Physics 213 Formula Sheet

First law: $\boldsymbol{dU = dQ + dW_{on}}$
Second law: $\boldsymbol{dS \geq 0}$

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

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