1 Cognitive reasoning in the chemical sciences 2.9

1. Let's simplify a submarine to be just an iron hull surrounding a chamber of regular air. Let's assume this submarine floats under water, that is, it has the same average density as water. Iron has the density of 8 g/mL. To one significant figure, for such a submarine, what is the ratio of the volume of air to the volume of iron?

2. A tire is a lot like a roll of toilet paper. As a roll of toilet paper unrolls on a floor it leaves a track of toilet paper. Normal tires leave a track one atom thick of rubber (unless you slam on the brakes: if you slam on the brake you leave a lot of rubber on the road.) In the case of a normal tire, the single layer of atoms is so small that we can not actually see the atoms - but they really are there.

   (a) Assume that a normal car tire lasts for 100,000 miles before all the rubber is worn off. A normal car tire has a diameter of 30 inches. Using the fact that the circumference of a tire is three times the diameter, estimate to one significant figure the number of times a tire is rotated in its 100,000 mile lifetime.

   (b) A tire has rubber which is around 1 cm thick. Each time a tire travels a full rotation, one layer of atoms is lost to the highway. Based on your answer in the first part of this question and that a tire which has travelled 100,000 miles is almost completely worn through, estimate in cm the order of magnitude of the width of atoms. Please show your work: for credit, you must use the facts given above about tires to deduce the width of atoms.

3. A metal M forms an oxide X. X has the empirical formula MO_2 and is 13.38 mass percent oxygen. When heated, X gives off oxygen and converts to Y, which is 9.334 mass percent oxygen. (a) What is the identity of metal M? (b) What is the empirical formula of the compound Y?

4. A mystery compound, Y, has *empirical* formula $C_2H_3O_2S$. Compound Y reacts with aqueous sodium hydroxide to produce water and the compound Z according to the *balanced* equation,

$$2\text{NaOH(aq)} + \text{Y} \longrightarrow 2\text{H}_2\text{O(aq)} + \text{Z(aq)}$$

   5.00 g of compound Y and 27.5 ml of 2.0 M NaOH(aq) react completely, with neither material left over. What is the *molecular* formula of Y?

5. There are two basic sets of equations which govern waves.

   (a) For waves moving at the speed of light:

$$v = \nu\lambda$$

$$E = h\nu.$$

   (b) For electron waves moving orders of magnitude slower than the speed of light:

$$v = \nu\lambda$$

$$E_K = \frac{1}{2}mv^2$$

$$p = mv$$

$$p = \frac{h}{\lambda}.$$

   (c) Consider two ocean waves. Both ocean waves travel at the same velocity and have the same amplitude, but the frequency of wave A is 5 times faster than wave B. Which wave has a bigger wavelength? What is the ratio of the two wavelengths? Draw a picture of wave A and wave B. Which ocean wave imparts more energy per second against a sea-wall or dike? Can we understand qualitatively why increasing the wavelength decreases the energy in both the case of light and electron waves (electron waves are called orbitals)?

6. An iteratively solved pair of chemistry problems:

   (a) The frequency of gizmos obeys the formula $\nu = Cm^2$, where C is a constant and m are integers. Three adjacent measured frequencies of gizmos is 12, 27, and 48 s^{-1}. What is the value of C? Unlike almost all Chem 2070 problems, you may need to iteratively guess sets of possible values of C and m. In each iteration, you will determine a new guess which fits the data better. You continue the process iteratively until you find a reasonable answer to the problem

   (b) Hydrogen is discovered to emit light at four adjacent wavelengths (it emits at other wave lengths as well): 410.1 nm, 434.0 nm, 486.1 nm and 656.3 nm. Calculate the energies and frequencies of these four wavelengths. The hydrogen atom obeys the equation

$$\nu = C(\frac{1}{2^2} - \frac{1}{n^2}).$$

   C is a constant while n are integers. Based on this data, iteratively calculate the value of C and n. Please do not look up this value on the web or in your text-book until after you have solved the problem.