Acids, Bases and Salts

Industrial Manufacture of Ammonia

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Nanyang Girls' High School

Acids, Bases and Salts

What do I need to know and understand about ammonia?

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Ammonia

(a) Describe the use of nitrogen, from air, and hydrogen, from cracking oil, in the manufacture of ammonia.

(b) State that some chemical reactions are reversible, *e.g.* manufacture of ammonia.

(c) Describe the essential conditions for the manufacture of ammonia by the Haber process.

(d) Describe the displacement of ammonia from its salts.

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Why is ammonia so important? What is it used for?

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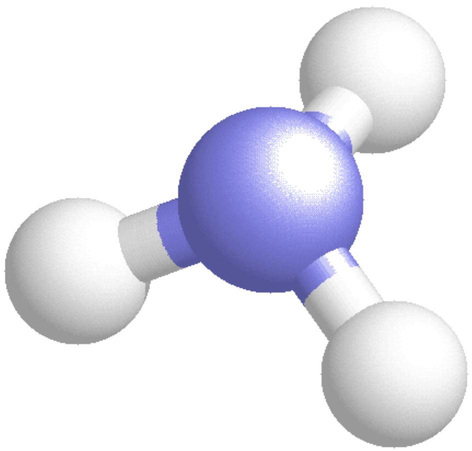

Ammonia is a very important chemical, used in the manufacture of:

- Nitric acid, HNO_3
- Fertilisers, such as ammonium nitrate, NH_4NO_3
- Explosives, such as 2,4,6-trinitrotoluene (TNT), $C_7H_5N_3O_6$
- Plastics, such as nylon

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How is ammonia manufactured on an industrial scale?

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

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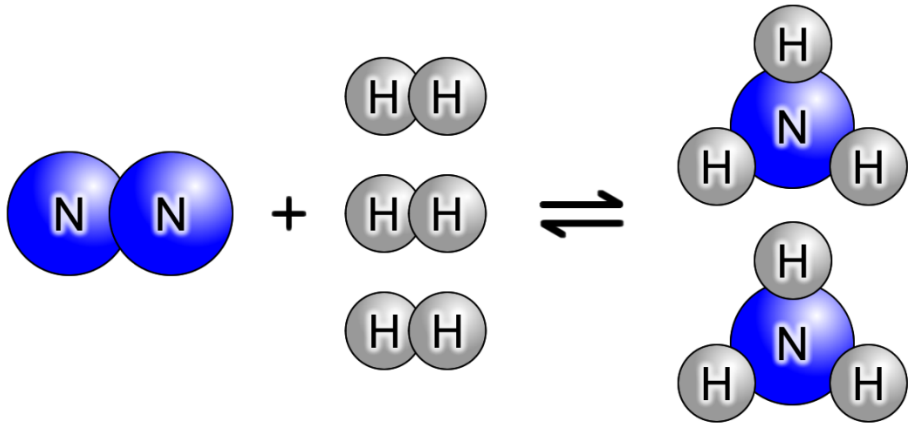
Nitrogen + Hydrogen ⇌ Ammonia



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

- Ammonia is manufactured on an industrial scale by reacting nitrogen gas directly with hydrogen gas under a specialised set of conditions.

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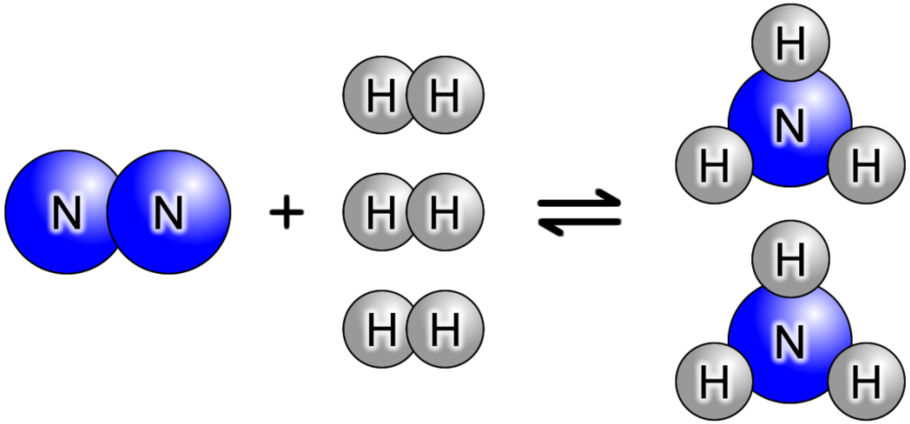
Nitrogen + Hydrogen $\rightleftharpoons$ Ammonia



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

- Note that the balanced chemical equation does not use a conventional arrow, but instead uses a double-headed arrow. This indicates that the reaction is *reversible*.

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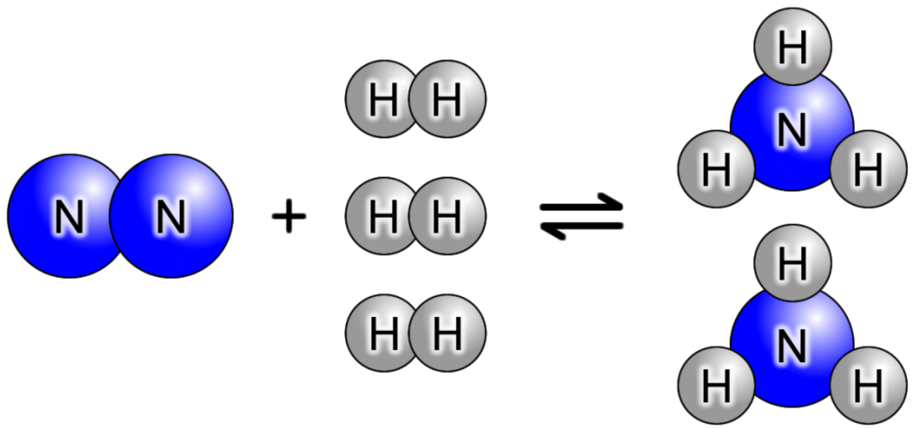
Nitrogen + Hydrogen $\rightleftharpoons$ Ammonia



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

- The chemical reaction used to manufacture ammonia on an industrial scale is *reversible*. This means that while nitrogen and hydrogen react to form ammonia, ammonia reacts to form nitrogen and hydrogen.

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- Analogy for a reversible reaction.
- Imagine that you stand on an escalator and start to move forwards.
- This is the same as the nitrogen and hydrogen molecules colliding and reacting to form ammonia:

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

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- Analogy for a reversible reaction.
- Now imagine that you turn around and start to run back down the escalator while it is still slowly moving forwards.
- This is the same as the ammonia molecules colliding and reacting to form nitrogen and hydrogen:

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

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- Analogy for a reversible reaction.
- Now imagine walking back down the escalator at the *same rate* that the escalator is moving forwards.
- You are now at *equilibrium* on the escalator. It appears that you are standing still, although the escalator is still moving and your legs are still moving.

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- Analogy for a reversible reaction.

- The reaction between nitrogen and hydrogen reaches *equilibrium* when the rate of the forward reaction equals the rate of the backward reaction. It appears that the reaction has stopped, although chemical changes are still taking place:

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

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- Hydrogen required for the manufacture of ammonia is obtained by *cracking* long-chain hydrocarbons from crude oil, *e.g.*

$$C_{20}H_{42(s)} \rightarrow C_8H_{16(l)} + C_{12}H_{24(l)} + H_{2(g)}$$

- Nitrogen required for the manufacture of ammonia is obtained from the *fractional distillation* of liquefied air (remember, the Earth's atmosphere is approximately 78% nitrogen).

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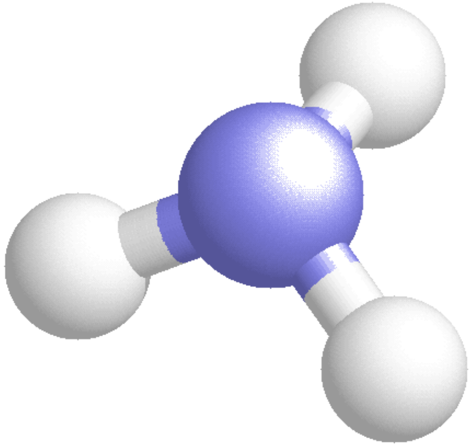

The conditions used for the industrial manufacture of ammonia were discovered almost 100 years ago by a German scientist called *Fritz Haber*. His discovery was so important that he was awarded the 1918 Nobel Prize in Chemistry. The conditions that he discovered are still used in factories around the world today.

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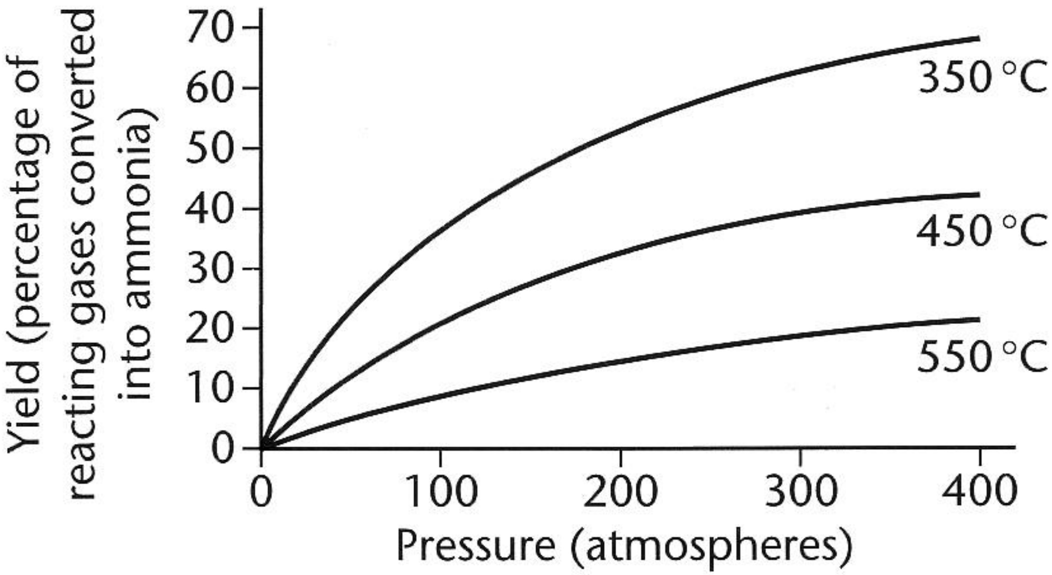
Industrial Manufacture of Ammonia – Haber Process



- Based upon the information provided in the graph, what conditions would you use to manufacture ammonia?
- Think about the *yield* of ammonia and the *rate* at which the ammonia is produced.

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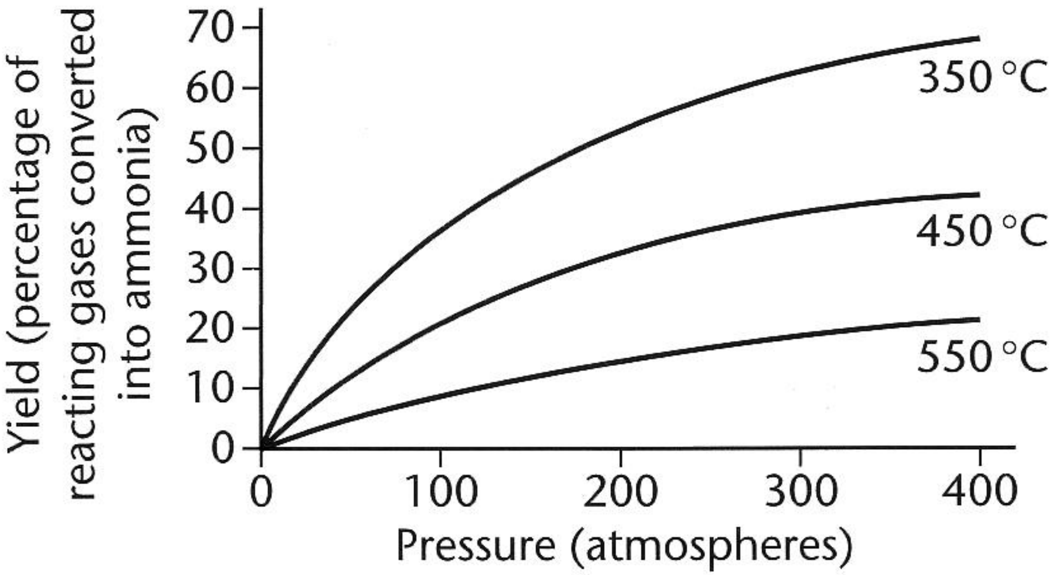

- What are the different consequences of using a *high temperature* or a *low temperature*?
- What are the different consequences of using a *high pressure* or a *low pressure*?

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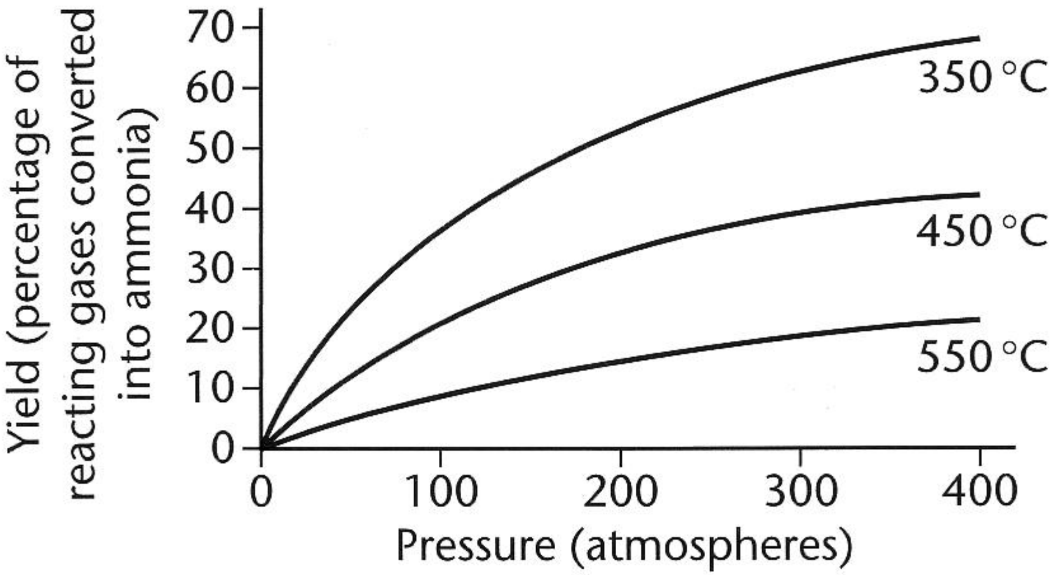

- A *low temperature* favours the production of ammonia, but if the temperature is too low, the *rate* at which the ammonia is formed is very *slow*. A temperature of *450 °C* is a compromise, giving a reasonably good yield of ammonia at an acceptable rate.

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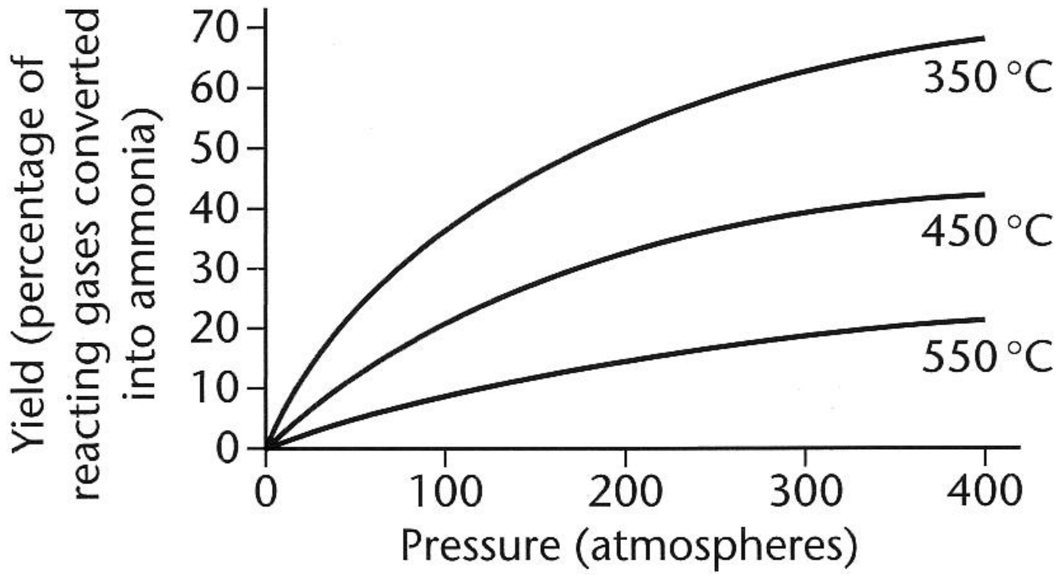

→ → → Low temperature favours the forward reaction → → →

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

←←← High temperature favours the backward reaction ←←←

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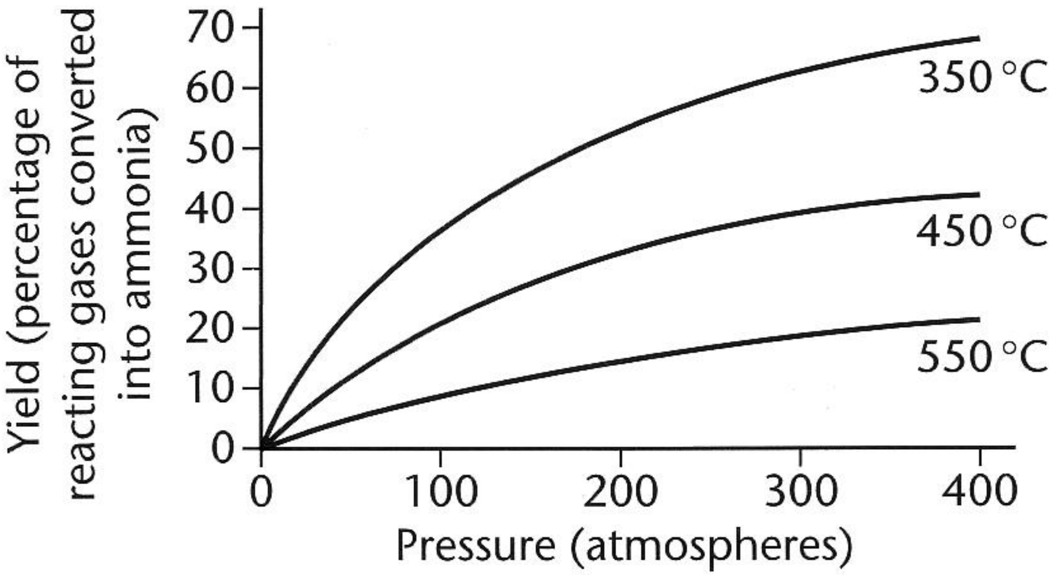

- A *high pressure* favours the production of ammonia, but using a very high pressure on an industrial scale is both expensive and potentially dangerous. A pressure of *250 atm.* is a compromise that gives a reasonably good yield of ammonia, that is both cost effective and relatively safe.

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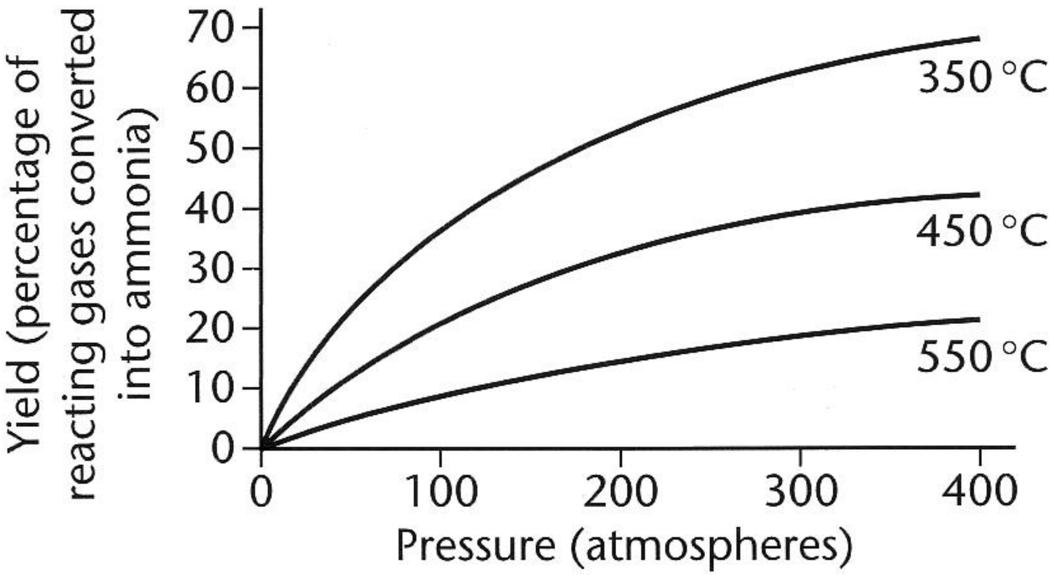

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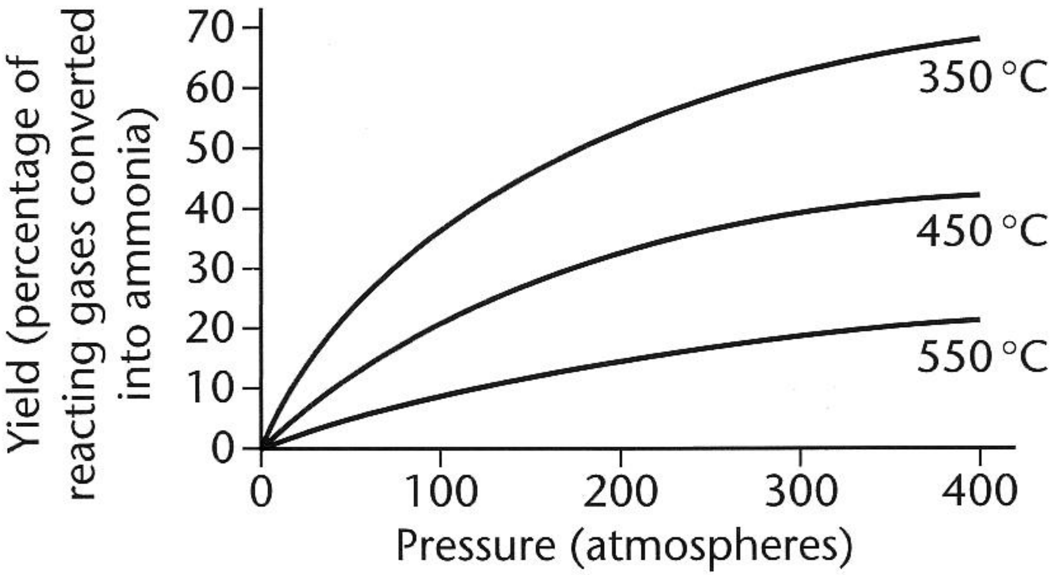

- Apart from *temperature* and *pressure*, what else might affect the yield of ammonia and / or the rate at which the ammonia is produced?

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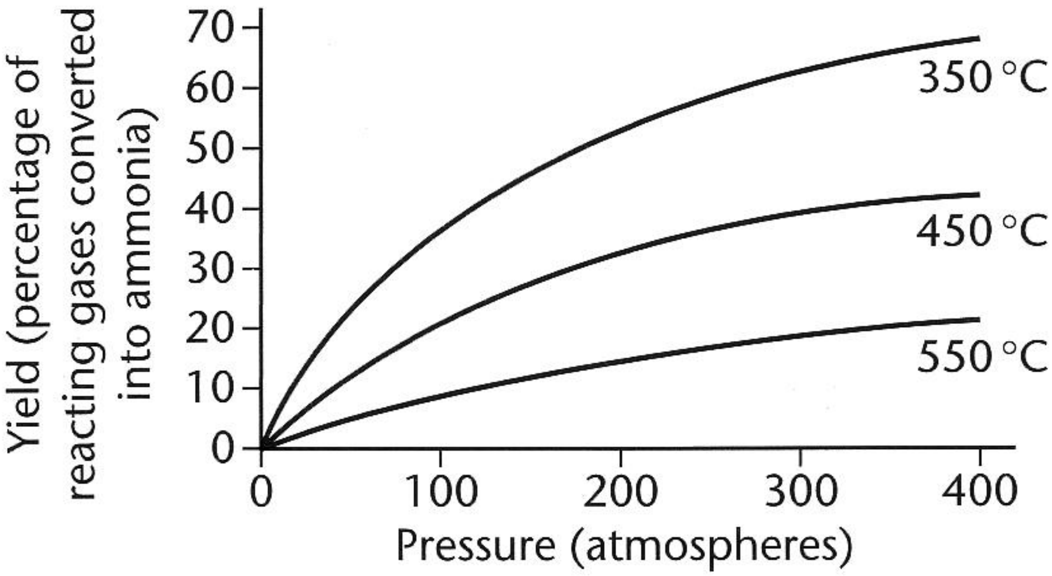

- To increase the rate at which nitrogen and hydrogen react to form ammonia, an *iron catalyst* is used. Note: a catalyst will only increase the *rate* of a chemical reaction, it will not affect the *yield* of the product that is formed.

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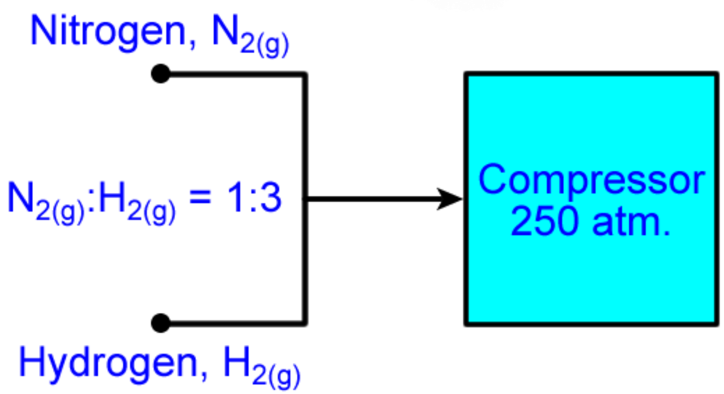
$$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$$



- According to the balanced chemical equation, *1 mol of nitrogen* reacts with *3 mol of hydrogen*, so the nitrogen and hydrogen are combined together in a ratio of *1:3*.

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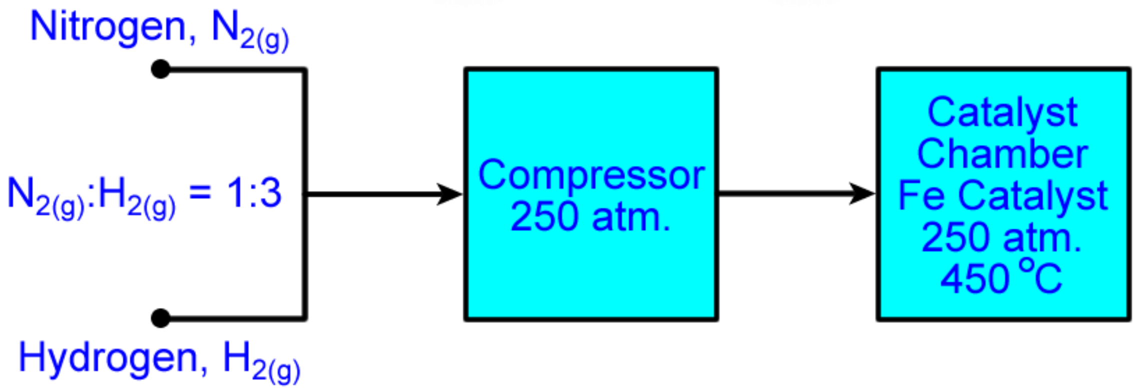
$$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$$



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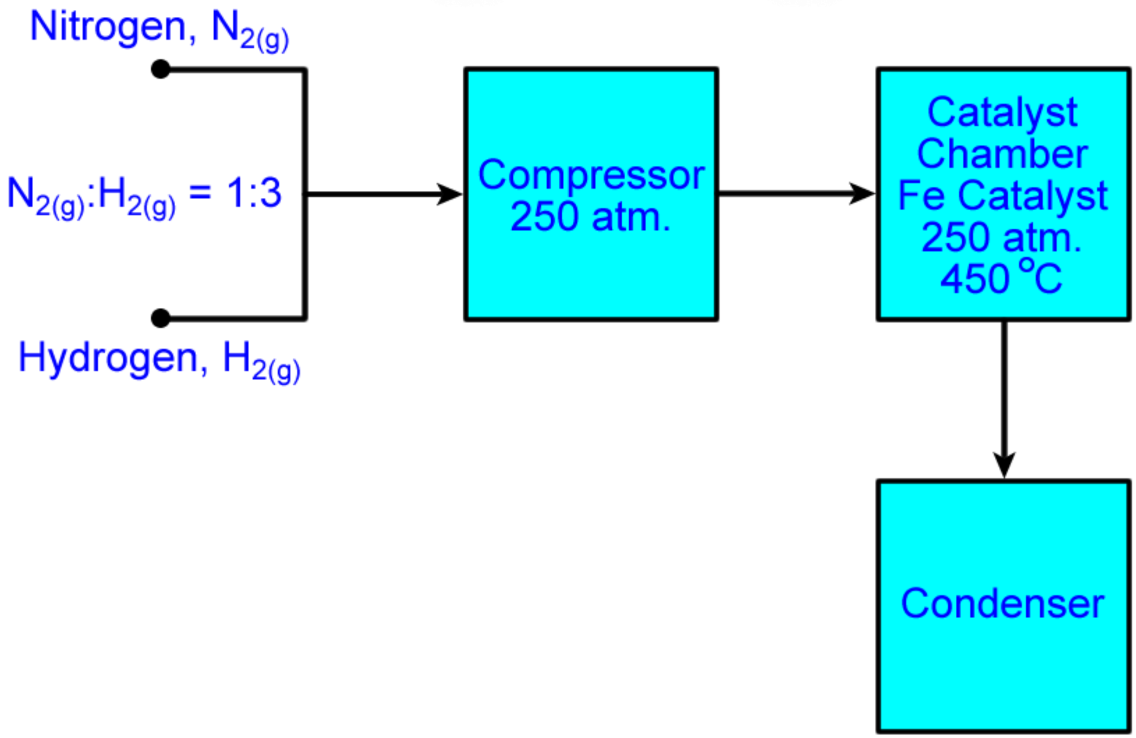

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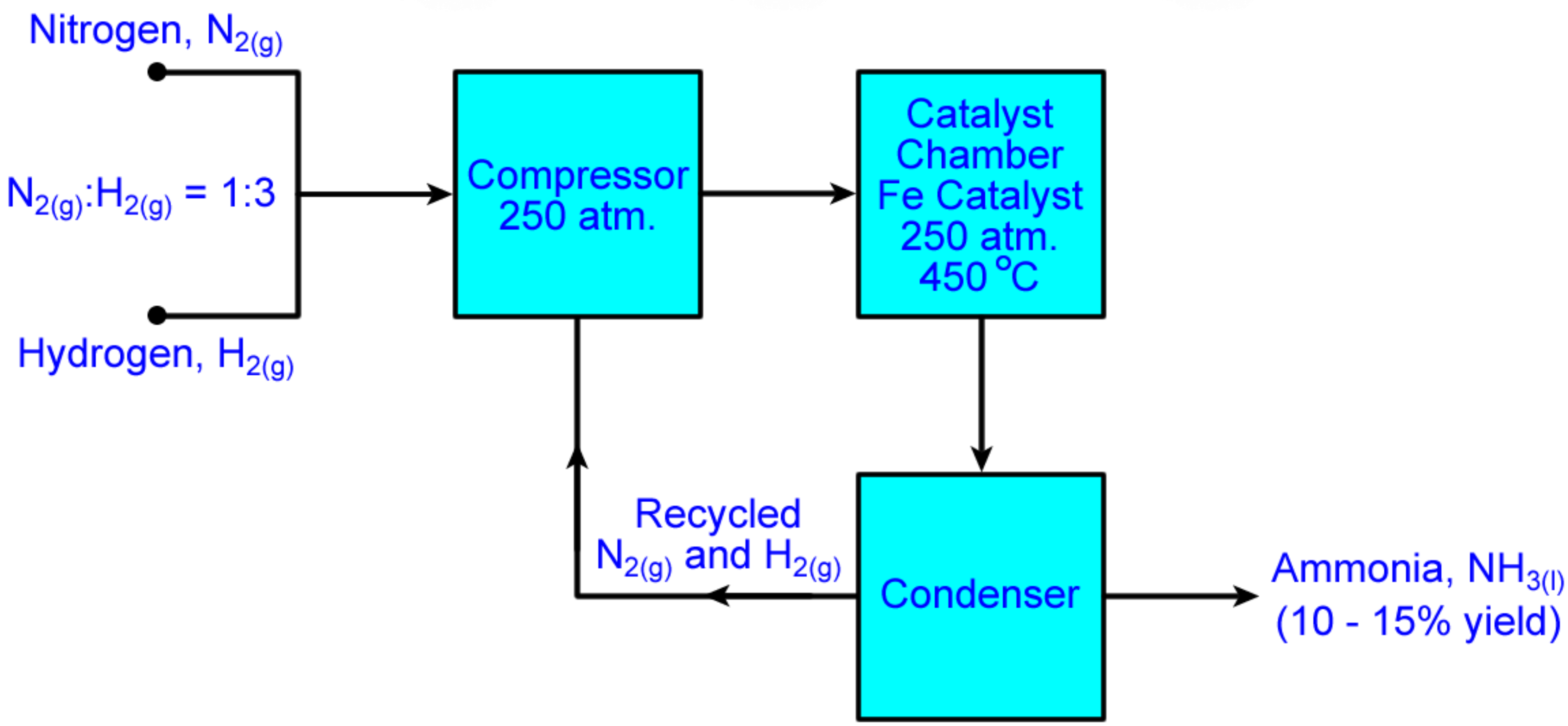

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Industrial Manufacture of Ammonia – Haber Process

Summary

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

- Hydrogen is obtained from cracking hydrocarbons.
- Nitrogen is obtained from the fractional distillation of liquefied air.
- Catalyst = Iron
- Temperature = 450 °C
- Pressure = 250 atm.

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How can I prepare a small sample of ammonia in the laboratory?

- The displacement of ammonia from ammonium salts.

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ammonium salt + alkali → salt + water + ammonia

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ammonium salt + alkali $\rightarrow$ salt + water + ammonia

ammonium chloride + calcium hydroxide

$\downarrow$

Acids, Bases and Salts

ammonium salt + alkali $\rightarrow$ salt + water + ammonia

ammonium chloride + calcium hydroxide

$\downarrow$

calcium chloride + water + ammonia

$$2NH_4Cl_{(aq)} + Ca(OH)_{2(s)} \rightarrow CaCl_{2(aq)} + 2H_2O_{(l)} + 2NH_{3(g)}$$

Acids, Bases and Salts

ammonium salt + alkali → salt + water + ammonia

ammonium chloride + calcium hydroxide

↓

calcium chloride + water + ammonia

$$2NH_4Cl_{(aq)} + Ca(OH)_{2(s)} \rightarrow CaCl_{2(aq)} + 2H_2O_{(l)} + 2NH_{3(g)}$$

ammonium sulfate + sodium hydroxide

↓

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ammonium salt + alkali → salt + water + ammonia

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calcium chloride + water + ammonia

$$2NH_4Cl_{(aq)} + Ca(OH)_{2(s)} \rightarrow CaCl_{2(aq)} + 2H_2O_{(l)} + 2NH_{3(g)}$$

ammonium sulfate + sodium hydroxide

↓

sodium sulfate + water + ammonia

$$(NH_4)_2SO_{4(aq)} + 2NaOH_{(s)} \rightarrow Na_2SO_{4(aq)} + 2H_2O_{(l)} + 2NH_{3(g)}$$

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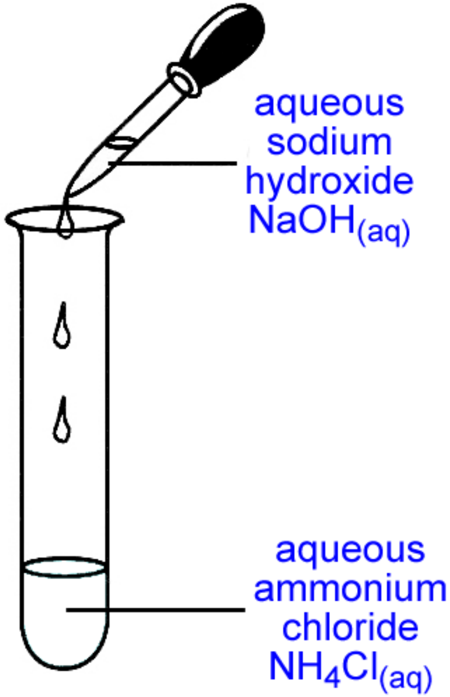
ammonium salt + alkali → salt + water + ammonia



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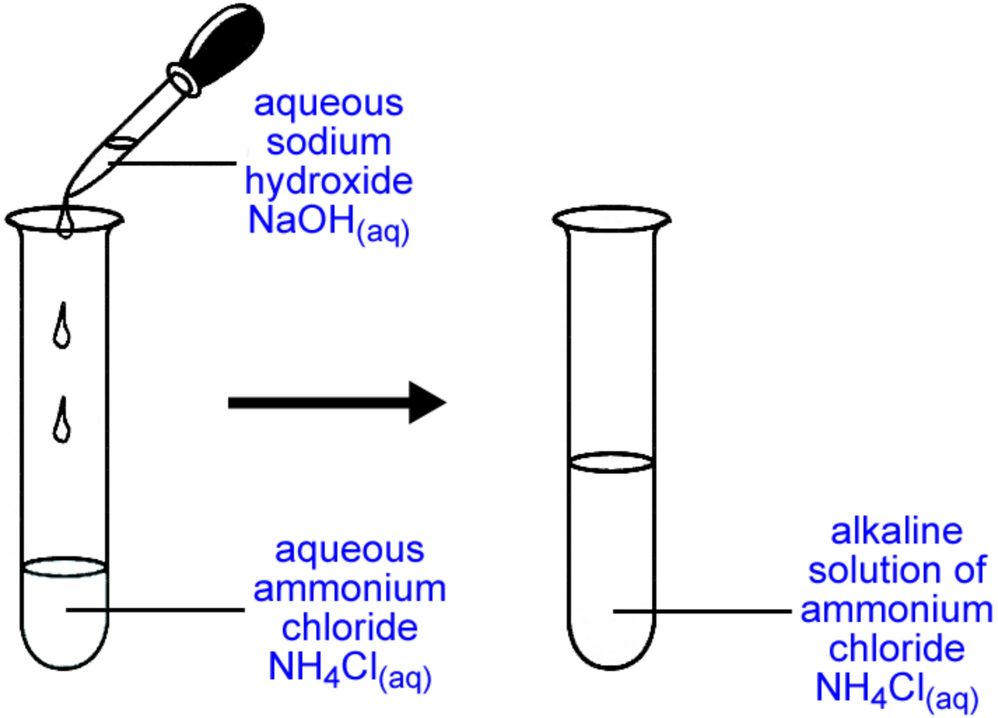

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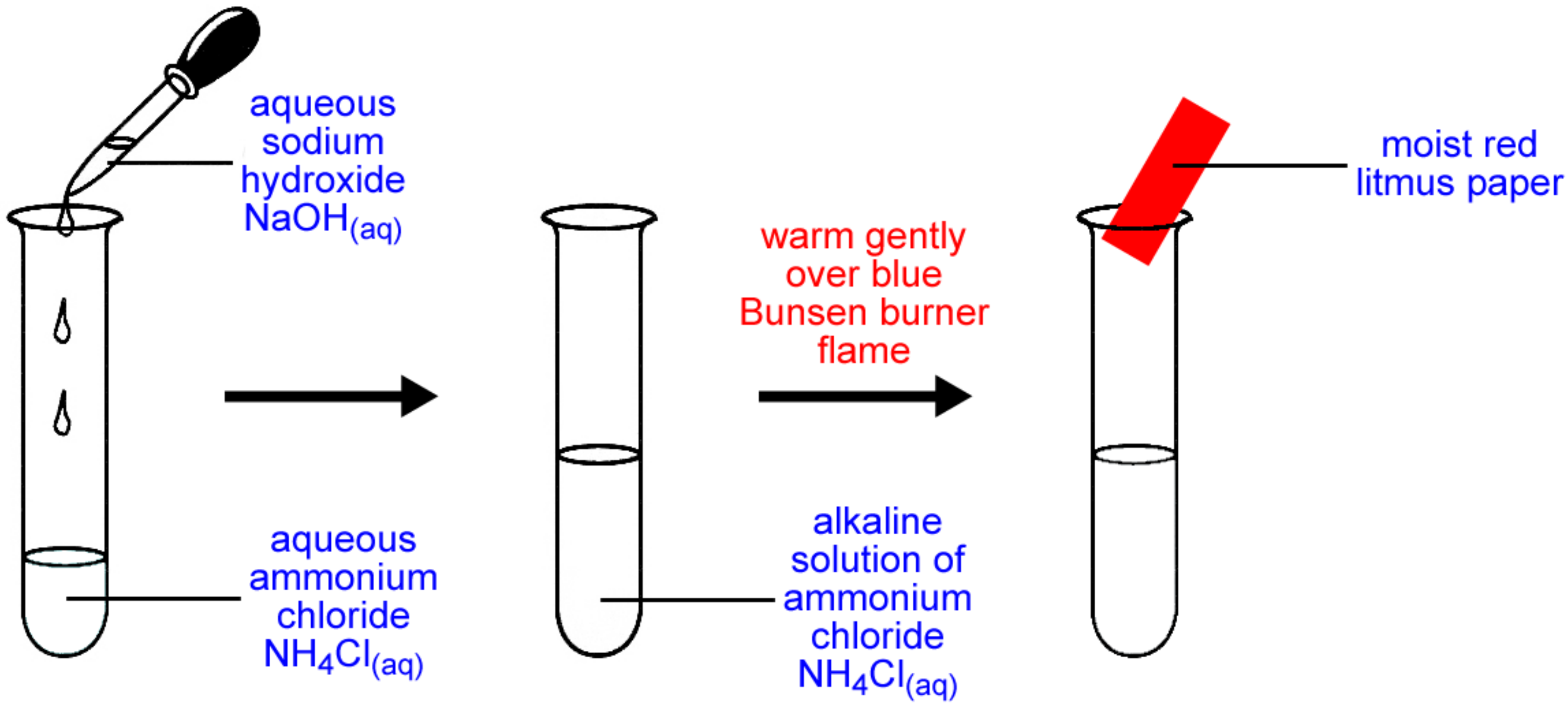
ammonium salt + alkali → salt + water + ammonia



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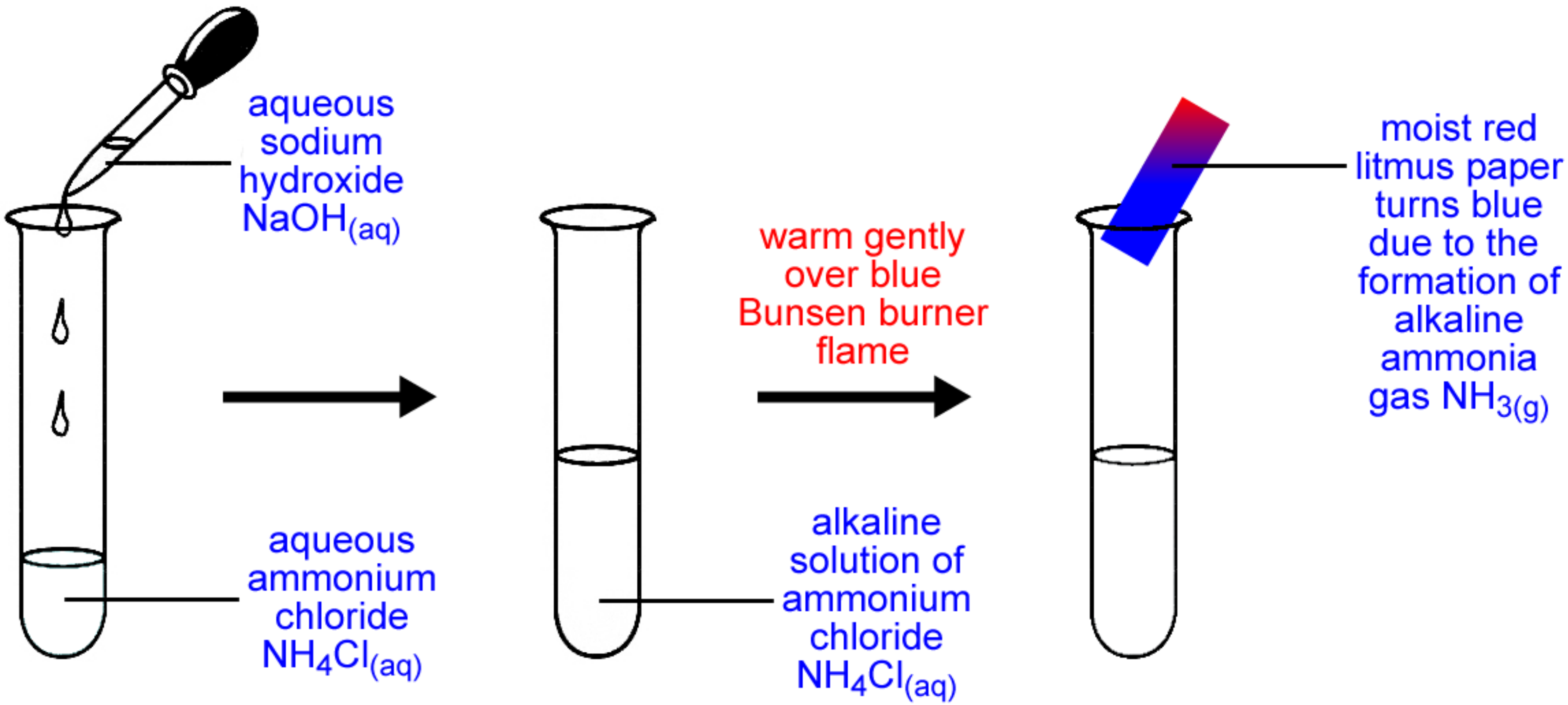
ammonium salt + alkali → salt + water + ammonia



Ammonium Chloride + Sodium Hydroxide → Sodium Chloride + Water + Ammonia

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

$$NH_4{}^+{}_{(aq)} + OH^-{}_{(aq)} \rightarrow H_2O_{(l)} + NH_{3(g)}$$

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Presentation on

the Manufacture of Ammonia

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