Name.....Student I.D. ..... Seat no.

King Mongkut's University of Technology Thonburi

Final Examination, Second Semester (2/2012)

Course: CHE 242 Thermodynamics II Chemical Engineering, 2nd year

Date: Friday 17th May2013 Time: 13.00 – 16.00

Please follow the instructions.

1. There are 4 questions in 5 pages, including the covering page and Tables. Do all problems in the answering book.
2. A calculator and one A4 paper are allowed in the exam.

After you have finished with the examination, raise your hand for permission to leave the examination room,

Students are not allowed to take the examination paper out of the examination room.

If any disallowable material is found in your occupation in the examination room, you will be punished as serious as retirement.

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1) The excess Gibbs energies for liquid argon (Ar) and methane mixtures were measured at several temperatures. The results can be expressed by the following equation.

$$\frac{G^E}{RT} = x_{Ar}(1-x_{Ar})\left[A - B(1-2x_{Ar})\right]$$

where A and B are the constant values at a temperature. The values of A and B at temperatures are given below.

T(K)	A	B
109	0.3024	-0.01453
112	0.2929	-0.01169
115	0.2792	0.05115

Determine the following:

a) The activity coefficients of argon and methane at 112 K and $x_{Ar} = 0.5$ (15 points)

b) The molar isothermal enthalpy change on producing an $x_{Ar} = 0.5$ at 112 K. (10 points)
Hint: it is supposed that the interval between temperatures given in the above table is small enough.

2) The solubility of ethane in water is very small at 25°C and 1 bar partial pressure. The mole fraction of ethane at this condition is 0.33×10^{-4}. What is the solubility of ethane at 25°C when the partial pressure is 35 bar? At 25°C, the compressibility factor of ethane in the solution is given by the following equation.

$$\bar{Z} = 1 - 7.63 \times 10^{-3}P - 7.22 \times 10^{-5}P^2$$

where P is in bar. At 25°C, the saturation pressure of ethane is 42.07 bar and that of water is 0.0316 bar (assuming gas phase is ideal at 1 bar and the Henry constant is not a function of pressure). (25 points)

3) Estimate the equilibrium conversion, composition of each component at equilibrium and the fraction of acetylene reacts, if there are initially 10 mol of nitrogen and 5 mol of acetylene for the following reaction at 1500K 2 bar. Assume ideal gases.

$$N_2\,(g) + C_2H_2\,(g) \rightarrow 2HCN\,(g)$$ (25 points)

Name.....Student I.D. .....

4) (a) A binary mixture between 25% mol n-butane and 75% mol n-hexane is at the pressure of 200 kPa. Estimate the composition of the liquid phase and/or the vapour phase at the temperature of about 330 K and 360 K. Assume an ideality of all mixtures.

$$\ln P^* \text{ (kPa)} = A - \frac{B}{T(K)+C}$$

Data n-butane: A = 13.6608, B = 2154.7 , C = –34.361

n-hexane: A = 13.8193, B = 2696.04 , C = –48.833 (22 points)

(b) Explain the importance of dew point or bubble points in the chemical process industries. (3 points)

$R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1} = 83.14 \text{ cm}^3 \text{ bar mol}^{-1} \text{ K}^{-1} = 8{,}314 \text{ cm}^3\text{kPa mol}^{-1} \text{ K}^{-1}$

Conversion factor table for Pressure

mm Hg	in. Hg	bar	atm	kPa	psia
1	$3.937\text{x}10^{-2}$	$1.333\text{x}10^{-3}$	$1.316\text{x}10^{-3}$	0.1333	$1.934\text{x}10^{-2}$
25.4	1	$3.386\text{x}10^{1}$	$3.342\text{x}10^{-2}$	3.386	0.4912
750.06	29.53	1	0.9869	100.0	$1.415\text{x}10^{-3}$
760.0	29.92	1.013	1	101.3	14.696
75.02	0.2954	$1.000\text{x}10^{-2}$	$9.872\text{x}10^{-3}$	1	0.1451
51.71	2.036	$6.893\text{x}10^{-2}$	$6.805\text{x}10^{-2}$	6.893	1

1 mmHg = 0.1333 kPa = $1.333\text{x}10^{-3}$ bar = $1.316\text{x}10^{-3}$atm = $1.934\text{x}10^{-2}$psia

Table C.4: Standard Enthalpies and Gibbs Energies of Formation at 298.15 K†

Joules per mole of the substance formed

Chemical species		State (Note 2)	ΔH°_{f298} (Note 1)	ΔG°_{f298} (Note 1)
Paraffins:				
Methane	CH_4	(*g*)	−74 520	−50 460
Ethane	C_2H_6	(*g*)	−83 820	−31 855
Propane	C_3H_8	(*g*)	−104 680	−24 290
n-Butane	C_4H_{10}	(*g*)	−125 790	−16 570
n-Pentane	C_5H_{12}	(*g*)	−146 760	−8 650
n-Hexane	C_6H_{14}	(*g*)	−166 920	150
n-Heptane	C_7H_{16}	(*g*)	−187 780	8 260
n-Octane	C_8H_{18}	(*g*)	−208 750	16 260
1-Alkenes:				
Ethylene	C_2H_4	(*g*)	52 510	68 460
Propylene	C_3H_6	(*g*)	19 710	62 205
1-Butene	C_4H_8	(*g*)	−540	70 340
1-Pentene	C_5H_{10}	(*g*)	−21 280	78 410
1-Hexene	C_6H_{12}	(*g*)	−41 950	86 830
1-Heptene	C_7H_{14}	(*g*)	−62 760	
Miscellaneous organics:				
Acetaldehyde	C_2H_4O	(*g*)	−166 190	−128 860
Acetic acid	$C_2H_4O_2$	(*l*)	−484 500	−389 900
Acetylene	C_2H_2	(*g*)	227 480	209 970
Benzene	C_6H_6	(*g*)	82 930	129 665
Benzene	C_6H_6	(*l*)	49 080	124 520
1,3-Butadiene	C_4H_6	(*g*)	109 240	149 795
Cyclohexane	C_6H_{12}	(*g*)	−123 140	31 920
Cyclohexane	C_6H_{12}	(*l*)	−156 230	26 850
1,2-Ethanediol	$C_2H_6O_2$	(*l*)	−454 800	−323 080
Ethanol	C_2H_6O	(*g*)	−235 100	−168 490
Ethanol	C_2H_6O	(*l*)	−277 690	−174 780
Ethylbenzene	C_8H_{10}	(*g*)	29 920	130 890
Ethylene oxide	C_2H_4O	(*g*)	−52 630	−13 010
Formaldehyde	CH_2O	(*g*)	−108 570	−102 530
Methanol	CH_4O	(*g*)	−200 660	−161 960
Methanol	CH_4O	(*l*)	−238 660	−166 270
Methylcyclohexane	C_7H_{14}	(*g*)	−154 770	27 480
Methylcyclohexane	C_7H_{14}	(*l*)	−190 160	20 560
Styrene	C_8H_8	(*g*)	147 360	213 900
Toluene	C_7H_8	(*g*)	50 170	122 050
Toluene	C_7H_8	(*l*)	12 180	113 630

Table C.4 (Continued)

Chemical species		State (Note 2)	ΔH°_{f298} (Note 1)	ΔG°_{f298} (Note 1)
Miscellaneous inorganics:				
Ammonia	NH_3	(*g*)	−46 110	−16 450
Ammonia	NH_3	(*aq*)		−26 500
Calcium carbide	CaC_2	(*s*)	−59 800	−64 900
Calcium carbonate	$CaCO_3$	(*s*)	−1206 920	−1 128 790
Calcium chloride	$CaCl_2$	(*s*)	−795 800	−748 100
Calcium chloride	$CaCl_2$	(*aq*)		−8 101 900
Calcium chloride	$CaCl_2 \cdot 6H_2O$	(*s*)	−2607 900	
Calcium hydroxide	$Ca(OH)_2$	(*s*)	−986 090	−898 490
Calcium hydroxide	$Ca(OH)_2$	(*aq*)		−868 070
Calcium oxide	CaO	(*s*)	−635 090	−604 030
Carbon dioxide	CO_2	(*g*)	−393 509	−394 359
Carbon monoxide	CO	(*g*)	−110 525	−137 169
Hydrochloric acid	HCl	(*g*)	−92 307	−95 299
Hydrogen cyanide	HCN	(*g*)	135 100	124 700
Hydrogen sulfide	H_2S	(*g*)	−20 630	−33 560
Iron oxide	FeO	(*s*)	−272 000	
Iron oxide (hematite)	Fe_2O_3	(*s*)	−824 200	−742 200
Iron oxide (magnetite)	Fe_3O_4	(*s*)	−1118 400	−1 015 400
Iron sulfide (pyrite)	FeS_2	(*s*)	−178 200	−166 900
Lithium chloride	$LiCl$	(*s*)	−408 610	
Lithium chloride	$LiCl \cdot H_2O$	(*s*)	−712 580	
Lithium chloride	$LiCl \cdot 2H_2O$	(*s*)	−1012 650	
Lithium chloride	$LiCl \cdot 3H_2O$	(*s*)	−1311 300	
Nitric acid	HNO_3	(*l*)	−174 100	−80 710
Nitric acid	HNO_3	(*aq*)		−111 250
Nitrogen oxides	NO	(*g*)	90 250	86 550
	NO_2	(*g*)	33 180	51 310
	N_2O	(*g*)	82 050	104 200
	N_2O_4	(*g*)	9 160	97 540
Sodium carbonate	Na_2CO_3	(*s*)	−1130 680	−1 044 440
Sodium carbonate	$Na_2CO_3 \cdot 10H_2O$	(*s*)	−4081 320	
Sodium chloride	$NaCl$	(*s*)	−411 153	−384 138
Sodium chloride	$NaCl$	(*aq*)		−393 133
Sodium hydroxide	$NaOH$	(*s*)	−425 609	−379 494
Sodium hydroxide	$NaOH$	(*aq*)		−419 150
Sulfur dioxide	SO_2	(*g*)	−296 830	−300 194
Sulfur trioxide	SO_3	(*g*)	−395 720	−371 060
Sulfur trioxide	SO_3	(*l*)	−441 040	
Sulfuric acid	H_2SO_4	(*l*)	−813 989	−690 003
Sulfuric acid	H_2SO_4	(*aq*)		−744 530
Water	H_2O	(*g*)	−241 818	−228 572
Water	H_2O	(*l*)	−285 830	−237 129

†From *TRC Thermodynamic Tables—Hydrocarbons*, Thermodynamics Research Center, Texas A & M Univ. System, College Station, TX; "The NBS Tables of Chemical Thermodynamic Properties," *J. Phys. and Chem. Reference Data*, vol. 11, supp. 2, 1982.

Notes

1. The standard property changes of formation ΔH°_{f298} and ΔG°_{f298} are the changes occurring when 1 mol of the listed compound is formed from its elements with each substance in its standard state at 25°C (298.15 K).
2. Standard states: (*a*) Gases (*g*): pure ideal gas at 1 bar and 25°C (298.15 K). (*b*) Liquids (*l*) and solids (*s*): pure substance at 1 bar and 25°C (298.15 K). (*c*) Solutes in aqueous solution (*aq*): Hypothetical ideal 1-molal solution of solute in water at 1 bar and 25°C (298.15 K).

Table C.1: Heat Capacities of Gases in the Ideal-Gas State†

Constants in equation $C_P^{ig}/R = A + BT + CT^2 + DT^{-2}$ T (kelvins) from 298.15 K to T_{max}

Chemical species		T_{max}	$C_{P_{298}}^{ig}/R$	A	$10^3\,B$	$10^6\,C$	$10^{-5}\,D$
Paraffins:							
Methane	CH_4	1500	4.217	1.702	9.081	−2.164	
Ethane	C_2H_6	1500	6.369	1.131	19.225	−5.561	
Propane	C_3H_8	1500	9.011	1.213	28.785	−8.824	
n-Butane	C_4H_{10}	1500	11.928	1.935	36.915	−11.402	
iso-Butane	C_4H_{10}	1500	11.901	1.677	37.853	−11.945	
n-Pentane	C_5H_{12}	1500	14.731	2.464	45.351	−14.111	
n-Hexane	C_6H_{14}	1500	17.550	3.025	53.722	−16.791	
n-Heptane	C_7H_{16}	1500	20.361	3.570	62.127	−19.486	
n-Octane	C_8H_{18}	1500	23.174	4.108	70.567	−22.208	
1-Alkenes:							
Ethylene	C_2H_4	1500	5.325	1.424	14.394	−4.392	
Propylene	C_3H_6	1500	7.792	1.637	22.706	−6.915	
1-Butene	C_4H_8	1500	10.520	1.967	31.630	−9.873	
1-Pentene	C_5H_{10}	1500	13.437	2.691	39.753	−12.447	
1-Hexene	C_6H_{12}	1500	16.240	3.220	48.189	−15.157	
1-Heptene	C_7H_{14}	1500	19.053	3.768	56.588	−17.847	
1-Octene	C_8H_{16}	1500	21.868	4.324	64.960	−20.521	
Miscellaneous organics:							
Acetaldehyde	C_2H_4O	1000	6.506	1.693	17.978	−6.158	
Acetylene	C_2H_2	1500	5.253	6.132	1.952	.....	−1.299
Benzene	C_6H_6	1500	10.259	−0.206	39.064	−13.301	
1,3-Butadiene	C_4H_6	1500	10.720	2.734	26.786	−8.882	
Cyclohexane	C_6H_{12}	1500	13.121	−3.876	63.249	−20.928	
Ethanol	C_2H_6O	1500	8.948	3.518	20.001	−6.002	
Ethylbenzene	C_8H_{10}	1500	15.993	1.124	55.380	−18.476	
Ethylene oxide	C_2H_4O	1000	5.784	−0.385	23.463	−9.296	
Formaldehyde	CH_2O	1500	4.191	2.264	7.022	−1.877	
Methanol	CH_4O	1500	5.547	2.211	12.216	−3.450	
Styrene	C_8H_8	1500	15.534	2.050	50.192	−16.662	
Toluene	C_7H_8	1500	12.922	0.290	47.052	−15.716	
Miscellaneous inorganics:							
Air		2000	3.509	3.355	0.575	.....	−0.016
Ammonia	NH_3	1800	4.269	3.578	3.020	.....	−0.186
Bromine	Br_2	3000	4.337	4.493	0.056	.....	−0.154
Carbon monoxide	CO	2500	3.507	3.376	0.557	.....	−0.031
Carbon dioxide	CO_2	2000	4.467	5.457	1.045	.....	−1.157
Carbon disulfide	CS_2	1800	5.532	6.311	0.805	.....	−0.906
Chlorine	Cl_2	3000	4.082	4.442	0.089	.....	−0.344
Hydrogen	H_2	3000	3.468	3.249	0.422	.....	0.083
Hydrogen sulfide	H_2S	2300	4.114	3.931	1.490	.....	−0.232
Hydrogen chloride	HCl	2000	3.512	3.156	0.623	.....	0.151
Hydrogen cyanide	HCN	2500	4.326	4.736	1.359	.....	−0.725
Nitrogen	N_2	2000	3.502	3.280	0.593	.....	0.040
Nitrous oxide	N_2O	2000	4.646	5.328	1.214	.....	−0.928
Nitric oxide	NO	2000	3.590	3.387	0.629	.....	0.014
Nitrogen dioxide	NO_2	2000	4.447	4.982	1.195	.....	−0.792
Dinitrogen tetroxide	N_2O_4	2000	9.198	11.660	2.257	.....	−2.787
Oxygen	O_2	2000	3.535	3.639	0.506	.....	−0.227
Sulfur dioxide	SO_2	2000	4.796	5.699	0.801	.....	−1.015
Sulfur trioxide	SO_3	2000	6.094	8.060	1.056	.....	−2.028
Water	H_2O	2000	4.038	3.470	1.450	.....	0.121

†Selected from H. M. Spencer, *Ind. Eng. Chem.*, vol. 40, pp. 2152–2154, 1948; K. K. Kelley, *U.S. Bur. Mines Bull.* 584, 1960; I. R. Pankratz, *U.S. Bur. Mines Bull.* 672, 1982.