Photoelectric Effect

Teacher's Guide

Overview

This guide contains:

- Activity overview and background information
- Tips for guiding students through the activity
- Common questions and misconceptions that arise during the activity

Before you begin…

- Activity is designed for grades 7-12.
- Any time the word *energy* is used, you can also say wavelength, frequency, or color depending on your audience
  - Color applies only to wavelengths in the visible part of the EM spectrum, but it's the simplest way to connect young students with the concept of wavelength/frequency/energy

Before you begin…

- Two disclaimers to give students before you begin:
    - This activity includes use of lasers and UV lights, make sure to give a safety disclaimer to your students before beginning the activity: **Don't shine any of the included lights into your own eye or anyone else's. Do not expose your skin directly to the UV flashlight for more than one minute at a time.**
    - The light sources you're using in this experiment are fragile. **Don't hit any of the flashlights or lasers against hard surfaces!**

Activity Learning Objectives

1. Explain the particle-wave duality.
2. Describe how particles of light (photons) can interact with electrons in certain types of materials.
3. Describe how photoelectric effect works.
4. Connect the photoelectric effect to quantum computers.

Connections to NGSS - Middle School

Disciplinary Core Ideas	MS-PS1-1: Atomic composition of simple molecules and extended structures (LO1, LO2)	MS-PS4-2: Develop and use a model to describe how light waves interact with matter (LO1, LO2, LO3)	
Crosscutting Concepts	**Scale, proportion & quantity**: use models to study systems that are too small (LO1, LO2)	**Energy & matter**: Describe how energy and matter interact (LO1, LO2, LO3)	
Science & Engineering Practices	**Developing & using models**: Use models to predict the properties of light and how it affects the charged tinsels	**Planning & carrying out investigations:** Conduct an experiment to identify how different light sources affect the charged tinsel	**Analyzing & interpreting data**: Analyze data from an experiment and use it to uncover if different light sources affect the charged tinsel

Connections to NGSS - High School

Disciplinary Core Ideas	HS-PS4-1: Mathematical relationship between wavelength, frequency, and speed of waves (LO1, LO2, LO3)	HS-PS4-3: Wave & particle nature of light (LO1, LO2)	HS-PS4-4: Effects different frequencies of electromagnetic radiation have when absorbed by matter (LO3)	HS-PS4-5: Using wave behavior and wave interactions with matter to transmit and capture information and energy (LO4)
Crosscutting Concepts	**Scale, proportion, & quantity**: use models to study systems that are too small (LO1, LO2)	**Energy & matter**: Describe how energy and matter interact (LO1, LO2, LO3)		
Science & Engineering Practices	**Developing & using models**: Use models to predict the properties of light and how it affects the charged tinsel	**Planning & carrying out investigations**: Conduct an experiment to identify how different light sources affect the charged tinsel	**Analyzing & interpreting data**: Analyze data from an experiment and use it to uncover if different light sources affect the charged tinsel	

Suggested Activity Timeline

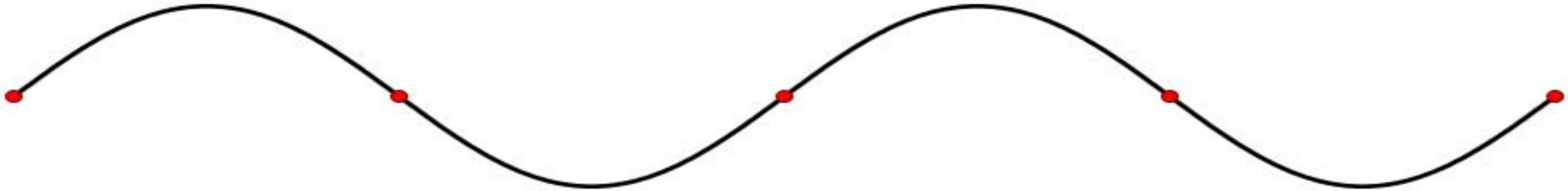
Background information & discussion	20 minutes
Activity	20 minutes
Discussion	20 minutes
	Total time: 60 minutes

Suggested Activity Timeline

Background information & discussion	25 minutes
Activity	15 minutes
Discussion	20 minutes
	Total time: 60 minutes

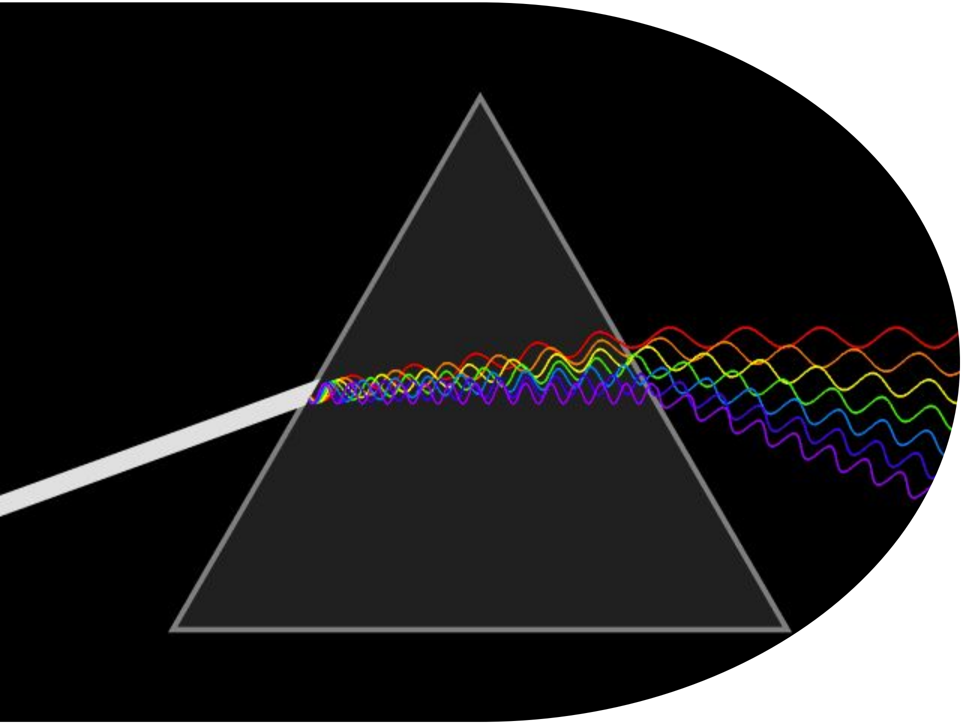
Background Information - Classical Physics

- Light acts like a wave
    - It spreads out or **diffracts** after passing through an opening
    - It bends or **refracts** when moving into a different medium, such as when light moves from air into water
    - It bounces back or **reflects** when it hits a barrier like a mirror
    - It adds together or cancels out with other light waves of the same or different phases in a process known as **interference**.



- All of these properties are observed in other transverse waves, and so light acts like a wave!

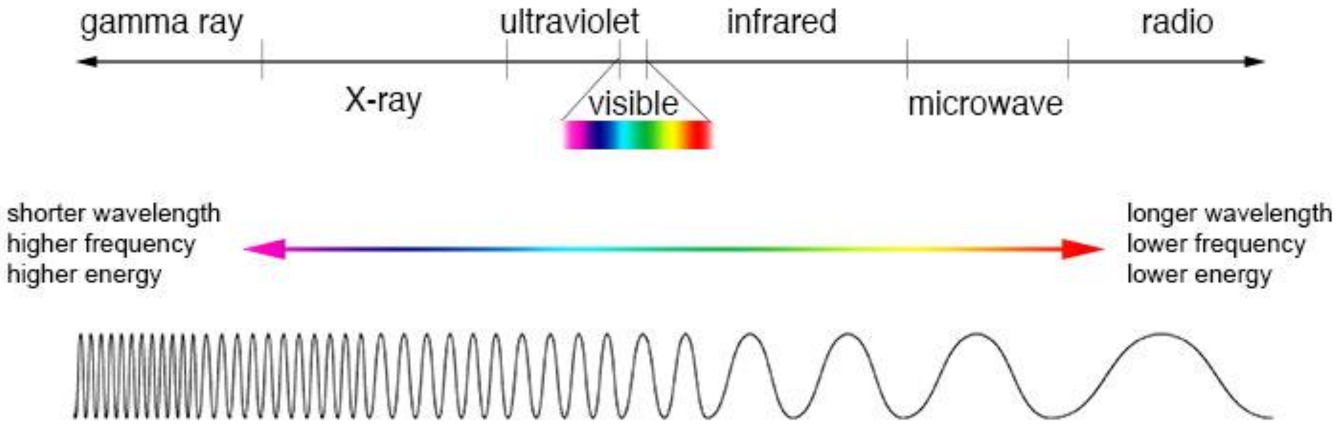
Background Information - Classical Physics



- Because light is a wave, it can be spread out spatially in a **spectrum** using a prism or diffraction grating
  - Spectra tell us how much light there is at a given energy on the electromagnetic (EM) spectrum
  - When we take the spectrum of white light, like light from an LED flashlight, we find it contains all colors of visible light

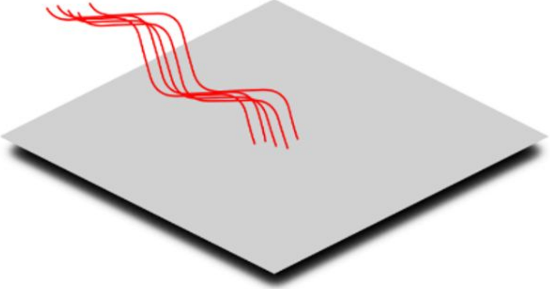
Background Information - EM Spectrum

- The EM spectrum is a way to categorize light
  - Light the human eye can see is in the visible part of the EM spectrum
  - Higher energy light has shorter wavelengths and higher frequencies
  - Lower energy light has longer wavelengths and lower frequencies

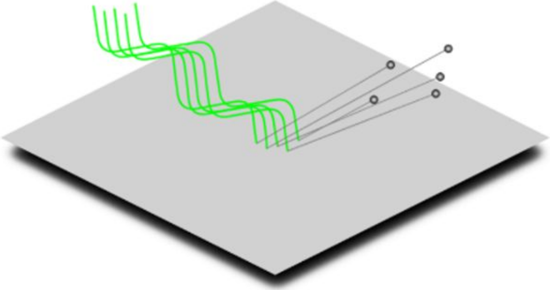


Background Information - Quantum Physics

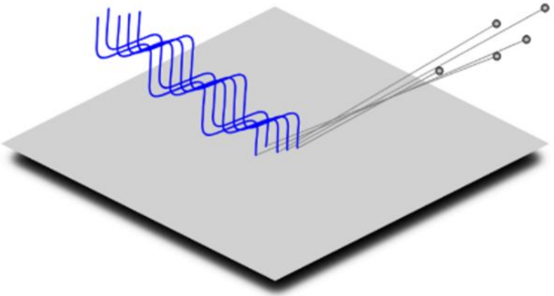
- Light acts like a particle when interacting with microscopic matter
  - A particle of light is called a **photon**
  - Light is quantized → photons can only have one value for their energy
  - Photons can collide with electrons to transfer energy
  - In some metals, a photon can give an outer shell electron enough energy to escape the metal (photons must have the right energy to do this)
  - These escaping electrons can generate an electric current!



Red light does not eject electrons even if it is very bright



Green light ejects electrons even if it is very dim



Blue light ejects electrons with more energy even if it is very dim

Background Information -
Wave vs. Particle Nature of Light? (grades 9-12)

For light, its wave and particle behaviors aren't separate, competing features but part of its wave-particle duality.

- Because light acts like a **wave**, it can be described by its wavelength/frequency/energy

- Because light acts like a **particle**, it has only **one** discrete value for its wavelength/frequency/energy

Background Information - Wave + Particle Nature of Light (grades 9-12)

Wave properties of light	Particle properties of light
• Diffracts, refracts, reflects, and undergoes interference	• Has one value for their energy (quantized)
• Propagates forward until absorbed	• Can only be emitted or absorbed at a particular energy
• Exhibits the Doppler Effect (light’s frequency changes depending on if its emitter is moving toward or away from observer)	• Photoelectric effect - only light with high enough energy can eject electrons from atoms

Background Information - Wave + Particle Nature of Light (grades 9-12)

- When is the wave nature of light most useful?
  - Thinking of light as a wave is useful for explaining an object's brightness and color, and how light interacts with surfaces on large scales
  - Real world example: In astronomy, the wave nature of light is used to determine the rate that distant galaxies are moving away from us using the Doppler Effect.

Background Information - Wave + Particle Nature of Light (grades 9-12)

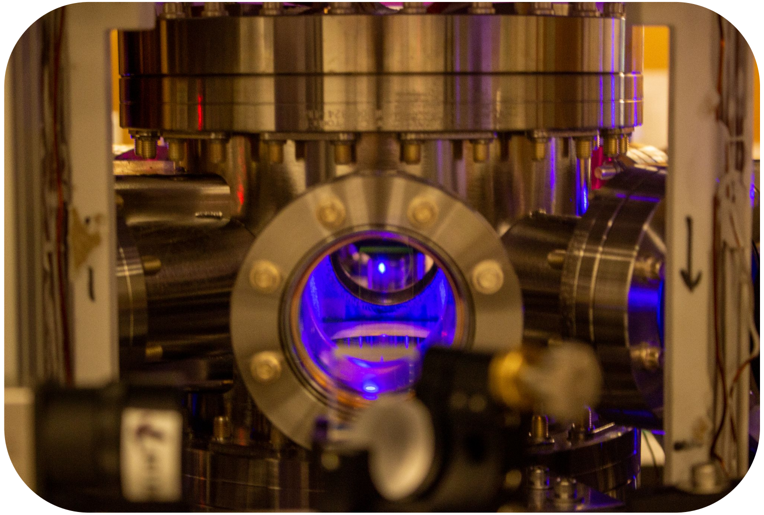
- When is the particle nature of light most useful?
  - Thinking of light as a particle is useful for explaining how light interacts with the very smallest things, like atoms and subatomic particles
  - Real world example: By understanding how light and electrons interact, quantum scientists can manipulate electron energy levels to store information.

Background Information - Quantum Physics

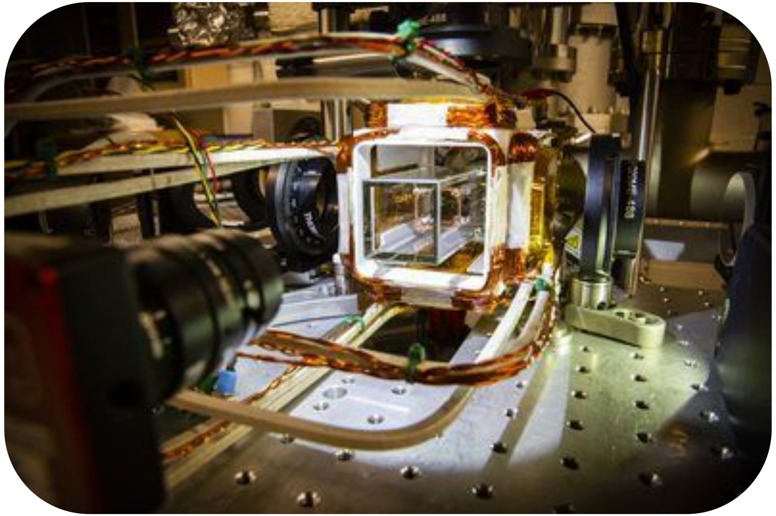
- Particle nature of light is **essential** for quantum science
    - All atoms absorb and emit photons at a unique set of energies, so all atoms have their own set of unique electron transitions that are precisely measured**.** Because we can create lasers that emit photons with specific energies, that means we can use these to create very precise and very small currents using the photoelectric effect.

Background Information - Quantum Physics

- Being able to precisely control the behavior of atoms and electrons is the cornerstone of many quantum technologies, including atomic clocks and quantum computers



Atomic clock @ University of Wisconsin
(Kolkowitz Lab)



IQUIST quantum testbed @ University of Illinois
Urbana-Champaign (DeMarco Lab)

Connecting Electron Transitions to Quantum Computers

- Quantum scientists use the understanding of how atoms interact with photons to make **quantum computers**
  - One way to create a quantum computer: manipulate electrons to store information in what are known as **qubits**
  - Instead of storing information as a 0 or 1, which is how regular computer bits work, qubits store information as a combination of 0 and 1

SQMS Quantum Computing Lab at Fermilab

Connecting Electron Transitions to Quantum Computers

- Quantum computers are **very powerful**! They can...
  - help scientists make calculations that would take regular computers thousands of years
  - help simulate quantum systems much more reliably and precisely
  - enable extremely secure and private communication networks

Facilitation Tips

- Groups of 3-4 are best for this activity - having more than 4 students per group will lead to some students not being able to engage with the kit materials.

- Have the students complete the experiment 2-3 times to make sure they are getting consistent results. This is a good opportunity to teach about the importance of reproducing results and why scientists repeat experiments many times.

Facilitation Tips

- When working with younger students, focus on terms they already know
  - Instead of introducing concepts like wavelength, frequency, or energy, refer to the light's color.

- Make sure the students set up the tinsel in a way that makes it clear when it is charged, when charged the strands should very clearly repel each other. Remember to not touch the can while doing the experiment since doing so will discharge it immediately.