# Heat and Thermodynamics

## ① KTG

1 lit-atm = 101.3 J

$K = \frac{R}{N_A} \Rightarrow 1.38 \times 10^{-23}$ J/mole-K

① $V_{rms} = \sqrt{\frac{3RT}{M}}$ ② $\bar{V}_{av} = \sqrt{\frac{8RT}{\pi M}}$ ③ $V_{mp} = \sqrt{\frac{2RT}{M}}$

$\sqrt{\frac{3KT}{m}}$ $\sqrt{\frac{8KT}{\pi m}}$ $\sqrt{\frac{2KT}{m}}$

$V_{rms} > \bar{V}_{av} > V_{mp}$

$\sqrt{3} : \sqrt{\frac{8}{\pi}} : \sqrt{2}$

② $\boxed{V_{rms} = \sqrt{\frac{3}{\gamma}}\, V_{sound}}$ $V_{sound} = \sqrt{\frac{\gamma RT}{M}}$

③ Pressure of an ideal gas

$\boxed{\vec{V} = V_x\hat{i} + V_y\hat{j} + V_z\hat{k}}$

a) change in momentum of molecule in collision

$\boxed{\Delta P = -2mV_x}$

$\boxed{\cancel{\Delta P} = \Delta F = \frac{M}{L}\Sigma V_x^2}$ $\boxed{\Delta P = \frac{M}{L}V_x^2}$

b) $\boxed{P_x = P_y = P_z}$

$\boxed{\frac{F_x}{A} = \frac{M}{AL}\Sigma V_x^2} = \frac{ma}{A} = \frac{mV}{At} \Rightarrow \frac{mV^2}{AL}$

④ $\bar{V^2} = 3\bar{V_x}^2 = 3\bar{V_y}^2 = 3\bar{V_z}^2$ $\boxed{\bar{V_x}^2 = \frac{\bar{V}^2}{3}}$

⑤ $\boxed{(V_{rms})_x = (V_{rms})_y = (V_{rms})_z = \frac{1}{\sqrt{3}} V_{rms}}$

⑥ $\boxed{PV = \frac{1}{3} mN(\bar{V^2}) = \frac{1}{3} mN (V_{rms})^2}$

$K.E. = \frac{3}{2}PV = \frac{3}{2}\cdot\frac{1}{2}mv^2 = \cancel{\frac{3}{2}RT} = \frac{1}{3}mv^2$

⑦ Relation b/w pressure and kinetic energy

$\boxed{\bar{K} = \frac{3}{2}PV} \Rightarrow \boxed{\frac{3}{2}k_B T}$ $\boxed{1e\cancel{x} = \frac{3}{2}PV}$

⑧ Mole conservation → Refer Notebook

a) $\boxed{n_1 + n_2 = n_1' + n_2'}$ b) $\boxed{\frac{P_1V_1}{RT_1} = \frac{P_2V_2}{RT_2}}$

→ depth of lake in fluid mech., calculated by mole conservation always.

| | | f |
|---|---|---|
| Monoatomic | → | 3 |
| Diatomic | → | 5 |
| Triatomic (non-linear) | → | 6 |
| Triatomic (linear) | → | 7 |

⑩ Degree of freedom (f)

$\boxed{F = 3N - R}$ N = No. of particles (mono, di, ...) R = No. of single bonds

⑪ Law of equipartition of Energy

$\boxed{K_{Gas} = \frac{f}{2} nRT = \frac{f}{2} PV}$

⑫ Internal Energy

$\boxed{\Delta U = \frac{f}{2} nR\Delta T = \frac{f}{2}(P_2V_2 - P_1V_1)}$

⑬ Mean free path ($\lambda$) $\boxed{n = N/V}$

$\boxed{\lambda = \frac{1}{\sqrt{2}\pi n d^2}} = \frac{RT}{\sqrt{2}\pi P N_A d^2} \Rightarrow \boxed{\frac{K_B T}{\sqrt{2}\pi P d^2}}$

d = diameter of molecule

# Thermodynamics

① $\boxed{W_{Total} = \int P\, dV}$ compression : −ve, expansion : +ve

| | Isobaric | Isochoric / Isometric | Isothermal |
|---|---|---|---|
| Work done | $P\Delta V = nR\Delta T$ | 0 | $2.3RT \log_{10}\frac{V_2}{V_1}$ or $\frac{P_1}{P_2}$ |

→ Bulk modulus

$\boxed{B_{Isothermal} = P}$

compressibility $\Rightarrow \boxed{K = 1/B}$

② First law of thermodynamics

$\boxed{\Delta Q = \Delta U + W}$ ~~$\Delta t=$~~

$\Delta U = \frac{f}{2}(P_2V_2 - P_1V_1) = \frac{f}{2} nR\Delta T$

## Heat Engine

$Q_{abs} > Q_{rej}$

① $Q_{abs} = Q_{rej} + W$

② $\eta = \frac{\text{output work}}{\text{input heat}}$ (input work / input heat)

$\boxed{\eta = 1 - \left[\frac{Q_{rej}}{Q_{abs}}\right]}$

$\Delta U$ = path function (not) — state function

→ For cyclic process $\boxed{\Delta U = 0}$

## Refrigerator

$Q_{rej} > Q_{abs}$

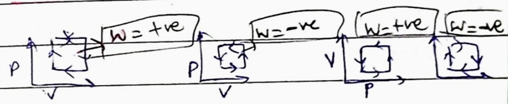
① $Q_{abs} + W = Q_{rej}$

② Coeff. of performance

$\boxed{K = \frac{Q_{abs}}{Work}}$ $\boxed{K = \frac{1}{\left(\frac{Q_{rej}}{Q_{abs}} - 1\right)}}$

$\boxed{K = \frac{1}{(\eta)} - 1}$ $\boxed{\frac{1}{\cancel{K}} = \frac{1}{\cancel{\beta}} + 1}$

③ closed cyclic P-V diagrams




④ gram sp. heat cap. $\boxed{\Delta Q = ms\Delta T}$

Molar sp. heat cap. $\boxed{\Delta Q = nC\Delta T}$

$\boxed{C = ms}$

⑤ $\boxed{C_V = f/2\, R}$

⑥ $\Delta Q_V = \Delta U = nC_V\Delta T = f/2\, nR\Delta T \rightarrow$ Isochoric process

⑦ $\boxed{C_P = C_V + R}$ → mayor's formula

$= \frac{f}{2}R + R$ $\boxed{\gamma = 1 + 2/f}$

⑧ $\boxed{C_P - C_V = R}$ → Molar s.H.C

$\boxed{S_P - S_V = R/M}$ → Gram s.H.C

⑨ $C_P$ and $C_V$ in terms of $\gamma$.

$\boxed{C_V = \frac{R}{(\gamma - 1)}}$ $\boxed{C_P = \frac{\gamma R}{(\gamma - 1)}}$

$\Delta Q = nC_P\Delta T$

$\Delta W = \Delta Q - \Delta U = n(C_P - C_V)\Delta T$

⑩ $\boxed{(\Delta Q)_V = nC_V\Delta T = \frac{nR\Delta T}{(\gamma - 1)} = \frac{P_2V_2 - P_1V_1}{(\gamma - 1)}}$

$\boxed{(\Delta Q)_V = nC_V\Delta T = \frac{f}{2}nR\Delta T = \frac{f}{2}(P_2V_2 - P_1V_1)}$

⑩ Mix. of Gas

$\boxed{(C_V)_{mix} = \frac{n_1 C_{V_1} + n_2 C_{V_2}}{n_1 + n_2}}$ $\boxed{C_{P_{mix}} = C_{V_{mix}} + R}$ $\boxed{\gamma_{mix} = \frac{C_{P_{mix}}}{C_{V_{mix}}}}$

Triple point of water → $273.16\,K$

↳ vapour, liquid, solid

$\boxed{\Delta Q = nC\Delta T}$

(11) $C_{process} = C$

(12) $C_{process}$ from eqⁿ $P$–$V$.

$$\boxed{C_{process} = C_V + \frac{R}{(1-a)}}$$

$\boxed{PV^a = \text{const}}$ $\boxed{\text{w.done} = \frac{nR\Delta T}{1-a}}$

(13) $W_{isobaric} > W_{isothermic} > W_{adiabatic} > W_D > W_m > W_{isocho}$

## Adiabatic process

a) $\boxed{PV^\gamma = \text{const}}$

b) $\boxed{TV^{\gamma-1} = \text{const}}$

c) $\boxed{P^{1-\gamma} \cdot T^\gamma = \text{const.}}$

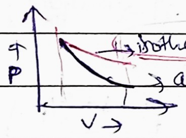
(1) Work done $\frac{P_2V_2 - P_1V_1}{1-\gamma}$ $\boxed{\frac{nR(T_2-T_1)}{1-\gamma}}$

(2) $\boxed{PV^\gamma = \text{const}}$

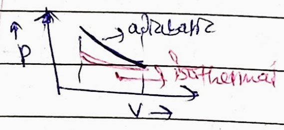
(3) $\Delta Q = \Delta U + W$

$\boxed{\Delta U = -W}$

expansion graph




compression graph




## Carnot engine

(1) $Q_{abs} = Q_{rej} + W$

(2) $\boxed{\frac{Q_{rej}}{Q_{abs}} = \frac{T_{sink}}{T_{source}}}$

(3) $\boxed{\eta = 1 - \frac{Q_{rej}}{Q_{abs}}}$

$\boxed{\eta = 1 - \frac{T_{sink}}{T_{source}}}$

$\boxed{\frac{1}{\beta} = \frac{1}{\alpha} + 1}$

## Carnot Refrigerator

(1) $Q_R = Q_a + W$.

(2) $\boxed{\frac{Q_R}{Q_a} = \frac{T_{source}}{T_{sink}}}$

(3) coeff. of performance

$$K = \frac{1}{\left(\frac{Q_R}{Q_a}\right) - 1} = \frac{1}{\left(\frac{T_{SO}}{T_{SI}} - 1\right)}$$

$\boxed{K = \frac{1}{\eta} - 1}$

efficiency of engine → $\frac{\text{work output}}{\text{Heat input}}$

superficial & cubical expansion

$\boxed{A_F = A_0(1+\beta\Delta T)}$ $\boxed{V_F = V_0(1+\gamma\Delta T)}$

$\gamma = \alpha_1 + \alpha_2 + \alpha_3$ → for Anisotropic $\boxed{\beta = \frac{2}{3}(\alpha_1 + \alpha_2 + \alpha_3)}$

$\boxed{\gamma = 3\alpha}$ → for isotropic

$\boxed{\beta = 2\alpha}$

## # 2nd law of thermo #

(1) change in entropy $(dS)$ = $\frac{\text{Heat absorbed by system}}{\text{Absolute temp.}}$

$$\boxed{dS = \frac{dQ}{T}}$$

(2) $\Delta S_{isotherm} = 2.3\, nR \log_{10} \frac{V_2}{V_1}$ or $\frac{P_1}{P_2}$

(3) $\boxed{S_{adi} = \text{const}}$

(3) $S_{isochoric} = 2.3 \log_{10} \frac{T_2}{T_1}\, nC_V$

(4) $S_{isobaric} = 2.3\, nC_p \log_{10} \frac{T_2}{T_1}$

(5) Melting pt or Boiling pt. → $\boxed{\Delta S = \frac{mL}{T}}$

(6) when change in temp occurs → $\boxed{\Delta S = 2.3\, ms \log_{10} \frac{T_2}{T_1}}$

## Thermal expansion

(1) $\frac{C - 0°C}{100° - 0°C} = \frac{°F - 32°F}{212F - 32F} = \frac{K - 273.15}{373.15 - 273.15}$

Reaumer → Rankine

$\frac{R - 0°R}{80R - 0°R} = \frac{Ra - 460°}{672 - 460°}$

(2) Linear expansion

$\boxed{L_F - L_0 = L_0\alpha\Delta T}$ $\boxed{L_F = L_0(1+\alpha\Delta T)}$

(2) If change in length remains const of 2 diff Rods

$\boxed{L_1\alpha_1 = L_2\alpha_2}$

(1) equivalent temp. coeff.

(1) series.

$\boxed{\alpha_{eq} = \frac{\Sigma L\alpha}{\Sigma L}}$

(2) Parallel

$\boxed{\Sigma = \frac{\Sigma \alpha/L}{\Sigma 1/L}}$

(3) pendulum

(1) at calibration temp

$\boxed{T = 2\pi\sqrt{l/g}}$

(2) At higher/lower temp

$\boxed{\Delta T = \frac{1}{2}\alpha.\Delta\theta.T}$ → time (1 day)

↳ time

$\boxed{V_{F_l} = V_0(1+\gamma_L\Delta T)}$

$\boxed{V_{F_C} = V_0(1+\gamma_C\Delta T)}$

$\boxed{V_{F_S} = V_0(1+3\alpha_S)\Delta T}$

$\Delta V_{app} = V_0 \gamma_{app}.\Delta\theta$ → $\boxed{V_0(\gamma_L - 3\alpha_S).\Delta T}$

$\gamma_{app} = \gamma_{liq} - \gamma_{solid}$