PEandQuantizationKey

Tuesday, January 24, 2017 8:57 AM

When a laser is pointed at a zinc metal surface (Φ = 7.85 x 10^{-13} μJ), an electron is ejected with a velocity of 1.44 x 10^5 mm/ms. What is the wavelength of light that is emitted by the laser? Report your answer in nm.

Ok, let's think about this problem in pieces:

1. Consider the equation $E_{photon} = \Phi + E_k$
   a. Which variable is explicitly told to you in the problem? Is it in SI units? If not, convert it.

$$\phi = 7.85 \times 10^{-13}\,\mu J \left| \frac{10^{-6}\,J}{1\,\mu J} \right. = 7.85 \times 10^{-19}\,J$$

   b. Can you determine either of the other variables from the information you are given and the extra info below? If so, calculate that value. Make sure you are careful with units (when in doubt, use SI units).

$E_{photon} = h\nu = \frac{hc}{\lambda}$ $\qquad$ $h = 6.626 \; x \; 10^{-34}\,Js$ $\qquad$ $c = 2.998 \; x \; 10^{8}\,ms^{-1}$

$\boxed{E_K = \frac{1}{2} mv^2}$ $\qquad$ $m_{electron} = 9.109 \; x \; 10^{-31} kg$ $\qquad$ $c = \lambda\nu$

$$V = 1.44 \times 10^5 \frac{mm}{ms} \left| \frac{10^{-3}\,m}{1\,mm} \right| \frac{1\,ms}{10^{-3}\,s}$$

$$V = 1.44 \times 10^5\,m/s$$

$$E_K = \frac{1}{2}(9.109 \times 10^{-31}\,kg)\left(1.44 \times 10^5 \frac{m}{s}\right)^2$$

$$E_K = 9.44 \times 10^{-21}\,J$$

   c. Now put it all together and solve for the 3rd term in the equation $E_{photon} = \Phi + E_k$

$$E_{photon} = 7.85 \times 10^{-19}\,J + 9.44 \times 10^{-21}\,J$$

$$E_{photon} = 7.944 \times 10^{-19}\,J$$

   d. Is this the answer that you need? If not, use the information given above to solve for the variable that you want. Make sure to note that the problem is asking for the answer in a specific unit.

$$E = \frac{hc}{\lambda} \qquad \lambda = \frac{hc}{E} = \frac{(6.626 \times 10^{-34}\,Js)(2.998 \times 10^8 \frac{m}{s})}{7.944 \times 10^{-19}\,J}$$

$$\lambda = 2.50 \times 10^{-7}\,m \left| \frac{1\,nm}{10^{-9}\,m} \right. = 250\,nm$$

2. Now try it yourself. Determine the velocity of an electron that is ejected from a Uranium surface when 145 nm light is directed at that surface. The threshold energy of Uranium is 3.6 eV (note that 1 eV = 1.602 x 10^{-19} J).

$$\lambda = 145\,nm \left| \frac{10^{-9}\,m}{1\,nm} \right. = 1.45 \times 10^{-7}\,m$$

$$E_{photon} = \frac{(6.626 \times 10^{-34}\,Js)(2.998 \times 10^{8}\,\frac{m}{s})}{1.45 \times 10^{-7}\,m}$$

$$E_{photon} = 1.37 \times 10^{-18}\,J$$

$$\phi = 3.6\,eV \left| \frac{1.602 \times 10^{-19}\,J}{1\,eV} \right. = 5.767 \times 10^{-19}\,J$$

$$1.37 \times 10^{-18}\,J = 5.767 \times 10^{-19}\,J + E_K$$

$$E_K = 7.93 \times 10^{-19}\,J$$

$$7.93 \times 10^{-19} = \frac{1}{2}(9.109 \times 10^{-31}\,kg)\,v^2$$

$$v^2 = 1.74 \times 10^{12}\,\frac{m^2}{s^2}$$

$$v = 1.32 \times 10^{6}\,m/s$$

3. The threshold energy of carbon is 4.81 eV while aluminum is 4.08 eV. Using your understanding of Coulomb's Law, explain why it takes less energy to release and electron from aluminum. Think critically about the variables (q_1, q_2, and r) to guide your answer.

Aluminum's outermost electrons $E_p \alpha \frac{q_1 q_2}{r}$ are in the 3rd shell while carbon's are in the 2nd. Electrons in the 2nd shell are closer to the nucleus, so the have a smaller "r" and a more negative Ep. Consequently, it takes more energy to remove them

4. Determine the frequency of a photon required to release an electron from carbon. The conversion factor between eV and J is give in problem 2.

$$4.81\,eV \left| \frac{1.602 \times 10^{-19}\,J}{1\,eV} \right. = 7.71 \times 10^{-19}\,J$$

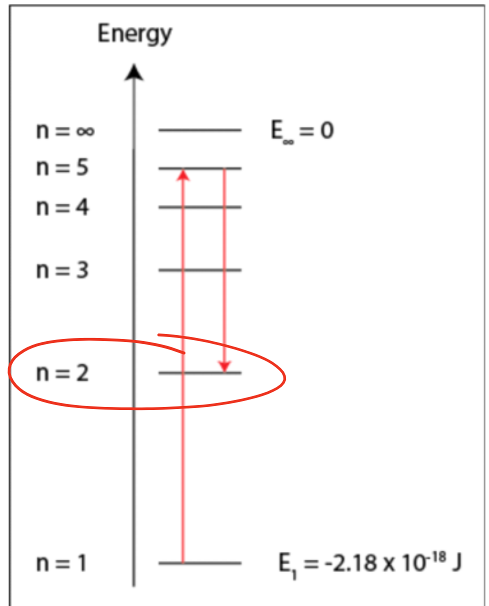
$$E = h\nu \qquad \nu = \frac{E}{h} = \frac{7.71 \times 10^{-19}\,J}{6.626 \times 10^{-34}\,Js} = 1.16 \times 10^{15}\,s^{-1}$$

Quantization of Energy

5. What is meant by the quantization of energy?

e^- that interact with an atom are restricted to very specific energies.

6. Use the diagram to the right to answer the following questions:



Energy level diagram for a **hydrogen** atom.

   a. Why does it make sense that each of these energy levels are less than zero? That is, what does it mean for an electron to have a negative potential energy?

   The interaction between an e^- and a nucleus is based on Coulomb's Law. (-) E is favorable energy

   b. Which arrow corresponds with an absorbance process? ↑

   c. Which arrow corresponds with an emission process? ↓

   d. What are two sources of energy that can result in an electron moving to a higher level?

   heat and photons (think light rays)

   e. Which of these levels corresponds to the ground state?

   n=1

   f. The first excited state is the energy level closest to the ground state. Circle the 1st excited state on the diagram. n=2

   g. What level corresponds to the 2nd excited state? n=3

   h. Calculate the energy of the 2nd excited state. Remember that you can use $E_n = \frac{-2.18x1\ ^{-18}J}{n^2} Z^2$ for a single electron atom.

   $E_3 = \frac{-2.18 \times 10^{-18} J}{3^2}(1)^2 = -2.42 \times 10^{-19} J$

   i. Calculate the energy that an electron needs to absorb to go from n = 1 to n = 3.

   $\Delta E = E_3 - E_1 = -2.42 \times 10^{-19} J - (-2.18 \times 10^{-18} J) = 1.94 \times 10^{-18} J$

   j. What is the wavelength (λ) of a photon that can accomplish the excitation from 6i?

   $\lambda = \frac{hc}{E} = \frac{(6.626 \times 10^{-34} Js)(2.998 \times 10^{8} m/s)}{1.938 \times 10^{-18} J} = 1.025 \times 10^{-7} m$

   102.5 nm

7. Now let's try putting all of this together in a problem. If a hydrogen atom emits a photon with a wavelength of 433.92 nm, what energy level (n) does the electron **begin** during this emission process?

   a. Determine the final energy level based on the wavelength. $n=2$ This is the Balmer Series
   b. Determine E_{photon}.
   c. Determine the energy of the unknown level (remember $E_{photon} = \Delta E$).
   d. Determine the unknown level (n)

$$E_2 = \frac{-2.18\times10^{-18}J\,(1)^2}{2^2} = -5.45\times10^{-19}J$$

$$E_{photon} = \frac{hc}{\lambda} = \frac{(6.626\times10^{-34}J\cdot s)(2.998\times10^8 m/s)}{4.3392\times10^{-7}m} = 4.58\times10^{-19}J$$

$$\Delta E = 4.58\times10^{-19}J = E_n - (-5.45\times10^{-19}J)$$

$$E_n = -8.72\times10^{-20}J \qquad -8.72\times10^{-20} = \frac{-2.18\times10^{-18}\,(1)^2}{n^2}$$

$$n^2 = 25 \longrightarrow \boxed{n=5}$$

8. The idea of threshold energy can be applied to what we have discussed regarding the quantization of energy. To completely remove an electron from an atom, all attractive/stabilizing energy must be removed. Consequently, the electron needs to be excited from its resting state all the way to the infinite energy level (n = ∞).

   a. What is the energy of the level n = ∞? Either Coulomb's law or $E_n = \frac{-2.18x10^{-18}J}{n^2}Z^2$ can help you answer this question. Hint: n = ∞ has a radius of ∞.

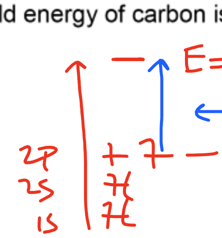
   $E_\infty = \varnothing$ if an e^- is an infinite distance from the nucleus, it has absolutely no attraction

   b. Why can't $E_n = \underbrace{\frac{-2.18x10^{-18}J}{n^2}Z^2}_{\text{only for single } e^- \text{ atoms}}$ be used to calculate the energy of other energy levels in carbon?

   6 electrons

   c. What type of orbital holds the highest energy electron in carbon? Is this electron part of a pair or is it unpaired? C: $1s^2 2s^2 \boxed{2p^2}$ highest energy, so 2P orbital

   d. Noting that the threshold energy is the amount of energy needed to remove the highest energy electron (the one you identified in part c), what must be the energy of that electron? Recall that the threshold energy of carbon is given in problem 3 (4.81 eV). → $7.71\times10^{-19}J$



← e^- need to gain this much energy.

$$\phi = \Delta E = 0 - E_{2p}$$

$$7.71\times10^{-19}J = 0 - E_{2p}$$

$$E_{2p} = -7.71\times10^{-19}J$$