

Nitrogen and sulfur

A-Level Chemistry

Why nitrogen is unreactive

Nitrogen gas, N_2 , makes up most of the air but reacts with very little. There are two reasons:

- the two nitrogen atoms are joined by a **triple bond** 三键, which has a very high **bond energy** 键能. A lot of energy is needed to break it.
- the molecule has no **polarity** 极性—it is perfectly symmetrical, so nothing pulls other molecules towards it.



strong triple bond: very high
bond energy $\Rightarrow$ hard to break

symmetrical molecule $\Rightarrow$ no polarity $\Rightarrow$ nothing pulls it into a reaction

Nitrogen is unreactive for two reasons: a very strong triple bond, and a symmetrical, non-polar molecule

Ammonia and the ammonium ion

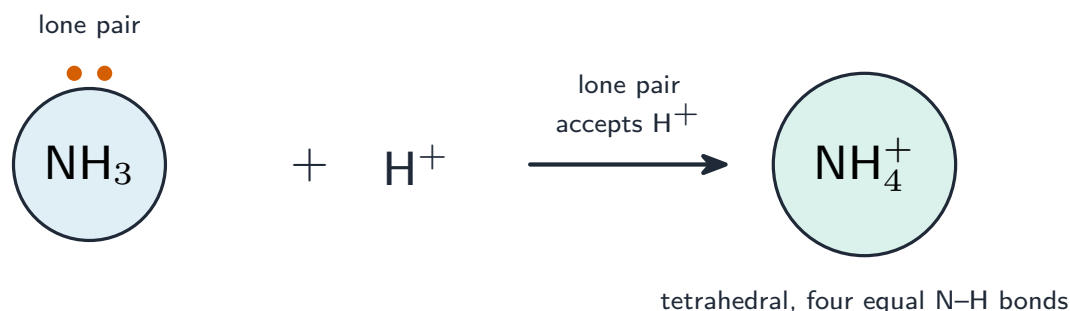
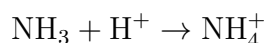


Ammonia is converted into nitrogen fertilisers in industrial plants on a huge scale.

Image: M J Richardson, CC BY-SA 2.0 (commons.wikimedia.org)

Basicity of ammonia

The **basicity** 碱性 of ammonia (its ability to act as a base) comes from the **lone pair** 孤对电子 of electrons on the nitrogen atom. Using the Brønsted–Lowry theory, ammonia is a base because this lone pair can accept a **proton** 质子 (H^+):



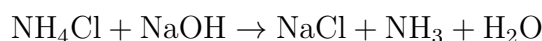
Ammonia acts as a base because the lone pair on its nitrogen accepts a proton, making the ammonium ion

The ammonium ion

When the lone pair forms a bond to H^+ , it makes the **ammonium ion** 铵离子, NH_4^+ . Because both shared electrons came from the nitrogen, this new bond is a **coordinate bond** 配位键. The ion has four identical N–H bonds and a tetrahedral shape.

Displacement of ammonia from its salts

If you warm an ammonium salt with a base (such as sodium hydroxide), you push out ammonia gas. This is an acid–base **displacement** 置换:



The sharp smell of ammonia, and damp red litmus turning blue, is a test for an ammonium salt.

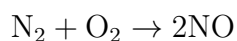
Oxides of nitrogen and air pollution

Where they come from

Oxides of nitrogen (NO and NO_2 , together called NO_x) come from two sources:

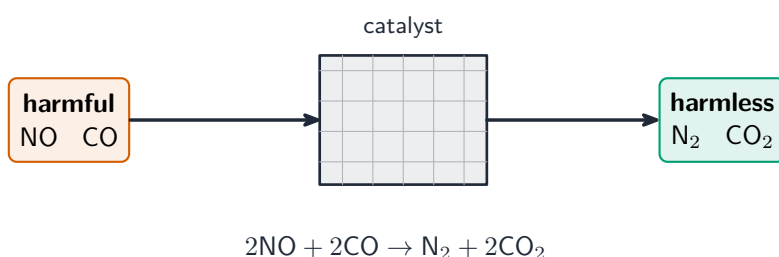
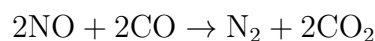
- **natural**: lightning gives enough energy for nitrogen and oxygen in the air to combine.

- **man-made:** the high temperature inside an **internal combustion engine** 内燃机 makes nitrogen and oxygen react:



Removing them from car exhaust

A **catalytic converter** 催化转化器 cleans the **exhaust gases** 尾气. It lets the harmful gases react together to form harmless ones:



In a catalytic converter the harmful gases NO and CO react over the catalyst to form harmless N₂ and CO₂

Photochemical smog

In sunlight, NO and NO₂ react with unburned **hydrocarbons** to form peroxyacetyl nitrate (PAN). PAN is a harmful part of **photochemical smog** 光化学烟雾, the brown haze seen over busy cities.



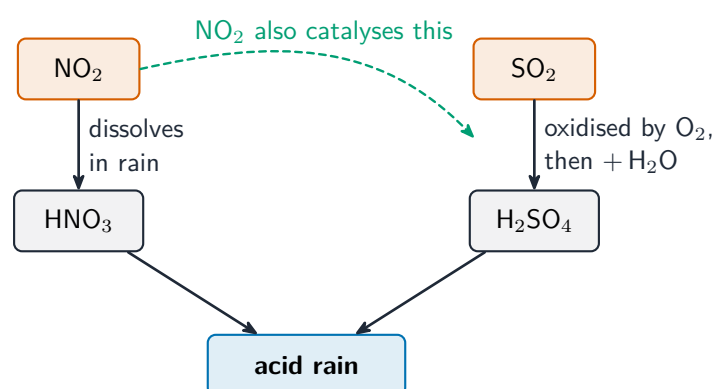
Photochemical smog over a big city. The brown layer is trapped low down, exactly where the traffic fumes are —sunlight turns those nitrogen oxides and unburned hydrocarbons into the haze you can see

Image: Creator:Fidel Gonzalez, CC BY-SA 3.0 (commons.wikimedia.org)

Acid rain

The oxides of nitrogen also help make **acid rain** 酸雨 in two ways:

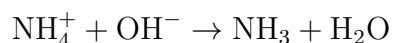
- directly: NO_2 dissolves in rain to form nitric acid.
- as a catalyst: NO_2 speeds up the oxidation of atmospheric **sulfur dioxide** 二氧化硫 (SO_2) into SO_3 , which then forms sulfuric acid in the rain.



Nitrogen and sulfur oxides make acid rain: NO_2 forms nitric acid directly and also catalyses the oxidation of SO_2 to sulfuric acid

Worked example. A white solid is warmed with aqueous NaOH , and a gas is released that turns damp red litmus blue. Identify the gas and the ion in the solid, and explain the reaction. The only common gas that turns damp red litmus **blue** is **ammonia**, NH_3 ,

so the solid contains the **ammonium ion**, NH_4^+ . The hydroxide ion is the stronger base, so it takes the proton back from the ammonium ion:



This is the standard test for NH_4^+ . Always say the litmus is **damp**: the ammonia must dissolve in the water before it can show its basicity, so dry litmus would give no colour change at all.

Exam tips

- N_2 is unreactive because of its **strong triple bond** (very high bond energy) —state this exactly.
- **Ammonia** is a base and a ligand because of its **lone pair**; the ammonium ion forms by a dative bond.
- Explain how **oxides of nitrogen** form (high temperature in engines) and their link to acid rain and photochemical smog.
- Give balanced equations and correct observations for reactions of ammonia and the ammonium ion.