Chapter 1. The properties of gases

Gas - a form of matter that fills any container it occupies

Physical state - the state of physical properties of a sample such as volume, mole, pressure, and temperature

Mole - the number of atoms or molecules equal to Avogadro’s number \( \text{N}_A = 6.022137 \times 10^{23} \), which is defined as the number of atoms in exactly 12 grams of \(^{12}\text{C}\).

Pressure - the amount of force applied to a surface of unit area

\text{SI unit of force : Newton (N) = 1 kgms}^{-2}

\text{SI unit of pressure : Pascal (Pa) = 1 N m}^{-2}

1 bar = 100,000 Pa, 1 atm = 101,325 Pa
Temperature

(1) The **degree of hotness** or coldness (general chemistry)

(2) The property that indicates the **direction of flow of energy** through a thermally conducting, rigid wall (Atkins and de Paula)

(3) Unique physical property that determines the **direction of heat flow** between two objects placed in thermal contact (macroscopic definition, wikipedia)

(4) **Average energy** of microscopic motions of a single particle in the system per degree of freedom (microscopic definition, wikipedia)

(5) A universal measure that determines the **capability of a system to give out or take in heat energy**

*Heat* - a form of non-mechanical energy due to the **random or uncontrollable** motion of atoms and molecules
Temperature scale

**Celsius scale** \( \theta \) : expressed in \( ^\circ C \)

Thermodynamic temperature scale: expressed in K, kelvins

\[ T/K = \frac{\theta}{^\circ C} + 273.15 \]

**Fahrenheit scale** \( f \) : expressed in \( ^\circ F \)

\[ f = 9 \frac{\theta}{5} + 32 \]

Standard ambient temperature and pressure (SATP) : 298.15 K and 1 bar

Standard temperature and pressure (STP): 273.15 K and 1 atm

**Diathermic** - transfer heat, **Adiabatic** - do not transfer heat

**Zeroth law of thermodynamics** - If systems A and B are in thermal equilibrium and systems B and C are also in thermal equilibrium, then A and C should be in thermal equilibrium when brought into thermal contact.
Ideal (perfect) gas law

\[ pV = nRT \quad \text{or} \quad pV_m = RT, \ V_m = V/n \]

\[ R = 8.31447 \ J K^{-1} \text{mol}^{-1} \]

Joule (J): Unit of energy, \( 1 \text{J} = 1 \text{kg m}^2 \text{ s}^{-2} \)

Real gas law - Virial equation of state

\[ pV_m = RT \left( 1 + B'p + C'p^2 + \ldots \right) \]

, or equivalently

\[ pV_m = RT \left( 1 + \frac{B}{V_m} + \frac{C}{V_m^2} + \ldots \right) \]

\( B', C', B, C, \ldots \) are temperature dependent parameters

Compression factor: \[ Z = \frac{pV_m}{RT} \]
Boyle Temperature, $T_B$

The second virial coefficient $B(T_B) = 0$.

Condensation - transformation of real gas to liquid at high pressure or low temperature

Critical Temperature, $T_c$

If $T > T_c$, no condensation, supercritical fluid

Critical pressure and volume, $p_c$ and $V_c$ - the pressure and volume where condensation starts to occur just below $T = T_c$
van Der Waals equation

\[ p = \frac{nRT}{V - nb} - a \left( \frac{n}{V} \right)^2 = \frac{RT}{V_m - b} - \frac{a}{V_m^2} \]

Decrease of volume due to finite size of molecules or atoms
Decrease of pressure due to attractive interactions between molecules or atoms

Can explain condensation - need Maxwell construction

\[ V_c = 3b, \quad T_c = \frac{8a}{27bR}, \quad p_c = \frac{a}{27b^2}, \quad Z_c = \frac{3}{8} = 0.375 \]

Compression factors of actual gases:
Ar - 0.292, CO\textsubscript{2} - 0.274, He - 0.305, O\textsubscript{2} - 0.308
Principle of corresponding states (PCS) - Real gases at the same reduced volume and reduced temperature exert the same reduced pressure. See Fig. 1.19

**Reduced variables**

\[ p_r = \frac{p}{p_c}, \quad V_r = \frac{V_m}{V_c}, \quad T_r = \frac{T}{T_c} \]
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van der Waals equation:

\[ p_r p_c = \frac{R T_r T_c}{V_r V_c - b} - \frac{a}{V_r^2 V_c^2} \]

\[ p_r \frac{a}{27 b^2} = \frac{T_r}{(3V_r - 1)} \frac{8a}{27b^2} - \frac{a}{V_r^2} \frac{1}{9b^2} \]

\[ p_r = \frac{8T_r}{(3V_r - 1)} - \frac{3}{V_r^2} \]

Consistent with the PCS.

True for any equation with two parameters.