LAB 3: THE PHOTOELECTRIC EFFECT

Hamilton College Physics Department

In this experiment, you will shine light onto a metal surface and study the electrons that are emitted. Specifically, we measure both the maximum kinetic energy of emitted electrons and the number of electrons (photocurrent), while varying the frequency and intensity of the light.

PRELAB ASSIGNMENT

To be handed in at the start of lab.

> Light of wavelength 356 nm falls onto a metal surface causing it to emit electrons (which are then called photo-electrons). If the resulting photo-current can be brought to zero by applying a potential of 1.3 V, what is the work function of the metal?

THE APPARATUS

The equipment used for this experiment consists of an emitting surface and circular collecting wire housed in an evacuated glass tube (fig. 1). A metal housing shields the tube from extraneous light and also serves as an electrostatic shield. Light from a compact fluorescent bulb enters through an aperture in the shield, passes through the glass, and strikes the emitting surface. Emitted electrons are collected on a loop of thin wire in front of the emitting surface.

In separate experiments, we measure the stopping voltage V_{stop} and the photocurrent, both with a device called an electrometer (pronounced uh-lek-TRAA-mtr). Fig. 1 shows how an electrometer is connected. The electrometer (discussed below) can be used to measure both current and voltage.

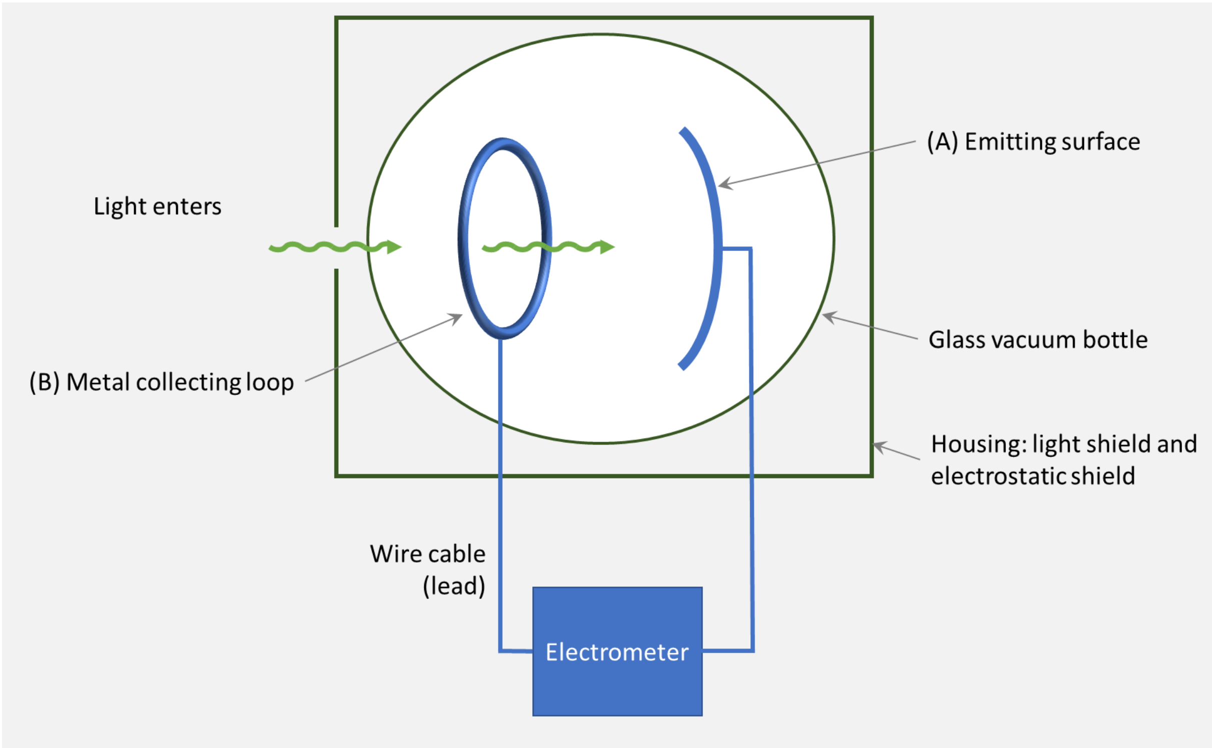

Figure 1. Schematic view of the photoelectric tube and electrometer. The emitting surface is labeled A and the current collecting loop is labeled B.

If a large enough external potential difference is applied across the tube terminals A and B, the emitted photo-electrons will be repelled by the collector and unable to reach it. The voltage that is just barely able to stop the fastest electrons is the critical stopping potential V_{stop}. V_{stop} directly measures the kinetic energy of the fastest electrons: $eV_{stop}=KE_{max}$ (why?).

In practice, we use a clever way to measure V_{stop}. A capacitor, connected as in fig. 2, becomes charged when electrons move through the vacuum from the emitter to the collector. The process continues until the accumulation of charge corresponds to a potential difference across the capacitor equal to the stopping potential V_{stop}. This can take a few minutes while you watch! Since the stopping potential prevents any more electrons from reaching the collector and, hence, the capacitor, the voltage across the capacitor will become steady at a value of V_{stop}. We can measure the voltage across the capacitor in order to determine the stopping potential. In our case, the capacitor is actually the "equivalent capacitance" associated with the electrometer.

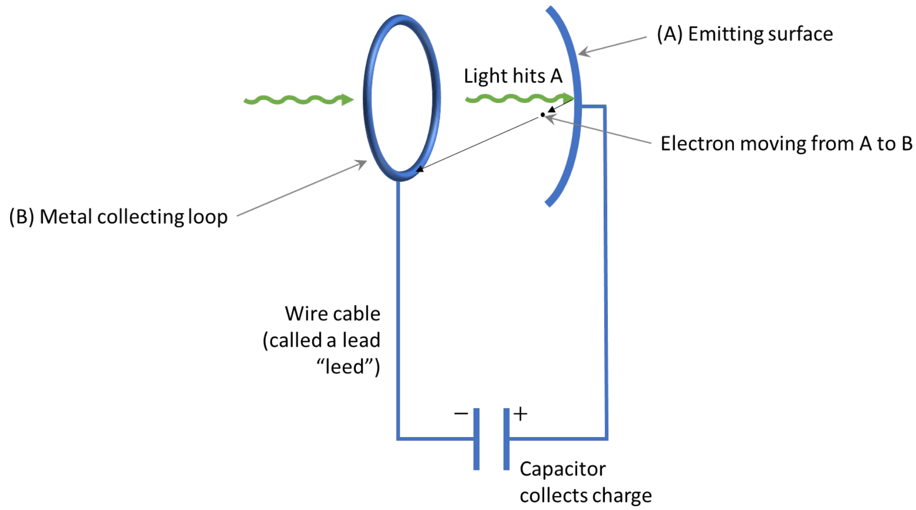

Figure 2. Schematic apparatus with hypothetical capacitor.

If you have learned about resistors and voltmeters, you might be interested to read the note at the end about how we use the electrometer as a capacitor.

Special precautions with this apparatus in order to take high quality data:

- Both collector and emitter are made of metals, so they are equally able to emit electrons when illuminated. Make sure that the optics is aligned so that light is focused onto the emitter and misses the collector (circular ring of fine wire).
- Turn on the electrometer and lamp 15 minutes before taking readings.
- Avoid moving or flexing any cables or contacts; slight movements, even you moving near the bench, can cause erratic readings by changing the effective capacitance of the circuit.
- Depress the "zero check" button on the electrometer while changing the illumination. This will discharge the internal capacitor before each trial.
- If you have a filter with an arrow on it, the arrow points in the direction light is traveling.

THE EXPERIMENTS

After each experiment, make sure you understand your results in terms of the physics behind the photoelectric effect. Discuss your interpretation with your partner and record your discussions in your notebook.

Experiment 1) Stopping voltage vs. light frequency.

a) The light source uses a compact fluorescent bulb to generate light with several well-defined wavelengths on top of a broader spectrum. You can see this if you compare the spectrum of your light source with that from one of the desk lamps using the handheld spectroscopes.

You have filters to isolate each individual wavelength and block out the others. Measure the stopping voltage for each wavelength. Make sure that no stray light can reach your sensor.

b) In Excel, plot a graph of V_{stop} vs. frequency. Fit the best straight line to the plotted points and use the LINEST* function to determine the fitting parameters (slope and intercept) and their uncertainties. From the slope and intercept, derive the work function U_{Wf} for the emitting material and Planck's constant h. Use the LINEST information to calculate δh and δU_{Wf}; write your measurements of both constants in standard form.
* LINEST is a Control-Shift-Enter array function. A two-by-two block of cells will get you slope, intercept, slope error, and intercept error. (See also: Error analysis in a nutshell)

c) Compare your value of Planck's constant to the accepted value. Discuss the evidence for both random and systematic errors in the measurement. Which do your values of δh and δU_{Wf} measure?

Show your graph to your lab instructor.

d) Your writing assignment for the week is to write the theory and results sections for **this** part 1 measurement. Note that you should include a diagram that includes all parts of the apparatus essential to the measurement and physics.

Experiment 2) Photocurrent vs. light intensity at fixed frequency.

Change the electrometer to operate as an ammeter (most likely on the nA scale). Select one of the color filters; preferably one that you expect to yield a large intensity. Using the neutral density filters provided, graph the photo-current versus light intensity.
Note: We will use optical filters called "neutral density" filters to reduce the intensity of the incoming light in a systematic way. The filters are labeled with their optical density (OD) values. The transmission of a filter is given by $I_{out} = \frac{I_{in}}{10^{OD}}$. For OD = 1, the transmission intensity is I = 0.1; that is, 1/10 of the light is transmitted and the other 9/10 is reflected away.

Show your graph to your lab instructor.

Experiment 3) Does Stopping Voltage depend on Intensity?

Keep that same color filter that gives you a large photocurrent and re-measure the stopping voltage. Is your answer consistent with part 1? If it is not then consult with the instructor about what you may have changed.
Leaving that color filter in place add an OD = 0.3 filter. This will reduce the intensity of the light reaching the photocathode by a factor of two. Again measure the stopping voltage. Repeat with the OD = 0.5 filter. Discuss how your findings support or do not support Einstein's quantum theory of light.

SPECTRUM OF LIGHT SOURCE

In order to understand the wavelengths that you are shining onto the emitter surface, Figure 3 shows the spectrum of the lamp together with information about the various filters. We have purchased these filters specifically to match the spectrum of the fluorescent lamps.

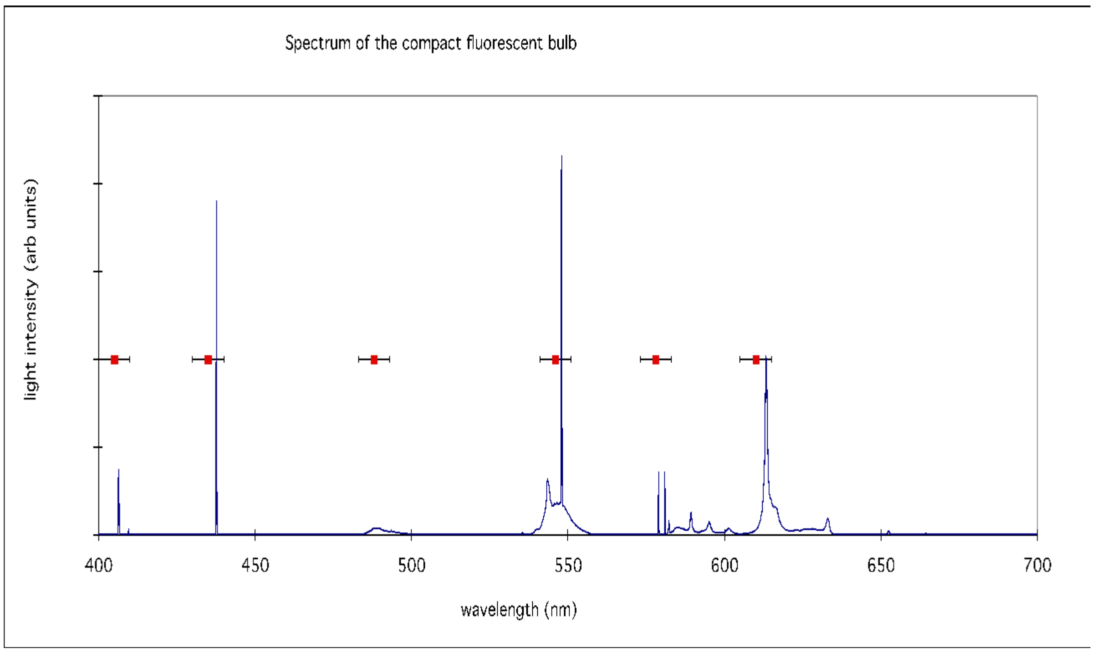

Figure 3. Spectrum of fluorescent lamp. The markers that look like error bars represent the transmission bands of your various color filters. The red marker is the specified wavelength and the lines show the width of the band that is transmitted by the filter.

LAB WRITE-UP ASSIGNMENT

Write up the Theory and Results sections for Experiment #1 in this lab. Include a diagram showing the essential pieces of the apparatus. Your description of the theory and diagram should include enough detail to allow the reader to understand the physical phenomenon that occurs. Note: YOU create the diagram; do not copy-paste figures from the lab handout.

Tip: See video for example of how to draw a scientific diagram in MS Powerpoint: https://newyork6.hosted.panopto.com/Panopto/Pages/Viewer.aspx?id=41e4fa10-9460-4180-a21f-b1e7010af1fc

Preferred submission formats include LaTex, Word, and Google Docs. This writeup will be graded for credit.

As you do your writing, refer to the comments from last week's lab and the writing aids we have put up on the course website, including the Anatomy of a Lab Report and the Lab Writeup Self-Eval.

EXPERIMENTAL NOTE ABOUT ELECTROMETER

This optional section might have too much new physics if you haven't learned about resistors and voltages yet. The main idea is that a capacitor can collect and hold charge.

Special experimental note about using the electrometer as a capacitor:

Due to the incredibly small amount of charge that we will be working with, we need a special type of voltmeter to measure this voltage. An "ideal voltmeter" has infinite resistance and zero capacitance; that is what we assume when we do in circuit analysis in physics classes. But we are working with experimental apparatus in the laboratory, so it can't be ideal. Typical voltmeters have resistances of $\sim 10^7\ \Omega$, a large enough resistance for most applications, but they do still let a small amount of current through. An *electrometer* is a voltmeter with a *very* high internal resistance $\sim 10^{13}\ \Omega$. Figure 4 shows the equivalent circuit for our electrometer. Note the very large value for the equivalent resistance and the very small value for the equivalent capacitance. The circle with a "V" in it represents an *ideal* voltmeter having infinite resistance and no capacitance. For experiments 1 and 3, we will take advantage of the effective capacitance associated with the meter and circuit, and we will simply connect the meter (in voltmeter mode) to the photoelectric tube. Thus, the voltage we read will be the voltage built up on the internal capacitance of the meter. For experiment 2, we use the electrometer as a current meter.

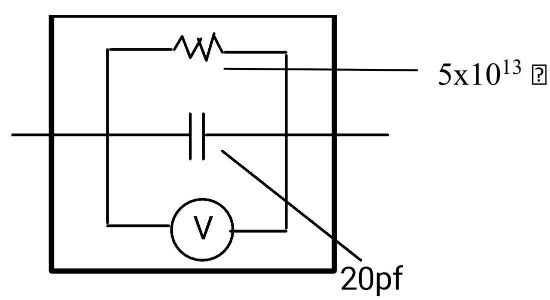

Figure 4. Circuit representing the electrometer itself. Inside the electrometer box (bold square), we have a circuit that is essentially a resistor of $5 \cdot 10^{13}\ \Omega$, a capacitor of 20 picofarads, and an ideal voltmeter, connected in parallel.