


Non-obvious controls:

- Select **Show photons** in the **Options** menu to show the light beam as composed of individual photons.
- Select **Control photon number instead of intensity** in the **Options** menu to change the **Intensity** slider to a **Number of photons** slider.
- Use the camera icon () to take a snapshot of the graphs so that you can compare graphs for different settings.
- You can **Pause** the sim and then use **Step** to incrementally analyze.
- If you are doing a lecture demonstration, set your screen resolution to 1024x768 so the simulation will fill the screen and be seen easily.

Important modeling notes / simplifications:

- Electrons are emitted with a range of energies because photons can eject electrons with a range of binding energies. If more of a photon's energy is used to release an electron, the emitted electron will have less kinetic energy. Note that this behavior is different from the simplified model used by some textbooks, in which all electrons are emitted with the same kinetic energy. If you want to use this simplified model, you can check the "show only highest energy electrons" option. This option does not change the graphs because current is still calculated based on all the electrons.
- Not every photon emits an electron, even if the photons have enough energy to emit electrons. If a photon is absorbed by an electron with binding energy greater than the photon energy, the electron will not be released. Photons with higher energies are more likely to release electrons because a greater proportion of the electrons in the metal have binding energy less than the photon energy. Therefore, as you increase the frequency, the number of emitted electrons (and therefore the current) will increase until all photons are emitting electrons. Note that this behavior is different from the simplified model used by many textbooks, in which every photon with frequency greater than the threshold frequency releases an electron, so the current is constant above the threshold frequency.
- In the default setting, since the intensity of light is proportional to the number of photons times the frequency, if you increase the frequency while holding the intensity constant, the number of photons will decrease. Therefore, if you increase the frequency past the point where all photons are emitting electrons (see previous bullet), the number of emitted electrons (and therefore the current) will start to decrease. Note that this is different from the simplified model used by many textbooks, in which current is constant above the threshold frequency. If you want to be able to change the frequency without changing the number of photons, select "Control photon number instead of intensity" in the Options menu.
- We assume that all electrons are ejected perpendicular to the plate for computational simplicity. In a real experiment, photons are ejected in all directions. Students often ask whether the electrons actually come off at different angles, and are generally willing to accept that this is just a simplification of the simulation.
- We ignore advanced issues such as contact potential, thermionic emission, and reverse current.

Insights into student use / thinking:

- Research¹ shows that students often have difficulty understanding the basic circuit involved in the photoelectric effect. For example, students may think that the voltage rather than the light makes the electrons come off the plate, or attempt to apply $V = IR$. It is worth spending some time addressing such student difficulties.
- Many students have difficulty understanding the relationship between current and electron speed. Our students often have heated debates about whether increasing the speed of the electrons leads to an increase in current. The simulation is a critical tool in resolving these debates, because students can see upon close inspection that increasing the speed of the electrons does not increase the number arriving per second on the plate, and therefore does not increase the current.
- In interviews, we found that even students with no science background were able to figure out how the photoelectric effect experiment works by playing with this simulation, but they needed further guidance to understand the implications of the experiment for the photon model of light.

Suggestions for sim use:

- For tips on using PhET sims with your students see: [Guidelines for Inquiry Contributions](#) and [Using PhET Sims](#)
- The simulations have been used successfully with homework, lectures, in-class activities, or lab activities. Use them for introduction to concepts, learning new concepts, reinforcement of concepts, as visual aids for interactive demonstrations, or with in-class clicker questions. To read more, see [Teaching Physics using PhET Simulations](#)
- For activities and lesson plans written by the PhET team and other teachers, see: [Teacher Ideas & Activities](#)
- We recommend using a guiding inquiry activity to help students “discover” the model of light that explains the behavior seen in the simulation.
- Give students a table of work functions for different materials, and ask them to use the simulation to determine the mystery metal (marked “?????”).
- You can demonstrate the concept of stopping potential very dramatically by showing that if you set the battery voltage just below the stopping potential, the electrons just make it to the opposite plate and turn around. This often elicits laughter from students the first time they see it.
- Ask students to figure out a way to use the simulation to determine Planck’s constant.
- Ask students how the graph of current vs. voltage would change if the simplification of electrons being ejected only perpendicular to the plate were not made. (It would level off at some positive voltage, rather than at 0 volts, because more of the electrons flying off at sharp angles would be attracted back to the positive plate.)
- For more information about the use of this simulation in a modern physics class, see: S. B. McKagan, W. Handley, K. K. Perkins, and C. E. Wieman, “A Research-Based Curriculum for Teaching the Photoelectric Effect,” *American Journal of Physics* **77**, 87 (2009): http://per.colorado.edu/papers/McKagan_et al/photoelectric.pdf

¹ R. N. Steinberg, G. E. Oberem, and L. C. McDermott, “Development of a computer-based tutorial on the photoelectric effect,” *American Journal of Physics* **64**, 1370 (1996).

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