Lab II: The Photoelectric Effect

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Abstract:

To gain an experimental understanding of how light behaves as a particle, we investigate the work function of mercury to Planck's constant using the photoelectric effect. Our results yield an experimental derivation of Planck's constant.

Introduction:

The classical wave model for light predicted that the energy of the emitted electrons would increase as the light's brightness increase. However, in 1902, Phillip Lenard found in an experiment that the intensity of light did not affect the energy of emitted electrons. Instead, it was the frequency of light that determined the change of energy of the electrons. He also found that a certain voltage, the emitted electrons would not reach the collector. These findings led to the development of the Photoelectric Effect model.

In 1905, the photoelectric effect model was developed by Albert Einstein. He used Max Planck's theory of quantized light to develop a mathematical explanation to Planck's findings. Planck's theory expressed the energy of a 'photon' of light to be determined by a constant multiplied by the frequency of light. In other words, $E=hv$, where v is the frequency and h is the constant that is now known as Planck's constant. Assuming that light is quantized, Einstein concluded that the photon's energy could be absorbed by an electron upon impact. The absorbed energy would cause the electron to move toward the surface. If the electron were close enough to the surface, it would be emitted with kinetic energy toward the detector. Using conservation of energy, Einstein determined that the photon's total energy must be equal to a minimum amount of energy absorbed by the photon in order for it to leave the material, W_0 or Work Function, and a maximum kinetic energy, KE_{max}. The resulting equation for the photoelectric effect was $E_{photon} = hv = KE_{max} + W_0$. This led to an experimental method for deriving Planck's constant.

Shortly after Einstein, experimentalists derived work functions for materials. When the work function of a material is known, Planck's constant can be found once data on the stopping potential is found at a range of frequencies. When we algebraically modify the equation for Planck's constant, we find that $h = (KE_{max} – W_0)/v$.

In this experiment, we investigate the relationship of the work function of Mercury to Planck's constant using the photoelectric effect. The experiment gave us a visual example of how the classical wave model cannot explain the particle nature of light.

Methods:

To set up the photoelectric apparatus, we placed the equipment as shown in Figure 1. The PASCO Photoelectric Effect Apparatus, Model No. AP-8209, consists of an enclosed mercury light enclosure (2) and a photodiode enclosure (3) facing each other when attached to a base (4). The two enclosures are attached to a power supply (5) and the Photoelectric Effect Measuring Apparatus (6). The measuring apparatus for then photoelectric effect, Figure 2, contains a series of switches that we used to change the parameters of our experiment.

Figure 1: Photoelectric Effect Equipment

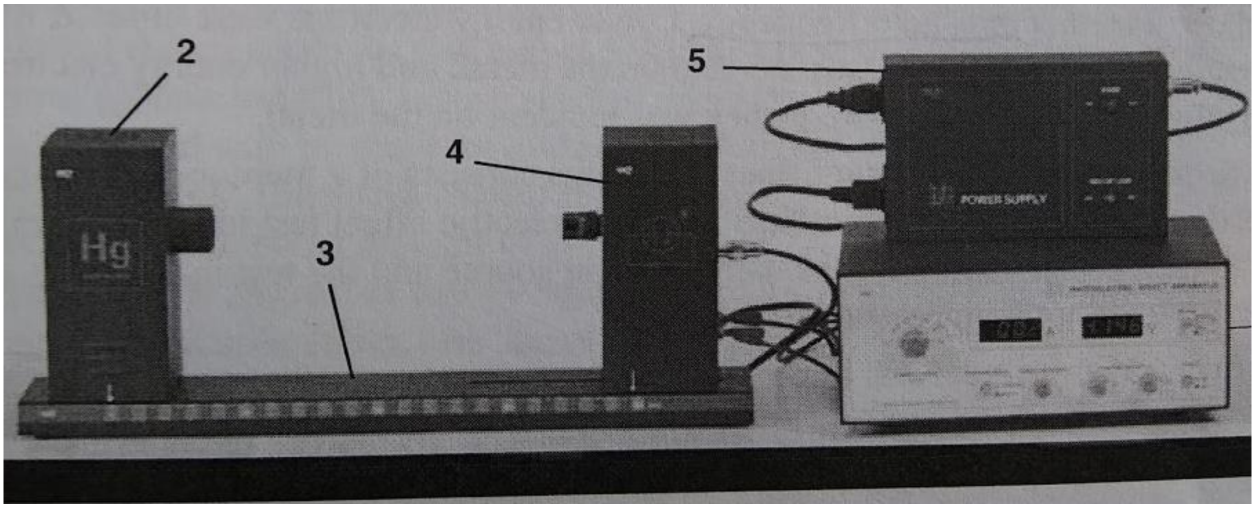
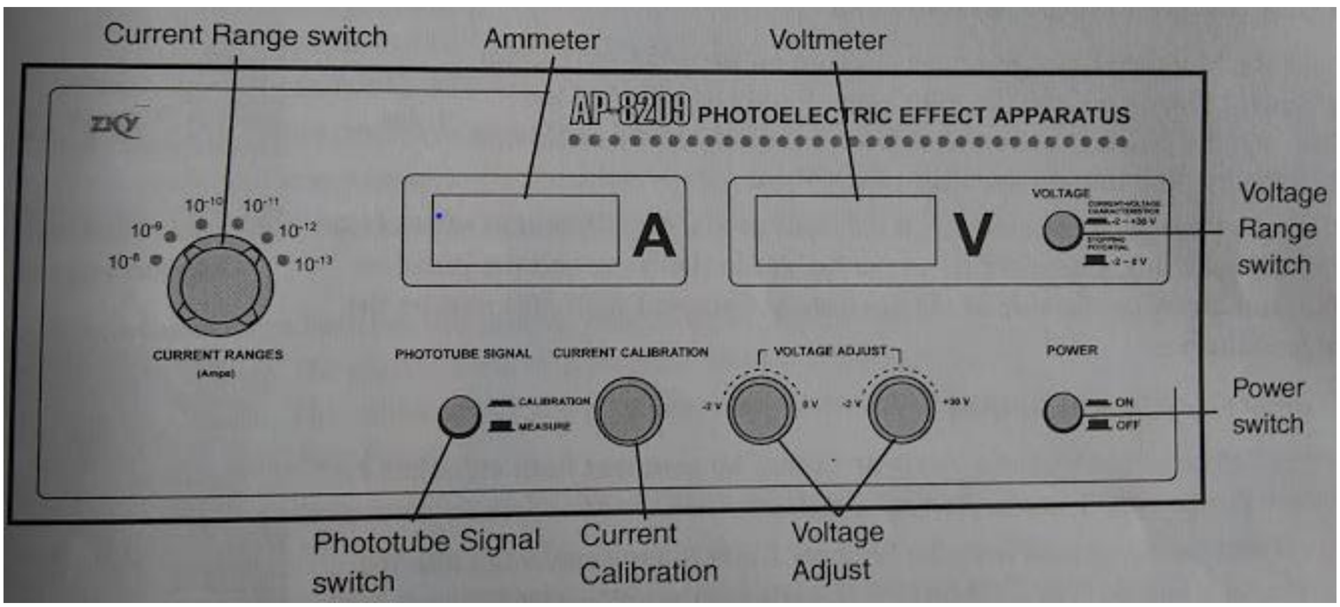


Figure 2: Photoelectric Effect Measuring Apparatus Diagram



To prepare the equipment for experiment, we first covered the window of the Mercury light enclosure and placed a photodiode cap on the opening of the photodiode enclosure. Next, we turned on the power supply for the photoelectric apparatus. We also turned on the mercury lamp and waited 20 minutes for it to warm up. After the lamp was warm, we set the voltage range switch on the measuring apparatus to **V** and the current range switch to 10^{-13}. We then set the ground amplifier to zero by disconnecting the ‘A’, ‘K’, and ‘GROUND’ cables from the apparatus's back panel. Then we pressed the phototube signal button in to calibration, adjusted the current calibration knob until the current was zero, and switched the phototube signal button to measure. Once this was done, we reconnected the cables to the apparatus's back panel.

To take measurements, we uncovered the window of the Photodiode enclosure and replaced it with a 4mm diameter aperture and a 365 nm filter. Then we uncovered the Mercury light. Next, we set the voltage adjust knob until the current was zero on the ammeter. We then recorded the magnitude of the stopping potential and covered the Mercury lamp. We repeated this procedure with the 4mm diameter aperture to find the stopping potentials for 405 nm, 436 nm, 546 nm, and 577 nm filters. Then we did a second round of data collection so we could reduce the amount of random error in our results.

We next attempted to repeat the procedure for the 4mm diameter aperture on the 2mm and 8 mm diameter apertures. However, we found that our equipment gave inconsistence data readings 8mm aperture. This resulted in us discarding the data and moving on to finding Planck's constant using the data from the two 4 mm diameter trials and 2mm diameter trials.

To derive Planck's constant from our data, we first plotted a graph of the Stopping Potential against the Frequency of light. We found the frequency of light by dividing the speed of light by the wavelength of the filter. Next, we used Microsoft Excel to find a line of best fit on the graph. Once we had that value, we multiplied it by the charge of an electron (1.602 x 10-19 C). The calculated value we then compared to the accepted value of Planck 's constant (6.626 x 10^{-34} Js).

Results:

Table 1: Experiment Data

Aperture Size	Wavelength (nm)	Frequency (10^14 Hz)	Stopping Potential (V) Trial 1	Stopping Potential (V), Trial 2
4mm	365	8.214	-1.1	-1.235
4mm	404.7	7.408	-0.999	-1.02
4mm	435.8	6.079	-0.895	-0.888
4mm	546.1	5.49	-0.591	-0.592
4mm	577	5.196	-0.614	-0.615
2mm	365	8.214	-2	-1.575
2mm	404.7	7.408	-1.945	-1.225
2mm	435.8	6.079	-1.695	-0.942
2mm	546.1	5.49	-0.601	-0.58
2mm	577	5.196	-0.6	-0.599
8mm	365	8.214	8.214	-1.999
8mm	404.7	7.408	7.408	-1.78
8mm	435.8	6.079	6.879	-1.74
8mm	546.1	5.49	5.49	*data varied too much to continue
8mm	577	5.196	5.196	

Figure 1: Graph of Stopping Potentials and Frequencies

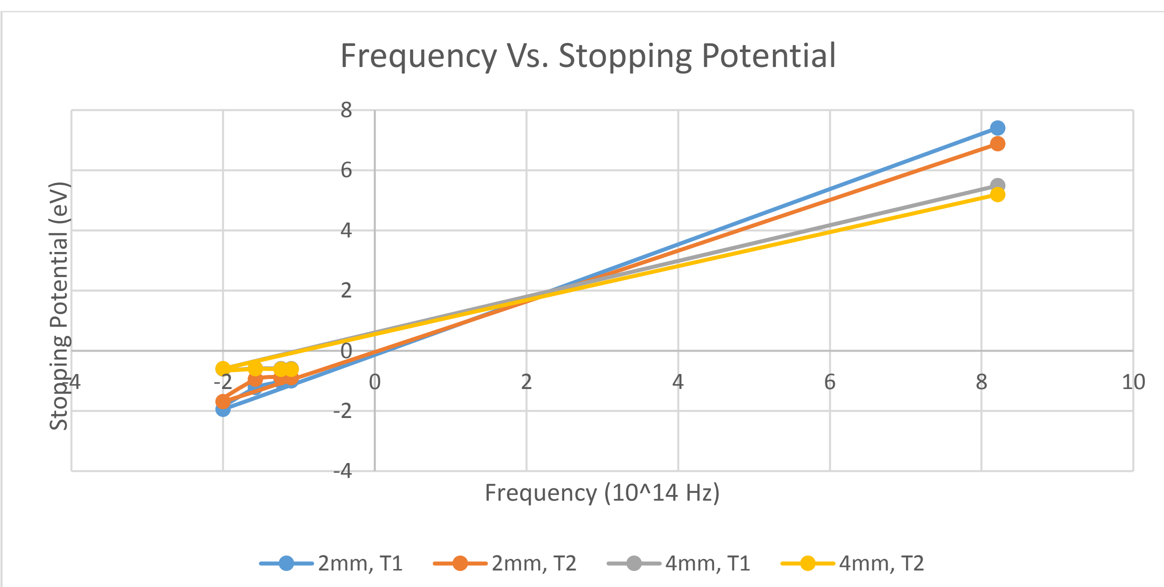


Table 2: Comparison of results to accepted values

Aperature Size, Trial	Slope (10^-15 V/Hz)	h exp (10^-34 Js)	% Difference to h_0
4mm, 1	5.643340858	9.040632	36.44177483
4mm, 2	4.725897921	7.570888	14.26030788
2mm, 1	1.87726445	3.007378	-54.61246604
2mm, 2	3.07314075	4.923171	-25.69920012

Discussion:

Our results differ from the accepted value by over 14 percent in all cases. There are multiple reasons this could be. First, the changes in voltage we are measuring are very small. It could be that we did non calculate over a large enough amount of frequencies for this to be the case. Second, the accepted value of Planck's constant was measured over multiple materials. We were limited to using only Mercury. Finally, we may have calibrated our equipment incorrectly, resulting in false readings for our stopping potentials.

References:

1. Handout

2. Taylor- Photoelectric Effect

3. Equipment Manual

4. Modern Physics Textbook

5. Microsoft Excel for Data

Acknowledgements:

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