

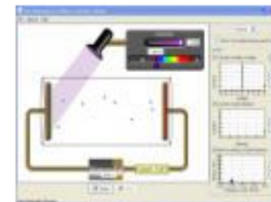
36 – Quantum Mechanics – The Photoelectric Effect

Purpose: Investigate the interaction of photons with metals and the resulting ejection of high-energy electrons.

Apparatus: PhET Simulation-Photoelectric Effect

PhET Simulations → Play With Sims → Quantum Phenomena → Photoelectric Effect Run Now!

Discussion: That light can diffract and refract tells us light behaves like a wave. How do we know that light behaves like a particle? The photoelectric effect leads us to this. How does your solar-powered calculator work? Solar PV cells (*photovoltaic*) convert the energy in light to electric energy (DC current). The same principles that allow a solar-powered calculator to work also act in your cell phone's digital camera. For those materials that we classify as *photosensitive* (most metals, metalloids), light comes in, electrons come out. *If we reverse the process...lasers...*



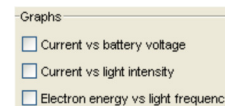
Photoelectric Effect

Important Formulas and Constants: $E = hf$ $E = pc$ $c = f\lambda$

$KE_{\max} = hf - \phi$	$\phi = hf_t$	$1.00\text{eV} = 1.60 \times 10^{-19}\text{ CV} = 1.60 \times 10^{-19}\text{ J}$	$h = 6.63 \times 10^{-34}\text{ Js}$	$1\text{V} = 1\text{J}/1\text{C}$
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Procedure, Part I: Determining the Energy threshold electrons.

1. Take some time and familiarize yourself with the excellent simulation. You can change the photosensitive metal observed, the light intensity (brightness), voltage added, and the very important EM wavelength.
2. Remember...wavelength is used in the simulation, and frequency is used in the formulas. The product of the two is the speed of light, $3.00 \times 10^8\text{ m/s}$. $c = f\lambda$
3. Click on the boxes to show the graphs of ***I vs V***, ***I vs A***, and ***E vs f***
4. Using **sodium, Na** as our metal, change the wavelength to a value that just begins to cause current to flow.



Threshold wavelength required eject electrons from sodium: _____ nm

Threshold frequency of this wavelength: _____ Hz

Minimum energy each photon must contain: _____ J and _____ eV

5. Next, set the wavelength to 400 nm and intensity to 50% record the current flow here: _____ A
6. What effect does increasing the intensity (at this wavelength) have on the current flow?

7. Set the wavelength to 700nm. What effect does increasing the intensity (at this wavelength) have on the current flow? _____

8. Why is this? _____

9. Sketch sample graphs of current as intensity changes and energy and frequency changes:

I vs Intensity

E vs f

10. Find the threshold wavelengths and frequencies for each of the photosensitive metals in the simulation. Then calculate the energy of the incident radiation for each photon incident upon the metals at that frequency.

Metal	λ (threshold) nm	f (threshold) Hz	E (J)	E (eV)
Na				
Zn				
Cu				
Pt				
Ca				
??				

Procedure, Part II: Determining the Work Function of the Metals, ϕ (pronounced “fee”).

In actuality, the energy of a photon is never directly proportional to the energy of an ejected electron because the electron must overcome a potential energy barrier (due to a number of quantum and molecular factors). We call this barrier the *work function*, ϕ . The kinetic energy of an ejected particle is the difference between the energy of the incident radiation and the work function, usually given in eV. The “eV” or electron-volt is an energy unit that results when one electron passes through a potential of one volt ($U_e = qv$). This is useful because (as you will do in the next step) if you know the energy (in eV) of an incident photon, and the voltage required to keep the ejected electron from moving (the *stopping potential*) you can calculate the work function of the metal you’re investigating.

11. Using each of the metals in the simulation, select two wavelengths far below that metal’s threshold and then adjust potential until the electrons are stopped. Fine adjustment of the potential (voltage) will **require you to input values using the keyboard**. Complete the data table below. Remember, for each electron $\rightarrow V \sim eV$

Metal	λ , nm \leftarrow you choose \rightarrow f, Hz	E (J)	E (eV)	V(stopping, eV)	ϕ (eV)
Na					2.28 eV
Na					2.28 eV
Zn					
Zn					
Cu					
Cu					
Pt					
Pt					
Ca					
Ca					
??					
??					

Conclusion Calculations and Questions:

1. Describe the line (and intercepts) on the graph of current versus intensity.
2. Describe the line (and intercepts) on the graph of energy versus frequency.
3. At a frequency below the frequency required to overcome the work function, increasing the light intensity causes the current to *increase / decrease / remain the same*.
4. At a frequency above the frequency required to overcome the work function, increasing the light intensity causes the current to *increase / decrease / remain the same*.
5. Old darkrooms (for developing film) were once illuminated with a faint red light (765nm). If this was the limit of the silver compound used in the film, solve for the work function of the silver compound.
6. Consider the following scenario: On a partly cloudy day you find that a household photo voltaic array outputs 2.4 amps of current. If the clouds part and the sun comes out, exactly doubling the amount of light incident on the PV array, we should expect the array to output *2.4 A / 4.8 A / more than 4.8 A / less than 2.4 A / between 2.4 and 4.8 A*. (careful) Why?
7. The work function for cesium is 1.96 eV. (a) Find the cutoff wavelength for the metal, (b) what is the maximum kinetic energy for the emitted electrons when 425 nm light is incident on the metal?
8. In certain metal, the stopping potential is found to be 3.70 V. When 235 nm light is incident on the metal, electrons are emitted. What is the maximum kinetic energy given to the electrons in eV and J?
9. What is the work function of the metal?