Gizmos

Name: ______________________________________ Date: ________________________

Student Exploration: Photoelectric Effect

Vocabulary: electron volt, frequency, photoelectric effect, photon, photon flux, voltage, wavelength, work function

Prior Knowledge Questions (Do these BEFORE using the Gizmo.)

1. Suppose you went bowling, but instead of a bowling ball you rolled a ping pong ball down the alley. What do you think would happen? ______________________________________

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2. Suppose you rolled a lot of ping pong balls at the bowling pins. Do you think that would change the results of your experiment? Explain. __________________________________

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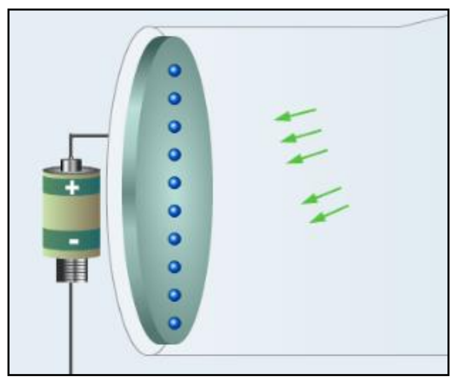
Gizmo Warm-up

The **photoelectric effect** occurs when tiny packets of light, called **photons**, knock electrons away from a metal surface. Only photons with enough energy are able to dislodge electrons.



In the *Photoelectric Effect* Gizmo, check that the **Wavelength** is 500 nm, the **Photon flux** is 5 γ/ms, the **Voltage** is 0.0 volts, and **Potassium** is selected. Click **Flash the light** to send photons of light (green arrows) toward a metal plate encased in a vacuum tube.

1. The blue dots on the metal plate are electrons. What happens when the photons hit the electrons? ____

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2. What happens when the electrons reach the light bulb? ____________________________

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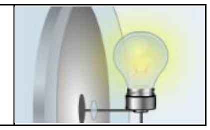
   When electrons reach the light bulb they complete a circuit, causing the bulb to glow briefly.

Activity A: Wavelength and flux	Get the Gizmo ready: • Check that the **Voltage** is 0.0 volts and **Potassium** is selected.	

Introduction: Through the centuries, many scientists have debated whether light is a wave or a stream of tiny particles. In the 1800s, most scientists agreed that phenomena such as refraction and diffraction supported the "light as a wave" theory. However, Albert Einstein's explanation of the photoelectric effect showed that light can act like a stream of particles as well.

Question: What factors affect the ability of light to free electrons from a metal surface?

1. Observe: Click **Flash the light** with a variety of **wavelength** values. What do you notice?

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2. Observe: The **photon flux** is a measure of how bright the light is. It is equal to the number of photons that are released in a given time. It is given as photons (γ) per millisecond (ms).

   Click **Flash the light** with a variety of **Photon flux** values. What do you notice? __________

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3. Form hypothesis: Answer the following questions based on what you have observed so far.

   A. Which factor determines how many photons will strike the metal? _______________

      Explain: ____

   B. Which factor determines how much energy each photon has? __________________

      Explain: ____

4. Investigate: Set the **Photon flux** to 1 γ/ms. Use the Gizmo to find the longest wavelength

   that will dislodge an electron from the metal surface. What is this wavelength? ___________

5. Predict: Set the **Wavelength** to 540 nm. What do you think will happen if you flash the light with a photon flux of 1 γ/ms? What if you flash the light with a flux of 10 γ/ms?

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(Activity A continued on next page)

Activity A (continued from previous page)

6. Test: Click **Flash the light** with a **Photon flux** of 1 γ/ms and again with a flux of 10 γ/ms.

   What happened? ____

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7. Explore: Set the **Wavelength** to 400 nm. Experiment with different photon fluxes.

   A. Does the photon flux affect how many electrons are emitted? ___________________

      Explain: ____

      ____

   B. Does the photon flux affect the energy (speed) of the emitted electrons? __________

      Explain: ____

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8. Infer: For mechanical waves, such as sound waves or ocean waves, increasing the intensity of the wave increases both the amplitude (height) of the wave and the energy it carries. In that situation, a low-frequency but high-intensity wave should have the same effect as a high-frequency but low-intensity wave. How does light behave differently from this model?

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9. Think and discuss: How is firing photons at the surface of a metal analogous to rolling different types of balls at a set of bowling pins? If possible, discuss your answer with your classmates and teacher.

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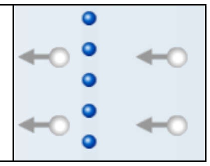
Activity B: **Voltage gradients**	Get the Gizmo ready: • Set the **Wavelength** to 300 nm, the **Photon flux** to 10 γ/ms, and the **Voltage** to 0.0 volts. • Turn on **Show voltage gradient**.	

Introduction: The electrons that are freed from the surface of the metal have a specific amount of kinetic energy. Faster electrons have greater energies than slower ones. The energy of emitted electrons is measured by setting up an electrical field that opposes their motion. The **voltage** of the field is a measure of its strength.

Goal: Use a voltage gradient to measure the energy of emitted electrons.

1. Observe: Check that **Potassium** is selected. Click **Flash the light** and observe the emitted electrons. Increase the **Voltage** to 1.5 volts, and click **Flash the light** again.

   How does the electrical field affect the motion of the emitted electrons? _________________

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2. Measure: The energy of an emitted electron is measured in **electron volts** (eV). An electron with an energy of 1 eV can overcome an electrical field of 1 volt. In the Gizmo, increase the voltage until you find the highest voltage that still allows the electrons to reach the light bulb.

   What is this value? ____________ This is equal to the energy of the emitted electrons in eV.

3. Gather data: With the **Wavelength** set to 300 nm, measure the energy of emitted electrons for potassium, calcium, and uranium. Then measure the same values with wavelengths of 250 nm and 200 nm to complete the table.

Element	**Energy of emitted electrons (eV)**		
	300 nm	**250 nm**	**200 nm**
Potassium			
Calcium			
Uranium			

4. Analyze: What patterns do you notice in your data? ___________________________________

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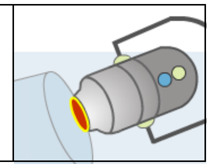
5. Infer: Based on your data, which element is hardest to extract electrons from? ____________

   Explain: ____

Activity C: **Work functions**	Get the Gizmo ready: • Set the **Voltage** to 0.0 volts and select **Potassium**. • You will need a calculator and a copy of the periodic table of the elements for this activity.	

Introduction: It is easier to remove electrons from some elements than others. The energy required to free an electron from the surface of a solid is the **work function** of the element.

Question: How much energy is required to liberate electrons from a material?

1. Predict: In general, the difficulty of removing electrons increases from left to right across each row of the periodic table. Look up potassium (K), calcium (Ca), and uranium (U). Based on their positions in the periodic table, which of these elements do you expect to have the lowest work function? Which element will have the highest work function?

   Lowest work function: _________________ Highest work function: _________________

2. Gather data: Use the Gizmo to determine the highest wavelength for each element that still removes electrons. Fill in the first column below. (Leave the other columns blank for now.)

Element	Wavelength (nm)	Frequency (Hz)	Work function (eV)
Potassium			
Calcium			
Uranium			

3. Calculate: The **frequency** of a wave, measured in hertz (Hz), is the number of waves that passes a point each second. To calculate the frequency (f) of an electromagnetic wave, divide the speed of light (c) by the wavelength (λ):

$$f = \frac{c}{\lambda}$$

   The speed of light is 299,792,458 m/s, or approximately 3.0×10^{17} nm/s. Using the equation, calculate the frequency of each wavelength given in the table. Fill in the second column.

4. Calculate: The energy of a photon depends on its frequency. The energy of a photon (E) in electron volts is equal to its frequency (f) multiplied by Planck's constant (h):

$$E \text{ (eV)} = h \cdot f$$

   In this calculation, h is equal to 4.136×10^{-15} eV·s. Calculate the work function of each element in the table above. (Note: The values in your table are approximations.)

(Activity C continued on next page)

Activity C (continued from previous page)

5. Draw conclusions: Based on the calculated work function for each element, which element holds onto its electrons most tightly? Explain.

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6. Think and discuss: When the photoelectric effect was discovered, scientists were surprised that low-frequency light was unable to remove electrons, even when the light was very bright In other words, scientists expected the low frequency to be offset by the light's brightness.

   How does thinking about light as a stream of particles, rather than a single wave, explain this result? If possible, discuss your answer with your classmates and teacher.

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