

8 Temperature and Ideal Gases

Thermal Equilibrium

Two bodies or regions in thermal contact are said to be in **thermal equilibrium** with each other if they have equal temperature. There will be no net heat between them.

Temperature Scales

An **empirical scale** depends on the physical variation of a particular substance with temperature, e.g. the Centigrade scale depending on the melting and boiling point of water.

An **absolute temperature scale** is one that is independent of any physical property of matter, e.g. the thermodynamic scale known as the Kelvin scale. **Absolute zero** is the temperature at which all substances have minimal internal energy.

One **Kelvin** is defined as the fraction $\frac{1}{273.16}$ of the thermodynamic temperature of the triple point of water (0.01°C).

$$T \text{ in K} = T \text{ in } ^\circ\text{C} + 273.15 \text{ (given)}$$

The Ideal Gas Equation

An **ideal gas** is one which obeys the equation of state under all conditions of pressure, volume, and temperature.

The equation of state (i.e. ideal gas equation) is $pV = nRT$ (value of R given).

Another equivalent form of ideal gas equation is $pV = NkT$ (value of k given).

Boyle's Law (T constant)	Gay-Lussac's Law (V constant)	Charles' Law (p constant)
$p_1V_1 = p_2V_2$	$\frac{p_1}{T_1} = \frac{p_2}{T_2}$	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$

Kinetic Theory of Gases

Assumptions of the Kinetic Theory of Gases

D – Duration of collisions is negligible compared to the time interval between collisions

A – Attractive intermolecular forces between molecules are negligible

V – Volume of gas molecules is negligible compared to volume of gas/container

E – Perfectly elastic collisions

$$\text{Derivation of } p = \frac{Nm\langle c^2 \rangle}{V}$$

A molecule of mass m and velocity v_x is directed towards the right side of a box of length L .

Leftwards $F_{\text{wall on molecule}} = \frac{-2mv_x}{\Delta t}$. By N3L, $F_{\text{molecule on wall}} = \frac{2mv_x}{\Delta t}$ --- ①.

Time taken between collisions with *same* wall $\Delta t = \frac{2L}{v_x}$ --- ②.

② into ①: $F_{\text{molecule on wall}} = \frac{mv_x^2}{L}$.

For a box with N molecules, mean-square

$$\text{velocity } \langle v_x^2 \rangle = \frac{v_{x,1}^2 + v_{x,2}^2 + \dots + v_{x,N}^2}{N}$$

Thus, $F_{\text{total by } N \text{ molecules}} = \frac{Nm\langle v_x^2 \rangle}{L}$ --- ③.

Since $c^2 = v_x^2 + v_y^2 + v_z^2$,

thus $\langle c^2 \rangle = \langle v_x^2 \rangle + \langle v_y^2 \rangle + \langle v_z^2 \rangle$.

Since molecules are moving randomly, $\langle v_x^2 \rangle = \langle v_y^2 \rangle = \langle v_z^2 \rangle$, thus $\langle v_x^2 \rangle = \frac{1}{3}\langle c^2 \rangle$ --- ④.

④ into ③: $F_{\text{total by } N \text{ molecules}} = \frac{Nm\langle c^2 \rangle}{3L}$, and p of

one wall = $\frac{F}{A} = \frac{Nm\langle c^2 \rangle}{V}$ (given).

$$p = \frac{1}{3} \frac{Nm\langle c^2 \rangle}{V}$$

Kinetic Energy of a Molecule

Average KE of a molecule = $\frac{3}{2}kT = \frac{1}{2}m\langle c^2 \rangle$