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States of Matter

Boyle's Law

"At constant temperature, the volume of a given mass of gas is inversely proportional to its pressure."

$$P \propto \frac{1}{V} \Rightarrow PV = K$$
$$P_1V_1 = P_2V_2 = K$$

Also,

$$d \propto P \quad \text{and} \quad d \propto \frac{1}{V}$$
$$\frac{d_1}{d_2} = \frac{P_1}{P_2} = \frac{V_2}{V_1}$$

Low pressure at high altitudes reduces air density, necessitating oxygen cylinders for climbers.

Charles's Law

"At constant pressure, the volume of a gas is directly proportional to its absolute temperature."

$$V \propto T \Rightarrow \frac{V_1}{T_1} = \frac{V_2}{T_2}$$
$$d \propto \frac{1}{T} \Rightarrow \frac{d_1}{d_2} = \frac{T_2}{T_1}$$

Gay-Lussac's Law

"At constant volume, the pressure of a gas is directly proportional to its absolute temperature."

$$P \propto T \Rightarrow \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Avogadro's Law

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

$$V \propto n \Rightarrow V = Kn$$

Ideal Gas Equation

Combining all gas laws:

$$PV = nRT$$

R values:

- 0.0821 L atm mol⁻¹ K⁻¹
- 8.314 J mol⁻¹ K⁻¹
- 1.987 cal mol⁻¹ K⁻¹

Also,

$$M = \frac{wRT}{PV} \quad \text{and} \quad d = \frac{PM}{RT}$$

Dalton's Law of Partial Pressures

"The total pressure of a gas mixture equals the sum of partial pressures of each gas."

$$P_{total} = P_1 + P_2 + \dots \quad \text{where} \quad P_i = X_i P_{total}$$

Graham's Law of Diffusion

"Rate of diffusion is inversely proportional to square root of molar mass."

$$\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}} = \sqrt{\frac{d_2}{d_1}}$$

Kinetic Theory of Gases

- Gases consist of tiny particles in constant motion.
- Collisions are elastic.
- Negligible volume and no intermolecular forces.
- KE is proportional to temperature.

$$PV = \frac{1}{3}mnc^2$$

Real Gases and Deviations

Compressibility Factor:

$$Z = \frac{PV}{nRT} \quad Z = 1(\text{ideal}), Z \neq 1(\text{real})$$

- $Z > 1$: Repulsive forces dominate
- $Z < 1$: Attractive forces dominate

Van der Waals Equation:

$$\left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT$$

a corrects for attraction, b for volume.

Liquefaction of Gases

- **Critical Temperature (T_c):** Above which gas cannot liquefy.
- **Critical Pressure (P_c):** Pressure required at T_c .
- **Critical Volume (V_c):** Volume at T_c and P_c .

Solid State

Amorphous vs Crystalline Solids

- Amorphous: Disordered, isotropic, e.g., glass.
- Crystalline: Ordered, anisotropic, e.g., NaCl.

Types of Crystalline Solids

Type	Constituents	Forces	Properties	Example
Molecular	Molecules	van der Waals/H-bond	Soft, non-conductor	Ice, CO ₂
Ionic	Ions	Electrostatic	Hard, conductor when molten	NaCl, MgO
Covalent	Atoms	Covalent bonds	Hard, high T_m , poor conductor	Diamond, Si
Metallic	Positive ions + e ⁻	Metallic bond	Conductive, malleable	Fe, Cu

Unit Cell and Lattices

- **Simple Cubic:** $Z = 1$
- **Body-Centered Cubic (BCC):** $Z = 2$
- **Face-Centered Cubic (FCC):** $Z = 4$

Crystal Systems

System	Axes	Angles	Examples
Cubic	$a = b = c$	$\alpha = \beta = \gamma = 90^\circ$	NaCl, Cu
Tetragonal	$a = b \neq c$	$\alpha = \beta = \gamma = 90^\circ$	TiO ₂
Orthorhombic	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90^\circ$	KNO ₃
Hexagonal	$a = b \neq c$	$\alpha = \beta = 90^\circ, \gamma = 120^\circ$	Graphite
Rhombohedral	$a = b = c$	$\alpha = \beta = \gamma \neq 90^\circ$	Calcite
Monoclinic	$a \neq b \neq c$	$\alpha = \gamma = 90^\circ, \beta \neq 90^\circ$	Na ₂ SO ₄ · 10H ₂ O
Triclinic	$a \neq b \neq c$	$\alpha \neq \beta \neq \gamma \neq 90^\circ$	CuSO ₄ · 5H ₂ O

Cubic Density Formula

$$\rho = \frac{Z \cdot M}{a^3 \cdot N_A}$$

Where Z = number of particles, M = molar mass, a = edge length, N_A = Avogadro number.