Study Guide for Midterm, PHYS404, Fall 2012

ver. 1.0

Heat, work (on or by), temperature, [internal] energy, heat capacity, latent heat, entropy, enthalpy

3 basic models: paramagnet (2-state), Einstein solid, ideal gas

– What N and q (or U) mean for each,
and the resulting multiplicities $\Omega(N,...)$

$$\Omega(N, N_\uparrow) = \frac{N!}{N_\uparrow!\left(N - N_\uparrow\right)!}$$

$$\Omega(N, q) = \frac{(q + N - 1)!}{q!\left(N - 1\right)!}$$

$$\Omega(U, V, N) = f(N) V^N U^{fN/2}$$

2 weakly interacting systems, thermodynamic limit
Application of models to other physical systems

Equipartition theorem at thermal equilibrium:
$U = (f/2)\, N k_B T$; determining f: 3 for atoms,
5 for diatomic molecules at low T, 7 at higher T,
2 for each direction of an Einstein oscillator

Ideal gas law $pV = Nk_BT = nRT$

Entropy $S = k_B \ln \Omega = \int dQ_{\mathrm{rev}}/T$
Ideal gas $S = Nk_B\, [(V/(N\Lambda^3) + 5/2]$; $\Lambda = h/\sqrt{(2\pi m k_B T)}$
Paramag $S = Nk_B\, [\ln(2 \cosh x) - x \tanh x]$; $x = \mu B/k_BT$

Quasistatic vs. free expansion, microstate vs. macrostate; intensive vs. extensive

Laws of thermodynamics, and what they mean

$\Delta U = Q + W_{\mathrm{on}} = Q - W_{\mathrm{by}}$ $\qquad\qquad$ $\Delta S \geq 0$

Spreadsheet computations of Ω, S, U, T, C for paramagnets and Einstein solid

Constants: $k_B \approx 10^{-4}$ eV/K = 1.38×10^{-23} J/K
C_V of 1 gm of water (ice) is 1 cal/K (~½ cal/K)
R ~ 8.3J/K $\qquad$ $N_A = 6.02\times10^{23}$
Meaning of mole: mass = atomic wgt grams
Heat engines, Carnot cycles, refrigerators, efficiency, coefficient of performance

Very large numbers; Stirling's approximation,
$\ln n! \approx n \ln n - n$, and how to use it

Expansions in $\varepsilon \ll 1$:
$\ln(1\pm \varepsilon) \approx \pm\, \varepsilon\, [-\, \varepsilon^2/2]$, $\quad \exp(\pm\, \varepsilon) \approx 1 \pm \varepsilon\, [+\varepsilon^2/2!]$

pV diagrams, inc. Otto and Diesel cycles

Change in internal energy, change in temperature, heat, work, during "simple" processes:
isobaric ($\Delta p = 0$), isochoric ($\Delta V = 0 = W$), isothermal ($\Delta U = \Delta T = 0$), adiabatic ($Q = 0$).
Along an isobar, $W_{\mathrm{by}} = p(V_f - V_i)$; along an isotherm $W_{\mathrm{by}} = Nk_BT \ln(V_f/V_i)$
Along an adiabat pV^γ is constant, as is (using the ideal gas law) $TV^{\gamma-1}$ Note $\gamma = (f+2)/f$

Helmholtz and Gibbs free energies $\quad$ F(T,V,[N]) = U – TS +μN $\qquad$ G(T,p,[N]) = U + pV –TS +μN
U(V,S [,μ]) $\quad$ H(p,S [,μ]) $\qquad$ Φ = U –TS –μN

Electrolysis, fuel cells

Thermo. identities: $dU = TdS - p\, dV + \mu dN$
$dF = -S\, dT - p\, dV + \mu\, dN$
$dG = -S\, dT + V\, dp + \mu\, dN$, etc. $\quad$ & uses

Maxwell relations: 2nd deriv of thermo functions do not depend on order of derivs

$\Delta S_{\mathrm{mix}} = -Nk_B[x \ln x + (1-x) \ln(1-x)]$

$\beta = V^{-1}\, \partial V/\partial T|_p \qquad \kappa_T = -V^{-1}\, \partial V/\partial p|_T$