[ ] – denotes allocation of mark

PART A - *Short* Answer (point form acceptable)

1. On Mark Each

a) Circle all of the ions that will affect the concentration of a water sample's hardness:

[1] i) CO_3^{2-} (ii) Fe^{2+} iii) Na^+ (iv) Ca^{2+} (v) Sr^{2+}

b) Circle all of the ions that will affect the concentration of a water sample's alkalinity:

[1] i) Na^+ (ii) CO_3^{2-} (iii) H^+ (iv) OH^- v) SO_4^{2-}

(4)

c) For the following reactions or circumstances, show the Z that would be used:

[1] (i) to calculate the molar concentration of calcium corresponding to a hardness concentration of 100 mg/L as $CaCO_3$ Z = 2

[1] (ii) to calculate the normality of a solution of H_3PO_4 involved in the reaction: $H_3PO_4 \rightleftharpoons 2H^+ + HPO_4^{2-}$ Z = 2

2. Not all organic compounds of environmental concern are toxic. Briefly describe 2 other potential characteristics of organic compounds that can make them have adverse effects in receiving environments.

(2) [1] – colour

[1] – oxygen demand

3. Briefly explain how hardness ions interfere with the effectiveness of natural soaps. How is hardness removed with heating?

(3)

[2] – must precipitate all of M^{2+} ions before any dirt is removed

[1] – at high temperatures water evaporates and M^{2+} ions precipitate from solution to produce a white scale

4. What characteristic of a microorganism makes it a "pathogen", and why are coliform microorganisms monitored in drinking water?

(2)

• pathogen characteristics:

[1] – capable of infecting or transmitting a disease to humans

– are not native to aquatic systems, require a host for growth and reproduction

• coliform:

[1] – are used to indicate possible pathogen contamination

PART B - Numerical Problems

5. 150 mg/L of Ferric chloride ($FeCl_3$) is added to water during treatment. What is the Ferric chloride's concentration expressed as:
   (a) mg/L as Fe
   (b) molarity
   (c) ppm

(6) (Fe = 55.8 g/mol; Cl = 35.4 g/mol) **State any relevant assumptions.**

assume complete dissociation $FeCl_3 \leftrightharpoons Fe^{3+} + 3Cl^-$

$MW_{FeCl_3} = 55.8 + 3(35.4) = 162\ g/mol$

[2] a) $150\frac{mg}{L} \times \frac{1\ mol\ FeCl_3}{162\ g} \times \frac{1\ mol\ Fe}{1\ mol\ FeCl_3} \times \frac{55.8\ g}{1\ mol\ Fe} = 51.7\ mg/L\ Fe$

[2] b) $M = \frac{mol\ solute}{1\ L\ solution}$

$M = 150\frac{mg}{L} \times \frac{1\ g}{1000\ mg} \times \frac{1\ mol\ FeCl_3}{162\ g} = 9.26 \times 10^{-4}\ mol/L$

[2] c) $ppm = \frac{mass\ solute}{mass\ solute + mass\ solvent}$

- assume specific gravity of solution = 1. $\therefore 150\ mg/L = 150\ ppm$

6. While performing a BOD test, you realize that you will not be able to measure the final DO (Dissolved Oxygen) concentrations on Day 5 of the test, and so will not be able to directly get a value of BOD_5 for the sample. You are able to measure the final DO on Day 6. The test proceeds with a rate constant k of 0.43 d^{-1} at 20°C. What is the percent increase of the BOD_5 value that will have been measured on Day 6?
   Note: $BOD(t) = L(1 - e^{-kt})$

$BOD(t) = L(1 - e^{-kt})$, $k = 0.43\ d^{-1}$, $T = 20°C\ (293°K)$

(4)

[1] $BOD(5) = L(1 - e^{-(0.43)(5)}) = 0.88L$

[1] $BOD(6) = L(1 - e^{-(0.43)(6)}) = 0.92L$

[1] $\%\ inc. = \left[\frac{BOD(6) - BOD(5)}{BOD(5)}\right] \times 100\%$

$= \left[\frac{(0.92\ L) - (0.88\ L)}{(0.88L)}\right] \times 100\%$

[1] $= 4.5\%$

7. A water sample has a total hardness of 375 mg/L as $CaCO_3$ and a total alkalinity of 256 mg/L as $CaCO_3$. Is non-carbonate hardness present and, if so, how much?

TH = 375 mg/L as $CaCO_3$, ALK = 256 mg/L as $CaCO_3$

(2)

$$NCH = TH - ALK$$
$$= (375) - (256)$$
$$= 119 \text{ mg/L as } CaCO_3$$

[2]

8. Pentachlorophenol (C_6Cl_5OH) is a wood preservative that may be applied to wood as a 0.25 M aqueous solution. The acid dissociation of pentachlorophenol may be written as:

$$C_6Cl_5OH \rightleftharpoons C_6Cl_5O^- + H^+ \qquad K_A = 10^{-5.2}$$

If pure pentachlorophenol is added to water to prepare the aqueous preservative solution, at what pH is this solution? Solve algebraically with any approximations you feel are appropriate. **State all assumptions.**

(6) governing equations:

① ion product of water: $H_2O \rightleftharpoons H^+ + OH^-$

$K_w = [H^+][OH^-] = 10^{-14}$

② equil. expression for acid: $C_6Cl_5OH \rightleftharpoons H^+ + C_6Cl_5O^-$

$$K_a = \frac{[H^+][C_6Cl_5O^-]}{[C_6Cl_5OH]} = 10^{-5.2}$$

③ electroneutrality: $\Sigma \text{cations} = \Sigma \text{anions}$

$[H^+] = [C_6Cl_5O^-] + [OH^-]$

④ mass balance for acid: $C_T = [C_6Cl_5OH] + [C_6Cl_5O^-] = 0.25\,M$

[2]

assume $[H^+] >> [OH^-]$ [1]

⑤ from ③ $[H^+] = [C_6Cl_5O^-]$

⑥ from ② $\frac{[H^+]^2}{[C_6Cl_5OH]} = 10^{-5.2} \rightarrow \frac{[H^+]^2}{10^{-5.2}} = [C_6Cl_5OH]$

[1]

apply ⑤ & ⑥ to ④

$$0.25 = [C_6Cl_5OH] + [C_6Cl_5O^-]$$

$$0.25 = \frac{[H^+]^2}{10^{-5.2}} + [H^+]$$

$$0 = [H^+]^2 + 6.31\times10^{-4}[H^+] - 1.58\times10^{-6}$$

apply quadratic equation

$[H^+] = 1.25\times10^{-3}$ mol/L or $\underbrace{-1.23\times10^{-3}\ \text{mol/L}}_{\text{erroneous root}}$

$\therefore [H^+] = 1.25\times10^{-3}$ mol/L .

$pH = -\log[H^+]$

$= -\log(1.25\times10^{-3})$

$= 2.9$ [1]

check assumption!

from ① $10^{-14} = [H^+][OH^-]$

$10^{-14} = (1.25\times10^{-3})[OH^-]$ [1]

$[OH^-] = 8\times10^{-12}$

$\therefore$ the assumption, $[H^+] \gg [OH^-]$, is valid

BONUS QUESTION

9. The local municipal wastewater treatment plant has recently upgraded to incorporate a phosphate (PO_4^{3-}) removal step by precipitating the phosphate from solution with ferrous ion, Fe^{2+}:

$$2\ PO_4^{3-} + 3\ Fe^{2+} \rightleftharpoons Fe_3(PO_4)_{2(s)}$$

$K_{sp,\ Fe_3(PO_4)_{2(s)},\ 25°C} = 1.0 \times 10^{-32}$
gmw PO_4^{3-} = 94.97 g/mol
gmw Fe^{2+} = 55.85 g/mol
gmw $Fe_3(PO_4)_2$ = 262.5 g/mol

Theoretically, if they dose the Fe^{2+} to an equilibrium Fe^{2+} concentration of 0.030 mg/L, which they can monitor with an on-line ion selective electrode, will they be able to meet the MOEE guideline for PO_4^{3-} of 0.02 mg/L?

(3)

1 $K_{sp} = 10^{-32} = [PO_4^{3-}]^2 \cdot [Fe^{2+}]^3$

2

$0.03\ \frac{mg}{L} \times \frac{1\ g}{1000\ mg} \times \frac{1\ mol\ Fe^{2+}}{55.85\ g} = 5.37 \times 10^{-7}\ mol/L$

$[PO_4^{3-}] = \sqrt{\frac{10^{-32}}{(5.37 \times 10^{-7})^3}} = 2.54 \times 10^{-7}\ mol/L$

$2.54 \times 10^{-7}\ \frac{mol}{L} \times \frac{94.97\ g}{1\ mol\ PO_4^{3-}} \times \frac{1000\ mg}{1\ g} = 0.0241\ mg/L$

2 is greater than 0.02 mg/L

∴ will not meet the guideline