

Physics 213 Formula Sheet

First law: $dU = dQ + dW_{on}$

Second law: $dS \geq 0$

Entropy:

- $S \equiv k \ln \Omega$
- $S_{total} = S_1 + S_2$

Temperature, pressure, and chemical potential:

- $T^{-1} \equiv \left(\frac{dS}{dU}\right)_{V,N}$
- $p \equiv T \left(\frac{dS}{dV}\right)_{U,N}$
- $-\mu \equiv T \left(\frac{dS}{dN}\right)_{U,V}$
 $= -\left(\frac{dF}{dN}\right)_{T,V}$

Fundamental relation:

$$dS = \frac{1}{T} dU + \frac{p}{T} dV - \frac{\mu}{T} dN$$

Ideal Gas Law:

$$pV = NkT$$

Thermodynamic potentials:

- $F \equiv U - TS$
- $G \equiv U - TS + pV$

Work:

$$dW_{on} = -dW_{by} = -pdV$$

First Law:

$$dU = dQ - pdV$$

Equipartition:

$U = \left(\frac{1}{2}\right) k_B T$ per quadratic degree of freedom

Heat Capacity:

- $C \equiv \frac{dQ}{dT}$
- Constant volume: $C_V = \frac{dU}{dT}$
- Constant pressure:
 $C_p = \frac{dU}{dT} + p \frac{dV}{dT}$

Thermodynamic Processes:

- Isothermal: $T = \text{const.}$
- Isobaric: $p = \text{const.}$
- Isochoric: $V = \text{const.}$
- Adiabatic: $Q = 0$

Boltzmann Factor:

- $P(E_i) = Z^{-1} e^{-\frac{E_i}{k_B T}}$,
- $Z = \sum_i e^{-E_i/k_B T}$

Thermal Radiation

- $J = \sigma_B T^4$

Counting particles

- Distinguishable: $\Omega = M^N$
- Indistinguishable: $\Omega = \frac{M^N}{N!}$
- q quanta in N oscillators:
 $\binom{N-1+q}{q} = \frac{(N-1+q)!}{q!(N-1)!}$

Constants, Data, Definitions

- Temperature: $0 \text{ K} = -273.15^\circ\text{C} = -459.67^\circ\text{F}$
- Avogadro's number: $N_A = 6.022 \times 10^{23} / \text{mole}$
- Boltzmann constant: $k = 1.38 \times 10^{-23} \frac{\text{J}}{\text{K}} = 8.617 \times 10^{-5} \frac{\text{eV}}{\text{K}}$ [note: also written as k_B]
- Universal gas constant: $R = k N_A = 8.314 \frac{\text{J}}{\text{mol}\cdot\text{K}} = 8.206 \times 10^{-2} \frac{\text{J}\cdot\text{atm}}{\text{mol}\cdot\text{K}}$ (Universal gas const.)
- Planck's constant: $h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s} = 4.136 \times 10^{-15} \text{ eV}\cdot\text{s}$, $\hbar = \frac{h}{2\pi} = 1.055 \times 10^{-34} \text{ J}\cdot\text{s}$,
- Magnetic moments: electron: $\mu_e = 9.2848 \times 10^{-24} \frac{\text{J}}{\text{T}}$, proton: $\mu_p = 1.4106 \times 10^{-26} \frac{\text{J}}{\text{T}}$
- Mass: electron: $m_e = 9.109 \times 10^{-31} \text{ kg}$, proton: $m_p = 1836 m_e = 1.673 \times 10^{-27} \text{ kg}$
- STP: $T = 0^\circ\text{C}$, $p = 100 \text{ kPa}$
- Stefan-Boltzmann constant: $\sigma_B = 5.670 \times \frac{10^{-8} \text{ W}}{\text{m}^2\text{K}^4}$
- $c = 2.998 \times 10^8 \frac{\text{m}}{\text{s}}$, $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$, $g = 9.8 \frac{\text{m}}{\text{s}^2}$, $1 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$, $1 \text{ liter} = 10^{-3} \text{ m}^3$

particle	g/mol
N ₂	28
O ₂	32
He	4
Ar	40
CO ₂	44
H ₂	2
Si	28
Ge	73
Cu	64
Al	27

