NAME

GROUND RULES: This is a closed-book/closed-note exam, except that you are permitted one sheet of notes. Do your work on the paper provided. After the exam, staple your work to this exam sheet. Please be sure that your name is written on each page you submit. Also, please be sure that the problem number and your answer are clearly indicated.

The total score possible is 20 points, and the time allowed is 50 minutes. Use the time wisely. Good luck!

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

HINTS:
(1) If you seem to be missing an important piece of information, assume a reasonable value, state your assumption, and proceed.
(2) Partial credit is granted, but only if your work can be understood (and your thinking is reasonable).
(3) See below for potentially relevant information.

#1 (3 possible) ________ #2 (1 possible) _______ #3 (1 possible) ________

#4 (3 possible) ________ #5 (2 possible) _______ #6 (3 possible) ________

#7 (2 possible) ________ #8 (2 possible) _______ #9 (3 possible) ________

TOTAL SCORE (out of 20) EQ \X(   )

DATA AND RELATIONSHIPS
ATOMIC MASSES (g/mol): H - 1, C - 12, N - 14, O - 16
APPROXIMATE COMPOSITION OF DRY ATMOSPHERE: N_2 - 79%, O_2 - 21%

IDEAL GAS LAW: $pV = nRT$ GAS CONSTANT: $R = 82.05 \times 10^{-6}$ atm mol^{-1} m^3 K^{-1}

CONVERSION FACTORS:

pressure: 1 atm = 1.01325×10^5 Pa volume: $1\ m^3 = 1000$ L $1\ L = 1000\ cm^3$

temperature: T (K) = T (°C) + 273

DEFINITIONS: $pH = -\log_{10}([H^+])$ $pK_A = -\log_{10}(K_A)$

ACID DISSOCIATION EQUILIUBRIUM: $HA \Leftrightarrow H^+ + A^-$ $K_A = [H^+][A^-]/[HA]$

DISSOCIATION OF WATER: $H_2O \Leftrightarrow H^+ + OH^-$ $K_w = [H^+]\,[OH^-] = 10^{-14}$ M^2

STANDARD OXIDATION STATES OF ELEMENTS IN COMPOUNDS: $X_O = -2$; $X_H = +1$

ANAEROBIC BIODEGRADATION OF CARBOHYDRATES IN SEDIMENTS

All of the questions/problems in this exam concern the system depicted on page 3 and described below. Although each problem or question is related to this system, they can be solved or answered independently and in any order.

A closed vessel of 3 L volume contains 1 L of condensed-phase materials and 2 L of gas space. The condensed phase materials are initially pure water plus some sediment. The sediment contains 1 g of biodegradable organic material that does not dissolve into the water. The gas space contains nitrogen (N_2) at a pressure of 1 atmosphere. There is no gaseous or dissolved oxygen (O_2) in the system. The temperature of the system is 293 K.

For the purposes of this exam, we will represent the biodegradable organic matter as a carbohydrate with the chemical formula $C_6H_{12}O_6$. Beginning immediately after the vessel is sealed, this organic material undergoes anaerobic decomposition, forming methane (CH_4) and carbon dioxide (CO_2) as its products. The process generates bubbles in the sediment that rise through the water and burst when they reach the surface. Methane and carbon dioxide each partition between the gas and aqueous phases. Dissolved carbon dioxide undergoes further chemistry according to the carbonate system that we studied.

(3 points) The bubbles formed in this process contain only two gases, CO_2 and CH_4. If the mole fraction of methane in the bubble is 75%, the pressure is 1 atm, and the temperature is 293 K, what is the bubble gas density?
(1 point) In addition to the gas density, what other property or properties of a **bubble** will influence its rise velocity?
(1 point) What property or properties of the **water** can influence the rise velocity of the bubbles?
(3 points) Write a stoichiometrically balanced reaction for the anaerobic decomposition of $C_6H_{12}O_6$ in water yielding the products CO_2 and CH_4. (*Hint 1*: Because this reaction occurs in water, you are free to use H^+, OH^-, or H_2O as products or as reactants. *Hint 2:* You should not assume that the mole fraction of CH_4 in the products is 75%, as suggested in problem 1.)
(2 points) In the conversion of $C_6H_{12}O_6$ into CO_2 and CH_4, identify which element is being reduced and which element is being oxidized. Specify the change in oxidation state that occurs for the reduced element and also for the oxidized element.
(3 points) Assume that the carbohydrate decomposition process occurs as a first-order reaction with a rate constant $k = 0.03\ h^{-1}$. What fraction of the initial 1 g of carbohydrate decomposes during the first 24 h after the vessel is sealed?

(2 points) The generated methane will partition between the gas phase and the dissolved phase. State the two basic principles or relationships that can be used to determine the amounts of methane in these two states at equilibrium. (*Hint:* No need to write equations here. Just state the answer in words.)

(2 points) Consider the pH of the water at the end of the biodegradation process. Will it be higher, lower, or unchanged relative to the initial condition of pH = 7? Justify your answer.

(3 points) Assume that after the biodegradation reaction has come to completion, the 1 g of carbohydrate is entirely converted to gaseous products. What is the total gas pressure in the vessel?

FIGURE. The system consists of a sealed vessel (V_t = 3 L) containing a gas space (V_g = 2 L) and a condensed phase (V_c = 1 L). The condensed phase contains initially pure water plus sediment, and the sediment contains 1 g of biodegradable organic matter. Before the biodegradation process begins, the gas phase contains only nitrogen at P = 1 atm. The biodegradation process generates methane (CH_4) and carbon dioxide (CO_2).