tube slowly without shaking it.

★ What is the observation?

- -

Formation of a brown ring at the junction where the two solutions meet indicates the presence of nitrate.

Now we are familiar with the methods of preparation and the general characteristics of industrially important compounds like ammonia and sulphuric acid. The reactions by which they are prepared are reversible reactions. Many reactions employed in the industry are reversible in nature. Hence, a clear understanding of the factors which influence reversible reactions helps in effectively controlling the processes and getting a better yield of the products.

Follow up Activities

1. $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)} + \text{heat}$

   (a) Analyse this equation and complete the table.

Reactants	.....
Products	.....

   (b) ✓ the correct ones.

   (i) Exothermic reaction : (forward reaction / backward reaction)

   (ii) Endothermic reaction: (forward reaction / backward reaction)

   (c) Complete the table.

Change brought about in the system at equilibrium	The reaction becoming faster according to Le Chatelier's principle *(forward reaction / backward reaction)*
The amount of the reactant is increased	
The amount of the product is increased	
The pressure of the system is increased	
The product is removed from the system	
The amount of the reactant is decreased	
The temperature of the system is increased	
The temperature is decreased	

2. $2CO_{(g)} + O_{2(g)} \rightleftharpoons 2CO_{2(g)}$

   (a) What is the total number of the reactant molecules in this equation?

   (b) What is the total number of molecules of the products?

   (c) If pressure is increased at equilibrium, what will be the change occurring in the system?

   (d) To decrease the pressure, in which direction should the reaction take place?

3. A, B and C are three gases. 1 mole of A combines with 1 mole of B to give 2 moles of C. This is a reversible reaction. Answer the questions given below regarding this reaction.

(a) Write down the equation for this chemical reaction.

(b) What will be the effect of change in pressure when this reaction is at equilibrium?

(c) What happens if the quantity of A is increased?

(d) And if the amount of C is increased?

4. An equation pertaining to Contact process is given below. (The symbols used are not real).

$$2X_{(g)} + Y_{(g)} \rightleftharpoons^{V_2O_5} 2Z_{(g)} + \text{heat}$$

(a) What are the substances denoted as X, Y and Z?

(b) Predict the effect of the following changes carried out at equilibrium on the amount of the product formed.

(i) an appropriate catalyst is added

(ii) the quantity of X is increased

(iii) the quantities of both X and Y are increased

(iv) Z is removed

(v) temperature is decreased

(vi) pressure is increased

5. The details of the experiments done to detect some salts are given in the table. Complete the table.

Experiment	Observation	Inference
$NaCl + AgNO_3$	.....	Presence of chloride
$AgCl + NH_4OH$	.....	.....
.....	.....	Presence of sulphate
$BaSO_4$ + Conc. HCl	.....	.....