CE 111: Environmental Engineering MIDTERM EXAM #1 9 October 2013

Your Name: [redacted]

Groundrules:
- This is a closed-book exam; you are permitted one sheet of notes.
- Do your work on the paper provided. After the exam, submit your work and this exam sheet.
- Please be sure that your name is written on each page you submit. Also, please be sure that the problem and your answer are clearly indicated.
- You are expected to use a calculator. But you are not allowed to use a personal computer. Nor are you permitted to use any device capable of wireless communication.
- To receive proper credit, you must not only show the correct results, but also clearly indicate the work leading up to the results. For problems that require analysis, points are deducted if the grader cannot follow the logical flow from problem statement to answer.

Reminder: Read the questions **carefully**, and be certain you are responding appropriately.

Hints:
- If you seem to be missing an important piece of information, assume a reasonable value, state your assumption, and proceed.
- Partial credit is granted, but only if your work can be understood (and your thinking is reasonable).
- The multipart problems do not need to be solved in the order presented.
- See attached sheet (inside covers of text) for potentially relevant information.
- The total score possible is 20 points, and the time allowed is 50 minutes. Use the time wisely.
- Good luck!

PROBLEM #1 (5 possible)

PROBLEM #3 (5 possible)

[redacted]

Very good!

1. Elements of environmental engineering (5 points; 1 point each)

Solve the following challenges. For full credit, quantitative answers need to be accurate with appropriate precision and proper units of measure; qualitative answers should explain the key physical or chemical principal or process.

(a) The *electroneutrality* equation (EN) has been described as a *conservation* equation. What chemical or physical property is being conserved when we write EN?

(b) How does a *weak* acid differ from a *strong* acid?

(c) A sample of water has a volume of 5 liters and contains benzene (C_6H_6, MW = 78 g/mol) at a level of 5 ppb. What is the *mass concentration* of benzene in this water sample?

(d) At $T = 293$ K, the saturation vapor pressure of water is 2340 Pa = 0.023 atm. What is the *mass concentration* of water vapor in a parcel of air that has a temperature of 293 K and a relative humidity of 70%?
(e) At $T = 288$ K, the water solubility of benzene (C_6H_6, MW = 78 g/mol) is 1790 mg/L and the saturation vapor pressure is 7800 Pa. What is the *Henry's law constant* for benzene at $T =$ 288 K? Express your answer in units of M/atm.

2. Environmental redox: Denitrification (5 points)

Denitrification is an important process in wastewater treatment plants. In the process, nitrogen is converted from the nitrate ion (NO_3^-) to gaseous nitrogen (N_2). The bacteria that carry out this process can use methanol (CH_3OH) as a food source, converting the carbon to CO_2, which is also released as a gas.
(a) Give the oxidation states of N in NO_3^- and in N_2? (1 point)
(b) Give the oxidation states of C in CH_3OH and in CO_2? (1 point)
(c) Write a properly balanced chemical reaction that converts nitrate and methanol in water to N_2 and CO_2. (3 points)

3. Kinetics in a batch reactor (5 points)

In a batch reactor, the following reaction occurs:

reaction: $A \rightarrow B$
rate law: $R = k\,[A]$
initial conditions: $[A](0) = A_o$
$[B](0) = B_o$
$B_o < A_o$

(a) Write the differential equations that describe the rates of change of [A] and [B]. (1 point)
(b) What is the characteristic time for this reaction to proceed to completion? (1 point)
(c) Sketch a plot of $[B](t)$ versus time t. For full credit, your figure must exhibit these three characteristics: (i) the coordinate axes are properly labeled; (ii) the plot line has the correct shape; (iii) the axes and plot line indicate the proper starting and ending concentrations as well as the proper characteristic time for the reaction. (3 points)

4. Ammonia is a basic gas (5 points)

We've learned that CO_2 is a water-soluble gas that produces carbonic acid, a diprotic weak acid. Cloud drops exposed to 400 ppm of gaseous CO_2 have a pH of 5.6. Ammonia (NH_3) is another gaseous species that can influence the pH of cloud drops. Consider cloud drops that are simultaneously exposed to CO_2 at 400 ppm and NH_3 at an unknown mole fraction, Y. What value of Y would produce pH = 7 in the cloud drops?

Equilibrium relationships and data (if not otherwise designated, species are aqueous):

$H_2O \Leftrightarrow H^+ + OH^-$	$K_w = 10^{-14}$ M^2
CO_2 (gas) $(+ H_2O) \Leftrightarrow H_2CO_3^*$	$K_{HC} = 0.034$ M/atm
$H_2CO_3^* \Leftrightarrow H^+ + HCO_3^-$	$K_{c1} = 4.47 \times 10^{-7}$ M
$HCO_3^- \Leftrightarrow H^+ + CO_3^{2-}$	$K_{c2} = 4.68 \times 10^{-11}$ M
NH_3 (gas) $(+H_2O) \Leftrightarrow NH_3$	$K_{HN} = 62$ M/atm
$NH_4^+ \Leftrightarrow H^+ + NH_3$	$K_N = 5.89 \times 10^{-10}$ M
$P = 1$ atm	total air pressure