Planck's Constant – Measuring h

Dr. Darrel Smith[1]
Physics Department
Embry-Riddle Aeronautical University

(Dated: 11 August 2025)

This experiment makes use of the photoelectric effect to measure Planck's constant, h, a constant that describes the *quantum of action* in quantum mechanics. The light source for this lab is a mercury lamp having five primary wavelengths (i.e., five different photon energies). The light will have sufficient energy to release bound electrons from a clean metallic surface called the photocathode, thus producing photoelectrons with five different maximum kinetic energies, depending upon the light filter being used. This experiment measures the opposing potential (volts) required to stop the flow of ejected electrons (i.e., the current produced) from the photocathode in the photocell. A linear relationship is observed between the maximum kinetic energy of the ejected electrons and the photon frequency ($f = c/\lambda$). After plotting the kinetic energy (or stopping potential energy) versus the frequency, two parameters are measured using a straight-line fit, the work function W, and Planck's constant h.

I. BACKGROUND

The Planck's Constant Apparatus is described in the instruction manual found on my `physicsx` website. At the beginning of the 20th century, Max Planck constructed a model that described the radiation spectra emitted from a blackbody source. The success of his model hinged on the assumption that electromagnetic radiation was quantized (i.e., the radiation of frequency f can only be emitted in integral multiples of the basic quantum hf). However, it was Einstein who correctly described the photoelectric effect in terms of Planck's constant h.

II. THE EXPERIMENT

In this experiment, light from a mercury lamp is incident on a clean metallic surface (i.e., the photocathode). Since the electrons on the photocathode are bound to the surface, they must absorb the "whole" photon to overcome the work function (W), the binding energy holding the electron to the surface. Any excess energy becomes kinetic energy for the electron. We can write this relationship using conservation of energy:

$$K_{\max} = eU_s = hf - W \tag{1}$$

where $K_{\max}$ is the maximum kinetic energy, eU_s is the fundamental charge times the stopping potential, f is the frequency, and W is the work function measured in eV.

The kinetic energy of the electrons in Eq. 1 produces a current when incident on the collector and this is recorded on the ammeter shown in Fig. 1. A variable voltage source provides a reverse-biased voltage that slows the electrons during their transit. The voltage is increased until the most energetic electrons are finally brought to rest. The voltage at which this occurs (U_s) is recorded in order to calculate the maximum kinetic energy ($K_{\max} = eU_s$).

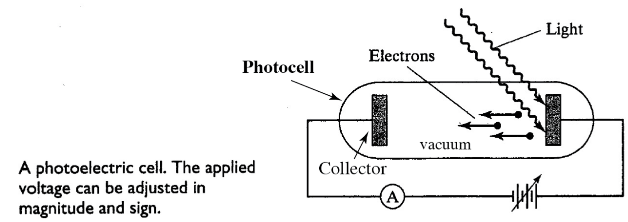

FIG. 1. This figure shows monoenergetic photons incident on a clean metallic surface causing photoelectrons to be ejected from the surface. The photoelectrons move to the left inside the evacuated photocell where they are incident on a collector thus completing the circuit and producing a current in the ammeter. Figure is from Taylor and Zafiratos, *Modern Physics*, plus some editing of my own (D. Smith).

III. THE EQUIPMENT

The equipment is from Lambda Scientific (LEAI-50) and includes the following:

1. The basic apparatus with a photocell, voltmeter, nanometer and Hg lamp. The photocell is a vacuum tube where the electrons drift unimpeded between the photocathode and the collector plate as shown in Fig. 1,

2. five bandpass filters (λ = 460 nm, 500 nm, 540 nm, 570 nm, and 635 nm) described in Table I below,

3. a black cap for covering the photocell collector tube when it's not in use.

The equipment is described in more detail in the instruction manual found on my `physicsx` website

Note: The photocell in the Planck's constant apparatus is highly sensitive. Bright light without filters can cause it to age quickly and can cause permanent damage.

TABLE I. This table shows the filter wavelengths for the five filters corresponding to 5 nearby Hg emission lines.

Filter (nm)	Hg wavelength (nm)	Color
460	435.8	deep blue
500	491.6	blue-green
540	546.1	green-yellow
570	578.2	yellow doublet
635	623	orange/red

Following such irradiation, it needs to be left in a dark environment for a long period of time before it regains its stability. **Proper handling of the equipment includes the following:**

- You should not open the top of the photocell assembly. The packing material used for protecting the photocell during transport has been removed.
- When the Planck's Apparatus is not being used, or you are finished taking data, place the blank cap over the receiver tube extending from the photocell assembly, the same place where you mount the bandpass filters.
- Keep the apparatus secure so that it does not get shaken and do not expose it to extreme temperatures, high humidity, moisture or direct sunlight.

A picture of the equipment is shown in the instruction manual as well as in Fig. 2 (see below).

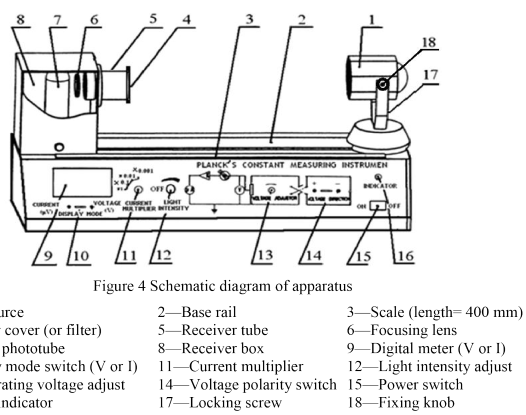

FIG. 2. This figure shows the equipment used in the Planck's Constant Apparatus. The different parts of the unit are described in the legend below the picture. The power supplies, voltage and current meters are built into this one assembly.

IV. PROCEDURE

You will find more information regarding the photoelectric experiment in the following material:

- my `physicsx` webpage (e.g., the Instruction Manual), and
- your Modern Physics textbook

There are two parts to the procedure and they are found in the instruction manual section 5 (pp. 4-5)– **Experimental Procedures**. In section 5 there are instructions for obtaining the stopping potentials U_s [volts] for each of the 5 filters. In section 6 you will find an example of a graph for eU_s vs. f. The slope of this straight line fit (see Fig. 3 below) is Planck's constant in units of eV·sec. The intercept (not shown) measures the work function (W).

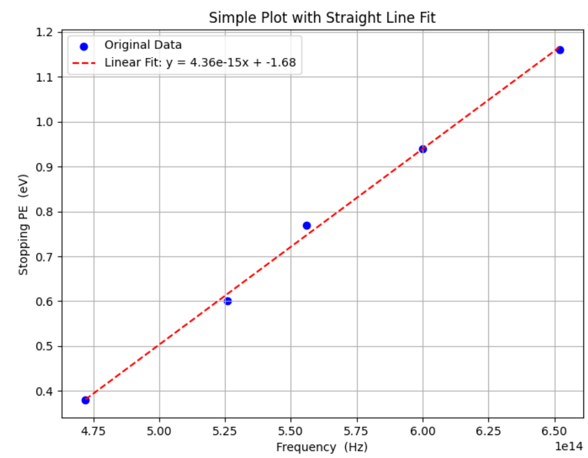

FIG. 3. This figure shows the linear relationship described by Eq. 1. The data were taken using the LEAI-50 apparatus. A straight-line fit was performed and the best fit values for h and W are shown at the top of the graph. The accepted value for Planck's constant is $h = 4.136 \times 10^{-15}$ eV·s.

A. Two experiments to perform

There are two parts to this experiment. The first part is to measure the I vs. U characteristic curve for a particular filter. The second part is to use all 5 filters to obtain a straight-line fit and measure Planck's constant h and the work function W.

1. I vs. U characteristic curve

In this part of the experiment, pick one of the five bandpass filters and mount it in the receiver tube on the photocell assembly. Vary the voltage in both the positive and negative regions and record the current. Select ∼10 different voltages and measure the current and record these values in a table. Plot the coordinate pairs I vs. U. Also make sure to include U_s, the stopping potential, as one of your voltages. Your curve should look similar to Fig. 3 in the Instruction Manual.

2. Straight-line fit to measure h

In this part of the experiment, find the stopping voltage (U_s) for each of the five filters and record these values in a table. Make sure to include both the wavelength (λ) and its corresponding frequency (f) for each entry. Make a plot similar to Fig. 3 (this leaflet); however, include the following in your plot or in the figure caption, as appropriate:

- vertical error bars on each of your 5 data points,
- the best fit values for W and h, and their uncertainties, and
- the χ^2 value for your best fit parameters, and the # of degrees of freedom.

B. The Goal

The goal of this experiment is to measure Planck's constant and compare it to the accepted value of 6.62607015 $\times 10^{-34}$ J·s, or 4.135667697 $\times$ 10^{-15} eV·s. For the purpose of your analysis, let's assume that the wavelengths (frequencies) are known with high precision (i.e., no uncertainties). As you vary the fine voltage knob to obtain a "zero current", see if you can determine the instrumental uncertainty (σ) in the stopping voltage. Use this uncertainty for your error bars when using the `curve_fit` routine in your Python program. Also, include the vertical error bars when making your plot (not shown in Fig. 3).

Another approach to determine the instrumental uncertainty for all 5 data points is to set your $\chi^2 = 3.00$ (the no. of degrees of freedom) to determine the value of σ, the standard deviation. While this approach is acceptable for determining the unknown instrumental uncertainty, it subverts the usefulness of the χ^2 statistic. So, I encourage you to use the first technique and make your best guess of the instrumental uncertainty (i.e., the vertical error bars) and proceed with your straight line fit. With this value of σ, `curve_fit` can determine the uncertainties of the slope and intercept (δh, δW).

C. Supplemental Material

There are no other leaflets or manuals for this experiment other than this leaflet and the instruction manual on my website. However, I encourage you to read about the photoelectric effect from other sources, for example, your modern physics textbook and other modern physics textbooks found in the library, as well as reliable sources on the internet.

V. IMPORTANT CONSIDERATIONS

- Keep the photocell in a dark environment when it is not being used. So, when you are finished taking measurements, remove the last bandpass filter and put the black cap on the receiver tube where the filters were connected.
- Don't be in a hurry to make measurements. Before you install the bandpass filter, move the V-I digital meter switch to *Voltage* to protect the current meter. Let the photocell sit for a minute to adapt to the new filter before you start zeroing the current to determine U_s. You can leave the Hg light intensity at a moderate level throughout the experiment. Hg lamps take a few minutes to warm up, so there is no need to turn it off-and-on between bandpass filter installations. Photocells are finicky devices, similar to phototubes. If you expose them to room light, with voltage on for extended periods of time, they can take an hour or so to settle down. Unlike batteries (which are voltage sources), photocells are current sources. These photocells are generating currents in the nanoamps when connected to a circuit. That may not sound like a lot of current; however, the ammeter is a very sensitive device.
- Make sure to read section 5–**Experimental Procedures** in the Instruction Manual regarding the operation of the nano-ammeter before using it. Make your first measurement of the current using the coarse scale ($\times$1). Afterwards keep zeroing the current as you progress step-by-step until you reach the fine scale ($\times$0.001). If you accidentally start your current measurements using the fine scale ($\times$0.001), you can unexpectedly saturate the nano-ammeter.
- **Do not look directly into the Hg lamp when it is on**, especially when its illumination is at a high level. This is not good for your eyes.
- Handle the equipment with care. Make sure that no moisture gets inside the equipment.
- Please handle the bandpass filters by their outer rims. **Do not touch** the surface of the filters.

I will probably rewrite this leaflet once we have operated the experiment a few times and become more familiar with it. When in doubt, direct your questions to me or the lab assistants.

If you come across any mistakes or typos in this leaflet, please let me know and I will correct them. Thanks.