Photoelectric Effect

Unit: Quantum and Particle Physics

MA Curriculum Frameworks (2016): HS-PS4-3

AP® Physics 1 Learning Objectives: N/A

Mastery Objective(s): (Students will be able to…)

- Explain the photoelectric effect.
- Calculate the work function of an atom and the kinetic energy of electrons emitted.

Success Criteria:

- Descriptions & explanations account for observed behavior.
- Variables are correctly identified and substituted correctly into the correct equation.
- Algebra is correct with correct units and reasonable rounding.

Language Objectives:

- Explain why a minimum amount of energy is needed in order to emit an electron.

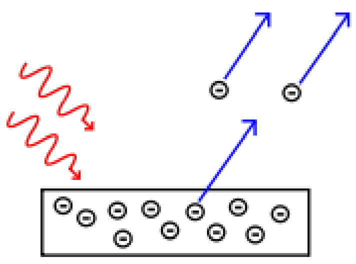
Tier 2 Vocabulary: work function

Labs, Activities & Demonstrations:

- threshold voltage to light an LED
- glow-in-the-dark substance and red *vs.* green *vs.* blue laser pointer

Notes:

The photoelectric effect was discovered in 1887 when Heinrich Hertz discovered that electrodes emitted sparks more effectively when ultraviolet light was shone on them. We now know that the particles are electrons, and that ultraviolet light of sufficiently high frequency (which varies from element to element) causes the electrons to be emitted from the surface of the element:



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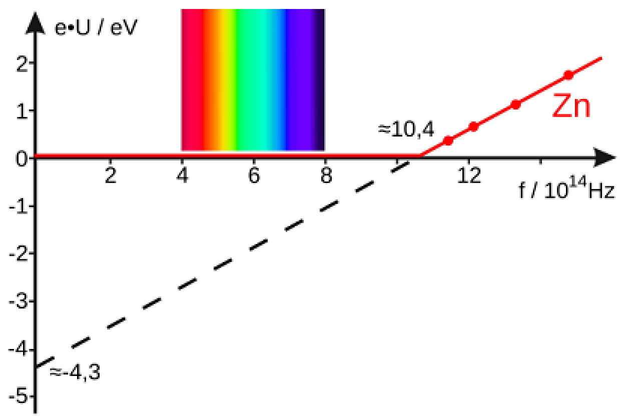
The photoelectric effect requires light with a sufficiently high frequency, because the frequency of the light is related to the amount of energy it carries. The energy of the photons needs to be above a certain threshold frequency in order to have enough energy to ionize the atom.

For example, a minimum frequency of 10.4×10^{14} Hz is needed to dislodge electrons from a zinc atom:



The maximum kinetic energy of the emitted electron is equal to Planck's constant times the difference between the frequency of incident light (f) and the minimum threshold frequency of the element (f_o):

$$K_{max} = h(f - f_o)$$

The quantity hf_o is called the "work function" of the atom, and is denoted by the variable ϕ. Thus the kinetic energy equation can be rewritten as:

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

Values of the work function for different elements range from about 2.3–6 eV. ($1\text{ eV} = 1.6\times10^{-19}$ J)

The importance of this discovery was that it gave rise to the idea that light can behave both as a wave and as a particle.

In 1905, Albert Einstein published a paper explaining that the photoelectric effect was evidence that energy from light was carried in discrete, quantized packets. This discovery, for which Einstein was awarded the Nobel prize in physics in 1921, led to the birth of the field of quantum physics.

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Homework Problems

1. **(M)** The work function for gold is 4.8 eV.

   a. What is the minimum frequency of light required to remove electrons from gold?

   Answer: 1.16×10^{15} Hz

   b. What is the wavelength of this frequency of light?

   Answer: 2.58×10^{-7} m or 258 nm

   c. In what part of the spectrum is light of this frequency & wavelength?

   Answer: ultraviolet

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2. **(S)** A beam of light from a 445 nm blue laser pointer contains how much energy?

   Answer: 4.45×10^{-19} J or 2.78 eV

3. **(M)** Photons of energy 6 eV cause electrons to be emitted from an unknown metal with a kinetic energy of 2 eV. If photons of twice the wavelength are incident on this metal, what will be the energy of the emitted electrons? (If no electrons are emitted, explain why.)

   Answer: no electrons will be emitted.

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