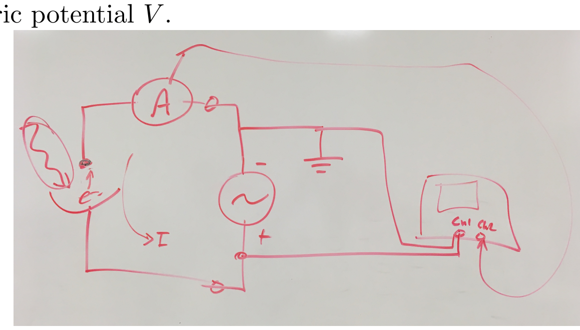
4 Waves as Particles

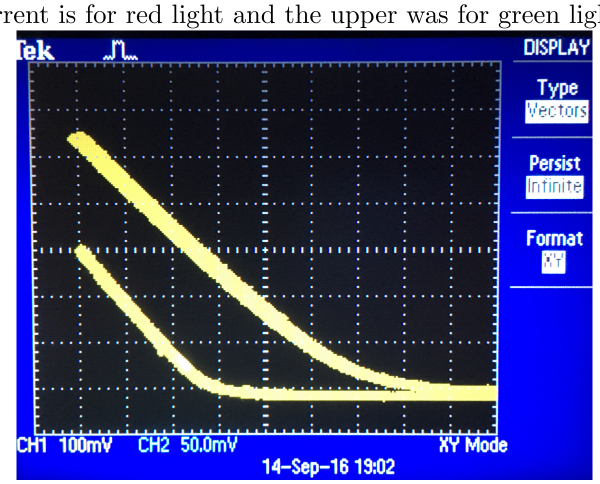
§ 4.1 Photoelectric Effect

Introduction

When photons strike a metal target the photons can knock loose electrons. It is possible to collect these electrons at a separate piece of metal and then return the electrons back to the target through a wire. The current of these electrons flowing through the wire can be measured. If an electric potential is established between the two plates it is found that the amount of current will depend on the strength of the electric potential V.



Below is the current versus voltage for two different colors of light. The lower current is for red light and the upper was for green light.



Theory

Theoretically the photo-current I is predicted to be a function of the stopping potential V, photon energy hf, temperature T, and the chemical potential μ and work function W of the metal target.

$$
\begin{aligned}
I(V) &= \beta kT \int_{W+Ve-hf}^{\infty} \ln\left[1+e^{(\mu-\epsilon)/kT}\right] d\epsilon \\
&= \beta k^2T^2 \int_{x-x_0}^{\infty} \ln\left[1+e^{-u}\right] du \qquad \text{with } u=(\epsilon-\mu)/kT \\
&= \beta k^2T^2 \frac{1}{6}\left[\pi^2+3(x-x_0)^2+6\ \mathrm{Li}_2(-e^{x-x_0})\right] \\
&= \eta\left[\pi^2+3(x-x_0)^2+6\ \mathrm{Li}_2(-e^{x-x_0})\right] \equiv \eta F(x-x_0)
\end{aligned}
$$

where β is a proportionality constants, k is the Boltzmann constant, $-e$ is the charge of an electron, $\eta = \frac{\beta k^2 T^2}{6}$, $x = \frac{eV}{kT}$, $x_0 = \frac{eV}{kT}$, $V_0 = \frac{W-\mu-hf}{e}$, and $\mathrm{Li}_s(z) = \sum_{n=1}^{\infty} \frac{z^n}{n^s}$. We can fit the measured current versus voltage by the theoretical curve

$$I = \eta\ F\left[\frac{e}{kT}(V-V_0)\right]$$

by trying different values of η and V_0 until we find the combination that minimizes the difference between the theoretical and the measured values. In this way we can estimate V_0 for any given light source. We do this for various sources with different frequencies. If we then graph V_0 versus the frequency we expect a straight line with a slope of $-\frac{h}{e}$ and thus we can determine the value of h.

§ 4.2 Photon Counting

Light arrives in packets.