

Nitrogen and Sulfur

01 · WHY N₂ IS UNREACTIVE

The N≡N triple bond has a very high bond enthalpy (994 kJ mol⁻¹), so the activation energy for any reaction is large.

N₂ is also non-polar with no permanent dipole, so nothing attacks it readily. This is why 78 % of the air is chemically inert nitrogen.

02 · AMMONIA — SHAPE AND BASICITY

NH₃ is trigonal pyramidal, bond angle 107°, because the lone pair repels the three bonding pairs more strongly.

That **lone pair accepts a proton**, so ammonia is a Brønsted base: NH₃ + H⁺ → NH₄⁺. The resulting bond is dative covalent, and NH₄⁺ is tetrahedral at 109.5°.

03 · THE HABER PROCESS



Conditions ~450 °C, ~200 atm, iron catalyst. High pressure favours the side with fewer gas moles; the temperature is a compromise between yield and rate.

Ammonia is condensed out and unreacted gases recycled, so the overall conversion is far higher than the single-pass yield.

04 · AMMONIUM SALTS AND FERTILISERS

NH₃ + acid → ammonium salt: NH₃ + HNO₃ → NH₄NO₃, used as fertiliser because it supplies soluble nitrogen for protein synthesis.

Never mix an ammonium fertiliser with lime:

NH₄⁺ + OH⁻ → NH₃ + H₂O releases ammonia and wastes the nitrogen. Warming with NaOH and testing with damp red litmus is the test for NH₄⁺.

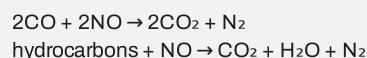
Excess fertiliser leaches into rivers and causes eutrophication.

05 · OXIDES OF NITROGEN

Formed in engines where the temperature is high enough to overcome the N≡N bond: N₂ + O₂ → 2NO, then 2NO + O₂ → 2NO₂.

NO₂ dissolves to give acid rain and, with unburnt hydrocarbons and sunlight, photochemical smog. NO also catalyses the oxidation of SO₂ to SO₃ in the atmosphere.

06 · CATALYTIC CONVERTERS



Pt/Rh on a honeycomb ceramic gives a huge surface area. The gases adsorb onto active sites, react and desorb.

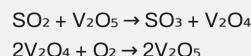
07 · THE CONTACT PROCESS



Conditions ~450 °C, ~2 atm, V₂O₅ catalyst. The yield is already about 96 %, so high pressure is not worth its cost.

SO₃ is absorbed into concentrated H₂SO₄ to give oleum, then diluted — adding SO₃ directly to water is dangerously violent.

08 · THE V₂O₅ CATALYST



Vanadium cycles between +5 and +4, which is why a transition metal makes a good catalyst: it can lend and take back electrons.

09 · SULFUR DIOXIDE AND ACID RAIN

SO₂ comes from burning sulfur-containing fossil fuels. SO₂ + H₂O → H₂SO₃, and oxidation gives H₂SO₄, both far stronger than the natural acidity of rain from dissolved CO₂.

Effects: limestone buildings eroded, lakes acidified, trees damaged. Control: flue-gas desulfurisation with CaO or CaCO₃, giving CaSO₃ which is oxidised to gypsum.

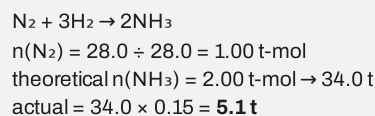
10 · USES OF SULFURIC ACID AND SO₂

H₂SO₄ — fertilisers, detergents, paints, and as the electrolyte in lead-acid batteries. It is the most produced industrial chemical by mass.

SO₂ — food preservative and bleach for paper, in both cases acting as a reducing agent that kills bacteria or destroys coloured compounds.

11 · WORKED EXAMPLE — HABER YIELD

28.0 t of N₂ reacts with excess H₂ and the yield is 15 %. What mass of NH₃ is formed?

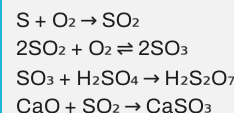
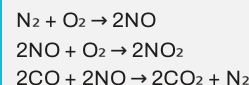
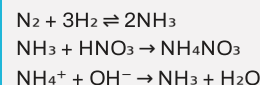


The unreacted gas is recycled, so the process yield is far higher than 15 % overall.

12 · TESTS TO KNOW

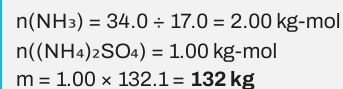
Test	Result
NH ₄ ⁺ + NaOH, warm	NH ₃ turns damp red litmus blue
SO ₄ ²⁻ + BaCl ₂ / HCl	white precipitate
SO ₂ + acidified Cr ₂ O ₇ ²⁻	orange → green

13 · EQUATIONS TO KNOW



14 · WORKED EXAMPLE — AMMONIA IN A FERTILISER

What mass of ammonium sulfate is made from 34.0 kg of ammonia?



Nitrogen content = 28.0 ÷ 132.1 × 100 = 21.2 %.

MARKS LOST HERE

— Saying N₂ is unreactive "because it is a gas" instead of quoting the strong triple bond and high E_a.

— Giving the Contact process a high pressure; it runs at about 2 atm.

— Writing SO₃ + H₂O as the industrial step; SO₃ is absorbed in H₂SO₄ first.

— Explaining ammonia's basicity without mentioning the lone pair.