Chemistry 410B **Exam 5** **Spring 2008**

NAME:

Instructions:

1. Keep this exam closed until instructed to begin. Please write your name on this page but not on any other page.
2. Please silence any noisy electronic devices you have.
3. Attached sheet(s) provide potentially useful constants and equations. You may detach these from the exam if you prefer.
4. To receive full credit for your work, please
   (a) show all your work, using the back of this sheet if necessary,
   (b) specify the correct units, if any, for your final answers,
   (c) stop writing and close your exam immediately when time is called.

Other notes:

- **Your best scores on 4 of the 5 questions will contribute to your grade.**
- Partial credit is usually available for all problems, so try each problem and do not erase any of your work.
- Each question is worth 25 points.

1. Calculate ΔG for the isothermal expansion of 2.00 mol of an ideal gas from 1.00 L to 20.0 L at 298 K.

2. The vapor pressure of ethanol at 298 K is 0.320 bar, and the normal boiling point is 351 K. Find the standard enthalpy of vaporization for ethanol.

3. We transfer 50.0 kJ of heat into a 36.0 g sample of liquid water initially at 350 K, so that all the water heats up to the boiling point and some evaporates, all at 1 bar. What is the mass of water remaining as liquid at the end of this process? $C_{Pm}(l) = 75.3$ J K^{-1} mol^{-1}.

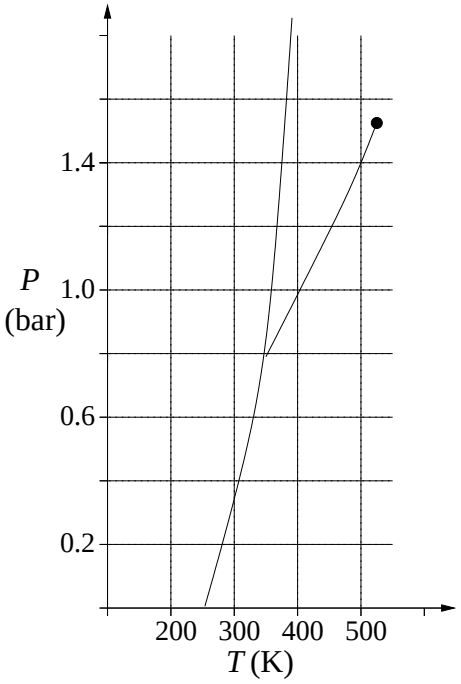
4. A sample contains a mixture of water and ammonia at a pressure and temperature such that the water is present in three phases (solid, liquid and gas) but the ammonia exists only as liquid and gas. Calculate how many degrees of freedom this system has at equilibrium, using the same method used to obtain the Gibbs phase rule.

5. For the phase diagram sketched below:

(a) What is the maximum pressure at which sublimation occurs?

(b) What is $T_b^{\ominus}$?

(c) Estimate $\Delta_{\text{vap}}H_m^{\ominus}$ for the substance.



Fundamental Constants

Avogadro's number	$\mathcal{N}_A$	$6.0221367 \cdot 10^{23}$ mol^{-1}
Bohr radius	$a_0 = \frac{4\pi\epsilon_0\hbar^2}{m_e e^2}$	$5.29177249 \cdot 10^{-11}$ m
Boltzmann constant	k_B	$1.380658 \cdot 10^{-23}$ J K^{-1}
electron rest mass	m_e	$9.1093897 \cdot 10^{-31}$ kg
fundamental charge	e	$1.6021773 \cdot 10^{-19}$ C
permittivity factor	$4\pi\epsilon_0$	$1.113 \cdot 10^{-10}$ C^2 J^{-1} m^{-1}
gas constant	R	8.314510 J K^{-1} mol^{-1}
	R	0.08314510 L bar K^{-1} mol^{-1}
	R	0.08206 L atm K^{-1} mol^{-1}
hartree	$E_\mathrm{h} = \frac{m_e e^4}{(4\pi\epsilon_0)^2\hbar^2}$	$4.35980 \cdot 10^{-18}$ J
Planck's constant	h	$6.6260755 \cdot 10^{-34}$ J s
	$\hbar$	$1.05457266 \cdot 10^{-34}$ J s
proton rest mass	m_p	$1.6726231 \cdot 10^{-27}$ kg
neutron rest mass	m_n	$1.6749286 \cdot 10^{-27}$ kg
speed of light	c	$2.99792458 \cdot 10^{8}$ m s^{-1}

Unit Conversions

	K	cm^{-1}	kJ mol^{-1}	kcal mol^{-1}	erg	kJ
kHz =	$4.799 \cdot 10^{-8}$	$3.336 \cdot 10^{-8}$	$3.990 \cdot 10^{-10}$	$9.537 \cdot 10^{-11}$	$6.626 \cdot 10^{-24}$	$6.626 \cdot 10^{-34}$
MHz =	$4.799 \cdot 10^{-5}$	$3.336 \cdot 10^{-5}$	$3.990 \cdot 10^{-7}$	$9.537 \cdot 10^{-8}$	$6.626 \cdot 10^{-21}$	$6.626 \cdot 10^{-31}$
GHz =	$4.799 \cdot 10^{-2}$	$3.336 \cdot 10^{-2}$	$3.990 \cdot 10^{-4}$	$9.537 \cdot 10^{-5}$	$6.626 \cdot 10^{-18}$	$6.626 \cdot 10^{-28}$
K =	1	0.6950	$8.314 \cdot 10^{-3}$	$1.987 \cdot 10^{-3}$	$1.381 \cdot 10^{-16}$	$1.381 \cdot 10^{-26}$
cm^{-1} =	1.4388	1	$1.196 \cdot 10^{-2}$	$2.859 \cdot 10^{-3}$	$1.986 \cdot 10^{-16}$	$1.986 \cdot 10^{-26}$
kJ mol^{-1} =	$1.203 \cdot 10^{2}$	83.59	1	0.2390	$1.661 \cdot 10^{-14}$	$1.661 \cdot 10^{-24}$
kcal mol^{-1} =	$5.032 \cdot 10^{2}$	$3.498 \cdot 10^{2}$	4.184	1	$6.948 \cdot 10^{-14}$	$6.948 \cdot 10^{-24}$
eV =	$1.160 \cdot 10^{4}$	$8.066 \cdot 10^{3}$	96.49	23.06	$1.602 \cdot 10^{-12}$	$1.602 \cdot 10^{-22}$
hartree =	$3.158 \cdot 10^{5}$	$2.195 \cdot 10^{5}$	$2.625 \cdot 10^{3}$	$6.275 \cdot 10^{2}$	$4.360 \cdot 10^{-11}$	$4.360 \cdot 10^{-21}$
erg =	$7.243 \cdot 10^{15}$	$5.034 \cdot 10^{15}$	$6.022 \cdot 10^{13}$	$1.439 \cdot 10^{13}$	1	10^{-10}
J =	$7.243 \cdot 10^{22}$	$5.034 \cdot 10^{22}$	$6.022 \cdot 10^{20}$	$1.439 \cdot 10^{20}$	10^{7}	10^{-3}
dm^3 bar =	$7.243 \cdot 10^{24}$	$5.034 \cdot 10^{24}$	$6.022 \cdot 10^{22}$	$1.439 \cdot 10^{22}$	$1.000 \cdot 10^{9}$	0.1000
kJ =	$7.243 \cdot 10^{25}$	$5.034 \cdot 10^{25}$	$6.022 \cdot 10^{23}$	$1.439 \cdot 10^{23}$	10^{10}	1

distance	1 Å =	10^{-10} m	
mass	1 amu =	$1.66054 \cdot 10^{-27}$ kg	
energy	1 J =	1 kg m^2 s^{-2}	$= 10^7$ erg
force	1 N =	1 kg m s^{-2}	$= 10^5$ dyn
electrostatic charge	1 C =	1 A s	$= 2.9979 \cdot 10^9$ esu
	1 D =	$3.3357 \cdot 10^{-30}$ C m	$= 1 \cdot 10^{-18}$ esu cm
magnetic field strength	1 T =	1 kg s^{-2} A^{-1}	$= 10^4$ gauss
pressure	1 Pa =	1 N m^{-2}	= 1 kg m^{-1} s^{-2}
	1 bar =	10^5 Pa	= 0.98692 atm

thermo derivatives:

$$dE = TdS - PdV + \mu_1 dn_\cdot + ...$$
$$dH = TdS + VdP + \mu_1 dn_\cdot + ...$$
$$dF = -SdT - PdV + \mu_1 dn_\cdot + ...$$
$$dG = -SdT + VdP + \mu_1 dn_\cdot + ...$$

entropy changes:

$$\Delta_{\text{expand}} S = nR \ln \frac{V_f}{V_i}$$
$$\Delta_{\text{heat}} S = nC_{Pm} \ln \frac{T_f}{T_i}$$
$$\Delta_{\text{mix}} S = -R \left(n_{\text{A}} \ln X_{\text{A}} + n_{\text{B}} \ln X_{\text{B}} \right)$$
$$\Delta_{\text{mix}} G = RT \left(n_{\text{A}} \ln X_{\text{A}} + n_{\text{B}} \ln X_{\text{B}} \right)$$
$$\Delta_\phi S_m = \frac{\Delta_\phi H_m}{T_\phi}$$

Clapeyron:

$$\frac{dP}{dT} = \frac{\Delta_\phi H}{T \Delta_\phi V}$$

Clausius-Clapeyron:

$$\ln P(\text{bar}) = \frac{\Delta_{\text{vap}} H_m^\circ}{R} \left(\frac{1}{T_b^\circ} - \frac{1}{T} \right)$$

Gibbs phase:

$$o = k - p + 2$$

Substance	T_f (K)	$\Delta_{\text{fus}} H_m^\circ$ (kJ mol^{-1})	T_b (K)	$\Delta_{\text{vap}} H_m^\circ$ (kJ mol^{-1})
He	—	—	4.22	0.0829
H_2	13.96	0.12	20.28	0.898
Ne	24.7	0.34	27.07	1.71
N_2	63.15	0.719	77.36	5.57
CO	68	0.83	81.6	6.04
F_2	53.5	0.51	85.03	6.62
Ar	83.8	1.12	87.30	6.43
O_2	54.5	0.44	90.20	6.820
CH_4	90.75	0.94	111.67	8.19
Kr	115.8	1.37	119.93	9.08
Xe	161.5	1.81	165.11	12.62
C_2H_6	90.3	2.86	184.55	14.69
C_3H_8	85.5	3.53	231.0	19.04
Cl_2	171.6	6.40	239.11	20.41
NH_3	195.41	5.66	239.82	23.33
CH_3Cl	176.1	6.431	249.06	21.40
CH_2Cl_2	178.01	6	313	28.06
Br_2	265.9	10.57	331.9	29.96
$CHCl_3$	209.6	8.8	334.32	29.24
CCl_4	250.0	3.28	349.9	29.82
H_2O	273.15	6.008	373.15	40.65
$C_{10}H_{22}$ (n-decane)	243.5	28.78	447.30	38.75
I_2 (rhombic)	386.8	15.52	457.6	41.57
Hg	234.32	2.29	629.88	59.11
TiI_4	423	19.8	650	58.4
S (monoclinic)	388.36	1.72	717.75	45
AgCl	728	13.2	1820	199
Pb	600.61	4.77	2022	179.5
Al	933.47	10.71	2792	294
B	2348	50.2	4300	480