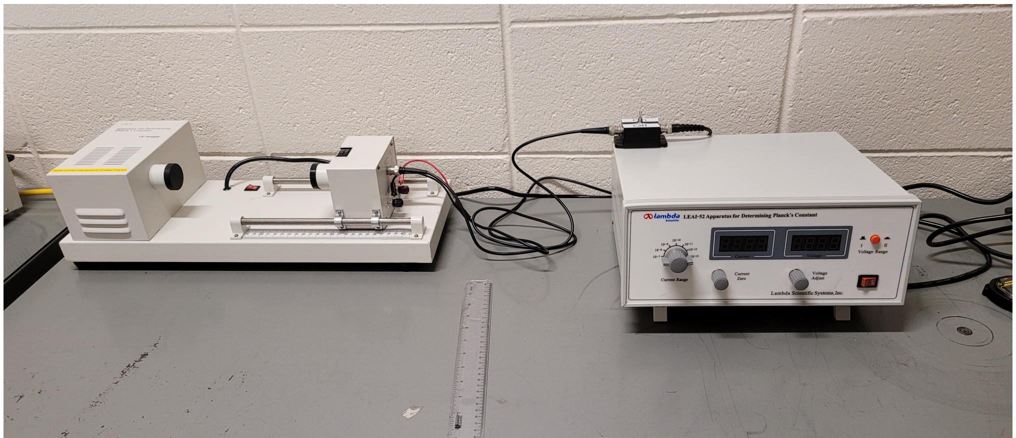
PHYS 2150
#5: Photoelectric Effect

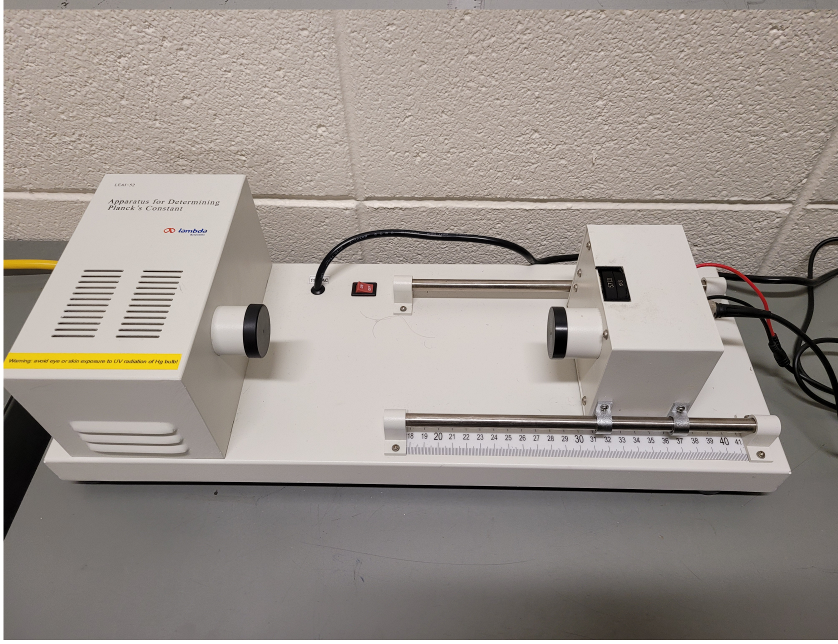
Cassidy Bliss &
Lab Partner: Sean Gopalakrishnan

Abstract/Introduction

In this lab, we use a device that allows us to collect data on the photoelectric effect, first discovered by Heinrich Hertz in 1897. A current can be created under the right circumstances (with voltage, anode and cathode) when light hits a metal surface, by knocking electrons off of the metal. The dark current of the photo-tube measured in part 1 is obtained by covering the apertures of the light source and photo-tube and then varying voltage to quantify what current exists without other variables, and therefore allowing for calibration of the photoelectric device. It was found in the analysis of part 1 that the dark current is very low, and very consistent beyond zero volts, and therefore negligible to our further experiments. The determination of an experimental Plank's constant was derived in part 2 through collecting data under circumstances where the voltage was recorded when the current to go to zero, therefore giving us the "stopping voltage", and was repeated for varying wavelength filters. Our experimental value for h (Plank's constant) was well within a factor of the accepted value, with an error of about 3.3 %. In part 3, we were able to obtain characteristics of the photo-tube system itself by examining the experimental current~voltage curve, where we found that the curve did not flatten as quickly as expected. This could suggest that the resistance in the system is not ideally as consistent as we would hope and could cause some minor problems in our data. In part 4, we experimentally found the relationship between aperture size and photo-current by choosing an appropriate constant voltage. The outcome of the analysis for part 4 was consistent with the way we understand flux, and confirmed that the more light that is able to get into the photo-tube will generate a higher photo-current. In part 5, our objective was to confirm the Inverse-Square Law by varying the distance of the photo-tube to the light source and keeping voltage, etc. constant. The outcome of the analysis of part 5 was indeed conclusive with a linear relationship between photo-current and 1/ distance^2 as well as a correlation coefficient of almost exactly 1.

Apparatus:





Above, on the left, we have a picture of the photoelectric device and readout unit, on the right we have a closer view of the photoelectric device, with the mercury lamp on the left and the photo-tube on the right.

How it works:

The photoelectric device has two main components, as shown above. The first is a mercury lamp which emits the light. The photo-tube is the second main component, as seen on the adjustable rail system in the box. The light emitted from the mercury lamp is received by the photo-tube. The readout unit, as seen in the figure above on the left, is what reads the photo-current generated by the photoelectric effect. On the readout unit, you can also control the voltage/potential between the anode and cathode within the photo-tube unit.

Within the photo-tube itself, there is a metal plate, an anode and cathode. When there is potential between the anode and the cathode, as electrons (energized by the incident light) overcome the work necessary to be “knocked off” the metal plate, they can travel to the anode and then the readout unit.

Description of Experimental Procedure

Part 1: Dark Current:

1. While the mercury lamp in the device was heating up, we covered both the opening on the photoelectric tube box as well as the mercury lamp source.
2. Turn the photo-current input switch to the “off” position.
3. Turn the ammeter knob to the lowest setting, in our case: 10 ^ -13.
4. Set the “Current Zero” knob to zero.
5. Turn the photo-current input switch to the “on” position.
6. Be sure to leave the “Current Zero” knob on zero for the remainder of the experiment .
7. On the aperture of the photoelectric tube, rotate the wavelength selector to “B”.
8. On the readout unit, set the “Voltage Range” button to the “in” position to set range to (-3 to +20 V).
9. Set the “Voltage Range” knob fully counterclockwise (to the lowest position).
10. Rotate the “Voltage Adjust” knob slowly, increasing the voltage in intervals and for each interval, record the dark current value. Do this for a wide range of voltage readings.

Part 2: Determination of h/e:

1. Now if the mercury lamp has been heating up for at least 20 minutes, we can begin collecting stopping-voltage data for a variety of frequencies of light to obtain h/e.
2. Adjust the face of the photo-tube to be 30 cm from the light source. On this apparatus, the distance measurement is built into the base , making it easy to adjust.
3. Set the “Voltage Range” button to the “out” position by clicking it once. This sets the voltage range to (-2 to +2 V).
4. Turn the voltage to the lowest possible setting by turning the “Voltage” knob counterclockwise.
5. Change the wavelength filter to 435.8 nm by rotating the wheel selector on the top of the photo-tube aperture.
6. On the rotating wheel right next to the wavelength one, on top of the photo-tube aperture, turn the aperture size selector to 8mm.
7. Remove the caps from the light source and the photo-tube and set them aside.
8. Increase the voltage slowly using the “Voltage knob” until the current-meter reads zero. Record the voltage at which this happens as well as the wavelength filter.
9. Repeat for the wavelength filter options: 404.7 nm, 435.8 nm, 546.1 nm, 577.0 nm. keep the aperture size setting on 8mm.

Part 3: I~V Characteristics

1. Check that the photo-tube is still 30 cm from the light source.
2. Set the "Current Range" knob to 10^-13 setting.
3. Set the "Voltage Range" button to the "in" position, to set the range to (-2 to +2 V).
4. Rotate the wavelength filter selector wheel on top of the photo-tube aperture to the 435.8 nm setting.
5. Make sure that the aperture size is still set to 8mm, on the wheel next to the wavelength filter selector.
6. Turn the "Voltage" knob counter clockwise until reading the lowest setting (around -2 V)
7. Increase the voltage in small increments, being careful to let the reading "settle" before recording current and voltage. Make sure to make increments small enough to obtain at least 30 data points, and to also cover the entire voltage range. remember that you may want to change the "Current Range" knob and to mark down when you do change to a different decimal place.

Part 4: Aperture size vs Photo-current:

1. Choose a constant voltage, ideally that sits around where the data points in the previous part have plateaued and that you will not have to adjust the current range knob. Set this voltage as a constant through this part.
2. For each of the following aperture sizes: 2 mm, 4 mm and 8 mm; and for each of the following wavelength filters: 365.0 nm, 404.7 nm, 435.8 nm, 546.0 nm, 577.0 nm, record the current reading in a table.
3. These two variables can be adjusted on the wheels on top of the photo-tube aperture.

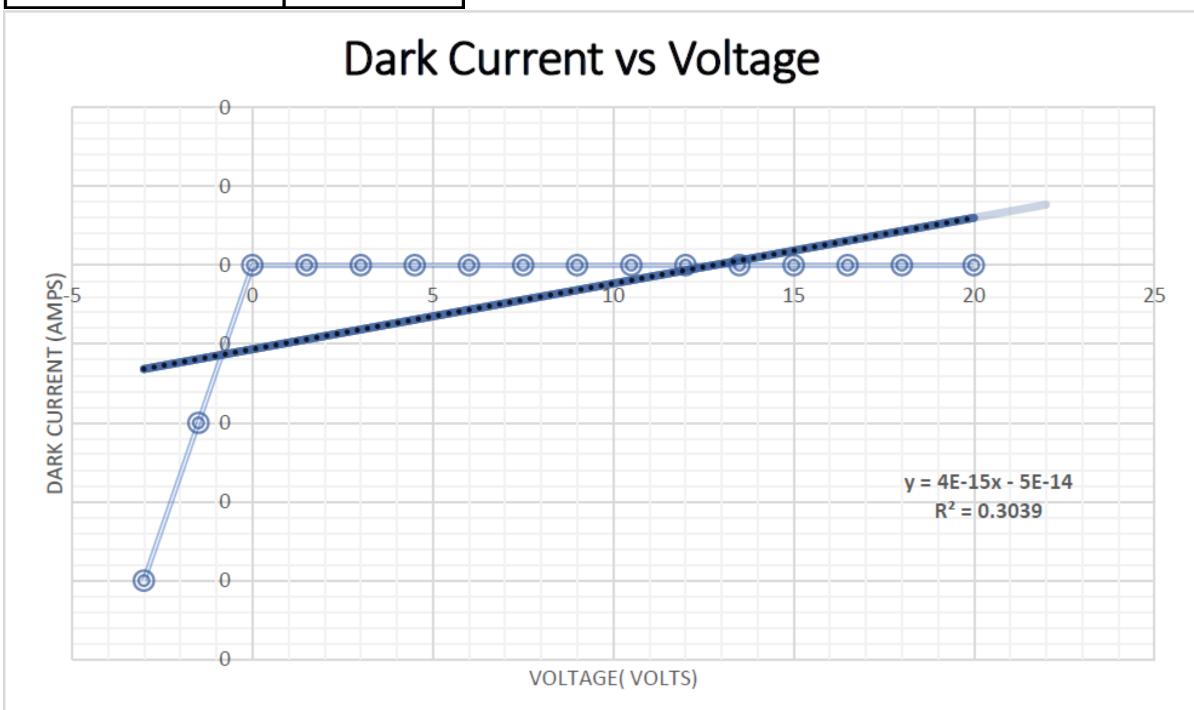
Part 5: The Inverse Square Law:

1. Choose a fixed aperture size and adjust the device accordingly.
2. Choose a fixed wavelength filter and adjust the device accordingly.
3. Choose a fixed voltage and adjust the device accordingly.
4. Varying only the distance between the light source and the photo-tube, record the photo-current at each distance for a variety of distances.

Results

Part 1: Dark Current:

Dark Current	Voltage
0	-3.01
-1E-13	-1.5
0*10^-13	0
2.0*10^-13	1.5
4*10^-13	3
6*10^-13	4.5
8*10^-13	6
9*10^-13	7.5
10*10^-13	9
10*10^-13	10.5
11*10^-13	12
12*10^-13	13.5
13*10^-13	15
13*10^-13	16.5
14*10^-13	18
14*10^-13	19.99



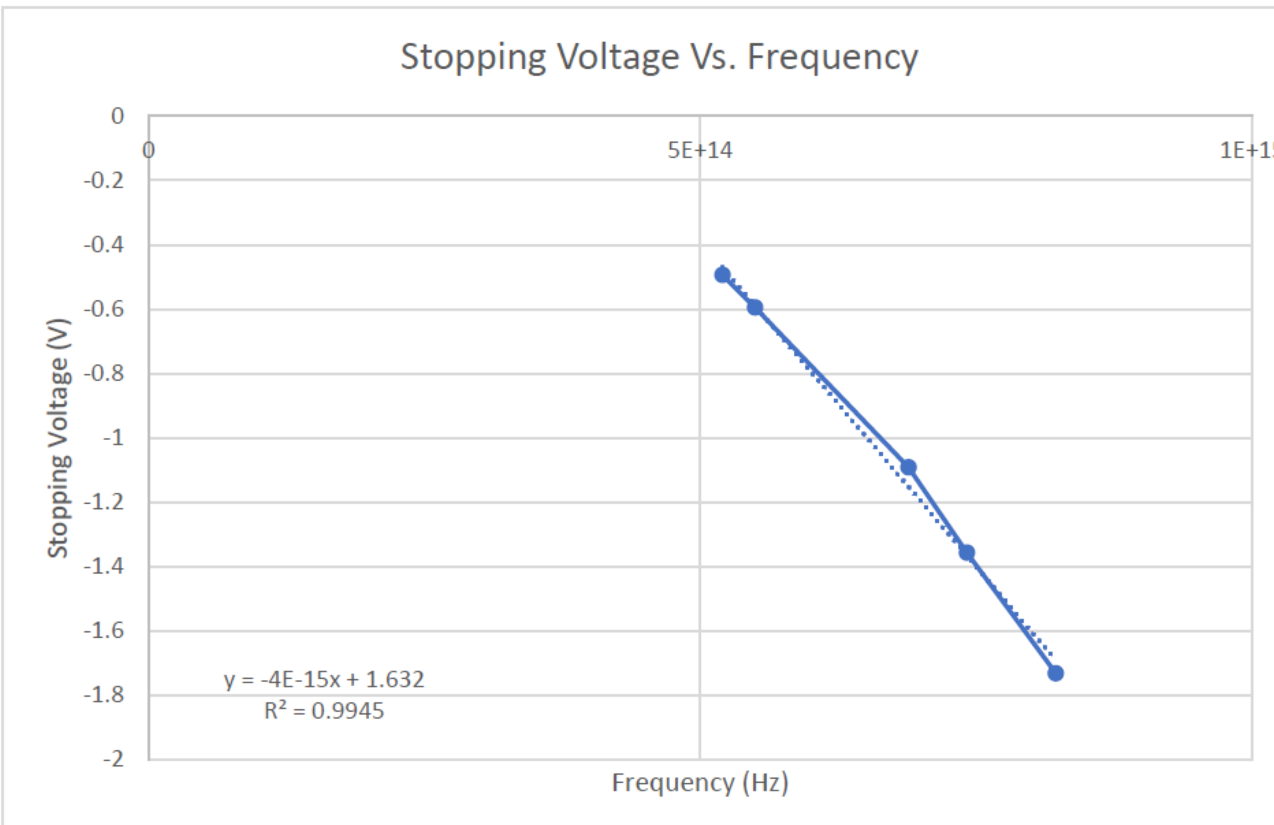
uncertainty current:	$\pm 1 \times 10^{-13}$
uncertainty voltage:	± 0.005

*Data above was inputted into excel, graphed in excel, and calculations done in excel.

The dark current measured in this experiment was found to be very minimal and remained beyond 0 volts. It is safe to say this is a negligible amount, but is good information to look at for contributing factors if current measured in proceeding parts of the experiment are consistently above expected values.

Part 2:

filter wavelength (m)	frequency (Hz)	voltage (volts)
0.000000365	8.21918E+14	-1.731
4.047E-07	7.4129E+14	-1.356
4.358E-07	6.88389E+14	-1.091
5.461E-07	5.4935E+14	-0.595
0.000000577	5.19931E+14	-0.494



h/e:

slope of best fit:	-4×10^{-15}

uncertainty voltage:	±0.0005
uncertainty frequency:	unknown

slope of best fit:	-4E-15
h/e:	-4×10^{-15}
e:	1.602E-19
Plank's experimental value	-6.408E-34
plank's accepted value:	6.62607E-34
difference:	2.1807E-35
error :	0.032910933
percent error:	3.3

```
exp_Plank =
 -4 * (10^-15) * (1.602 * (10^-19)) (* Multiply h/e x e to get h (Plank's constant) *)
```

Out[119]= -6.408×10^{-34}

```
accepted_Plank = 6.62607015 * (10^-34)
```

```
error_Plank = (Abs[ABS[accepted_Plank] - ABS[exp_Plank]]) / accepted_Plank
```

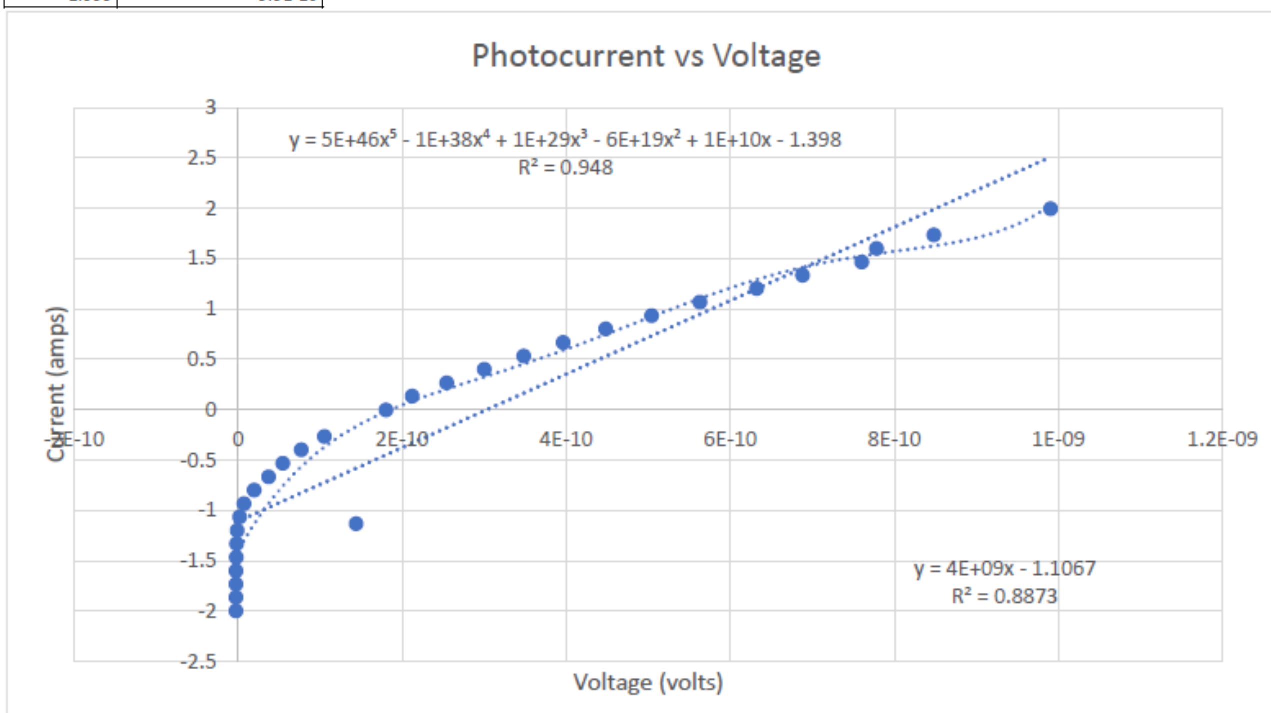
Out[134]= $\frac{\text{Abs[ABS[accepted\_Plank] - ABS[exp\_Plank]]}}{\text{accepted\_Plank}}$

*Data above was inputted into excel, graphed in excel, and calculations done in excel.

Given above is the Graphical analysis of the Stopping Voltage vs. Frequency, as well as the equation for the line of best fit, and the slope of that line representing h/e. I have had a lot of trouble with computing in Mathematica, however, I was able to compute the error between the experimental and accepted value of Plank's constant to be around 3.3 %. The difference in between the accepted value and our experimental value was to the factor of 10 to the -35, which is a whole factor below the accepted value. This was a decent result that we were happy with, although it would have been ideal to have the error be 1% or lower. The uncertainty in the voltage was plus or minus 0.005 V, and the uncertainty of the frequency is unknown due to not having enough information about the filters themselves.

Part 3:

voltage (v)	photocurrent (amps)
-1.997	-2.8E-12
-1.863	-2.8E-12
-1.73	-2.7E-12
-1.597	-2.7E-12
-1.464	-2.4E-12
-1.33	-2.1E-12
-1.197	-1.3E-12
-1.063	1.81899E-12
-0.93	7E-12
-0.797	1.95E-11
-0.664	3.72E-11
-0.53	5.44E-11
-0.397	7.7E-11
-0.263	1.05E-10
-1.13	1.436E-10
0	1.801E-10
0.136	2.12E-10
0.27	2.54E-10
0.403	3E-10
0.536	3.48E-10
0.67	3.96E-10
0.803	4.48E-10
0.936	5.04E-10
1.069	5.63E-10
1.204	6.32E-10
1.336	6.88E-10
1.469	7.6E-10
1.602	7.78E-10
1.737	8.48E-10
1.999	9.9E-10



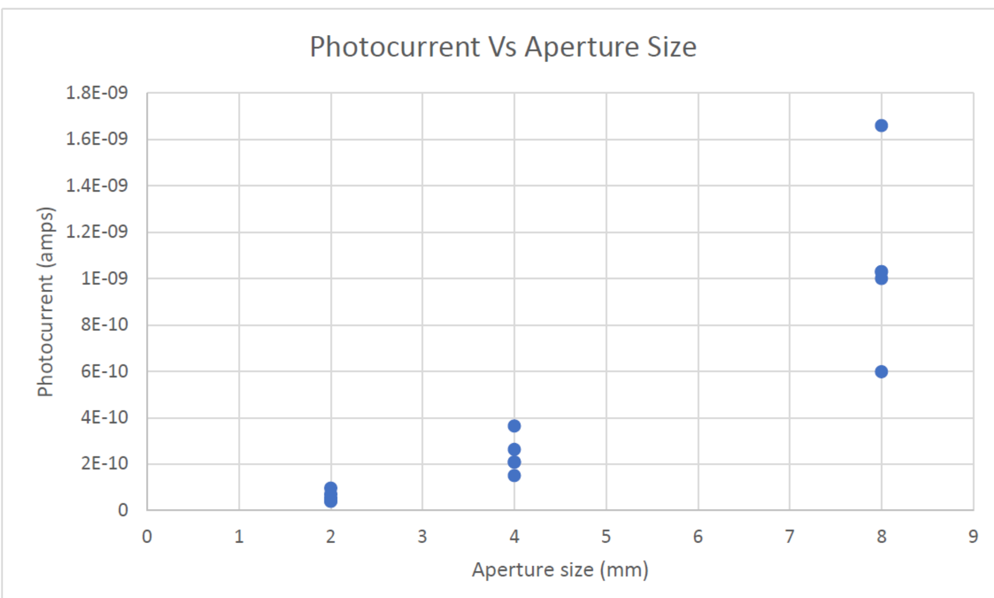
uncertainty current:	$\pm 1 \times 10^{-13}$
uncertainty voltage:	± 0.005

*Data above was inputted into excel, graphed in excel, and calculations done in excel .

Given above is the current vs voltage curve, the slope of which gives us the resistance in the system of the photo-tube. As expected, it does flatten out after zero volts. Not as expected, it does not flatten out as quickly as it maybe should.

Part 4:

Aperture size (mm)	filter wavelength (nm)	photo current (amps)	area (mm^2)
2	365	9.6E-11	6.283185307
4	365	3.64E-10	25.13274123
8	365	1.66E-09	100.5309649
2	404.7	4E-11	6.283185307
4	404.7	2.08E-10	25.13274123
8	404.7	0.000000001	100.5309649
2	435.8	5.4E-11	6.283185307
4	435.8	2.09E-10	25.13274123
8	435.8	1.03E-09	100.5309649
2	546	7.1E-11	6.283185307
4	546	2.63E-10	25.13274123
8	546	1.03E-09	100.5309649
2	577	4E-11	6.283185307
4	577	1.5E-10	25.13274123
8	577	5.98E-10	100.5309649



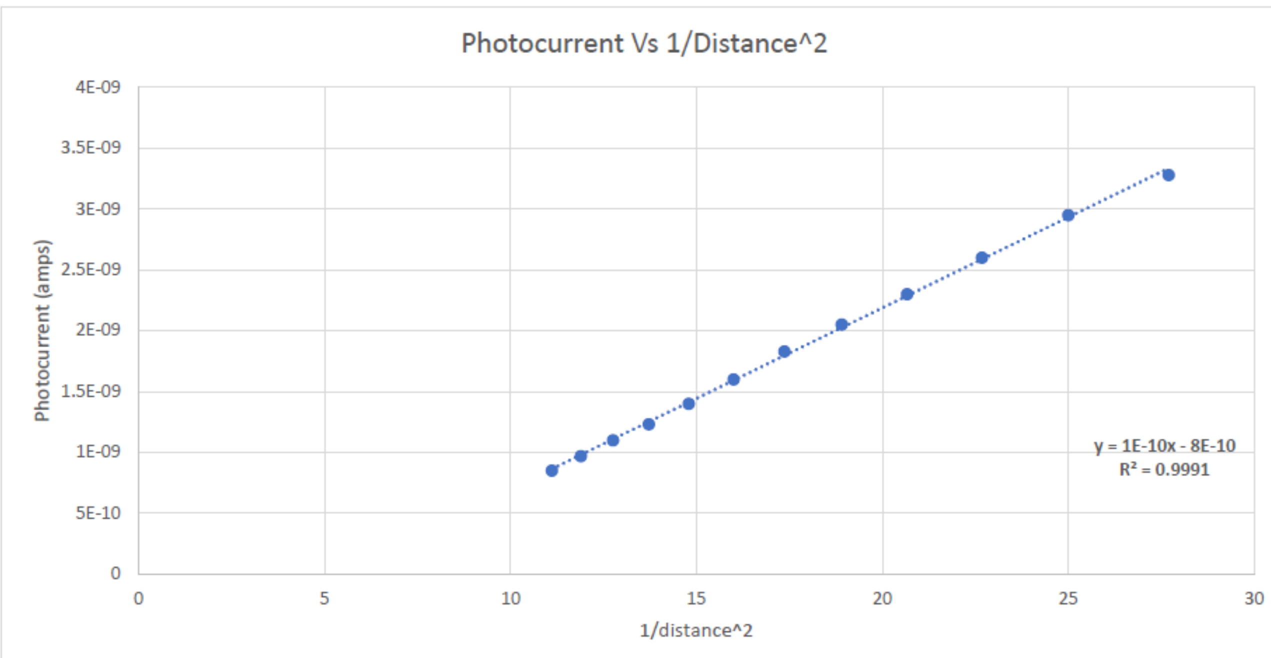
uncertainty current:	$\pm 1 \times 10^{-13}$
uncertainty voltage:	± 0.005

*Data above was inputted into excel, graphed in excel, and calculations done in excel .

Seen above is the photo-current given different aperture sizes and different wavelength filters. As expected, the larger aperture sizes allow more light to be received by the photo-tube system, and the photo-current increases.

Part 5:

Distance (m)	1/d^2	Photocurrent (amps)	Aperture size (mm)	Wavelength Filter (nm)	Voltage (volts)
0.19	27.70083102	3.28E-09	8	435.8	1.987
0.2	25	2.95E-09	8	435.8	1.987
0.21	22.67573696	2.6E-09	8	435.8	1.987
0.22	20.66115702	2.3E-09	8	435.8	1.987
0.23	18.90359168	2.05E-09	8	435.8	1.987
0.24	17.36111111	1.83E-09	8	435.8	1.987
0.25	16	1.6E-09	8	435.8	1.987
0.26	14.79289941	1.4E-09	8	435.8	1.987
0.27	13.71742112	1.23E-09	8	435.8	1.987
0.28	12.75510204	1.1E-09	8	435.8	1.987
0.29	11.89060642	9.7E-10	8	435.8	1.987
0.3	11.11111111	8.5E-10	8	435.8	1.987



uncertainty current:	$\pm 1 \times 10^{-13}$
uncertainty voltage:	± 0.005

Correlation Coefficient	**0.999528988**

*Data above was inputted into excel, graphed in excel, and calculations done in excel .

Seen above is the photo-current to 1/distance^2 (to allow for a linear correlation) of the experimentally obtained data. As expected, there is a highly linear relationship between 1/d^2 and the photo-current produced. This is further emphasized in the correlation calculation provided above which is very close to 1.

Discussion

Part 1: Dark Current:

During the analysis of the dark current, the value was found to be very small, and what I think could be negligible with the amount of uncertainty in the experiment. The dark current is the amount of current in the system without any light entering the photo-tube, and therefore should not contribute to the photo-current collected during the experiment. Once the voltage was above zero, the dark current seemed to stay pretty consistent. The best fit line of dark current vs. voltage had a slope that was to the factor of 10 to the negative fifteen, and the dark current itself did not get above the factor of 10 to the negative thirteen. This was ideal in the experiment, because the dark current was found to be negligible and therefore it was not required to take it into account during the rest of our data recording, or later in the analysis of other parts. It is, however, a very important step in calibrating the device and the data within the experiment. If the dark current had been a higher value, it would have been necessary to take this into account for the rest of the data points taken in the experiment. The uncertainty of the voltage was plus or minus 0.005 volts, and the uncertainty of the current was plus or minus 10 to the negative 13.

Part 2: Determination of h/e

The slope of the line of best fit for the data collected was found to be around -4 to the negative 15. This slope can be considered h/e, where h is Plank's constant. Therefore, we can easily multiply the value experimentally found for h/e by e (1.602 to the negative 19 coulombs) to obtain our value found for h (Plank's constant). This results in an experimental Plank's constant of -6.408 to the negative 34. The difference between this experimental value and the accepted value is around -1.459 to the negative 35. The uncertainty for voltage in this experiment was plus or minus 0.005 volts. The uncertainty in the frequency/ wavelength is unknown, because no information was available on the filters. This was a satisfactory value experimentally obtained for Plank's constant, as the difference between the accepted and the experimental value was a factor of ten below the value itself. This error computes to be about 3.3 percent error. The uncertainty in the voltage may have contributed to this error. It is not likely that the dark current contributed to this error, because the experimental value of Plank's constant was found to be lower than the accepted value and not over. Other contributing factors to this error could have been fluctuations in the light source, or material properties of the metal inside of the photo-tube. Lastly, we may not have let the voltage settle enough before recording the reading, which could have given us at least a few inaccurate data points.

Part 3: Characteristics

The resultant curve of the voltage vs current data that was obtained experimentally gives insight on the characteristics of the photo-tube components. According to Ohm's law, voltage and current are directly proportional to each other in the same system. The slope of the current vs voltage curve is the resistance in the system. Therefore, because we ended up with a curve and not a linear relationship, we can conclude that there was very little resistance until voltage was above zero volts. Beyond that point, the data seems to tell us that resistance varied and then became more and more constant as the voltage went up. This show us that the optimal point at which resistance is the most predictable within the system inside of the photo-tube is at voltages higher than around 1.5. The curve obtained through experimentation does not flatten out as quickly as expected, and so it follows that I would question how good of shape the components within the photo-tube are. Alternatively, the uncertainty in voltage or current (+- 0.005 V, +- 1x10^-13) could have contributed to this, as well as not letting the voltage reading settle enough before recording values.

Part 4: Aperture size vs. Photo-current

The analysis on part four of the data experimentally obtained confirms that the current generated by the photoelectric effect in this experiment was lower when the aperture size was smaller, and was larger in value when the aperture size was larger. We know that this is because the amount of flux through the aperture decreased as area of the aperture decreased. That is to say that less light is able to get to the photo-tube and work within the system to generate a photo-current.

Part 5: The Inverse Square Law

The Inverse Square Law tells us that the intensity of the light is inversely proportionate to the distance from the source. We found this to be true through our experiment in part 5 because the graphical analysis of the photo-current vs 1/distance^2 gave us a linear relationship, and furthermore, provided a correlation coefficient of almost exactly 1.

Conclusion

In conclusion, by studying the Photoelectric effect experimentally, we have been able to calibrate dark current to a satisfactory negligible amount, have obtained an experimental value for Plank's constant with a 3.3 percent error, have gained insight on the resistance of our system within the photo-tube, confirmed the relationship of current to aperture size to be consistent with the way we understand flux, and lastly confirmed the Inverse-Square Law by comparing photo-current with 1/distance^2.

Scanned Sheets from Lab Notebook

The Photoelectric Effect
physics 2150 Experiment 5
University of colorado

9/7/2021

Cassidy Bliss
Labpartner: Sean Gopalakrishnan

Part I: Dark current

[Voltage range: -3 to 20V]

Voltage (V)	Dark current #($\times 10^{-13}$)
~~3.01~~ (bad writing) -3.01	(misread) ~~-0.02~~ -2
-1.5	~~-0.01~~ -1
-0.00	~~-0.00~~ 0
1.50	~~0.02~~ 2
3.00	4
4.50	6
6.00	8
7.50	9
9.00	10
10.50	10
12.00	11
13.50	12
15.00	13
16.50	13
18.00	14
19.99	14

uncertainty:
Current ~~Voltage~~ $\pm 1 \times 10^{-13}$ Amps
Voltage $\pm$ ~~0.5~~ 0.005 V

The Photoelectric Effect
Physics 2150 Experiment 5
University of Colorado

9/7/2021

Cassidy Bliss

Lab partner:

Part II: Determination of h/e

Filter wavelength (nm)	voltage	aperture size (mm)	current
365.0 (nm)	-1.731	8	0
404.7 (nm)	-1.356	8	0
435.8 (nm)	-1.091	8	0
546.1 (nm)	-0.595	8	0
577.0 (nm)	-0.494	8	0

* set @ 30cm ± 1 mm away from detector

Uncertainty: corrected after T.A. helped
Voltage : ± ~~[illegible]~~ 0.0005 ✓
Current : ± 1 x10^{-13}

The Photoelectric Effect
PHYSICS 2150 Experiment 5
University of Colorado

9/7/2021

Cassidy Bliss
Lab partner:

Part III : I ~ V Characteristics

wavelength filter (nm)	aperture size (mm)	voltage (Volts)	photocurrent	had to change not
435.8	8	-1.997	-28	
435.8	8	-1.863	-28	
435.8	8	-1.730	-27	
435.8	8	-1.597	-27	
435.8	8	-1.464	-24	
435.8	8	-1.330	-21	
435.8	8	-1.197	-13	
435.8	8	-1.063	8	$\times 10^{-13}$ Amps
435.8	8	-0.930	70	
435.8	8	-0.797	195	
435.8	8	-0.664	372	
435.8	8	-0.530	544	↑
435.8	8	-0.397	770	
~~435.8~~	~~8~~	~~[illegible]~~	messed up this one	
435.8	8	-0.263	1050	
435.8	8	-0.130	1436	
435.8	8	0.000	1801	
435.8	8	0.136	212	↓
435.8	8	0.270	254	
435.8	8	0.403	300	
435.8	8	0.536	348	$\times 10^{-12}$ Amps
435.8	8	0.670	396	
435.8	8	0.803	448	
435.8	8	0.936	504	
435.8	8	1.069	563	
435.8	8	1.204	632	
435.8	8	1.336	688	
435.8	8	1.469	760	
435.8	8	1.602	778	
435.8	8	1.737	848	
435.8	8	1.999	99	$\times 10^{-11}$ Amps

The Photoelectric Effect — 9/7/2021
Physics 2150 Experiment 5
University of Colorado — Cassidy Bliss
Lab partner:

Part IV: Aperture size vs. Photocurrent

Aperture size (nm)	2 mm	4 mm	8 mm	Voltage
I 365.0	96×10^{-12}	364×10^{-12}	1660×10^{-12}	1.989
I 404.7	40×10^{-12}	208×10^{-12}	1000×10^{-12}	1.989
I 435.8	54×10^{-12}	209×10^{-12}	1030×10^{-12}	1.989
I 546.0	71×10^{-12}	263×10^{-12}	1030×10^{-12}	1.989
I 577.0	40×10^{-12}	150×10^{-12}	598×10^{-12}	1.989

[Current: $\times 10^{-12}$]

$\pm 1 \times 10^{-12}$

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Part V: Inverse Square Law

Aperture size (mm)	Wavelength (nm)	U_{KA} (V)	distance (cm) (light source → photo tube)	current
8	435.8	1.987	19 cm	328 $\times 10^{-11}$
8	435.8	1.987	20 cm	295 $\times 10^{-11}$
8	435.8	1.987	21 cm	260 $\times 10^{-11}$
8	435.8	1.987	22 cm	230 $\times 10^{-11}$
8	435.8	1.987	23 cm	205 $\times 10^{-11}$
8	435.8	1.987	24 cm	183 $\times 10^{-11}$
8	435.8	1.987	25 cm	160 $\times 10^{-11}$
8	435.8	1.987	26 cm	140 $\times 10^{-11}$
8	435.8	1.987	27 cm	123 $\times 10^{-11}$
8	435.8	1.987	28 cm	110 $\times 10^{-11}$
8	435.8	1.987	29 cm	97 $\times 10^{-11}$
8	435.8	1.987	30 cm	85 $\times 10^{-11}$

Kate Dick