CH353 – Physical Chemistry I
Spring 2015, Unique 51170

Exam 3 – March 7, 2015

Name: Key

Always assume ideal gas unless directed otherwise.

You may use any material that does not have a heartbeat and does not connect to the internet or cellular network. Calculators may be used for computing arithmetic only

Honor Code:

"The core values of the University of Texas at Austin are learning, discovery, freedom, leadership, individual opportunity, and responsibility. Each member of the University is expected to uphold these values through integrity, honesty, trust, fairness, and respect toward peers and community "

I certify that the work on this exam is entirely my own.

Signature Date

Periodic Table of the Elements

Chemistry Reference Sheet

California Standards Test

Key

11 — Atomic number
Na — Element symbol
Sodium — Element name
22.99 — Average atomic mass*

Period	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1	1 **H** Hydrogen 1.01																	2 **He** Helium 4.00
2	3 **Li** Lithium 6.94	4 **Be** Beryllium 9.01											5 **B** Boron 10.81	6 **C** Carbon 12.01	7 **N** Nitrogen 14.01	8 **O** Oxygen 16.00	9 **F** Fluorine 19.00	10 **Ne** Neon 20.18
3	11 **Na** Sodium 22.99	12 **Mg** Magnesium 24.31											13 **Al** Aluminum 26.98	14 **Si** Silicon 28.09	15 **P** Phosphorus 30.97	16 **S** Sulfur 32.07	17 **Cl** Chlorine 35.45	18 **Ar** Argon 39.95
4	19 **K** Potassium 39.10	20 **Ca** Calcium 40.08	21 **Sc** Scandium 44.96	22 **Ti** Titanium 47.87	23 **V** Vanadium 50.94	24 **Cr** Chromium 52.00	25 **Mn** Manganese 54.94	26 **Fe** Iron 55.85	27 **Co** Cobalt 58.93	28 **Ni** Nickel 58.69	29 **Cu** Copper 63.55	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.72	32 **Ge** Germanium 72.61	33 **As** Arsenic 74.92	34 **Se** Selenium 78.96	35 **Br** Bromine 79.90	36 **Kr** Krypton 83.80
5	37 **Rb** Rubidium 85.47	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.91	40 **Zr** Zirconium 91.22	41 **Nb** Niobium 92.91	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.91	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.87	48 **Cd** Cadmium 112.41	49 **In** Indium 114.82	50 **Sn** Tin 118.71	51 **Sb** Antimony 121.76	52 **Te** Tellurium 127.60	53 **I** Iodine 126.90	54 **Xe** Xenon 131.29
6	55 **Cs** Cesium 132.91	56 **Ba** Barium 137.33	57 **La** Lanthanum 138.91	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.95	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.21	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.22	78 **Pt** Platinum 195.08	79 **Au** Gold 196.97	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.38	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
7	87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (266)	107 **Bh** Bohrium (264)	108 **Hs** Hassium (269)	109 **Mt** Meitnerium (268)									

58 **Ce** Cerium 140.12	59 **Pr** Praseodymium 140.91	60 **Nd** Neodymium 144.24	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.96	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.93	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.97
90 **Th** Thorium 232.04	91 **Pa** Protactinium 231.04	92 **U** Uranium 238.03	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)

* If this number is in parentheses, then it refers to the atomic mass of the most stable isotope.

1. (15 points) Determine if the following statements are true or false.

a. True **False** The Clausius-Clapeyron equation describes the slope of the phase transition boundary between any two phases.

b. True **False** The chemical potential of liquid water is less than solid water (ice) at -10°C.

c. **True** False Two phases with identical chemical potentials at the same temperature and pressure are in equilibrium.

d. True **False** An ideal solution has no intermolecular forces.

e. True **False** There is a single point in *P T, V* space where the solid, liquid, and gas phases are all in equilibrium.

2. (15 points) Show mathematically what the change in enthalpy is when mixing two pure components, ΔH_{mix}?

$$\Delta G_{mix} = nRT(\chi_A \ln \chi_A + \chi_B \ln \chi_B)$$

$$\Delta S_{mix} = -nR(\chi_A \ln \chi_A + \chi_B \ln \chi_B)$$

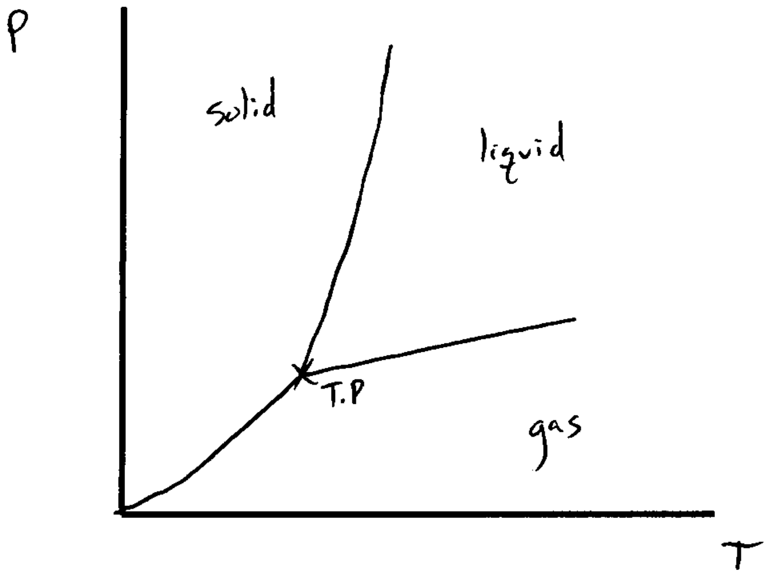
$$\Delta G_{mix} = \Delta H_{mix} - T\Delta S_{mix}$$

$$\Delta H_{mix} = \Delta G_{mix} + T\Delta S_{mix}$$

$$\Delta H_{mix} = nRT(\chi_A \ln \chi_A + \chi_B \ln \chi_B) + T(-nR(\chi_A \ln \chi_A + \chi_B \ln \chi_B))$$

$$\boxed{\Delta H_{mix} = 0}$$

3. (20 points) A typical phase transition diagram is shown below:



a. Label the axis. ✓

b. Mark the figure showing where you expect to find stable solid, liquid, and vapor phases. ✓

c. Label the triple point. ✓

d. Does the material described by this phase diagram have a denser solid or liquid condensed phase? Justify your answer.

$$\frac{dP}{dT} = \frac{\Delta H_{trans}}{T_{trans}\,\Delta V_{trans}}$$

$\frac{dP}{dT} > 0$ for solid → liquid

$\Delta H_{trans} > 0$ ⇒ $\Delta V > 0$, or $V_l > V_s$

Denser Solid

e. Which phase transition boundary has the steepest slope and why? Justify your answer.

The solid-liquid boundary has the steepest slope

$$\frac{dP}{dT} = \frac{\Delta H_{trans}}{T_{trans}\,\Delta V_{trans}}$$

As $V_l \approx V_s$ ΔV is very small, giving a large dP/dT or slope.

4. (20 points)

a. Derive an expression for the temperature dependence of Gibbs free energy at constant pressure and number of moles.

$$dG_m = V_m dP - S_m dT + \mu dn$$

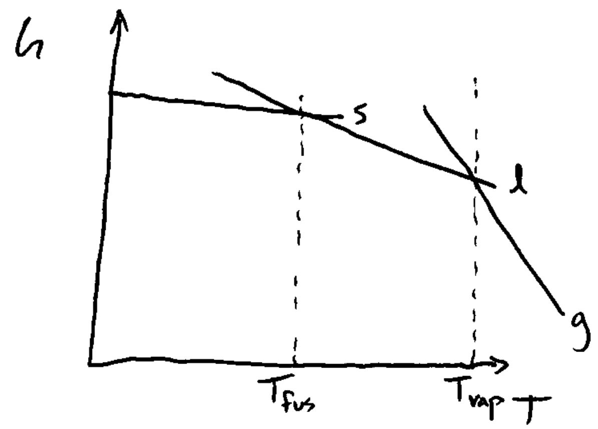
$\div dT$

$$\left(\frac{dG_m}{dT}\right) = V_m\left(\frac{dP}{dT}\right)^{\to 0} - S_m\left(\frac{dT}{dT}\right) + \mu\left(\frac{dn}{dT}\right)^{\to 0}$$

@ const. P, n

$$\boxed{\left(\frac{\partial G_m}{\partial T}\right)_{P,n} = -S_m}$$

b. Plot a figure of G vs. T showing three lines for the solid, liquid, and vapor phases. Indicate T_{fus} and $T_{vap.}$ (T should be on the x-axis, G should be on the y-axis.)



$S_{m,g} > S_{m,l} > S_{m,s}$

5. (15 points) Would you expect water and hexane to form an ideal solution? Justify your answer.

No, hexane is a hydrophobic molecule while water is hydrophilic. Also water is capable of hydrogen bonding while hexane is not. Because the components have different types of intermolecular forces, they won't form an ideal solution.

6. (15 points) Ethanol boils at 78°C at 1 atm. What is the boiling point of ethanol at 5 atm? ΔS^o_{vap} of ethanol is 120.5 J mol^{-1} K^{-1}, and you may assume it does not change over this pressure range.

B/c l→g transition, use Clausius-Clapeyron.

$P_1 = 1 \text{atm}$

$T_1 = 78 + 273 = 351 \text{K}$

$P_2 = 5 \text{atm}$

$T_2 = ?$

$$\ln\left(\frac{P_2}{P_1}\right) = \frac{-\Delta H_{trans}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

$$\Delta S_{trans} = \frac{\Delta H_{trans}}{T_{trans}}$$

$$\Delta H_{trans} = \Delta S_{trans} T_{trans} = (120.5 \text{ J/mol K})(351 \text{ K})$$

$$\Delta H_{trans} = 42295 \text{ J/mol}$$

$$\ln\left(\frac{P_2}{P_1}\right) = \frac{-\Delta H_{trans}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

$$\frac{1}{T_2} = \ln\left(\frac{P_2}{P_1}\right)\left(\frac{-R}{\Delta H_{trans}}\right) + \frac{1}{T_1}$$

$$\frac{1}{T_2} = \ln\left(\frac{5 \text{atm}}{1 \text{atm}}\right)\left(\frac{-8.314 \text{ J/mol K}}{42295 \text{ J/mol}}\right) + \frac{1}{351 \text{K}}$$

$$\frac{1}{T_2} = 0.0025326 \text{ K}^{-1}$$

$$\boxed{T_2 = 395 \text{ K}}$$