Photoelectric Effect PhET Lab

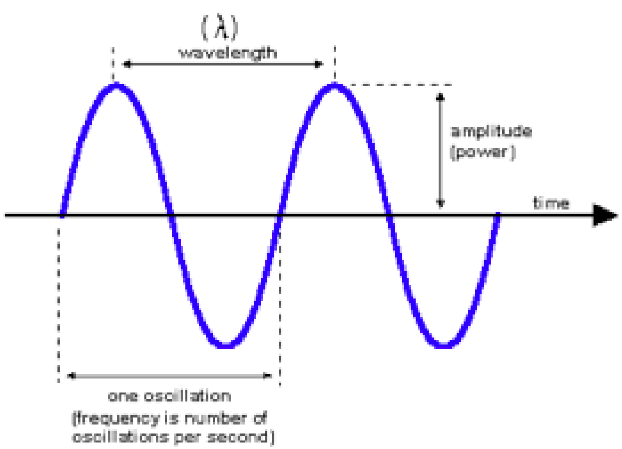
Relevant Next Generation Science Standard:

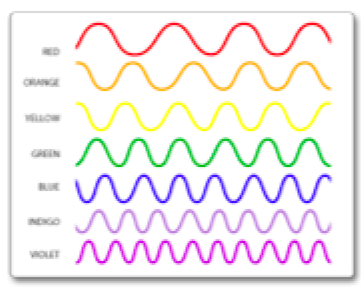
HS-PS4-3. ***Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.***

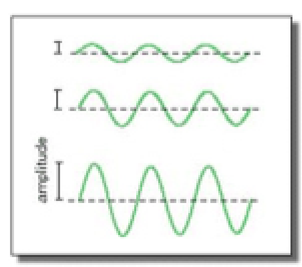
Today, you will use the Photoelectric Effect PhET Lab to explore what happens when light interacts with matter. Light can diffract and refract, like water waves, indicating that light behaves like a wave. However, light sometimes behaves like a particle. How do we know that light behaves like a particle? The photoelectric effect leads us to this.

When light shines on a polished, unoxidized metal surface, or some other photosensitive material, electrons can be ejected from the surface of the metal. This is the photoelectric effect, a cornerstone of our understanding of light as a particle. When we discuss the particle nature of light, we refer to light particles as "photons." It was Einstein's explanation of the photoelectric effect, not his work on relativity, that was honored in his Nobel Prize.

Waves







In the model of a wave at left above, note the meaning of wavelength, frequency and amplitude.

Since wavelength is the 'length' of an oscillation (one crest and one trough) of the wave, it is measured in distance units. Visible light wavelengths are often measured in nanometers (1 nm = 10^{-9} meters).

The model in the top right shows waves with the same amplitude but different wavelengths (and thus frequencies and colors).

The model at bottom right shows waves with the same wavelength (and thus frequency and color) but different amplitudes. Notice how the color of the wave is not affected by a change in amplitude. This is because wavelength is the only variable that affects the color of a wave.

Think about your experience with ocean waves, and what you have seen on the news about tsunamis and beach erosion caused by hurricanes and other severe storms.

1. Considering all of this carefully, do you think that the energy of a wave is directly related to its amplitude, or directly related to its frequency? Explain your reasoning below.

Particles

Albert Einstein and Max Planck developed a theory that light is composed of particles, called photons (little packets of light). They theorized that the energy (E) of each of these photons was proportional to the frequency (f) of the light, or $E=hf$. In this equation, h is a proportionality constant, called Planck's constant.

2. If light is composed of particles as described in this theory, should the energy of light be directly related to its amplitude or to its frequency? Explain your reasoning below.

Waves vs Particles and the Photoelectric Effect

In a photoelectric effect device, light shines on a metal surface and bombards the material's atoms. Since electrons are on the outermost parts of the atoms, they can be knocked off and removed **if the light has enough energy**. If the light has more than enough energy to knock an electron out of an atom on the surface, **the extra energy is used to make the electrons move faster as they leave the surface**. (Think of the breaking shot in pool with light being the cue ball and the electrons being the pool balls on the outside// Other examples: Large wave hitting a coconut tree, wave=light, coconuts=electrons)

Assuming that light is acting like a wave, the intensity of the light is directly related to the amplitude of the light waves.

The wavelength (and color) of the light are inversely related to the frequency. In other words, longer (larger number) wavelength = lower frequency.

Predictions – Open the Photoelectric Effect PhET Simulation. Go to: http://phet.colorado.edu/en/simulation/photoelectric download it. Click on the download and open it.

Before adjusting anything, answer the questions below

1. What do you think will happen to the metal surface when light strikes it?

2. If light is acting like a wave, then what should you adjust in the simulation to make faster-moving electrons leave the metal surface?

3. If light is acting like a particle, then what should you adjust in the simulation to make faster-moving electrons leave the metal surface?

Part 1 – Intro to the Photoelectric Effect

Check the box that says 'Show only highest energy electrons' in the upper right.

1. Keep the intensity constant (but not zero!) and adjust the wavelength of the light. Describe how changing the wavelength affects the emission of electrons. When doing so, pay attention to how it affects:
   1. whether or not electrons are emitted.
   2. how fast the electrons move.
   3. how many electrons are emitted.

2. Keep the wavelength constant (at a wavelength that allows electrons to be emitted) and change the intensity. Describe how changing the intensity affects the emission of electrons. When doing so, pay attention to how it affects:

1. whether or not electrons are emitted.
2. how fast the electrons move.
3. how many electrons are emitted.

3. According to

   a. your observations from Questions 1 and 2,
   b. how the energy of the light should affect the emission of electrons (hint: see bold and underlined phrases above), and
   c. our discussion above about what should affect the energy of light as a wave and as a particle

is the light acting like a particle, or like a wave? Explain your reasoning.

Part 2 – How can we change the number of electrons liberated from the surface?

You have probably noticed that changing the conditions of the simulation can affect how many electrons are liberated from the surface, not just the energy of the individual electrons.

1. Assuming that light is composed of particles (photons), how do you think you can adjust the conditions in the simulation to make more photons come out of the light source?

2. In the 'options' drop-down menu, select 'show photons.' Test the hypothesis you made in Question 1 and report your results here.

3. Thinking about light as being made of photons helps explain what determines the number of electrons liberated from a metal surface. How many electrons do you think a single photon can remove from the surface? To check this, first unclick 'show only highest energy electrons.'

4. Based on your answer to Question 3, what should you adjust to increase the number of electrons liberated from the surface? Try it out and describe and explain your results here.

Part 3 – What determines if electrons are liberated from the surface?

1. You have probably noticed in Parts 1 and 2 that under some conditions, no electrons are liberated from the metal surface. Remember that it takes energy to remove electrons from the metal. Why can't all light cause electrons to leave the surface?

2. If you run the simulation under a particular set of conditions and no electrons are being emitted, what could you adjust to make electrons start coming out? Try this, and then describe and explain your results.

3. It turns out that it takes different amounts of energy for electrons to be liberated from different metal surfaces. To investigate this, start with the light at a long wavelength (low energy) and slowly move the wavelength slider until you begin to see electrons move across the screen.

Record the longest wavelength (lowest energy) at which electrons can be emitted on the table below:

Metal	**Maximum Wavelength for Electrons to be Liberated (nm)**
Sodium	
Zinc	
Copper	
Platinum	
Calcium	

4. Which metal requires the least energy to liberate an electron? Which one requires the most energy to liberate an electron? Remember that larger values for wavelength correspond to lower energies!

Most energy needed:

Least energy needed:

5. Metals tend to react by losing electrons. Do you think a material that requires a lot of energy to remove electrons from would be reactive or unreactive? Explain.

6. Considering this, which of the metals identified in Question 4 would you predict to be most reactive? Which would you predict to be least reactive? Either from your personal experience, or by looking up information about the reactivity of these two metals, check to see if your prediction is correct.

Conclusion Questions

1. For sodium, even at 100% intensity, a green photon with a wavelength of 557 nm will never eject any electrons, but at 1% intensity, a UV photon at 235 nm always knocks out an electron. Einstein's interpretation of this event (or one just like it) earned him a Nobel prize. It's your turn. Why does this result clearly indicate particle-like properties of light (which Einstein referred to photons)?

2. Electricity consists of a flow of electrons. Given this fact, answer the following two questions.

a. Solar PV (photovoltaic) cells utilize the photoelectric effect. Electricity is a flow of electrons. Describe how you think solar cells work, in terms of what we observed in this activity.

b. Some smoke detectors (called ionization smoke alarms) contain a radioactive material that emits ionizing radiation regularly, which ionizes atoms (removing electrons) in the air within the detector, producing a flow of electrons - a measurable electric current. When smoke enters the detector, the smoke blocks the detector from detecting the electrons, triggering the alarm.

Other smoke detectors (called photoelectric smoke alarms) contain a beam of light, which is not aimed at a metal surface. When smoke enters the detector, some of the light is scattered by the smoke and reflects toward the metal surface, producing a current of electrons that is detected and triggers the alarm.

Explain how the photoelectric effect is used in photoelectric smoke alarms.

Extra Credit

Imagine 2 electrons on a plate of sodium metal. One electron is found right on the surface of the metal. The other electron is buried several layers below.

A. Which electron needs the least energy to escape? Why?

B. Which electron will be moving faster when it absorbs the energy from a photon and escapes? Why?

C. 'Unclick' the box that says 'show only the highest energy electrons,' in the upper right of the simulation and observe how that changes what you see in the simulation. Explain this change based on your answers to parts A and B.