Problem Set #1

Part A: Review of fundamentals

1. (Sig. Fig. Review) Solve for x in the following problems.
   (a) $x = (2.5902 \times 10^{-1}) + (2.67 \times 10^{-2})$
   (b) $x = (1.83 \times 10^{-2})(9.32 \times 10^{-3}) - (4.924 \times 10^{-4})/3.00$
2. (Fundamentals Section E) You have a mass of 4.099 g of NaCl.
   (a) How many moles do you have?
   (b) How many molecules?
3. (Fundamentals Section F) Caffeine, the chemical we all know and love that gives coffee and soda their stimulant properties, is the world's most widely consumed psychoactive drug. It works by blocking the action of adenosine on its receptor which prevents drowsiness. It also stimulates portions of the autonomic nervous system. Caffeine has a mass percentage composition of 49.5% carbon, 5.2% hydrogen, 28.9% nitrogen, and the balance being oxygen. What is the empirical formula of caffeine?
4. (Fundamentals Section G) Potassium sulfate is a chemical often used in fertilizer. A chemist is studying the properties of the sulfate ions ($SO_4{}^{-2}$) and so prepared a solution with water containing 7.211 g of K_2SO_4 in a flask of volume 255.0 mL. What volume of solution should the chemist transfer to a test tube to provide:
   (a) 2.821 mmol K_2SO_4
   (b) 4.143 mmol $SO_4{}^{-2}$
5. (Fundamentals Section L) Hydrazine is a colorless and flammable liquid often used in rocket fuels. It is dangerous to handle, but when it combusts with oxygen in a rocket engine the reaction will release a lot of energy. The reaction for combusting hydrazine is:

   $$H_2NNH_2 + O_2 \longrightarrow N_2 + 2\,H_2O \text{ (+ energy)}$$

   In order for a rocket to burn 1.235×10^5 g of glucose, what mass of molecular oxygen (O_2) is required in the reaction?
6. (Fundamentals Section L) Engineers and scientists can reduce iron(III) oxide to iron metal in a blast furnace. Unfortunately, carbon dioxide is a result of this two-step reaction. In the first step, carbon and oxygen are combined to form carbon monoxide in the reaction $2\,C(s) + O_2(g) \longrightarrow 2\,CO(g)$. The carbon monoxide reduces the iron(III) oxide into liquid iron through the reaction $Fe_2O_3(s) + 3\,CO(g) \longrightarrow 2\,Fe(l) + 3\,CO_2(g)$.
   (a) What mass of oxygen generates 458 g of CO(g)?
   (b) What mass of Fe_2O_3 can be converted in the furnace by 34.1 g of C?
7. (Fundamentals Section M) Iron(II) sulfide reacts with hydrochloric acid to produce the malodorous and toxic gas, hydrogen sulfide. A chemist (very carefully) mixes 2.91 g iron(II) sulfide with 4.32 g hydrochloric acid

$$FeS(s) + 2\,HCl(aq) \longrightarrow FeCl_2(aq) + H_2S(g)$$

(a) What is the limiting reactant?

(b) Determine how much hydrogen sulfide will be produced.

(c) Calculate the mass of excess reactant remaining.

8. (Fundamentals Section M) A compound found in the nucleus of a human cell was found to be composed of carbon, hydrogen, and nitrogen. A combustion analysis of 1.35 g of the compound produced 2.20 g of CO_2 and 0.901 g of H_2O. When a separate 0.500-g sample of the compound was analyzed for nitrogen, 0.130 g of N_2 was produced. What is the empirical formula of the compound?

Part B: The Quantum World

9. Briefly answer the following questions about Rutheford's α particle backscattering experiments:

   (a) What did Rutheford expect to happen to the α particles when they encountered the Au foil? Why?

   (b) Why did a *tiny* percentage of particles backscatter at significant angles?

10. Sodium vapor lamps, used for public lighting, emit yellow light of wavelength 589 nm. How much energy is emitted by

    (a) an excited sodium atom when it generates a photon;

    (b) 5.00 mg of sodium atoms emitting light at this wavelength

    (c) 1.00 mol of sodium atoms emitting light at this wavelength

11. In astronomy, adaptive optics is a technology used to produce clearer, higher quality telescope images by reducing the effect of wavefront distortions. These systems use a laser guide star, an artificial "star" created by firing a powerful sodium laser into the sky. This laser energizes sodium atoms present in the mesosphere about 90 km above the earth's surface. This guide "star" is used as a reference to improve the images captured by the associated telescope.

    These powerful lasers produce a beam of light with a per-photon energy of 3.37×10^{-19} J and with an intensity of 22 W. (1 W = 1 J/s)

    (a) Calculate the wavelength of the light emitted by the Na laser.

    (b) Calculate the number of photons emitted by the laser per second.

12. Consider the following statements about electromagnetic radiation and decide whether they are true or false. If they are false, correct them

    (a) Photons of infrared radiation have more energy than photons of ultraviolet radiation.

    (b) The rate of electrons being ejected from a metal surface (e^- / s) when the metal is irradiated with ultraviolet radiation is proportional to the frequency of the incident radiation.

    (c) The energy of a photon is proportional to the wavelength of that photon.

13. The velocity of an electron that is emitted from a metallic surface by a photon is 3.6×10^3 km·s^{-1}.

    (a) What is the wavelength of the ejected electron?

    (b) No electrons are emitted from the surface of the metal until the frequency of the radiation reaches 2.50×10^{16} Hz. How much energy is required to remove the electron from the metal surface?

    (c) What is the wavelength of the radiation that caused photoejection of the electron?

    (d) What kind of electromagnetic radiation was used?

14. The work function of chromium metal is 4.37 eV. What wavelength of radiation must be used to eject electrons with a velocity of 1.5×10^3 km·s^{-1}?