The Photoelectric Effect

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1 Results

Cathode electrons are ejected by incident monochromatic light and travel under the influence of a laboratory controlled electric field, with kinetic energy determined by the difference between the photon energy and their previous electronic binding energy. When the electric field points towards the cathode, freed electrons are drawn towards the anode, resulting in a positive current as measured by our circuit.

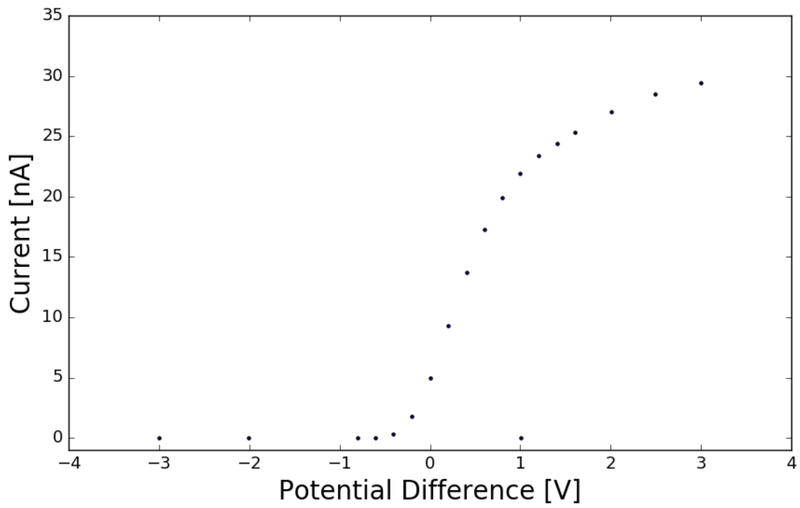

Figure 1: Current-Voltage plot for the potential difference across the cathode-anode gap.

We verified this behavior in our apparatus, as seen in Figure 1, and we see that when the anode plate acts as an electron repellent, there is no current. Also note that there was no current when the light source was off. As the potential difference is increased past zero, more of the stray trajectory ejected electrons succumb to the electric force and are pulled in as contributions to the current until a plateau begins to form for high voltage, when none of the airborne electrons escape.

Some of the electrons will carry their full energy directly towards the collecting plate, which is the reason for the approximately 2 nA signal when $\Delta V = 0$. Thus there exists a least negative potential difference, termed the stopping voltage V_S, required to deflect all incoming electrons, and to determine the stopping voltage is to measure the maximum kinetic energy of the ejected electrons.

Table 1: Stopping voltage required for increasing values of the photocurrent, which were achieved by increasing the intensity of light on the cathode.

$V_S[V]$	Photocurrent [nA]
0.742	5.06
0.786	6.11
0.744	4.04
0.736	3.12
0.751	7.08

In Table 1, we show our measurements of the stopping voltage for various intensities of incident monochromatic light. Where we consider the intensity in terms of the photocurrent when $V = 0$, because as the intensity increases, so does the photon density, and there are more photons to eject electrons, each contributing additively to the photo current. By averaging these values, and using the standard deviation of the mean as an uncertainty estimate, We find a stopping voltage $V_S = 0.752 \pm 0.011$ V, and is independent of the incoming light intensity. This is evidence that the ejection process is a particle interaction that behaves independent to the rate that energy is dumped onto the surface, which is evidence for Einstein's proposed light quanta because these electrons appear to absorb a common unit of energy in the ejection process regardless of the incoming energy density.

2 Analysis

If we consider the electron as being a bound state, with energy minus ϕ, where ϕ is called the binding energy and is a material property for the amount of energy required to eject an outer electron, then the stopping potential at which photocurrent is zero is

$$U_S = qV_S = hf - \phi \tag{1}$$

where q is the electron charge, h is Planck's constant, and f is the incoming light frequency [1]. Equation 1 is a linear relation of V_S, h, λ, ϕ, thus by using the accepted value $q = 1.6 \times 10^{-9}$ C we can perform a linear least squares fit with our measurements of f and V_S to determine f and ϕ, which we shown in Figure 2. From this we determine the value $h = (6.9 \pm 0.1) \times 10^{-34}$ Js, where we have thrown out a stray data point for the $\lambda = 578$ nm line, as indicated in red, because this line is an unresolved blend of wavelengths 577 nm and 579 nm, which we believe determines an unreliable measurement. This measurement of h is within three standard deviations of the accepted value, $h = 6.626 \times 10^{-34}$ Js. Additionally, we found the work function $\phi = 1.64 \pm 0.05$ eV, which is reasonable for a conductive metal, Aluminum's being 4.08 eV, and Copper's being 4.7 eV. This choice of low work function metal allows our experiment to function with a lower energy light source.

A threshold frequency occurs when the electrons are imparted with just enough energy to be ejected but do not receive any kinetic energy, below this point electrons are not ejected at all, in this case, $f_{thresh} = \phi/h = (3.80 \pm 0.13) \times 10^{14}$ Hz, corresponding to a wavelength of 790 ± 30 nm, which is in the low energy range of visible light.

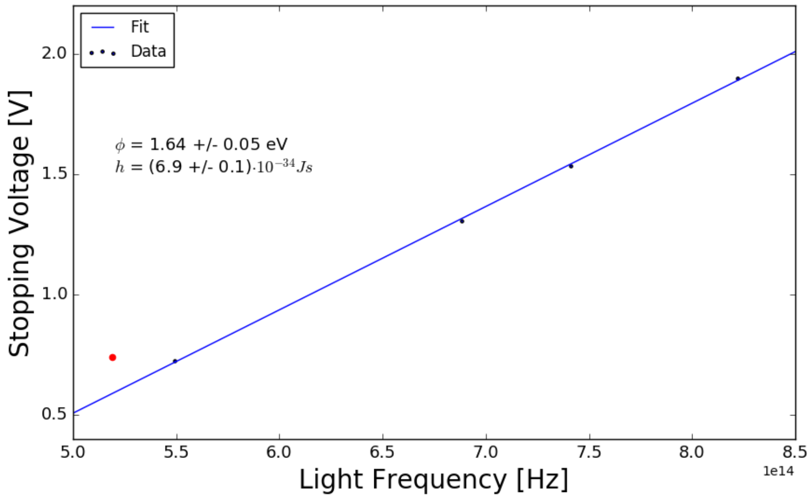

Figure 2: Linear least squares fit results for determining the work function and Planck's constant.

3 Conclusion

We have demonstrated that incident light on a metal can impart enough energy on the surface electrons to eject them from their bound state, and we can measure the presence of the ejected electrons by capturing them with an anode and measuring the resultant current. As evidence for Einstein's proposed theory of light quanta, we have found that the stopping voltage of this setup is independent of the incident light intensity. That is, an increase in incident energy density does not impart more energy to the freed electrons, they absorb a common and fixed amount of energy in each ejection. Furthermore, the amount of absorbed energy increases linearly with the frequency of incident light, which suggests that metallic bound electrons are absorbing the energy of light quanta, where the energy of the light quanta is proportional, by Planck's constant, to its frequency. The electrons then carry kinetic energy equal to the energy of the incoming radiation minus their binding energy, which we find, for our material, to be $\phi = 1.64 \pm 0.05$ eV. Further evidence for Einstein's theory may be obtained by varying the light frequency until a threshold is reached where electrons are no longer ejected. From our measurements, we found the threshold wavelength to be 790 ± 30 nm, where for any wavelengths greater than this threshold value, the bound electrons can not absorb enough energy to escape.

References

[1] Randy Harris. *Modern Physics*. Pearson, 1998.