Topic 14: Answers
Ammonia & Sulfur Dioxide

SYLLABUS RELEVANCE & TEXTBOOK CHAPTERS		
O-LEVEL PURE (5072)	✓	Chapter 11.6 & 19
O-LEVEL SCIENCE (5116)	✗	
N-LEVEL SCIENCE (5155)	✗	

Lesson Package & Accompanying Slides Designed by Alex Lee (2010)
Last Modified by Alex Lee (2011)

1. Ammonia & Sulfur Dioxide – A Comparison

Ammonia and sulfur dioxide provide an interesting comparison when placed side by side. In some aspects, they are very similar – both are colourless with a pungent odour. In other aspects, they are vastly different – ammonia is basic, while sulfur dioxide has acidic properties.

	ammonia	sulfur dioxide
Formula:	NH_3	SO_2
Colour:	colourless	colourless
Odour:	pungent smell	choking/pungent smell
Acidity:	alkaline	acidic
Confirmatory Test:	test with a piece of moist red litmus paper; it will turn blue	test with filter paper soaked in acidified potassium dichromate(VI); it will turn from orange to green

Industrially, they both have significant uses, especially in the production of acids. Ammonia is a precursor to nitric acid, but may also be directly used to manufacture fertilizers and detergents.

uses for sulfur dioxide

- manufacture of paper by bleaching wood pulp
- used to preserve food by killing bacteria
- manufacture of sulfuric acid
  - used as a battery acid
  - manufacture fertilizers
  - manufacture detergents

2. The Haber Process – A Reversible Reaction

Ammonia can be manufactured industrially through the ....Haber process...., a reversible reaction as expressed in equation below.

$$N_2\,(g) + 3\,H_2\,(g) \rightleftharpoons 2\,NH_3\,(g)$$

You will notice that there is a double-headed arrow ($\rightleftharpoons$) in the above equation. This indicates that the reaction is reversible.

A **reversible reaction** is one in which ....both the forward and backward reactions.... occur ....simultaneously...., leading to an equilibium mixture of both reactants and products.

Since both the forward and backward reactions are occurring at the same time, reversible reactions are never complete. Instead, they reach **equilibrium**, i.e. the 'balancing point' between reactants and products.

When a reversible reaction reaches **equilibrium**, it means that the ....rate of the forward reaction and the rate of the backward reaction.... are equal.

Typically, equilibrium is viewed as the 'ending point' of a reversible reaction, since a reversible reaction is never complete. However, the position of this equilibrium may vary, depending on external factors such as pressure and temperature.

Assuming equilbrium has been reached,

$N_2\,(g)$ +	$3\,H_2\,(g)$	$\rightleftharpoons$	$2\,NH_3\,(g)$
20 %	20 %		80 %

A **high equilibrium yield** refers to a relatively high proportion of products compared to reactants.

$N_2\,(g)$ +	$3\,H_2\,(g)$	$\rightleftharpoons$	$2\,NH_3\,(g)$
70 %	70 %		30 %

A **low equilibrium yield** refers to a relatively high proportion of reactats compared to products.

Effect of Temperature

The Haber process is a heat-producing reaction ('exothermic'), and a ....low temperature.... favours a high equilibrium yield. However, in reality, this is still conducted at high temperatures to achieve ....a fast rate of reaction.....

Effect of Pressure

From the equation, we can observe that four moles of gas are converted into two moles of gas. Hence a ....high pressure.... favours a high equilibrium yield.

3. **Raw Materials & Conditions for the Haber Process**

In the Haber process, nitrogen and hydrogen are allowed to react under special conditions.

$$N_2\,(g) + 3\,H_2\,(g) \rightleftharpoons 2\,NH_3\,(g)$$

Nitrogen, obtained from ……………………………… ……………………………………… ………………………………………

Hydrogen, obtained from ……………………………… ……………………………………… ………………………………………

Conditions:
- temperature of ……………………,
- pressure of …………………………,
- catalyst of …………………………………………….

The graph below shows the relationship between temperature, pressure and yield of ammonia in the Haber process.

yield

250 °C

350 °C

450 °C

550 °C

pressure

(a) (i) State the relationship between temperature and percentage yield of the reaction.

The higher the temperature, the lower the percentage yield.

(ii) Suggest why it is inefficient to conduct the Haber process at 550 °C instead of 450 °C.

The yield will be too low and the costs will be too expensive.

(iii) Suggest why it is inefficient to conduct the Haber process at 350 °C instead of 450 °C.

The rate of reaction will be too slow.

(b) (i) State the relationship between pressure and percentage yield of the reaction.

The higher the pressure, the higher the percentage yield.

(ii) Suggest why the Haber process is carried out at 200 atm, and not at 300 atm.

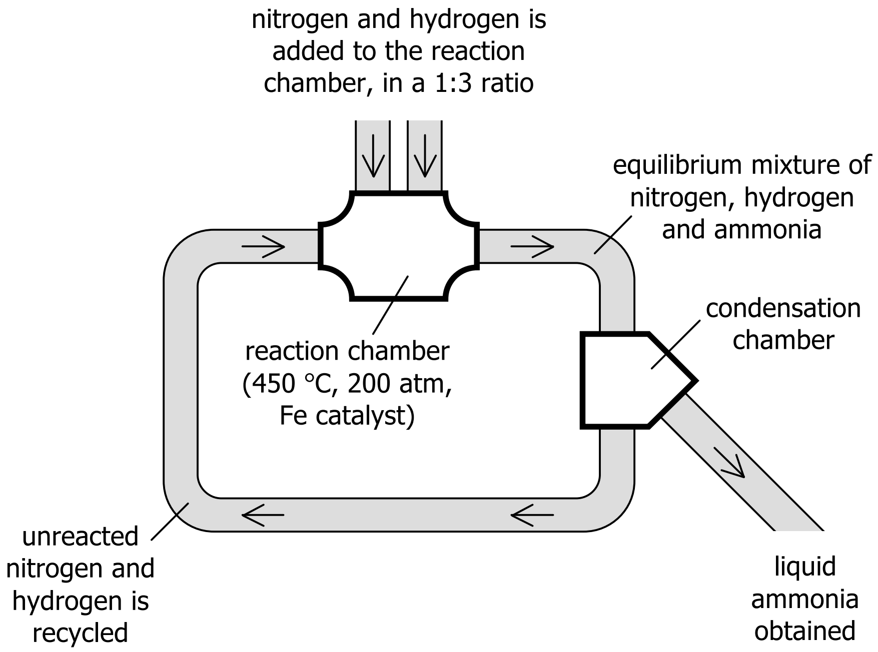
The costs will be too expensive.

4. **Separation of Reactants and Products**

During the Haber process, an equilibrium mixture of three gases, ...nitrogen......, ...hydrogen...... and ......ammonia......, is obtained. These three gases are separated by their ......boiling points.......

Gas	ammonia	nitrogen	hydrogen
Boiling Point	−33 °C	−196 °C	−253 °C

As you can observe, ammonia has a significantly higher boiling point than the other two gases. The equilibrium mixture is ......cooled...... until ammonia condenses into a liquid. The liquid ammonia is then collected and stored. Industrially, this yield is very low – around 25 %.



Due to the low percentage yield, there is a relatively large volume of ......unreacted nitrogen...... ......and hydrogen....... These gases are recycled to ......conserve resources and save costs.......

5. **Laboratory Preparation of Ammonia**

The Haber process is not feasible for laboratory preparation of ammonia.

(a) Briefly state how ammonia should be prepared in a laboratory.

By warming an ammonium salt with an alkali (e.g. sodium hydroxide).

(b) Construct the chemical equation for the preparation of ammonia gas, using ammonium sulfate and aqueous sodium hydroxide as the starting reagents.

$(NH_4)_2SO_4 + 2\ NaOH \longrightarrow Na_2SO_4 + 2\ H_2O + 2\ NH_3$

Self-Designed Summary

Supplementary Questions

1. Ammonium sulfate can be manufactured by absorbing ammonia gas in a suspension of calcium sulfate in water and then passing in carbon dioxide. Calcium carbonate is the other product of the reaction.
   (a) Write an equation, including state symbols, for the manufacture of ammonium sulfate by this method. How can ammonium sulfate be obtained from the mixture of ammonium sulfate and calcium carbonate?
   (b) How would you prepare a dry sample of ammonium sulfate crystals from aqueous ammonia and dilute sulfuric acid?
   (c) Give one commercial use of ammonium sulfate.
   (d) When ammonium chloride is heated, thermal dissociation takes place. Explain what is meant by *thermal dissociation*. Describe clearly what you would see if ammonium chloride were heated in a test-tube and write an equation for the reaction.

2. (a) Describe briefly the preparation of ammonia from an ammonium salt. (A diagram of the apparatus is not required.)
   (b) (i) Explain why ammonia cannot be dried using concentrated sulfuric acid.
   (ii) Suggest a suitable substance for drying ammonia.
   (c) When dry ammonia is passed over heated sodium, hydrogen and the solid sodamide ($NaNH_2$), are formed. Sodamide reacts violently with cold water to give sodium hydroxide and ammonia.
   (i) Why must the ammonia be dried before reacting with sodium?
   (ii) Construct an equation, including state symbols, for the reaction between sodium and ammonia.
   (iii) Construct an equation, including state symbols, for the reaction between sodamide and water.
   (iv) If, in this experiment, 240 cm^3 of hydrogen were formed at room temperature and pressure, what mass of sodamide was obtained?
   (d) What would you observe if aqueous iron(III) chloride were added to the solution obtained by adding sodamide to water? *(JUNE 84)*

3. Sulfur dioxide and oxygen react as shown:

$$\mathbf{2\,SO_2\,(g) + O_2\,(g) \rightleftharpoons 2\,SO_3\,(g)}$$

   (a) (i) What does the symbol $\rightleftharpoons$ represent?
   (ii) How is the sulfur dioxide needed for this reaction obtained industrially?
   (b) Sulfur dioxide, if released into the atmosphere, is an air pollutant.
   (i) State the key source of sulfur dioxide as an air pollutant.
   (ii) State a natural source of sulfur dioxide.
   (c) Construct a chemical equation, including state symbols, for
   (i) the combustion of sulfur to sulfur dioxide,
   (ii) the further oxidation of sulfur dioxide to sulfur trioxide,
   (iii) the reaction of sulfur trioxide with water.
   (d) Outline the key uses for sulfuric acid and sulfur dioxide, clearly differentiating between the two compounds.

Supplementary Questions (Answers)

Question 1
(a) $2\ NH_3\ (g) + CaSO_4\ (s) + CO_2\ (g) + H_2O\ (l) \longrightarrow (NH_4)_2SO_4\ (aq) + CaCO_3\ (s)$
It can be obtained by filtration, as ammonium sulfate is soluble in water whereas calcium carbonate (and any unreacted calcium sulfate) is insoluble in water. Hence ammonium sulfate will be the filtrate.
(b) Titration method:
1. Using a pipette, measure out a fixed volume of dilute sulfuric acid and place in a conical flask.
2. Add a few drops of phenolphthalein to the solution.
3. Using a burette, add aqueous ammonia to the conical flask dropwise, ensuring that the conical flask is thoroughly swirled between each drop.
4. Stop once the reaction turns a faint pink. Record down the volume of aqueous ammonia used.
5. Repeat the experiment without indicator to obtain a pure solution of ammonium sulfate.
6. Place the solution into an evaporating dish and heat it till dryness.

(c) As a fertilizer
(d) Thermal dissociation refers to the breaking down of a single compound using heat only to become two or more substances.
As ammonium chloride crystals are heated, the white solid will gradually decrease in size, and a colourless, pungent smelling gas would be evolved.
$NH_4Cl\ (s) \longrightarrow NH_3\ (g) + HCl\ (g)$
Near the mouth of the test-tube, a white deposit would be formed.
$NH_3\ (g) + HCl\ (g) \longrightarrow NH_4Cl\ (s)$

Question 2
(a) To a sample of an ammonium salt, add aqueous sodium hydroxide. Warm the mixture gently. Ammonia gas should be evolved.
(b) (i) Ammonia is alkaline, and would react with the sulfuric acid to form ammonium sulfate.
(ii) Pass the ammonia gas through fused calcium chloride (or quicklime).
(c) (i) If the ammonia was not dried, the sodium metal would react with the water vapour present to form sodium hydroxide and hydrogen gas. This will reduce the yield of the reaction.
(ii) $2\ Na\ (s) + 2\ NH_3\ (g) \longrightarrow 2\ NaNH_2\ (s) + H_2\ (g)$
(iii) $NaNH_2\ (s) + H_2O\ (l) \longrightarrow NaOH\ (aq) + NH_3\ (g)$
(iv) 7.80 grams
(d) The brown iron(III) chloride solution will decolourize, and a reddish-brown precipitate would be formed.

Question 3
(a) (i) It is a reversible reaction.
(ii) Through the combustion of sulfur.
(b) (i) By the combustion of sulfur-containing fossil fuels.
(ii) From volcanoes.
(c) (i) $S\ (s) + O_2\ (g) \longrightarrow SO_2\ (g)$
(ii) $2\ SO_2\ (g) + O_2\ (g) \longrightarrow 2\ SO_3\ (g)$
(iii) $SO_3\ (g) + H_2O\ (l) \longrightarrow H_2SO_4\ (aq)$
(d) Sulfur dioxide – bleach, manufacture of wood pulp for paper, food preservative
Sulfuric acid – manufacture of detergents and fertilizers, used as a battery acid

Lecture Slides

Ammonia & Sulfur Dioxide

Anglo-Chinese School (Barker Road)

CHEMISTRY
Prepared by Alex Lee

Chapter Overview

In This Chapter, We Will Learn …

1. Properties of Ammonia & Sulfur Dioxide
2. Uses for Sulfur Dioxide & Sulfuric Acid
3. Reversible Reactions
4. Haber Process (Manufacture of Ammonia)
5. Laboratory Preparation of Ammonia

Ammonia & Sulfur Dioxide

- Ammonia and sulfur dioxide provide an interesting comparison as they share many similarities and yet many differences.
- For example, both are colourless gases with a pungent or choking odour. Both are also good reducing agents.
- In contrast, ammonia dissolves to form an alkaline solution, while sulfur dioxide dissolves to form an acidic solution.

Ammonia – Some Properties

AMMONIA

formula: NH_3

colour: colourless

odour: pungent smell

acidity: alkaline

confirmatory test: test the gas with a piece of moist red litmus paper; moist red litmus paper will turn blue

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Sulfur Dioxide – Some Properties

SULFUR DIOXIDE

formula: SO_2

colour: colourless

odour: choking smell

acidity: acidic

confirmatory test: test with filter paper soaked in acidified potassium dichromate(VI); it will turn from orange to green

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Sulfur Dioxide – Uses

MUST MEMORISE!

- Sulfur dioxide is most commonly used
  – to **manufacture of paper**, by **bleaching wood pulp**
  – as a **food preservative**, by **killing bacteria**
  – to manufacture of sulfuric acid

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Sulfuric Acid – Uses

MUST MEMORISE!

- Sulfuric acid, formed from sulfur dioxide, is used
  - as a **battery acid**
  - to **manufacture fertilisers**
  - to **manufacture detergents**

Recall: Preparation of Salts
This is because most sulfate salts are manufactured from sulfuric acid in the first place!

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Haber Process

- Ammonia can be manufactured industrially through the **Haber process**, invented in 1909 by Fritz Haber for the manufacture of ammonia.

$$N_2\,(g) + 3\,H_2\,(g) \rightleftharpoons 2\,NH_3\,(g)$$

- Prior to the Haber process, there was no known way to produce ammonia on an industrial scale.
- Hence this paved the way for the manufacture of other substances, such as fertilisers, detergents, explosives and nitrate compounds.

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Haber Process: A Reversible Reaction

- You will notice that there is a double-headed arrow in the chemical equation:

$$N_2\,(g) + 3\,H_2\,(g) \rightleftharpoons 2\,NH_3\,(g)$$

- This indicates that the reaction is **reversible**.
- A reversible reaction is one in which **both the forward and the backward reactions** occur **simultaneously**, leading to an equilibrium mixture of both reactants and products.

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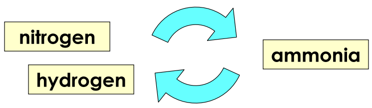
Haber Process: A Reversible Reaction

- A reversible reaction is **never complete** – as the forward reaction occurs, the backward reaction 'reverses' the process.



- Instead, it reaches a 'balancing point' in which the amount of reactants and products become constant. This is known as **equilibrium**.

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Haber Process: A Reversible Reaction

- When a reversible reaction is at **equilibrium**, it means that the **rate of the forward reaction and the rate of the backward reaction** are equal.
- Hence the concentration of reactants and products will remain constant.
  - Any conversion of reactants to products (forward) will be equal to the conversion of products to reactants (backward).

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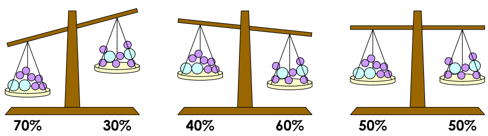
Haber Process: Position of Equilibrium

- The position of equilibrium depends on the pressure and temperature of the surroundings.



- A **high equilibrium yield is desirable**; we want to achieve a high percentage of products (and hence a low percentage of reactants).

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Haber Process: Position of Equilibrium

EFFECT OF TEMPERATURE

- The Haber process is a heat-producing reaction (known as 'exothermic').
- Hence maintaining a **low temperature** favours a high equilibrium yield.
  - *analogy: imagine you are feeling hot, would you rather be in a warm room or a cold room?*
- However, in reality, a **high temperature is still used to ensure a fast rate of reaction**.

Haber Process: Position of Equilibrium

EFFECT OF PRESSURE

- The Haber process converts four moles of gas (one N_2 and three H_2) into two moles of gas (two NH_3)
- Hence maintaining a **high pressure** favours a high equilibrium yield.
- A high pressure also provides a fast rate of reaction, but is very expensive to maintain.

Haber Process: Position of Equilibrium

SUMMARY OF FACTORS

factor	preferred temperature	preferred pressure
equilibrium yield	low	high
rate of reaction	high	high
costs	low	low

- We have to remember that yield is not the only factor – time (rate of reaction) and cost are important too!

Haber Process: Conditions

MUST MEMORISE!

$$N_2\,(g) + 3\,H_2\,(g) \rightleftharpoons 2\,NH_3\,(g)$$

Nitrogen is obtained from the **fractional distillation of liquid air**.

Hydrogen is obtained from the **catalytic cracking of crude oil**.

Conditions:
- temperature of **450 °C**
- pressure of **200 atm**
- catalyst of **finely divided iron**

Haber Process: Separation of Products

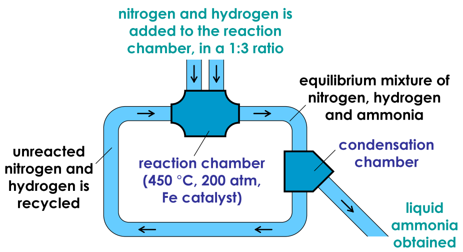
- In the Haber process, an **equilibrium mixture of nitrogen, hydrogen and ammonia** is obtained.
- These gases can be separated by their **boiling points**.

Gas	ammonia	nitrogen	hydrogen
Boiling Point	–33 ° C	–196 ° C	–253 ° C

Ammonia has a significantly higher boiling point than the other two gases.

Haber Process: Separation of Products

- The equilibrium mixture is **cooled** until ammonia condenses into a liquid. This yield is low – about 25 %.



Haber Process: Separation of Products

- Due to the low percentage yield, there is a relatively large volume of unreacted nitrogen and hydrogen.
- These gases are recycled (i.e. re-used) in order to **conserve resources and save costs**.

Laboratory Preparation of Ammonia

- The Haber process is an industrial process, and is not feasible for the laboratory preparation of ammonia.
- Instead, ammonia should be prepared by **warming an ammonium salt** (e.g. ammonium sulfate) with an **alkali** (e.g. aqueous sodium hydroxide).

Recall: Alkali-Ammonium Salt Reaction (chapter of Acids & Bases)

- Chemical equation:

$$(NH_4)_2SO_4 + 2\ NaOH \longrightarrow Na_2SO_4 + 2\ H_2O + 2\ NH_3$$