On the Photoelectric Effect and the Work Function of Zinc

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Abstract

The photoelectric effect was first observed by Hertz in 1887. However, the phenomenon was not fully explained until 1905 by Albert Einstein in his paper titled, "On a Heuristic Point of View Concerning the Production and Transportation of Light." The work was significant because it correctly explained the effect observed by Hertz using the same assumption used by Planck in his explanation of black–body radiation. Namely, that light travels in discrete packets later deemed "quanta" as opposed to a continuous wave. Over the years, the theory's validity has been confirmed numerous times, paving the foundations for many modern technologies such as photovoltaic cells. In this poster, we conduct one such experiment designed to assess the theory's validity further. The main apparatus in our setup includes an electroscope modified to have a Zinc surface, a high–intensity UV (280 – 315 nm) light source, and aluminum leaves. The objective of the experiment was to confirm the release of photo-electrons by the charged leaves upon the Zinc surface being shone by electromagnetic radiation in the UV spectrum. The distance by which the aluminum leaves approached each other is directly related to the number of photo-electrons released.

Introduction

Prior to Einstein's theory of the photoelectric effect, it was believed that a relationship existed between the intensity of light interacting with a metal and the number of photoelectrons released. Through experimentation, however, it was shown that frequency and not intensity was the important quantity. In other words, if a beam of light is shone in a metal with a certain work function that is not overcome by the frequency of the light, regardless of the intensity of the beam, the photoelectrons will not be released. This criterion is shown in the following equation:

$$KE = hf - \alpha$$

where *KE* is the kinetic energy of the photoelectron, *hf* the energy of the incoming photon, and α the work function of the material. From the equation we again deduce that if $hf < \alpha$, the electron will not be released from the metal. Besides this finding, Einstein's theory of the photoelectric effect was notable because it helped pave the way for the wave – particle duality interpretation of light and prompted further development in the field of wave – mechanics.

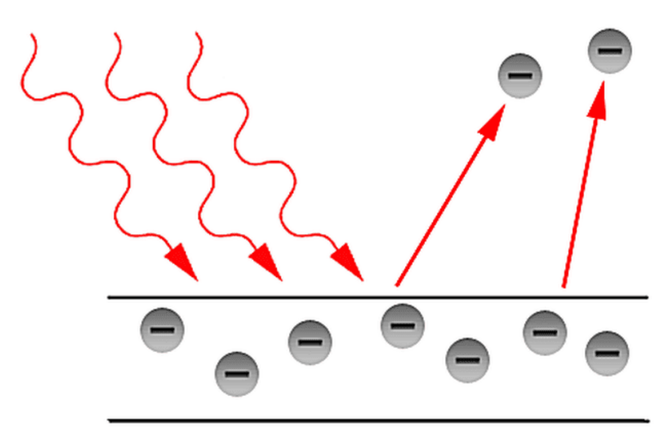

Figure 1. The photoelectric effect

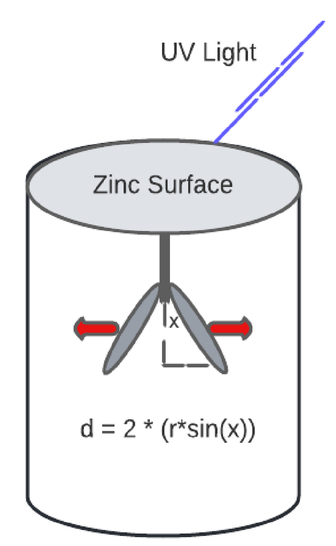

Figure 2. Experimental setup

In this experiment, we replicated the description introduced previously using an electroscope as the main apparatus to achieve this.

Methods and Materials

Using the materials pictured in 1), an electroscope was built. The materials in 1) include aluminum foil, scotch tape, a mason jar, zinc, and a UV light source. Not depicted but used include a balloon used during the experimentation to polarize the aluminum leaves depicted in 2) and 3) within the electroscope. Once the leaves were polarized, the light source was shone above the zinc surface to release the photoelectrons in the latter material. This decrease in charge was manifested in a decreased separation distance between the leaves relative to the distance between them before the UV light source was shone above the electroscope. Once this apparatus was constructed, the corresponding measurements could be done. For this experiment, the measurement recorded was the change in separation distance. To improve the accuracy of our measurements, the setup shown in 4) was used.

Results

Trial	Before	After
1	6.2	0.89
2	6.2	0.29
3	6.2	0.89
4	8.2	0
5	7.4	0.59
6	7.1	0.59
7	5.9	0.89
8	7.1	0.3
9	6.8	0.3
10	7.6	0
Average	6.87	0.474

Figure 3. Recorded data in mm.

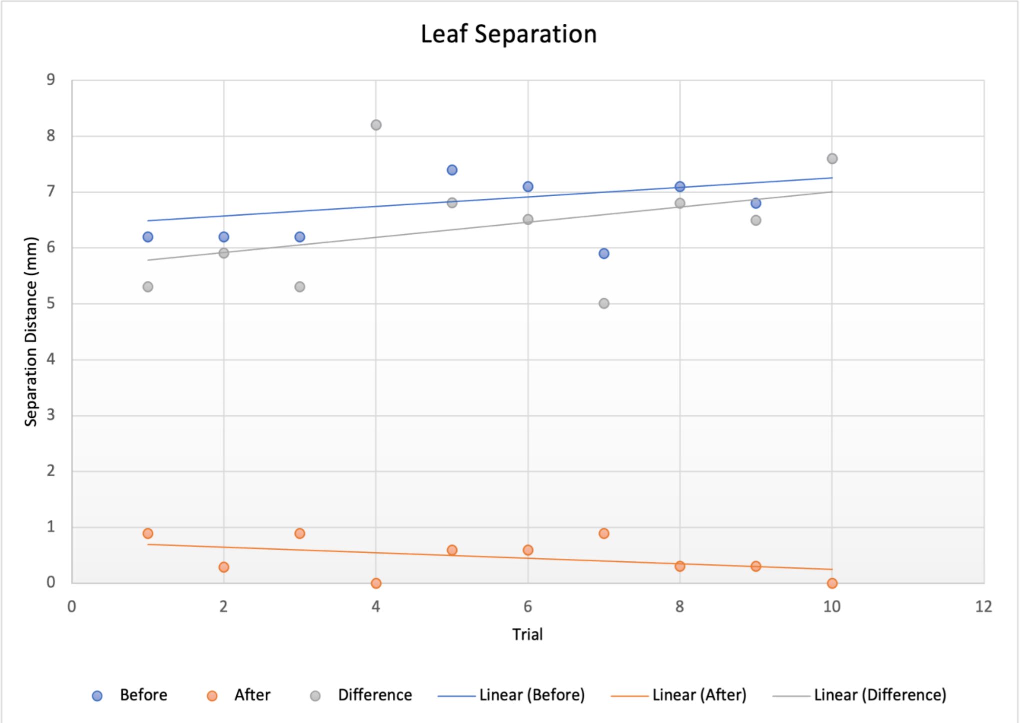

Figure 4. Leaf separation during 10 trials. Before represents the distance before the light was shone in the zinc surface, after represents after the event.

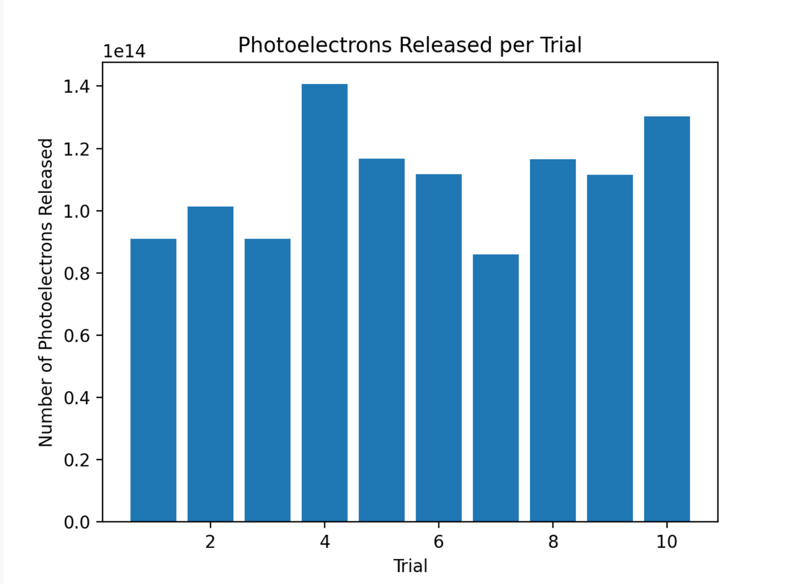

Figure 5. Number of photoelectrons released during each trial.

How was the number of photoelectrons released calculated?

In order to do this, a few assumptions were made. Namely, that the potential difference induced to polarize the setup corresponds to the literature value of voltage generated by rubbing a balloon against hair which is approximately *25, 000* volts. Besides this, we used the following formulas to obtain the charge:

$$W = Fr = e\Delta V$$

$$\frac{ke^2}{r} = e\Delta V$$

$$e = \frac{r\,\Delta V}{k}$$

$$number\ photoelectrons = \frac{e}{charge\ per\ electron}$$

where *r* represents the change in separation, ΔV the potential induced by the balloon, and *k* the coulomb constant.

Discussion

The experiment's goal was to confirm the photoelectric effect and determine the amount of released photoelectrons.

When first experimenting, we were unknowledgeable of zinc's oxide layer, which increased the work function because it decreased the material's conductivity. This led to no change in leaf separation due to the lack of a high enough frequency UV light. After further research, we were able to remove the layer by sanding the surface of the zinc with sandpaper.

Further, we expected the separation of the aluminum leaves before and after to be more consistent and precise. In retrospect, to make the experiment more precise, we could have implemented a grounding technique to prevent excess charge from a previous trial from interfering. Also, a uniform technique to charge the balloon with the same charge each trial; as for our experiment, we charged the balloon by rubbing it on our hair. Redoing the experiment with a variable frequency and intensity would render more informative results.

Conclusions

The experiment presented here confirmed the validity of the photoelectric effect. It was shown that a direct relationship exists between the number of photoelectrons released and the distance of closest approach displayed by the aluminum leaves upon the Zinc surface being shone with electromagnetic radiation in the UV range. Two different attempts were made to demonstrate the effect successfully. The first attempt failed due to having a light source with insufficient frequency to successfully overcome the work function of the Zinc surface employed (4.33 eV). We replaced the light source on the second attempt, and thus, more positive results were obtained. This simple yet interesting experiment further confirms the validity of a theory proposed over 100 years ago that is noted for the introduction of a discrete nature to light.

References

1. Einstein, A. (1905) Concerning an Heuristic Point of View toward the Emission and Transformation of Light. Annalen der Physik, 17, 132-148.
2. File: Photoelectric effect.png. (2021, December 8). *Wikimedia Commons, the free media repository*.
3. Krane, K. S. (2019). *Modern Physics* (4th ed.). Wiley.