H133: 1094 Session 2 KEY

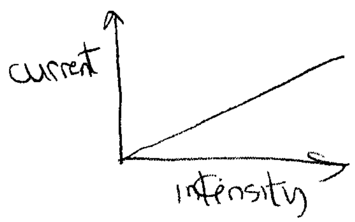
Write your name and answers on this sheet and hand it in at the end.

There are a variety of activities today; watch the time and try to get through them all. Work with others at your table on these activities. Argue about the answers but work efficiently!
After the indicated time, move on to the next activity!

1. Q3: The Photoelectric Effect [20 min.]

Start up the PhET applet "The Photoelectric Effect" (Start->Programs->PhET, choose "Quantum Phenomena" from the left menu, and click once on the Photoelectric icon). The simulation shows light with a well-defined wavelength and intensity (which you control), incident on a metal plate (cathode), which causes the emission of electrons (depicted as little balls). The electrons can travel (if they have enough energy) to another plate (anode), completing an electric circuit. You can apply a voltage and measure the current.

a. Increase the intensity so that electrons flow. Sketch here your prediction for what a graph of the current vs. the light intensity would look like. Then select the "Current vs light intensity graph" and move the intensity through its entire range. Fix your graph as needed. Is this result consistent with the wave model or particle model of light, or both? Explain.



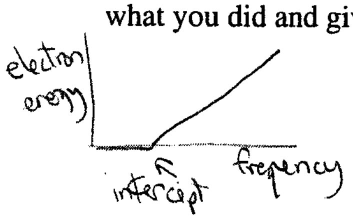
The current should be linearly proportional to the intensity — double the energy per sec. and you should double the electrons per second = current. This is consistent with both the wave and particle models.

b. Set the intensity halfway. Adjust the voltage to make the electrons just stop, so the current drops to zero (this is called the stopping voltage). Why is the polarity of the voltage such that the anode is negative? How is the stopping voltage related to the maximum kinetic energy of the electrons? You can read off the wavelength of the light and the stopping voltage. Calculate the work function for sodium (and give an appropriate number of significant figures).

- The anode is negative so that it repels the e^-'s ⇒ they are going "up hill".
- The negative of the stopping voltage times e is the maximum KE in eV's.
- With $\lambda = 400$ nm, we find $V_{stop} = -0.86$. So $K_{max} = 0.8$ eV

$K = \frac{hc}{\lambda} - W \Rightarrow W = \frac{hc}{\lambda} - K_{max} = \frac{1240\,\text{eV-nm}}{400\,\text{nm}} - 0.8\,\text{eV} \approx 2.3\,\text{eV}$ (two significant figures at most!)

c. Note that the initial target is Sodium. Devise a way using the "Electron energy vs light frequency graph" to rank the work functions of all the possible targets from lowest to highest. Try it out. Explain what you did and give your result. (Hint: Move the wavelength through its entire range.)



The intercept is the frequency where $hf = W$, so just line up the metals from lowest to highest intercept:

Na < Ca < Zn < Cu < Pt
≈0.7 ≈0.75 ≈0.9 ≈1.0 ≈1.5

2. Q4: The Wave Nature of Matter [15 min.]

Start up the PhET applet "Quantum Wave Interference". This applets simulates wave phenomena from both light (photons) and particles (electrons, neutrons, helium atoms).

a. Turn on the light gun and then (on the right) click on the "Double Slits". Look at the pattern on the screen. Predict below (qualitatively) how it will change when you change the slit separation, then test your prediction with the "Slit Separation" slider. The interference pattern has light and dark stripes. The first dark stripes are when $d \sin\theta = \frac{1}{2}\lambda$ or at $\theta = \sin^{-1}\frac{\lambda}{2d}$. So increasing the slit separation d will make θ smaller, meaning the dark stripes move closer to the center. They do!

b. Now switch from photons to electrons (using the pulldown menu above the Gun Controls). Explain the pattern you see now. Predict what will happen to the pattern when you decrease the electron velocity to 700 km/s and then test your prediction.

Same type of interference pattern. Decreasing the velocity will increase the wavelength, so increase θ, so the dark stripes move further apart.

c. Do problem Q4B.2. (Hints: Follow Example Q4.1. 1 keV = 1000 eV.) What will happen if a beam of such electrons passes through a 0.01 nm slit?

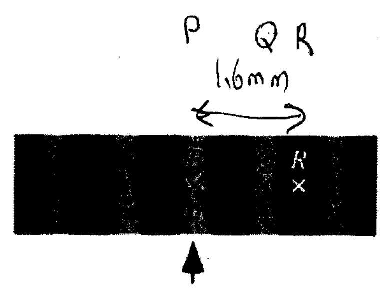
Use $\lambda = \frac{hc}{\sqrt{2Kmc^2}} = \frac{1240\ \text{eV}\cdot\text{nm}}{\sqrt{2(3200\ \text{eV})(511{,}000\ \text{eV})}} = 0.022\ \text{nm}$

With λ >> the slit width, the beam will spread out entirely from diffraction.

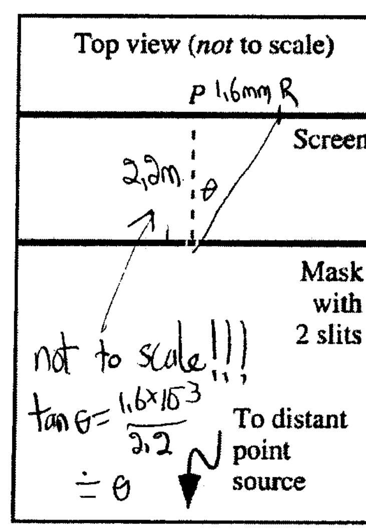
d. Look at problem Q4R.2 (but don't solve it). What is the effect of making h much larger than in our universe? Why are there places to stand where you won't be hit by bats?

With h larger, wave affects for macroscopic objects can become noticable. There will be destructive interference of the bats, so you can stand in a "dark stripe".

3. Group Problems [10 min.]



Center of screen



a. Why do radio waves diffract around buildings, although light waves do not? Radio wavelengths are comparable (or larger) than buildings while light (visible) wavelengths are very much smaller, so no diffraction is noticable.

b. The photograph shows the pattern on a screen from a distant source of red light that passes through two very narrow slits. Point P is the center, which is bright, and Q is another bright region. Point R marks a minimum of intensity.

- Find the path difference in terms of the wavelength lambda for each of the points P, Q, R.

  P: 0λ (symmetric) R: $\frac{3}{2}\lambda$ (destructive)

  Q: λ (constructive)

- The distance from P to R is 1.6 mm and the screen is 2.2 m from the slits. What is the slit separation?

  We'll use $d \sin\theta = \frac{3}{2}\lambda$ with $\lambda \sim 700\ \text{nm}$ (red)

  $\Rightarrow d = \frac{3}{2} 700\times10^{-9}\ \text{m} / \theta$ using $\sin\theta \doteq \theta$!!

  $= 1.5 \times 700\times10^{-9}\ \text{m} / \left(\frac{2.2}{1.6\times10^{-3}}\right) \doteq 1.4\times10^{-3}\ \text{m} \doteq$ **1.4 mm**

c. Give two reasons why the usefulness of large telescopes increases as we increase the lens diameter.

- less diffraction ⇒ better resolution of stars with small angular separation.
- increased light collection ⇒ can detect dimmer stars.