Measuring Planck's Constant Within the Framework of the Photoelectric Effect

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The Roots of the Photoelectric Effect

Origins

- In 1887 Heinrich Hertz discovered the photoelectric effect.
- Motivated by the UV light from sparks of his radio wave generator causing electric current to flow between the electrodes of the generator.

Advancements

- Meanwhile, Philip Leonard concluded that charge-to-mass ratio of emitted charge was identical to the electrons which had already been discovered by J.J. Thomson.
- Albert Einstein later officially linked the idea of quantized emissions with the photoelectric effect

Particle-Wave Duality and the Motivation for Photocurrent

- In 1900, Max Planck proposed crucial idea that matter radiates energy in "packets" or *quanta* of energy given by $h\nu$
- Idea: demonstrate this by having beams of light incident on a metal surface eject electrons
- Remaining kinetic energy of electron after being ejected given by $K = h\nu - \phi$
  - ν is the frequency of incident light,
  - ϕ is the work function of the material; represents binding energy holding electron,
  - h is Planck's constant– our constant of interest.
- An opposing electric field, generated by a retarding voltage, may hinder the photoelectrons. We define a stopping voltage V to be such that the induced electric field stops photocurrent:

$$eV = K = h\nu - \phi = 0$$

where e is the electron charge ($1.6 \cdot 10^{-19}$ Coulombs)

Cutoff Voltages and Detecting Photocurrent

- Solving above equation for stopping voltage gives $V_{\text{stop}} = \frac{h}{e}\nu - \frac{\phi}{e}$
- The above relation relates V_{stop} to incident frequencies.

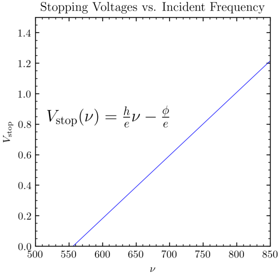


Figure: A sample theoretical plot of stopping voltage over frequencies.

We will investigate this linear relationship with different frequencies and stopping voltages to find an estimate for Planck's constant.

Apparatus

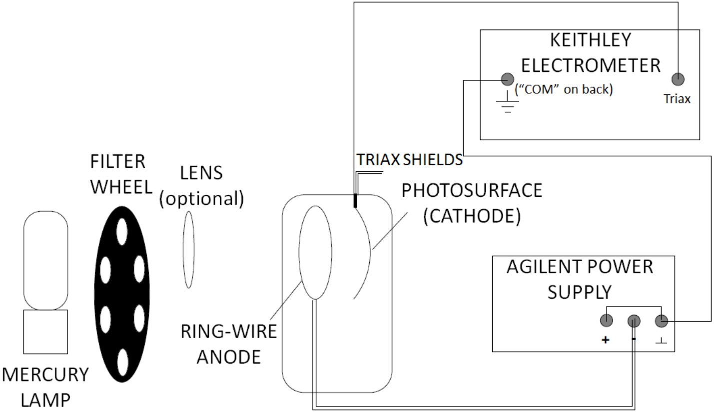


Figure: Signal chain for the photoelectric effect apparatus.

How Photocurrent Varies with Voltage and Filter

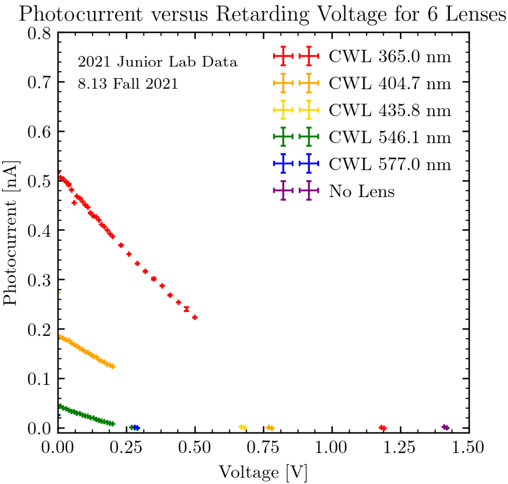
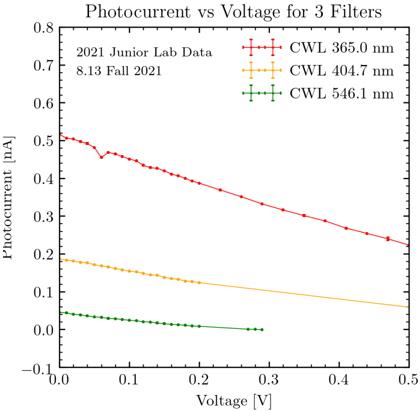
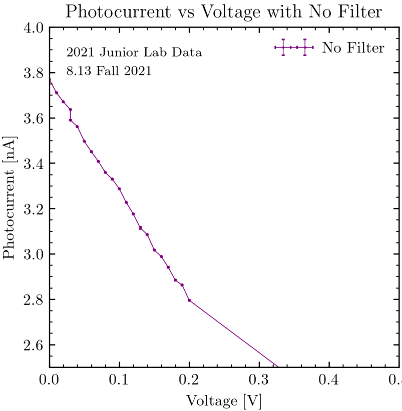


Figure: The photocurrent vs. retarding voltage relation for 6 filters.

Variation of Photocurrent with Retarding Voltage





The left figure displays the photocurrent variation with retarding voltage across 3 different filters with different central wavelengths. The right figure displays the same plot but with no filter.

Stopping Voltage Vs. Incident Frequency

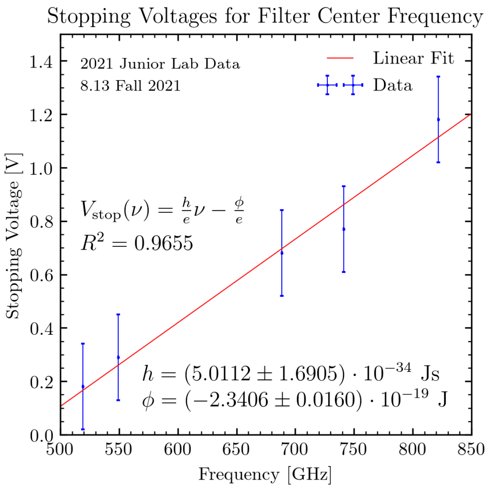


Figure: A linear fit to the V_{stop} vs Frequency data, with stadard error bars.

Results and Interpretation

- For Planck's constant, I find a somewhat imprecise result:

$$h = (5.0112 \pm 1.5302_{sys} \pm 0.1603_{\text{stat}}) \cdot 10^{-34} J \cdot s$$

- Contributors to the systematic error:
  - Missing calibration in the photocell $\rightarrow$ due to inhomogeneities in the metal surface, work function is not uniform. We did not always ensure that the same region was illuminated
  - distance from the mercury lamp to the photodiode was not recorded or kept constant.
- Other sources of error:
  - each frequency (i.e. filter) used, but generally only 1 trial for each. Contributed to higher standard error
  - some fluctuations in the electrometer when measuring photocurrent leads to uncertainty of where they actual V_{stop} is.

Summary and Conclusions

- We calculated Planck's constant *h* to within 24% of the known value
- We could have improved our experimental process by more stricty observing sources of systematic uncertainty; i.e. calibration
- We could also have budgeted our lab time to allow for more repeated data collection
- More broadly, we did oberse an increading stopping voltage with higher incident frequency, meaning that we accurately observed the behavior of the photoelectric effect.
  - the increasing stopping voltage indicates that light waves do indeed behave as particles, in that greater energy is required to eject electrons against stronger retarding voltages