

ANSWERS**1. Elementary ideas in environmental engineering**

- (a) Divide mass concentration by atomic mass (40 g/mol) to obtain $[Ca^{2+}] = 50 \mu M = 0.050 \text{ mM}$.
- (b) Divide mass concentration by molecular mass (96 g/mol) and multiply by 2 (net charges per ion) to obtain $125 \mu eq/L = 0.125 \text{ meq/L}$.
- (c) Density is mass concentration and for air density equals $(P \times MW)/(R \times T)$. With fixed P and T, increasing the RH causes the MW to decrease, since $MW_{H_2O} = 18 \text{ g/mol} < MW_{\text{dry air}} = 29 \text{ g/mol}$. With a lower mass for each mole of air, the density decreases.
- (d) Clean background air contains CO_2 at about 380 ppm. Some CO_2 dissolves into the raindrop (according to Henry's law) and forms carbonic acid, $H_2CO_3^*$, a weak, diprotic acid. Some of the acid dissociates, liberating H^+ and lowering the pH.
- (e) The partial pressure of water vapor is the total air pressure multiplied by the mole fraction of water vapor in the gas. The mole fraction is obtained from stoichiometry: $Y_{H_2O} = 2/10.56 = 0.189$. So $P_{H_2O} = 0.189 \text{ atm}$.

2. Kinetics in a batch reactor

- (a) $R = k [A]$
- (b) $\tau \sim 1/k$
- (c) $d[A]/dt = -R = -k[A]$ so $[A](t) = A_0 \exp(-kt)$. For $t = 1/k$, $[A] = A_0/e$.
- (d) Use stoichiometry: $[A](t) - A_0 = [B](t) - B_0$. Therefore, at $t = 1/k$, $[B] = B_0 - A_0 + A_0/e$.
- (e) Use stoichiometry. The reaction is complete when all [A] has been consumed. (Some [B] will remain since $A_0 < B_0$.) Each mole of A consumed produces one mole of C. Therefore $[C] = C_0 + A_0$.

3. Naphthalene: No NAPL

The approach: Figure out how many moles of naphthalene are in the water when it is saturated and in the air when it is saturated. Add the results to obtain the desired M .

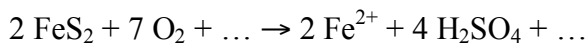
In water: $31 \text{ mg/L} \div 128 \text{ g/mol} = 0.24 \text{ mM}$; $0.24 \text{ mM} \times 2 \text{ L} = 0.48 \times 10^{-3} \text{ mol}$

In air: $P_s = 10.6 \text{ Pa} = 0.000105 \text{ atm}$; $n_s = P_s V / (RT) = 0.21 \times 10^{-3} \text{ mol}$

Total: $0.69 \times 10^{-3} \text{ moles}$

4. Acid-mine drainage is a redox phenomenon

- (a) S must be at $-I$, since the molecule is neutral and Fe is $+II$.
- (b) S must be at $+VI$, since the molecule is neutral, O is $-II$ and H is $+I$.
- (c) Note that S is going from $-I$ to $+VI$, which is a change of 7, and O is going from 0 to $-II$, a change of -2 . A balanced reaction will have 2 S atoms for every 7 O atoms. Working with integers, we can begin by writing:



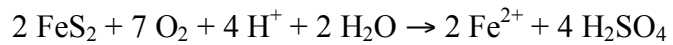
We have balanced Fe, S and the oxidation states. It remains to balance H, O, and +/-:

H: $0 \rightarrow 8$

O: $14 \rightarrow 16$

+/-: $0 \rightarrow +4$

Remedies: add 4 H⁺ to the left and add 2 H₂O to the left. Then everything balances:



Superficially, we don't see acidification here, since the reaction seems to consume, rather than produce H⁺. The resolution is in the fact that sulfuric acid is strong and diprotic. So all of the H₂SO₄ will fully dissociate to H⁺ and SO₄²⁻ ions. A better way to write the balanced reaction is like this:

