Unit 7 · States of Matter

STUDY NOTES

WHAT NEB'S GRADE 11 EXAM ASKS

- **CDC's grid (2077):** Physical Chemistry (Units 1–8 together): 28 of 75 marks
- **The paper:** 11 MCQs × 1 · 8 short × 5 · 3 long × 8; 3 hours; 1 mark per expected point
- **CDC's model paper:** MCQ: the property of crystals with similar chemical composition (isomorphism); short question (OR): derive $PV = nRT$ from the gas laws; two conditions for a real gas to behave ideally
- **MCQ (1 mark)**
  - Boyle at double pressure; Boyle's graph; the law of a heated piston; volume rise per °C (1/273); volume zero at
  - gas over water; fastest diffusing; which smell spreads first; a gas from effusion times; partial pressure from moles
  - most ideal at; closed vessel heated to 2T; boiling point lowest where; salt in water; pressure cooker
  - most viscous; capillary action; liquid crystal properties; molecular solid; efflorescence; unit cell; diamond; water in $CuSO_4$, gypsum, washing soda
- **Short (5 marks, in parts)**
  - kinetic postulates (which explains pressure); state Boyle, Charles, Dalton with graphs and uses
  - differences: diffusion/effusion, real/ideal gas, evaporation/boiling, crystalline/amorphous, efflorescent/deliquescent/hygroscopic
  - reasons: hot air balloon, LPG, NH_3 faster than O_2, tyres burst in summer, glycerine on skin, liquid crystals
  - R's value and unit; molar mass from PV = nRT; moist gas over water; mixtures' partial pressures; Graham's forms; absolute zero
  - $CuSO_4 \cdot 5H_2O \rightarrow CuSO_4$: % water (250 g → 160 g: 36%); SC and FCC cells; ice's lattice
- **Long (8 marks)**: partial pressures of mixed gases (two bulbs, stopcock); Boyle's isotherms, real gases, a balloon rising; Charles's line and 0 K; Graham with numbers (NH_3 and HCl in a 24 cm tube); vapor-pressure curves; drops and surface tension; hydrides' boiling points; marbles in liquids (viscosity)

Key terms

Pressure: force per unit area; 1 atm = 101 325 Pa = 760 mmHg = 760 torr; 1 bar = 10^5 Pa.

STP: 0 °C (273.15 K) and 1 atm; 1 mol of gas fills 22.4 L.

Absolute zero: −273.15 °C (0 K), where an ideal gas's volume would be zero; can't be reached.

Partial pressure: pressure one gas of a mixture would exert alone in the same volume.

Mole fraction χ: moles of one gas ÷ total moles.

Aqueous tension f: vapor pressure of water at that temperature.

Diffusion: spreading of a gas by itself through another; **effusion**: escape through a tiny hole.

Ideal gas: obeys $PV = nRT$ exactly: no molecular volume, no attractions.

Compressibility factor: $Z = PV/nRT$; 1 for an ideal gas.

Vapor pressure: pressure of a vapor in equilibrium with its liquid.

Boiling point: temperature at which vapor pressure = pressure above the liquid.

Surface tension γ: force along the surface per unit length (N/m).

Viscosity η: resistance to flow (Pa s; 1 poise = 0.1 Pa s).

Liquid crystal: flows like a liquid with its molecules partly ordered (nematic, smectic, cholesteric).

Anisotropic: properties differ with direction (crystals); **isotropic**: the same (amorphous solids).

Isomorphism: different substances of similar formula with the same crystal form (KH_2PO_4, KH_2AsO_4; the alums).

Polymorphism: one substance in more than one crystal form ($CaCO_3$: calcite, aragonite); for an element, **allotropy** (diamond, graphite; rhombic, monoclinic sulphur).

Transition temperature: where two forms are in equilibrium and one turns into the other (rhombic $\rightleftharpoons$ monoclinic sulphur, 95.6 °C).

Crystal habit: the outward shape a crystal grows into (NaCl cubes from water, octahedra from urea solution).

Efflorescent: loses water of crystallization to air; **hygroscopic**: takes up moisture, stays solid; **deliquescent**: takes up moisture and dissolves.

Water of crystallization: water held in fixed proportion in a crystal ($CuSO_4 \cdot 5H_2O$).

Unit cell: smallest repeating unit of a crystal lattice (a, b, c, α, β, γ).

Formulas

$P_1V_1 = P_2V_2$	n, T fixed **Use:** Boyle
$\frac{V_1}{T_1} = \frac{V_2}{T_2}$	n, P fixed; T in K **Use:** Charles
$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$	fixed n **Use:** combined
$PV = nRT = \frac{w}{M}RT$	R = 0.0821 L atm/(mol K) **Use:** ideal gas
$d = \frac{PM}{RT}$	R = 8.314 J/(mol K) **Use:** gas density
$P_1 = \chi_1 P$	P total; dry = moist − f **Use:** Dalton
$\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}} = \sqrt{\frac{d_2}{d_1}}$	$= t_2/t_1 = V_1/V_2 = l_1/l_2$ **Use:** Graham
$\left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT$	a, b per gas **Use:** van der Waals
$\frac{\gamma_1}{\gamma_2} = \frac{n_2 d_1}{n_1 d_2}$	n drops **Use:** drop count
$F = \eta A \frac{dv}{dx}$	η in Pa s **Use:** viscosity

Gases

Kinetic theory

1. tiny particles in constant random straight-line motion
2. their own volume negligible
3. no attractions or repulsions
4. collisions perfectly elastic
5. **pressure from hits on the walls**
6. average kinetic energy $\propto T$

The laws

- **Boyle**: at constant T, $V \propto 1/P$; P–V a hyperbola (farther out when hotter), P–1/V a line through 0, PV–P flat; double P, half V
- **Charles**: at constant P, $V \propto T$; 1/273 of V_0 per °C; V–t line meets −273 °C
- **pressure law** (Gay-Lussac): $P \propto T$ at constant V: tyres burst in summer, sag in winter
- **Avogadro**: $V \propto n$ at constant T, P

The ideal gas equation

1. $V \propto 1/P$ (Boyle), $V \propto T$ (Charles), $V \propto n$ (Avogadro)
2. so $V \propto nT/P$, $V = RnT/P$
3. $PV = nRT$

- R = PV/nT: work per mole per kelvin; $1 \times 22.414/273.15 = 0.0821$ L atm/(mol K); 8.314 J/(mol K); 1.987 cal/(mol K)
- 3.20 g in 2.0 L at 17 °C, 380 mmHg: $M = wRT/PV = 3.20 \times 0.0821 \times 290/(0.500 \times 2.0) = 76.2$ g/mol

Dalton: total pressure = sum of partial pressures (non-reacting gases)

- 2 mol N_2 + 3 mol O_2 at 10 atm: N_2 4 atm
- over water: 645 − 23.8 = 621 mmHg dry

Graham: rate $\propto 1/\sqrt{M}$ (same KE, heavier slower)

- H_2 4 times as fast as O_2
- NH_3 (17) and HCl (36.5), 24 cm tube: meet 14.3 cm from the NH_3 end ($l_1/l_2 = 1.465$)
- H_2 escapes before He from equal holes

Real gases: deviate at **high P, low T**

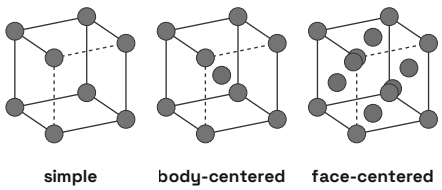
- molecules' own volume matters (Z > 1) and attractions matter (Z < 1)
- ideal at **low pressure and high temperature**; Z → 1 as P → 0
- CO_2 liquefies at ~60 atm; an ideal gas never would

Liquids

- **evaporation**: at the surface, at any temperature, cools the liquid; faster when hotter, larger surface, weaker forces

- **vapor pressure** rises with T; lower for stronger forces (ether 0.70 > ethanol 0.08 > water 0.03 atm at 25 °C)
- **boils** when vapor pressure = outside pressure: lower up a mountain (Jomsom); higher in a pressure cooker; salt raises it
- **surface tension**: unbalanced inward pull at the surface; falls with T and with soap; round drops, capillary rise
  - water: adhesion > cohesion, concave, rises; mercury: convex, falls
- **viscosity**: falls with T; higher for big molecules and strong forces (glycerol: three OH, H-bonds); Ostwald viscometer
- **liquid crystals** (Reinitzer, 1888): nematic (aligned), smectic (aligned, in layers), cholesteric (twisting); anisotropic; LCDs, strip thermometers

Solids



Simple cubic, body-centered and face-centered cubic cells.

Crystalline	Amorphous
long-range order	short-range only
definite shape, flat faces	no definite shape
sharp melting point	soften over a range
anisotropic, cleave	isotropic, break curved
NaCl, quartz, ice, Cu	glass, rubber, plastic

Type	Particles	Held by	Example
ionic	ions	ionic bonds	NaCl
network	atoms	covalent bonds	diamond, SiO_2
molecular	molecules	weak forces	ice, I_2, dry ice
metallic	cations, electrons	metallic bond	Cu

- efflorescent: $Na_2CO_3{\cdot}10H_2O$, $Na_2SO_4{\cdot}10H_2O$ (mass falls); hygroscopic: CaO, silica gel, anhydrous $CuSO_4$; deliquescent: NaOH, KOH, $CaCl_2$, $MgCl_2$
- $CuSO_4 \cdot 5\,H_2O \xrightarrow{\Delta} CuSO_4 + 5\,H_2O$: blue → white; water turns it blue again
- water of crystallization: $CuSO_4{\cdot}5H_2O$ 5, gypsum $CaSO_4{\cdot}2H_2O$ 2, washing soda 10; % water = mass lost ÷ mass taken × 100
- **crystallization**: nucleation then growth; slow cooling → big crystals; purifies solids
- **unit cell**: 7 crystal systems; cubic a = b = c, all 90°
- atoms per cell: **SC 1** ($8 \times ⅛$), **BCC 2**, **FCC 4** ($8 \times ⅛ + 6 \times ½$)

COMMON MISTAKES

✗ R = 8.324 J/(mol K); 224 L
✓ 8.314; 22.4 L.

✗ Avogadro: $V_1 n_1 = V_2 n_2$
✓ $V_1/n_1 = V_2/n_2$.

✗ gas chromatography uses Graham's law
✓ it separates by how the column holds each gas.

✗ rails' gaps show Charles's law
✓ solids' thermal expansion.

✗ water's critical temperature 3744 K
✓ 647 K (374 °C).

✗ surface molecules have more energy
✓ same average; only the fast ones at the surface escape.

✗ heating a hydrate is efflorescence
✓ efflorescence is losing water to the air at room temperature.

✗ crystalline solids are generally soluble
✓ diamond, quartz, metals don't dissolve.