ANSWERS

1. Environmental engineering basics

(a) According to the ideal gas law, if the temperature increases, then the number of moles per volume will decrease (n/V = P/RT). Since density = MW × (n/V), the air density will $\boxed{\text{decrease}}$.

(b) In water, 0.005 mg/L = 5 μg/L implies 5 μg of PCE per kg of water. Hence, the mass fraction is $\boxed{\text{5 ppb}}$.

(c) One or more $\boxed{\text{electrons}}$.

(d) The unpolluted atmosphere contains carbon dioxide at about 400 ppm. Carbon dioxide dissolves (albeit sparingly) into water and forms carbonic acid, a weak diprotic acid. The dissociation of some carbonic acid to HCO_3^- causes an increase in $[H^+]$, which causes pH to decrease from the neutral value of 7.

2. NAPL of naphthalene

Compute the moles of naphthalene in the gas phase and in the aqueous phase from the equilibrium partial pressure and saturated water concentration, respectively. Determine the moles of naphthalene in the NAPL by conservation of total naphthalene in the system.

Naphthalene in air: $N_{air} = (P_{sat} \times V_a) / (RT) = 0.19$ millimoles

Naphthalene in water: $N_{water} = (C_{sat} \times V_w) \div \text{MW} = 31 \text{ mg/L} \times 5 \text{ L} \div 128 \text{ g/mol} = 1.2$ millimoles

Naphthalene in NAPL: $N_{NAPL} = 3 - 1.2 - 0.19 = \boxed{1.6 \text{ millimoles}}$

3. Environmental redox: Industrial boilers

Each iron atom is oxidized through +III while each oxygen atom is reduced by –II. Consequently, the balanced redox reaction will require 3 oxygen atoms for every 2 iron atoms. The partially balanced reaction looks like this:

$$2\,Fe(s) + 1.5\,O_2 + \ldots \rightarrow 2\,Fe^{3+} + 3\,(OH^-) + \ldots$$

Note that we have freely used OH^- to balance the oxygen and that the iron is also balanced. However, in this reaction, the H atoms are not balanced (0 → 3) and the charge is also not balanced (0 → +3). By inspection, and recognizing that OH^-, H^+, and H_2O can be freely used for redox chemistry in water, we see that the reaction can be balanced by adding 3 H^+ to the left hand side.

$$\boxed{2\,Fe(s) + 1.5\,O_2 + 3\,H^+ \rightarrow 2\,Fe^{3+} + 3\,(OH^-)}$$

To confirm the answer, check balance across the reaction for each element and for ionic charge:

Fe: 2 → 2
O: 3 → 3
H: 3 → 3
+/-: 3+ → 3+

Everything balances, so the answer is okay. Other permutations are okay, too. As stated, the problem requires that Fe(s) and O_2 are on the reactant side and Fe^{3+} is on the product side. All three elements plus ionic charge must balance in the final state.

4. Combustion of a synthetic fuel

To balance the combustion reaction, we note that the oxygen in the fuel is to be included in the combustion chemistry, which reduces the required O_2.

$$CH_3OCH_3 + \alpha\,(O_2 + 3.78\,N_2) \rightarrow 2\,CO_2 + 3\,H_2O + 3.78\alpha\,N_2$$

Balance the oxygen atoms to determine α:

$$1 + 2\alpha = 4 + 3 \Rightarrow \alpha = 3$$

So, the balanced combustion reaction is:

$$CH_3OCH_3 + 3\,(O_2 + 3.78\,N_2) \rightarrow 2\,CO_2 + 3\,H_2O + 11.3\,N_2$$

The air-to-fuel mass ratio, M_{af}, is determined as follows:

$$\boxed{M_{af} = [3 \times (32 + 3.78 \times 28)] \div [2 \times 12 + 6 + 16] = 9.0}$$

For each g of DME, 9.0 g of air is required for complete oxidation in the combustion reaction.

5. Neutralizing a strong acid with a strong base

A key to this problem is to recognize that the strong acid will fully dissociate according to this reaction:

$$HA \Leftrightarrow H^+ + A^-$$

For the initial low pH mixture, the concentration of H^+ will be the same as the concentration of the conjugate base A^-.

$$[H^+] = [A^-] = 10^{-2}\ M \qquad \text{Acidic solution at pH = 2}$$

The amount of the conjugate base of the strong acid, $[A^-]$, will not be affected by the addition of the strong base. To finish with a pH = 7 solution, it is required, by electroneutrality, that

$$[Na^+] = [A^-] = 10^{-2}\ M \qquad \text{Neutralized solution at pH = 7}$$

The dose required, therefore, is 10 millimoles per liter of water:

$$\text{Dose} = 0.010\ \text{mol/L} \times 40\ \text{g/mol} = \boxed{0.40\ \text{g/L}}$$