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FSc / ICS Part-II Chemistry — Punjab Board

CHAPTER 3

Group IIIA and Group IVA Elements

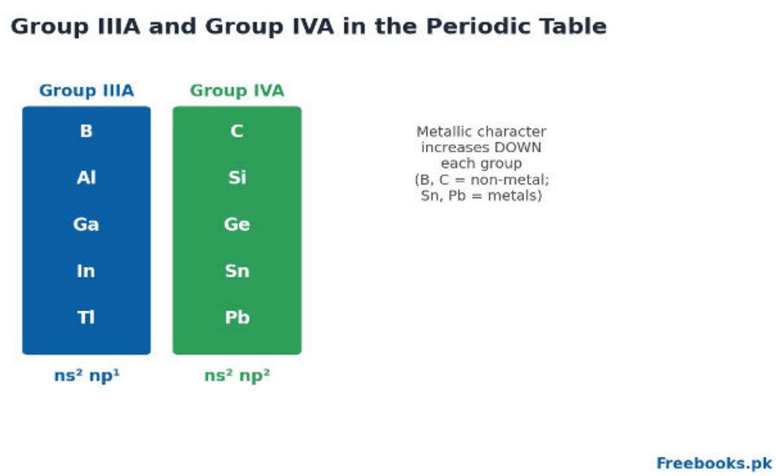

Figure 3.1 — Group IIIA (boron family) and Group IVA (carbon family).

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1. Chapter Overview

This chapter deals with two families of p-block elements. Group IIIA (the boron family: B, Al, Ga, In, Tl) has the outer configuration ns^2 np^1, while Group IVA (the carbon family: C, Si, Ge, Sn, Pb) has ns^2 np^2. These groups are special because they show a clear change from non-metal at the top to metal at the bottom, they display more than one oxidation state, and they include some of the most useful materials on Earth — aluminium, carbon (in diamond, graphite and all of organic chemistry), and silicon (the heart of every computer chip).

A recurring idea in this chapter is the inert pair effect, which explains why the heavier members (thallium and lead) prefer a lower oxidation state. We also study important compounds such as borax, boric acid, aluminium oxide, carbon monoxide and dioxide, silicates and silicones.

2. Learning Objectives

- List the members and electronic configurations of Groups IIIA and IVA.
- Explain how metallic character changes down each group.
- Define and apply the inert pair effect to predict stable oxidation states.
- Describe the unusual (anomalous) behaviour of boron and carbon.
- Explain catenation and the allotropy of carbon (diamond and graphite).
- Describe the amphoteric nature and uses of aluminium.
- State the preparation and uses of borax, boric acid, silica, silicates and silicones.
- Explain why silicon and germanium are used as semiconductors.

3. Key Concepts

3.1 The Two Families

Group	Name	Members
IIIA (ns^2np^1)	Boron family	B, Al, Ga, In, Tl
IVA (ns^2np^2)	Carbon family	C, Si, Ge, Sn, Pb

In both groups the top element is a non-metal (or metalloid) and the character becomes more metallic as we move down. In Group IIIA, boron is a metalloid while aluminium and the rest are metals. In Group IVA, carbon is a non-metal, silicon and germanium are metalloids (semiconductors), and tin and lead are metals.

> **Memory Trick**
> **IIIA order:** “Bara Aluminium Gaya India Thailand” → B, Al, Ga, In, Tl.
> **IVA order:** “Carbon Se Germany Sn Pb” → C, Si, Ge, Sn, Pb.

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3.2 Oxidation States and the Inert Pair Effect

Group IIIA elements can show a +3 state (using all three outer electrons) and Group IVA a +4 state. However, as we go down each group, the lower oxidation state (+1 for IIIA, +2 for IVA) becomes increasingly stable. This happens because the outer ns^2 pair of electrons becomes reluctant to take part in bonding — an idea called the inert pair effect. That is why thallium is most stable as Tl^+ and lead as Pb^{2+}, whereas aluminium is stable as Al^{3+} and the top of Group IVA prefers +4.

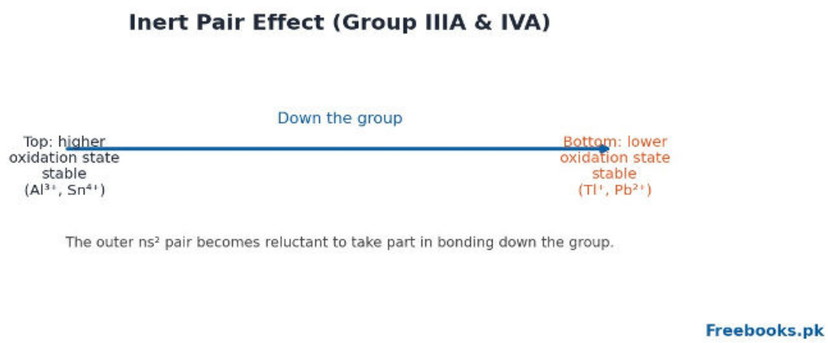

Figure 3.2 — The inert pair effect stabilises lower oxidation states down the group.

3.3 Anomalous Behaviour of Boron and Carbon

Boron. Because it is very small and has a high ionization energy, boron is a non-metal (metalloid), forms only covalent compounds, and its compounds are electron-deficient (e.g. BF_3 can accept a lone pair, acting as a Lewis acid). The other members are metals.

Carbon. Carbon is unique in its ability to form strong C–C bonds with itself (catenation) and to form multiple bonds (C=C, C≡C). This is the reason carbon forms millions of compounds and is the basis of all organic chemistry. It also shows allotropy.

3.4 Catenation and Allotropy of Carbon

Catenation is the self-linking of atoms of the same element to form long chains and rings. Carbon shows catenation to the greatest extent because the C–C bond is very strong. Carbon also exists in different physical forms called allotropes; the two most important crystalline allotropes are diamond and graphite.

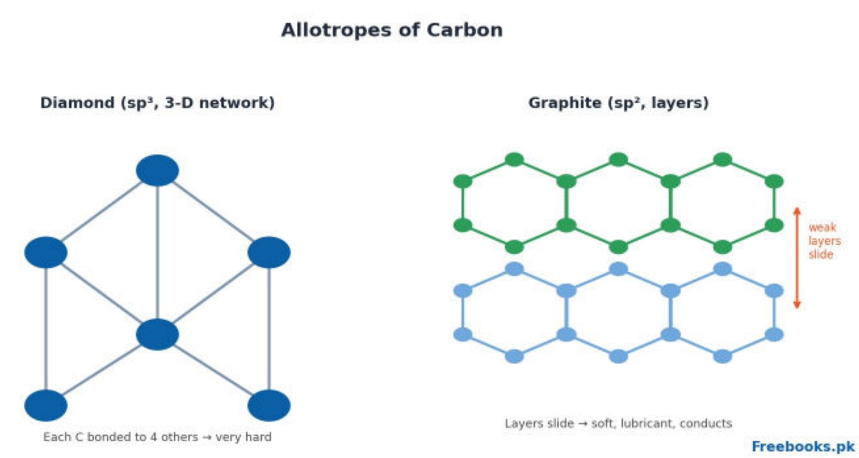

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Figure 3.3 — Diamond (rigid 3-D network) versus graphite (sliding layers).

Property	Diamond	Graphite
Hybridization	sp^3	sp^2
Structure	3-D tetrahedral network	Flat layers of hexagons
Hardness	Hardest natural substance	Soft, slippery
Electrical conduction	Non-conductor	Good conductor
Main use	Cutting/abrasives, jewellery	Lubricant, pencil lead, electrodes

3.5 Aluminium — the Amphoteric Metal

Aluminium is the most abundant metal in the earth's crust. It is light, strong and resists corrosion because a thin oxide layer protects its surface. Aluminium is amphoteric: it reacts with acids to give a salt and hydrogen, and also with strong alkalis to give an aluminate and hydrogen.

Amphoteric Aluminium — Key Reactions

With acid: $2Al + 6HCl \rightarrow 2AlCl_3 + 3H_2\uparrow$

With alkali: $2Al + 2NaOH + 2H_2O \rightarrow 2NaAlO_2 + 3H_2\uparrow$

Thermite reaction: $2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$ (used for welding rails; strongly exothermic)

Uses of aluminium include electrical cables, aircraft and vehicle bodies, cooking utensils, packaging foil, and the thermite process for welding.

3.6 Important Compounds

Borax ($Na_2B_4O_7 \cdot 10H_2O$). A white solid used in glass and enamel making, as a water softener, and in the borax-bead test to identify metals.

Boric acid (H_3BO_3). A weak acid used as a mild antiseptic (eye-wash) and in glazes.

Oxides of carbon. Carbon monoxide (CO) is a colourless, poisonous gas and a good reducing agent used in metal extraction; carbon dioxide (CO_2) is an acidic oxide, used in fire extinguishers and photosynthesis, and is a greenhouse gas.

Silica and silicates. Silicon dioxide (SiO_2, sand/quartz) is a giant covalent solid used to make glass. Silicates form rocks, clays and cement; man-made silicones are water-repellent polymers used in sealants, lubricants and medical implants.

3.7 Silicon and Germanium as Semiconductors

Silicon and germanium are metalloids whose electrical conductivity lies between that of metals and non-metals and increases with temperature. By adding tiny amounts of other elements (doping), their conductivity can be controlled precisely. This makes them the basic materials of transistors, diodes, solar cells and computer chips.

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4. Important Definitions

Term	Definition
Inert pair effect	The reluctance of the outer ns^2 electron pair to take part in bonding, stabilising the lower oxidation state down a group.
Catenation	The self-linking of like atoms to form chains and rings (greatest in carbon).
Allotropy	The existence of an element in two or more different physical forms in the same physical state.
Amphoteric	A substance that reacts with both acids and bases (e.g. Al, Al_2O_3).
Metalloid	An element with properties intermediate between metals and non-metals (e.g. B, Si, Ge).
Semiconductor	A material whose conductivity is between a conductor and an insulator and rises with temperature.

5. Formulas / Rules

Must-Know Facts

Group IIIA: ns^2np^1, main state +3; heavier prefer +1 (inert pair).

Group IVA: ns^2np^2, main state +4; heavier prefer +2 (Pb^{2+}).

Borax = $Na_2B_4O_7 \cdot 10H_2O$ | Boric acid = H_3BO_3 | Silica = SiO_2

Metallic character increases down a group; acidic nature of oxides decreases down.

Diamond = sp^3 (hard, insulator); Graphite = sp^2 (soft, conductor).

6. Diagrams / Illustrations

Collected diagrams for quick revision:

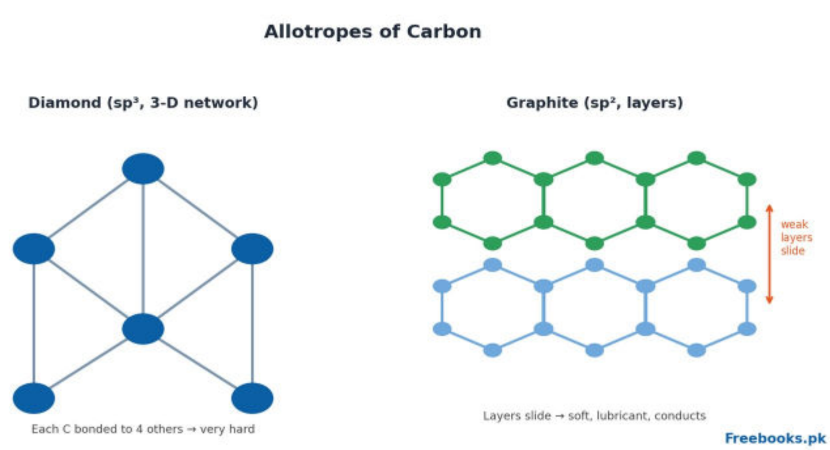

Diagram 1 — Diamond vs graphite.

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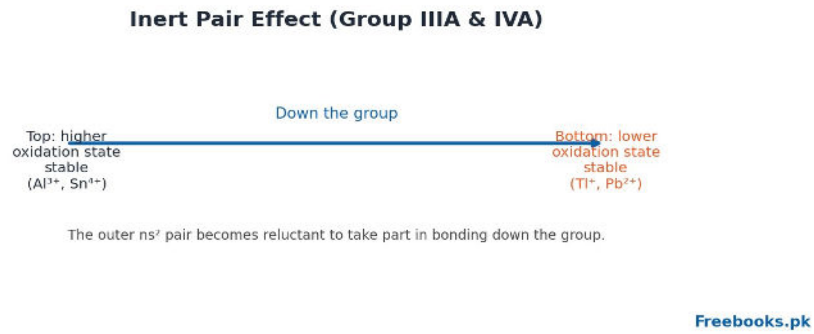

Diagram 2 — Inert pair effect.

7. Solved Examples

Example 1 — Predicting oxidation state

Q: Which oxidation state is more stable for lead, +2 or +4? Why?

Solution: +2 is more stable. Lead is at the bottom of Group IVA, where the inert pair effect makes the outer $6s^2$ electrons reluctant to bond, so Pb^{2+} is favoured over Pb^{4+}.

Example 2 — Amphoteric behaviour

Q: Show that aluminium is amphoteric.

Solution: It reacts with acid ($2Al + 6HCl \rightarrow 2AlCl_3 + 3H_2$) and with base ($2Al + 2NaOH + 2H_2O \rightarrow 2NaAlO_2 + 3H_2$). Reacting with both acid and base means it is amphoteric.

Example 3 — Why graphite conducts

Q: Why does graphite conduct electricity but diamond does not?

Solution: In graphite each carbon is sp^2 and one electron per atom is delocalised between the layers, so it can carry current. In diamond every electron is used in sp^3 C–C bonds, leaving none free, so it is an insulator.

8. Short Questions

Q1. What is the inert pair effect?
Ans. The reluctance of the outer ns^2 electron pair to bond, which stabilises the lower oxidation state down a group.

Q2. Why is boron a non-metal while aluminium is a metal?
Ans. Boron is very small with high ionization energy, so it forms only covalent bonds; aluminium is larger and loses electrons to behave as a metal.

Q3. Define catenation.
Ans. The self-linking of atoms of the same element into chains and rings; carbon shows it most.

Q4. Why is diamond hard but graphite soft?
Ans. Diamond is a rigid 3-D network of sp^3 carbons; graphite has sp^2 layers that slide over each other.

Q5. What is the thermite reaction?

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Ans. $2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$; a highly exothermic reaction used to weld iron/steel rails.

Q6. Give two uses of borax.
Ans. Making heat-resistant glass and enamels, and as a flux (borax-bead test).

Q7. Why are Si and Ge called semiconductors?
Ans. Their conductivity lies between metals and non-metals and increases with temperature and doping.

Q8. Which is a stronger reducing agent, CO or CO_2?
Ans. CO, because it readily takes up oxygen to become CO_2, reducing metal oxides.

9. Long Questions

Q1. Discuss the general trends in Groups IIIA and IVA.

Both groups belong to the p-block, with outer configurations ns^2np^1 (IIIA) and ns^2np^2 (IVA). Down each group the atomic size increases and ionization energy decreases, so metallic character rises: the top elements (B, C) are non-metals or metalloids, the middle members (Si, Ge, Ga) are metalloids, and the lower members (Sn, Pb, Tl) are true metals. The common higher oxidation state (+3 for IIIA, +4 for IVA) becomes less stable down the group because of the inert pair effect, which favours the lower state (+1, +2) for the heaviest members such as Tl^+ and Pb^{2+}. The acidic nature of the oxides decreases and their basic nature increases down each group, in line with the growing metallic character.

Q2. Compare diamond and graphite in terms of structure and properties.

Diamond and graphite are both allotropes of carbon but differ completely in structure, which gives them opposite properties. In diamond every carbon atom is sp^3 hybridised and bonded to four others in a rigid three-dimensional tetrahedral network; there are no free electrons, so diamond is the hardest natural substance, has a very high melting point, and does not conduct electricity. In graphite each carbon is sp^2 hybridised and bonded to three others in flat hexagonal layers, with the fourth electron delocalised between the layers; the layers are held only by weak forces, so they slide easily. This makes graphite soft and slippery (a good lubricant and pencil 'lead') and a good conductor of electricity. Thus a single element gives two materials with dramatically different uses.

Q3. Describe the amphoteric nature and important uses of aluminium.

Aluminium is described as amphoteric because it reacts with both acids and alkalis. With dilute acids it behaves as a metal, giving a salt and hydrogen: $2Al + 6HCl \rightarrow 2AlCl_3 + 3H_2$. With hot concentrated alkalis it dissolves to form an aluminate and hydrogen: $2Al + 2NaOH + 2H_2O \rightarrow 2NaAlO_2 + 3H_2$. Its oxide, Al_2O_3, is likewise amphoteric. In practice aluminium is extremely useful: it is light yet strong, resists corrosion (a protective oxide film), and conducts electricity well, so it is used in overhead power cables, aircraft and car bodies, cooking utensils, packaging foil, and in the thermite reaction ($2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$) to weld railway tracks.

10. Multiple Choice Questions (MCQs)

1. The outer electronic configuration of Group IIIA is:

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(A) ns^2 (B) ns^2np^1 (C) ns^2np^2 (D) ns^2np^3

2. The inert pair effect is most pronounced in:
(A) B (B) Al (C) Ga (D) Tl

3. The hardest allotrope of carbon is:
(A) Graphite (B) Diamond (C) Coke (D) Charcoal

4. Which element shows the greatest catenation?
(A) Silicon (B) Carbon (C) Tin (D) Lead

5. Aluminium reacting with NaOH shows it is:
(A) Acidic (B) Basic (C) Amphoteric (D) Neutral

6. Borax formula is:
(A) H_3BO_3 (B) $Na_2B_4O_7 \cdot 10H_2O$ (C) B_2O_3 (D) BF_3

7. Which is used as a semiconductor?
(A) Lead (B) Silicon (C) Boron (D) Thallium

8. The most stable oxidation state of lead is:
(A) +4 (B) +3 (C) +2 (D) +1

9. Graphite conducts electricity because it has:
(A) sp^3 carbons (B) free (delocalised) electrons (C) ionic bonds (D) metallic lattice

10. Carbon monoxide acts as a:
(A) Oxidising agent (B) Reducing agent (C) Acid (D) Base

MCQ Answer Key

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

11. Quick Revision / Summary

- IIIA (B,Al,Ga,In,Tl) = ns^2np^1, state +3; IVA (C,Si,Ge,Sn,Pb) = ns^2np^2, state +4.
- Metallic character increases down each group; top members are non-metals/metalloids.
- Inert pair effect → lower state stable at bottom (Tl^+, Pb^{2+}).
- Carbon: catenation + allotropy (diamond sp^3 hard insulator; graphite sp^2 soft conductor).
- Aluminium is amphoteric; thermite = $2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$.
- Borax = $Na_2B_4O_7 \cdot 10H_2O$; boric acid = H_3BO_3; silica = SiO_2.
- Si and Ge are semiconductors used in electronics.

12. Exam Tips

Teacher's Note

Inert pair effect is a favourite exam topic — always link it to 'lower oxidation state stable at the bottom'.

For diamond vs graphite, structure explains every property — always mention hybridisation and free electrons.

Remember amphoteric examples: Al, Al_2O_3, Be, Zn, Pb — reacting with BOTH acid and

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base.
Learn the three aluminium reactions (acid, alkali, thermite) with balanced equations.
Do not confuse borax ($Na_2B_4O_7 \cdot 10H_2O$) with boric acid (H_3BO_3).

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