

The Haber Process & NPK Fertiliser Notes

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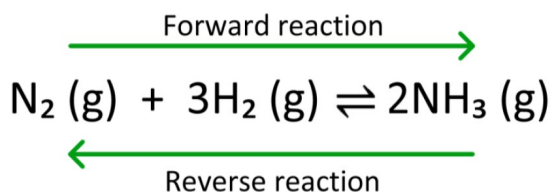
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The Haber Process

What is the Haber process? It's the reaction of nitrogen gas and hydrogen gas to give ammonia gas, NH_3 .

Why is it called the Haber process? It's named after the man who developed it, Fritz Haber.

Equation for the Haber process:



Where do we get the raw materials for the Haber process?

1. Nitrogen gas, $\text{N}_2 (\text{g})$, is obtained by the fractional distillation of liquid air.
2. Hydrogen gas, $\text{H}_2 (\text{g})$, can be made from natural gas/methane.

What are the conditions for Haber process?

Temperature: 450 °C.

Pressure: 200 atmospheres.

Catalyst: Finely divided/powdered iron.

What is the ammonia made used for? The main use of ammonia is to make ammonium nitrate which is widely used as a fertiliser to promote plant growth.

To get the best possible yield of ammonia, the conditions of the reaction must be controlled carefully. The conditions needed to obtain the best yield can be predicted using **Le Chatelier's Principle**.

Le Chatelier's Principle states that:

The position of equilibrium will shift so as to minimise the effect of any change in conditions.

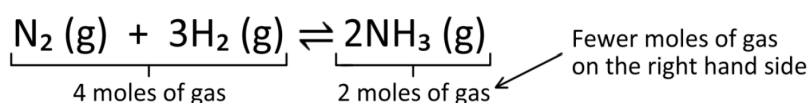
In simpler terms, if a change is made to a system at equilibrium, the position of equilibrium will move to counteract the change that was made. For the OCR A GCSE we can be asked how changing the **pressure**, **temperature** and **concentration** can affect the position of equilibrium.

Changing the Pressure

How does changing the pressure affect the position of equilibrium? If the pressure is increased, the equilibrium position moves to the side of the equation with fewer moles. Do not say the side with less moles, say fewer.

There are **fewer** moles of gas on the right-hand side of the Haber process. So, by Le Chatelier's Principle, if the pressure of the reaction mixture is increased, the equilibrium will shift to the right to minimise the increase in pressure.

Equation for the Haber process:

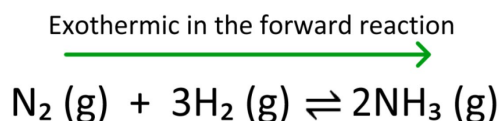


If the pressure is as high as possible, we get the best yield of ammonia. However, this high pressure can be dangerous. So, we use a compromise pressure of 200 atmospheres. This ensures a good enough yield in a fast-enough time.

Changing the Temperature

How does changing the temperature affect the position of equilibrium? By Le Chatelier's Principle, if the temperature of the equilibrium mixture is decreased in an exothermic reaction the equilibrium will shift to the right to minimise the decrease in temperature.

In a reversible reaction, if the reaction is exothermic in one direction, it is endothermic in the other direction. If the temperature is increased, the equilibrium position moves in the direction of the endothermic process (i.e. the left)



If the temperature is as low as possible, we get the best yield of ammonia. However, the rate of reaction is too low. So, we use a compromise temperature of 450 °C. This ensures a good enough yield in a fast-enough time.

Changing the Concentration

If the concentration of a reactant (on the left) is increased, the equilibrium position moves in the direction away from this reactant, and so more of the products are produced (on the right). If one of the products is removed from a reaction (on the right), then the position of equilibrium moves to the right to make more of that product.

Presence of a Catalyst

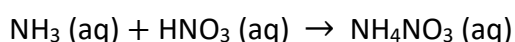
How does adding a catalyst affect the position of equilibrium? It doesn't! This question is a trap. They want to catch you out and get you to say it shifts left or right. Both are incorrect. A catalyst does not alter the position of an equilibrium, but does speed up the rate at which equilibrium is reached.

This is because it speeds up both forward and reverse reactions equally. This means that a lower temperature can be used for a given rate of reaction and this will result in a higher yield. The catalyst used is finely divided iron.

Fertilisers

The main use of ammonia is to make ammonium compounds (by reaction with acids) which are widely used as fertilisers to promote plant growth. The equation below shows the reaction of ammonia and nitric acid to produce ammonium nitrate.

ammonia + nitric acid → ammonium nitrate



NPK fertilisers: are fertilisers that contain nitrogen compounds (ammonium ions, NH_4^+ , and nitrate ions, NO_3^-), phosphorus ions (phosphate ions, PO_4^{3-}) and potassium ions (K^+). Both of these can be mined from rocks.

Questions on these fertilisers tend to focus on applying them. You could be presented with a scenario where a farmer is trying to decide which fertiliser (out of two or three) they should buy. You must read the information given and decide which fertiliser is best for a particular crop.

What are the advantages of NPK fertilisers?

1. **Increased crop yield** – this is the main benefit. Fertilisers provide the essential nutrients (Nitrogen, Phosphorus, Potassium) that plants need for good growth.
2. **They are reliable and have consistent nutrients** – this allows farmers to apply exactly what the soil needs for a specific crop.
3. **They are easy to store and transport.**

Are there disadvantages of NPK fertilisers? A few...

1. **They can cause eutrophication** – if washed into rivers and lakes this can cause an algal bloom, which blocks sunlight, leading to the death of underwater plants. Bacteria then decompose the dead plants, using up all the oxygen in the water and killing fish and other aquatic animals.
2. **High energy cost** – a huge amount of energy is needed with can increase the cost of fertilisers.

The Contact Process

The Contact process is a really useful chemical reaction, it's the reaction to produce sulfuric acid H_2SO_4 and H_2SO_4 is heavily used by the chemical industry.

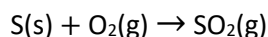
Exam note: questions about the Contact Process tend to come up as application questions. Examiners love to give students the equations for the Contact Process in the exam and ask them to apply their knowledge of Le Chatelier's principle to it, just like they do with the Haber process.

With this in mind, let's go through the Contact process 😊

The Contact process itself happens in three stages. Let's look at each one.

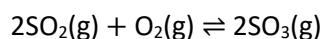
Stage 1: Making sulfur dioxide.

First, we need to make sulfur dioxide. We do this by burning sulfur in oxygen (from the air).



Stage 2: Making sulfur trioxide.

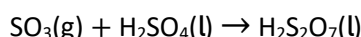
This is the most important step for your exams as this is the reversible stage. The sulfur dioxide is reacted with more oxygen to make sulfur trioxide. This is a reversible reaction, which means it reaches a dynamic equilibrium.



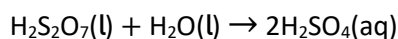
Note: The forward reaction is exothermic.

Stage 3: Making the sulfuric acid.

You might think we just add water to the sulfur trioxide. We don't! Adding water directly to SO_3 is a highly exothermic reaction that produces a highly dangerous, uncontrollable acidic mist. So, we avoid that one! Instead, we dissolve the SO_3 into concentrated sulfuric acid to make a thick liquid called oleum.



Then, we safely add water to the oleum to produce twice as much concentrated sulfuric acid!



The Conditions of the Contact Process

Just like the Haber process, we need to use Le Chatelier's Principle to choose the best conditions for Stage 2 to get the highest yield of sulfur trioxide for the lowest cost.

Temperature: 450 °C.

Pressure: 2 atmospheres.

Catalyst: Vanadium(V) oxide (V_2O_5)

Why these specific conditions? Exam questions love to ask you to explain these!

- Temperature (450 °C)** – the forward reaction is exothermic. So, by Le Chatelier's principle, decreasing the temperature would shift the equilibrium to the right, giving a higher yield. However, a low temperature makes the rate of reaction far too slow. So, 450 °C is used as a compromise temperature to get a good enough yield in a fast-enough time.
- Pressure (2 atmospheres)** – High pressure would increase the yield (as there are fewer moles of gas on the right). But, the yield is already 99% at just 2 atmospheres! Because high-pressure equipment is dangerous and expensive, increasing the pressure simply isn't worth the extra cost.
- Catalyst (Vanadium(V) oxide)** – just like in the Haber process, the catalyst does not change the position of the equilibrium or increase the yield. It simply speeds up both the forward and reverse reactions equally, meaning the reaction reaches equilibrium much faster.

Exam hint: we must learn the name of the catalyst! In the Haber process it is iron, but in the Contact process it is Vanadium(V) oxide. Don't get them mixed up 😊.