Unit 7 · Chemical Bonding

STUDY NOTES

Key terms

Covalent bond: mutual sharing of a pair of electrons, each atom giving one; half-filled orbitals overlap.

Covalency: number of covalent bonds an atom makes = its unpaired outer electrons.

Lone pair: outer pair belonging to one atom alone.

Bond length / bond energy: distance between bonded nuclei / energy to break 1 mole of the bonds (H–H: 74 pm, 436 kJ/mol).

Sigma (σ) bond: head-on (axial) overlap, on the axis between the nuclei.

Pi (π) bond: sideways (lateral) overlap of parallel p orbitals, above and below the axis.

Coordinate covalent (dative) bond: shared pair, both electrons from one atom; A→B, donor to acceptor.

Avogadro number N_A: particles in one mole, 6.022×10^{23}.

Gram atom: atomic mass in grams; 6.022×10^{23} atoms.

Gram mole (gram molecule): molecular mass in grams; 6.022×10^{23} molecules.

Mole (mol): amount with 6.022×10^{23} particles.

Molar volume: volume of 1 mole of any gas at STP, 22.4 L.

Atomicity: atoms in one molecule of an element.

Vapor density (VD): mass of a volume of a gas ÷ mass of the same volume of hydrogen, same temperature and pressure.

Formulas

$n = m/M$	n moles; m mass (g); M molar mass (g/mol) **Use:** moles from a mass
$N = n \times N_A$	N particles **Use:** how many particles
$n = V/22.4$ L	V volume at STP (L) **Use:** gas at STP only
$V_1/n_1 = V_2/n_2$	constant temperature, pressure **Use:** Avogadro's law
molecular mass $= 2 \times$ VD	hydrogen is H_2, mass 2 **Use:** mass from vapor density

- mass of one molecule = $M \div N_A$: CO_2 $44 \div 6.022 \times 10^{23} = 7.31 \times 10^{-23}$ g
- say what you count: 1 gram atom O = 16 g; 1 gram mole O_2 = 32 g

Why atoms bond

- bonded atoms have **less energy** than apart; noble gases already lowest (duplet or octet)
- **transfer** (metal → non-metal): ions, electrovalent bond, Na^+Cl^-
- **sharing** (non-metals): covalent bond
- electronegativity difference > about 1.7 → mostly ionic (Na, Cl: 2.23); less → covalent; a guide only (HF 1.78, covalent)

Covalent bond

- both nuclei attract the shared pair between them = the bond; protons repel if too close → one distance of lowest energy
- half-filled orbital + half-filled orbital, opposite spins; more overlap → stronger

Atom	Outer	Unpaired	Covalency
H	$1s^1$	1	1
Cl	$3s^2\ 3p^5$	1	1
O	$2s^2\ 2p^4$	2	2
N	$2s^2\ 2p^3$	3	3
C	$2s^2\ 2p^2$	2, 4 in compounds	4

- carbon: 2s electron moves to empty 2p → 4 unpaired; two extra bonds pay for the move
- dot-and-cross: every outer electron. Structural: one line per shared pair (single, double, triple)
- H_2O: 2 lone pairs, bent 104.5°. CO_2: O=C=O, straight, 4 lone pairs
- **polar**: more electronegative atom pulls the pair (H δ+, Cl δ−); **non-polar**: same atoms
- Lewis 1916; Langmuir named it 1919; Pauling's book 1939

Covalent compounds

1. gases, liquids, soft solids (ionic: hard crystals)
2. low m.p., b.p.: only weak forces between molecules are overcome (CH_4 −182 °C; NaCl 801 °C)
3. poor conductors: no ions, no free electrons. Exceptions: graphite; HCl forms ions with water
4. most insoluble in water, soluble in kerosene, alcohol; **like dissolves like**; polar ones (sugar, ethanol, NH_3, HCl) dissolve in water
5. slow reactions: bonds broken and remade; ionic in solution almost instant
6. fixed shapes: bonds are directional → isomers

- organic melt lower than inorganic because covalent, not because "organic": water, NH_3, CO_2 low too; **giant covalent**: quartz about 1,700 °C, graphite solid to about 3,600 °C

Organic	m.p. / b.p. (°C)	Ionic	m.p. / b.p. (°C)
methane	−182 / −162	NaCl	801 / 1,413
ethanol	−114 / 78	$CaCl_2$	772 / 1,935
ethanoic acid	17 / 118	CaO	2,613 / 2,850
naphthalene	80 / 218	MgO	2,852 / 3,600

Sigma and pi

σ	π
head-on, on the axis	sideways, above and below
s–s, s–p, p–p	p–p (or d) only
large overlap; stronger	smaller overlap; weaker
can exist alone	only after a σ bond
atoms can rotate	no rotation (flat, rigid)

- bonds:
  - single 1 σ
  - double 1 σ + 1 π
  - triple 1 σ + 2 π
- every line between two atoms has one σ: CO_2 2 σ, 2 π; H–C≡N 2 σ, 2 π
- N≡N: one p pair head-on, σ; two p pairs sideways, 2 π; 945 kJ/mol, so N_2 (78% of air) hardly reacts

Bond	kJ/mol	pm
C–C	347	154
C=C	614	134
C≡C	839	120

- π adds only 614 − 347 = 267 → alkenes, alkynes react at π; alkanes don't
- O_2 paramagnetic: 2 unpaired in π orbitals (Grade 11); for exams O=O, 1 σ + 1 π

Coordinate covalent bond

- **donor**: lone pair; **acceptor**: empty orbital, two electrons short
- once formed, **exactly like** any covalent bond; the arrow only records where the pair came from

Covalent	Coordinate
each gives one electron	both from one atom
needs unpaired electrons	lone pair + empty orbital
A–B: H_2, Cl_2, H_2O, CH_4	A→B: NH_4^+, H_3O^+, O_3, SO_3

- $NH_3 + H^+ \rightarrow NH_4^+$: four identical N–H, tetrahedron, 109.5°; salts: NH_4Cl, ammonium sulphate, DAP
- $H_2O + H^+ \rightarrow H_3O^+$: the "$H^+$" of every acid
- O_3: O=O→O, bent; SO_3: one S=O, two S→O, flat triangle; $SO_3 + H_2O \rightarrow H_2SO_4$
- really resonance hybrids: both O–O in O_3 128 pm (single 148, double 121); all S–O 142 pm; in exams draw as above
- $H_3N{\rightarrow}BF_3$ (B has 6 outer electrons); C≡O: one pair from O to C
- CO gives its lone pair to iron in hemoglobin, held about 200–250 × as tightly as O_2: no charcoal fire in a closed room

The mole

Element	Atomic mass	1 gram atom
H, C	1, 12	1 g, 12 g
Na, Fe	23, 56	23 g, 56 g

- 9 g H_2O = 0.5 mol = 3.011×10^{23} molecules = 6.022×10^{23} H atoms
- **22.4 L at STP** (0 °C, 1 atm); IUPAC's 1 bar gives 22.7 L; use 22.4 unless told
- 11 g CO_2 = 0.25 mol = 5.6 L = 1.51×10^{23} molecules
- water has no molar volume at STP: not a gas

Avogadro's law

Equal volumes of all gases, at the same temperature and pressure, contain equal numbers of molecules.

- Gay-Lussac 1808: gases react in whole-number volumes; Avogadro 1811; Cannizzaro, Karlsruhe 1860
- why: molecules tiny against the space; same temperature → same average kinetic energy → same push each

Uses

1. molar volume: 22.4 L for any gas at STP
2. atomicity: 1 vol H_2 + 1 vol Cl_2 → 2 vol HCl → $n + n \rightarrow 2n$ molecules → each H molecule gives 2 HCl, so it has at least 2 atoms: H_2
3. VD = (n × mass of gas molecule) ÷ (n × mass of H_2) = $M \div 2$
4. gas reactions: numbers in the equation = volumes: $N_2 + 3H_2 \rightarrow 2NH_3$ is 1 : 3 : 2

- balloon: 0.50 mol, 12 L + 0.25 mol → 18 L
- 10 L CH_4 + 20 L O_2 → 10 L CO_2 (water condenses)
- propane: 1 L needs 5 L O_2 = 5 ÷ 0.21 ≈ 24 L of air

COMMON MISTAKES

✗ two σ in a double bond
✓ 1 σ + 1 π.

✗ coordinate bond is different once formed
✓ identical to the others (NH_4^+).

✗ boiling water breaks O–H bonds
✓ only separates the molecules.

✗ n = 22.4 ÷ V
✓ n = V ÷ 22.4.

✗ VD = 2 × M
✓ M = 2 × VD (SO_2: M 64, VD 32).

✗ atoms = $n \times N_A$
✓ multiply by the atoms in a molecule too.

✗ volume ratio from masses
✓ from the equation's numbers, for gases at the same T and P.

✗ 22.4 L for water, or away from STP
✓ gases at STP only.