Thermodynamics Master Cheat Sheet

Comprehensive Formulas, Laws, and Cycles for Elite Scholars

1. Fundamental Definitions

System Types:

- **Closed:** Mass constant, energy transfers (heat/work).
- **Open:** Both mass and energy cross boundaries.
- **Isolated:** Neither mass nor energy crosses boundaries.

State Postulate: The state of a simple compressible system is completely specified by two independent, intensive properties.

2. The Laws of Thermodynamics

Zeroth Law: If two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other ($T_A = T_C$ and $T_B = T_C \implies T_A = T_B$).

First Law (Conservation of Energy):

$$\Delta U = Q - W$$

For a cycle: $\oint dQ = \oint dW$. Specific form (control volume):

$$\dot{Q} - \dot{W} = \sum_{out} \dot{m}\left(h + \frac{V^2}{2} + gz\right) - \sum_{in} \dot{m}\left(h + \frac{V^2}{2} + gz\right)$$

Second Law:

- **Kelvin-Planck Statement:** No heat engine can convert all heat extracted from a single reservoir into work.
- **Clausius Statement:** Heat cannot spontaneously flow from a cooler body to a warmer

body.

Entropy formulation:

$$dS = \frac{dQ_{rev}}{T} + \sigma$$

where $\sigma \geq 0$ is entropy generation.

Third Law: As absolute temperature approaches zero ($T \to 0$ K), the entropy of a pure crystalline substance approaches zero ($S \to 0$).

3. Thermodynamic Properties

Enthalpy (H):

$$H = U + PV$$

Entropy Relations (Tds Equations):

$$TdS = dU + PdV$$

$$TdS = dH - VdP$$

Specific Heats:

$$C_v = \left(\frac{\partial U}{\partial T}\right)_V, \quad C_p = \left(\frac{\partial H}{\partial T}\right)_P$$

For ideal gases: $C_p - C_v = R$, and $\gamma = \frac{C_p}{C_v}$.

4. Ideal Gases

Equation of state:

$$PV = mRT \quad \text{or} \quad P\bar{v} = \bar{R}T$$

Internal energy and enthalpy changes:

$$\Delta U = \int C_v dT, \quad \Delta H = \int C_p dT$$

Polytropic Processes ($PV^n =$ const):

- $n = 0$: Isobaric ($P =$ const)
- $n = 1$: Isothermal ($T =$ const)
- $n = \gamma$: Adiabatic ($Q = 0$)
- $n = \infty$: Isochoric ($V =$ const)

Work in polytropic process ($n \neq 1$):

$$W = \frac{P_2V_2 - P_1V_1}{1-n}$$

5. Heat Engines and Cycles

Thermal Efficiency of a Heat Engine:

$$\eta_{th} = \frac{W_{net}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$$

Coefficient of Performance (COP):

$$\text{Refrigerator:} \quad \text{COP}_R = \frac{Q_L}{W_{net}} = \frac{Q_L}{Q_H - Q_L}$$

$$\text{Heat Pump:} \quad \text{COP}_{HP} = \frac{Q_H}{W_{net}} = \frac{Q_H}{Q_H - Q_L} = \text{COP}_R + 1$$

Carnot Efficiency (Maximum Theoretical):

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

6. Maxwell Relations

Derived from exact differentials of thermodynamic potentials:

$$\left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial P}{\partial S}\right)_V$$

$$\left(\frac{\partial T}{\partial P}\right)_S = (/frac\partial V\partial S)_P$$

$$(/frac\partial P\partial T)_V = \left(\frac{\partial S}{\partial V}\right)_T$$

$$\left(\frac{\partial V}{\partial T}\right)_P = -\left(\frac{\partial S}{\partial P}\right)_T$$