# 16-CHEM-A1, PROCESS BALANCES and CHEMICAL THERMODYNAMICS

## DECEMBER 2019

## 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. The suggested texts are:

   Elementary Principles of Chemical Processes by Felder and Rousseau (3rd edition).

   Introduction to Chemical Engineering Thermodynamics by Smith, Van Ness, and Abbott (7th edition).

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) Consider the oxidation of toluene ($C_6H_5CH_3$) to benzaldehyde ($C_6H_5CHO$) given by the following reaction:

$$C_6H_5CH_3\ (g) + O_2\ (g) \rightarrow C_6H_5CHO\ (g) + H_2O\ (g)$$

Calculate the standard heat of reaction for oxidation of toluene.

DATA:

Gross heat of combustion of liquid benzaldehyde at 18 °C = – 841.3 kcal/gmol

Normal boiling point of benzaldehyde = 179 °C

Heat of vaporization of benzaldehyde at 179 °C = 86.48 cal/g

Specific heat capacity of liquid benzaldehyde = 0.428 cal/g °C

Specific heat capacity of benzaldehyde vapor = 31 cal/mol °C

Average molar heat capacity of liquid $H_2O$ = 18 cal/mol °C

Average molar heat capacity of $CO_2$ = 8.87 cal/mol °C

Average molar heat capacity of $O_2$ = 7.0 cal/mol °C

Standard heat of formation of $H_2O$ vapor = – 57.8 kcal/mol

Standard heat of formation of toluene vapor = 11.95 kcal/mol

2) Wood containing 45.9% carbon, 23.1% oxygen, 5.1% ash, and the rest containing moisture and hydrogen is burnt in a furnace. An Orsat analysis of the flue gas during a run shows 14.8% carbon dioxide, 1.66% carbon monoxide, 3.46% oxygen and 80.08% nitrogen.

Determine the following:

a) Complete analysis of the wood used.
b) Ratio of fuel to air by weight.
c) Percentage of excess air used.
d) Composition of the flue gas.

3) A grade of crude oil is heated to 237 °C and charged at 0.167 L/min to the flash zone of a laboratory distillation tower. The flash zone is at an absolute pressure of 1.1 atm. Assuming that the vapor and liquid are in equilibrium, calculate the following:

a) Percent vaporized
b) Amounts of the overhead and bottom streams

DATA:

Flash zone temperature = 483 K
Latent heat of vaporization = 291 kJ/kg
Density of vaporized crude = 0.75 kg/L
Specific heat capacity of vaporized crude = 2.89 kJ/kg.K
Density of unvaporized crude = 0.892 kg/L
Specific heat capacity of unvaporized crude = 2.68 kJ/kg.K
Density of feed crude = 0.85 kg/L
Specific heat capacity of feed crude = 2.85 kJ/kg.K

## PART B: CHEMICAL THERMODYNAMICS

1) A chemical species A is known to decompose according to the

$$A\ (g) \leftrightarrow B\ (g) + C\ (g)$$

A rigid container is filled with pure gaseous A at 300 K and 760 mmHg, and then heated. The pressure was observed to be 1114 mmHg at 400 K and 1584 mmHg at 500 K. Assuming ideal gas behavior and chemical equilibrium, estimate the pressure for a temperature of 600 K.

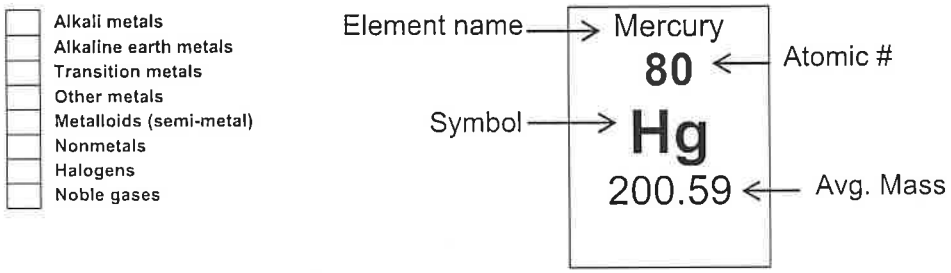
2) Calculate the fugacity of liquid hydrogen chloride at 277.4 K and 13.61 atm.

DATA: Vapor pressure of pure HCl at 277.4 K = 28.81 atm
Critical temperature of HCl = 324.68 K
Critical pressure of HCl = 81.5 atm

3) A cleaning solution is to be manufactured from equal masses of acetone and dichloromethane, both at 298 K. If these components are mixed adiabatically at a pressure of 1 bar, with negligible stirring work, what is the temperature of the cleaning solution formed?

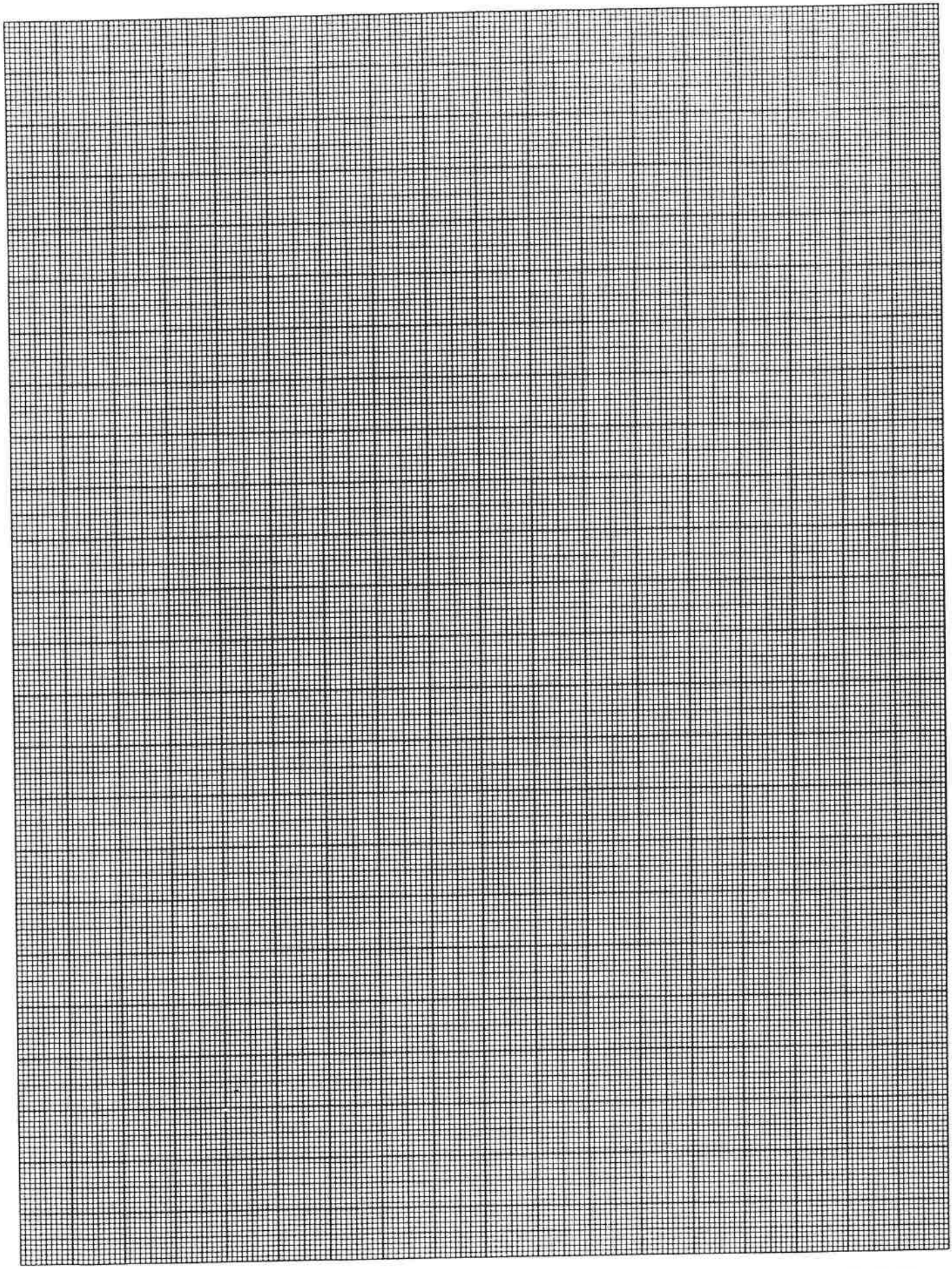
DATA:
Specific heat capacity of acetone at 1 bar and 298 K = 2.173 kJ/kg.K
Specific heat capacity of dichloromethane at 1 bar and 298 K = 1.193 kJ/kg.K
Heat of mixing of equal-mass solution at 1 bar and 293 K = 12.468 kJ/kg
Heat of mixing of equal-mass solution at 1 bar and 298 K = 12.380 kJ/kg
Heat of mixing of equal-mass solution at 1 bar and 303 K = 12.292 kJ/kg

# *The Periodic Table of the Elements*




| 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) |



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