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 Avogradro's number $N_A = 6.022137 \times 10^{23}$, which is defined as the number of atoms in exactly 12 grams of ^{12}C.

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

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

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 universial 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 θ : expressed in °C

Thermodynamic temperature scale: expressed in K, kelvins

$T/K = \theta/°C + 273.15$

Fahrenheit scale f: expressed in °F

$f = 9\,\theta/5 + 32$

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

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

$$R = 8.31447 \text{ JK}^{-1}\text{mol}^{-1}$$

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

Real gas law -Virial equation of state

$$pV_m = RT(1 + B'p + C'p^2 + \ldots)$$

, or equivalently

$$pV_m = RT(1 + \frac{B}{V_m} + \frac{C}{V_m^2} + \ldots)$$

$B', C', B, C, \ldots$ are temperature dependent parameters

Compression factor: $Z = \dfrac{pV_m}{RT}$

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 attactive interactions between molecules or atoms

Can explain condensation - need Maxwell construction

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

Compression factors of actual gases:

Ar - 0.292, CO_2 - 0.274, He - 0.305, O_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

$$p_r = \frac{p}{p_c}, V_r = \frac{V_m}{V_c}, T_r = \frac{T}{T_c}$$

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van der Waals equation:

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

↓

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

↓

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

Consistent with the PCS.

True for any equation with two parameters.