Exploration of the Photoelectric Effect

Philipp Lenard is generally credited with the discovery of the photoelectric effect, not because he was the first to discover it, but because he was the first to carry out some detailed experiments and establish some important generalizations. The purpose of this exploration is to investigate these generalizations and to review some of the physics involved so that you will be prepared to simulate Millikan’s photoelectric effect experiment. As you work through this exercise, have the applet open in a separate window. (If necessary click on the link, photoelectricEffect.swf.) If you need help understanding the apparatus and variables, see the Help menu for assistance before starting this exploration.

Note: The simulation is a model and like all models has some limitations. The simulation represents Einstein’s idea of what is believed to happen in the photoelectric effect. For measurements of stopping potential, the ammeter should be used, not the visual indication of the movement of electrons that is only approximately represented.

Frequency of the Incident Light

Shining light with a frequency, \( f = 6.91 \times 10^{14} \text{ Hz} \) (or \( \lambda = 434 \text{ nm} \)), onto a sodium metal surface produces a stream of photoelectrons as shown in the simulation when it first starts. For the following questions, keep all variables constant except the type of light.

1. Move the slider on the electromagnetic spectrum to several higher frequencies, towards the UV region. What changes, if any, occur?
2. Move the slider on the electromagnetic spectrum to the right, towards the infrared region. What changes, if any, occur?
3. Determine the lowest frequency of light that still produces photoelectrons from sodium metal. You can use the slider or type in specific wavelengths for a finer control.
4. On the Options menu, choose another metal and repeat #3. Then choose a third different metal. Are the answers the same?

What you determined in #3 and 4 is called the threshold frequency, \( f_o \), for each metal. As Lenard discovered, a substance will only show a photoelectric effect if the frequency of the light is above a certain minimum value, \( f_o \).

Emission of Photoelectrons

Set up the simulation for any metal so that a sufficient frequency and voltage allows photoelectrons to complete the circuit.

5. In the simulation, how quickly is the photoelectron produced at the cathode after the photon strikes?
6. Repeat this observation with several different metals including chemically reactive metals like potassium and inactive metals like silver.

The immediate emission of photoelectrons that occurs with any metal (assuming \( f > f_o \)) created significant problems for the classical wave theory of light. According the existing theory, it should take a noticeable length of time for the electron to accumulate enough energy to be emitted by the metal. Experimentally this does not happen even if the light intensity is very low.
Intensity of the Incident Light
In all of the above manipulations, the intensity, or brightness, of the light remained constant even when the type of light was changed. It seems logical to guess that perhaps the light needs to be more intense if the frequency is below the threshold value.

7. For any metal, keep the voltage at zero and adjust the frequency so that it is just below the threshold frequency for that metal. Move the Intensity slide at the bottom of the screen from its mid-point (0.5) to maximum brightness (1) in several increments. Try some different metals and write a generalization to describe the results.

8. According to Einstein’s original hypothesis, light is composed of quanta of energy called photons. Using the simulation, describe the intensity of light in terms of photons.

9. If the frequency is above the threshold value, what is the relation between the number of photons and the number of photoelectrons? Test your answer by observing the simulation and by manipulating the intensity and noting the current ($V = 0; f > f_o$).

Choose a particular metal, set the frequency above the threshold value for that metal, set the voltage at zero and the intensity at 0.1.

10. Slowly increase the voltage to determine the stopping potential; i.e., the voltage that first produces a current of zero as noted on the ammeter. Note the stopping potential.

11. Increase the intensity in several increments until you reach the maximum. For each intensity value, determine the stopping potential. Does the intensity of the light affect the stopping potential?

Maximum Kinetic Energy of Photoelectrons
Choose a particular metal, set the frequency a little above the threshold value for that metal, set the voltage at zero and the intensity at 0.5.

12. Slowly increase the voltage to determine the stopping potential. You can type in specific voltages when you get close to a zero current. Click “Record Data”.

13. Repeat #12 several times, each time increasing the frequency.

14. Click “Evidence” under the Options menu and review the observations. Does the stopping potential depend on the frequency of the incident light? (Optional: Cut and paste the evidence table into a spreadsheet and graph the results.)

15. What is the relation between voltage and maximum kinetic energy?

16. What does this mean about the relation between the maximum kinetic energy of the photoelectrons and the frequency of the incident light?

Significance of the Photoelectric Effect
The photoelectric effect has played a significant role in the development of modern physics. The explanation of the photoelectric effect introduced a revolutionary concept—a quantum of electromagnetic energy—that led to a whole new branch of physics called quantum theory. Like all revolutions in science, this novel idea was the subject of some controversy for many years within the scientific community. Even Millikan was convinced Einstein was wrong and set out to disprove Einstein’s prediction, but ended up providing clear supporting evidence. In science, the most important thing or “bottom
line” is the evidence. In the face of the results of his experiment, Millikan had to agree with Einstein’s explanation.