Planck's Constant – Measuring h

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The purpose of this experiment is to measure Planck's constant, h, a constant that describes the *quantum of action* in quantum mechanics. This experiment measures the kinetic energy of ejected electrons due to the photoelectric effect. In this lab, photons having five different wavelengths (i.e., different energies) are incident on a clean metal surface. A linear relationship is observed between the photon frequency ($f = c/\lambda$) and the kinetic energy of the ejected electrons. Two parameters are measured in the straight-line fit, the work function ϕ, 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 sources. 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.

FIGURE 4.2
A photoelectric cell. The applied voltage can be adjusted in magnitude and sign.

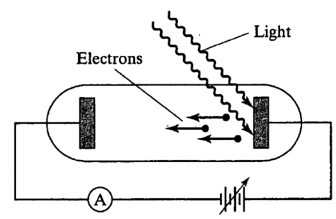

FIG. 1. This figures shown the *approximately* monoenergetic photons incident on a photocell causing electrons to be ejected from the metallic surface. The electrons are collected on the cathode to the left and a current is recorded on the ammeter. Figure is from Taylor and Zafiratos, *Modern Physics.*

II. THE EXPERIMENT

In this experiment, the photons from a light source pass through five different band-pass filters, one at a time. After the light passes through one of the filters, only a narrow range of frequencies (f) are permitted to pass to the photocell surface. Since the electrons are bound to the metallic surface, they must absorb the "whole" photon to overcome the work function (ϕ), the binding energy holding the electron to the surface. Any excess energy results in the kinetic energy of the electron. We can write this relationship using conservation of energy:

$$K_{\rm max} = hf - \phi \qquad (1)$$

where K is the kinetic energy , f is the frequency, and ϕ is the work function measured in eV.

The kinetic energy in Eq. 1 produces a current when collected on the cathode plate and this is recorded by the ammeter. 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 ($V_{\rm max}$) at which this occurs is recorded in order to calculate the maximum kinetic energy ($K_{\rm max} = eV_{\rm max}$).

III. THE EQUIPMENT

The equipment includes the following:

1. a mercury light source,
2. a set of 5 interference filters,
3. an object glass to focus the mercury lamp on the phototube's cathode plate,
4. a GD-2 phototube, and
5. a picoampere amplifier and control unit.

and these are described in the instruction manual. When you handle the interference filters, please make sure to keep your fingers, dust, and dirt off the surface. Handle them carefully by their edges. Also, make sure that you start with the coarse setting on the pico-ammeter ($\sim 10^{-10}$ A) before advancing to the more sensitive settings ($\sim 10^{-12}$ A). A picture of the equipment used in this experiment is shown in Fig. 2.

IV. PROCEDURE

You will find more information regarding the experimental procedure in the following material:

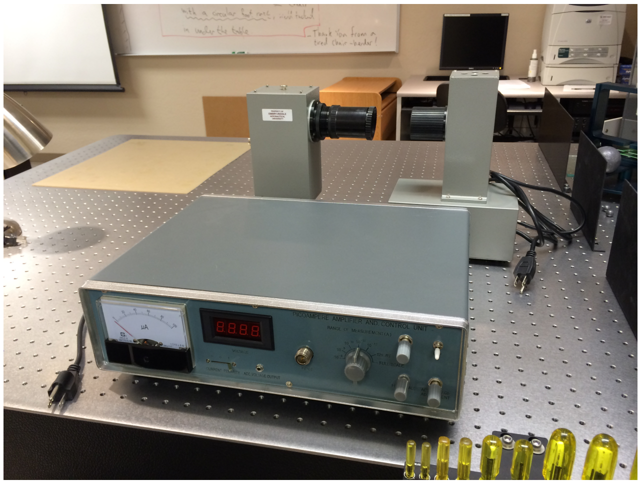

FIG. 2. This figures shows the equipment used in the Planck's Constant Apparatus. The unit in the foreground is the picoammeter. The two units in the background are the mercury lamp (right), and the photocell (left). Filters are attached to the photocell tube allowing a narrow range of wavelengths into the photocell.

- my `physicsx` webpage,
- your Modern Physics textbook (chapter 4.3)

The procedure is pretty straight forward. There are five interference filters, each with a range of bandpass frequencies. The transmission probability for each filter can be seen in Fig. 3. As you can see, there is a width associated with each filter (i..e., a range of frequencies are transmitted), not just one very narrow frequency. After inserting the first filter, adjust the

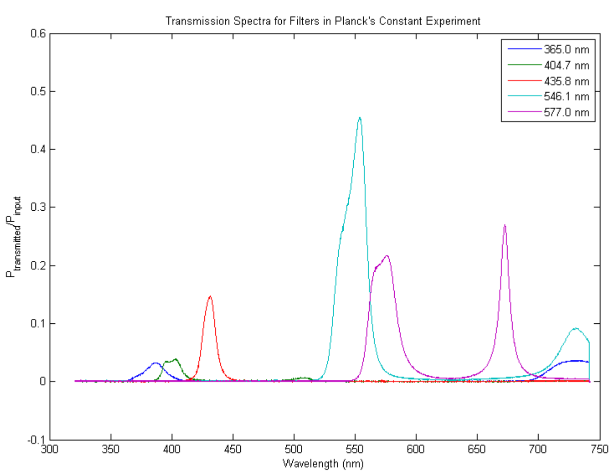

FIG. 3. The figure shows the transmission spectra for the five filters used in the Planck's Constant Apparatus. Data files for each spectrum can be found in my PS315 course on my `physicsx` website. *Courtesy of Dr. A. Gretarsson.*

reverse-bias voltage to where the current approaches zero. The value of the potential is the $V_{\max}$ for that particular frequency. Repeat this process for the other filters and determine the maximum potential $V_{\max}$ required to bring the current to *zero* on the picoammeter.

N.B. Please take some time to read *Section 5* titled "Operation" of the picoampere amplifier. The correct operation of the picoammeter is critical for obtaining good data from this experiment.

After making a table of the maximum potentials (*volts*), and the frequencies (*Hz*), you will make a plot of the $K_{\max}$ vs. f as shown in Fig. 4.

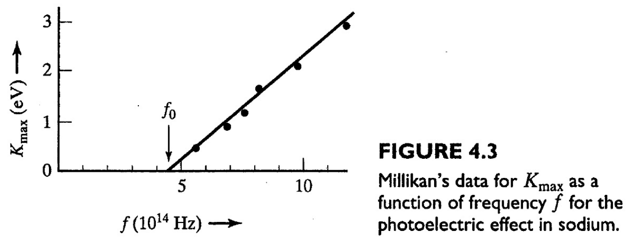

FIG. 4. This figure shows the linear relationship described by Eq. 1. Notice the cutoff frequency at f_o. Photons with frequency less than f_o have insufficient energy required to overcome the work function ϕ in order to remove the electron from the metallic surface. In other words, $hf_o < \phi$. Figure is from Taylor and Zafiratos, *Modern Physics*.

A. Supplemental Material

There are no other leaflets or manuals relating to this experiment; however, I encourage you to read about the photoelectric effect from other sources, for example, other modern physics textbooks found in the library, as well as reliable sources on the internet.

V. IMPORTANT CONSIDERATIONS

- Keep the filters clean. Hold them by their edges.
- Let the mercury lamp warm up (∼ 10-20 minutes before making measurements.
- Do not stare at the mercury lamp. It's pretty intense.
- Make sure to read section 5 on the operation of the picoammeter before using it.