FSc / ICS Part-II Chemistry — Punjab Board

CHAPTER 4

Group VA and Group VIA Elements

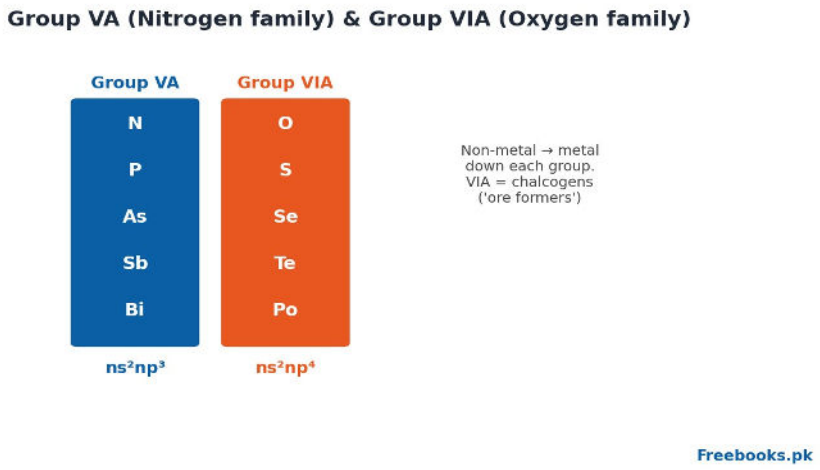

Figure 4.1 — Group VA (nitrogen family) and Group VIA (oxygen family / chalcogens).

1. Chapter Overview

This chapter covers Group VA — the nitrogen family (N, P, As, Sb, Bi) with outer configuration $ns^2\ np^3$ — and Group VIA — the oxygen family or chalcogens (O, S, Se, Te, Po) with $ns^2\ np^4$. Both groups begin with a typical non-metal at the top and become metallic towards the bottom. They contain elements essential to life and industry: nitrogen and phosphorus are the basis of fertilizers, while oxygen and sulphur are central to breathing, combustion and the manufacture of sulphuric acid — the 'king of chemicals'.

Two of the most important industrial processes in all of chemistry belong to this chapter: the Haber process for making ammonia and the Contact process for making sulphuric acid.

2. Learning Objectives

- List the members and configurations of Groups VA and VIA.
- Describe how metallic character and properties change down each group.
- Explain the manufacture of ammonia by the Haber process and its uses.
- Describe the oxides and oxoacids of nitrogen and sulphur.
- Explain the manufacture of sulphuric acid by the Contact process.
- Describe the allotropy of sulphur.
- Appreciate the importance of these elements in fertilizers and industry.

3. Key Concepts

3.1 The Two Families

Group	Name	Members
VA (ns^2np^3)	Nitrogen family (pnictogens)	N, P, As, Sb, Bi
VIA (ns^2np^4)	Oxygen family (chalcogens)	O, S, Se, Te, Po

In Group VA, nitrogen and phosphorus are non-metals, arsenic and antimony are metalloids, and bismuth is a metal. In Group VIA, oxygen, sulphur and selenium are non-metals, tellurium is a metalloid and polonium is a radioactive metal. In both groups metallic character increases down the group while the acidic strength of the oxides decreases.

> **Memory Trick**
> **VA order:** “Nanhe Papa Aaye Sab Bimar” → N, P, As, Sb, Bi.
> **VIA order:** “Oye Sona Send Tera Polo” → O, S, Se, Te, Po.

3.2 Nitrogen and the Haber Process

Nitrogen makes up about 78% of the air but is very unreactive because of the strong triple bond (N≡N) in the N_2 molecule. It is 'fixed' into useful compounds mainly as ammonia. Ammonia (NH_3)

is manufactured industrially by the Haber process, in which nitrogen and hydrogen combine over an iron catalyst under high pressure and moderate temperature:

Haber Process

Reaction: $N_2 + 3H_2 \rightleftharpoons 2NH_3$ (reversible, exothermic)

Conditions: ~200 atm pressure, ~450 °C, finely divided iron catalyst.

Le Chatelier: high pressure and moderate temperature favour a good yield; unreacted gases are recycled.

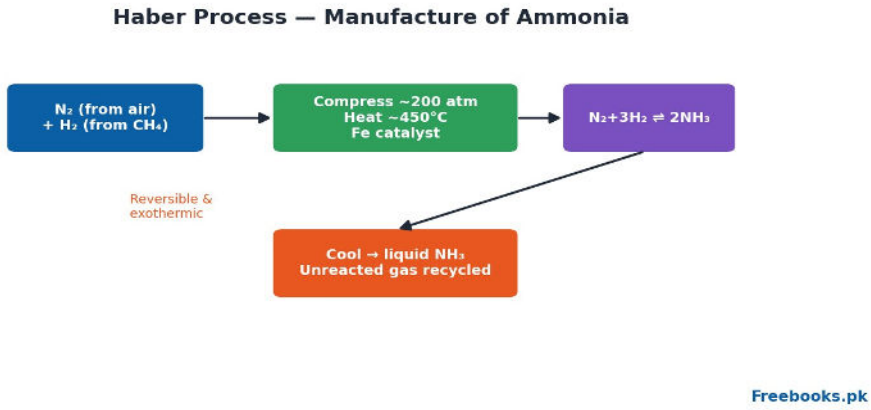

Figure 4.2 — The Haber process for ammonia.

Ammonia is used to make nitric acid, urea and ammonium fertilizers, and in the manufacture of nylon and explosives.

Teacher's Note

Students often ask why not use a very high temperature. Remind them the forward reaction is exothermic, so too high a temperature lowers the yield — 450 °C is a compromise between speed and yield.

3.3 Oxides and Oxoacids of Nitrogen

Nitrogen forms several oxides in which it shows oxidation states from +1 to +5, for example nitrous oxide (N_2O, 'laughing gas'), nitric oxide (NO) and nitrogen dioxide (NO_2, a brown gas). Its most important oxoacid is nitric acid (HNO_3), a strong acid and powerful oxidising agent made industrially by the Ostwald process (catalytic oxidation of ammonia).

3.4 The Oxygen Family and Allotropy of Sulphur

Oxygen is the most abundant element in the earth's crust and is essential for respiration and combustion. Sulphur is a yellow non-metal that shows allotropy: the two crystalline forms are rhombic (α) sulphur, stable at room temperature, and monoclinic (β) sulphur, stable above 96 °C. Both are made of S_8 puckered-ring molecules.

3.5 Sulphuric Acid and the Contact Process

Sulphuric acid (H_2SO_4) is called the 'king of chemicals' because it is used in so many industries. It is manufactured by the Contact process in three main stages: burning sulphur to sulphur dioxide, oxidising SO_2 to SO_3 over a vanadium(V) oxide catalyst, and absorbing SO_3 in concentrated sulphuric acid to form oleum, which is then diluted.

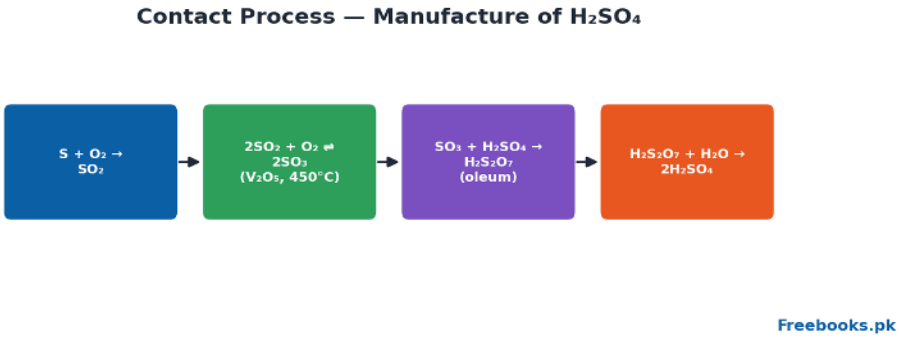

Figure 4.3 — The Contact process for sulphuric acid.

Contact Process — Key Reactions

1. $S + O_2 \rightarrow SO_2$

2. $2SO_2 + O_2 \rightleftharpoons 2SO_3$ (V_2O_5 catalyst, ~450 °C)

3. $SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$ (oleum)

4. $H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$

Concentrated sulphuric acid is a strong acid, a dehydrating agent (it removes water, e.g. it chars sugar) and an oxidising agent. It is used to make fertilizers, detergents, paints, batteries and many other chemicals.

4. Important Definitions

Term	Definition
Nitrogen fixation	The conversion of atmospheric N_2 into useful nitrogen compounds such as ammonia.
Haber process	Industrial manufacture of ammonia from N_2 and H_2 over an iron catalyst.
Contact process	Industrial manufacture of sulphuric acid using a V_2O_5 catalyst.
Allotropy	Existence of an element in two or more physical forms (e.g. rhombic and monoclinic sulphur).
Oleum	Fuming sulphuric acid, $H_2S_2O_7$, formed when SO_3 dissolves in H_2SO_4.
Dehydrating agent	A substance that removes water/hydrogen and oxygen from a compound (e.g. conc. H_2SO_4).

5. Formulas / Rules

Must-Know Facts

Group VA: ns^2np^3 (N,P,As,Sb,Bi). Group VIA: ns^2np^4 (O,S,Se,Te,Po).

Ammonia: $N_2 + 3H_2 \rightleftharpoons 2NH_3$ (Haber; Fe, 200 atm, 450 °C).

Sulphuric acid: Contact process; catalyst V_2O_5.

Sulphur allotropes: rhombic (stable <96 °C) and monoclinic (stable >96 °C), both S_8.

Conc. H_2SO_4 = strong acid + dehydrating agent + oxidising agent.

6. Diagrams / Illustrations

Key process diagrams for quick revision:

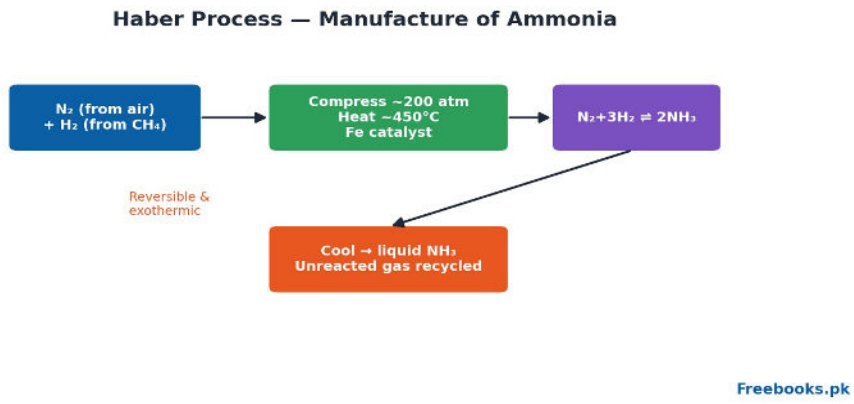

Diagram 1 — Haber process.

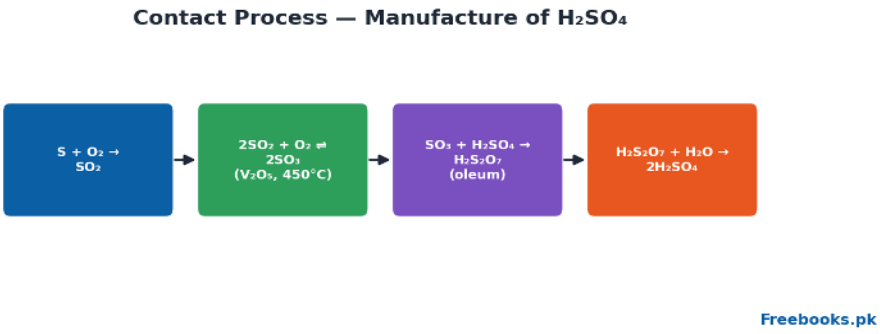

Diagram 2 — Contact process.

7. Solved Examples

Example 1 — Le Chatelier in the Haber process

Q: Why is high pressure used in the Haber process?

Solution: The forward reaction $N_2 + 3H_2 \rightleftharpoons 2NH_3$ decreases the number of gas molecules (4 → 2). By Le Chatelier's principle, high pressure shifts the equilibrium toward the side with fewer molecules, increasing the yield of ammonia.

Example 2 — Role of conc. H_2SO_4

Q: What happens when concentrated sulphuric acid is added to sugar?

Solution: It acts as a dehydrating agent, removing hydrogen and oxygen (as water) from the sugar and leaving a black mass of carbon. This shows the strong dehydrating property of conc. H_2SO_4.

Example 3 — Identifying a gas

Q: A brown gas is evolved when copper reacts with concentrated nitric acid. Name it.

Solution: The brown gas is nitrogen dioxide (NO_2), produced because concentrated HNO_3 is a strong oxidising agent.

8. Short Questions

Q1. Why is nitrogen gas so unreactive?
Ans. Because the two nitrogen atoms are held by a very strong triple bond (N≡N) that is hard to break.

Q2. State the conditions for the Haber process.
Ans. About 200 atm pressure, 450 °C, and a finely divided iron catalyst.

Q3. Why is a moderate (not very high) temperature used in the Haber process?
Ans. The forward reaction is exothermic, so too high a temperature reduces the yield; 450 °C balances rate and yield.

Q4. What is oleum?
Ans. Fuming sulphuric acid, $H_2S_2O_7$, formed when SO_3 dissolves in concentrated H_2SO_4.

Q5. Name the catalyst used in the Contact process.
Ans. Vanadium(V) oxide, V_2O_5.

Q6. What are the two crystalline allotropes of sulphur?
Ans. Rhombic (α) sulphur and monoclinic (β) sulphur.

Q7. Give three properties of concentrated sulphuric acid.
Ans. It is a strong acid, a dehydrating agent and an oxidising agent.

Q8. Why is sulphuric acid called the king of chemicals?
Ans. Because it is used in so many industries — fertilizers, detergents, paints, batteries and other chemicals.

9. Long Questions

Q1. Describe the manufacture of ammonia by the Haber process.

Ammonia is manufactured by combining nitrogen (from the fractional distillation of liquid air) with hydrogen (obtained from natural gas). The purified gases are mixed in a 1:3 ratio, compressed to about 200 atmospheres, and passed over a finely divided iron catalyst at about 450 °C, where

they combine according to the reversible, exothermic reaction $N_2 + 3H_2 \rightleftharpoons 2NH_3$. Because the forward reaction reduces the number of gas molecules and gives out heat, a high pressure and a moderate temperature give the best practical yield; a catalyst is used to speed up the reaction without being consumed. The mixture leaving the converter is cooled so that ammonia liquefies and is removed, while the unreacted nitrogen and hydrogen are recycled. Ammonia is then used to make nitric acid, urea and ammonium fertilizers.

Q2. Describe the manufacture of sulphuric acid by the Contact process.

In the Contact process, sulphur (or a sulphide ore) is first burned in air to give sulphur dioxide: $S + O_2 \rightarrow SO_2$. The purified, dried sulphur dioxide is then mixed with more air and passed over a vanadium(V) oxide catalyst at about 450 °C, where it is oxidised to sulphur trioxide in a reversible, exothermic reaction: $2SO_2 + O_2 \rightleftharpoons 2SO_3$. Because the reaction gives out heat and reduces the number of gas molecules, a moderate temperature and ordinary pressure are used. The sulphur trioxide is not dissolved directly in water (which would form a dangerous mist) but is absorbed in concentrated sulphuric acid to form oleum, $SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$, which is then carefully diluted with water to give sulphuric acid of the required concentration: $H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$.

Q3. Discuss the properties and uses of concentrated sulphuric acid.

Concentrated sulphuric acid shows three important kinds of behaviour. As a strong acid it reacts with metals, bases and carbonates to form sulphates. As a powerful dehydrating agent it removes the elements of water from other substances — for example it chars sugar and paper to carbon and is used to dry gases. As an oxidising agent, especially when hot and concentrated, it oxidises metals such as copper, itself being reduced to sulphur dioxide. Because of this versatility it is one of the most widely used industrial chemicals, employed in making fertilizers (superphosphate, ammonium sulphate), detergents, dyes, paints, explosives, and in car batteries and metal pickling.

10. Multiple Choice Questions (MCQs)

1. The outer configuration of Group VA elements is:
(A) ns^2np^2 (B) ns^2np^3 (C) ns^2np^4 (D) ns^2np^5

2. The catalyst used in the Haber process is:
(A) V_2O_5 (B) Fe (C) Pt (D) Ni

3. The catalyst used in the Contact process is:
(A) Fe (B) Pt (C) V_2O_5 (D) MnO_2

4. Which gas is 'laughing gas'?
(A) NO (B) NO_2 (C) N_2O (D) N_2O_5

5. Oleum is:
(A) H_2SO_4 (B) H_2SO_3 (C) $H_2S_2O_7$ (D) SO_3

6. Which is a brown gas?
(A) N_2O (B) NO (C) NO_2 (D) NH_3

7. Sulphur exists mainly as molecules of:
(A) S_2 (B) S_4 (C) S_6 (D) S_8

8. Chalcogens belong to group:
(A) IVA (B) VA (C) VIA (D) VIIA

9. Concentrated H_2SO_4 chars sugar because it acts as a:

(A) Reducing agent (B) Dehydrating agent (C) Base (D) Catalyst

10. Which element is a radioactive metal of Group VIA?

(A) Se (B) Te (C) Po (D) S

MCQ Answer Key

1-B 2-B 3-C 4-C 5-C 6-C 7-D 8-C 9-B 10-C

11. Quick Revision / Summary

- VA = ns^2np^3 (N,P,As,Sb,Bi); VIA = ns^2np^4 (O,S,Se,Te,Po); metallic character increases down.
- Ammonia: Haber process, $N_2+3H_2 \rightleftharpoons 2NH_3$, Fe catalyst, 200 atm, 450 °C.
- Sulphuric acid: Contact process, V_2O_5 catalyst; SO_3 absorbed as oleum then diluted.
- Sulphur allotropes: rhombic (<96 °C) and monoclinic (>96 °C), both S_8.
- Conc. H_2SO_4 = strong acid + dehydrating + oxidising agent.
- Nitrogen oxides show states +1 to +5; NO_2 is brown.

12. Exam Tips

Teacher's Note

Learn the Haber and Contact process conditions and equations perfectly — they appear almost every year.

Always justify the chosen conditions with Le Chatelier's principle (pressure, temperature).

Remember the catalysts: Fe for Haber, V_2O_5 for Contact — a common MCQ trap.

For conc. H_2SO_4, name its three roles: acid, dehydrating, oxidising — with one example each.

Note that SO_3 is absorbed in H_2SO_4 (not water) to avoid an acid mist.