

An Undergraduate Physics Experiment—The Photoelectric Effect

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Abstract:

In this paper we will be verifying the photoelectric effect experimentally. Theory states a particle such as an electron can exist as a particle or as a wave. A simple apparatus consisting of light-emitting diodes (LEDs) and a photo-multiplier will be used to measure the quantized value where electrons are converted to photoelectrons. As part of an undergraduate physics lab assignment, we intend to set up an apparatus to test this theory.

I. INTRODUCTION

The photoelectric effect, discovered by Hertz in 1887, confirmed Maxwell's electromagnetic theory of light. The photoelectric effect describes the way in which electrons can be emitted by materials. It also describes the state of the electron as being either a particle or a wave. Quantum theory suggests that electrons can serve as particles in matter and propagate as waves (Thornton and Rex, 2002). As part of an undergraduate physics project, an experiment will allow us insights into the dualistic nature of the electrons. We hope that we can accomplish this successfully with verifiable results.

There are some necessary assumptions regarding the experiment. First, the LEDs are enclosed in a cylindrical apparatus with the photo-multiplier. This cylinder can be opened and closed at any time; the transmission length of the emitted light will be in air and not in a vacuum. Second, the apparatus does not have the needed sensitivity to allow a measurement of energy lost in electron interactions. Third, the equipment used to gather data for the experiment (a multi-meter, a power supply) do not possess a great accuracy. This implies a large degree of error in the data. This data will not be used to try to prove any particular theory, but instead will serve to illuminate us to the more subtle theories in Modern Physics.

II. DESCRIPTION OF EXPERIMENT

In our experiment we intend to demonstrate:

- i. The saturation current depends on intensity.

- ii. V_0 depends on frequency.
- iii. V_0 related to h by quantum mechanics.
- iv. V_0 is independent of intensity.

The apparatus consists of a set of light emitting diodes (LEDs) mounted facing a photo-multiplier tube inside a plastic cylinder. A power supply is used to power the LED's and to provide an accelerating and retarding voltage in the photo-multiplier. All signals are DC and measured by digital multi-meters. The input signal, measured by the first meter, passes through the photo-multiplier tube and a pre-amplifier where it is measured by a second multi-meter. All signals are measured in volts. Measuring voltage instead of current is valid in terms of this experiment because the circuit has a constant impedance. An illustration of the apparatus appears in diagram 1.

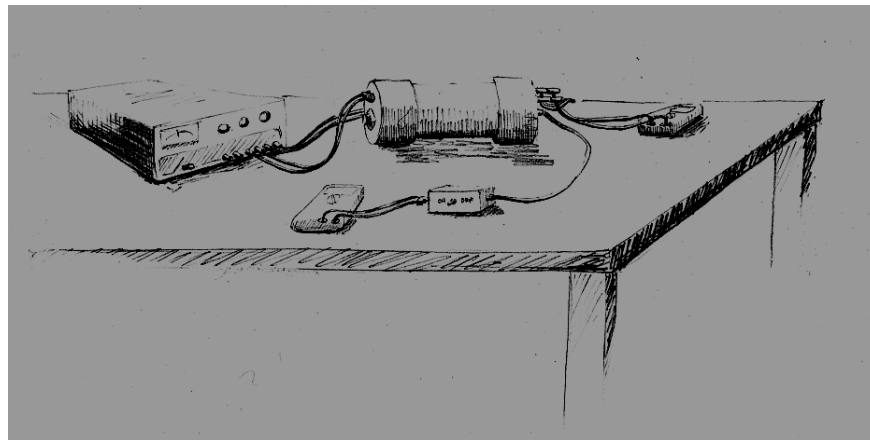


Diagram 1: Experimental setup.

III. RESULTS

Our first objective is to show the saturation current depends on light intensity (i). We set the intensity to a value of 5 volts and measured the signal as a function of retarding voltage. The first measurement was taken with the retarding voltage set at zero and was gradually increased until the output signal ceased. When the output signal ceased it showed that the propagation of photoelectrons had ceased in the photo-multiplier tube. We called this saturation. We changed the light intensity to 7.5 and 10 volts and repeated the measurement. The data from this gave us the information necessary to show that the quantity V_0 is independent of intensity.

To show that V_0 depends on frequency, we used a similar method to track the correlation between retarding voltage and current, but used only one light intensity throughout. We ran three trials using light of three different wavelengths. From the determined values of V_0 we were able to demonstrate that V_0 relates to V by some constant h .

To show that the saturation current produced in the photoelectric effect is dependent on the intensity of incoming light we collected data points, which compared the retarding voltage to the output voltage for yellow light at three different intensities. These points were then graphed in Figure 1 showing that as we increased the intensity or voltage supplied to the LED's, the point of saturation also increased. From Figure 1 we were able to see that for yellow light at an intensity of 5V, V_{out} saturated at about .01V. At an intensity of 7.5V, V_{out} saturated at .089V. At an intensity of 10V, V_{out} saturated at .1V. Figure 1 shows that at a certain retarding voltage the output voltage goes to a constant voltage independent of light intensity. For yellow light at 5V, 7.5V, and 10V V_{out} goes to .513V.

A second set of data was taken at three different wavelengths relating the retarding voltage to the output voltage with a constant intensity of 7.5V. This data is graphed in Figure 2. Figure 2 shows that each color of light has a different retarding voltage where the output voltage becomes constant. For green light—.55V, yellow—.45V, and orange—.35V. We concluded that for a smaller wavelength of incident light, a larger quantity V_0 was required to stop V_{out} .

Figure 3 shows the relation between the frequency of incoming light to the stopping voltage V_0 —the slope of which gives the quantum mechanical constant h . Using *xmgr* in Linux we created a linear fit of the data points and found the slope h , which turned out to be equal to $.366 \text{ V}\cdot\text{s} / 10^{14}$. In SI units the quantity is $6.0 \times 10^{-43} \text{ J}\cdot\text{s}$.

IV. CONCLUSION

This experiment served to illustrate the concept of the photoelectric effect for which Einstein won the Nobel Prize in 1921. It also taught us how fundamental constants in physics are quantized values. Our experiment agreed with theory; error was calculated at 10%. Most of the error was in the meters and in the analog display of output voltage from the power supply. These errors are systematic in the experimental apparatus. Improvements in this process would have to include more instruction at the beginning of the assignment such as the idea of how the experiment was to be performed. It would have streamlined the work substantially.

V. REFERENCES

Thornton, S. T., & Rex, A. (Eds.). (2002). *Modern Physics for Scientists and Engineers*.
Victoria, Australia: Brooks/Cole Publishing.