PHET SIMULATION PHOTOELECTRIC EFFECT-TEACHER'S GUIDE

Activity 8

Set-up

1. Have students navigate to http://k20.ou.edu/photoelectric and complete the following steps.
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. What do you observe?

   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?
   - Particles are moving from the zinc across the vacuum tube.
   - *~250 nm*
   - *Yes, the radiation that causes electrons to be ejected is in the UV range.*
   - *Radiation of sufficient energy give electrons energy to be ejected.*

5. Set the wavelength of the UV to 240 nm. Investigate the effects of changing the intensity by sliding the intensity bar between its highest and lowest settings. Intensity is a measurement of the rate at which energy is delivered over an area. Increasing the intensity of the photons will increase 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?

- Increasing the intensity causes more electrons to be ejected as shown by the increase in current.
- The graph is linear with a positive slope so there is a direct relationship.
- The kinetic energy is not affected by the intensity.

Have students 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?

Light is behaving as a particle because increasing the intensity of the light has no effect on the kinetic energy of the ejected electrons.

6. Change the intensity to 3%. Observe for a few minutes.
    a. Can a single photon cause an electron to be discharged? Yes
    b. Do all photons cause an electron to be discharged? Why or why not? No, they may not have sufficient energy to eject an electron. Not all electrons have the same energy requirement for ejection. Recall that electrons in atoms exist in orbitals with different energies. Electrons in lower energy orbitals will require more energy to eject.
    c. Think of a reason for this. Lower the wavelength to 100 nm. Does this help you answer the previous question? Yes, at the lower wavelength and higher energy, each photon is causing an electron to be ejected.

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 were 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? A particle because the electrons are ejected from the metal the instant the photon strikes the metal.

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

   Nothing happens because the red photons do not have sufficient energy to eject any of the electrons.

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?

   Light is behaving as a particle because as more and more photons strike the plate; the energy is not building up and eventually ejecting electrons.

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 $h\nu$.
c. Based on the equation you wrote, when will an ejected electron have no kinetic energy?

- The graph is linear.
- *y=mx+b*
- *y-variable is kinetic energy (KE), x-variable is frequency (ν)*
- *KE=hν – Φ, the work function value is negative so replace + sign with - sign*
- *KE=E_{photon}- Φ*
- *When the photon energy is equal to the work function.*

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 Journal.

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.

- Electrons are ejected around 500 nm and current is shown around 450 nm.
- These photons have longer wavelengths and are less energetic. These photons cause ejection.

10. Find the maximum wavelength that causes electrons to be ejected from the other metals on the list. Record your findings.
11. Rank all the metals in increasing order to increase 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.

Smallest: Na→Ca→Zn→Cu→Pt

12. Predict the position of the unknown metal in the series above.

The unknown falls between Ca and Zn.

Teacher Discussion Notes

What this experiment demonstrates about light:

- ***Wave theory incorrectly predicted*** that the maximum kinetic energy of the ejected electrons increases as the intensity of the light increased.
- The experiment shows that, at a given frequency, the **kinetic energy of the electrons is constant** as the intensity changes. This occurs when light behaves as a particle.
- ***Wave theory incorrectly predicted*** that electrons gradually gain energy from light until it had enough energy to ionize. This means that lower energy radiation over time would eventually cause ejection.

- ***There would be a lag*** between the collision and the ejection. The experiment shows that ***electrons are ejected instantaneously*** when light of sufficient wavelength is used.
- This supports the idea that ***energy is delivered in an instant*** by the light to the electrons in fixed amounts or quantities. This quantity of energy needs to be delivered by a particle of light or a photon.
- ***Light is behaving as particles.*** Each particle of light has a quantity of energy known as a quantum. Each particle of light that collides with an electron delivers its energy to that electron. This energy is described by the equation, $E_{photon}=KE-\Phi=hf$.
- Electrons will be ejected if the photon energy is larger than the work function.
- If the energy of the photon is larger than the work function, the additional energy will become the electron's kinetic energy.
- If all of the photons are delivering the same amount of energy, all of the electrons ejected from the same orbital will have ***the same kinetic energy***.
- Recall that electrons in atoms exist in shells. Electrons in different shells have different energies. It takes more energy to eject electrons in lower energy shells.
- In zinc atoms, electrons exist in many different shells. If an electron in a lower energy shell is hit with the same photon as an electron in a higher energy shell, it will have less kinetic energy. This is why the ejected electrons have different kinetic energies.
- Increasing the intensity of the photons causes more electrons to collide with photons, resulting in more electrons in the same shell being ejected with the same kinetic energy.

Energy can only be delivered in multiples of the quantity, hf. Energy is known to be quantized.

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