MSE160 Problem Set 1

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1 Question 1:

In 1921, Albert Einstein received a Nobel Peace Prize for his discovery of the law of the photoelectric effect. In his experiment, he shone light of particular wavelengths on a strip of metal (or different energies for the photons, according to Planck), and he discovered that the wavelength of the light had to be adequately to emit a photoelectron, which can be measured. Einstein discovered the maximum kinetic energy of the electrons before being removed from atomic binding to be defined as:

$$K_{max} = \frac{1}{2}m_e v_k^2 = h\nu - W \tag{1}$$

where W represents the work function, which denotes the minimum amount of energy required to remove the electron. The kinetic energy is the difference between the quantized photon energy (known as the net incident energy, hν) and the work function (the emission of energy during the release of the electron, W). A key importance is that the kinetic energy must be positive, meaning the incident energy must be greater than the work function.

In addition, the amount of photoelectrons emitted during this process is directly proportional to the intensity of the source; that is to say that as the intensity of the source increases (source becomes brighter), the amount of photoelectrons emitted increases.

2 Question 2:

Rydberg's equation can be used to find the wavelength of the photon emitted:

$$\frac{1}{\lambda} = R_H(\frac{1}{n_f^2} - \frac{1}{n_i^2}) \tag{2}$$

where n_i represents the initial state, n_f is the final state, and R_H is Rydberg's constant.

$$\lambda = \frac{1}{1.097 \times 10^7(\frac{1}{2^2} - \frac{1}{4^2})} = 4.86 \times 10^{-7}\text{m} \tag{3}$$

Next, Planck's equation can be used to determine the energy transmitted during the transition.

$$E = \frac{hc}{\lambda} = \frac{6.626 \times 10^{-34}\text{J} \cdot \text{s} \cdot 3 \times 10^8 \frac{\text{m}}{\text{s}}}{4.86 \times 10^{-7}\text{m}} = 4.09 \times 10^{-19}\text{J} \tag{4}$$

Alternatively, the energy can be calculated and expressed in terms of electron-volts (eV) using the equation:

$$E = h\nu = -13.6[\frac{1}{n_1^2} - \frac{1}{n_2^2}] \text{ eV} = -2.55 \text{ eV} \tag{5}$$

3 Question 3:

The energy can be calculated using Planck's equation:

$$E = \frac{hc}{\lambda} = \frac{6.626 \times 10^{-34}\text{J} \cdot \text{s} \cdot 3 \times 10^8 \frac{\text{m}}{\text{s}}}{1.28 \times 10^{-6}\text{m}} = 1.55 \times 10^{-19}\text{J} \tag{6}$$

The energy in Joules can be converted to electron-volts to be able to determine the energy range it lies in.

$$1.55 \times 10^{-19}\text{J} = -0.967 \text{ eV} \tag{7}$$

To go from energy level n = 5 to n = 3, it takes -1.51 eV - (-0.54 eV) = -0.97 eV, which matches the energy that is obtained by converting the energy in Joules to electron-volts. Therefore, it is a Paschen series transition (from n = 5 to n = 3).

4 Question 4:

The equation developed to determine the quantised radii of the hydrogen atom is:

$$r_n = \frac{h^2 \varepsilon_0 n^2}{(\pi m e^2)} = a_{Bohr} n^2 \tag{8}$$

where n is the orbit level of hydrogen.

The value found for n = 1 is the most probable distance between the nucleus and the electron of hydrogen in its ground state. The value for a_{Bohr}, known as the Bohr radius, has a value of 5.3 $\times 10^{-11}$ m.

Thus, the radii of the second and third Bohr orbits are 2.12 $\times 10^{-10}$ m and 4.77 $\times 10^{-10}$ m, respectively.

The value of the radii can be used to calculate the velocity of the electron, using the equation:

$$v = \frac{hn}{(2\pi m r)} \tag{9}$$

where h is Planck's constant and m is the mass of the electron.

$$v_2 = \frac{6.626 \times 10^{-34}\text{J} \cdot \text{s} \times 2}{2\pi \times 9.11 \times 10^{-31}\text{kg} \times 2.12 \times 10^{-10}\text{m}} = 1.09 \times 10^6 \text{m/s} \tag{10}$$

$$v_3 = \frac{6.626 \times 10^{-34}\text{J} \cdot \text{s} \times 3}{2\pi \times 9.11 \times 10^{-31}\text{kg} \times 4.77 \times 10^{-10}\text{m}} = 7.28 \times 10^5 \text{m/s} \tag{11}$$

The speeds of the electrons in the respective orbits are 1.09 $\times 10^6$ m/s and 7.28 $\times 10^5$ m/s.