Photoelectric effect — h/e

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1 h/e — Introduction

The purpose of this laboratory is to study the photoelectric effect and measure the ratio of Planck's constant h to the electron charge e. That is, we will measure h/e. The accepted value is 4.1357×10^{-15} Joule/Amp. (You can find it to higher accuracy if you so desire.)

The photoelectric effect happens when light striking a material causes electrons to be ejected. Each quantum of light can liberate one electron from a surface. The electron's kinetic energy will equal the energy of the light quantum minus the binding energy to the material (called the "work function"). The kinetic energy is proportional to the electric potential required to stop the electrons, where the electron's charge is the proportionality constant. The energy of a light quantum is proportional to its frequency, where the proportionality constant is Planck's constant.

Thus, measuring the stopping voltage at several frequencies gives the ratio of these two proportionality constants: h/e.

We will us an apparatus designed for this purpose, Pasco Scientific Model AP-9368.

References:

- There is not much on this in Melissinos, but the photoelectric effect is mentioned on page 312.
- Instruction Manual and Experiment Guide for the PASCO scientific Model AP-9368. (Attached.)

2 Experiment

Set up

Read the attached instruction manual! The Pasco AP-9368 is an excellent device for this purpose. A vacuum cell contains a photodiode whose cathode is connected to a very high impedence unit-gain amplifier. As electrons are emitted from this cathode to ground, its potential increases until the electrons no longer have enough energy to reach the anode. One can then read the potential at the output of the amplifier with an ordinary volt-meter.

Set up the equipment as shown in Fig. 5 of that manual.

Turn on the mercury lamp; the switch is on the back of the housing. It takes several minutes for the lamp to warm up and put out enough light to do the experiment. The light from this lamp leaves the housing and passed through a combined lens and diffraction grating. The diffraction grating separates the light from the mercury lamp into serveral colors, and the lens collimates the light.

You can adjust the position of the lens to focus the light onto the photocathode in the Pasco AP-9368. Focus the light from the mercury vapor light source onto the slot in the white reflective mask on the h/e apparatus. Tilt the light shield of the apparatus out of the way to reveal the white photodiode mask inside the apparatus. Slide the lens/grating assembly forward and back on its support rods until you achieve the sharpest image of the aperture centered on the hole in the photodiode mask. Secure the lens/grating by tightening the thumbscrew.

Align the system by rotating the h/e apparatus on its support base so that the same color light that falls on the opening of the light screen falls on the window in the photodiode mask, with no overlap of color from other spectral lines. Return the light shield to its closed position.

Check the polarity of the leads from your digital voltmeter (DVM), and connect them to the OUTPUT terminals of the same polarity on the h/e apparatus.

Experiment 1

1. Adjust the h/e apparatus so that only one of the spectral colors falls upon the opening of the mask of the photodiode. If you select the green or yellow spectral line, place the corresponding colored filter over the white reflective mask on the h/e apparatus.

2. Place the variable transmission filter in front of the white reflective mask (and over the colored filter, if one is used) so that the light passes through the section marked 100% and reaches the photodiode. Record the DVM voltage reading in the table such as shown below. Press the instrument discharge button, release it, and observe approximately how much time is required to return to the recorded voltage.

3. Move the variable transmission filter so that the next section is directly in front of the incoming light. Record the new DVM reading. Pay attention to the time it takes to recharge after the discharge button has been pressed and released.

Repeat Step 3 until you have tested all five sections of the filter.

Repeat the procedure using a second color from the spectrum.

Color #1 ________	%Transmission	Stopping Potential
	100	
	80	
	60	
	40	
	20	
Color #2 ________	%Transmission	Stopping Potential
	100	
	80	
	60	
	40	
	20	

Experiment 2

1. You can see five colors in the mercury light spectrum. Adjust the h/e apparatus carefully so that only one color (from the brightest order) falls on the opening of the mask of the photodiode.

2. For each of the five colors, measure the stopping potential with the DVM and record that measurement in a table such as the one below. Use the yellow and green colored filters on the reflective mask of the h/e apparatus when you measure the yellow and green spectral lines.

Color	Wavelength nm	Frequency $\times 10^{14}$ Hz	Stopping Potential Volts	uncertainty Volts
Yellow	578.000	518.672		
Green	546.074	548.996		
Blue	435.835	687.858		
Violet	404.656	740.858		
Ultraviolet	365.483	820.264		

You may struggle with what your uncertainty in the voltage measurements should be. Ordinary digital volt-meters such as the Hyelec MS8233D that is on the table are very *precise*, displaying readings of 1–2 Volts to millivolt precision. However, the rated accuracy of this device is just one percent.

3 Analysis

For your data in Experiment 1, plot a graph of the stopping potential vs. relative intensity. Hopefully, you will get something like this, but with only two wavelengths:

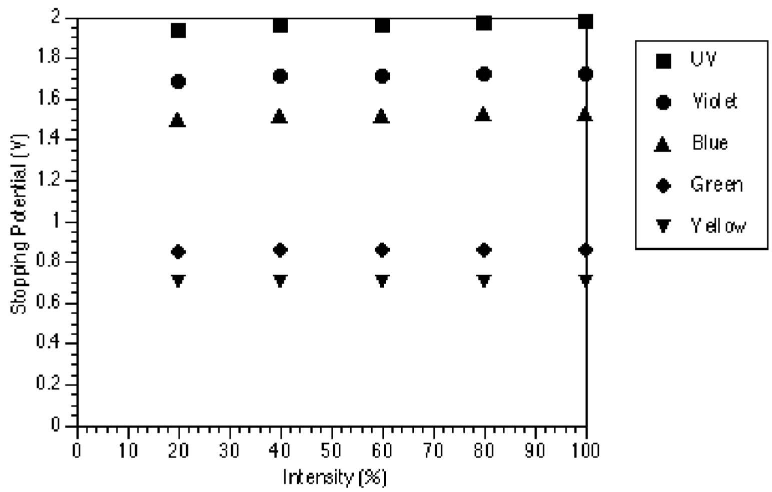

Figure 1: Sample data from Experiment 1.

What do you make of this? You may notice a slight drop in the measured stopping potential as the light intensity is decreased. The reason for this is that although the impedance of the zero gain amplifier is very high ($\sim 10^{13}\ \Omega$), it is not infinite and some charge leaks off. Thus, charging the apparatus is analogous to filling a bath tub with different water flow rates while the drain is partly open.

Explain the dependence of the stopping potential on varying intensity. How does this relate to the quantum (photon) model of light?

For your data of Experiment 2, plot a graph of the stopping potential (in Volts) vs. light frequency. For units, either express your frequency in THz, or make sure that your software can handle numbers as large as 10^{14}. Perform a weighted least-squares fit to the data to find the best estimate of the slope and intercept. When I performed the experiment, my data looked like this:

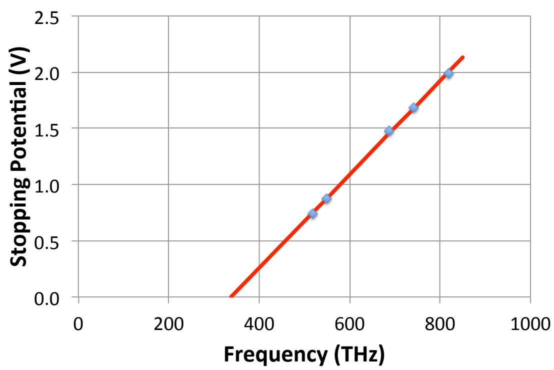

Figure 2: Sample data from Experiment 2. The diamonds are the measured stopping potentials and the red line is the best fit.

When I took the data shown in Fig. 2 I estimated my uncertainty at 10 mV. The error bars are too small to be seen in this figure, so I have also plotted residuals from the fit, shown here:

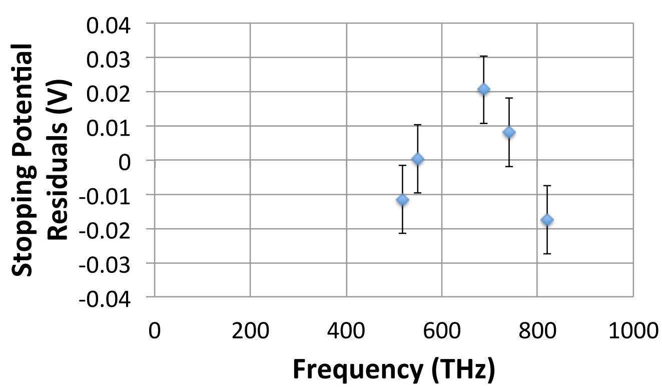

Figure 3: Residuals from the fit to the data in Fig. 2.

This figure shows that, while the data are scattered by an amount that is approximately equal to the estimated uncertainty, there seems to be some kind of systematic effect. The fit starts high, goes low, then high again.

For the sample data show in Fig 2 the best fit slope is $4.161(39) \times 10^{-15}$ J/A. The accepted value is 4.1357×10^{-15} J/A, so I have measured h/e to within 0.6% of its accepted value and the difference is smaller than my uncertainty.

What do you think could explain the systematic trend shown Fig. 3?

Try to explain the dependence of the stopping potential on the light frequency. How does this relate to the quantum (photon) model of light?

Do not treat the Pasco AP-9368 as a "black-box". Understand and explain how it works!