Problem Set 2a—KEY

CEEG 340–Introduction to Environmental Engineering
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Questions

1. **(13 pts)** What is the molar concentration of 10 grams/liter for each of the following chemicals?

$$[\text{NaOH}] = 10\,\frac{\text{g}}{\text{L}} \times \frac{1\,\text{mole}}{40\,\text{g}} = 0.25\,\frac{\text{mole}}{\text{L}}$$

$$[\text{Na}_2\text{SO}_4] = 10\,\frac{\text{g}}{\text{L}} \times \frac{1\,\text{mole}}{142\,\text{g}} = 0.07\,\frac{\text{mole}}{\text{L}}$$

$$[\text{K}_2\text{Cr}_2\text{O}_7] = 10\,\frac{\text{g}}{\text{L}} \times \frac{1\,\text{mole}}{294\,\text{g}} = 0.03\,\frac{\text{mole}}{\text{L}}$$

$$[\text{KCl}] = 10\,\frac{\text{g}}{\text{L}} \times \frac{1\,\text{mole}}{74.5\,\text{g}} = 0.13\,\frac{\text{mole}}{\text{L}}$$

2. **(13 pts)** (modified from Mihelcic and Zimmerman) Coliform bacteria (for example *E. coli*) are excreted in large numbers in human and animal feces. Water that meets a standard of less than one coliform per 100 mL is considered safe for human consumption. Is a 1 m^3 water sample that contains 9000 coliforms safe for human consumption? **Show your work.** *Answer: water is safe.*

$$[\text{Coliforms}] = 9000\,\frac{\text{coliform}}{\text{m}^3} \times \frac{1\,\text{m}^3}{1000\,\text{L}} \times \frac{1\,\text{L}}{1000\,\text{mL}}$$

$$[\text{Coliforms}] = 9 \times 10^{-3}\,\frac{\text{coliform}}{\text{mL}}$$

Therefore, in 100 mL, there are $9 \times 10^{-3}\,\frac{\text{coliform}}{\text{mL}} \times 100\,\text{mL} = 0.9\,\text{coliforms}$, and the water is safe to drink.

3. **(13 pts)** Vinyl chloride is used to produce polyvinyl chloride (PVC), which is a plastic material used in construction. Vinyl chloride is classified as a known carcinogen by the U.S. Environmental Protection Agency (EPA), and according to their website, "EPA has set an enforceable regulation for vinyl chloride, called a maximum contaminant level (MCL), at 0.002 mg/L or 2 ppb." Prove that 0.002 mg/L equals 2 ppb.

$\rho_{water} = 1\frac{\text{g}}{\text{mL}} = 1000\frac{\text{g}}{\text{L}}$

$$[VC] = 0.002\ \frac{\text{mg VC}}{\text{L total}} \times \frac{1\,\text{g VC}}{1000\,\text{mg VC}} \times \frac{1\,\text{L solution}}{1000\,\text{g solution}} = 2 \times 10^{-9}\ \frac{\text{g VC}}{\text{g solution}}$$

$$[VC] = 2 \times 10^{-9}\ \frac{\text{g VC}}{\text{g solution}} \times \frac{10^6\,\text{ppm}_\text{m}}{\frac{\text{g}}{\text{g}}} \times \frac{10^3\,\text{ppb}_\text{m}}{\text{ppm}_\text{m}} = 2\,\text{ppb}_\text{m}$$

4. (13 pts)

2.13 Mirex (MW = 540) is a fully chlorinated organic pesticide that was manufactured to control fire ants. Due to its structure, mirex is very unreactive; thus, it persists in the environment. Lake Erie water samples have had mirex measured as high as 0.002 µg/L and lake trout samples with 0.002 µg/g. (a) In the water samples, what is the aqueous concentration of mirex in units of (i) ppb_m, (ii) ppt_m, (iii) µM? (b) In the fish samples, what is the concentration of mirex in (i) ppm_m, (ii) ppb_m?

Solution:

a) i) in dilute solutions µg/L = ppb, thus the concentration is 0.002 ppb_m

ii) 1,000 ppt = 1 ppb, therefor, the concentration is 2 ppt_m

iii)

$$\frac{0.002\ \mu g}{L} \times \frac{1\ mole}{540\ g} = \boxed{3.7 \times 10^{-6}\ \mu M}$$

b) i)

$$\frac{0.002\ \mu g}{g} = \boxed{0.002\ ppm}$$

ii) In solids, ppb = µg/kg

$$\frac{0.002\ \mu g}{g} \times \frac{1000\ million}{1\ billion} = \boxed{2\ ppb}$$

5. (13 pts)

2.15 Leachate is produced when precipitation infiltrates a sanitary landfill , contacts the waste material, and appears at the bottom of the stored waste. Assume 6 kg of benzene (molecular formula of C_6H_6) were placed in the landfill and it is all dissolved in the 100,000 gallons of leachate produced during one year. What is the benzene concentration in the leachate during this one year in (a) mg/L; (b) ppb_m; and (c) moles/L?

Solution:

a) $\frac{6\ kg\ C_6H_6}{1.0\times10^5 gallons}\times\frac{1\ gallon}{3.758\ L}\times\frac{1000g}{1\ kg}\times\frac{1000\ mg}{1\ g} = 16\ \frac{\boldsymbol{mg\ C_6H_6}}{\boldsymbol{L}}$

b) 1 L water = 1 kg water (in water, mg/L = ppm)

$23\ \frac{mg\ C_6H_6}{L} = 13\ ppm_m\ C_6H_6 * \frac{10^3 ppb}{1\ ppm} = 1.6\ \times\mathbf{10^4 ppb_m\ C_6H_6}$

c) $13\ \frac{mg\ C_6H_6}{L}\times\frac{1\ mole}{78\ g} = 2.0\times\mathbf{10}^{-4}\frac{\boldsymbol{mole}}{\boldsymbol{L}}\quad \mathbf{C_6H_6}$

6. **(15 pts)** First Order Reaction:

$$A = A_0 \times e^{-kt}$$

(a) 90% of A destroyed, so 10% of initial concentration remains.

$$0.1A_0 = A_0 \times e^{-0.1t}$$

$$t = \frac{\ln(\frac{0.1}{1})}{-0.01\,\mathrm{day}^{-1}} = 230\,\mathrm{days}$$

(b) Same as part (a) except that 99% destroyed, so 1% remaining:

$$t = \frac{\ln(\frac{0.01}{1})}{-0.01\,\mathrm{day}^{-1}} = 460\,\mathrm{days}$$

(c) Same as part (a) except that 99.9% destroyed, so 0.1% remaining:

$$t = \frac{\ln(\frac{0.001}{1})}{-0.01\,\mathrm{day}^{-1}} = 690\,\mathrm{days}$$

7. **(20 pts)** Oil Spill nineteen years ago:

$C_0 = 400\ \frac{mg}{L}$ C after 19y $= 400\ \frac{mg}{L}$

i. Try a zero order rate equation:

$$\frac{dC}{dt} = -k$$

After integration:

$$C = C_0 - kt$$

where $C_0 = 400\ \frac{mg}{g}$
$C = 20\ \frac{mg}{g}$

t = 19 year

Solve for k = 20 t^{-1}, and substitute k into the integrated zero rate equation above to obtain

$$C = C_0 - 20\,\text{year}^{-1} \times 20\,\text{year} = 0$$

Answer: Yes the engineer is correct if the degradation rate is zero order.

ii. To find the "worst-case scenario," calculate the concentration of the pollutant after twenty years using a first order and second order rate equation.

First Order:

$$C = C_0 \times e^{-kt}$$

Solve for k:

$$k = -\frac{\ln\frac{C}{C_0}}{t} = -\frac{\ln\frac{20}{400}}{19\,\text{y}} = 0.16\,\text{y}^{-1}$$

Use k and solve for the time it will take to for $C = 1\ \frac{\text{mg}}{\text{kg}}$, assuming first-order kinetics:

$$t = -\frac{\ln\frac{C}{C_0}}{k} = -\frac{\ln\frac{1}{400}}{0.16\,\text{year}^{-1}} = 38\,\text{y}$$

Second Order:

$$C = \frac{C_0}{1 + C_0 kt}$$

Rearrange and solve for k:

$$k = \frac{\frac{1}{C} - \frac{1}{C_0}}{t} = \frac{\left(\frac{1}{20} - \frac{1}{400}\right)\frac{\text{kg}}{\text{mg}}}{19\,\text{y}} = 0.003\,\frac{\text{kg}}{\text{mg} \times \text{y}}$$

Use k and solve for the time it will take for $\mathrm{C} = 1\,\frac{\mathrm{mg}}{\mathrm{kg}}$, assuming second-order kinetics:

$$\mathrm{t} = \frac{\frac{1}{\mathrm{C}} - \frac{1}{\mathrm{C_0}}}{\mathrm{k}} = \;= \frac{\left(\frac{1}{1} - \frac{1}{400}\right)\frac{\mathrm{kg}}{\mathrm{mg}}}{0.003\,\frac{\mathrm{kg}}{\mathrm{mg}\times\mathrm{y}}} = 399\,\mathrm{y}$$

In conclusion the “worst-case scenario” is second order, in which case, it would take 399 y for the pollutant to degrade. However, first order is more likely.

(8)

10 pts

$$\frac{dC}{dt} = -kC^2$$

$$\int_{C(0)}^{C} \frac{dC}{C^2} = -k\int_{t=0}^{t} dt$$

$$-\frac{1}{C}\Big]_{C_0}^{C} = -kt\Big]_0^t$$

$$-\left[\frac{1}{C} - \frac{1}{C_0}\right] = -k(t-0)$$

$$\frac{1}{C} - \frac{1}{C_0} = kt$$

$$\frac{1}{C} = kt + \frac{1}{C_0}$$

$$\frac{1}{C} = \frac{C_0kt + 1}{C_0}$$

$$\boxed{C = \frac{C_0}{1 + C_0kt}}$$