THERMODYNAMICS

JEE MAINS Physics — Class 11 — Complete formula Sheet

LAWS OF THERMODYNAMICS

Zeroth Law: Thermal equilibrium ⇒ same temperature

First Law: $\Delta U = Q - W$

Second Law: Heat flows hot→cold spontaneously

Third Law: $S \to 0$ as $T \to 0\,\text{K}$

Sign Conventions

- $Q > 0$: heat absorbed by system
- $W > 0$: work done *by* system
- $W = P\,\Delta V = \int P\,dV$

THERMODYNAMIC PROCESSES

Process Summary Table

Process	Condition	W
Isothermal	$T = \text{const}$	$nRT\ln\frac{V_2}{V_1}$
Adiabatic	$Q = 0$	$\frac{P_1V_1 - P_2V_2}{\gamma - 1}$
Isochoric	$V = \text{const}$	0
Isobaric	$P = \text{const}$	$P\Delta V$

Isothermal ($T = \text{const}$)

$$PV = \text{const}$$
$$W = nRT\ln\frac{V_2}{V_1} = nRT\ln\frac{P_1}{P_2}$$
$$\Delta U = 0, \quad Q = W$$

Adiabatic ($Q = 0$)

$$PV^\gamma = \text{const}, \quad TV^{\gamma-1} = \text{const}$$
$$TP^{1-\gamma/\gamma} = \text{const}$$
$$W = \frac{P_1V_1 - P_2V_2}{\gamma - 1} = \frac{nR(T_1 - T_2)}{\gamma - 1}$$
$$\Delta U = -W$$

Isochoric ($\Delta V = 0$)

$$W = 0, \quad \Delta U = Q = nC_v\Delta T$$

Isobaric ($P = \text{const}$)

$$W = P\Delta V = nR\Delta T$$
$$Q = nC_p\Delta T, \quad \Delta U = nC_v\Delta T$$

SPECIFIC HEATS & RELATIONS

$$C_p - C_v = R \quad \text{(Mayer's relation)}$$
$$\gamma = \frac{C_p}{C_v}$$
$$C_v = \frac{R}{\gamma - 1}, \quad C_p = \frac{\gamma R}{\gamma - 1}$$

γ Values

Gas	f	γ
Monatomic	3	5/3
Diatomic	5	7/5
Polyatomic	6	4/3

HEAT ENGINE & EFFICIENCY

Heat Engine

$$\eta = 1 - \frac{Q_2}{Q_1} = \frac{W}{Q_1}$$
$$W = Q_1 - Q_2$$

Carnot Efficiency (Max)

$$\eta_{\text{Carnot}} = 1 - \frac{T_L}{T_H}$$

(temperatures in Kelvin)

Refrigerator / Heat Pump

$$\text{COP}_{\text{ref}} = \frac{Q_2}{W} = \frac{T_L}{T_H - T_L}$$
$$\text{COP}_{\text{HP}} = \frac{Q_1}{W} = \frac{T_H}{T_H - T_L}$$
$$\text{COP}_{\text{HP}} = \text{COP}_{\text{ref}} + 1$$

INTERNAL ENERGY & ENTHALPY

- $\Delta U = nC_v\Delta T$ (for ideal gas, any process)
- $H = U + PV$ (enthalpy)
- $\Delta H = nC_p\Delta T$ (isobaric)
- For ideal gas: U depends only on T

P-V DIAGRAM & WORK

- Area under P-V curve $= W$
- Clockwise cycle ⇒ $W > 0$ (engine)
- Anticlockwise cycle ⇒ $W < 0$ (refrigerator)
- Steepness: Adiabatic > Isothermal (for same state)

Polytropic Process

- $PV^n = \text{const}$
- $W = \frac{P_1V_1 - P_2V_2}{n - 1} = \frac{nR\Delta T}{1 - n}$ (note sign)
- $n = 0$: isobaric; $n = 1$: isothermal; $n = \gamma$: adiabatic; $n = \infty$: isochoric

ENTROPY

$$dS = \frac{dQ_{\text{rev}}}{T}$$
$$\Delta S \geq 0 \text{ (for isolated system)}$$
$$\Delta S = nC_v\ln\frac{T_2}{T_1} + nR\ln\frac{V_2}{V_1}$$

IMPORTANT TRICKS

- Adiabatic: $\Delta U = -W$ & $Q = 0$
- Isochoric: $W = 0$ always
- $\eta < \eta_{\text{Carnot}}$ always (irreversible)
- For same ΔT: $Q_{\text{isobaric}} > Q_{\text{isochoric}}$
- Slope of adiabatic $= \gamma\times$ slope of isothermal on P-V