

☐ - 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:

☐ 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:

☐ 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:

☐ (i) to calculate the molar concentration of calcium corresponding to a hardness concentration of 100 mg/L as CaCO_3 $Z = \underline{2}$

☐ (ii) to calculate the normality of a solution of H_3PO_4 involved in the reaction: $\text{H}_3\text{PO}_4 \rightleftharpoons 2\text{H}^+ + \text{HPO}_4^{2-}$ $Z = \underline{2}$

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) ☐ - colour

☐ - oxygen demand

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

(3)

☐ ☒ - must precipitate all of M^{2+} ions before any dirt is removed

☐ ☒ - 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:

☐ ☒ - capable of infecting or transmitting a disease to humans

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

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☐ ☒ • coliform:
- 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

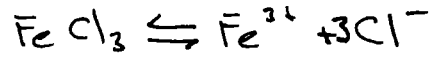
(b) molarity

(c) ppm

(Fe = 55.8 g/mol; Cl = 35.4 g/mol)

State any relevant assumptions.

assume complete dissociation



$$\text{MW}_{\text{FeCl}_3} = 55.8 + 3(35.4) = 162 \text{ g/mol}$$

[2] a)
$$150 \frac{\text{mg}}{\text{L}} \times \frac{1 \text{ mol FeCl}_3}{162 \text{ g}} \times \frac{1 \text{ mol Fe}}{1 \text{ mol FeCl}_3} \times \frac{55.8 \text{ g}}{1 \text{ mol Fe}} = 51.7 \text{ mg/L Fe}$$

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

$$M = 150 \frac{\text{mg}}{\text{L}} \times \frac{1 \text{ g}}{1000 \text{ mg}} \times \frac{1 \text{ mol FeCl}_3}{162 \text{ g}} = 9.26 \times 10^{-4} \text{ mol/L}$$

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

• assume specific gravity of solution is 1. $\therefore 150 \text{ mg/L} = 150 \text{ ppm}$

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: $\text{BOD}(t) = L(1 - e^{-kt})$

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

(4)

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

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

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

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

[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?

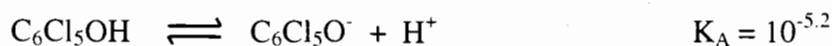
$$\text{TH} = 375 \text{ mg/L as } \text{CaCO}_3, \quad \text{ALK} = 256 \text{ mg/L as } \text{CaCO}_3$$

(2)

$$\begin{aligned} \text{NCH} &= \text{TH} - \text{ALK} \\ &= (375) - (256) \\ &= 119 \text{ mg/L as } \text{CaCO}_3 \end{aligned}$$

[2]

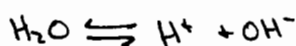
8. Pentachlorophenol ($\text{C}_6\text{Cl}_5\text{OH}$) is a wood preservative that may be applied to wood as a 0.25 M aqueous solution. The acid dissociation of pentachlorophenol may be written as:



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.**

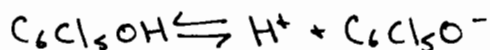
(6) governing equations:

① ion product of water



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

② equil. expression for acid



$$K_a = \frac{[\text{H}^+][\text{C}_6\text{Cl}_5\text{O}^-]}{[\text{C}_6\text{Cl}_5\text{OH}]} = 10^{-5.2}$$

③ electroneutrality

$$\sum \text{cations} = \sum \text{anions}$$

$$[\text{H}^+] = [\text{C}_6\text{Cl}_5\text{O}^-] + [\text{OH}^-]$$

④ mass balance for acid

$$C_T = [\text{C}_6\text{Cl}_5\text{OH}] + [\text{C}_6\text{Cl}_5\text{O}^-] = 0.25 \text{ M}$$

assume $[\text{H}^+] \gg [\text{OH}^-]$

[1]

⑤ from ③ $[\text{H}^+] = [\text{C}_6\text{Cl}_5\text{O}^-]$

⑥ from ②

$$\frac{[\text{H}^+]^2}{[\text{C}_6\text{Cl}_5\text{OH}]} = 10^{-5.2} \rightarrow \frac{[\text{H}^+]^2}{10^{-5.2}} = [\text{C}_6\text{Cl}_5\text{OH}]$$

[1]

apply ⑤ + ⑥ to ④

$$0.25 = [\text{C}_6\text{Cl}_5\text{OH}] + [\text{C}_6\text{Cl}_5\text{O}^-]$$

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

$$0 = [\text{H}^+]^2 + 6.31 \times 10^{-4} [\text{H}^+] - 1.58 \times 10^{-6}$$

apply quadratic equation

$$[\text{H}^+] = 1.25 \times 10^{-3} \text{ mol/L} \quad \text{or} \quad \underbrace{-1.23 \times 10^{-3} \text{ mol/L}}_{\text{erroneous root}}$$

$$\therefore [\text{H}^+] = 1.25 \times 10^{-3} \text{ mol/L}$$

$$\text{pH} = -\log [\text{H}^+]$$

$$= -\log (1.25 \times 10^{-3})$$

$$= 2.9$$

□

check assumption!

$$\text{from ①} \quad 10^{-14} = [\text{H}^+][\text{OH}^-]$$

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

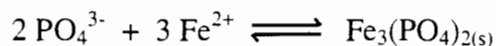
$$[\text{OH}^-] = 8 \times 10^{-12}$$

\therefore the assumption, $[\text{H}^+] \gg [\text{OH}^-]$, 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+} :



$$K_{\text{sp}} \text{Fe}_3(\text{PO}_4)_2(\text{s}), 25^\circ\text{C} = 1.0 \times 10^{-32}$$

$$\text{gmw } \text{PO}_4^{3-} = 94.97 \text{ g/mol}$$

$$\text{gmw } \text{Fe}^{2+} = 55.85 \text{ g/mol}$$

$$\text{gmw } \text{Fe}_3(\text{PO}_4)_2 = 262.5 \text{ g/mol}$$

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 $K_{\text{sp}} = 10^{-32} = [\text{PO}_4^{3-}]^2 \cdot [\text{Fe}^{2+}]^3$

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

2 $[\text{PO}_4^{3-}] = \sqrt{\frac{10^{-32}}{(5.37 \times 10^{-7})^3}} = 2.54 \times 10^{-7} \text{ mol/L}$

$2.54 \times 10^{-7} \frac{\text{mol}}{\text{L}} \times \frac{94.97 \text{ g}}{1 \text{ mol } \text{PO}_4^{3-}} \times \frac{1000 \text{ mg}}{1 \text{ g}} = \underline{0.0241 \text{ mg/L}}$

2 is greater than 0.02 mg/L

\therefore will not meet the guideline