

Reactions that go both ways

Chemistry grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · Lesson

Quick answer: A reversible reaction can go in both directions, and in a closed system it reaches dynamic equilibrium when the forward and reverse rates are equal and concentrations stay constant. Le Chatelier's principle says the equilibrium shifts to oppose any change. The Haber process makes ammonia from nitrogen and hydrogen using compromise conditions.

Level: Chemistry grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · **Curriculum:** HS-PS1-6

What is a reversible reaction?

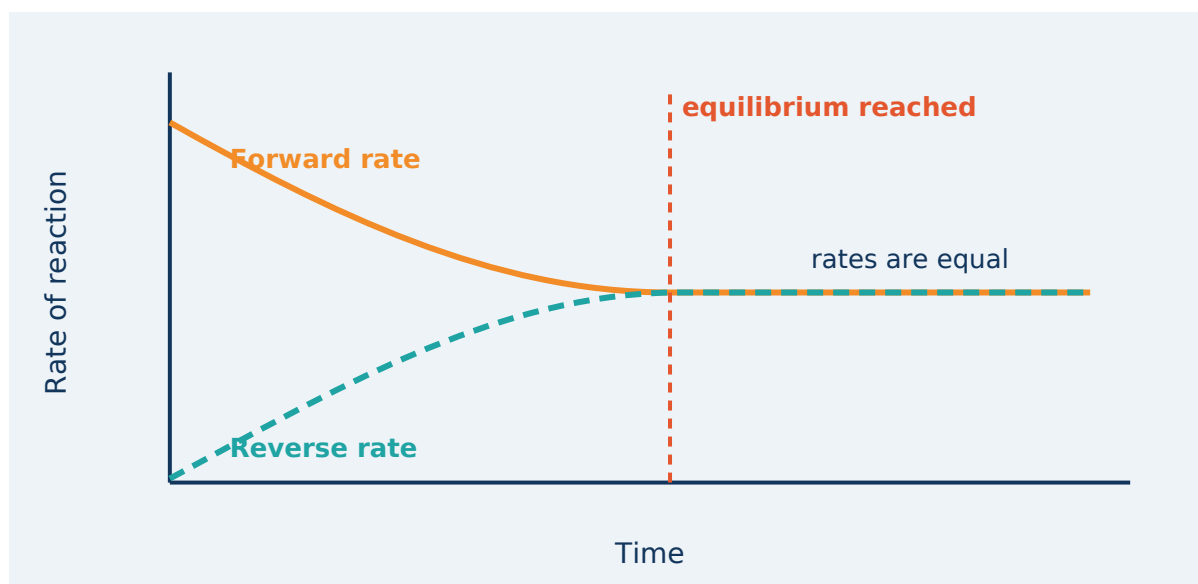
Many reactions go only one way: once a candle has burned, you cannot turn the gases back into wax. But some reactions can run in both directions. Heat blue hydrated copper(II) sulfate and it turns white, giving off water. Add water to the white powder and it turns blue again. Chemists show this with a double arrow: $\text{CuSO}_4 \cdot 5\text{H}_2\text{O} \rightleftharpoons \text{CuSO}_4 + 5\text{H}_2\text{O}$.

Definition

A **reversible reaction** is one in which the products can react to form the reactants again. In a **closed system**, a reversible reaction reaches **dynamic equilibrium**: the forward and reverse reactions both continue at the same rate, so the concentrations stop changing.

What does dynamic equilibrium mean?

At first only the forward reaction happens, and it is fast. As products build up, the reverse reaction begins and speeds up while the forward rate slows. Eventually the two rates are equal. Nothing seems to change, but particles are still reacting in both directions, which is why the equilibrium is *dynamic*.



At equilibrium the forward and reverse rates are equal.

Common mistake

Equilibrium does not mean equal amounts of reactants and products, and it does not mean the reaction has stopped. The amounts stay constant because the forward and reverse rates are equal. The system must also be closed, or gases can escape and equilibrium is never reached.

What is Le Chatelier's principle?

Key law

Le Chatelier's principle: if a change is made to a system at equilibrium, the position of equilibrium shifts to oppose the change.

Change made	Equilibrium shifts	Reason
Add a reactant	Towards the products	Uses up the extra reactant
Remove a product	Towards the products	Makes more product to replace it
Increase pressure	To the side with fewer gas molecules	Reduces the pressure
Increase temperature	In the endothermic direction	Absorbs the extra energy
Add a catalyst	No shift	Speeds up both directions equally

Worked example

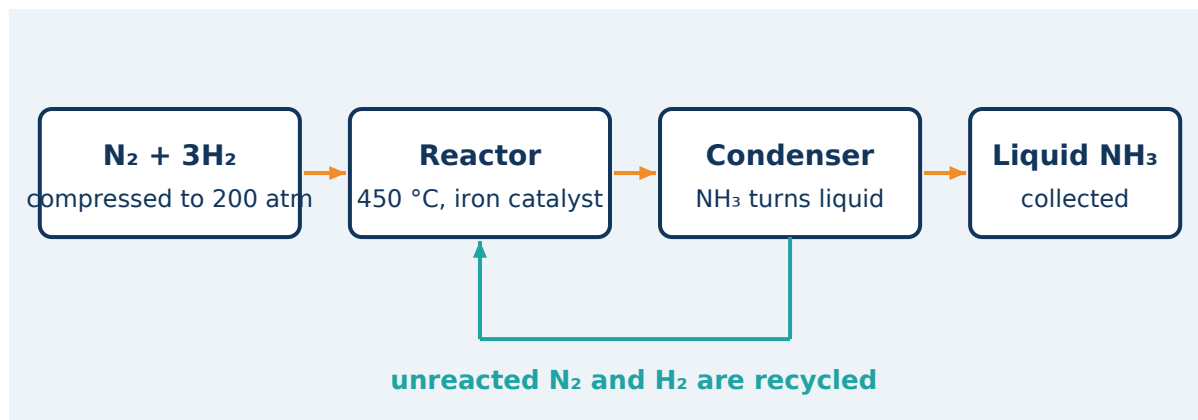
Predict the effect on the brown gas NO_2 in the reaction $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$, where the forward reaction is endothermic (colourless N_2O_4 , brown NO_2).

Heating favours the endothermic direction, so the equilibrium shifts right and the mixture turns **darker brown**. Raising the pressure favours the side with fewer gas molecules: 1

molecule on the left against 2 on the right, so it shifts left and the mixture turns **paler**.

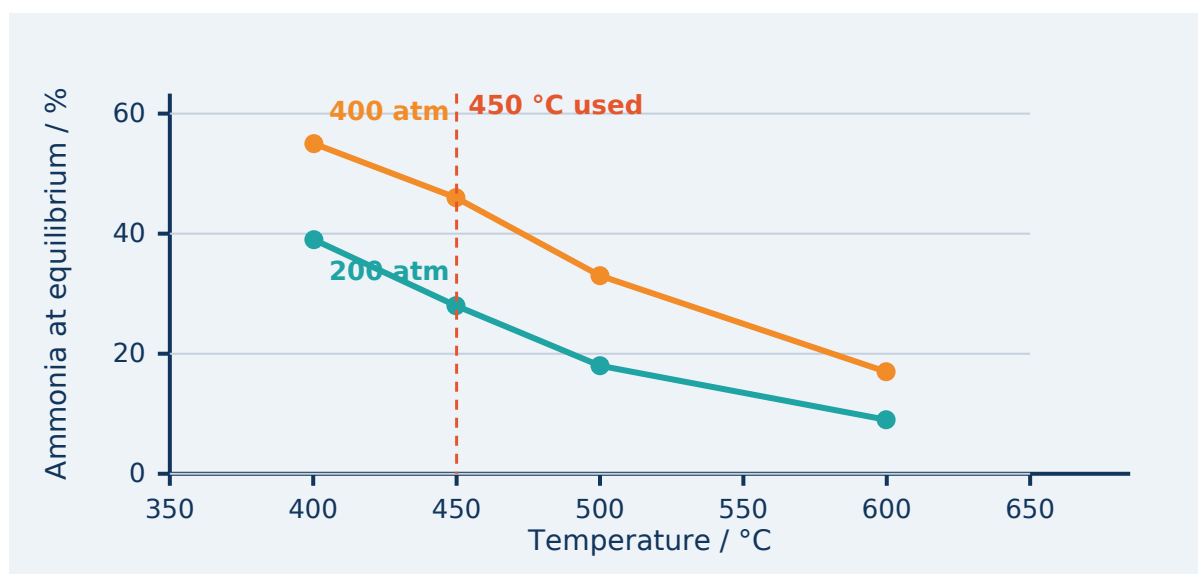
How is ammonia made in the Haber process?

Ammonia, used for fertilisers that feed crops from the Punjab to Kenya, is made from nitrogen (from the air) and hydrogen (from natural gas): $\text{N}_2 + 3\text{H}_2 \rightleftharpoons 2\text{NH}_3$. The forward reaction is exothermic ($\Delta H = -92 \text{ kJ/mol}$) and reduces the number of gas molecules from 4 to 2.



The Haber process loop: unreacted gases are recycled.

Le Chatelier suggests a low temperature and a high pressure would give the most ammonia. In industry the conditions are a compromise. Cold conditions make the reaction far too slow, so a temperature of about 450 °C and an iron catalyst give a reasonable rate. A very high pressure needs thick pipes and costly compressors, so about 200 atm is used. Only a fraction of the gases turns into ammonia on each pass; the ammonia is cooled until it turns liquid and the unreacted nitrogen and hydrogen are recycled.



Typical equilibrium yields: higher temperature lowers the yield, higher pressure raises it.

Worked example

A reactor holds 100 mol of N_2 and 300 mol of H_2 . At equilibrium 25% of the nitrogen has reacted. Find the amounts present and the percentage of ammonia in the mixture.

N_2 reacted = 25 mol, so N_2 left = 75 mol. H_2 reacted = $3 \times 25 = 75$ mol, so H_2 left = 225

mol. NH_3 formed = $2 \times 25 = 50$ mol. Total = $75 + 225 + 50 = 350$ mol, so $\text{NH}_3 = 50 \div 350 \times 100 = 14.3\%$.

Lina's tip

Check three things in every prediction: count the gas molecules on each side for pressure, look at the sign of ΔH for temperature, and remember that a catalyst never moves the position, it only gets there sooner.

Key points to remember

- Reversible reactions are shown with $\rightleftharpoons$ and reach equilibrium only in a closed system
- At equilibrium the forward and reverse rates are equal; concentrations are constant, not equal
- Le Chatelier: the equilibrium shifts to oppose the change made
- Higher pressure favours fewer gas molecules; heating favours the endothermic direction
- Haber process: $\text{N}_2 + 3\text{H}_2 \rightleftharpoons 2\text{NH}_3$, 450 °C, 200 atm, iron catalyst, recycle

Reactions that go both ways: frequently asked questions

What does dynamic equilibrium mean?

Both the forward and the reverse reactions keep happening at the same rate, so the amounts of reactants and products stay constant. The reaction has not stopped; it is balanced.

Does a catalyst change the position of equilibrium?

No. A catalyst speeds up the forward and the reverse reaction equally, so equilibrium is reached sooner but the amounts at equilibrium are the same.

Why is the Haber process run at 450 °C instead of a low temperature?

A low temperature gives a better yield of ammonia but the reaction is too slow. About 450 °C with an iron catalyst is a compromise between a reasonable yield and a fast rate.

How does pressure affect an equilibrium?

Raising the pressure shifts the equilibrium to the side with fewer gas molecules. In the Haber process there are 4 molecules on the left and 2 on the right, so higher pressure gives more ammonia.

Why is the unreacted gas recycled in the Haber process?

Only a fraction of the nitrogen and hydrogen reacts on each pass through the reactor. Recycling the rest saves raw materials and increases the overall yield.