PHET SIMULATION: THE PHOTOELECTRIC EFFECT

Set-up

1. Navigate to http://k20.ou.edu/photoelectric.
2. Start simulator. If asked, choose to run the Cheerpj version. Open the two bottom graphs on the right side of the simulator. Click on the "Options" menu and select "show photons."
3. Use the "pull down" menu to change the metal to zinc, which is the metal used in the electroscope demonstration.
4. Set the wavelength of light to 650nm, which is visible red light like the light produced by our laser pointer. You may type in exact wavelength values.

Experiment

1. Set the intensity to 50%. You should now see red photons coming from the sources and directed at a zinc plate. The zinc plate is located inside a vacuum tube with another metal plate on the opposite side of the tube. The pilates are connected in a circuit with an ammeter and a battery. The ammeter measures the current. Current is a measure of the rate of charge (electrons) per second flowing through the circuit.
    a. What do you observe happening inside the vacuum tube? (Note: Some of your observations may be that nothing is happening.)
2. Slowly decrease the wavelength until you observe something happening. Record your observations in your Science Notebook.
3. At which wavelength are electrons first ejected from the zinc metal? Is this consistent with what you observed with the electroscope? (Recall the UV source wavelength in the demonstration was 254nm.)
4. Based on your observations, what causes the electron particles to become ejected from the zinc atoms? The ejected electrons are known as photoelectrons.
5. Set the wavelength of the UV to 240 nm. Investigate the effect of changing the intensity by sliding the intensity bar between its highest and lowest setting. Intensity is a measurement of the rate at which energy is delivered over an area. Increasing the intensity of the photons increases the rate at which the energy is delivered by the photons per area. You may also think of intensity as the number of photons delivered to the area per time, where each photon is the energy carrier.

a. Observe the current value in the yellow box in the circuit and the two graphs on the right. The current will increase as more photoelectrons are produced over time. Record your findings in your Science Notebook.
b. Observe the graph of intensity and current (green). Describe the relationship between the intensity of light and the current. (Are they directly or inversely proportional?)
c. Observe the frequency vs kinetic energy graph (blue). What is the effect of the light intensity on the kinetic energy (y-axis variable on blue graph) of the electrons?

Select "Show only highest energy electrons" from upper right-hand corner.

If light is behaving as a wave, the maximum kinetic energy of the electrons should increase as the intensity increases. Based on this statement and your observations, is light behaving as a wave?

6. Change the intensity to 3%. Observe for a few minutes.
   a. Can a single photon cause an electron to be discharged?
   b. Do all photons cause an electron to be discharged?
   c. Think of a reason for this. Lower the wavelength to 100 nm. Does this help you answer the previous question?

If light is behaving as particles, it would deliver energy immediately and the electrons would ***instantly be ejected*** when hit by a photon. If light was behaving as ***waves, it would deliver energy over time,*** and there would be a ***lag in time*** between when the wave contacted the electron and when it was ejected.

Based on this statement and your observations, is light behaving as a wave or a particle?

7. Repeat steps 5 with the 650 nm red light. Record your findings in your Science Notebook. Explain your observation.

If light was behaving as a wave, the energy delivered would build up over time and eventually cause electrons to be ejected. Also, the ***energy would build up as the intensity is increased*** and cause electrons to be ejected.

Based on this statement and your observations, is light behaving as a wave?

8. Set the wavelength back at 240 nm with 50% intensity. Slowly decrease the wavelength while observing the frequency($\boldsymbol{\nu}$) of the light versus kinetic energy (KE) of the electron graph.
   a. Describe the blue graph curve 3. (Is it linear or exponential?)

b. Write a mathematical equation for the graph curve in terms of y, m, x, and b.
c. Identify the y and x variables in the equation.

The slope is constant once 240 nm is reached and passed. The slope represents Planck's constant, h.

The y-intercept, b, is known as the work function, Φ. (Note: You cannot see the y-intercept on the graph because it has a negative value.) The work function is the energy required to eject an electron from the metal surface. In chemistry, this value is known as the ionization potential or ionization energy or binding energy of an electron.

a. Write the mathematical equation in terms of KE, $\boldsymbol{\nu}$, h and Φ. Because Φ is negative, put a minus sign in front of it in the equation.

The energy of a photon of light is given by the formula, $E_{photon}=h\boldsymbol{\nu}$. This is known as a quantum of energy. A quantum of energy is the smallest individual amount of energy that a photon can possess.

b. Write your mathematical equation with E_{photon} in place of $h\boldsymbol{\nu}$.
c. Based on the equation you wrote, when will an ejected electron have no kinetic energy?

9. Change the metal from zinc to sodium. Find the maximum wavelength that causes electrons to be ejected from sodium atoms. Record your findings in your Science Notebook.

How does the energy of these photons compare to the energy of the photons of light required to eject electrons in zinc?

Does sodium have a larger or smaller work function than zinc? Explain.

10. Find the maximum wavelength that causes electrons to be ejected from the other metals on the list. Record your findings in your Science Notebook.
11. Rank all the metals in increasing order of increasing work function. You can do this by finding the point on the x-axis where the electrons first obtain energy. The closer the point is to the y-axis, the smaller the work function.
12. Predict the position of the unknown metal in the series above.

Extension:

You have established that the energy of a photon is its frequency times Planck's constant.

$$E=h\nu$$

- You have also established from previous lessons that $c=\lambda\nu$ or $\nu=c/\lambda$.
- Combining these two equations gives you $E=hc/\lambda$.
- You are probably familiar with Einstein's famous equation: $E=mc^2$.
- Therefore, $hc/\lambda=mc^2$ or $h/\lambda=mc$.
- One of the most important properties of particles is their momentum. Mathematically, momentum is the product of mass and velocity. The equation for momentum is $\rho=mv$. For light, $v=c$. Therefore, $\rho=mc$.
- Therefore, $h/\lambda=\rho$.
- This equation demonstrates both the wave(λ) and particle (ρ) properties of photons.

University of Colorado-Boulder. (n.d.). Photoelectric effect. PhET Interactive Simulations. https://phet.colorado.edu/en/simulation/legacy/photoelectric