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.

II. THE EXPERIMENT

In this experiment, the photons from five different light sources (i.e., LEDs), each with their own wavelength, are incident on a clean metallic surface (i.e., the photocell). Since the electrons on the clean metal surface 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 results in the kinetic energy of the electron. We can write this relationship using conservation of energy:

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

where $K_{\max}$ is the maximum kinetic energy, eU_o 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_o) is recorded in order to calculate the maximum kinetic energy ($K_{\max} = eU_o$).

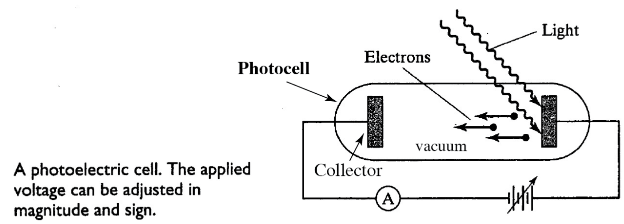

FIG. 1. This figure shows monoenergetic photons incident on a clean metallic surface causing photoelectrons to be ejected from the surface. The photoelectrons move to the left inside the evacuated photocell where they are incident on a collector thus completing the circuit and producing a current in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

III. THE EQUIPMENT

The equipment 3B Scientific and includes the following:

1. The basic apparatus with photocell, voltmeter, nanometer and LED power supply. The photocell is a vacuum tube where the electrons drift unimpeded between the clean metallic surface and the collector plate as shown in Fig. 1,
2. five LED light sources (λ = 472 nm, 505 nm, 525 nm, 588 nm, and 611 nm),
3. an empty sleeve for covering the photocell collector tube, and
4. a plug-in power supply (transformer), 12 V AC.

These are described in more detail in the instruction manual.

Note: The photocell in the Planck's constant apparatus is highly sensitive. Bright light can cause it to age quickly and can cause permanent damage. Following irradiation it ideally needs to be left in a dark environment for quite a long period of time before it regains its stability. **What steps should you follow?**

- The protective cover for the photocell should never be removed.
- When the experiment is complete, slide the empty sleeve over the collector tube of the photocell.
- 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).

1 LED with connecting lead
2 Nanoammeter
3 Voltmeter
4 Protective cover for photocell
5 Collector tube for photocell
6 Coaxial power socket for power supply
7 Power supply with connector socket for LED
8 Back EMF adjustment (coarse)
9 Back EMF adjustment (fine)
10 Intensity knob
11 Empty sleeve

FIG. 2. This figures shows the equipment used in the Planck's Constant Apparatus. The different parts of the unit are described in the legend below the picture. Four of the five LED cables are show below the apparatus while the fifth LED is powered by the box and installed into the photocell assembly.

IV. PROCEDURE

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

- my `physicsx` webpage,
- your Modern Physics textbook

There are two parts to the procedure and they can be found in the instruction manual section 6–**Operations**. In section 6.1 there are instructions for obtaining the stopping potentials U_o [volts] for each of the 5 LEDs. In section 6.2 you will find instructions for converting wavelengths into frequencies ($f = c/\lambda$) and how to draw your graph for eU_o vs. f. The slope of this straight line fit (see Fig. 3) is Planck's constant in units of eV·sec.

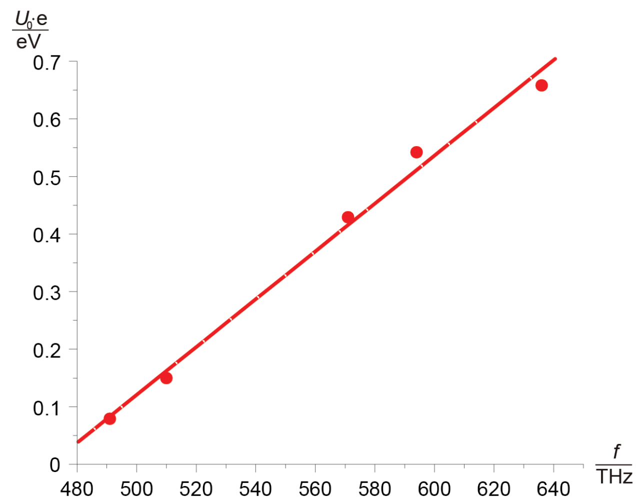

FIG. 3. This figure shows the linear relationship described by Eq. 1. Notice the cutoff frequency at f_o. Photons with frequency less than f_o have insufficient energy required to overcome the work function ϕ in order to remove the electron from the metallic surface. In other words, $hf_o < \phi$. Figure is from Taylor and Zafiratos, *Modern Physics*.

A. Experimental 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 ary the fine voltage knob to obtain a "zero current", see if you can determine empirically what the uncertainty in the stopping voltage might be. Since I have not done this experiment before, I do not know if this is a reasonable approach to assigning uncertainties (i.e., error bars) to the data points shown in Fig. 3).

Another empirical approach would be to assume that the instrumental uncertainties are the same for all 5 data points, in which case, set your $\chi^2 = 3.00$ (the no. of degrees of freedom) to determine the value of σ, the standard deviation. Using this value of σ, you can determine the uncertainties of the slope and intercept (δb, δa) as shown in my technical note, "Straight-Line Fit" found on my PS315 website or in my CANVAS Modules.

B. Supplemental Material

There are no other leaflets or manuals relating to 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 as well as 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 LED and put the empty optical sleeve over the port where the LED was connected.
- Don't be in a hurry to make measurements. Once you have connected the next LED, let it sit for a few minutes to dark adapt before zeroing the voltage and turning up the intensity to 75% as recommended in the instructions. Photocells are finicky devices, similar to phototubes. If you expose them to room light conditions, they can take as long as 12 hours 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. They can be worn out if not treated properly.
- Make sure to read section 6–**Operations** regarding the operation of the nanoammeter before using it.
- Handle the equipment with care. Make very sure that no moisture gets inside the equipment. Unplug the power supply to turn off the equipment.

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

Please direct any mistakes or typos in this leaflet to me and I will correct them. Thanks.