National Examinations, December 2005

98-Env-A3, Chemistry, Biology and Microbiology

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. Candidates may use one of two calculators, the Casio or Sharp approved models. This is a Closed Book exam.
3. Do any FOUR of Questions 1 - 5 and any ONE of Questions 6 or 7. Therefore, you should answer a total of 5 questions. If you answered more than five questions, only the first five will be marked.
4. All questions are of equal value.

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ANSWER ONLY FOUR OF THE FIRST FIVE QUESTIONS

1. Question One: Chemical equilibrium

   (a) Ammonia is a strong base that when dissolved in water can increase the pH to unacceptable levels. Calculate the pH of an aqueous solution exposed to ammonia gas at a partial pressure of 10^{-4} atm. [8 marks]

   $NH_3(aq) + H^+ \rightleftharpoons NH_4^+$ $\quad K = 3.16 \times 10^9$

   $NH_3(g) \rightleftharpoons NH_3(aq)$ $\quad K_H = 56.23$ mole/(l atm)

   $H_2O \rightleftharpoons H^+ + OH^-$ $\quad \log K_W = -14.2$

   (b) Ammonia, at high levels in water, can be toxic to aquatic life, depending on the form present. If a waste stream containing ammonia enters creek water at a pH of 7.0, what percentage of ammonia will be in the $NH_3(aq)$ form? Explain. [2 marks]

2. Question Two: $p\epsilon$ - pH Diagrams

   Environmental engineers often use equilibrium diagrams to determine what species are present in natural waters. You are required to report on which sulfur species exist as a function of redox potential and pH. To do so, you've been given the $p\epsilon$ versus pH diagram in Figure 1.

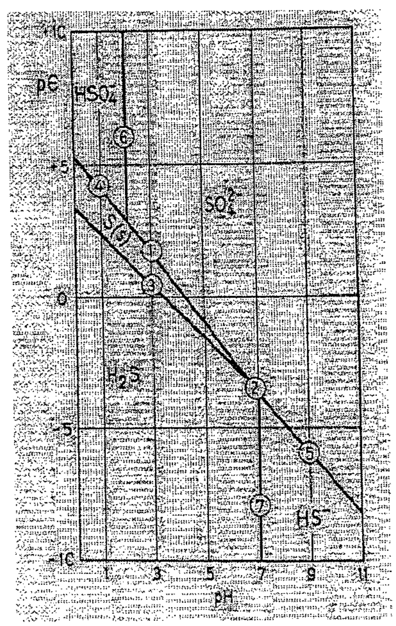


Figure 1: $p\epsilon$ versus pH diagram for SO_4-S(s)-H_2S system. Total dissolved S species is 10^{-2} M.

   (a) Sulfate (SO_4^{2-}) can be reduced to elemental sulfur (S(s)).

   $SO_4^{2-} + \nu_2 H^+ + \nu_3 e^- \rightleftharpoons S(s) + \nu_5\, H_2O \qquad \log K = 36.2$

   where , ν is a stoichiometric coefficient. Balance the above equation to find what ν_2, ν_3 and ν_5 are. [3 marks]

   (b) Using the Nernst Equation below, obtain the equation for line 1 in Figure 1. [3 marks]

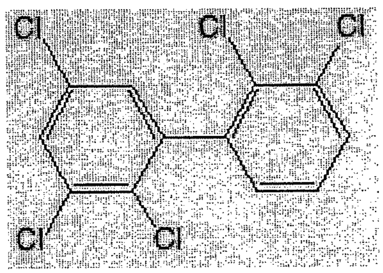
$$p\epsilon = p\epsilon^\circ + \frac{1}{n}\log\frac{\prod_i [ox]^{\nu_i}}{\prod_j [red]^{\nu_j}}$$

(c) Show how lines 3 and 7 in Figure 1 were obtained and use Figure 1 to infer what the equilibrium constants are for these two lines. [4 marks]

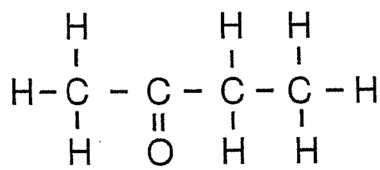
3. Question Three: Organic Chemistry

(a) Aryl hydrocarbons can contribute to pollution if they are uncontrollably released into the environment. Give two examples of widely used aryl hydrocarbon compounds, draw a sketch of their molecular structures and explain how they could be released into the environment. [4 marks]

(b) Name the following two compounds: [2 marks]



i.



ii.

(c) Link the macromolecules on the left with their sub-units on the right [4 marks].

a. cellulose	1. amino acids
b. DNA	2. glucose
c. proteins	3. fatty acids
d. phospholipids	4. nucleic acids

4. Question Four: Microbiology

(a) Sulfate-reduction by sulfate-reducing bacteria is an important microbiological process in anaerobic systems high in sulfate concentration. Sulfate is converted to sulfide as the bacteria consume low molecular weight C-sources, such as lactic acid ($CH_3CHOHCOOH$).

i. In this process, what is the electron acceptor and what is the electron donor? Explain. [2 marks]

ii. For each mole of sulfate reduced, how many moles of lactic acid are required if we assume that cell growth is minimal? [2 marks]

iii. In addition to a C-source, bacteria need N and P sources. For synthesis of what kinds of biochemical compounds do bacteria need N and P? [2 marks]

(b) If 0.01 gram of *E. coli* O157:H7 are released into a eutrophic system from pig waste, how many grams of *E. coli* will there be after a week if the doubling time for *E. coli* is 20 minutes? [4 marks]

5. Question Five: Cell Culture and Bioreactor Design

A typical waste water treatment bioreactor to reduce BOD in an effluent, consists of a continuous stirred tank reactor with recycle of settled solids. The settled solids contain organisms that degrade the BOD, which are recycled to the reactor to increase the solids concentration. Such a treatment process includes a 100 L bioreactor treating 400 litres per day of 1,000 mg/L BOD waste water. The bioreactor has a 10 day solids retention time and the effluent leaving the reactor contains 15 mg/L solids. The solids retention time is defined as:

$$\frac{\text{active biomass in the system}}{\text{production rate of active biomass}}$$

The rate of BOD removal by the solids follows Monod kinetics:

$$r_{ut} = \frac{\hat{q}S}{K+S} \text{ mg BOD/(mg solids - d)}$$

with $\hat{q} = 16$ mg BOD/(mg solids - d) and $K = 10$ mg BOD/L. For each mg of BOD reduced 0.35 mg of solids are formed. The organisms in the solids are dying at a rate of 0.2/day^{-1} times the solids concentration. What is the final BOD concentration in the effluent of this system? [10 Marks]

ANSWER ONLY ONE OF THE NEXT TWO QUESTIONS

6. Question Six: Pathogens and Water Treatment

The safety of our drinking water supply in Canada has been in the news lately. Discovery of pathogenic organisms in drinking water has prompted boil-water advisories in some places. How can pathogens enter the drinking water supply and what are some technical approaches that can be taken to prevent or remove them from the drinking water? [10 marks]

7. Question Seven: Public Health Measures.

There is always a big concern about disease epidemics such as SARS and bird-flu. What are some public health measures that are used to prevent these epidemics and how effective are they? [10 marks]