Project Worksheet: The Photoelectric Effect

Virtual Simulations and Millikan's 1916 Experiment

PHYS 214: Introductory Quantum Mechanics

Due Date: 02/25/2026 at 11:59 pm (On Moodle).

Introduction

This project explores the phenomenon that led to the quantum model of light: the Photoelectric Effect. You will first explore the qualitative behavior of the effect using the PhET interactive simulation. In the second part, you will perform a quantitative analysis using historical data from Robert Millikan's seminal 1916 paper, which experimentally verified Einstein's photoelectric equation and provided one of the first precise measurements of Planck's constant. This document is partially inspired by work from Sam McKagan, Kathy Perkins and Carl Wieman at PhET.

Learning Goals

You should be able to explain how the photoelectric effect experiment works and why a photon model of light is necessary to explain how the photoelectric effect experiment works and why a photon model of light is necessary to explain the results. You should also be able to determine how to calculate the wavelength of light, the work function of the metal, or the stopping potential, if given two out of three.

The following table of **work functions for metals** may be helpful for some of the problems in this homework.

Table 1: Work Functions for Common Metals (in eV)

Metal	**Φ (eV)**	**Metal**	**Φ (eV)**
Aluminum	4.08	Magnesium	3.68
Beryllium	5.00	Mercury	4.50
Cadmium	4.07	Nickel	5.01
Calcium	2.90	Niobium	4.30
Carbon	4.81	Platinum	6.35
Cesium	2.10	Potassium	2.30
Cobalt	5.00	Selenium	5.11
Copper	4.70	Silver	4.73
Gold	5.10	Sodium	2.28
Iron	4.50	Uranium	3.60
Lead	4.14	Zinc	4.30

Instructions

- This Project will be online on Thursday 02/12/2026. You have until **Thursday, 02/26/2026 at 11:59 pm** to complete and submit it via the link on Moodle.

- You should be working in groups of 2 or 3 (max). No group of 1 is allowed. Make sure to email me the name of your group partners. Make sure also to write the names of all the group members in the submission. I will assume that everyone contributed equally to the submission.

- The project has 2 parts. Feel free to simply fill the template for all the questions (but question 9) of Part I. You can work on Question 9 of Part I in a separate sheet.

- For Part 2, it should be a short file where your results, analysis with figures and answer to questions will appear.

- The whole submission should be a single file document (pdf, doc, docx, gdoc, rtf, odt, ...)

Part 1: PhET Virtual Experiment (Conceptual Analysis)

Tools needed: Computer with internet access.
Link: PhET Photoelectric Effect Simulation

1.1 The Setup

Open the simulation. You will see a lamp, a battery, and a vacuum tube containing two metal plates.

1. Set the **Target** to **Sodium**.
2. Set the **Intensity** to 50%.
3. Adjust the **Wavelength** until electrons are ejected.

1.2 Qualitative Predictions and Observations (18 pts)

1. **(4 pts) Suppose you set up the experiment so that the plate is ejecting electrons.** Predict which of the following changes to the experiment could **increase the maximum initial kinetic energy** of the ejected electrons. (Select all that apply) Then test your prediction.

   ☐ A. Increasing the intensity of the light beam
   ☐ B. Decreasing the intensity of the light beam
   ☐ C. Increasing the wavelength of light
   ☐ D. Decreasing the wavelength of light
   ☐ E. Increasing the frequency of light
   ☐ F. Decreasing the frequency of light
   ☐ G. Increasing the voltage of the battery
   ☐ H. Decreasing the voltage of the battery
   ☐ I. Replacing the target with a material that has a larger work function
   ☐ J. Replacing the target with a material that has a smaller work function

2. **(4 pts) Suppose now you set up the experiment so that the light intensity is non-zero but the plate is NOT ejecting electrons.** Predict which of the following changes to the experiment could **make the plate start ejecting electrons**? (Select all that apply) Then test your prediction.

   ☐ A. Increasing the intensity of the light beam
   ☐ B. Decreasing the intensity of the light beam
   ☐ C. Increasing the wavelength of light
   ☐ D. Decreasing the wavelength of light
   ☐ E. Increasing the frequency of light
   ☐ F. Decreasing the frequency of light
   ☐ G. Increasing the voltage of the battery

☐ H. Decreasing the voltage of the battery

☐ I. Replacing the target with a material that has a larger work function

☐ J. Replacing the target with a material that has a smaller work function

3. **(2 pts) What causes the electrons to be ejected from the left plate in this simulation?**

   ◯ A. The force exerted on the electrons by the battery

   ◯ B. The beam of light shining on the plate

   ◯ C. Both A and B.

   ◯ D. Neither A nor B.

4. **(4 pts) (Short Essays) Photon Model vs. Wave Model.** For each scenario below, explain what you observe, what conclusions you can draw about light, and how it is consistent/inconsistent with the classical wave model vs. the photon model.

   a. Light is shining on a metal and electrons are being emitted. You turn the intensity down very, very low. (2pts)

   b. Light is shining on a metal plate and electrons are being emitted. Without changing the intensity, you make the wavelength longer and longer. (2 pts)

5. **(1 pt each) True or False?** If the experiment is set up so that electrons are being emitted, which of the following are true?

T / F As long as conditions do not change, all emitted electrons have the same initial kinetic energy.

T / F The work function for the metal is different for different electrons.

T / F The energy of the photons hitting the plate must be less than the work function of the metal.

T / F The electrons emitted with the largest initial kinetic energy are those that were the least tightly bound in the metal.

1.3 Stopping Potential (22 pts)

6. **Graph Analysis**
   In the photoelectric effect experiment, the graph of current vs. battery voltage for a metal with light of a particular frequency shining on it looks like the curve below. This graph represents current vs. voltage for 200nm light shining onto Cadmium (Cd) which has a work function of 4.07 eV.

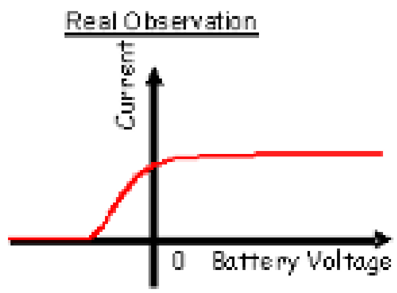

Figure 1: Current vs Voltage for 200nm light on Cadmium

   (a) **(5 pts) (Essay)** Explain your reasoning for why this curve has the shape that it does. Address: Why is current level at $V > 0$? Why does current go to zero at some negative voltage? Why does current start decreasing steadily at $V < 0$?

   (b) **(2 pts)** What is the stopping potential in this situation (in eV)? (Remember stopping voltage is expressed as a positive number).

   (c) **(11 pts) Comparative Graphs.** In the graphs below, the gray curve is always the same (Cadmium, 200nm). The red curves represent the result after a change in the experiment.

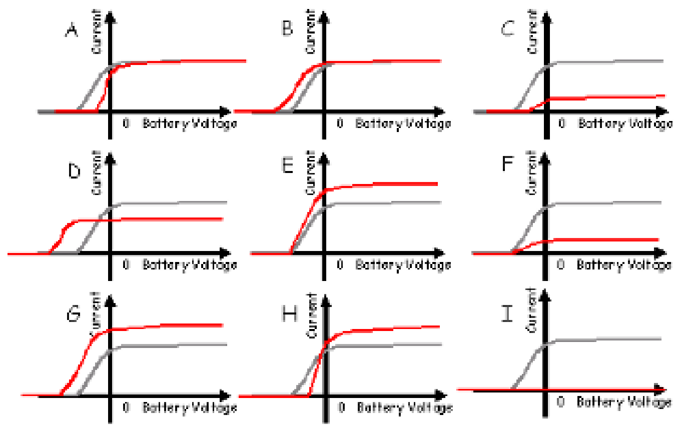

Figure 2: Multiple I-V Curves

i. **(2 pts)** If you decrease the wavelength of the light, what happens to the voltage where the current goes to zero?

☐ Becomes a larger, negative number

☐ Becomes a smaller, negative number

☐ Is unchanged

Briefly explain your reasoning:

ii. **(1 pt)** Which graph would represent this decrease in wavelength?

iii. **(1 pt)** Which graph would represent an increase in the intensity?

iv. **(1 pt)** Which graph would represent an increase in wavelength to 290nm?

v. **(1 pt)** Which graph would represent an increase in wavelength to 500nm?

vi. **(1 pt)** Which graph would represent a switch to sodium?

(d) **(4 pts)** What change or combination of changes would you need to explain the change observed in **Graph H**? (Check all that apply)

☐ Decrease in wavelength

☐ Increase in wavelength

☐ Decrease in intensity

☐ Increase in intensity

7. **(4 pts) Calculation Challenge.**
You have a colored spot light, but you don't know its precise wavelength. To find out the wavelength you shine your light on a sodium target ($\Phi = 2.3$ eV). If you set the battery voltage to -0.5 V, you find that the most energetic electrons nearly reach the right plate but turn around just before they get there.

What is the wavelength, in nm, of the colored light that you used?

1.4 The Threshold Frequency (20 pts)

8. **(3 pts) (Short Essay) Explain what the phrase - 'the work function for sodium' - means in a way that would make sense to a non-science person.**

9. **Mystery Material Analysis**
   You have a plate of metal, but you have no idea what kind of metal it is. You decide to measure its work function by using it as the target in a photoelectric effect experiment. You can perform this experiment virtually by selecting '???' as the target in the simulation.

   (a) **(15 pts for Write Up)** What is the work function, in eV, of the mystery metal? Include a useful picture and explain your reasoning. Use the *Strategy*, *Solution*, *Significance* approach to solve this problem: describe appropriately the steps, highlighting how you make use of the PhET simulation. Show clearly the Maths steps and your reasoning. Generate a useful figure/picture that could be taken from the PhET simulation, and that would illustrate. You should submit this question on a separate sheet, along with the writeup of the 2 part of this project.

   (b) **(2 pts) What is the mystery material?**

   ◯ Sodium (Na)
   ◯ Calcium (Ca)
   ◯ Cadmium (Cd)
   ◯ Aluminum (Al)
   ◯ Silver (Ag)
   ◯ Platinum (Pt)
   ◯ Magnesium (Mg)
   ◯ Nickel (Ni)
   ◯ Selenium (Se)
   ◯ Lead (Pb) [cite: 66]

Part 2: Numerical Analysis of Millikan's 1916 Data

2.1 Historical Context

In 1916, R.A. Millikan published *"A Direct Photoelectric Determination of Planck's 'h'"*. While Einstein had proposed the equation $K_{max} = hf - \Phi$ in 1905, it had not been conclusively verified. Millikan's experiment used a "machine shop in vacuo" to shave fresh surfaces of alkali metals (Sodium, Lithium) to obtain clean data.

2.2 The Data

The tables below contain data extracted from Millikan's 1916 paper for Sodium (Na) and Lithium (Li). The values represent the **Stopping Potential (V_{stop})** measured at various monochromatic light frequencies. The original paper of Millikan is accessible on Moodle for consultation. In the paper, the wavelength are reported in Angstrom (Å) and not Hertz, but have been converted here to simplify their usage. *Note: The stopping potential is the retarding voltage required to stop the fastest electrons. In this dataset, negative values indicate a retarding potential was applied.*

Table 2: Sodium (Na) Data (Source: Millikan 1916)

Frequency ($\times 10^{14}$ Hz)	**Stopping Potential** (Volts)
5.49	-2.10
6.91	-1.55
7.41	-1.33
8.23	-0.98
9.61	-0.42
11.83	+0.52

Table 3: Lithium (Li) Data (Source: Millikan 1916)

Frequency ($\times 10^{14}$ Hz)	**Stopping Potential** (Volts)
5.49	-1.61
6.91	-1.02
7.41	-0.82
8.23	-0.48
9.61	+0.09
11.83	+1.00

2.3 Analysis Tasks (20 pts)

For **each** metal (Sodium and Lithium), perform the following steps:

1. **Plot the Data:** Create a graph of Stopping Potential (V) on the y-axis versus Frequency (f) on the x-axis. Use a Python jupyter-notebook to plot the data and add the figure to your document. (3 pts)

2. **Linear Fit:** Perform a linear regression (line of best fit) to the data on your jupyter-notebook. The equation of the line is given by Einstein's photoelectric relation:

$$V_{stop} = \left(\frac{h}{e}\right) f - \frac{\Phi_{eff}}{e} \tag{1}$$

where h is Planck's constant, e is the elementary charge (1.602×10^{-19} C), and Φ_{eff} is the effective work function. (3 pts)

3. **Determine Planck's Constant (h):**
   (a) Extract the slope of your fit. (3 pts)
   (b) Use the accepted value of e to calculate h from the slope. (3 pts)
   (c) Calculate the percent error of your calculated h compared to the accepted value (6.626×10^{-34} J·s). Record the error for each metal. (3 pts)

4. **Determine the Work Function (Φ):**
   (a) From the y-intercept of your graph, calculate the effective Work Function in electron-volts (eV). (3 pts)
   (b) Compare this to the standard values (Na $\approx$ 2.3 eV, Li $\approx$ 2.9 eV). (2 pts)

2.4 Discussion Questions (20 pts)

1. **Average Planck's Constant:** Calculate the average h obtained from your Na and Li fits. How does this compare to the value Millikan reported in his paper (6.57×10^{-27} erg·s)? (5 pts)

2. **The "Contact Potential" Issue:** You likely found that your calculated work functions differ significantly from the textbook values. Millikan explains this is due to the **Contact Electromotive Force (EMF)** between the metal and the copper oxide collecting plate.

   - For Sodium, Millikan measured a contact EMF of roughly 2.51 V.
   - For Lithium, he measured roughly 1.52 V.

   How would subtracting these contact EMF values from your y-intercepts change your Work Function results? Do they align better with accepted values after this correction? (7 pts)

3. **Linearity Check:** Does your plot confirm Einstein's prediction that the stopping potential is linearly proportional to frequency? Discuss whether the classical wave model could explain a linear relationship with a threshold frequency. (8 pts)