16-CHEM-A1, PROCESS BALANCES and CHEMICAL THERMODYNAMICS

DECEMBER 2017

Three Hours Duration

NOTES:

1) If doubt exists as to the interpretation of any question, you are urged to submit a clear statement of any assumptions made along with the answer paper.

2) Property data required to solve a given problem are provided in the problem statement or are available in the recommended texts. If you are unable to locate the required data, do not let this prevent you from solving the rest of the problem. Even in the absence of property data, you still have the opportunity to provide a solution methodology.

3) This is an open-book exam.

4) Any non-communicating calculator is permitted.

5) The examination is in two parts – Part A (Questions 1 to 3): Process Balances
Part B (Questions 4 and 6): Chemical Thermodynamics

6) Answer **TWO** questions from Part A and **TWO** questions from Part B.

7) **FOUR** questions constitute a complete paper.

8) Each question is of equal value.

PART A: PROCESS MASS and ENERGY BALANCES

1) A solid material with 15% water by weight is to be dried to 7% water. Fresh air is mixed with recycled air and blown over the solid. Fresh air contains 0.01 kg moisture per kg of dry air and recycled air, which is part of the air leaving the drier, contains 0.1 kg moisture per kg of dry air. Mixed air entering the drier contains 0.03 kg moisture per kg of dry air. Determine the following:

   (a) The amount of water removed per 100 kg of wet material fed to the drier.
   (b) The amount of dry air in fresh air per 100 kg of wet material.
   (c) The amount of dry air in recycled air per 100 kg of wet material.

2) A gas containing 30% carbon monoxide and 70% nitrogen by volume is burnt with 100% excess air. Both reactants enter at 298 K, and the standard heat of formation of carbon dioxide and carbon monoxide are -393.7 kJ/mol and -110.6 kJ/mol, respectively. Find the theoretical flame temperature required to burn this gas.

   DATA:
   Mean specific heat capacity of CO_2 = 50.1 J/mol.K
   Mean specific heat capacity of O_2 = 33.3 J/mol.K
   Mean specific heat capacity of N_2 = 31.5 J/mol.K

3) A feed mixture containing 40% benzene, 30% toluene and 30% xylene by weight is fed to a distillation column. The distillate contains 99.5% benzene and 0.5% toluene. The residue from this unit is fed to another distillation column from which a distillate of composition 97% toluene, 2% benzene and 1% xylene, and a residue of composition 5% toluene and 95% xylene are obtained. Compute the following:

   (a) Composition of the three final outputs from the system.

   (b) Composition of the intermediate stream.

PART B: CHEMICAL THERMODYNAMICS

4) Carbon dioxide gas at 100 °C and 40.53 bar. The critical properties of CO_2 are $T_c = 304.2$ K, $P_c = 73.8$ bar and $V_c = 94$ cm^3/mol. Estimate the compressibility factor, residual Gibbs free energy, residual enthalpy and residual entropy for CO_2 at these conditions using the van der Waals equation of state with parameters determine from the following:

(a) T_c and V_c.

(b) T_c and P_c.

5) At 400 K, the equilibrium for the isomerization reaction A $\leftrightarrow$ B is rapidly established. At this temperature, the vapor pressures of A and B are 2 atm and 2.5 atm, respectively. Gaseous A and B are placed in a cylinder fitted with a piston and maintained at 400 K. The cylinder is filled at 1 atm and movement of the piston slowly decreases the volume of the reacting system. At a pressure of 2.2 atm, a dew point is observed. Assuming ideal-liquid solutions, calculate the following:

(a) Equilibrium constant for the reaction A (g) $\leftrightarrow$ B (g).
(b) Equilibrium constant for the reaction A (l) $\leftrightarrow$ B (l).

6) In order to air condition a house, air from the house at 75 °F is compressed adiabatically, cooled to 100 °F by heat exchange with outside air, and them expanded adiabatically through a turbine. The work from the turbine is applied to the compression step. The air leaves the turbine at 55 °F and enters the house's air-handling ductwork. Assuming air behaves as an ideal gas, calculate a Coefficient of Performance (COP) for this system for the following cases:

a) The compressor and turbine operate reversibly.
b) The compressor and turbine each have an efficiency (η_s) of 70%.

The Periodic Table of the Elements

- ☐ Alkali metals
- ☐ Alkaline earth metals
- ☐ Transition metals
- ☐ Other metals
- ☐ Metalloids (semi-metal)
- ☐ Nonmetals
- ☐ Halogens
- ☐ Noble gases

Element name → Mercury

80 ← Atomic #

Symbol → Hg

200.59 ← Avg. Mass

1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Hydrogen 1 H 1.01																		Helium 2 He 4.00
Lithium 3 Li 6.94	Beryllium 4 Be 9.01												Boron 5 B 10.81	Carbon 6 C 12.01	Nitrogen 7 N 14.01	Oxygen 8 O 16.00	Fluorine 9 F 19.00	Neon 10 Ne 20.18
Sodium 11 Na 22.99	Magnesium 12 Mg 24.31												Aluminum 13 Al 26.98	Silicon 14 Si 28.09	Phosphorus 15 P 30.97	Sulfur 16 S 32.07	Chlorine 17 Cl 35.45	Argon 18 Ar 39.95
Potassium 19 K 39.10	Calcium 20 Ca 40.08		Scandium 21 Sc 44.96	Titanium 22 Ti 47.88	Vanadium 23 V 50.94	Chromium 24 Cr 52.00	Manganese 25 Mn 54.94	Iron 26 Fe 55.85	Cobalt 27 Co 58.93	Nickel 28 Ni 58.69	Copper 29 Cu 63.55	Zinc 30 Zn 65.39	Gallium 31 Ga 69.72	Germanium 32 Ge 72.61	Arsenic 33 As 74.92	Selenium 34 Se 78.96	Bromine 35 Br 79.90	Krypton 36 Kr 83.80
Rubidium 37 Rb 85.47	Strontium 38 Sr 87.62		Yttrium 39 Y 88.91	Zirconium 40 Zr 91.22	Niobium 41 Nb 92.91	Molybdenum 42 Mo 95.94	Technetium 43 Tc (98)	Ruthenium 44 Ru 101.07	Rhodium 45 Rh 102.91	Palladium 46 Pd 106.42	Silver 47 Ag 107.87	Cadmium 48 Cd 112.41	Indium 49 In 114.82	Tin 50 Sn 118.71	Antimony 51 Sb 121.76	Tellurium 52 Te 127.60	Iodine 53 I 126.90	Xenon 54 Xe 131.29
Cesium 55 Cs 132.91	Barium 56 Ba 137.33	57-70 *	Lutetium 71 Lu 174.97	Hafnium 72 Hf 178.49	Tantalum 73 Ta 180.95	Tungsten 74 W 183.84	Rhenium 75 Re 186.21	Osmium 76 Os 190.23	Iridium 77 Ir 192.22	Platinum 78 Pt 195.08	Gold 79 Au 196.97	Mercury 80 Hg 200.59	Thallium 81 Tl 204.38	Lead 82 Pb 207.20	Bismuth 83 Bi 208.98	Polonium 84 Po (209)	Astatine 85 At (210)	Radon 86 Rn (222)
Francium 87 Fr (223)	Radium 88 Ra (226)	89-102 **	Lawrencium 103 Lr (262)	Rutherfordium 104 Rf (267)	Dubnium 105 Db (268)	Seaborgium 106 Sg (271)	Bohrium 107 Bh (272)	Hassium 108 Hs (270)	Meitnerium 109 Mt (276)	Darmstadtium 110 Ds (281)	Roentgenium 111 Rg (280)	Copernicium 112 Cn (285)	Ununtrium 113 Uut (284)	Ununquadium 114 Uuq (289)	Ununpentium 115 Uup (288)	Ununhexium 116 Uuh (293)	Ununseptium 117 Uus (294?)	Ununoctium 118 Uuo (294)

*lanthanides	Lanthanum 57 La 138.91	Cerium 58 Ce 140.12	Praseodymium 59 Pr 140.91	Neodymium 60 Nd 144.24	Promethium 61 Pm (145)	Samarium 62 Sm 150.36	Europium 63 Eu 151.97	Gadolinium 64 Gd 157.25	Terbium 65 Tb 158.93	Dysprosium 66 Dy 162.50	Holmium 67 Ho 164.93	Erbium 68 Er 167.26	Thulium 69 Tm 168.93	Ytterbium 70 Yb 173.04
**actinides	Actinium 89 Ac (227)	Thorium 90 Th 232.04	Protactinium 91 Pa 231.04	Uranium 92 U 238.03	Neptunium 93 Np (237)	Plutonium 94 Pu (244)	Americium 95 Am (243)	Curium 96 Cm (247)	Berkelium 97 Bk (247)	Californium 98 Cf (251)	Einsteinium 99 Es (252)	Fermium 100 Fm (257)	Mendelevium 101 Md (258)	Nobelium 102 No (259)