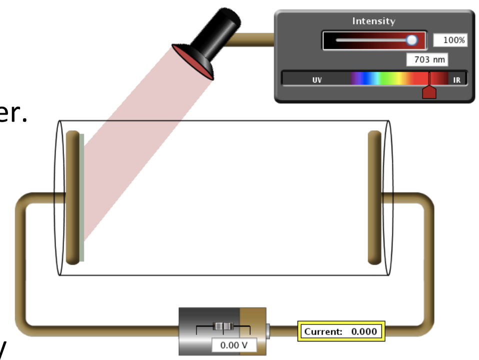
Photo-Electric Effect Tutorial



1. Open the Phet simulation and set the light color to red with the slider. Bring up the light intensity slowly toward 100%. Does the light have sufficient energy to dislodge electrons from the sodium metal?

2. Use the Options menu to select “Show Photons.” Move the intensity slider slowly back and forth. What is the intensity setting on the light source actually controlling?

3. Reset the intensity to zero and test yellow light and then green light shining on the metal. At what exact wavelength are electrons first dislodged from the surface of sodium? What is the frequency of this light?

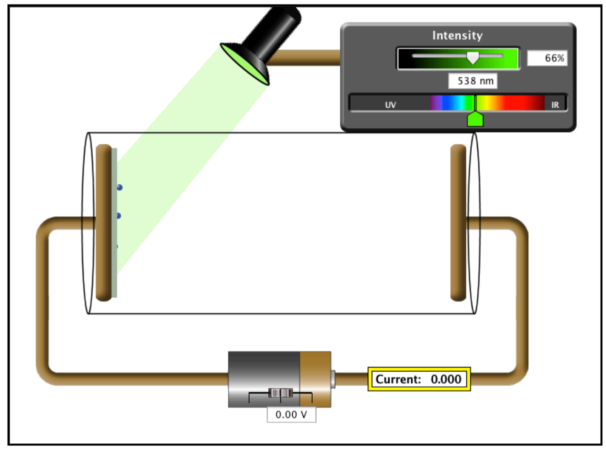
4. With the color slider at the minimum frequency for producing photo-electrons, what is effect of changing the intensity of the source light?

5. Reset the intensity to zero, and move the color slider to a shorter wavelength. Do you expect to see electrons ejected from the surface of the metal? Test your prediction.

6. Vary the intensity of the new color and describe the results. Are the observations at the new color the same or different from the experiment where electrons were first seen coming from the metal? Explain similarities and differences.

7. With the intensity at 50%, slide the color slider slowly to shorter wavelengths and observe the photo-electrons. What effect does higher frequency (shorter wavelength) have on the ejection of the electrons?

8. Return the color slider to the color that just barely ejects electrons from the metal surface (see #3 above). What is the energy of this photon in eV?

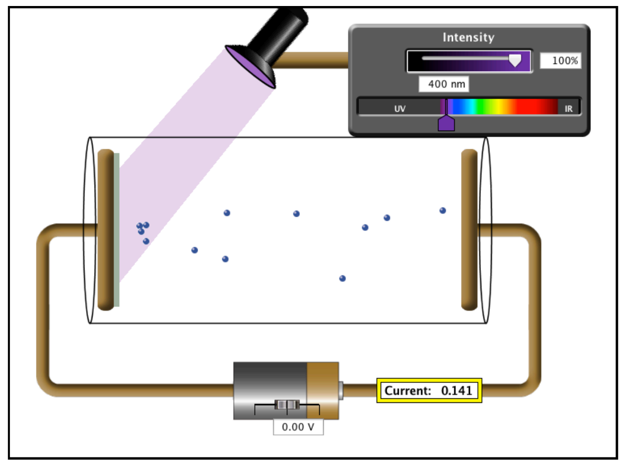


The amount of energy required to just lift an electron off the metal surface is called the **work function (ϕ)** of the metal. Different metals have different values for the work function. Since it is an amount of energy, units are Joules or eV.

9. Slide the wavelength to 430 nm (violet light).

   a. Calculate the energy of this photon in eV.

   b. Notice the speed at which the electrons are now ejected from the surface. Where did the photoelectrons get this extra energy of motion? (Hint: Compare your calculation in #9 to #8.)

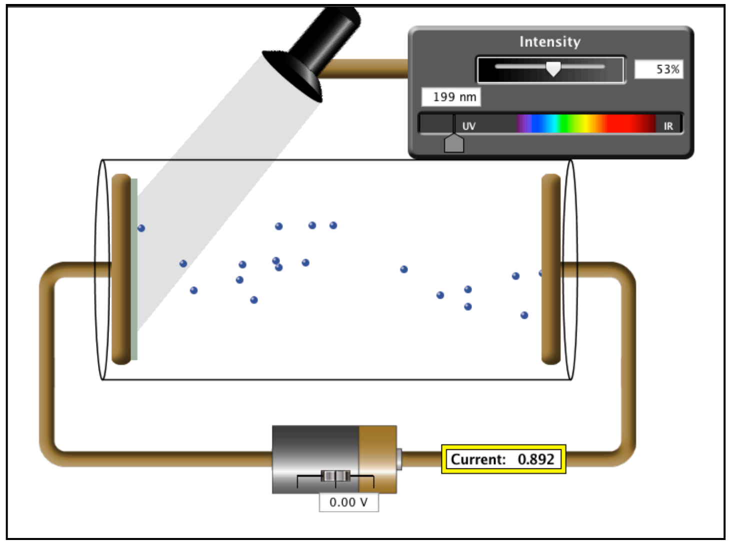


   c. How much kinetic energy (K) do the electrons have when violet light strikes the sodium metal (in eV)?

Energy is conserved at the atomic level. The maximum **kinetic energy** (***K_{max}***) of an electron ejected from the metal (sometimes called a "photoelectron") will be the **energy of the absorbed photon (*$E_p = hf = hc/\lambda$*)** minus the energy needed to lift the electron off the metal, the **work function (ϕ)**:

$$K_{\max} = hf - \phi$$

The simulation makes watching the behaviors of individual electrons easy, but in reality, measuring electron properties requires ingenuity. Physicists need ways to measure both the presence and energy of the photoelectrons ejected from the metal surface. They do this by placing the metal sample (in this case, sodium) in a vacuum tube and placing another metal plate some distance away. These two metal surfaces become *electrodes* when hooked up to a circuit. Voltage can be applied across the electrodes and the presence of electrons crossing in the gap can be measured with an ammeter.



Let's explore this experimental setup:

10. Set the intensity to 50% and the wavelength to 200 nm (ultraviolet). Starting with a voltage of zero, slide the variable voltage slowly to the right to **+ 5 volts**.

    a. What do you observe regarding the motion of the electrons? What do you observe regarding the current reading in the circuit?

    b. Are the electrons attracted or repelled by the right plate?

    c. Looking carefully at the simulation, what sign is shown on the right plate? Is this consistent with your previous answer?

11. Next predict the effect of increasing the intensity of the light. After making a prediction, slide the intensity slowly to the right. What change do you notice *in the circuit* that indicates the greater light intensity?

12. Return the voltage adjustment to zero and intensity to 50%. Predict what will happen to the motion of the ejected electrons if you slowly slide the voltage to apply **-5 volts** across the plates. Test your prediction using the simulation.

    a. Are the electrons attracted or repelled by the right plate? What is the sign shown now on the right plate?

   b. Repeat the observation by slowly adjusting the voltage from 0 to -5 V. What happens to the current in the circuit over the entire observation?

13. With the wavelength held at 200 nm, adjust the electric potential difference (V) between the plates to just barely stop the electrons from reaching the right plate. Record this value.

    This voltage is given the special name **stopping potential** or $\mathbf{V_{stop}}$.

14. What is the current in the circuit at V_{stop}? Does this make sense?

15. List or calculate each of the following values for sodium illuminated with 200 nm ultraviolet light:

    a. The energy of each incident photon: (in eV)

    b. The work function of the metal: (in eV)
    (Hint: This is the energy required to remove an electron from the metal's surface. The material has not been changed since starting the simulation.)

    c. The maximum kinetic energy of the ejected electrons: (in eV)

16. Is there any relation between the kinetic energy of the ejected electrons (K_{max}) in electron-volts [#15c] and V_{stop} , the electric potential required to stop an electron [#14]. Explain.

17. Consider the following change to the last experiment: If the wavelength of incident light is decreased (higher frequency), would the previous voltage still stop the electrons from reaching the right plate?

18. Predict how you would adjust the voltage to find a new V_{stop}. What information does the new value for V_{stop} give?

Summary for the photoelectric effect and its experimental setup:

- The minimum photon energy (*hf* or *hc/λ*) to just eject an electron from the metal surface will equal the work function (ϕ).

- Changing intensity of light increases the number of photons, and therefore, the number of ejected electrons and the current read by the ammeter.

- Photon energy higher than the minimum (higher frequency or shorter wavelength light) will increase the kinetic energy of the ejected electrons. Energy is conserved for each absorbed photon.

$$K_{max} = hf - \phi$$

- This kinetic energy (in eV) of the fastest ejected electrons can be directly measured by finding the voltage required to stop the electrons (V_{stop}). [So a stopping potential of 3 V means the electrons are ejected with a maximum of 3 eV kinetic energy.]

5. (10 points)

A sodium photoelectric surface with work function 2.3 eV is illuminated by electromagnetic radiation and emits electrons. The electrons travel toward a negatively charged cathode and complete the circuit shown above. The potential difference supplied by the power supply is increased, and when it reaches 4.5 V, no electrons reach the cathode.

(a) For the electrons emitted from the sodium surface, calculate the following.

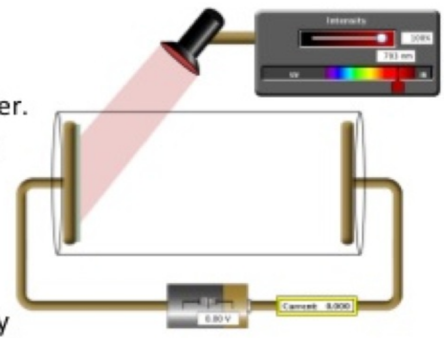
i. The maximum kinetic energy

ii. The speed at this maximum kinetic energy

(b) Calculate the wavelength of the radiation that is incident on the sodium surface.

(c) Calculate the minimum frequency of light that will cause photoemission from this sodium surface.

Photo-Electric Effect Tutorial



1. Open the Phet simulation and set the light color to red with the slider. Bring up the light intensity slowly toward 100%. Does the light have sufficient energy to dislodge electrons from the sodium metal?

   NO.

2. Use the Options menu to select “Show Photons.” Move the intensity slider slowly back and forth. What is the intensity setting on the light source actually controlling?

   THE NUMBER OF PHOTONS IN THE STREAM.

3. Reset the intensity to zero and test yellow light and then green light shining on the metal. At what exact wavelength are electrons first dislodged from the surface of sodium? What is the frequency of this light?

   538 nm

   $$c = f\lambda \rightarrow f = \frac{c}{\lambda} = \frac{3\times10^8}{538\times10^{-9}} = 5.58\times10^{14}\ \text{Hz}$$

4. With the color slider at the minimum frequency for producing photo-electrons, what is effect of changing the <u>intensity</u> of the source light?

   MORE INTENSITY, MORE EJECTED ELECTRONS

5. Reset the intensity to zero, and move the color slider to a shorter wavelength. Do you expect to see electrons ejected from the surface of the metal? Test your prediction.

   YES ✓

6. Vary the intensity of the new color and describe the results. Are the observations at the new color the same or different from the experiment where electrons were first seen coming from the metal? Explain similarities and differences.

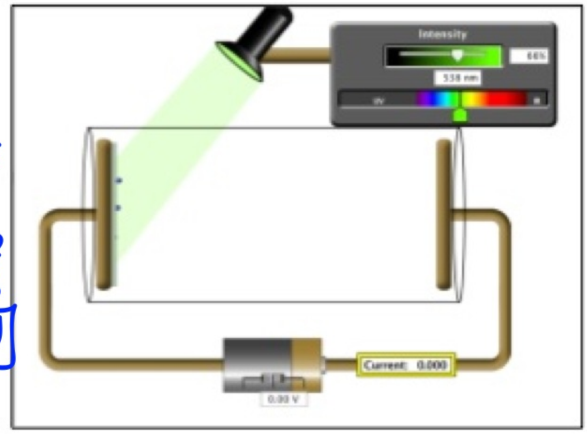
   MORE INTENSITY STILL GIVES MORE ELECTRONS EJECTED

   ELECTRONS COME OFF THE PLATE MOVING FASTER

7. With the intensity at 50%, slide the color slider slowly to shorter wavelengths and observe the photo-electrons. What effect does higher frequency (shorter wavelength) have on the ejection of the electrons?

   THEY EJECT AT HIGHER AND HIGHER SPEEDS

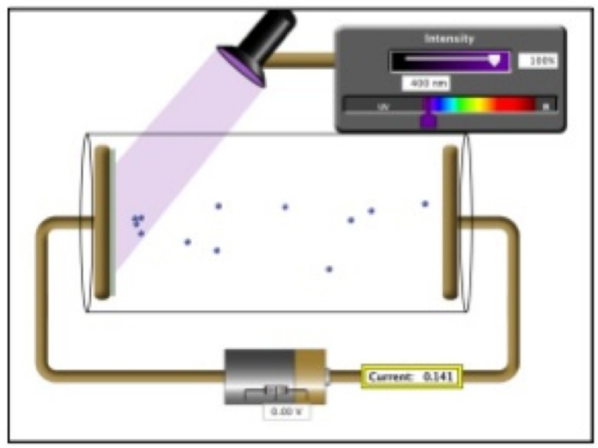
8. Return the color slider to the color that just barely ejects electrons from the metal surface (see #3 above). What is the energy of this photon in eV?



$E = hf = \frac{hc}{\lambda}$, YOU CAN SUBSTITUTE VALUES AND CONVERT TO eV, BUT NOTICE ON THE EQUATION SHEET: hc=1240eVnm, SO $E = \frac{1240}{538}$ $\boxed{=2.3\text{eV}}$

The amount of energy required to just lift an electron off the metal surface is called the **work function (ϕ)** of the metal. Different metals have different values for the work function. Since it is an amount of energy, units are Joules or eV.

9. Slide the wavelength to 430 nm (violet light).



a. Calculate the energy of this photon in eV.

$E = \frac{hc}{\lambda} = \frac{1240}{430} = 2.9\text{eV}$

b. Notice the speed at which the electrons are now ejected from the surface. Where did the photoelectrons get this extra energy of motion? (Hint: Compare your calculation in #9 to #8.)

2.9eV IS GREATER THAN THE WORK FUNCTION OF 2.3eV

c. How much kinetic energy (K) do the electrons have when violet light strikes the sodium metal (in eV)?

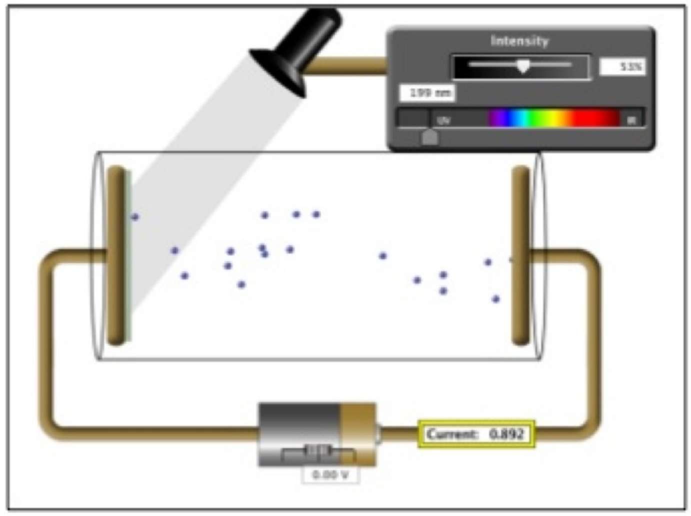
2.9eV ABSORBED, 2.3eV TO LIFT OFF THE METAL

SO 2.9−2.3 = .6eV LEFT OVER FOR K

Energy is conserved at the atomic level. The maximum **kinetic energy** (**K_{max}**) of an electron ejected from the metal (sometimes called a "photoelectron") will be the **energy of the absorbed photon ($E_p = hf = hc/\lambda$)** minus the energy needed to lift the electron off the metal, the **work function (ϕ)**:

$$K_{max} = hf - \phi$$

The simulation makes watching the behaviors of individual electrons easy, but in reality, measuring electron properties requires ingenuity. Physicists need ways to measure both the presence and energy of the photoelectrons ejected from the metal surface. They do this by placing the metal sample (in this case, sodium) in a vacuum tube and placing another metal plate some distance away. These two metal surfaces become *electrodes* when hooked up to a circuit. Voltage can be applied across the electrodes and the presence of electrons crossing in the gap can be measured with an ammeter.



Let's explore this experimental setup:

10. Set the intensity to 50% and the wavelength to 200 nm (ultraviolet). Starting with a voltage of zero, slide the variable voltage slowly to the right to **+ 5 volts**.

    a. What do you observe regarding the motion of the electrons? What do you observe regarding the current reading in the circuit?
    ELECTRONS SPEED UP AS MORE + V IS APPLIED.
    CURRENT STAYS THE SAME

    b. Are the electrons attracted or repelled by the right plate?
    ATTRACTED

    c. Looking carefully at the simulation, what sign is shown on the right plate? Is this consistent with your previous answer? + PLATE ATTRACTS − ELECTRONS

11. Next predict the effect of increasing the intensity of the light. After making a prediction, slide the intensity slowly to the right. What change do you notice *in the circuit* that indicates the greater light intensity? CURRENT INCREASES SINCE MORE ELECTRONS ARE EJECTED FROM THE LEFT PLATE.

12. Return the voltage adjustment to zero and intensity to 50%. Predict what will happen to the motion of the ejected electrons if you slowly slide the voltage to apply **-5 volts** across the plates. Test your prediction using the simulation.

    a. Are the electrons attracted or repelled by the right plate? What is the sign shown now on the right plate? NEGATIVE

b. Repeat the observation by slowly adjusting the voltage from 0 to -5 V. What happens to the current in the circuit over the entire observation? DECREASES TO ZERO AS GREATER −V IS APPLIED

13. With the wavelength held at 200 nm, adjust the electric potential difference (V) between the plates to just barely stop the electrons from reaching the right plate. Record this value.

$V = -4V$

This voltage is given the special name **stopping potential** or $\mathbf{V_{stop}}$.

14. What is the current in the circuit at V_{stop}? Does this make sense?

ZERO, SO V_{STOP} MEANS ELECTRONS STOPPED FROM CROSSING GAP.

15. List or calculate each of the following values for sodium illuminated with 200 nm ultraviolet light:

a. The energy of each incident photon: (in eV)

$E = \frac{1240}{200} = 6.2eV$

b. The work function of the metal: (in eV) (Hint: This is the energy required to remove an electron from the metal's surface. The material has not been changed since starting the simulation.) 2.3eV

c. The maximum kinetic energy of the ejected electrons: (in eV)

$K = E_p - \phi = 6.2 - 2.3 = 3.9eV$

16. Is there any relation between the kinetic energy of the ejected electrons (K_{max}) in electron-volts [#15c] and V_{stop}, the electric potential required to stop an electron [#14]. Explain.

YES $|V_{STOP}| = |K_{MAX}|$. A VOLTAGE OF −4V REQUIRES 4eV TO CROSS. THE ELECTRIC POTENIAL ENERGY ($U_e = Vq$) INCREASES FROM LEFT TO RIGHT. (LIKE THE ELECTRONS ARE ROLLING UP A RAMP.) SO INITIAL K IS TRANSFORMED TO U_e.

17. Consider the following change to the last experiment: If the wavelength of incident light is decreased (higher frequency), would the previous voltage still stop the electrons from reaching the right plate?

NO, THEY ARE EJECTED WITH MORE K NOW.

18. Predict how you would adjust the voltage to find a new V_{stop}. What information does the new value for V_{stop} give?

SLIDE V TO GREATER NEGATIVE ELECTRIC POTENTIAL

THE NEW V_{STOP} GIVES THE KINETIC ENERGY (IN eV) TO CROSS THE GAP. $V_{STOP} = K_{MAX}$ (IN eV)

Summary for the photoelectric effect and its experimental setup:

- The minimum photon energy (*hf* or *hc/λ*) to just eject an electron from the metal surface will equal the work function (ϕ).
- Changing intensity of light increases the number of photons, and therefore, the number of ejected electrons and the current read by the ammeter.
- Photon energy higher than the minimum (higher frequency or shorter wavelength light) will increase the kinetic energy of the ejected electrons. Energy is conserved for each absorbed photon.

$$K_{max} = hf - \phi$$

USE eV VERSIONS OF h OR hc TO MAKE CALCULATIONS EASIER. (ON THE EQUATION SHEET)

- This kinetic energy (in eV) of the fastest ejected electrons can be directly measured by finding the voltage required to stop the electrons (V_{stop}). [So a stopping potential of 3 V means the electrons are ejected with a maximum of 3 eV kinetic energy.]

5. (10 points)

ϕ

A sodium photoelectric surface with work function 2.3 eV is illuminated by electromagnetic radiation and emits electrons. The electrons travel toward a negatively charged cathode and complete the circuit shown above. The potential difference supplied by the power supply is increased, and when it reaches 4.5 V, no electrons reach the cathode.

V

V_{STOP}

(a) For the electrons emitted from the sodium surface, calculate the following.

i. The maximum kinetic energy $K_{MAX} = 4.5\,eV$.

(AN ELECTRON "DROPPED" THROUGH 1 VOLT PICKS UP 1 eV ENERGY. AN ELECTRON "TOSSED" UP 1 VOLT LOSES 1 eV ENERGY)

ii. The speed at this maximum kinetic energy

UNITS

$K = \frac{1}{2}mv^2 \rightarrow 4.5\,eV = 7.2\times10^{-19}\,J$

$7.2\times10^{-19} = \frac{1}{2}(9.11\times10^{-31}\,kg)\,v^2 \rightarrow \boxed{1.26\times10^{6}\,\frac{m}{s}}$

(b) Calculate the wavelength of the radiation that is incident on the sodium surface.

$K_{MAX} = E_p - \phi \rightarrow 4.5 = E_p - 2.3$

$E_p = 6.8\,eV = \frac{hc}{\lambda} = \frac{1240\,eV\,nm}{\lambda} \rightarrow \boxed{\lambda = 182\,nm}$

(c) Calculate the minimum frequency of light that will cause photoemission from this sodium surface.

JUST ENOUGH TO LIFT ELECTRONS OFF SURFACE

$\phi = 2.3\,eV$. A PHOTON WITH THIS ENERGY $E_p = hf$

$2.3\,eV = (4.14\times10^{-15}\,eV\cdot s)\,f \rightarrow \boxed{f = 5.6\times10^{14}\,Hz}$

UNITS