Planck's Constant and the Photoelectric Effect

Equipment:

6 Mercury Lamps (total)	4 PASCO h/e Apparatus (with Asseccories)
2 older h/e Apparatus	2 Voltage Sensors
Computer Interface	Voltagemeter
4 pairs of Red & Black Cables(total)	Stop Watch

Caution: We us UV light in this experiment. Do not look directly into the light.

Purpose:

In this lab you will determine the magnitude of Planck's constant, *h*, employing the photoelectric effect experiment and associated mathematical framework. The overall purpose of the activity is to demonstrate the particle nature of light.

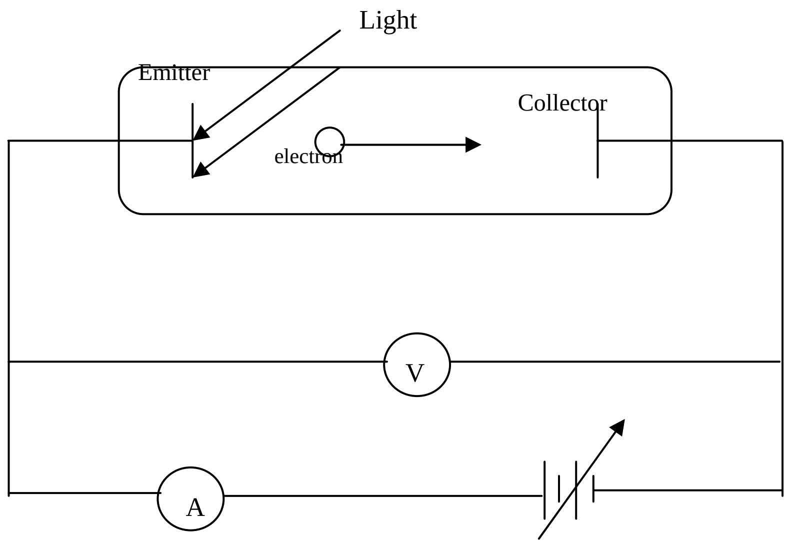


Figure 1: Schematic of the photoelectric effect apparatus.

Theory:

A schematic of the photoelectric effect apparatus is shown in figure 1. A light sensitive material, called an emitter is placed in a transparent evacuated tube along with a collector. This device is then connected to a variable voltage source which allows the generation of an adjustable (uniform) electric field between the emitter and the collector. As light is incident on the light sensitive emitter, electrons are released which have an initial kinetic energy. If the electric field does work on the charged particle equal to the charged particle's initial kinetic energy, the charged particle will come to rest. As a result, the electrical current between the emitter and the collector will go to zero.

The kinetic energy of the ejected electrons is determined by the frequency of the light striking the phototube. The quantity of ejected electrons is dependent on the intensity of the light. The maximum kinetic energy, K_{max}, of the photoelectrons is given by

$$K_{max} = hf - \phi$$

where h is equal to Planck's constant (4.14×10^{-15} eV.s), f is the frequency, and ϕ is the work function. Since the work function, which is the energy required to release an electron from the surface a metal, is a constant for any given material, the maximum kinetic energy depends directly on the frequency of the incident radiation.

If the potential applied to the anode is gradually decreased and made negative, the electrons ejected from the cathode will not have enough energy to reach the anode and will be repelled back to the cathode. At a certain voltage called the "stopping potential", V_S, the electron current from the cathode to the anode will go to zero. At that point, the maximum kinetic energy of the electrons is equal to the stopping potential where

$$eV_S = hf - \phi$$

where e is equal to the electronic charge (1.6×10^{-19} C), and V_S is the stopping potential (volts). By experimentally determining the stopping potential for several values of frequency and using the above equation, Planck's constant can be experimentally determined and compared with the known value. This experiment uses a mercury lamp to generate the photons incident on the light sensitive material. The apparatus is shown in figure 2.

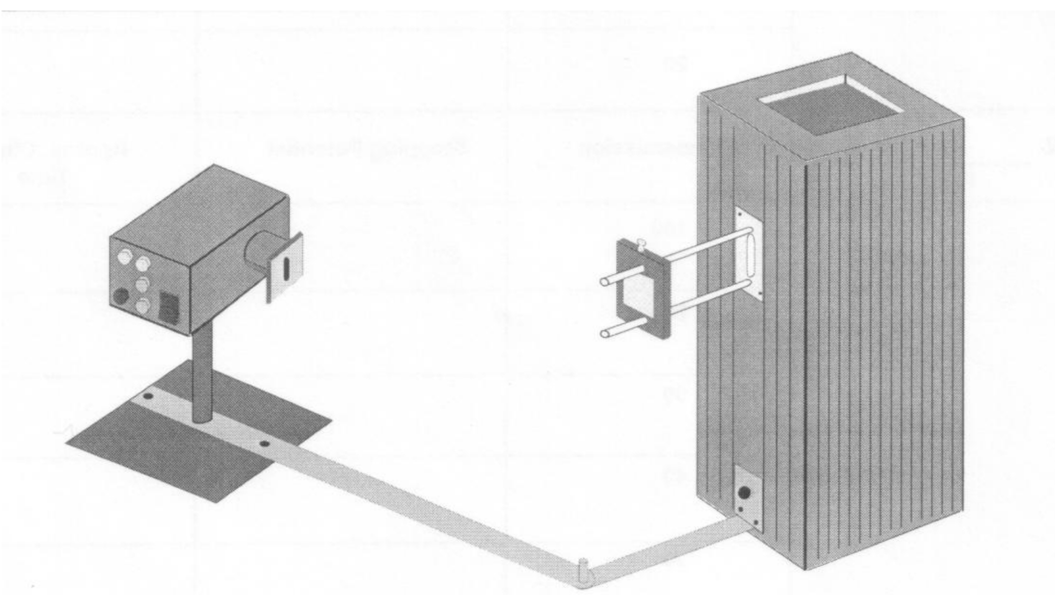


Figure 2. First Photoelectric effect apparatus used today showing the Mercury light source (right) and the phototube(left).

The mercury lamp has the spectrum shown in figure 3. By using a diffraction grating, it is possible to isolate photons of a single wavelength (energy) as schematically described in figure 4. This appartus uses a photodiode tube with a small capacitance which becomes charged by the photoelectric current. When the potential on this capacitance reaches the stopping potential of the photoelctrons, the current stabilizes. This final voltage between the emitter and collector is therefore the stopping potential of the photelectrons.

To let you measure the stopping potential, the anode is connected to a built-in amplifier with a high input impedance, and the output from this amplifier is connected to the output jack on the front panel of the apparatus. This high impedence amplifier has a gain of 1 so the output is still the stopping potential. However, due to its high impedance, the time constant is long and discharging the plates takes a long time. For this reason an electrical short is available. Simply push the “push to zero” button to short the plates and discharge the capacitor.

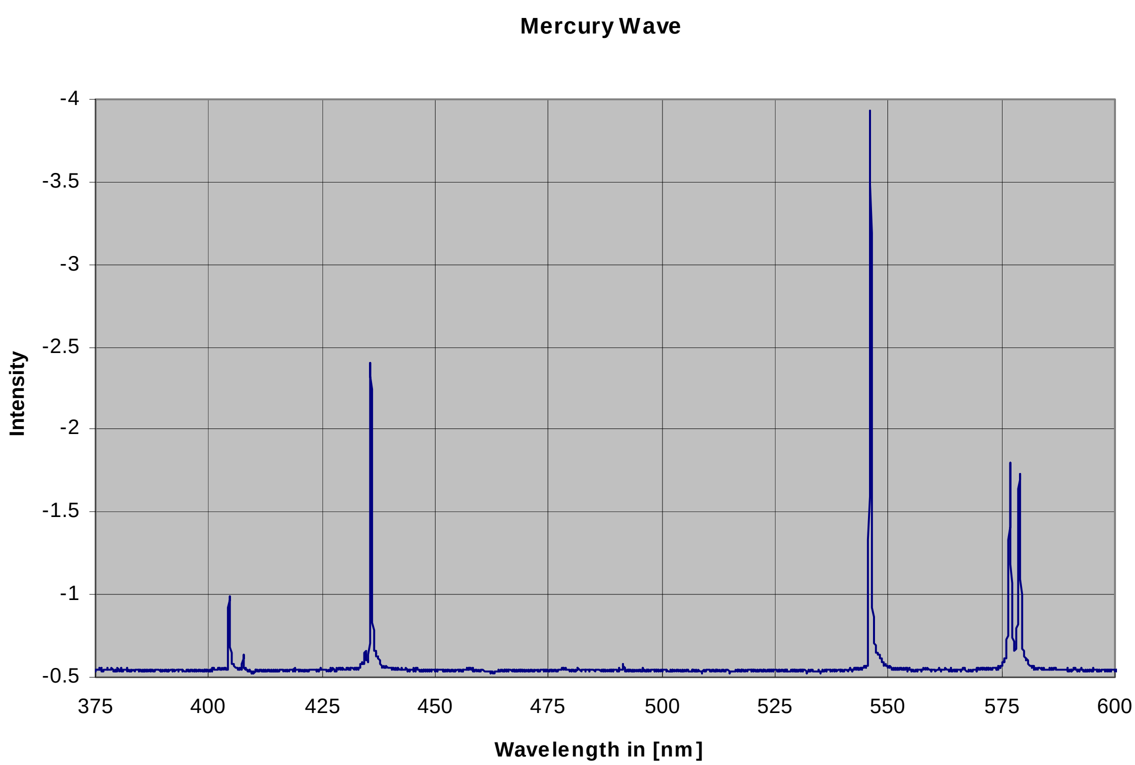
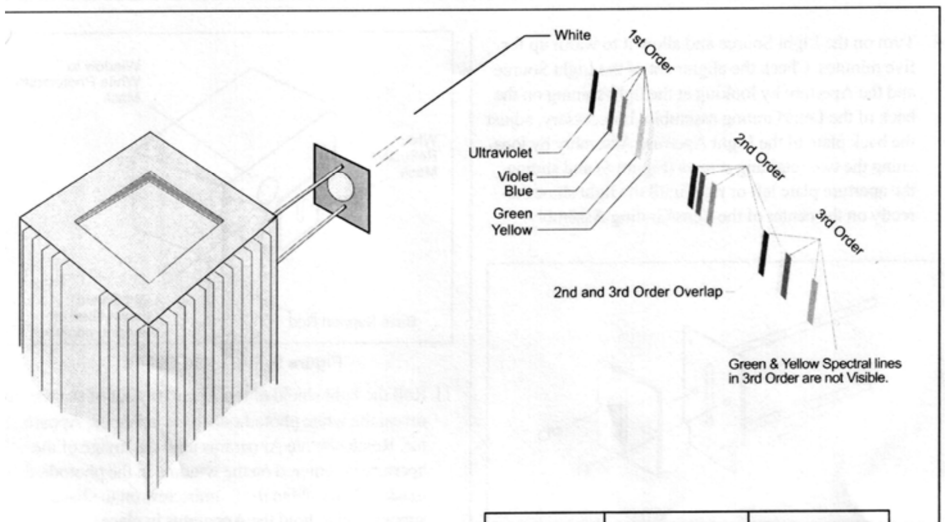


Figure 3 Wavelengths emitted by mercury.



All values except wavelength for yellow line are from *Handbook of Chemistry and Physics, 46th ed.* The wavelength of the yellow was determined experimentally using a 600 line/mm grating.

NOTE: The yellow line is actually a doublet with wavelengths of 578 and 580mm.

Color	Frequency (Hz)	Wavelength (nm)
Yellow	5.18672E+14	578
Green	5.48996E+14	546.074
Blue	6.87858E+14	435.835
Violet	7.40858E+14	404.656
Ultraviolet	8.20264E+14	365.483

Figure 4: Schematic showing the separation of wavelengths.

Procedure and Analysis:

Part I: Determine the stopping potential. (Apparatus 2 which is more like the schematic shown in figure 1.)

A: Experimental Set-up:

1. Connect your apparatus to the computer interface by using Channel A for the Mircoammeter (reading of the photocurrent) and Channel B (voltage at collector) for the Voltmeter.
2. In DataStudio create a graph of Photocurrent vs Collector voltage.
3. Select one of the four filters on the side of the apparatus. These filters select the wavelength of the light from the mercury which will hit the phototube.
4. Illuminate the tube with the high intensity mercury light source. After aligning the light source in front of the tube do not move either the light source or the Planck's Constant Apparatus for the duration of the experiment.
5. The room should be reasonably dark when performing the experiment as extraneous light of a slightly higher frequency than that of the spectral line of mercury under consideration may pass into the phototube and cause error.

B:Aquisition of Data and Representation:

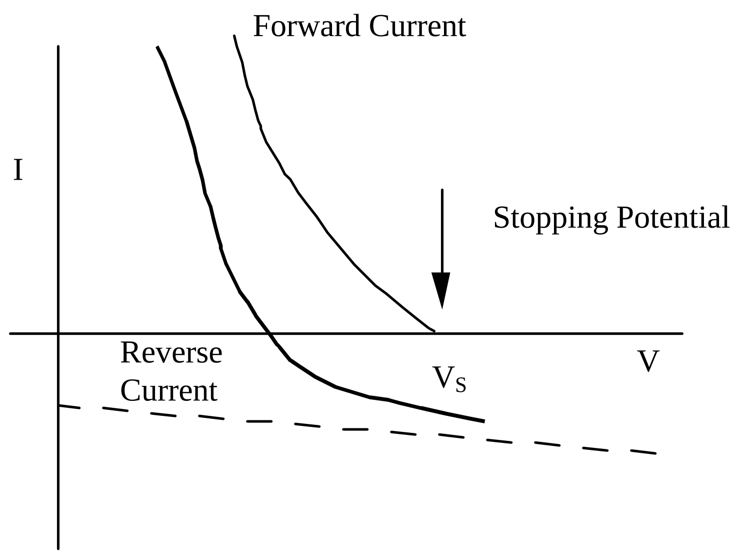
1. Start with the “Volt Adjust” knob at zero
2. Click the start button in DataStudio
3. Slowly turn knob till the photocurrent goes to zero (this is the stopping voltage)
4. Very slowly reverse the reduce the voltage back at the y-axis. Click stop to complete the graph.

5. Repeat for each filter. Identify the stopping voltage (see below) and record data in table 1.
6. Plot a graph of the stopping voltage vs frequency.
7. Determine Planck's constant and the workfunction from your graph.

> **Note:** Two of the filters will be more difficult to get a current reading. The line spectra of the mercury lamp used in the experiment.

Identification of Stopping Voltage:

In order to properly analyze the current-potential curves to obtain the stopping potential, the emission of electrons from the anode must be taken into account. Anode emission probably occurs because of a small amount of photosensitive material deposited on it during construction of the cell. Although the relative number of electrons emitted by the anode is very small, their contribution to the current is appreciable. Thus, the potential required to stop completely the electrons emitted by the cathode is greater than the potential at which the net current is zero. A typical experimental curve is given below (in bold). It can be seen to be composed of two curves: forward current (thin line) and reverse current (dashed line). The forward current is the electron current from cathode to anode, while the reverse current results from anode emission. The stopping potential is estimated as that value of the voltage at which the observed current becomes approximately constant.



In summary, the stopping potential could be a higher voltage than the voltage at which the photocurrent is zero.

When the average value of the stopping potential has been obtained for each frequency, stopping potential should be plotted against frequency. Planck's constant can be determined from the slope of the V-f curve by using the relation

$$h = e(\Delta V)/(\Delta f) \qquad \text{(slope of the line)}$$

The work function ϕ can be determined by the second fit parameter, the y-axis intercept at f = 0.

Part II: Setup in Figure 2

A: Wavelength Dependence of the Kinetic Energy of the Liberated Electron

1. Attach the grating to the mercury lamp and set-up the experiment as shown in Figure 2.
2. You can easily see five colors in the mercury light spectrum (see figure 4). Adjust the apparatus so that only one of the colors is incident on the evacuated cell (Note; use green and yellow filters for corresponding colors. Place the filter using the magnets on the white screen entering the evacuated cell).
3. Connect apparatus to Voltmeter, set to Voltage.
4. Push and release the "push to zero" button. Wait until the voltage stabilizes. This value is equivalent to the stopping voltage. Record the value in Table 2.
5. Repeat this for all five colors of light.
6. Create a plot of Stopping voltage versus light frequency.that will allow. Determine both the work function of the photosenstive material and Planck's constant from the plot. Report your results and calculate the error in your measured value of Planck's constant.

B: "Brightness" Dependence of the Energy of the Liberated Electron

1. Choose one light color and setup the apparatus so that light is incident on the evacuated cell. Now place the attenuator at the same location you placed the filter. If you are using yellow or green light, stack the attenuator and filter.
2. Measure the stopping voltage at different attenuation levels and fill-in table 3.
3. At each attenuation level, discharge the evacuated tube by holding down the "zero" button for 3 minutes.
4. Start time when you release the button and end timing when the voltage reaches a stable value. Record these values in table 3 as well.

Questions:
What does this imply about the intensity dependence of the energy of the electrons?
What does it tell you about the photoelectron current?

Part I:

Table 1: Wavelength Dependence of the Stopping Voltage of the Liberated Electron:

Wavelength(nm)	Frequency(c/λ)	Stopping Voltage
405		
435.8		
546		
577		

Work Function ____________________
Planck's Constant __________________ Per. Error _________________

Part II :

Table 2: Wavelength Dependence of the Stopping Voltage of the Liberated Electron:

Light Color	Wavelength(nm)	Frequency(c/λ)	Stopping Voltage	Max. Electron Energy(eV)
yellow	578.0			
green	546.1			
blue	435.8			
violet	404.7			
ultraviolet	365.5			

Work Function ____________________
Planck's Constant __________________ Per. Error _________________

Table 3: Light-intensity Dependence of the Energy of the Liberated Electron:

Color of line______________________________________
Wavelength______________________________

Attenuation	Stopping Voltage (V)	Time to charge (s)
0%		
20%		
40%		
60%		
80%		