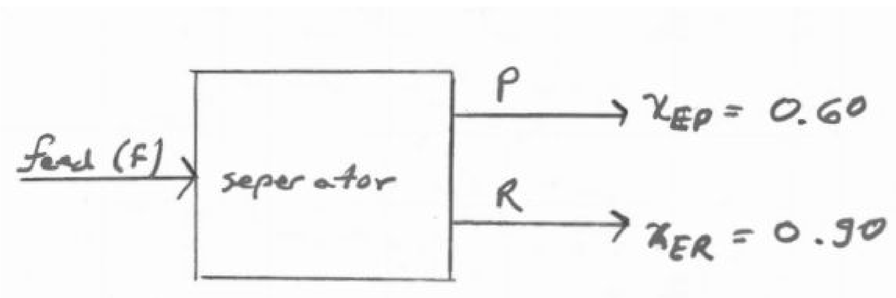
Name (Last, First): ________________________________ ID Number: __________________

WUCT: Individual Exam Sample

1. A difficult challenge many chemical engineers and chemists face is how to purify molecules from existing mixtures. In this problem, you will be acting as an operator for a liquid-liquid extraction device and answering questions regarding its production and the chemistry behind it. You will use the given phase diagram on page 2 to answer parts b-d.

    a. Ethanol and benzene are separated in a network of distillation and membrane separation steps. The unit operation you will be responsible for is a separator with one inlet stream with a flow rate of 8,000 kg/h and composition of 23% wt ethanol in benzene. This process has two exit streams where one exit stream called the permeate which contains 60% wt ethanol and the other exit stream called the retentate which contains 90% wt benzene. This system is at steady state. What percentage of the ethanol in the feed exits in the permeate? (% wt = percent weight).



Overall Mass Balance: $m_{IN} = m_{OUT}$ ∴ $m_{IN} = m_P + m_R$

Mole Balance on either Ethanol or Benzene (both will be counted as equally correct)

$m_{IN} \cdot x_{IN} = m_P \cdot x_P + m_R \cdot x_P$ (where x is a weight fraction)

Need to find m_P and m_R (2 equations and 2 unknowns)

Solve the system of equations to get
m_P = 2,080 kg/h

Find the percentage of ethanol in permeate:

$\% = (m_P \cdot x_P / m_{IN} \cdot x_{IN}) \cdot 100$

Answer = 68%

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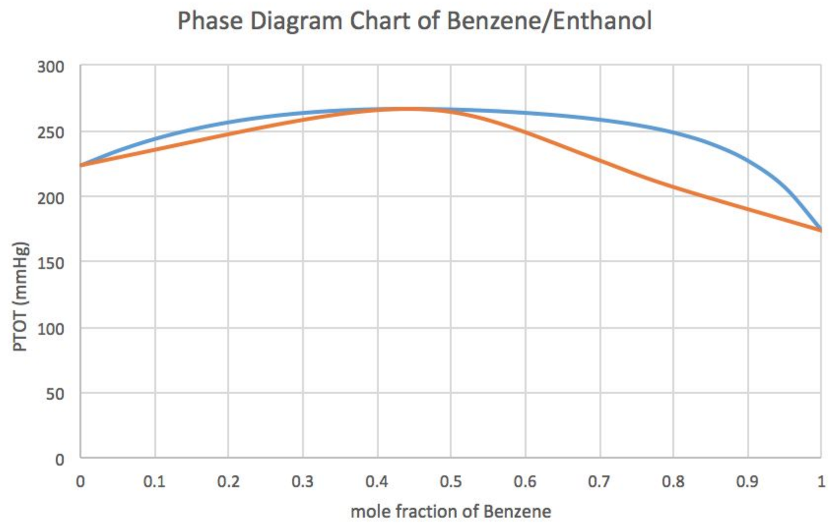

Aside: Students should recognize that as pressure increases the mixture becomes liquid. This means the vapor region is below the orange line and the liquid region is above the blue line.

b. Given the following phase diagram of benzene and ethanol above (which relates the total pressure of the system to mole fraction of benzene) explain why membrane separation is needed in addition to distillation in order to achieve high levels of separation.
There is an azeotrope present between benzene and ethanol which means that simple distillation is not sufficient and other chemical or physical process of separation must be utilized such as membrane separation.

c. Is the boiling point of benzene higher than ethanols? Explain why in 1-2 sentences.
Yes, the boiling point of benzene is higher than the bp of ethanol because the vapor pressure of pure ethanol is greater than the vapor pressure of pure benzene. (information obtained from graph at $x_{\text{benzene}} = 0$ and 1).

d. Imagine you are slowly increasing the pressure of a mixture that is 55% ethanol from 200 mmHg to 300 mmHg. Explain how both the phase and composition of the mixture change during this pressure increase.
This is at an azeotrope composition ∴ the composition remains constant as pressure increase. Initially, this mixture is gaseous, as the pressure increases, it becomes both gaseous and liquideous at around 265 mmHg when it intersects the phase lines. As you further increase the pressure the solution becomes completely liquid.

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2. The United States has one of the highest breast cancer rates in the world and the need to treat these patients is vital. A cutting-edge way that scientists are attempting to treat the tumors is through the use of gold nanoparticles which have a diameter of 30 nm. Gold is being used due to its intrinsic properties such as high chemical stability, convenient surface functionalization, and unique surface plasmon properties. These properties allow the gold nanoparticle to be a viable option for the treatment of certain diseases and are perfect candidates for drug delivery agents.

   Suppose that you want to use gold nanoparticles as drug carrier agents for the treatment of a breast cancer tumor at an early stage. Each nanoparticle can carry one Cytoxan (a chemotherapy drug, mass = 0.01 ng) per 10 nm^2 of its surface area and is assumed to be a perfect sphere. **Calculate the total amount of drug that can be delivered to the tumor through the circulatory system if you have 10 mL of 0.1 µM $HAuCl_4$ solution to produce gold NPs.**
   Assume that you have just enough reducing agent for the below reaction to take place:

$$4HAuCl_4 + 3NaBH_4 \Rightarrow 4Au + 6H_2 + 3NaCl + 3BCl_3 + 4HCl$$

Potentially useful information:

Density of Au = 19.32g/cm^3 — $1nm = 10^{-9}m$

Volume of sphere = (4/3)***π***$radius^3$ — $10^{-6}m = 1\mu m$

Surface area of sphere = 4***π***$radius^2$

Find mass of gold you can make from $HAuCl_4$ solution:

$$\frac{0.1\mu mol}{L} \cdot 10mL \cdot \frac{1L}{1000mL} \cdot \frac{1mol}{10^6\mu mol} = 1 \cdot 10^{-9} mol\ Au$$

Find the mass of 1 gold nanoparticle using volume of density

$$V_{Particle} = \frac{4}{3}\pi(15nm)^3 = 1.414 \cdot 10^4\ nm^3$$

$$\rho_{Au} = \frac{19.32g}{cm^3} \cdot \frac{(1cm)^3}{(10^7nm)^3} = 1.932 \cdot 10^{-20}\frac{g}{nm^3}$$

$$M_{nanoparticle} = \rho_{Au} \cdot V_{Particle} = 2.73 \cdot 10^{-16} g\ Au$$

Find total # of nanoparticles = mass of gold atoms/mass of gold per nanoparticle

$$\#Au_{Particles} = \frac{1.96 \cdot 10^{-7}g}{2.73 \cdot 10^{-16}g} = 7.22 \cdot 10^8 \text{ Au nanoparticles}$$

Find surface area of the total number of nanoparticle

$$SA_{TOTAL} = 4\pi(15nm)^2(7.22 \cdot 10^8) = 2.04 \cdot 10^{12} nm^2$$

Find mass of Cytoxan delivered

$$M_{Cytoxan} = 2.04 \cdot 10^{12} nm^2 \cdot \frac{0.01ng}{10nm^2} \cdot \frac{1g}{10^9 ng} = 2.04g \text{ of Cytoxan delivered to tumor}$$

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3. Copper is a soft, malleable, and ductile metal with a very high thermal and electrical conductivity. For these reasons, copper is widely used in buildings, wires, and many other everyday applications. This question will have you investigate many different problems involving copper.

   a. Under constant pressure conditions, a 2 pound (lb) block of copper (Cp = 0.0923Btu/lb-℉) initially at 257℉ is added to a mixture of 1 lb of water (Cp = 1 Btu/lb-℉) and 0.25 lb of ice at 0℃. As a result, the ice melts completely and the water and metal reach an equilibrium temperature. Given that the heat of fusion of water is 143.4 Btu/lb, determine the equilibrium temperature of this system given that no heat is lost to the surroundings.

$$-q_{Cu} = q_{H2O}$$

$$-2\ lb\ Cu \cdot \frac{0.0923 Btu}{lb - ℉} \cdot (x - 257℉) = 0.25\ lb\ Ice \cdot 143.4 \frac{Btu}{lb} + 1.25\ lb\ H20 \cdot 1 \frac{Btu}{lb - ℉} \cdot (x - 32℉)$$

Where x is the equilibrium temperature of the water and copper

x = 35.96℉ or 36℉ (both accepted)

   b. Copper is an unreactive metal and under normal circumstances does not react with dilute acid. However, copper is known to react with nitric acid in the given unbalanced reaction below.

$$1Cu\ (s) + 4HNO_3\ (aq) \rightarrow 1Cu(NO_3)_2 + 2NO_2 + 2H_2O$$

      i. Balance the reaction given on the lines above.

      ii. In this reaction what is the reducing agent?
      Cu(s) is getting oxidized ∴ it is the reducing agent

      iii. What is the oxidation number the nitrogen in $Cu(NO_3)_2$ and in NO_2?
      $Cu(NO_3)_2$: N has an oxidation number of 5+
      NO_2: N has an oxidation number of 4+

iv. What is the ground state electron configuration of copper?

2 acceptable answers:

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^{10}$ or [Ar] $4s^1 3d^{10}$

v. A Galvanic cell is constructed by connecting two half-cells at 298 K. The first half-cell contains a Cr electrode in 100 mL of 1.0 M Cr^{2+} solution and the second half-cell contains a 10.0 g Cu electrode in 100 mL of 1.0 M Cu^{2+} solution. Given the two half reaction below write the overall cell reaction and calculate the $\Delta\varepsilon^o$ of the cell.

$Cr(s) \rightarrow Cr^{2+} + 2e^- : \varepsilon^o = 0.91$ V

$Cu(s) \rightarrow Cu^{2+} + 2e^- : \varepsilon^o = -0.34$ V

$\Delta\varepsilon^o = 0.91V + 0.34\ V = 1.25\ V$

vi. If a current of 5 Coulombs/sec passes through the Galvanic cell from part v. at 298 K for 1 hour what are the molarity of the Cr^{2+} and the Cu^{2+} ions in their solutions?

Faraday's Constant = 96485 C/mol e^-

Mol Cu^{2+} consumed $= (3600s)(\frac{5.0C}{s})(\frac{mol\ electrons}{96485\ C})(\frac{mol\ Cu2+\ ions}{2\ mol\ electrons}) = 0.0933 mol\ Cu^{2+}$

$[Cu^{2+}] = \frac{0.1mol - 0.0933mol}{0.1L} = 0.0672M$

$[Cr^{2+}] = \frac{0.1mol + 0.0933mol}{0.1L} = 1.93M$