Thermal Physics I (Physics 3513) Formula Sheet

Thermodynamic Systems and Laws

Equation of State (Ideal Gas):

$$PV = nRT, \quad R = 8.314\,\mathrm{J\,mol^{-1}\,K^{-1}}$$

where P is pressure, V is volume, n is moles, T is temperature.

Zeroth Law of Thermodynamics: If two systems are in thermal equilibrium with a third, they are in equilibrium with each other.

First Law of Thermodynamics:

$$\Delta U = Q - W$$

where ΔU is change in internal energy, Q is heat added, W is work done by the system.

Work Done by a Gas:

$$W = \int P\,dV$$

Thermodynamic Processes

Isothermal Process (T constant):

$$W = nRT \ln\left(\frac{V_f}{V_i}\right), \quad \Delta U = 0$$

Adiabatic Process ($Q = 0$):

$$PV^{\gamma} = \text{constant}, \quad TV^{\gamma-1} = \text{constant}, \quad \gamma = \frac{C_P}{C_V}$$

where γ is the adiabatic index.

Isobaric Process (P constant):

$$W = P\Delta V$$

Isochoric Process (V constant):

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

Heat Capacities

Heat Capacity at Constant Volume:

$$C_V = \left(\frac{\partial U}{\partial T}\right)_V, \quad U = \frac{f}{2}nRT \quad \text{(ideal gas)}$$

where f is degrees of freedom ($f = 3$ for monatomic, 5 for diatomic).

Heat Capacity at Constant Pressure:

$$C_P = C_V + nR$$

Molar Heat Capacities (Ideal Gas):

$$C_{V,m} = \frac{f}{2}R, \quad C_{P,m} = C_{V,m} + R$$

Kinetic Theory of Gases

Average Kinetic Energy per Molecule:

$$\langle K \rangle = \frac{3}{2}kT, \quad k = 1.380\,649 \times 10^{-23}\,\mathrm{J\,K^{-1}}$$

where k is Boltzmann's constant.

Root-Mean-Square Speed:

$$v_{\text{rms}} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3kT}{m}}$$

where M is molar mass, m is molecular mass.

Pressure from Kinetic Theory:

$$P = \frac{1}{3}\frac{N}{V}m\langle v^2 \rangle$$

Mean Free Path:

$$\lambda = \frac{1}{\sqrt{2}\pi d^2 (N/V)}$$

where d is molecular diameter, N/V is number density.

Second Law and Entropy

Entropy Change:

$$\Delta S = \int \frac{dQ_{\text{rev}}}{T}$$

Entropy for Ideal Gas:

$$\Delta S = nC_V \ln\left(\frac{T_f}{T_i}\right) + nR\ln\left(\frac{V_f}{V_i}\right)$$

Second Law of Thermodynamics:

$$\Delta S_{\text{universe}} = \Delta S_{\text{system}} + \Delta S_{\text{surroundings}} \geq 0$$

Thermodynamic Cycles

Carnot Efficiency:

$$\eta = 1 - \frac{T_C}{T_H}$$

where T_H and T_C are absolute temperatures of hot and cold reservoirs.

Heat Engine Efficiency:

$$\eta = \frac{W}{Q_H} = 1 - \frac{Q_C}{Q_H}$$

where Q_H is heat absorbed, Q_C is heat rejected, W is work done.

Coefficient of Performance (Refrigerator):

$$\text{COP} = \frac{Q_C}{W} = \frac{Q_C}{Q_H - Q_C}$$

Statistical Mechanics (Introductory)

Boltzmann Distribution:

$$P(E) \propto e^{-E/(kT)}$$

Partition Function (Single Particle):

$$Z = \sum_i e^{-E_i/(kT)}$$

Average Energy:

$$\langle E\rangle = -\frac{\partial \ln Z}{\partial \beta}, \quad \beta = \frac{1}{kT}$$

Entropy from Partition Function:

$$S = k\left(\ln Z + \beta\langle E\rangle\right)$$