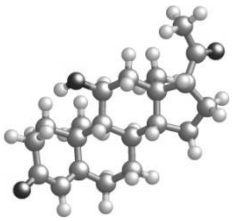

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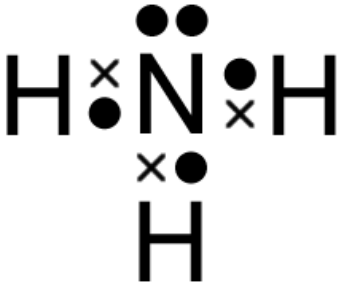
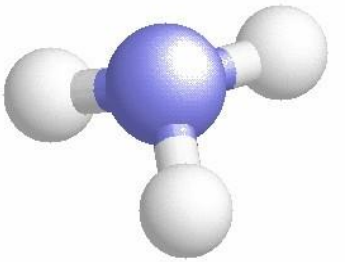
The Properties, Preparation and Uses of Ammonia – NH_3

Introduction:

Ammonia (formula: NH_3) is a simple covalent compound. The dot-and-cross diagram of an ammonia molecule is given in the diagram below, along with a computer generated diagram showing the shape of an ammonia molecule:





- The properties of ammonia are summarised in the table below:

Physical State at Room Temperature and Pressure	Gas.
Colour	Colourless.
Odour	Very sharp / pungent odour.
Density	Less dense than air.
Solubility in Water	Very soluble in water. Ammonia dissolves in water to form an aqueous solution of ammonium hydroxide: ammonia + water $\rightarrow$ ammonium hydroxide $NH_{3(g)} + H_2O_{(l)} \rightarrow NH_4OH_{(aq)}$
Acid / Base Nature	Alkaline. Ammonia will turn damp red litmus paper blue. Ammonia will neutralise an acid forming a salt as the reaction product, *e.g.* ammonia + hydrogen chloride $\rightarrow$ ammonium chloride $NH_{3(g)} + HCl_{(g)} \rightarrow NH_4Cl_{(s)}$ ammonia + sulphuric acid $\rightarrow$ ammonium sulphate $2NH_{3(g)} + H_2SO_{4(aq)} \rightarrow (NH_4)_2SO_{4(aq)}$

Industrial Preparation of Ammonia:

The 1918 Nobel Prize for Chemistry was awarded to Fritz Haber, "For the synthesis of ammonia from its elements." Ammonia is used in the production of nitric acid, which in turn is used in the manufacture of explosives and fertilisers. The industrial preparation of ammonia is the first key step in the preparation of any fertiliser.

Carl Bosch developed the industrial process for the large scale production of ammonia from Fritz Haber's laboratory scale experiments. The 1931 Nobel Prize for Chemistry was awarded to Carl Bosch, "In recognition of his contribution to the invention and development of chemical high pressure methods."

Postscript on Fritz Haber:
The importance of ammonia in feeding the world's population was recognised by the award of the 1918 Nobel Prize in Chemistry to Haber. However, in some ways Haber was an extraordinary choice for the post First World War Nobel Prize. The use of ammonia in the manufacture of explosives had prolonged the fighting and Haber had also supervised the production of chlorine, the first chemical weapon to be used during World War One. Haber's wife, Clara (the first female Ph.D. student from the University of Dahlem) strongly disagreed with him about the use of chemical weapons. On the evening that Haber was promoted for directing gas attacks against the Allied troops, she committed suicide.

Fritz Haber
Born: 1868
Died: 1934

Carl Bosch
Born: 1874
Died: 1940

The elements nitrogen and hydrogen are required to make ammonia.
The nitrogen is obtained by the fractional distillation of liquefied air.
The hydrogen is obtained from a variety of sources:

- The electrolysis of water:

$$\text{water} \rightarrow \text{hydrogen} + \text{oxygen}$$

$$2H_2O_{(l)} \rightarrow 2H_{2(g)} + O_{2(g)}$$

- Reacting together methane and steam:

$$\text{methane} + \text{steam} \rightarrow \text{carbon monoxide} + \text{hydrogen}$$

$$CH_{4(g)} + H_2O_{(g)} \rightarrow CO_{(g)} + 3H_{2(g)}$$

- Cracking hydrocarbons found in crude oil:

$$\text{butane} \rightarrow \text{ethene} + \text{hydrogen}$$

$$C_4H_{10(g)} \rightarrow 2C_2H_{4(g)} + H_{2(g)}$$

Once the nitrogen and hydrogen have been obtained, they are reacted together under the following conditions:

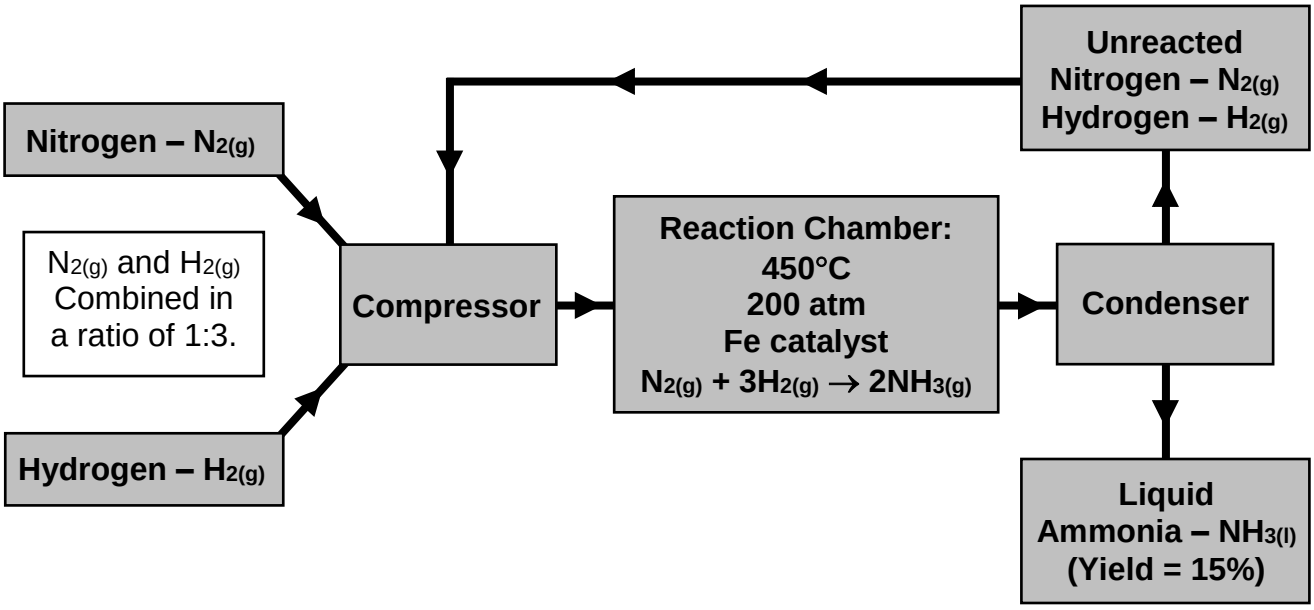
- The nitrogen and hydrogen are mixed together in a ratio of 1:3 as required by the balanced chemical equation.
- The reaction takes place at a temperature of 450°C
- The reaction takes place at a pressure of 200 atmospheres.
- An iron catalyst is used to increase the rate of the reaction.

The balanced chemical equation for the reaction is:

$$\text{nitrogen} + \text{hydrogen} \rightleftharpoons \text{ammonia}$$

$$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$$

One important thing to note about this reaction is that is ***reversible***. Because of this, not all of the nitrogen and hydrogen react to form ammonia, and so the yield of ammonia is quite low – approximately 15%. Any unreacted nitrogen and hydrogen are recycled. The ammonia is separated form the nitrogen and hydrogen by passing the mixture of gasses through a condenser. As the ammonia gas cools, it condenses into a liquid which can be easily separated from the mixture of nitrogen and hydrogen gas. An outline of the process is given in the diagram below:



Laboratory Preparation of Ammonia:

Ammonia gas can be prepared in the laboratory by heating an ammonium salt with an alkali, for example:

$$\text{ammonium chloride + sodium hydroxide} \rightarrow \text{sodium chloride + water + ammonia}$$

$$NH_4Cl_{(s)} + NaOH_{(s)} \rightarrow NaCl_{(s)} + H_2O_{(l)} + NH_{3(g)}$$

Once the ammonia gas has been produced, it is passed through an alkaline drying agent to remove the water that is produced as a side-product of the reaction. An alkaline drying agent must be used because the alkaline ammonia gas would react with an acidic drying agent. A typical alkaline drying agent is calcium oxide:

$$\text{calcium oxide + water} \rightarrow \text{calcium hydroxide}$$

$$CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2(s)}$$

Because ammonia gas is very soluble in water, it cannot be collected by the downward displacement of water. Instead, once the ammonia gas has been dried, it is passed directly into an upturned test tube. This is possible because ammonia gas is less dense than air.

Chemical Tests for Ammonia:

- Ammonia gas is alkaline, so it will turn moist red litmus paper blue.
- When ammonia gas comes into contact with hydrogen chloride gas, there is an immediate reaction which forms ammonium chloride as the product. This is observed as dense white fumes which are actually tiny crystals of solid ammonium chloride suspended in air:

$$\text{ammonia + hydrogen chloride} \rightarrow \text{ammonium chloride}$$

$$NH_{3(g)} + HCl_{(g)} \rightarrow NH_4Cl_{(s)}$$

This test could be carried out by allowing a gas jar of ammonia to mix with a gas jar of hydrogen chloride. Alternatively, a glass rod could be dipped into a bottle of concentrated hydrochloric acid and then held in the cloud ammonia. The concentrated hydrochloric acid attached to the glass rod will give-off hydrogen chloride gas which, in turn, will react with the ammonia to produce the white fumes of ammonium chloride.

The Manufacture, Advantages and Disadvantages of Fertilizers:

• One of the most important uses of ammonia is in the manufacture of fertilizers. Over twenty elements are required for plant growth. Of these elements, nitrogen is considered a primary nutrient. This means that it is essential, in large quantities, for the growth and development of all plants. Because ammonia contains nitrogen, it is an essential starting material for the manufacture of all fertilizers.

A simple way of preparing a fertilizer is to neutralise an acid with ammonia. For example:

ammonia + sulphuric acid → ammonium sulphate (*fertilizer*)

$$2NH_{3(aq)} + H_2SO_{4(aq)} \rightarrow (NH_4)_2SO_{4(aq)}$$

ammonia + nitric acid → ammonium nitrate (*fertilizer*)

$$NH_{3(aq)} + HNO_{3(aq)} \rightarrow NH_4NO_{3(aq)}$$

• Nitrate fertilizers, such as ammonium nitrate, are very soluble in water. If large quantities of nitrate fertilizers are spread on fields, and then it rains, the fertilizer will be washed into nearby streams, rivers and lakes. Here, the fertilizer will cause the rapid growth of plants and green algae. When this vast amount of plant material dies, it is broken down by bacteria. The bacterial decay of the plant material removes oxygen that is dissolved in the water, which in turn leads to the death of any fish living in the water. Eventually, the stream, river or lake has no oxygen dissolved in it, no plant life growing in it and no animal life living in it. The name given to this overall process is *eutrophication*.

• A large concentration of nitrates in drinking water can cause health problems, especially for babies and young children. Nitrates can reduce how efficiently blood transports oxygen around the body. This can cause the babies and young children to turn blue and eventually die.

• Farmers can neutralise soil that is too acidic for healthy plant growth by adding an alkali, such as calcium hydroxide (formula: $Ca(OH)_2$) to the soil. However, if calcium hydroxide is added to soil that has been treated with a fertilizer, it can result in loss of nitrogen from the soil. The reaction is similar to the one that was used to prepare ammonia in the laboratory:

ammonium nitrate + calcium hydroxide → ammonia + calcium nitrate + water

(*fertilizer*) (*to neutralise acid soil*)

$$2NH_4NO_{3(s)} + Ca(OH)_{2(s)} \rightarrow 2NH_{3(g)} + Ca(NO_3)_{2(s)} + 2H_2O_{(l)}$$

It can be seen from the balanced chemical equation that the nitrogen that was originally contained in the fertilizer has been lost from the soil in the form of ammonia gas.

Questions

Question One:

Which of the properties listed below correctly apply to ammonia gas? Place ☑ and ☒ in the appropriate boxes.

- Insoluble in water. True: ☐ False: ☐
- Colourless. True: ☐ False: ☐
- Less dense than air. True: ☐ False: ☐
- Acidic. True: ☐ False: ☐
- Odourless. True: ☐ False: ☐
- Can neutralise acids. True: ☐ False: ☐
- Turns damp red litmus blue. True: ☐ False: ☐

Question Two:

a) State the origin of the nitrogen gas used in the industrial manufacture of ammonia:

……

b) State a possible origin of the hydrogen gas used in the industrial manufacture of ammonia:

……

c) Write a balanced chemical equation, including state symbols, to show the formation of ammonia from nitrogen and hydrogen. Remember to indicate that the reaction is reversible:

……

d) What conditions are used for the industrial manufacture of ammonia?

i) Temperature: ……

ii) Pressure: ……

iii) Catalyst: ……

Question Three:

a) Complete the balanced chemical equation for the laboratory preparation of ammonia gas:

…… $NH_4Cl_{(s)}$ + …… $Ca(OH)_{2(s)}$ → …… + …… + ……

b) Why is it ***not*** advisable to dry the ammonia gas using an acidic drying agent such as concentrated sulfuric acid? Write a balanced chemical equation to explain your answer.

……

……

……

c) Why is it ***not*** advisable to collect the ammonia gas by the downward displacement of water?

……

……

d) What property of the ammonia gas allows it to be collected in an inverted test tube?

……

……

Question Four:

a) What would you observe when ammonia gas and hydrogen chloride gas are allowed to mix together?

……

b) Write a balanced chemical equation to describe the reaction that is taking place in Question Four **a)**:

……

Question Five:

a) What is a fertilizer?

……

b) Write a balanced chemical equation to show how a fertilizer can be prepared from ammonia:

……

c) Calculate which fertilizer contains the greatest percentage nitrogen:

i) ammonium nitrate, NH_4NO_3:

……

ii) ammonium sulphate, $(NH_4)_2SO_4$:

……

d) Why are high levels of nitrates in lakes and rivers dangerous?

……

e) Why would you advise a farmer ***not*** to add calcium hydroxide to a field that he has recently added ammonium nitrate fertilizer to? Write a balanced chemical equation to support your answer.

……

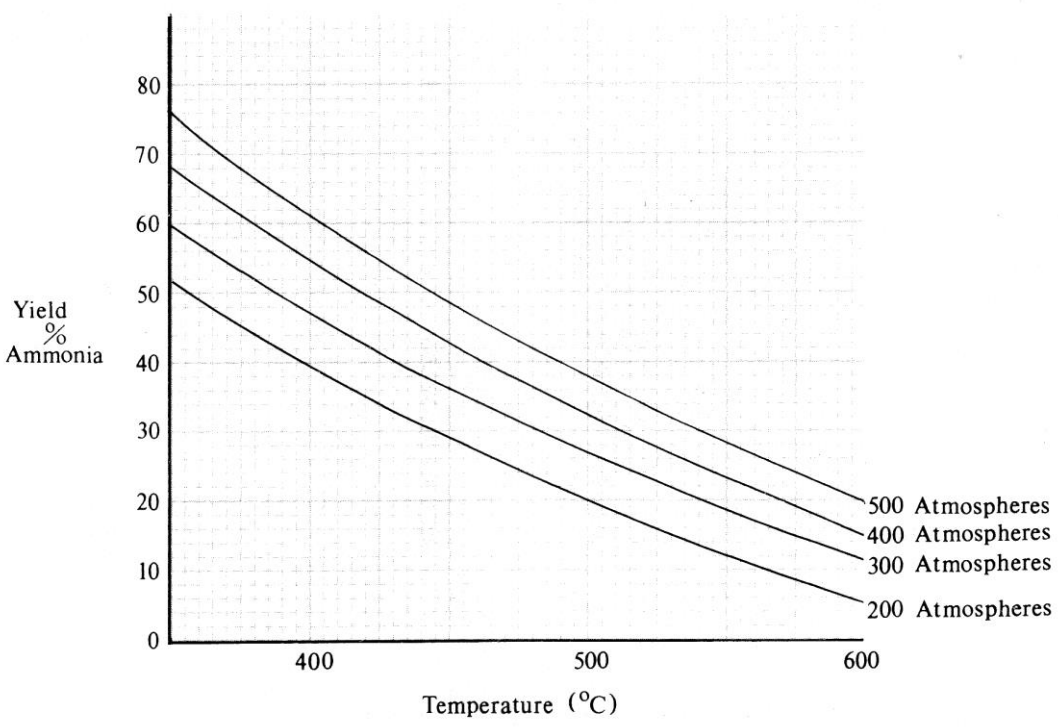
……

……

……

Question Six:

Between 1905 and 1915 Fritz Haber developed the process by which nitrogen and hydrogen may be combined to make ammonia. This is a difficult reaction to perform, so he had to do a great deal of work to find the correct temperature and pressure conditions for the process. Some of his measurements are shown in the graphs below:



a) What happens to the yield of ammonia when:

i) The temperature of the reaction is increased?

……

ii) The pressure of the reaction is increased?

……

b) A new works manager has been appointed who would like to increase the yield of ammonia from the process. Suggest a reason why she should ***not***…

i) Make a large increase in the pressure at which the process operates:

……

……

ii) Make a large decrease in the temperature at which the process operates:

……

……

- Click on the QR code below for the answers to this assignment.

http://www.chemist.sg/ammonia_equilibrium/ammonia_properties_ans.pdf