Physics 213 Formula Sheet

Spring 2013

Constants, Data, Definitions

$0\ \text{K} = -273.15\ °\text{C} = -459.67\ °\text{F}$

$N_A = 6.022 \times 10^{23}$ / mole

$k = 1.381 \times 10^{-23}$ J/ K $= 8.617 \times 10^{-5}$ eV / K

$R = kN_A = 8.314$ J / mol·K $= 8.206 \times 10^{-2}$ l·atm / mol·K

1 atm $= 1.013 \times 10^5$ Pa 1 liter $= 10^{-3}\ \text{m}^3$

STP → T = 0°C; p = 1 atm

$h = 6.626 \times 10^{-34}$ J·s $= 4.136 \times 10^{-15}$ eV·s

$\hbar = h/2\pi = 1.055 \times 10^{-34}$ J·s

1 eV $= 1.602 \times 10^{-19}$ J

$c = 2.998 \times 10^8$ m/s

$\mu_e = 9.2848 \times 10^{-24}$ J/T $\mu_p = 1.4106 \times 10^{-26}$ J/T

$m_e = 9.109 \times 10^{-31}$ kg $m_p = 1836\ m_e = 1.673 \times 10^{-27}$ kg

$g = 9.8\ \text{m/s}^2$

Fundamental Laws/Principles:

First law: $dU = dQ + dW$ Second Law: $d\sigma/dt \geq 0$

$P_i \propto \Omega_i \equiv e^{\sigma_i}$

Classical equipartition ⟨energy⟩ = ½ kT per quadratic term

Entropy & Temperature: $S = k\sigma = k \ln \Omega$; $\frac{1}{T} \equiv \left(\frac{\partial S}{\partial U}\right)_{V,N}$

Heat Capacities: $C_V \equiv (\partial U/\partial T)_V$; $C_p \equiv (\partial(U + pV)/\partial T)_p$

Special properties of α-ideal gases

$U = \alpha NkT = \alpha nRT$ $pV = NkT$ $p_{tot} = p_1 + p_2 + \ldots$

$C_V = \alpha Nk = \alpha nR$ $C_p = C_V + Nk$ n = # moles = N/N_A

$c_p/c_V = (\alpha + 1)/\alpha = \gamma$ $W_{by} = NkT \ln(V_f/V_i)$

VT^α = const., or pV^γ = const., $\gamma = (\alpha + 1)/\alpha$

$W_{by} = \alpha Nk(T_1 - T_2) = \alpha(p_1V_1 - p_2V_2)$

$\Delta S = C_V \ln(T_f/T_i) + Nk \ln(V_f/V_i)$

	α	γ
	3/2	5/3
	5/2	7/5

Processes , Heat Engines, etc

$\Delta U = Q - W_{by}$ $W_{by} = \int p\,dV$

Quasistatic: $dS = đQ/T$ so $\Delta S = \int(C/T)dT$

$đQ = dU + p\,dV$

$\varepsilon_{Carnot} = 1 - T_C/T_H$

Diffusion and Heat Conduction

$D = (\ell^2/3\tau) = v\ell/3$ $\tau = \ell/v$

$\langle x^2 \rangle = 2Dt$ $\langle r^2 \rangle = 6Dt$

$J_x = \kappa\,\Delta T/\Delta x$, $\kappa = D_H c$ where $c = C_V/V$

$H_x = J A = \Delta T/R_{th}$ $R_{th} = d/\kappa A$ $\Delta L/L = \alpha\,\Delta T$

$T_A(t) = T_f + (T_{A0} - T_f)\,e^{-t/\tau}$, $\tau = R_{th}C_A$

Spins

$\Omega(N, N_{up}) = \frac{N!}{N_{up}!\,N_{down}!} = \frac{N!}{N_{up}!(N - N_{up})!}$; $\Omega(m) = 2^N \sqrt{\frac{2}{\pi N}}\, e^{-m^2/2N}$; $P(m) = \Omega(m)/2^N$

$M = (N_{up} - N_{down})\,\mu \equiv m\mu$, $M = N\mu \tanh(\mu B/kT)$

SHO

$P_n = (1 - e^{-\varepsilon/kT})\,e^{-n\varepsilon/kT}$; $\langle E \rangle = \varepsilon/(e^{\varepsilon/kT} - 1)$ $\varepsilon = hf$; $\Omega = \frac{(q + N - 1)!}{q!(N - 1)!}$

Counting, Bin Statistics, Entropy

Ω	Occupancy: Unlimited	Occupancy: Single	(N<<M) Dilute
Distinct	M^N	$\frac{M!}{(M-N)!}$	M^N
Identical	$\frac{(N+M-1)!}{N!(M-1)!}$	$\frac{M!}{(M-N)!N!}$	$\frac{M^N}{N!}$

$\ln N! \approx N \ln N - N$

Particle	mass/mol
N_2	28g
O_2	32g
He	4g
Ar	40g
CO_2	44g
H_2	2g
Si	28g
Ge	73g
Cu	64g
Al	28g

$1\text{g} = 10^{-3}$ kg

Equilibrium

Boltzmann: $P_n = \frac{d_n e^{-E_n/kT}}{Z}$; $Z \equiv \sum_i d_i e^{-E_i/kT}$

Free energies: $F \equiv U - TS$ $G \equiv U - TS + pV$

Chemical potential:

$\mu = \left(\frac{\partial F}{\partial N}\right)_{V,T} = \left(\frac{\partial G}{\partial N}\right)_{p,T}$; equilibrium $\sum_i (\Delta N_i)\mu_i = 0$

$a\text{A} + b\text{B} \leftrightarrow c\text{C} \Rightarrow$

$a\mu_A + b\mu_B = c\mu_C$

$\frac{n_C^c}{n_A^a n_B^b} = \frac{n_{QC}^c}{n_{QA}^a n_{QB}^b} e^{c\Delta/kT}$

$\mu_i = kT \ln(n_i/n_{Ti}) - \Delta_i$ (ideal gas)

$n_Q = (2\pi mkT/h^2)^{3/2} = (10^{30}\text{m}^{-3})(m/m_p)^{3/2}(T/300\text{K})^{3/2}$

Semiconductors $n_e n_h = n_i^2$; $n_i = n_Q e^{-\Delta/2kT}$

Thermal Radiation

$J = \sigma_B T^4$, $\sigma_B = 5.670 \times 10^{-8}\ \text{W/m}^2\text{K}^4$ $\lambda_{max}T = 0.0029$ m-K