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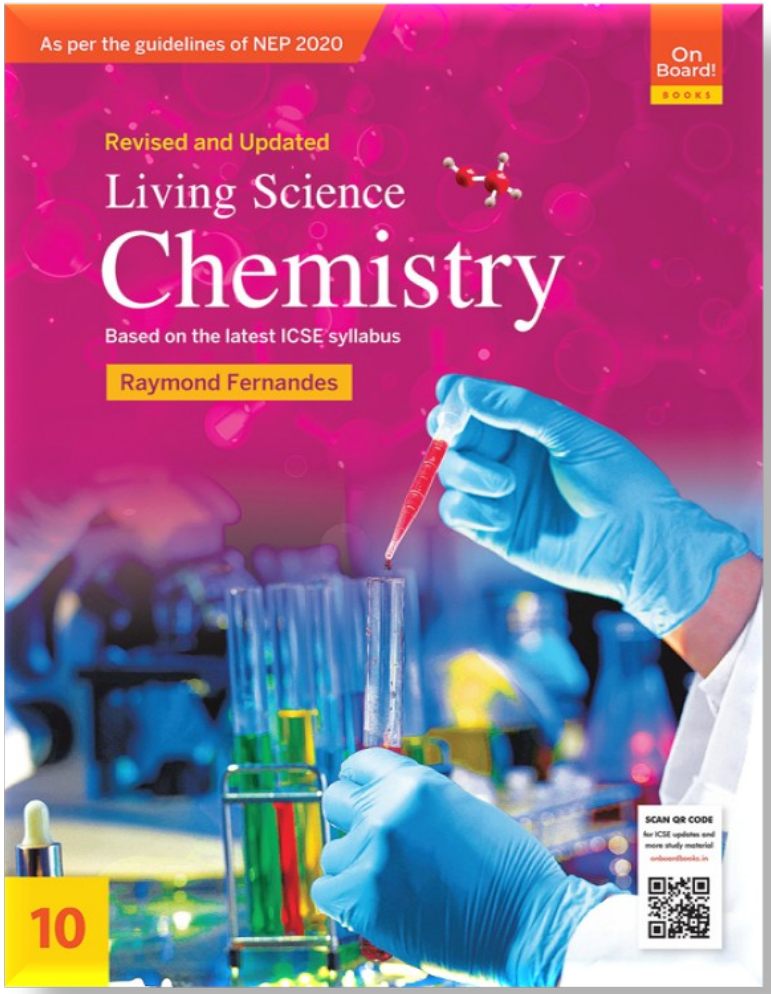
ICSE
Living Science
Chemistry

Class 10

Chapter-9 Study of Compounds - Ammonia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10

LEARNING OBJECTIVES

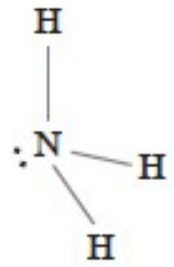
Ammonia

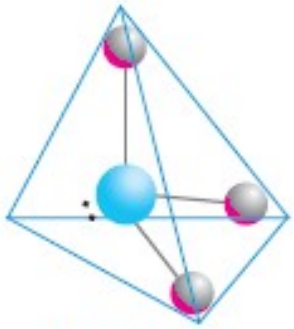
- Important characteristics of ammonia gas
- General preparation of ammonia gas
- Laboratory preparation of ammonia gas
- Physical properties of ammonia gas
- Chemical properties of ammonia gas
- Tests for ammonia gas
- Aqueous solution of ammonia gas
- Uses of ammonia gas
- Refrigerant gas and its suitable alternatives which are nonozone depleting
- Properties of ammonium salts

Occurrence

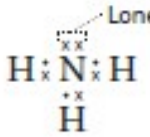
Small quantities of ammonia are found in air and in water. In the combined form, ammonia is found in ammonium salts. Ammonia is also available in the liquefied form called liquid ammonia. This liquefied form is used as a refrigerant.

Important Characteristics of Ammonia





Lewis diagram:



Molecular formula: NH_3

Molecular mass: 17 u

Vapour density: 8.5

Nature: Poisonous, basic gas

Solubility: Highly soluble in water

Common name: Alkaline air

Structure: The ammonia molecule has a trigonal pyramidal shape. The nitrogen atom in the molecule has a lone electron pair, and ammonia acts as a base, a proton acceptor. This shape gives the molecule an overall dipole moment and makes it polar so that ammonia readily dissolves in water.

Preparation of Ammonia Gas

Ammonia is one of the highly produced inorganic compounds because of its varied usage. Before World War I, most of the ammonia was obtained by the dry distillation of decomposed nitrogenous vegetable and animal waste. Ammonia can be prepared by various methods, some of which are discussed subsequently.

General methods of preparation

Reaction of ammonium salts with alkalis

All ammonium salts react with alkalis like caustic soda or potash or slaked lime to form their corresponding salts, water and liberate ammonia.

$$2NH_4Cl + \underset{\text{slaked lime}}{Ca(OH)_2} \longrightarrow CaCl_2 + 2H_2O + 2NH_3$$

$$(NH_4)_2SO_4 + \underset{\text{caustic potash}}{2KOH} \longrightarrow K_2SO_4 + 2H_2O + 2NH_3$$

$$NH_4Cl + \underset{\text{caustic soda}}{NaOH} \longrightarrow NaCl + H_2O + NH_3$$

$$(NH_4)_2SO_4 + \underset{\text{caustic soda}}{2NaOH} \longrightarrow Na_2SO_4 + 2H_2O + 2NH_3$$

Note: As ammonium nitrate (NH_4NO_3) is explosive in nature and decomposes on heating, it is not used for the preparation of ammonia

$$NH_4NO_3 \longrightarrow N_2O + 2H_2O$$

Laboratory preparation of ammonia

1.From ammonium chloride

Dry ammonium chloride reacts with calcium hydroxide when heated gently to form ammonia.

$$2NH_4Cl + Ca(OH)_2 \longrightarrow CaCl_2 + 2H_2O + 2NH_3$$

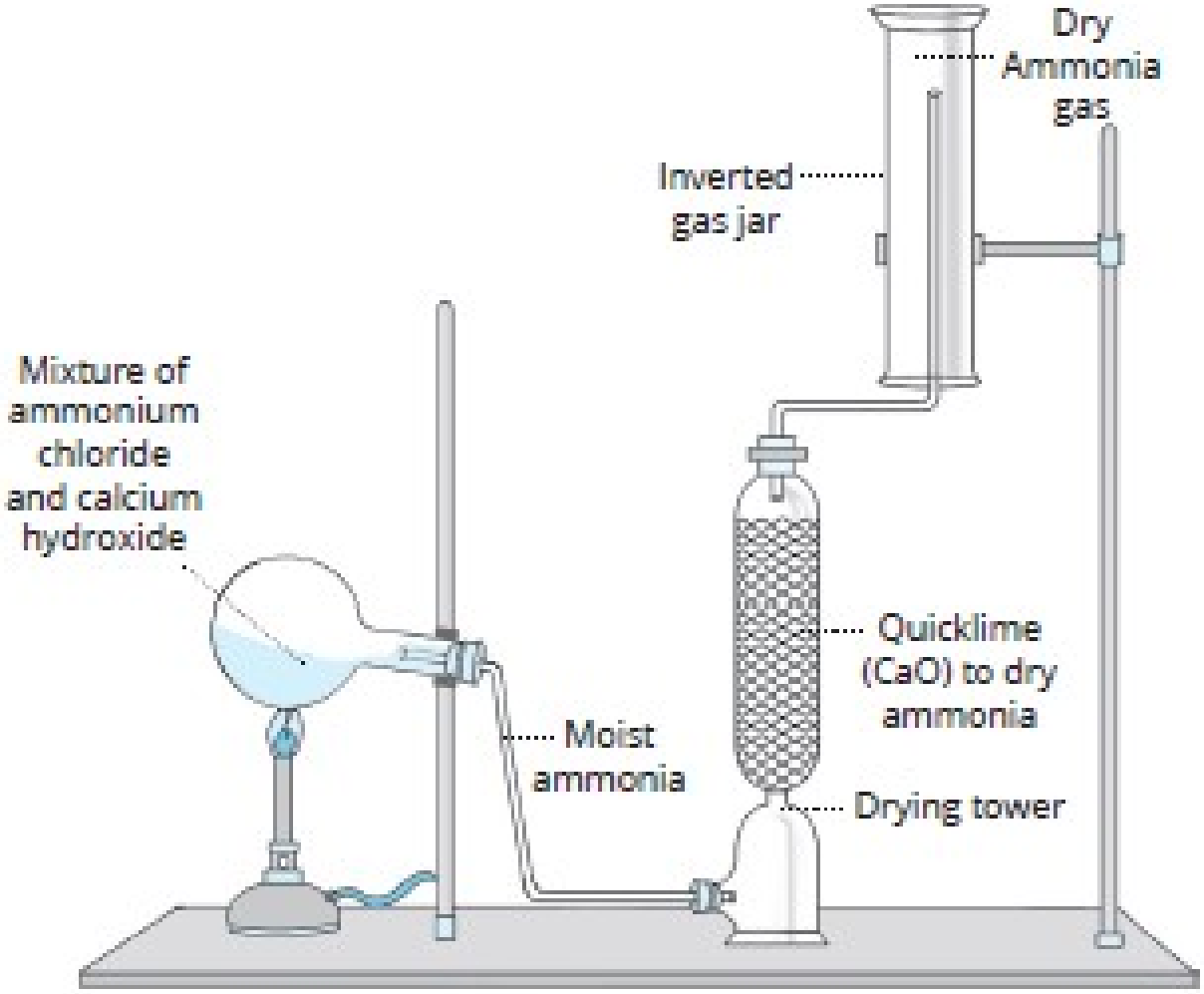
Condition and reactions: Excess of calcium hydroxide is used to counter the loss of ammonium chloride due to sublimation. Slaked lime is used instead of sodium hydroxide and potassium hydroxide because slaked lime is cheap and is not deliquescent like these caustic alkalis, and hence, does not wet the reaction mixture. Reactants should be in a grounded state so as to provide maximum surface area for reaction. The reaction mixture should be slightly warmed.

The reactants, ammonium chloride and calcium hydroxide, are grounded together such that a powdered form of them is obtained. Then, the reactants mixture is added to the round bottom flask kept in a slanting position and the mixture is heated gently. The reaction of ammonium chloride with calcium hydroxide produces ammonia which passes through a delivery tube into a drying tower and is collected in an inverted gas jar.

Quicklime (Calcium oxide, CaO) is used to dry ammonia gas because of the following reasons:

a. It is basic in nature.

b. It does not react with the gas like other drying agents.



Collecting ammonia:
Ammonia cannot be collected over water because it is highly soluble in water. It is collected by the downward displacement of air because it is lighter than air. Vapour density of ammonia gas is 8.5 and that of air is 14.4.

Identification of ammonia: Bring a glass rod dipped in concentrated hydrochloric acid near the mouth of the jar. The formation of dense white fumes of ammonium chloride near the mouth of the jar indicates that the jar is filled with ammonia. The presence of ammonia can also be tested by the moist red litmus paper. Dip the moist red litmus paper into the jar. If it turns blue in colour, it indicates that the jar contains ammonia.

Precautions:

a. The reactants should be in a finely powdered form.
b. The base, calcium oxide should be taken in excess.
c. The round bottom flask should be kept in a slanting position so that any water formed during the reaction does not trickle back into the hot flask and causes it to crack.

2. From metal nitrides

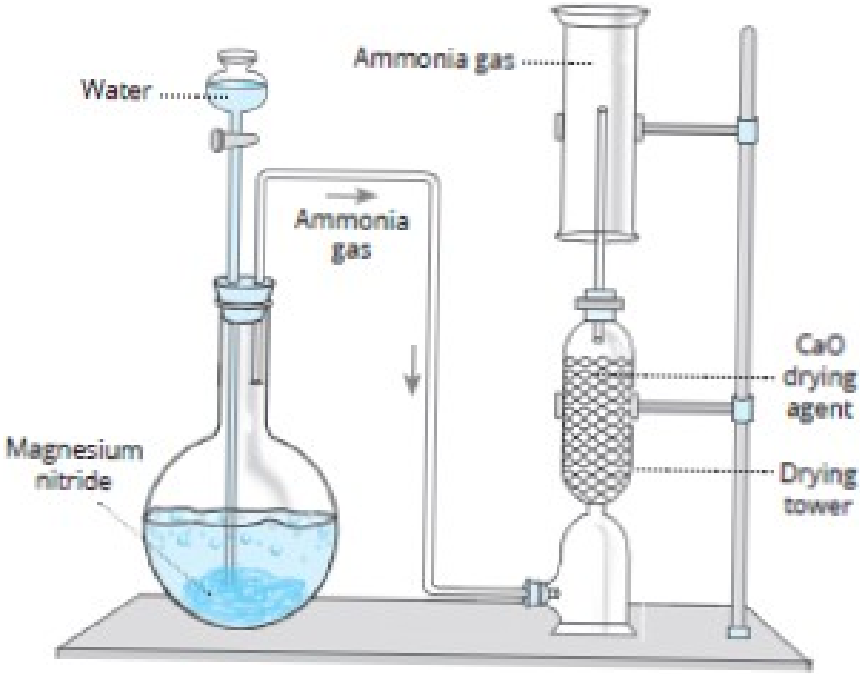
In laboratory, metals like magnesium, calcium and aluminium when burnt in nitrogen gas form their respective metal nitrides. When warm water is added in a dropwise manner to these nitrides, these nitrides undergo hydrolysis to liberate ammonia.

$$Mg_3N_2 + 6H_2O \longrightarrow 3Mg(OH)_2 + 2NH_3\uparrow$$

$$Ca_3N_2 + 6H_2O \longrightarrow 3Ca(OH)_2 + 2NH_3\uparrow$$

$$AlN + 3H_2O \longrightarrow Al(OH)_3 + NH_3\uparrow$$

The gas is dried over quick lime present in a drying tower.



Ammonia gas is collected in an inverted gas jar by the downward displacement of air.

Note: Magnesium nitride is not used commonly for the preparation of ammonia as it is an expensive as well as unstable compound.

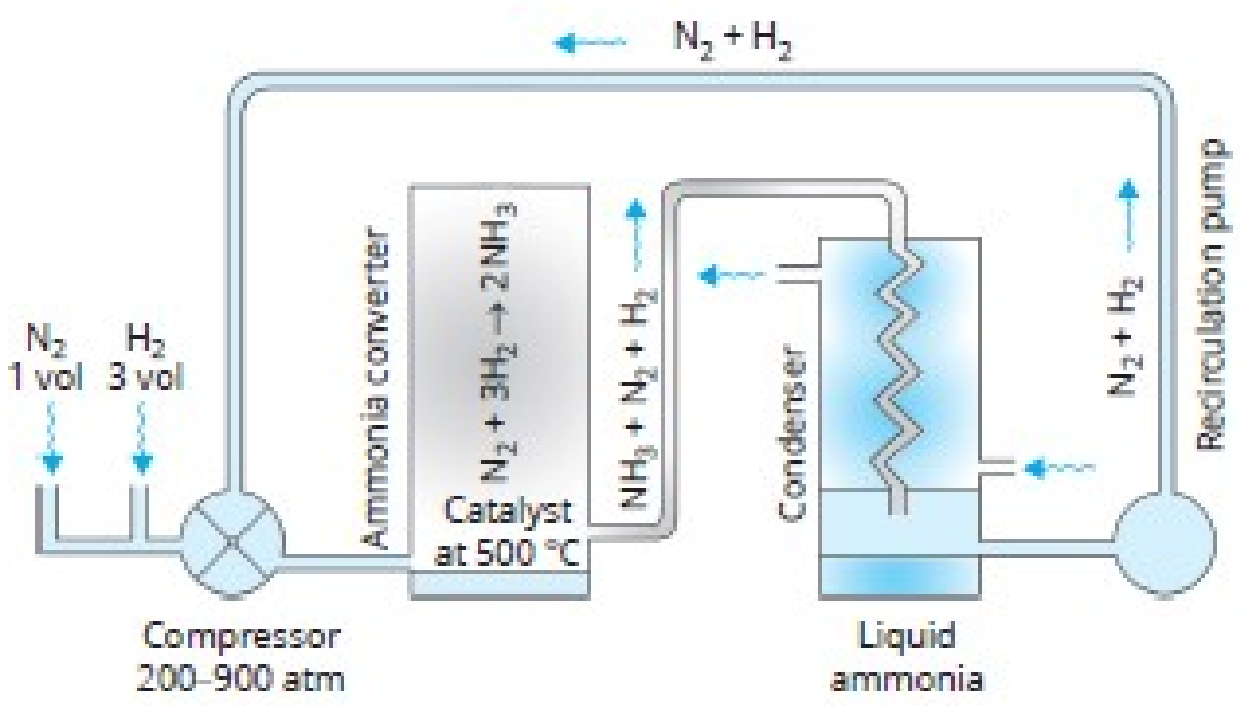
Haber-Bosch process

Haber-Bosch process is used for the large scale preparation, i.e. manufacturing of ammonia. In Haber's process, ammonia is prepared from nitrogen and hydrogen taken in the ratio of 1:3 by volume.

For Haber's process,

a. Nitrogen is obtained by the fractional distillation of air.

b. Hydrogen is obtained either from water gas through Bosch process or from natural gas.



Haber-Bosch Process

Dry nitrogen and hydrogen gas taken in the ratio of 1 : 3 in the presence of finely divided iron and molybdenum at a temperature of 500 °C and under a pressure of 200 atmospheres react to give ammonia.

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

1 vol 3 vol 2 vol

This reaction is reversible, exothermic and proceeds with a decrease in volume. Only 15% of the reacting gases are converted to ammonia.

Reaction conditions:

Temperature: 500 °C

Pressure: 200 atmosphere

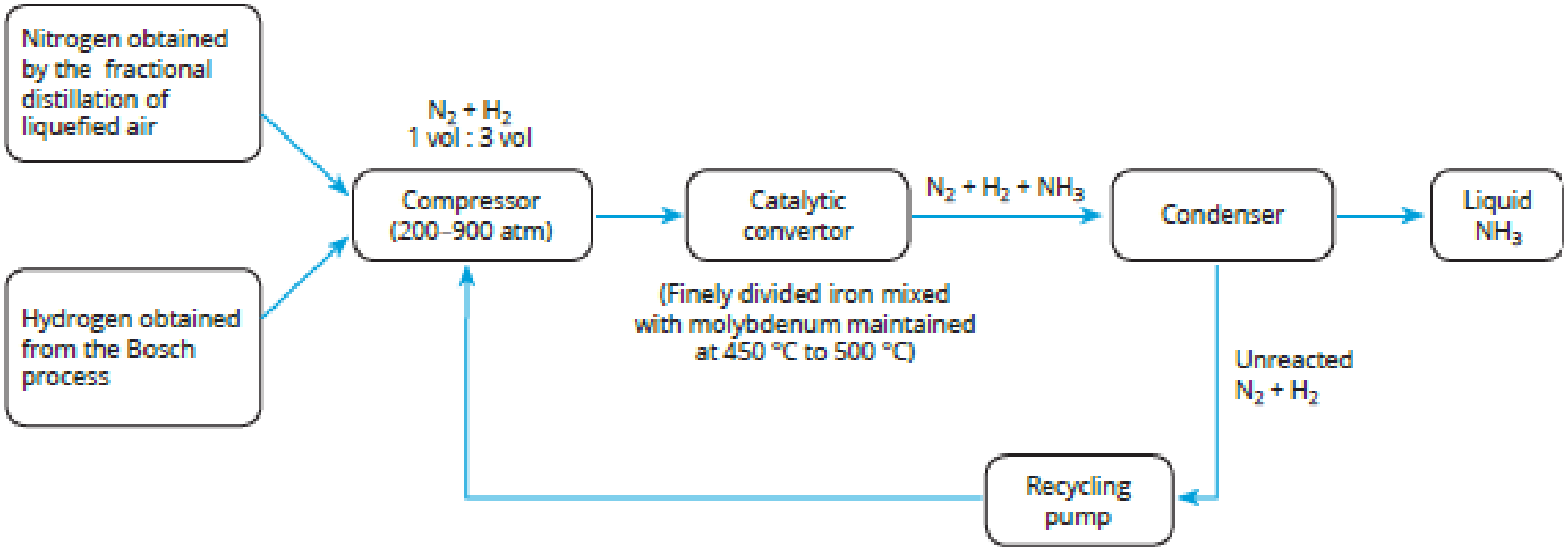
Catalyst: Finely divided iron in the presence of molybdenum. Molybdenum increases the activity of iron catalyst and thus, acts as a promoter (In this reaction, iron as a catalyst increases the rate of formation of ammonia).

Favourable conditions:

1. Temperature: As this reaction is exothermic in nature, low temperature will favour the formation of ammonia. However, at low temperature, the speed of the reaction would be slow. Therefore, the temperature should be kept around 500°C.

2. High pressure: As this reaction proceeds with a decrease in volume, high pressure will favour the formation of ammonia. The reaction is carried out at a pressure of 200–900 atmospheres.

Note: Increase in the concentration of the reactants favours the reaction in the forward direction to give an optimum yield of ammonia.



A flow chart of Haber-Bosch process

Physical properties of ammonia

1. Colour: Ammonia is a colourless gas.

2. Odour: It has a sharp, pungent and characteristic odour.

3. Taste: It has a slightly alkaline taste.

4. Solubility: It is highly soluble in water. This can be demonstrated by fountain experiment. A saturated solution of ammonia in water is called liquor ammonia or ammoniacal water (NH_4OH).

5. Density: It is lighter than air.

6. Liquefaction: When cooled under pressure, ammonia condenses to form a colourless liquid, which boils at –33.4 °C and freezes to form snow like crystals at –77.7 °C.

Caution: Ammonia is quite poisonous. It causes serious damage to the respiratory system and affects tear glands.

Chemical properties of ammonia

1. Basic nature

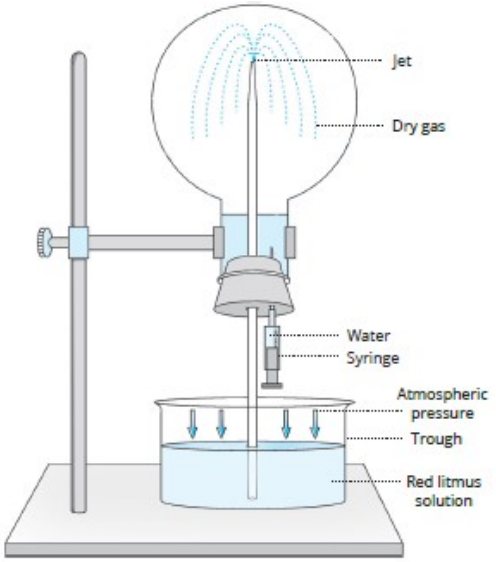
Dry ammonia gas is neutral in nature. But when ammonia is dissolved in water, it generates hydroxyl ions and thus behaves like an alkali.

$$NH_3 + H_2O \longrightarrow NH_4OH \longrightarrow NH_4^+ + OH^-$$

Therefore, it turns moist red litmus paper blue, methyl orange to yellow and colourless phenolphthalein solution to pink

Fountain experiment to demonstrate high solubility of ammonia in water

The apparatus is set up as shown in the figure.
When the syringe is squeezed, the water entering the flask dissolves almost the entire ammonia gas, thus creating a partial vacuum. This happens because ammonia dissolves rapidly in water. The vacuum sucks up the litmus solution, which spurts into the round bottom flask and turns blue when it comes in contact with the undissolved ammonia.



a. Red litmus turns blue, which shows that ammonia is a basic gas.

b. The fountain proves that ammonia is highly soluble in water.

2. Reaction with acids

Ammonia gas reacts with all acids to form their respective ammonium salts. This is because ammonia is basic in nature due to the presence of lone pair of electrons on nitrogen atom. It accepts hydrogen ions (or protons) given by acid to form ammonium ions.

a. Ammonia gives dense **white fumes** with a rod dipped in concentrated hydrochloric acid.

$$NH_3 + HCl \longrightarrow NH_4Cl$$

white fumes

b. With sulphuric acid, it forms ammonium sulphate

$$2NH_3 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$$

c. With nitric acid it forms ammonium nitrate.

$$NH_3 + HNO_3 \longrightarrow NH_4NO_3$$

3. Reaction with oxygen

a. Ammonia is neither combustible nor does it support combustion. It extinguishes a burning splinter. However, ammonia burns in oxygen with a greenish yellow flame forming nitrogen and water vapour.

$$4NH_3 + 3O_2 \longrightarrow 2N_2 + 6H_2O$$

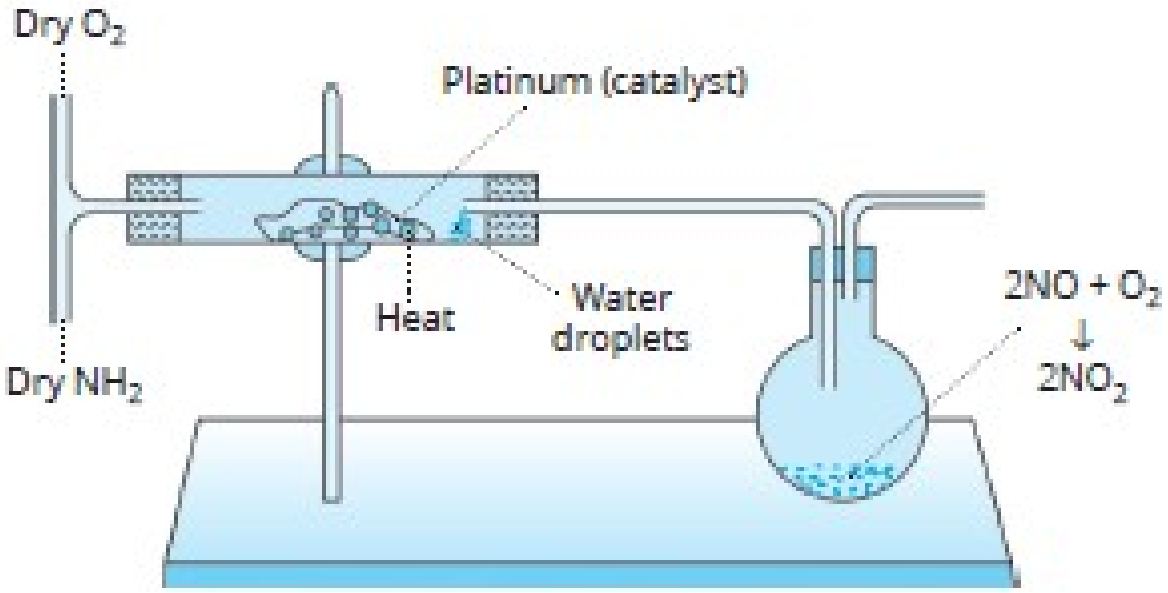
b. Ammonia reacts with oxygen in the presence of platinum catalyst to form nitric oxide and water.

$$4NH_3 + 5O_2 \longrightarrow 4NO + 6H_2O + \text{heat}$$

$$2NO + O_2 \longrightarrow 2NO_2$$

The catalyst is heated to about 800 °C and the heating is discontinued once the reaction is initiated, yet the catalyst glows red hot because the reaction is exothermic.

This is also the initial reaction for the large-scale manufacturing of nitric acid by the Ostwald's process.



4. Reducing action of ammonia

a. Reduction of chlorine by ammonia

i. When chlorine is in excess: Ammonia reacts with excess chlorine to form nitrogen trichloride and hydrogen chloride gas.

$$NH_3 + 3Cl_2 \xrightarrow{\text{(excess)}} NCl_3 + 3HCl$$

A yellow coloured liquid (NCl_3) is formed which is highly explosive in nature.

ii. When ammonia is in excess: When ammonia is in excess, it reacts with limited amount of chlorine to liberate nitrogen gas and forms dense white fumes of ammonium chloride.

$$8NH_3 + 3Cl_2 \longrightarrow 6NH_4Cl + N_2$$

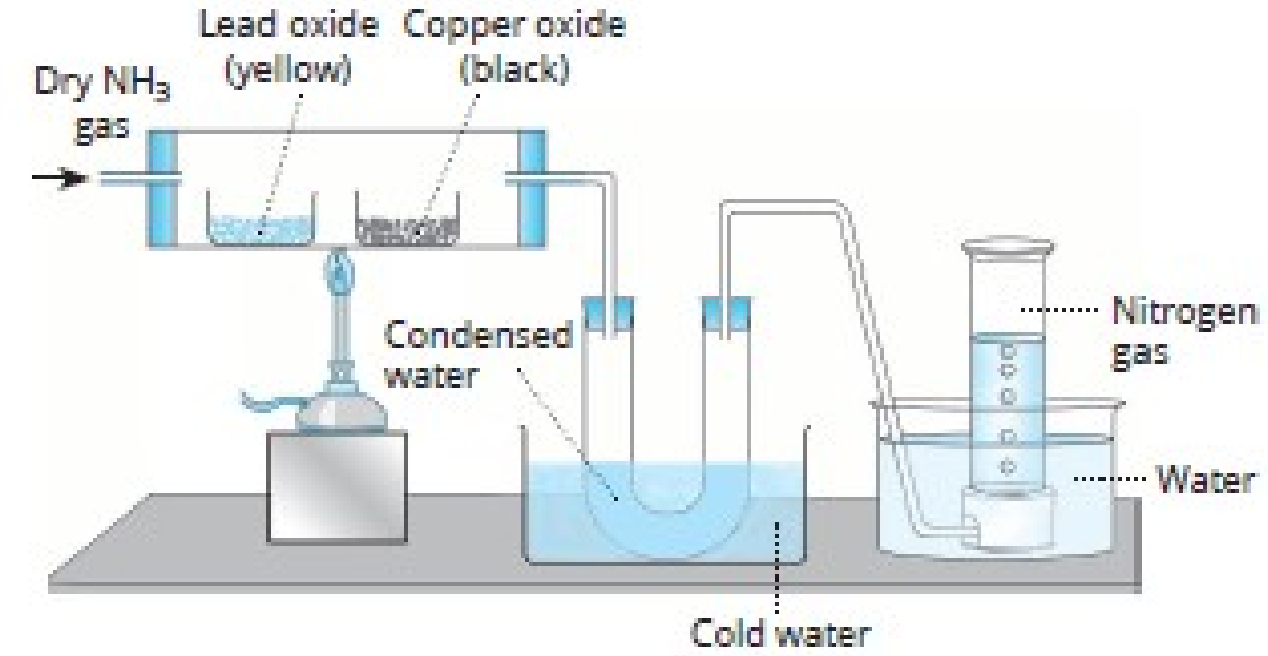
The yellow-green colour of gaseous chlorine disappears and dense white fumes of ammonium chloride are formed.

b. Reduction of metal oxides by ammonia

Ammonia reduces heated copper oxide and lead oxide to their corresponding metals and itself gets oxidized to nitrogen gas.

Reduction of lead oxide:

Ammonia gas is passed over heated lead oxide taken in a crucible



$$3PbO + 2NH_3 \longrightarrow 3Pb + 3H_2O + N_2\uparrow$$

A yellow coloured lead(II) oxide is reduced to grey coloured lead metal.

5. Reaction with carbon dioxide

Ammonia reacts with moist carbon dioxide to form ammonium carbonate.

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

Dry ammonia and carbon dioxide when reacted at about 150 °C and 200 atm pressure form urea, a nitrogenous fertilizer.

$$2NH_3 + CO_2 \longrightarrow NH_2CONH_2 + H_2O$$

urea

Tests for ammonia gas

1. Turns **moist** red litmus blue.
2. Gives **dense white** fumes with a rod dipped in conc. HCl.
3. Turns colourless Nessler's reagent [K_2HgI_4] **brown.**

On passing excess ammonia through Nessler's reagent, a brown precipitate is formed.

4. Turns moist turmeric paper brown and phenolphthalein solution pink.
5. Gives a **bluish white precipitate** when bubbled through aqueous **copper sulphate solution**.

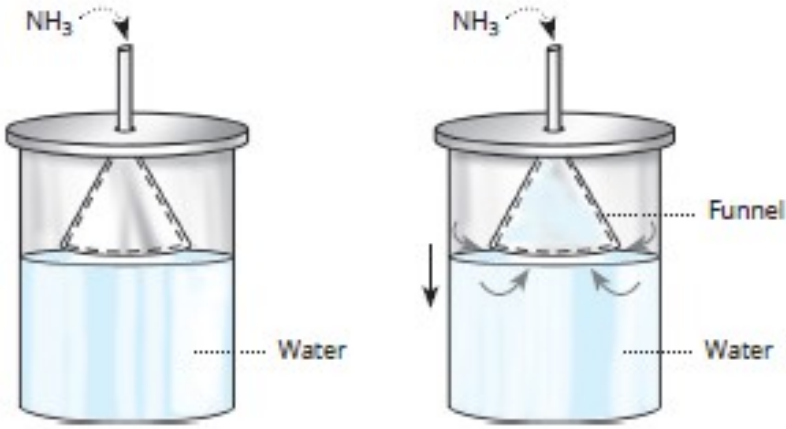
This precipitate dissolves if excess ammonia is passed through the solution forming a **deep blue solution**.

Aqueous solution of ammonia

The solution of ammonia in water is called ammonium hydroxide (NH4OH) or liquor ammonia while the saturated solution of ammonia in water is called liquor ammonia fortis. Ammonia fortis has a specific gravity of 0.88.

Preparation of the aqueous solution of ammonia

To prepare ammonia fortis, ammonia is dissolved in water. The difficulty encountered in doing so is that ammonia dissolves rapidly in water, thus causing back suction.



Back suction is prevented by using the funnel arrangement. The funnel provides a large surface area, which aids in preventing back suction.

Chemical properties of ammonium hydroxide

1. Dissociation in water

Ammonium hydroxide dissociates partially in solution to form the hydroxyl ions.

$$NH_4OH \longrightarrow NH_4^+ + OH^-$$

2. Reaction with indicators

The hydroxyl ion formed when ammonium hydroxide is dissociated in water is responsible for the basic property. Therefore, it reacts with indicators as follows:

a. It turns moist red litmus blue. **b.** It turns turmeric paper brown.

c. It turns phenolphthalein pink.

3. Reaction with acids: Ammonium hydroxide neutralizes acids to form salt and water

$$NH_4OH + HCl \longrightarrow NH_4Cl + H_2O$$
$$NH_4OH + HNO_3 \longrightarrow NH_4NO_3 + H_2O$$
$$2NH_4OH + H_2SO_4 \longrightarrow (NH_4)_2SO_4 + 2H_2O$$

This method is also employed to prepare ammonium salts in the laboratory.

4. **Reaction with soluble salts**: Ammonium hydroxide reacts with soluble salts of metals to form their insoluble metallic hydroxides with different colours and solubility. This property of ammonium hydroxide is very important in qualitative analysis to identify positive radicals.

$$Pb(NO_3)_2 + 2NH_4OH \longrightarrow Pb(OH)_2\downarrow + 2NH_4NO_3$$
lead nitrate — precipitate is white insoluble in excess

$$Zn(NO_3)_2 + 2NH_4OH \longrightarrow Zn(OH)_2\downarrow + 2NH_4NO_3$$
zinc nitrate — precipitate is white soluble in excess

Note: Silver hydroxide is soluble in excess of ammonium hydroxide due to the formation of soluble complex, diamminesilver(I) chloride.

$$AgCl + 2NH_4OH \longrightarrow [Ag(NH_3)_2]Cl + 2H_2O$$
[diamminesilver(I) chloride]

This reaction is used in the separation of lead chloride and silver chloride.

$$CuSO_4 + 2NH_4OH \longrightarrow Cu(OH)_2\downarrow + (NH_4)_2SO_4$$
copper sulphate — precipitate is bluish white insoluble in excess

When excess ammonium hydroxide is added to the above mixture, an inky blue solution of tetraammine copper sulphate is formed.

$$Cu(OH)_2 + (NH_4)_2SO_4 + 2NH_4OH \longrightarrow [Cu(NH_3)_4]SO_4 + 4H_2O$$
tetraamminecopper sulphate inky blue solution

Uses of ammonia

1. It is used in the manufacture of fertilizers like ammonium sulphate, ammonium nitrate, ammonium phosphate and urea.
2. It is used in the manufacture of nitric acid by Ostwald's process.
3. It is used in the manufacture of washing soda and baking soda.
4. Liquefied ammonia (or liquid ammonia) is used as a refrigerant in ice plants and cold storages because

a. it is highly volatile.

b. it has high specific latent heat of vaporization, due to which it produces a large cooling effect.

c. It liquefies easily under pressure at room temperature.

Advantages: As a refrigerant, ammonia offers distinct advantages. Unlike chlorofluorocarbon, it does not destroy atmospheric ozone and does not contribute to greenhouse effect. Also, it has good thermodynamic properties. As a result, ammonia refrigeration systems use less electricity.

Disadvantages: It cannot be used in copper pipes as it rapidly reacts with copper. It is poisonous in high concentration, so in the cases of leakage, it poses threat to living organisms.

5. It is used as a cleansing agent for removing grease stains from clothes as ammonia solution emulsifies fats and grease.
6.It is used as a laboratory reagent.
7. It is used in dry cells as a neutral electrolyte.
8. Many ammonium salts are used in medicines. Inhaling the fumes produced by rubbing ammonium carbonate in the hands can revive fainted people.
9. It is used in the manufacture of explosives.

Refrigerant gas (Chlorofluorocarbons) and its suitable alternatives which are nonozone depleting

A refrigerant is a substance which easily undergoes a reversible phase change from a liquid to a gas. Traditionally, fluorocarbons, especially chlorofluorocarbons were used as refrigerants. But they are being phased out because of their ozone depleting effects. Other common refrigerants used in various applications are ammonia, sulphur dioxide, and non-halogenated hydrocarbons such as methane.

CFC is an organic compound that contains carbon, chlorine and fluorine, and is produced as a volatile derivative of methane and ethane. A subclass of CFCs includes the hydrochlorofluorocarbons (HCFCs) which contain hydrogen as well. They are also commonly known by the trade name freon.

Possible alternatives

Possible alternatives for chlorofluorocarbons include:

a. **Hydrochlorofluorocarbons (HCFCs) such as CF_3CHCl_2:** They break down more quickly in the atmosphere. Though they have a lower percentage of chlorine and hence a lower ozone depletion potential than CFCs, they could damage ozone if overused.

b. **Hydrofluorocarbons (HFCs) such as CF_3CH_2F:** They have no chlorine and thus are 'ozone safe'. However, safety question on toxicity is still unsolved.

c. **Hydrocarbons such as butane and propane:** They are cheap and readily available. As they contain no chlorine, they are 'ozone safe'. However, they are flammable and poisonous.

d. **Water and steam:** They are effective for some cleaning applications and thus can replace some CFCs as solvents in cleaning.

Properties of ammonium salts

1. Ammonium salts can be prepared by neutralization method in the laboratory.
2. They are soluble in water and react with alkalis to liberate ammonia.
3. Ammonium chloride undergoes **thermal dissociation** on heating.
4. Ammonium nitrate on heating gives out laughing gas while ammonium nitrite gives nitrogen gas.

Some uses of ammonium salts

Salt	Uses
Ammonium chloride	Used in dry cells, medicine, dyeing, textile industry
Ammonium sulphate	Used as an important fertilizer, in alum preparation
Ammonium nitrate	Used in making nitrous oxide and explosives
Ammonium carbonate	Used as a component of smelling salt, baking powder, dyeing industry

SUMMARY

1. **Preparation of ammonia**

$$2NH_4Cl + Ca(OH)_2 \rightleftharpoons CaCl_2 + 2H_2O + 2NH_3$$

$$(NH_4)_2SO_4 + 2KOH \longrightarrow K_2SO_4 + 2H_2O + 2NH_3$$

$$Mg_3N_2 + 6H_2O \longrightarrow 3Mg(OH)_2 + 2NH_3$$

$$AlN + 3H_2O \longrightarrow Al(OH)_3 + NH_3$$

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

2. **Drying of ammonia**

Ammonia gas is dried by passing over calcium oxide (CaO). Other drying agents like conc. H_2SO_4, P_2O_5 and $CaCl_2$ are not used because they react with ammonia.

$$2NH_3 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$$

$$6NH_3 + P_2O_5 + 3H_2O \longrightarrow 2(NH_4)_3PO_4$$

$$8NH_3 + CaCl_2 \longrightarrow CaCl_2 \cdot 8NH_3$$

3. **Collection of ammonia**

Ammonia being lighter than air and highly soluble in water is collected by downward displacement of air.

4. **Manufacture of ammonia**

Ammonia is manufactured by Haber's process. Favourable conditions are:

Low temperature : 500 °C

High pressure : 900 atmosphere

Catalyst : Iron

Promoter : Molybdenum

5. Aqueous solution of ammonia is prepared by the funnel arrangement to avoid back suction.

6. **Properties of ammonia**

a. **Reaction with oxygen:**

i. **Oxidation of ammonia in the absence of a catalyst**

$$4NH_3 + 3O_2 \longrightarrow 2N_2 + 6H_2O$$

ii. **Oxidation of ammonia in the presence of a catalyst**

$$4NH_3 + 5O_2 \xrightarrow[800\ °C]{Pt} 4NO + 6H_2O + \text{heat}$$

b. **Reducing action of ammonia**

i. **Reaction with chlorine**

- **Ammonia reacting with excess chlorine**

$$NH_3 + 3Cl_2 \longrightarrow \underset{\text{yellow compound}}{NCl_3} + 3HCl$$

- **Ammonia reacting with a limited supply of chlorine**

$$8NH_3 + 3Cl_2 \longrightarrow 6NH_4Cl + N_2\uparrow$$

ii. **Reaction with metal oxides**

$$3CuO + 2NH_3 \longrightarrow 3Cu + N_2 + 3H_2O$$

$$3PbO + 2NH_3 \longrightarrow 3Pb + N_2 + 3H_2O$$

c. **Reaction of ammonia with acids**

$$NH_3 + HCl \longrightarrow NH_4Cl$$

$$2NH_3 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$$

d. **Reaction of ammonia with carbon dioxide**

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

$$2NH_3 + CO_2 \longrightarrow NH_2CONH_2 + H_2O$$

7. **Reactions of ammonium hydroxide**

a. Neutralization of ammonium hydroxide

$$NH_4OH + HCl \longrightarrow NH_4Cl + H_2O$$

$$NH_4OH + HNO_3 \longrightarrow NH_4NO_3 + H_2O$$

b. Reaction of ammonium hydroxide with soluble salts

$$PbSO_4 + 2NH_4OH \longrightarrow (NH_4)_2SO_4 + Pb(OH)_2\downarrow$$

$$ZnSO_4 + 2NH_4OH \longrightarrow (NH_4)_2SO_4 + Zn(OH)_2\downarrow$$

$$FeSO_4 + 2NH_4OH \longrightarrow (NH_4)_2SO_4 + Fe(OH)_2\downarrow$$

$$CuSO_4 + 2NH_4OH \longrightarrow (NH_4)_2SO_4 + Cu(OH)_2\downarrow$$

- Pale blue precipitate of $Cu(OH)_2$ is soluble in excess of NH_4OH and gives deep blue coloured solution due to the formation of a complex.

$$Cu(OH)_2 + (NH_4)_2SO_4 + 2NH_4OH \longrightarrow [Cu(NH_3)_4]SO_4 + 4H_2O$$

8. Aqueous solution of ammonia is basic in nature and hence, gives following tests:
   a. It turns red litmus blue.
   b. It turns colourless phenolphthalein solution pink.
   c. It gives white dense fumes with HCl.
9. Ammonia gas is used in the preparation of fertilizers, washing soda, baking soda and nitric acid. Liquid ammonia is used as a refrigerant.

THANK YOU