1 Cognitive reasoning in the chemical sciences 3.3

1. **Bohr model:** the model for the single electron of H, He^{+}, Li^{2+}, Be^{3+}, etc...

   (a) Recall the relation $E_{total} = -R_H \frac{Z^2}{n^2}$, an equation which should be memorized. The total energy is always the sum of the kinetic energy, E_{trans} and the potential energy, E_{pot}. In the case of electrostatic forces, the forces holding together electrons and protons, the kinetic energy, $E_{trans} = -\frac{1}{2}E_{pot}$, this latter relation is called the *virial theorem*. State an equation, with an equal sign, relating the kinetic energy of an electron to R_H, Z and n.

   (b) Recall that for a particle not moving at the speed of light, $p = \frac{h}{\lambda}$, $p = mv$, and $E_{trans} = \frac{1}{2}mv^2$, three equations which should be memorized. State an equation, with an equal sign, relating the kinetic energy of an electron to h, m_e (the mass of an electron) and λ.

   (c) Assuming R_H, H, and m_e are constant, express the proportionality relationship between λ and Z and n.

   (d) If one doubles n, keeping Z constant, what happens to λ? If one doubles λ, keeping Z constant, what happens to n?

   (e) If Z is constant why in general is it not possible to increase λ by exactly 35%?

   (f) It is not possible for $E_{pot} > 0$. Please use the fact that kinetic energy is always ≥ 0 and the virial theorem to deduce this statement.

   (g) What is the highest possible energy for a hydrogen electron?

   (h) When a hydrogen electron has this highest energy, what does the kinetic energy equal?

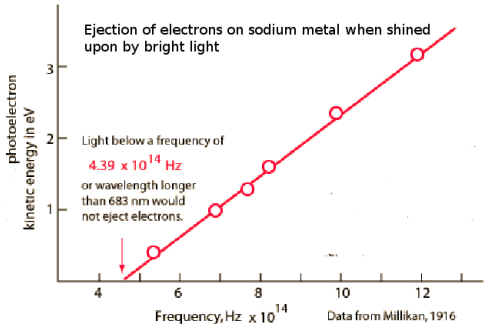
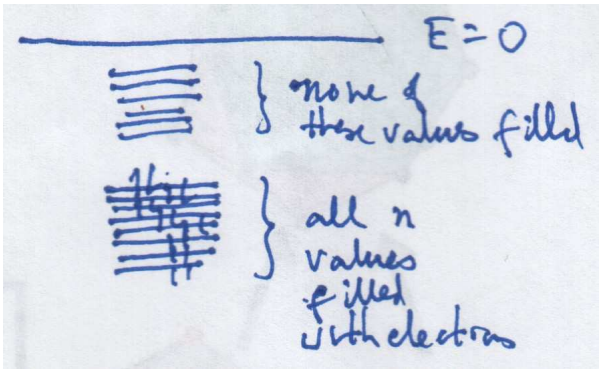


Figure 1: The photoelectric effect based on the original data from Millikan.

2. Examine a chemical compound with the electron energy diagram shown on the next page. Explain why a compound with this energy diagram could have the sodium photoelectron energy graph shown above.

3. **A mystery element**

   An ion has a single electron. The longest wavelength of radiation absorbed by this ion in its lowest energy state is 7.60 nm. (a) Which ion is this? (b) What is the minimum energy (in units of J) required to completely remove this electron from the ion in its lowest energy state?



4. **The Bohr model, atomic orbitals, and the photoelectric effect**

   (a) An electron in a Li^{2+} occupies the $4p_x$ atomic orbital. What is the shortest wavelength of light that can be emitted by this ion?

   (b) Light is absorbed by this same ion, causing an electron to fly off with speed 1.60×10^6 m s^{-1}. What is the frequency of this light?

5. **"Sacrebleu, I will violate the photoelectric effect!"**

   (a) The French scientist La Cheville-Tordue is investigating the photoelectric effect on a material whose work function is 180.66 kJ/mol. Calculate the value of ν_o for this value of the work function.

   (b) (10 pts) Prof. La Cheville-Tordue knows that the energy orbital diagram of this same material is as shown below. Based on her knowledge of the energy orbital diagram, Professor La Cheville-Tordue tries shining the material sequentially with two frequencies of light, both of whose frequencies are *smaller* than ν_o with the hope of nevertheless ejecting an electron from the material. Based on the given energy orbital diagram, state a possible value for the first of the two frequencies chosen. For credit, briefly explain the process by which Prof. La Cheville-Tordue hopes to eject an electron.