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INORGANIC

CH 06

p-Block Elements I — Boron & Carbon Families (Groups 13–14)

Trends and anomalies in groups 13 and 14, the inert pair effect, borax, boric acid, diborane and its banana bonds, aluminium, allotropes of carbon, CO and CO_2, silica, silicones, silicates and zeolites — with an exam trap gallery, graded MCQs and a one-page revision sheet.

WHAT YOU WILL BE ABLE TO DO

- Explain trends in size, ionisation enthalpy and oxidation states in groups 13 and 14, including the inert pair effect
- Explain the Lewis acidity of boron halides and the structure of diborane
- Write the preparation and key reactions of borax, boric acid and diborane
- Compare the allotropes of carbon and the chemistry of CO, CO_2 and SiO_2
- Describe silicones, silicates and zeolites

INSIDE

A The big picture
B Group 13: trends
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D Borax and boric acid
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F Group 14: trends
G Allotropes of carbon
H Carbon monoxide and carbon dioxide

HOW TO USE THESE NOTES

IN ONE LINE The core idea of a section	**KEY IDEA** The concept to remember	**EXAM TRAP** Where marks are usually lost
SOLVED EXAMPLE Worked step by step	**CHECK YOURSELF** Quick self-test	**MEMORY HOOK** A line that sticks

SECTION A

The big picture

A

First member odd, last member lazy.

IN ONE LINE

In groups 13 and 14 the first element (B, C) is small, non-metallic and limited to four bonds; going down, metallic character rises and the ns^2 pair becomes reluctant to bond, so the lower oxidation state (+1 for Tl, +2 for Pb) becomes the stable one.

Property	Group 13 (B → Tl)	Group 14 (C → Pb)
Valence configuration	$ns^2\ np^1$	$ns^2\ np^2$
Common oxidation states	+3; +1 grows down (Tl^+ most stable)	+4; +2 grows down (Pb^{2+} most stable)
Character	B non-metal; Al to Tl metals	C, Si non-metals; Ge metalloid; Sn, Pb metals
Oxides	B_2O_3 acidic → Al_2O_3, Ga_2O_3 amphoteric → In_2O_3, Tl_2O_3 basic	CO_2, SiO_2, GeO_2 acidic; SnO_2, PbO_2 amphoteric

THINK OF IT LIKE THIS

Picture the ns^2 pair as two old residents of a building who get more comfortable — and less willing to move out — as the building (atom) grows taller. In boron and carbon they join every bond. By thallium and lead they mostly stay home, and only the p electrons go out to bond.

SECTION B

Group 13: trends

B

Data first, then the exceptions.

Property	B	Al	Ga	In	Tl
Atomic radius / pm	85	143	135	167	170
ΔiH_1 / kJ mol^{-1}	801	577	579	558	589

Property	B	Al	Ga	In	Tl
Electronegativity (Pauling)	2.0	1.5	1.6	1.7	1.8
m.p. / K	2453	933	303	430	576
b.p. / K	3923	2740	2676	2353	1730

- **Ga is smaller than Al** — the ten poorly shielding 3d electrons raise the effective nuclear charge (d-block contraction).
- **Ionisation enthalpies are irregular** for the same reason: Ga's ΔiH_1 is slightly above Al's, and Tl's is raised by poor 4f/5d shielding.
- **Electronegativity** falls from B to Al, then rises slightly — again because of d and f contraction.
- **Ga melts at 303 K** (it melts in the hand) but boils at 2676 K — the widest liquid range of any element, so it is used in high-temperature thermometers.
- Boron is very hard and high-melting because it forms a giant covalent network (B_{12} icosahedra).

Oxidation states and the inert pair effect

- Down the group the **+1 state becomes more stable**: Tl^+ is more stable than Tl^{3+}, so Tl^{3+} is a strong oxidising agent.
- B and Al are almost always +3; Ga, In show +1 and +3; Tl mainly +1.
- **Cause:** the ns^2 electrons in the heavier elements are held more tightly (poor shielding by d and f electrons), and the bonds formed by the heavier atoms are weaker, so the energy gained from two extra bonds no longer pays for unpairing the ns^2 pair.

SECTION C

Group 13: compounds and Lewis acidity

Electron-deficient halides and amphoteric aluminium.

- Trihalides MX_3 have only six electrons around M → **Lewis acids** (electron-pair acceptors): $BF_3 + NH_3 \rightarrow F_3B \leftarrow NH_3$.
- **Lewis acid strength of boron halides:** $BF_3 < BCl_3 < BBr_3 < BI_3$ — the opposite of what electronegativity suggests. In BF_3 the small F atom back-donates a lone pair into boron's empty 2p orbital (pπ–pπ back bonding), partly filling it. The overlap is poorer for the larger halogens.
- **$AlCl_3$** exists as the dimer Al_2Cl_6 in the vapour and in non-polar solvents (each Al completes its octet using a lone pair from a bridging Cl). It is the Lewis-acid catalyst of Friedel–Crafts reactions.
- **Boron cannot exceed four bonds** ($[BF_4]^-$, no d orbitals); aluminium can form $[AlF_6]^{3-}$.
- B_2O_3 is acidic, Al_2O_3 amphoteric, Tl_2O_3 basic — metallic character rises down the group.

Aluminium

$$2Al + 6HCl \rightarrow 2AlCl_3 + 3H_2$$

$$2Al + 2NaOH + 6H_2O \rightarrow 2Na[Al(OH)_4] + 3H_2$$

Amphoteric metal: dissolves in both acid and alkali

- Aluminium is rendered **passive** by conc. HNO_3 (a protective oxide film).
- Al_2O_3 is amphoteric; $Al(OH)_3$ dissolves in excess NaOH to give $[Al(OH)_4]^-$.
- Uses: light alloys (duralumin), wires, foil, packaging; thermite welding (Al reduces Fe_2O_3 with great heat).

SOLVED EXAMPLE 01 — RANKING LEWIS ACIDITY

Arrange BF_3, BCl_3 and BBr_3 in increasing Lewis acid strength and explain.

SOLUTION

1. All three have an empty 2p orbital on boron.
2. F's 2p orbital matches B's 2p closely, so back-donation from F is strongest and partly fills B's empty orbital.
3. Cl (3p) and Br (4p) overlap less well, so boron stays more electron-deficient.

ANSWER $BF_3 < BCl_3 < BBr_3$ (back bonding is strongest in BF_3).

CHECK YOURSELF

C1 Why is $AlCl_3$ a dimer in the vapour phase?

C2 Why is Tl^{3+} a good oxidising agent?

Answers at the end of the chapter.

SECTION D

D

Borax and boric acid

Two boron compounds every exam asks about.

Borax

- Formula $Na_2B_4O_7 \cdot 10H_2O$, more correctly $Na_2[B_4O_5(OH)_4] \cdot 8H_2O$ — the anion contains two tetrahedral and two trigonal boron atoms.
- Aqueous borax is **alkaline**: $Na_2B_4O_7 + 7H_2O \rightarrow 2NaOH + 4H_3BO_3$ (a salt of a strong base and weak acid). It is used as a primary standard for titrating acids.
- On heating it loses water and swells, then melts to a clear glass: $Na_2B_4O_7 \cdot 10H_2O \rightarrow Na_2B_4O_7 \rightarrow 2NaBO_2 + B_2O_3$ (transparent bead).

- **Borax bead test:** the glassy $NaBO_2 + B_2O_3$ bead fused with a transition-metal salt gives a coloured metaborate. Co gives a **blue** bead ($Co(BO_2)_2$); Cu blue-green; Ni brown; Cr green.

Boric acid, H_3BO_3

- Made by acidifying borax: $Na_2B_4O_7 + 2HCl + 5H_2O \rightarrow 2NaCl + 4H_3BO_3$.
- A **weak monobasic Lewis acid** — it does not give H^+ itself; it accepts OH^- from water: $B(OH)_3 + 2H_2O \rightarrow [B(OH)_4]^- + H_3O^+$.
- Layered crystal: planar $B(OH)_3$ units joined by hydrogen bonds, so it is soft and slippery.
- On heating: $H_3BO_3 \rightarrow HBO_2$ (metaboric acid, about 370 K) $\rightarrow B_2O_3$ (red heat).
- Its acid strength increases in the presence of polyhydroxy compounds (glycerol, mannitol), which bind $[B(OH)_4]^-$ — this allows it to be titrated with NaOH.

SOLVED EXAMPLE 02 — **WHY BORIC ACID IS MONOBASIC**

H_3BO_3 has three O–H groups, yet it is a monobasic acid. Explain.

SOLUTION

1. Boron has only six electrons around it in $B(OH)_3$ and an empty p orbital.
2. It accepts an OH^- ion from water: $B(OH)_3 + H_2O \rightarrow [B(OH)_4]^- + H^+$.
3. Only one H^+ is released per molecule, and not from its own O–H groups.

ANSWER It behaves as a Lewis acid that accepts one OH^-; it is monobasic.

SECTION E

Diborane

E

The molecule that broke the two-electron-bond rule.

Preparation

- **Lab:** $2NaBH_4 + I_2 \rightarrow B_2H_6 + 2NaI + H_2$.
- **From BF_3:** $4BF_3 + 3LiAlH_4 \rightarrow 2B_2H_6 + 3LiF + 3AlF_3$ (in ether).
- **Industrial:** $2BF_3 + 6NaH \rightarrow B_2H_6 + 6NaF$ (450 K).

Structure

- Two BH_2 units are joined by two bridging H atoms above and below the plane of the four terminal H atoms.
- **Terminal B–H bonds (4):** ordinary two-centre two-electron bonds, 119 pm.
- **Bridging B–H–B bonds (2): three-centre two-electron (3c–2e) "banana" bonds**, 134 pm — one electron pair holds three atoms together.
- Each boron is roughly sp^3 hybridised. B_2H_6 has 12 valence electrons — too few for 8 ordinary bonds, which is why the 3c–2e bonds exist (it is **electron-deficient**).

Reactions

Reagent	Product	Note
O_2	$B_2O_3 + 3H_2O$	$\Delta H = -1976$ kJ mol^{-1}; burns spontaneously
H_2O	$2B(OH)_3 + 6H_2$	Hydrolysis
Lewis bases (CO, NH_3, $N(CH_3)_3$)	Adducts: $BH_3{\cdot}CO$, $BH_3{\cdot}N(CH_3)_3$	Symmetric cleavage of the bridges
NH_3 (heated)	$B_3N_3H_6$ (borazine) via $B_2H_6{\cdot}2NH_3$	Borazine is “inorganic benzene”
NaH (in ether)	$2NaBH_4$	Sodium borohydride, a reducing agent
LiH	$2LiBH_4$	Lithium borohydride

SOLVED EXAMPLE 03 — **COUNTING BONDS IN DIBORANE**

How many electrons does B_2H_6 have for bonding, and how are they used?

SOLUTION

1. Valence electrons: 2 × 3 (B) + 6 × 1 (H) = 12.
2. Four terminal B–H bonds use 8 electrons.
3. The remaining 4 electrons form two 3c–2e B–H–B bridges.

ANSWER 12 electrons: 4 normal bonds (8 e$^-$) + 2 banana bonds (4 e$^-$).

CHECK YOURSELF

C3 What is the colour of the cobalt borax bead?

C4 How many 3-centre-2-electron bonds are in diborane?

Answers at the end of the chapter.

SECTION F

Group 14: trends

F

From non-metal carbon to metallic lead.

Property	C	Si	Ge	Sn	Pb
Covalent radius / pm	77	118	122	140	146
ΔiH_1 / kJ mol^{-1}	1086	786	761	708	715
Electronegativity	2.5	1.8	1.8	1.8	1.9

Property	C	Si	Ge	Sn	Pb
m.p. / K	4373 (sublimes)	1693	1218	505	600
Element–element bond enthalpy / kJ mol^{-1}	C–C 348	Si–Si 297	Ge–Ge 260	Sn–Sn 240	—

- **Catenation** (self-linking into chains and rings) falls sharply: C ≫ Si > Ge ≈ Sn; Pb does not catenate. The C–C bond is strong; Si–Si and below are much weaker.
- **pπ–pπ multiple bonds:** carbon forms C=C, C≡C, C=O easily; Si and heavier elements hardly do (poor sideways overlap of large orbitals). That is why CO_2 is a molecule but SiO_2 is a giant network.
- **+2 state stabilises down the group:** Sn^{2+} is a reducing agent (it goes to Sn^{4+}); Pb^{4+} is a strong oxidising agent (PbO_2). PbI_4 does not exist — Pb^{4+} would oxidise I^- to I_2.
- **Halides:** all form MX_4 (except $PbBr_4$ and PbI_4). CCl_4 does not hydrolyse, but **$SiCl_4$ hydrolyses readily** ($SiCl_4 + 4H_2O \rightarrow Si(OH)_4 + 4HCl$): silicon has vacant 3d orbitals to accept a lone pair from water, while carbon has none.
- Oxides: CO neutral; CO_2, SiO_2, GeO_2 acidic; SnO, PbO, SnO_2, PbO_2 amphoteric; GeO is acidic.

SOLVED EXAMPLE 04 — HYDROLYSIS OF TETRACHLORIDES

Why does $SiCl_4$ fume in moist air while CCl_4 does not react with water?

SOLUTION

1. Hydrolysis begins with water donating a lone pair to the central atom.
2. Si has empty 3d orbitals and is larger, so it can accept the lone pair and expand its coordination.
3. Carbon has no d orbitals in its valence shell and is crowded by four Cl atoms.

ANSWER **$SiCl_4$ hydrolyses to $Si(OH)_4$ + HCl (the fumes are HCl); CCl_4 cannot.**

SOLVED EXAMPLE 05 — PBO_2 AS AN OXIDANT, $SNCL_2$ AS A REDUCTANT

Write one reaction showing PbO_2 as an oxidising agent and one showing $SnCl_2$ as a reducing agent, and explain both with the inert pair effect.

SOLUTION

1. $PbO_2 + 4HCl \rightarrow PbCl_2 + Cl_2 + 2H_2O$ — Pb(IV) is reduced to the more stable Pb(II).
2. $SnCl_2 + 2HgCl_2 \rightarrow SnCl_4 + Hg_2Cl_2$ — Sn(II) is oxidised to the more stable Sn(IV).

ANSWER **Pb prefers +2, Sn prefers +4: the inert pair effect is strong for Pb but weak for Sn.**

SECTION G

Allotropes of carbon

G

Same element, very different solids.

Allotrope	Hybridisation	Structure	Key properties
Diamond	sp^3	3D network of tetrahedra; C–C 154 pm	Hardest natural substance; insulator; high refractive index
Graphite	sp^2	Hexagonal layers; C–C 141.5 pm in a layer; layers 340 pm apart, held by weak forces	Soft, slippery (lubricant); conducts along layers (delocalised π electrons)
Fullerene C_{60}	sp^2	Cage of 20 hexagons and 12 pentagons (“buckyball”)	Molecular; soluble in organic solvents; pure form of carbon
Graphene	sp^2	A single graphite layer	Very strong, excellent conductor
Carbon nanotubes	sp^2	Graphene rolled into tubes	Very strong, light; electronics

- **Graphite is the thermodynamically most stable allotrope** ($\Delta_f H^\circ = 0$); diamond has $\Delta_f H^\circ = +1.9$ kJ mol^{-1}.
- Impure forms (amorphous): coke, charcoal, carbon black — made by heating carbon-containing materials with little air. Activated charcoal adsorbs gases and poisons.

SECTION H

Carbon monoxide and carbon dioxide

H

Two oxides, very different behaviour.

	CO	CO_2
Laboratory preparation	$HCOOH \rightarrow H_2O + CO$ (conc. H_2SO_4, 373 K)	$CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$
Industrial	Water gas: $C + H_2O \rightarrow CO + H_2$ (473–1273 K); producer gas: $2C + O_2 + 4N_2 \rightarrow 2CO + 4N_2$ (1273 K)	Burning carbon fuels; heating limestone
Nature	Neutral oxide; colourless, odourless, very poisonous	Acidic oxide; $CO_2 + H_2O \rightleftharpoons H_2CO_3$
Key use or role	Reducing agent in metallurgy ($Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$); ligand in $Ni(CO)_4$	Photosynthesis; solid CO_2 (dry ice) as refrigerant; fire extinguishers; greenhouse gas

KEY IDEA

Why CO is so toxic: it binds to the iron of haemoglobin about 300 times more strongly than O_2, forming carboxyhaemoglobin, which cannot carry oxygen. **Why CO is a good ligand:** it donates a lone pair from carbon (σ) and accepts metal d electrons back into its empty π∗ orbitals (π back-bonding).

- CO has a triple bond (one σ, two π) with a lone pair on each atom; CO_2 is linear (O=C=O, sp carbon) with zero dipole moment.
- The carbonic acid–bicarbonate buffer keeps blood pH between 7.26 and 7.42.

SECTION I

Silica, silicones, silicates and zeolites

I

Silicon's chemistry is built on Si–O bonds.

Silicon dioxide, SiO_2

- A **3D network**: each Si is bonded tetrahedrally to four O atoms, each O shared by two Si. That is why SiO_2 is a hard, high-melting solid while CO_2 is a gas.
- Crystalline forms: quartz, cristobalite, tridymite. Quartz is piezoelectric (used in clocks, pressure gauges). Amorphous forms: silica gel (drying agent, chromatography), kieselguhr.
- Very unreactive, but attacked by HF and by hot NaOH: $SiO_2 + 4HF \rightarrow SiF_4 + 2H_2O$; $SiO_2 + 2NaOH \rightarrow Na_2SiO_3 + H_2O$.

Silicones

- Polymers with a –Si–O–Si– backbone and organic groups on Si: general formula $(R_2SiO)_n$.
- Made from alkylchlorosilanes: $2CH_3Cl + Si \rightarrow (CH_3)_2SiCl_2$ (Cu catalyst, 573 K); hydrolysis gives $(CH_3)_2Si(OH)_2$, which condenses into chains.
- $(CH_3)_3SiCl$ caps the chain (chain terminator); CH_3SiCl_3 gives cross-linked (3D) polymers.
- Water-repellent (outer alkyl groups), heat-resistant, electrical insulators, chemically inert, non-toxic: used in sealants, greases, electrical insulation, water-proofing fabrics and surgical implants.

Silicates and zeolites

Silicate type	Unit	Example
Orthosilicate	Discrete SiO_4^{4-}	Zircon $ZrSiO_4$, olivine
Pyrosilicate	$Si_2O_7^{6-}$ (two tetrahedra share one O)	Thortveitite
Cyclic / chain	$(SiO_3)_n^{2n-}$ — two O shared per tetrahedron	Beryl (cyclic); pyroxenes (chains)

Silicate type	Unit	Example
Sheet	$(Si_2O_5)_n^{2n-}$ — three O shared	Mica, talc, clays
3D	All four O shared (SiO_2); some Si replaced by Al in aluminosilicates	Quartz; feldspar, zeolites

- **Zeolites** are aluminosilicates with a honeycomb of pores; they act as shape-selective catalysts and ion exchangers. **ZSM-5** converts alcohols directly into gasoline; hydrated zeolites soften hard water.

SOLVED EXAMPLE 06 — WHY SiO_2 IS A SOLID BUT CO_2 IS A GAS

Explain the difference in physical state between CO_2 and SiO_2.

SOLUTION

1. Carbon forms strong pπ–pπ double bonds with oxygen, so CO_2 is a small discrete molecule held to others only by weak van der Waals forces.
2. Silicon is too large for effective pπ–pπ overlap, so it forms four single Si–O bonds instead.
3. Each O bridges two Si atoms, building a giant covalent network.

ANSWER CO_2 is molecular (gas); SiO_2 is a covalent network solid (m.p. about 1983 K).

SOLVED EXAMPLE 07 — ROLE OF CHAIN TERMINATORS

What is the effect of adding $(CH_3)_3SiCl$ to the hydrolysis mixture of $(CH_3)_2SiCl_2$ in silicone manufacture?

SOLUTION

1. $(CH_3)_2Si(OH)_2$ has two –OH groups and links at both ends, growing a chain.
2. $(CH_3)_3SiOH$ has only one –OH, so when it joins a chain end, no further growth is possible at that end.

ANSWER It caps the chains and controls the chain length (and hence viscosity) of the silicone.

CHECK YOURSELF

C5 Which allotrope of carbon conducts electricity, and why?

C6 Why does $SiCl_4$ hydrolyse but CCl_4 does not?

Answers at the end of the chapter.

SECTION J

Advanced problems

J

Each needs two ideas from the chapter.

SOLVED EXAMPLE 08 — HYDROGEN FROM ALUMINIUM

What volume of H_2 at STP is released when 5.4 g of Al dissolves completely in excess NaOH solution?

SOLUTION

1. $2Al + 2NaOH + 6H_2O \rightarrow 2Na[Al(OH)_4] + 3H_2$: 2 mol Al → 3 mol H_2.
2. 5.4 g Al = 0.20 mol → 0.30 mol H_2.
3. 0.30 × 22.4 L.

ANSWER 6.72 L of H_2 at STP.

SOLVED EXAMPLE 09 — BORAX AS A PRIMARY STANDARD

Write the reaction of borax with HCl and explain why borax is used to standardise acids.

SOLUTION

1. $Na_2B_4O_7{\cdot}10H_2O + 2HCl \rightarrow 2NaCl + 4H_3BO_3 + 5H_2O$.
2. Boric acid is too weak to affect methyl orange, so the end point reflects only the HCl used.
3. Borax is a pure, stable, non-hygroscopic crystalline solid of high molar mass (381 g mol^{-1}).

ANSWER One mole of borax neutralises exactly two moles of HCl; its purity and stability make it a primary standard.

SOLVED EXAMPLE 10 — WHY BCl_3 IS A MONOMER BUT $AlCl_3$ DIMERISES

BCl_3 exists as a monomer, while $AlCl_3$ forms Al_2Cl_6. Explain.

SOLUTION

1. Boron is small; four large Cl atoms cannot fit comfortably around it, and B–Cl back bonding partly relieves its electron deficiency.
2. Al is larger: it can accommodate four Cl atoms, and it completes its octet by accepting a lone pair from a bridging Cl.

ANSWER Size: small B cannot dimerise through bulky Cl bridges; larger Al can.

SOLVED EXAMPLE 11 — GRAPHITE AND DIAMOND: CONDUCTIVITY

Explain why graphite conducts electricity while diamond does not, though both are pure carbon.

SOLUTION

1. Diamond: every carbon is sp^3 and uses all four electrons in localised σ bonds — no mobile electrons.
2. Graphite: each carbon is sp^2, bonded to three others; the fourth electron is in a p orbital delocalised over the whole layer.

ANSWER Delocalised π electrons in graphite carry current along the layers; diamond has none.

SECTION K

Exam trap gallery

K

Where marks are lost in this chapter.

✗ TRAP 01 · WHAT STUDENTS WRITE	✓ WHAT IS ACTUALLY CORRECT
BF_3 is the strongest Lewis acid among the boron halides (F is most electronegative).	BF_3 is the weakest: $BF_3 < BCl_3 < BBr_3 < BI_3$.

WHY pπ–pπ back bonding partly fills boron's empty p orbital in BF_3.

✗ TRAP 02 · WHAT STUDENTS WRITE	✓ WHAT IS ACTUALLY CORRECT
Boric acid is a tribasic protonic acid.	It is a monobasic Lewis acid.

WHY It accepts OH^- from water to give $[B(OH)_4]^- + H^+$.

✗ TRAP 03 · WHAT STUDENTS WRITE	✓ WHAT IS ACTUALLY CORRECT
Diborane has 8 two-centre two-electron bonds.	4 two-centre bonds and 2 three-centre two-electron bonds.

WHY Only 12 valence electrons are available.

✗ TRAP 04 · WHAT STUDENTS WRITE	✓ WHAT IS ACTUALLY CORRECT
Al is smaller than Ga.	Ga (135 pm) is smaller than Al (143 pm).

WHY Poor shielding by 3d electrons in Ga.

✗ TRAP 05 · WHAT STUDENTS WRITE	✓ WHAT IS ACTUALLY CORRECT
Tl^{3+} is more stable than Tl^+.	Tl^+ is more stable (inert pair effect).

WHY Tl^{3+} is therefore an oxidising agent.

✗ TRAP 06 · WHAT STUDENTS WRITE	✓ WHAT IS ACTUALLY CORRECT
Pb^{4+} compounds are more stable than Pb^{2+}.	Pb^{2+} is more stable; PbO_2 is a strong oxidant; PbI_4 does not exist.
WHY Inert pair effect.	

✗ TRAP 07 · WHAT STUDENTS WRITE	✓ WHAT IS ACTUALLY CORRECT
CCl_4 hydrolyses like $SiCl_4$.	CCl_4 does not hydrolyse.
WHY Carbon has no vacant d orbitals.	

✗ TRAP 08 · WHAT STUDENTS WRITE	✓ WHAT IS ACTUALLY CORRECT
Diamond is the most stable allotrope of carbon.	Graphite is the most stable ($\Delta fH^\circ = 0$).
WHY Diamond is metastable at room conditions.	

✗ TRAP 09 · WHAT STUDENTS WRITE	✓ WHAT IS ACTUALLY CORRECT
Diamond conducts because it is carbon like graphite.	Diamond is an insulator.
WHY All four electrons are in localised σ bonds (sp^3).	

✗ TRAP 10 · WHAT STUDENTS WRITE	✓ WHAT IS ACTUALLY CORRECT
CO is an acidic oxide.	CO is neutral.
WHY It does not react with water or bases under ordinary conditions.	

✗ TRAP 11 · WHAT STUDENTS WRITE	✓ WHAT IS ACTUALLY CORRECT
$(CH_3)_3SiCl$ gives cross-linked silicones.	It is a chain terminator; CH_3SiCl_3 gives cross-links.
WHY One –OH caps; three –OH groups branch.	

✗ TRAP 12 · WHAT STUDENTS WRITE	✓ WHAT IS ACTUALLY CORRECT
Aqueous borax is acidic because it contains boric acid units.	Aqueous borax is alkaline.
WHY It hydrolyses to NaOH (strong base) + H_3BO_3 (weak acid).	

MEMORY HOOK

"F back-feeds boron" — BF_3 is the weakest boron-halide Lewis acid.

"Twelve electrons, two bananas" — diborane.

"Lazy pair at the bottom" — Tl^+, Pb^{2+}.

"Si says yes to water, C says no" — tetrachloride hydrolysis.

SECTION L

Practice MCQs

L

Levels: Easy, Moderate, Tough.

Q01 The most stable oxidation state of thallium is: [EASY]

(a) +1 (b) +2
(c) +3 (d) +4

Q02 Boric acid is: [EASY]

(a) a tribasic acid (b) a monobasic Lewis acid
(c) a strong acid (d) a base

Q03 Colour of the cobalt borax bead: [EASY]

(a) green (b) blue
(c) brown (d) red

Q04 The hardest natural substance is: [EASY]

(a) graphite (b) diamond
(c) fullerene (d) quartz

Q05 CO is: [EASY]

(a) acidic (b) basic
(c) neutral (d) amphoteric

Q06 Which element does not show catenation? [EASY]

(a) C (b) Si
(c) Ge (d) Pb

Q07 Formula of borax: [EASY]

(a) $Na_2B_4O_7{\cdot}10H_2O$ (b) $Na_2B_4O_7{\cdot}5H_2O$
(c) $NaBO_2$ (d) H_3BO_3

Q08 Correct order of Lewis acid strength: [MODERATE]

(a) $BF_3 > BCl_3 > BBr_3$ (b) $BBr_3 > BCl_3 > BF_3$
(c) $BCl_3 > BF_3 > BBr_3$ (d) all equal

Q09 Number of 3c–2e bonds in diborane: [MODERATE]

(a) 1 (b) 2
(c) 4 (d) 6

Q10 $AlCl_3$ exists as a dimer because: [MODERATE]

(a) Al has d orbitals (b) Al completes its octet using a lone pair of bridging Cl
(c) it is ionic (d) of hydrogen bonding

Q11 Which is amphoteric? [MODERATE]

(a) B_2O_3
(b) Al_2O_3
(c) Tl_2O_3
(d) CO_2

Q12 Ga has a smaller atomic radius than Al because of: [MODERATE]

(a) inert pair effect
(b) poor shielding by 3d electrons
(c) lanthanoid contraction
(d) higher electronegativity only

Q13 Diborane reacts with NH_3 on heating to give: [MODERATE]

(a) B_2O_3
(b) borazine
(c) $NaBH_4$
(d) boric acid

Q14 Hybridisation of carbon in graphite: [MODERATE]

(a) sp
(b) sp^2
(c) sp^3
(d) sp^3d

Q15 Fullerene C_{60} contains: [MODERATE]

(a) 20 pentagons and 12 hexagons
(b) 12 pentagons and 20 hexagons
(c) 30 hexagons
(d) 60 pentagons

Q16 Which hydrolyses readily? [MODERATE]

(a) CCl_4
(b) $SiCl_4$
(c) both
(d) neither

Q17 Producer gas is a mixture of: [MODERATE]

(a) $CO + H_2$
(b) $CO + N_2$
(c) $CO_2 + H_2$
(d) $CH_4 + H_2$

Q18 Which does not exist? [MODERATE]

(a) $PbCl_4$
(b) PbF_4
(c) PbI_4
(d) $SnCl_4$

Q19 ZSM-5 is used to: [MODERATE]

(a) soften water only
(b) convert alcohols to gasoline
(c) make silicones
(d) purify CO

Q20 Terminal and bridging B–H bond lengths in B_2H_6 are: [TOUGH]

(a) 134 and 119 pm
(b) 119 and 134 pm
(c) both 119 pm
(d) both 134 pm

Q21 Aqueous solution of borax is: [TOUGH]

(a) acidic
(b) neutral
(c) alkaline
(d) amphoteric

Q22 Cross-linked silicones are obtained by hydrolysis of: [TOUGH]

(a) $(CH_3)_3SiCl$ (b) $(CH_3)_2SiCl_2$

(c) CH_3SiCl_3 (d) $SiCl_4$ only

Q23 In the silicate $Si_2O_7^{6-}$, the number of oxygen atoms shared is: [TOUGH]

(a) 0 (b) 1

(c) 2 (d) 3

Q24 CO is a good ligand because it is: [TOUGH]

(a) a σ-donor only (b) a π-acceptor only

(c) both a σ-donor and π-acceptor (d) ionic

Q25 Which is the strongest reducing agent? [TOUGH]

(a) $SnCl_2$ (b) $PbCl_2$

(c) CCl_4 (d) $SiCl_4$

Answer key with explanations

Q01 **(a) +1** — Inert pair effect.

Q02 **(b) a monobasic Lewis acid** — Accepts OH^-.

Q03 **(b) blue** — $Co(BO_2)_2$.

Q04 **(b) diamond** — sp^3 network.

Q05 **(c) neutral** — Neutral oxide.

Q06 **(d) Pb** — Weak Pb–Pb bond.

Q07 **(a) $Na_2B_4O_7{\cdot}10H_2O$** — Decahydrate.

Q08 **(b) $BBr_3 > BCl_3 > BF_3$** — Back bonding strongest in BF_3.

Q09 **(b) 2** — Two B–H–B bridges.

Q10 **(b) Al completes its octet using a lone pair of bridging Cl** — Electron-deficient Al.

Q11 **(b) Al_2O_3** — Reacts with acid and base.

Q12 **(b) poor shielding by 3d electrons** — d-block contraction.

Q13 **(b) borazine** — "Inorganic benzene".

Q14 **(b) sp^2** — Planar layers.

Q15 **(b) 12 pentagons and 20 hexagons** — Soccer-ball cage.

Q16 **(b) $SiCl_4$** — Vacant 3d orbitals on Si.

Q17 **(b) CO + N_2** — Air used instead of steam.

Q18 **(c) PbI_4** — Pb^{4+} oxidises I^-.

Q19 **(b) convert alcohols to gasoline** — Shape-selective zeolite catalyst.

Q20 **(b) 119 and 134 pm** — Bridging bonds are longer.

Q21 **(c) alkaline** — NaOH + weak H_3BO_3.

Q22 **(c) CH_3SiCl_3** — Three –OH groups.

Q23 **(b) 1** — Pyrosilicate.

Q24 **(c) both a σ-donor and π-acceptor** — Synergic bonding.

Q25 **(a) $SnCl_2$** — $Sn^{2+} \rightarrow Sn^{4+}$ readily.

Check-yourself answers

C1 Each Al has only six electrons in $AlCl_3$; a lone pair from a Cl of the other molecule completes its octet, so two units bridge through Cl.

C2 Tl^{+} is the more stable state (inert pair effect), so Tl^{3+} readily gains two electrons.

C3 Blue.

C4 Two.

C5 Graphite: each carbon uses three electrons in σ bonds; the fourth is delocalised over the layer and carries current.

C6 Silicon has vacant 3d orbitals that accept a lone pair from water; carbon has none.

QUICK REVISION

One-page revision

Read this page the night before the exam.

Group 13 trends

- ns^2np^1; +3, and +1 down (Tl^+ stable)
- Ga (135) < Al (143) — d contraction
- Ga m.p. 303 K, b.p. 2676 K
- B_2O_3 acidic, Al_2O_3 amphoteric, Tl_2O_3 basic

Boron compounds

- BF_3 < BCl_3 < BBr_3 (back bonding)
- Borax $Na_2[B_4O_5(OH)_4]\cdot 8H_2O$; alkaline
- Co bead blue; H_3BO_3 monobasic Lewis acid
- B_2H_6: 4 terminal + 2 banana bonds

Diborane and Al

- $2NaBH_4 + I_2 \rightarrow B_2H_6$
- $B_2H_6 + NH_3 \rightarrow$ borazine; + NaH → $NaBH_4$
- Al dissolves in HCl and NaOH; passive to HNO_3
- $AlCl_3$ dimer Al_2Cl_6

Group 14 trends

- ns^2np^2; +4 and +2 (Pb^{2+} stable)
- Catenation C ≫ Si > Ge ≈ Sn; Pb none
- $SiCl_4$ hydrolyses, CCl_4 does not
- PbI_4 does not exist

Carbon

- Diamond sp^3, graphite sp^2 (most stable)
- C_{60}: 12 pentagons, 20 hexagons
- CO neutral, toxic; σ-donor π-acceptor
- CO_2 acidic, linear; dry ice

Silicon

- SiO_2 3D network; attacked by HF, NaOH
- Silicones $(R_2SiO)_n$; R_3SiCl caps; $RSiCl_3$ cross-links
- Silicates: ortho, pyro, chain, sheet, 3D
- Zeolites; ZSM-5 alcohol → gasoline

END OF NOTES · RAMGOVINDYADAV.COM