1. (22 points) Ionization involves completely removing an electron from an atom or ion. How much ***energy*** is required to ionize a hydrogen atom in its ground (or lowest energy) state? What ***wavelength of light*** contains enough energy in a single photon to ionize this atom?

$$E_{ionization} = E_{free} - E_1 = E_\infty - E_1 = \left(-\frac{R_H}{\infty^2}\right) - \left(-\frac{R_H}{1^2}\right) = R_H = 2.180 \times 10^{-18}\ \text{J}$$

$$\lambda = \frac{hc}{E} = \frac{\left(6.626 \times 10^{-34}\ \text{J s}\right)\left(2.998 \times 10^{8}\ \text{m s}^{-1}\right)}{2.180 \times 10^{-18}\ \text{J}} = 9.112 \times 10^{-8}\ \text{m}$$

2. (27 points) Textbook Problem 8-101: Ozone, absorbs ultraviolet radiation and dissociates into O_2 molecules and O atoms:

$$O_{3(g)} + h\nu \rightarrow O_{2(g)} + O_{(g)}$$

A 1.00 L sample of air at 22 °C and 748 mmHg contains 0.25 ppm of O_3. How much energy, in joules, must be absorbed if all the O_3 molecules in the sample of air are to dissociate? Assume that each photon absorbed causes one molecule to dissociate, and that the wavelength of the radiation is 254 nm.

$$N_{O_3} = \frac{PV}{RT} = \frac{(748\ \text{mmHg})(1.00\ \text{L})}{(62.364\ \text{L mmHg mol}^{-1}\ \text{K}^{-1})(295\ \text{K})} \times \frac{0.25\ \text{mol O}_3}{10^6\ \text{mol gas}} \times \frac{6.0221\times10^{23}\ \text{molec}}{1\ \text{mol O}_3} = 6.121158\times10^{15}\ \text{molec}$$

$$E_{photon} = \frac{hc}{\lambda} = \frac{(6.626\times10^{-34}\ \text{J s})(2.998\times10^{8}\ \text{m s}^{-1})}{254\times10^{-9}\ \text{m}} = 7.820767\times10^{-19}\ \text{J/photon}$$

$$E_{total} = 6.121158\times10^{15}\ \text{molec} \times \frac{1\ \text{photon}}{1\ \text{molecule}} \times \frac{7.820767\times10^{-19}\ \text{J}}{\text{photon}} = 4.8\times10^{-3}\ \text{J}$$

3. (21 points) Write the ***electron configuration and orbital diagram*** for the following elements using the noble gas shorthand. Give the ***quantum numbers (n, l, m_l, m_s)*** of the last electron to be filled in each.

a. silver $[Kr]\ 5s^1\ 4d^{10}$ [Kr] ↑ (5s) ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ (4d)

n = 4, l = 2, m_l = +2, m_s = -½

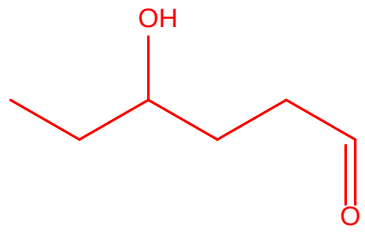
b. gadolinium $[Xe]\ 6s^1\ 4f^8$ [Rn] ↑ (6s) ↑↓ ↑ ↑ ↑ ↑ ↑ ↑ (4f)

n = 4, l = 3, m_l = −3, m_s = −½

c. arsenic $[Ar]\ 4s^2\ 3d^{10}\ 4p^3$ [Kr] ↑↓ (4s) ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ (3d) ↑ ↑ ↑ (4p)

n = 4, l = 1, m_l = +1, m_s = +½

4. (25 points) ***Balance*** the reaction for the combustion of 4-hydroxyhexanal and estimate its ***enthalpy of reaction (in kJ)*** using bond energies.



$+ \ 8\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$

Break
5 C-C (346 kJ)
11 C-H (414 kJ)
1 C-O (358 kJ)
1 C═O (745 kJ)
1 O-H (463 kJ)
8 O═O (498 kJ)

Form
12 C=O (799 kJ)
12 O-H (463 kJ)

$$\Delta H \approx \left[(5)(346\ \text{kJ}) + (11)(414\ \text{kJ}) + (1)(358\ \text{kJ}) + (1)(745\ \text{kJ}) + (1)(463\ \text{kJ}) + (8)(498\ \text{kJ})\right] - \left[(12)(799\ \text{kJ}) + (12)(463\ \text{kJ})\right] = -3310.\ \text{kJ}$$

5. (25 points) The Li^{2+} ion has a line in its spectrum at 102.51 nm due to the electron dropping from the n = 9 energy level to a lower one. To which lower energy level is the electron dropping?

$$\frac{1}{\lambda} = \frac{Z^2 R_H}{hc}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$\frac{1}{n_f^2} = \frac{1}{n_i^2} + \frac{hc}{\lambda Z^2 R_H} = \frac{1}{(9)^2} + \frac{(6.626\times10^{-34}\ \text{J s})(2.998\times10^{8}\ \text{m s}^{-1})}{(102.51\times10^{-9}\ \text{m})(3)^2(2.180\times10^{-18}\ \text{J})} = 0.1111140$$

$$n_f = \frac{1}{\sqrt{0.1111140}} = 2.9999605 \approx 3$$

6. (30 points) Formic acid is responsible for the sting of ant bites. By mass, formic acid is 26.10% C, 4.38% H, and 69.52% O. The molar mass of formic acid is 46.02 g/mol. Find the molecular formula of formic acid and draw its Lewis structure with the optimum formal charges, state whether or not the ion has ***resonance*** (yes or no), state the ***electron group and molecular geometries***, determine the ***polarity*** (polar or nonpolar), state the ***hybridization*** on the central atom and give the number of ***σ and π bonds*** in the structure, and give its IUPAC systematic name. (Hint: remember that in oxygen containing acids the acidic hydrogen is attached to oxygen.)

$$26.10\ \text{g C} \times \frac{1\ \text{mol C}}{12.0107\ \text{g C}} = 2.17306\ \text{mol C}/2.17306\ \text{mol} = 1\,\text{C}$$

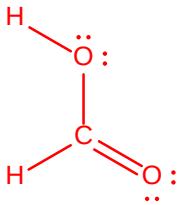
$$4.38\ \text{g H} \times \frac{1\ \text{mol H}}{1.00794\ \text{g H}} = 4.345497\ \text{mol H}/2.17306\ \text{mol} = 2\ \text{H}$$

$$69.52\ \text{g O} \times \frac{1\ \text{mol O}}{15.9994\ \text{g O}} = 4.3451929\ \text{mol O}/2.17306\ \text{mol} = 2\ \text{O}$$

Empirical formula is CH_2O_2 with an emprical mass of 46.0254 g mol^{-1}.

$$\frac{MM}{EM} = \frac{46.02\ \text{g mol}^{-1}}{46.0254\ \text{g mol}^{-1}} = 1.000117 \approx 1$$

The molecular formula is also CH_2O_2.



There is no resonance. It has trigonal planar electron group and molecular geometry around the carbon. It is polar. It has sp^2 hybridization on the carbon. There are 4 σ bonds and 1 π bond. The IUPAC systematic name is methanoic acid.