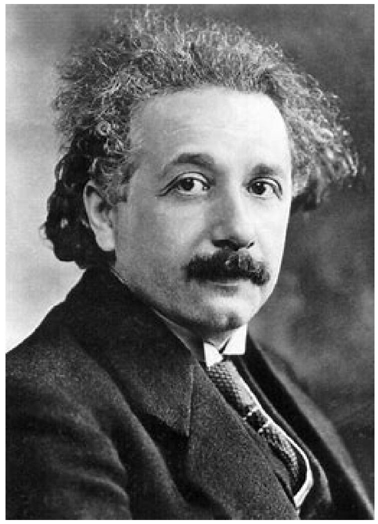
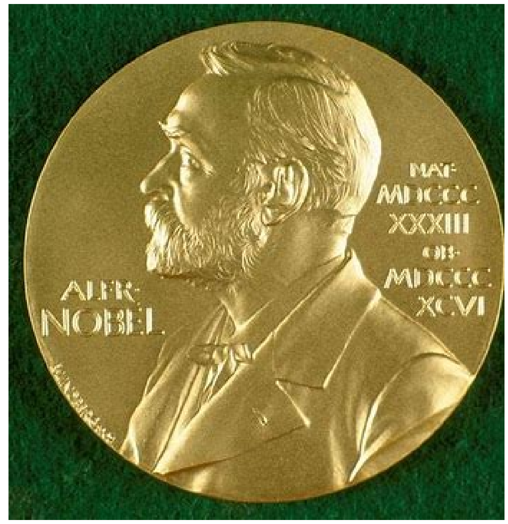
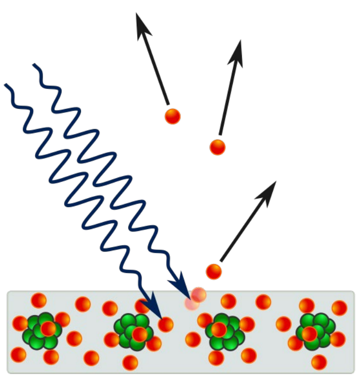
PhET Photoelectric Effect

Link: https://phet.colorado.edu/en/simulations/photoelectric





In 1921, Albert Einstein won the Nobel Prize in Physics for his work on the photoelectric effect. That work was part of his miracle year in 1905, where he showed that the photoelectric effect implies that light acts like particles, which were later named photons. The photoelectric effect is rather simple—shine light on a metal in a vacuum, and it will emit electrons, which can be counted by collecting them on a metal plate and measuring the current flow. The interesting things are how this behavior changes as we change the frequency and intensity of the light, and how the current varies with the voltage between the metal surface and the collector plate.

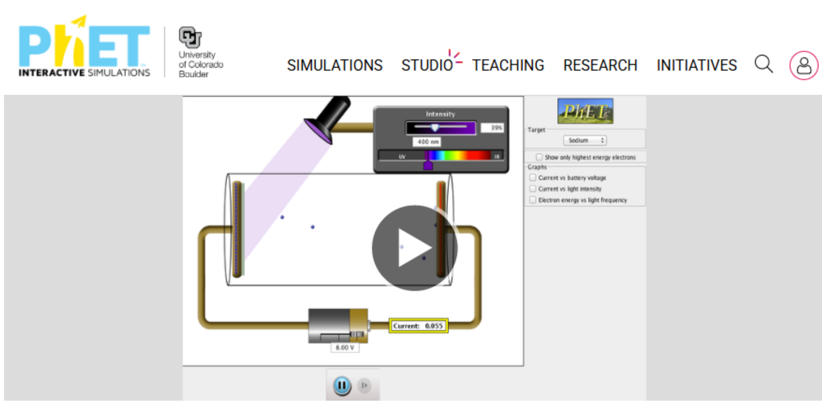


The PhET simulation was created by the University of Colorado Boulder and offers a visual and interactive way to explore the photoelectric effect. A schematic for how this works is shown in the figure on the left. The schematic is not intended to be a realistic visualization, but you may find it useful in formulating your model for how the experiment works. In a real photoelectric experiment, the process is entirely invisible. Light shines onto a metal surface inside a vacuum tube, and the only evidence of the photoemission is a measurable current detected by an ammeter connected to the collector plate. There are no visible particles and no intuitive way to see that photon-electron energy transfer. This disconnect means you may leave the simulation with a superficial understanding, thinking you've "seen" the effect when in fact you've only seen a symbolic model. So be careful!

We will explore the photoelectric effect in detail, as it is the entry toward understanding what a photon is and how we can detect it, even if we cannot ever directly see it.

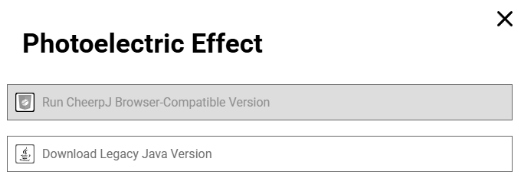
Starting the Simulation

(1) Go to the link or search "Phet Photoelectric Effect" on Google and click the first link.

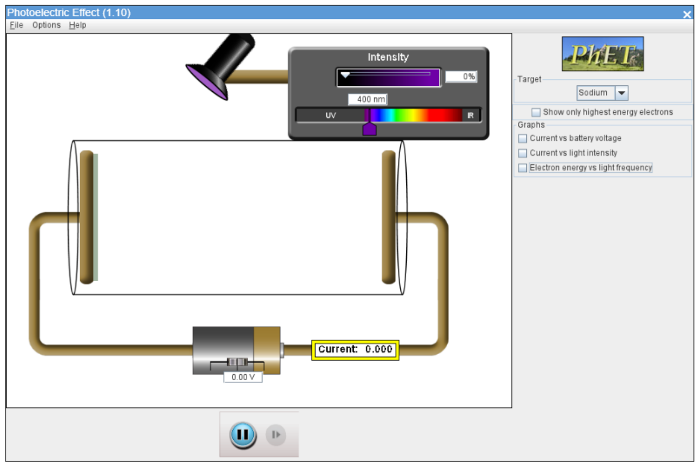


(2) Click on the play symbol on top of the simulation of the Photoelectric Effect.

A small window should appear as shown below, click on “Run CheerpJ Browser-Compatible Version



(3) Example of starting screen for simulation shown below:



(4) Current settings. Locate where all of these are and check that you know how to manipulate all of these parameters. Once you confirm you can change these, set them back to the original settings
   a. Intensity - 0%
   b. Wavelength - 400 nm
   c. Voltage - 0.00 V
   d. Target - Sodium

(5) For now, let’s have the graphs open. Click the 3 boxes next to the 3 graph options: 1) Current vs Battery Voltage, 2) Current vs Light Intensity, 3) Electron Energy vs Light Frequency

(6) To start, let’s turn on photon visualization. In the top left corner, under the Options tab, click the box next to “Show Photons”.

<u>You are now ready to explore!</u>

Photons emit electrons with a frequency threshold

Why this is important: Unlike waves, where the amplitude determines the energy transferred, photons distribute energy to electrons via their frequency. This is quantum, not classical behavior.

To do: Use the PheT simulations to demonstrate this behavior. You may need to adjust a number of different parameters to establish this (frequency and intensity—keep the voltage at 0).

Record your results: After verifying this phenomena holds, write a short paragraph explaining what was observed, how you arrived at your conclusion, why the photon frequency determines the electron emission, and why this leads to a particle picture for photons. Consider the effect of increasing the intensity of light for a particle picture.

Explore the kinetic energy of the emitted electrons

Why this is important: Experimentally, we find a stopping voltage, which is the voltage that first prevents any electrons from reaching the collection plate. Understanding why this is critical to the effect.

To do: Use the PheT simulations to determine the stopping voltage for sodium (Na). You may find that visualizing the electrons helps you find the stopping voltage most easily.

Record your results: Describe what determines the kinetic energy of the emitted electron as the color of light is changed. Explain how the voltage is used to measure the maximal kinetic energy of an emitted electron.

Photons are particles of light

Why this is important: The photoelectric effect is interpreted as illustrating the particle nature of light. The response to changing frequency and changing intensity can only be interpreted in a particle picture.

To do: Analyze different scenarios using the simulation to illustrate why this is true.

Record your results: Write a short description of why one must interpret this experiment using a particle picture for light. Does this mean light IS a particle?

Caution: PheT simulations illustrate simplified and unobservable phenomena

Why this is important: Individual electrons and photons are invisible. They are quantum objects, which have wave-particle duality and behave in complicated non intuitive ways. Nevertheless, Phet displays them as visible moving particles.

To do: Think about how a real experiment would work—what can be observed and what cannot. How does one make the conclusions about the existence of photons using just the limited information available in an actual experiment?

Record your results: While this can be useful for developing physical models for how the photoelectric effect works, one should always bear in mind that this is a simplified representation and not what will be actually observed. It can also lead to misconceptions so be careful. Summarize what can be observed and what cannot in an actual experiment and how it still leads to the photon picture.

Want to learn more about photons?

Deep Dive: The photoelectric effect is often hailed as proof that photons are particles. Interestingly, a formal quantum treatment of the problem shows all of this behavior even if one uses a classical electric field for the photons. How is this possible? Quantum mechanics describes the transition of the electron from a bound state in the metal to a free state outside the metal, via a time-dependent transition process. If this transition is driven by a field oscillating at the frequency corresponding to the energy difference between the bound state and the free state, then the amplitude of the free state resonantly grows. But once the electron has a substantial amplitude in the free state, it moves away from the metal and is emitted. So, formally, one does not need the photon to actually describe the photoelectric effect. This takes nothing away from Einstein's work, as the conclusions all still hold. The true story is just more nuanced. In fact, we will describe in more detail how one verifies the existence of single photons and what they really are next.

Take-home message: The photoelectric effect has single-quantum sensitivity—one can send in a single photon with a high enough energy, and it will emit a single electron from the metal. This sensitivity allows the effect to be employed to detect single photons. It requires us to amplify the emitted single electron to many, so we can measure them using classical equipment. This device is called a photomultiplier tube, and we will discuss later how it is used as a single-photon detector.