Middle East Technical University
Department of Physics

PHYS307 Applied Modern Physics LABORATORY REPORTS

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ORTA DOĞU TEKNİK ÜNİVERSİTESİ
FİZİK TOPLULUĞU
PHYSICS SOCIETY
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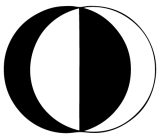

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Department of Physics

PHYS307 Applied Modern Physics

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Exp. MP-AS Atomic Spectra

Group Members: Cem MADEN, İrem KÜL, Deniz AKYÜREK
Experiment Date: November 20, 2015
Report Submit Date: November 27, 2015

Colour	θ_R	θ_L	θ	$\sin\theta$	λ	Percentage Error	$\Delta\lambda$
Violet	164°	196°26′	16.21°	0.279	4652 Å	6.62%	590.7 Å
Green	160°55′	197°31′	18.2°	0.312	5205 Å	8.49%	592.9 Å
Yellow	159°5′	201°24′	20.75°	0.354	5904 Å	0.25%	595.9 Å
Red	158°10′	202°25′	22.13°	0.376	6275 Å	1.96%	597.5 Å

Table 1: Spectral lines of Na with the grating (Grating constant d=16666 Å)

Colour	n	θ_{d1}	θ_{d2}	$\sin\theta_{d1}$	$\sin\theta_{d2}$	λ_1	λ_2	$\Delta\lambda_{exp} = \lambda_1 - \lambda_2$	$\Delta\lambda_{theo}$	$\Delta\lambda_{p.err}$
Red	2	223.60°	223.65°	.6896	.6902	5746 Å	5751 Å	5 Å	3 Å	66.7%
Red	3	250.28°	250.35°	.9413	.9417	5229 Å	5231 Å	2 Å	2 Å	0
Yellow	2	221.61°	221.68°	.6640	.6649	5533 Å	5540 Å	7 Å	3 Å	75.0%
Yellow	3	243.25°	243.4°	.8929	.8941	4960 Å	4967 Å	7 Å	3 Å	75.0%
Green	2	220.16°	220.21°	.6449	.6455	5373 Å	5378 Å	5 Å	2 Å	150%
Green	3	233.8°	234.230°	.8069	.8113	4482 Å	4507 Å	25 Å	-	-

Table 2: Fine structure of some spectral lines of Na (Grating constant d=16666 Å)

An example calculation for $\Delta\lambda$ where

$$\Delta\lambda = \lambda\sqrt{(\frac{\Delta\theta}{\theta})^2 + (\frac{\Delta d}{d})^2} \tag{1}$$

For yellow colour; d=16666 Å, $\Delta\theta = 2°$, $\Delta d = 500$ Å, $\theta = 20.75°$ and $\lambda = 5904$ Å

$$\Delta\lambda = 5904\mathring{A}\sqrt{(\frac{2^\circ}{20.75^\circ})^2 + (\frac{500\mathring{A}}{16666\mathring{A}})^2} \tag{2}$$

$$\Delta\lambda = 5904\mathring{A}\sqrt{9.29 \times 10^{-3} + 9.0 \times 10^{-4}} \tag{3}$$

Therefore

$$\Delta\lambda = 595.98\mathring{A} \tag{4}$$

Remark: Percentage error is calculated according to following equation

$$\%error = \frac{|ExperimentalValue - TheoreticalValue|}{TheoreticalValue} \times 100 \tag{5}$$

Below table has taken from *Experiments in Modern Physics* [1]. Green colour has not 3rd order

Colour	n	θ_1	θ_2	λ_1	λ_2	$\Delta\lambda$
Red	2	41.45	41.48	5516 Å	5519 Å	3 Å
Red	3	55.96	56	4603 Å	4605 Å	2 Å
Yellow	2	40.35	40.38	5395 Å	5398 Å	3 Å
Yellow	3	53.81	53.86	4483 Å	4486 Å	3 Å
Green	2	39.53	39.55	5304 Å	5306 Å	2 Å

Table 3: Theoretical data for fine structure of Na

spectrum that is why I did not calculate $\Delta\lambda_{theo}$ for green in Table 2. An example calculation for n=2 order wavelength of yellow as follows

$$\lambda = \frac{d\sin\theta}{n} \tag{6}$$

$$\lambda = \frac{16666\mathring{A} \times \sin 40.35}{2} \tag{7}$$

$$\lambda = 5395\mathring{A} \tag{8}$$

1. What is the most important general statement that you can make from the results of the first part of the experiment? Make a comment on the data you have taken.

As we know there are three different spectrum: continuous, absorption and emission. In this part we have seen the emission spectrum of sodium. We can realize emission spectrum by observing background. If background is dark and if we see bright lines that means we are observing emission spectrum as we did in this experiment. This part shows that Sodium has different coloured lines. Each colour can be visible in different diffraction angles.

2. What causes the specta of different elements to differ?

Each element has different that means each element releases photons of different color when its atoms return to their lower energy states. Since each atom has many excited states, different colors of light can be emitted by each element. As we realized in this experiment, group of individual colors emitted by an element is called its spectrum. Since the spectrum of each element is unique, spectra can be used like fingerprints to identify unknown elements.

3. What is the most important general statement that you can make from the results of the second part of the experiment? Make a comment on the data you have taken.

In the second part of the experiment, we measured different orders of Sodium atom. The most important thing in this part is fine structure of sodium. Used energy levels were *n=2* and *n=3*. The energy difference of these two levels is known as fine structure, and is due to the spin-orbit coupling, the interaction of the orbital angular momentum with the spin angular momentum. We have seen same yellow lines in Michelson Interferometer Experiment *(PHYS222 Optics and Waves Laboratory Exp. OW-6).*

4. If the agreement between the obtained experimental data and the values given in Figure 1 (see Appendix) is fair, explain what could be the source of error in the measured values.

Actually our experimental result and theoretical values are very close to each other in the first part of the experiment. However, in the second part of the experiment, percentage error is very high. As we know, grating spectrometer that we used in the experiment is old fashioned. We had to align manually and we had to read degree of spectrometer. Since spectrometer has its own error causes whose stated in lab manual, we have also some errors caused by eyes. We were observing lines with naked eyes and sometimes observing black line was difficult.

5. What is the advantage of using higher orders in diffraction pattern, rather than the first order?

Sodium atom has 11 electron therefore electron configuration is $1s^2\ 2s^2\ 2p^6\ 3s^1$. In the first order of Sodium, we observe a spectrum which is very familiar with Hydrogen spectrum. However, when we observe 2nd and 3rd order we can see bright doublet sodium spectrum which is known as Sodium D-lines [2] and this line can be observed at 5890 Åof the $3S_{1/2} - 3P_{3/2}$ transition [3]. Another advantage of using higher orders is that the Sodium doublet is further spit by the application of an external magnetic field which is known as Zeeman Effect.

Discussion and Conclusion

In this experiment we studied an important topic in physics and chemistry which is known as spectrum of an atom. This experiment shows us an atom can have different quantum number and these quantum numbers can have different emission spectrums. We conclude this results while doing experiment because we saw very different in the second part. For instance in the second part we did not observe violet colour line. Indeed, this experiments requires further readings it because atomic spectra is a wide topic. If we want to talk about this topic widely, we need to mention Bohr's atom theory, selection rules for related elements, Hydrogen like atoms, Coulomb degeneracy and etc [4]. If we look at the experimental results and theoretical values we can state that the first part of experiment is very succesful it is because we have very low percentage error. However, in the second part of experiment percentage error starts to increasing. Actually I could not realize the cause of these high percentage errors. As I mentioned before I calculated $\Delta\lambda_{theo}$ values in Table 2 according to values are given in Table 3. I am not sure about these values but they seems like that they are correct. By the way, while I was scanning literature, I saw that most of books do not mention *n=3* order for green colour. For instance, Melissinos and Napolitano [1] stated *n=2* and *n=4* quantum numbers for green colour, not for *n=3*. To sum up, in my opinion, experiment is accomplished at least for first part. I wish we would observe other elements' spectrums such as Hyrdogen and Mercury. That would be beneficial for us to understand the difference of spectrums.

References

[1] A. Melissinos, *Experiments in Modern Physics* (Academic Press Inc., 1966) p.38.

[2] Irodov, I. (1983). *Problems in Atomic and Nuclear Physics* p.43. Moscow: Mir.

[3] Haroche, S., Gross, M., & Silverman, M. P. (1974). *Observation of fine-structure quantum beats following stepwise excitation in sodium D states.* Physical Review Letters, 33(18), 1063.

[4] Hecht, E. (2002). Optics (4th ed.) p.480. Reading, Mass.: Addison-Wesley

Appendix

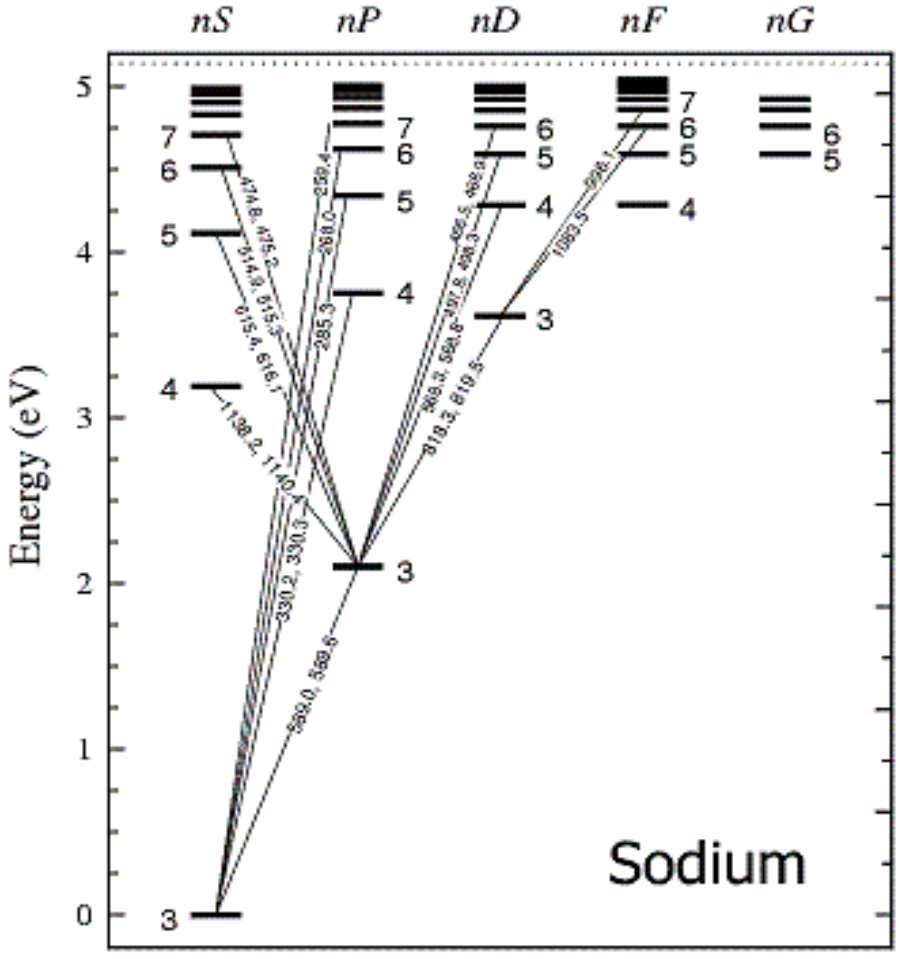
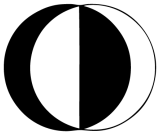


Figure 1: Energy level diagram for sodium



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Exp. MP-AS Franck-Hertz Experiment*

Group Members: Cem MADEN, İrem KÜL, Deniz AKYÜREK
Experiment Date: November 6, 2015
Report Submit Date: November 13, 2015

Table 1: Data for different filament and collector voltages at instant oven temperature

	Filament Voltage: 6.0 V Collector Voltage: 2.0 V Oven Temperature: 160°C		Filament Voltage: 6.0 V Collector Voltage: 2.0 V Oven Temperature: 160°C	
Voltage at first minimum/maximum [V]	0	2.2	0	2.2
Voltage at second minimum/maximum [V]	4.6	5.2	4.3	7.2
Voltage at third minimum/maximum [V]	9.6	12.4	-	-
Voltage difference between first and second minima/maxima [V]	4.6	3.0	4.3	5.0
Voltage difference between second and third minima/maxima [V]	5.0	7.2	-	-
Mean of Voltage difference between the minima/maxima [V]	4.8	5.1	4.3	5.0

Data & Results

Mean and the standard deviation of the first excited energy level: **4.8±0.2 eV**
Calculation of standard deviation σ as follows:

$$(4.6 - 4.8)^2 = -0.2^2 = 0.04 \tag{1}$$

$$(5.0 - 4.8)^2 = 0.2^2 = 0.04 \tag{2}$$

$$\frac{0.04 + 0.04}{2} = 0.04 \tag{3}$$

Therefore standard deviation σ in this case

$$\sigma = \sqrt{0.04} = 0.2 \tag{4}$$

*Nobel Prize in Physics, 1925

Accepted value of the first excited energy level: **4.9 eV**
Contact Potential difference between the anode and the cathode: **4.0 V** and **6.0 V**

1. What are the advantages and disadvantages of the method used in this experiment by comparing with the optical methods?

Optical methods of determining the excitation states suggested by Niels Henrik David Bohr. One important postulates of Bohr's is that radiation is only emitted when an atom makes transitions between stationary states:

$$E_{ph} = E_m - E_n \tag{5}$$

Main disadvantage of optical method is that atoms do not absorb at all the same wavelengths that it emits. Isolated atoms are normally found in the ground state - excited states live for very short time periods ($\approx$ 1 ns) before decaying to the ground state. The absorption spectrum therefore contains only transitions from the ground state ($n = 1$). To observe transitions from the first excited state ($n = 2$) would require a significant number of atoms to occupy this state initially. Another disadvantage when try to determine excited states of atoms we need to use their thermal energies this states that to excite an atom to the first excited state from the ground state requires temperature that satisfies [1]

$$k_B T = E_2 - E1 = 10.2eV \tag{6}$$

which gives a temperature

$$T = \frac{(10.2eV)(1.6 \times 10^{-19} J/eV)}{1.38 \times 10^{-23} J/K} \approx 1.2 \times 10^5 K \tag{7}$$

which much larger than the room temperature (surface of the sun has temperature of 6.3×10^3 K.). If we need to provide a disadvantage of Franck-Hertz experiment that may be the experiment only must be performed by monoatomic gas like mercury (Hg), neon (Ne) and argon (Ar).

Discussion and Conclusion

In this we carried out a crucial experiment in Physics which is done by James Franck and Gustav Hertz in 1914. This experiment is proof of Bohr's Model. However, J. Franck and G. Hertz were not trying to test Bohr's model. As J. Franck admitted later, in fact, they were not even aware of Bohr's theory. They won their Nobel Prize 11 years later in 1925 because when they publish their paper *Collision between Electrons and Mercury Vapor Molecules and the Ionization Potential of Such Molecules* there were some mistakes [2]. In the summary part of the paper, the fourth result claim that *ionization potential of mercury is 4.9 volts.* However, this result is not quite correct because The mercury atoms are not being ionized by their collisions with electrons; they are simply being bumped upwards into an excited state [3]. Although J. Franck and G. Hertz made some mistakes in their work, Franck-Hertz Experiment can prove the Bohr's model. The deficiencies of Bohr model are as follows:

•Cannot be applied to multi-electron atoms.
•Does not predict fine structure of atomic spectral lines.
•Does not provide a method to calculate relative intensities of spectral lines.
•Predicts the wrong value of angular momentum for the electron in the atom.
•Violates the Heisenberg uncertainty principle (although Bohr's model preceded this by more than a decade)

In summary, in this experiment we studied the excitation state of mercury atom. We realized there are two different way to find excitation state of an atom: optical method and this experiment. While doing experiment, we had to set temperature at $\approx 160^\circ$ C but we could not do that. That is why our results are not quite correct. Normally we can determine $n = 5$ state but we reached to $n = 3$ state. Therefore we can say that our experiment is nearly incomplete. Figure 1 shows this result.

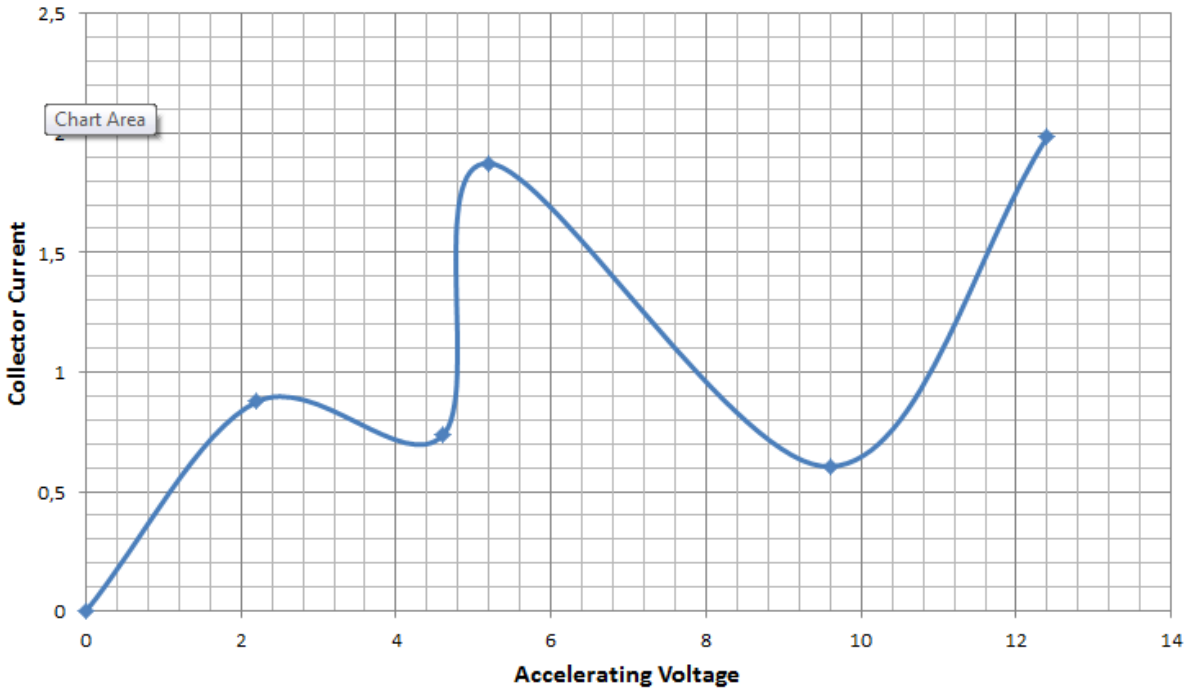
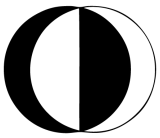


Figure 1: Collector Current I_c versus Accelerating Voltage V_a

References

[1] A. Melissinos, *Experiments in Modern Physics* (Academic Press Inc., 1966) p.14.
[2] J. Franck & G. Hertz, *Verhand. Deut. Physik, Ges.,* 16 (1914), 457-467.
[3] Mott and Massey, *The theory of atomic collisions*, (Oxford University Press, 1971) p.185, 3rd ed.



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Exp. MP-ZE Zeeman Effect

Group Members: Cem MADEN, İrem KÜL, Deniz AKYÜREK
Experiment Date: December 11, 2015
Report Submit Date: December 18, 2015

Magnetic Current I [A]	**Magnetic Field Strength B [T]**	2δa	δa	$\delta a/\Delta a$
18	0.494	0.175	0.0875	0.486
16	0.445	0.14	0.07	0.388
14	0.421	0.13	0.065	0.361
12	0.336	0.115	0.0575	0.319
10	0.279	0.10	0.05	0.277
8	0.223	0.08	0.04	0.222

Table 1: Splitting of a spectral line under various magnetic field strengths($\Delta a = 0.18$ mm)

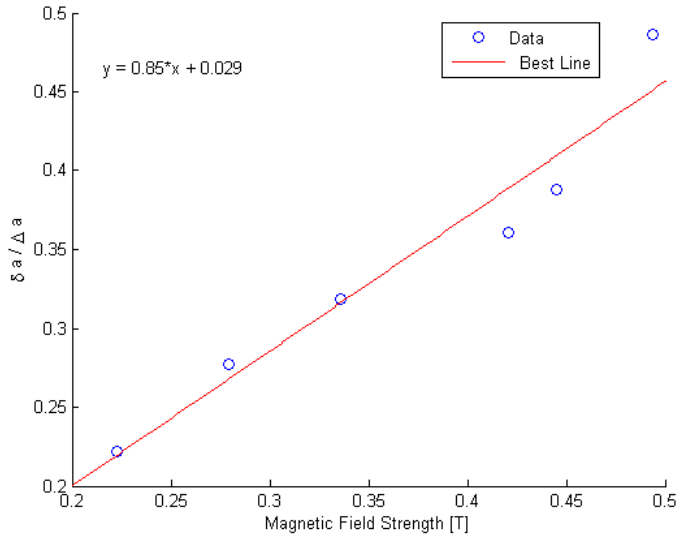


Figure 1: $\delta a/\Delta a$ versus Magnetic Field Strength

- **The slope of the best line = 0.85 T^{-1}**

	x	y	(x-x̄)	(x-x̄)²	x²	y²	ŷ	xy	(y-ŷ)	(y-ŷ)²
	0,494	0,486	0,128	0,0164	0,244	0,2362	0,48	0,2401	0,006	4E-05
	0,445	0,388	0,079	0,0062	0,198	0,1505	0,38	0,1727	0,008	6E-05
	0,421	0,361	0,055	0,003	0,1772	0,1303	0,36	0,152	0,001	1E-06
	0,336	0,319	-0,03	0,0009	0,1129	0,1018	0,31	0,1072	0,009	8E-05
	0,279	0,277	-0,087	0,0076	0,0778	0,0767	0,27	0,0773	0,007	5E-05
	0,223	0,222	-0,143	0,0204	0,0497	0,0493	0,22	0,0495	0,002	4E-06
Σ	2,198	2,053	0,002	0,0546	0,8598	0,7448	2,02	0,7987	0,033	0,0002

Figure 2: Calculation of slope by using Appendix II

We can calculate slope by following calculations if $m = b \pm \Delta b$ where b is correspond to $\frac{e}{m}$ and Δb is correspond to $\Delta\frac{e}{m}$

$$b = \frac{\sum xy - \frac{\sum x \sum y}{n}}{\sum x^2 - \frac{(\sum x)^2}{n}} \tag{1}$$

$$b = \frac{0.7987 - \frac{(2.198)\cdot(2.053)}{6}}{0.8598 - \frac{(0.0002)^2}{6}} \tag{2}$$

$$b = \frac{0.04661}{0.05459} \tag{3}$$

$$\boxed{\frac{e}{m}\text{=b=0.853(7)}}$$

$$\Delta b = \sqrt{\frac{\frac{1}{n-2}\sum(y-\hat{y})^2}{\sum(x-\bar{x})^2}} \tag{4}$$

$$\Delta b = \sqrt{\frac{\frac{1}{4} \times 0.0002}{0.0546}} \tag{5}$$

$$\boxed{\Delta\frac{e}{m}=\Delta b = 0.03}$$

Therefore, slope of $\delta a/\Delta a$ versus magnetic field strength graph is

$$\boxed{\text{m=0.853} \pm 0.03}$$

1. What is the most important general statement you can make after performing this experiment?

When a magnetic field is applied to atoms, some of the atomic energy levels may be changed and some levels which had identical energies may be split into levels with different energies.In this experiment we measured the energy level splitting and polarizations due to the Zeeman Effect.

2. What do you think the spectral lines may correspond to?

Spectral lines are correspond to the splitting of energy levels due to external magnetic field. This effect was a part of the classic theory of electron which is predicted by H. A. Lorentz in 1895 and experimentally confirmed by P. Zeeman.

3. In the measurement of the splitting, you measured $2\delta a$ instead of δa. Does this make any sense? Why?

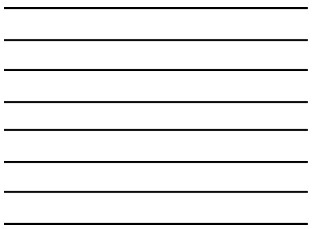


Figure 3: Spectral lines when $B = 0$

Figure 4: Observed spectral lines when $B \neq 0$

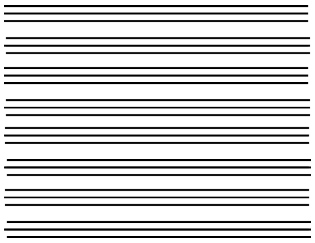


Figure 5: Expected spectral lines when $B \neq 0$

According to theory, when the Zeeman effect is viewed in a direction perpendicular to the direction of the magnetic field B, a triplet is observed. The lines of this triplet should be sharp lines as seen Figure 5. However, in the experiment these lines are not sharp, in fact, these line are blurred or distorded as seen in Figure 4. In this case, we could not be sure about the edges of the lines. That is why, we calculated $2\delta a$ instead of δa to have more accurate data. In Figure 6, we can see the measured splitting.

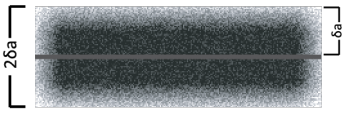
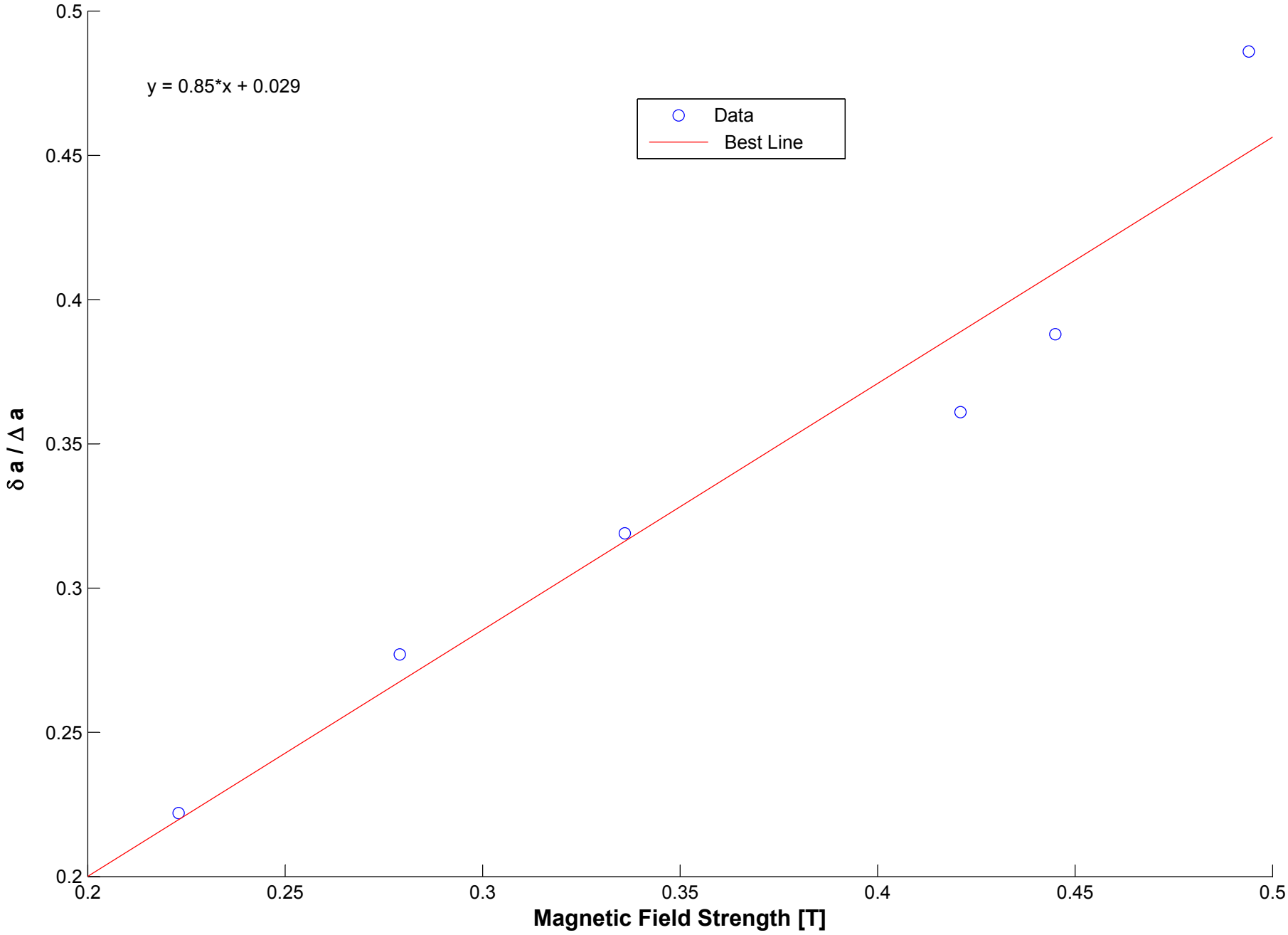


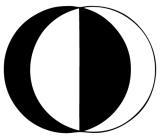
Figure 6: Close view of a spectral line

Discussion and Conclusion

In this experiment we carried out crucial topic in Physics which is Zeeman Effect. The splitting of energy levels of an atom when it is placed in an external magnetic field is known as Zeeman Effect. P. Zeeman discovered this effect in 1896. There are two types of this effect: Normal Zeeman Effect and Anomalaus Zeeman Effect. As we mentioned above, in the experiment we could not observe three sharp lines. Even with a high resolution spectrometer the magnetic field splits spectral lines in to more than three lines. This is called as Anomalaus Zeeman Effect and it was not discovered for a long time. This effect observed in the experiment. According to our results, when magnetic field strenth increses $\delta a/\Delta a$ ratio also increases (See Figure 1). In this experiment we only observed plane polarised effect. There is also circularly polarised effect. To sum up, according to our results, this experiment is accomplished.



Plotted with MATLAB



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Exp. MP-PE Photoelectric Effect

Group Members: Cem MADEN, İrem KÜL, Deniz AKYÜREK
Experiment Date: January 8, 2016
Report Submit Date: January 15, 2016

λ=436 nm					
2 mm		4 mm		8 mm	
1,4	0	-1,4	0	-1,4	0
-2	-9,20E-13	-2	-2,33E-12	-2	-8,35E-12
-1,5	-4,80E-13	-1,5	-1,30E-12	-1,5	-3,29E-12
-1	7,30E-12	-1	3,45E-11	-1	1,30E-10
-0,5	2,38E-11	-0,5	9,47E-11	-0,5	3,89E-10
0	4,92E-11	0	1,60E-10	0	6,43E-10
5	6,83E-11	5	2,45E-10	5	1,04E-09
10	9,50E-11	10	3,28E-10	10	1,43E-09
15	1,27E-10	15	4,37E-10	15	1,79E-09
20	1,62E-10	20	5,62E-10	20	2,20E-09
25	1,84E-10	25	6,18E-10	25	2,57E-09
30	2,07E-10	30	7,08E-10	30	2,85E-09

Figure 1: Currents versus voltages for the light having constant wavelength at different intensities

Aperture = 4 mm							
λ=365 nm		λ=405 nm		λ=546 nm		λ=577 nm	
V [V]	I [A]	V [V]	I [A]	V [V]	I [A]	V [V]	I [A]
-2	0	-1,6	0	-0,8	0	-0,7	0
-2	0	-2	-1,20E-11	-2	-2,01E-12	-2	-9,00E-13
-1,5	4,06E-11	-1,5	5,60E-12	-1,5	-1,88E-12	-1,5	-8,50E-13
-1	1,07E-10	-1	2,28E-11	-1	-1,47E-12	-1	-7,80E-13
-0,5	1,82E-10	-0,5	5,63E-11	-0,5	3,83E-11	-0,5	1,02E-11
0	2,92E-10	0	9,15E-11	0	1,16E-11	0	3,64E-11
5	3,98E-10	5	1,41E-10	5	2,06E-10	5	8,12E-11
10	5,28E-10	10	1,87E-10	10	3,03E-10	10	1,12E-10
15	6,78E-10	15	2,47E-10	15	3,67E-10	15	1,31E-10
20	8,46E-10	20	3,08E-10	20	4,14E-10	20	1,46E-10
25	1,08E-09	25	3,78E-10	25	4,65E-10	25	1,64E-10
30	1,20E-09	30	4,21E-10	30	5,12E-10	30	1,78E-10

Figure 2: Current versus voltages for the light having constant intensity at different wavelengths

λ [nm]	365	405	436	546	577
f [$\times 10^{14}$ Hz]	8.214	7.408	6.879	5.490	5.196
V_0 [V]	-2.0	-1.6	-1.4	-0.8	-0.7

Table 1: Stopping potentials versus different frequencies of light

Apparent value of Planck Constant = 4.282×10^{-15} eV·s
Accepted value of Planck Constant = 4.135×10^{-15} eV·s
Work function = 1.5426
Percentage Error in Planck Constant =

$$P.E. = \frac{|4.135 \times 10^{-15} - 4.282 \times 10^{-15}|}{4.135 \times 10^{-15}} \times 100 = 3.55\% \tag{1}$$

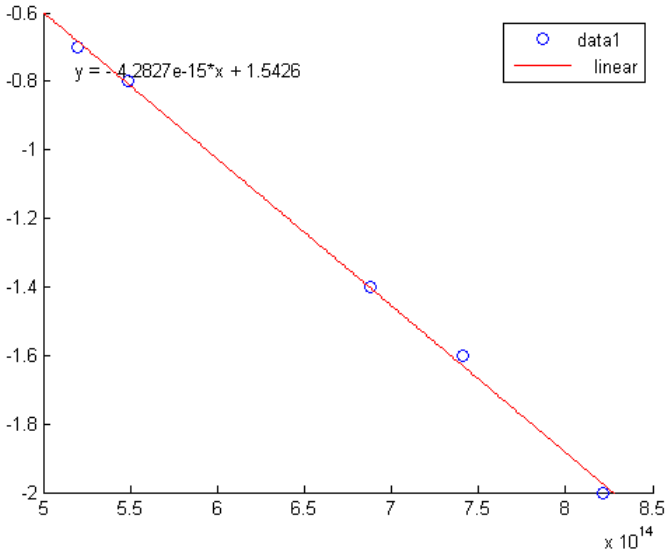


Figure 3: Plot of stopping potential versus frequency

1. What is the most important general statement you can make from the results of your experiment?

After this experiment, we state that light can behave as a particle. Besides, by using data that we took in experiment, we proved the Planck's Constant with an error lower than 5%. Note that Plancks constant has two different values. In this experiment, we used in eV·s unit.

2. What are some advantages and disadvantages of the various yield characteristics (efficiencies) in Fig. PE.5.?

In figure PE.5. there is three different phototubes. Since these phototubes have different properties, they have different curves. For instance, as stated in manual, S1 phototube is gas filled or S4 phototube is vacuum tube. By using different phototubes, we can observe different photoelectric efficiencies. Besides, modern phototubes are made with cesium antimonide surface.

3. Even if the bias voltage is zero, you can still measure a photocurrent. Explain why?

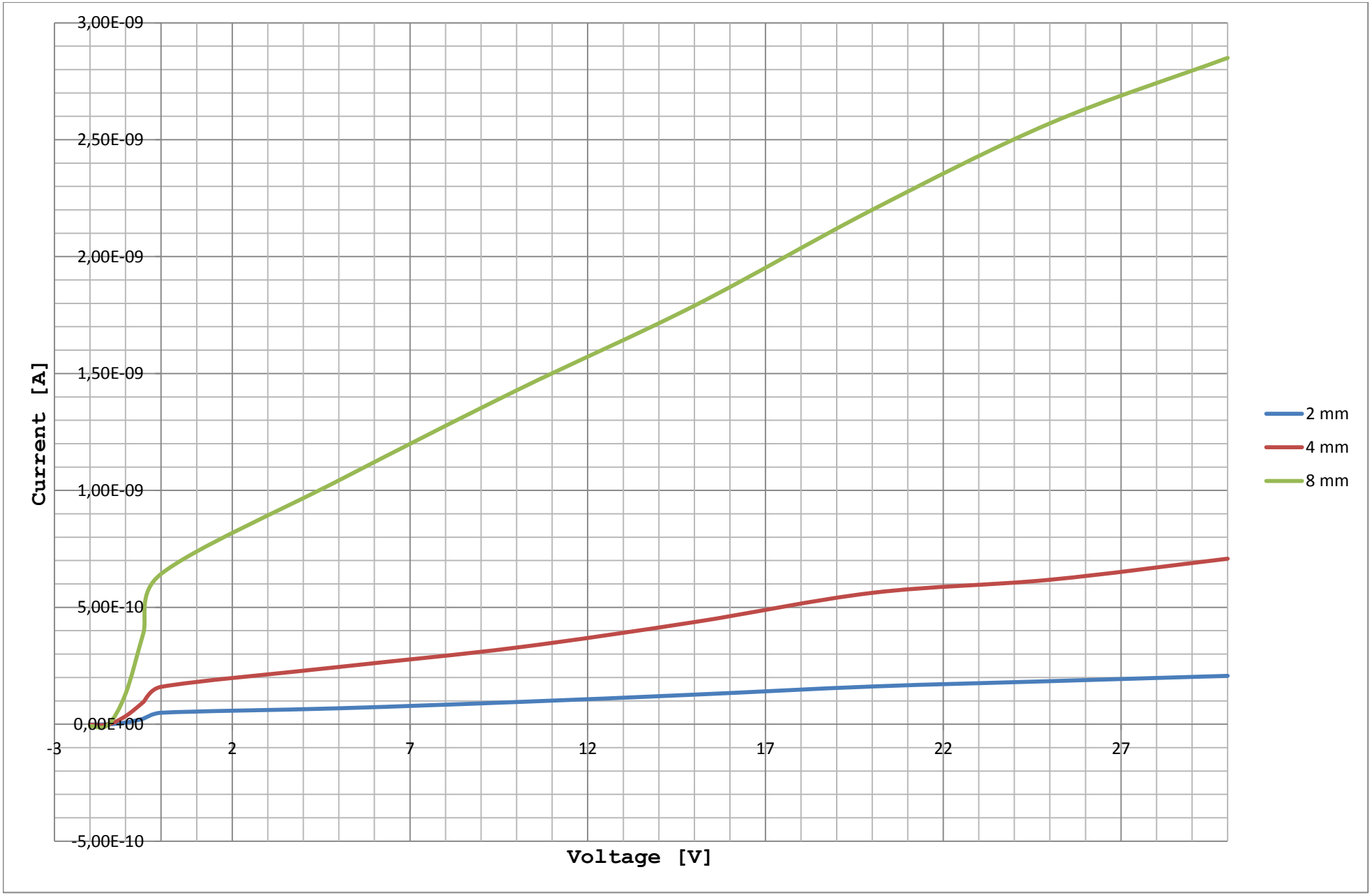
Normally electrons collected in cathode. However, in this experiment, electrons are also collected in anode surface. That is why we measured some photocurrent when bias voltage is zero.

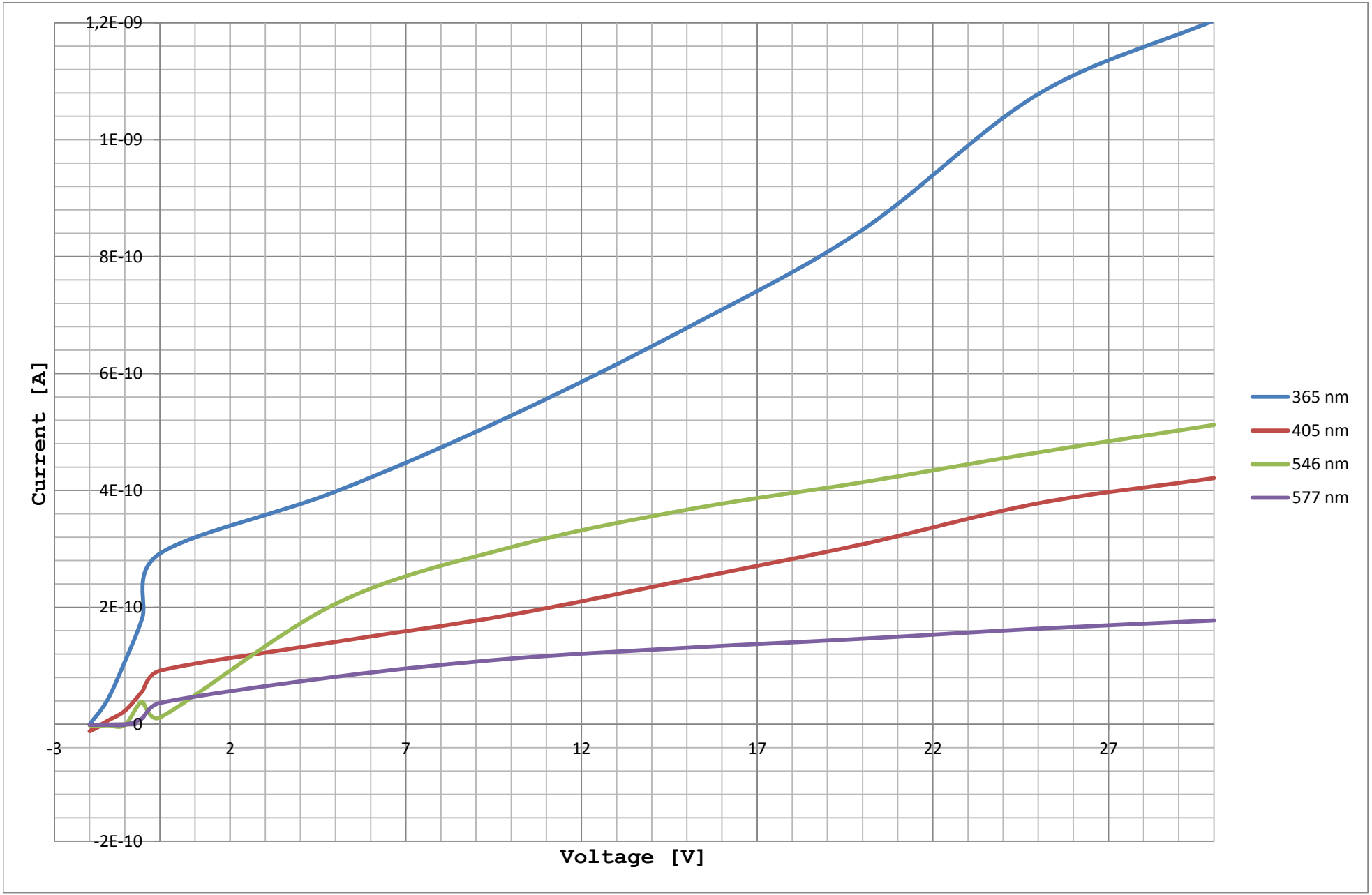
4. When the anode is positive with respect to the cathode, why does not the current immediately rise to its saturation value? What happens to the electrons which do not reach anode?

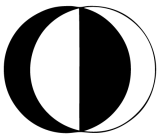
Stopping potential is the electrons whose do not reach to anode. When we applied negative potential to anode, then we have stopping potential. Current immediately rise to its saturation value if the voltage between the cathode and anode is greater than the stopping voltage, the photocurrent will increase quickly and eventually reach saturation.

Discussion and Conclusion

In this experiment we studied particle behaviour of light. We proved that light depends on energy and wavelength. In this experiment, we also stated the Planck's Constant with less than 5% error. As we mentioned before, Planck's constant has different values for different units. Since we applied voltage and current, we found Planck's constant in eV·s.


3,00E-09
2,50E-09
2,00E-09
1,50E-09
1,00E-09
5,00E-10
0,00E+00
-5,00E-10
Current [A]
-3
2
7
12
17
22
27
Voltage [V]
2 mm
4 mm
8 mm


1,2E-09
1E-09
8E-10
6E-10
4E-10
2E-10
0
-2E-10
Current [A]
-3
2
7
12
17
22
27
Voltage [V]
365 nm
405 nm
546 nm
577 nm



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Exp. MP-CE The Compton Effect

Group Members: Cem MADEN, İrem KÜL, Deniz AKYÜREK

Scattering Angle	Energy of the Scattered Photon [keV]	Wavelength of the Scattered Photon [m]	Compton Wavelength [m]
30°	538.5	2.30×10^{-12}	3.69×10^{-13}

Table 1: Energy and wavelength of the scattered photon

Experimentally found mean and standard deviation of Compton Wavelength = 0.369 pm
Expected value of the Compton Wavelength = 2.36 ± 0.14 pm

1. Explain. Why are there relatively many counts at energies less than the energy of the incident photons in both spectra obtained by the use of two Cs^{137} source with different activities.

It is because we did not calibrate the experiment setup.

2. Explain. Why are there relatively many counts at energies less than the energy of the expected scattered photons.

There was background radiation which is caused by other radioactive elements on in the laboratory, cosmic rays and used radiation source Cs-137 in the experiment. Another cause is that when a γ-photon enters it scatters several times. After each scattering photon loses some energy and a free electron is produced.

3. In a Compton scattering an electron is accelerated straight ahead in the same direction as that of the incident γ-ray photon. Which way does the scattered photon move?

Momentum conservation requires that the total initial momentum be equal to the total final momentum. The total initial momentum consists only of the forward momentum of the incoming photon.

Therefore, the direction of the final total momentum of the recoiling electron and the scattered photon must point in the +x direction. There can be no component of the final total momentum along the +y or –y direction. Thus, in order for the y component of the total final momentum to be absent, the scattered photon must move either in the +x or –x direction.

4. A photon can undergo Compton scattering from a molecule such as nitrogen, just as it does from an electron. However, the change in photon wavelength is much less than when the scattering is from an electron. Explain why?

To see why, let examine below equation which gives the difference between the wavelength λ' of the scattered photon and the wavelength λ of the incident photon in terms of the scattering angle θ.

$$\lambda' - \lambda = [h/(mc)](1 - \cos\theta) \tag{1}$$

The mass of a nitrogen molecule is much greater than the mass of an electron. Therefore, the factor h/mc will be much smaller if the target particle is a nitrogen molecule. Consequently, the change in the photon wavelength, $\lambda' - \lambda$ is much less than it is when the target particle is an electron.

5. In a specific experiment 500 keV energetic γ-rays are required but unfortunately there is only a Cs^{137} source in the laboratory. How would you manage to convert the gamma photon from Cs^{137} to 500 keV photons?

If photons are Compton scattered, we can have 500 keV photons. For this value we have to determine the angle of scattering by using following calculation
Wavelength of 500 keV photons

$$\lambda = \frac{hc}{E} = \frac{(4.135 \times 10^{-15} eV \cdot s) \cdot 3.0 \times 10^{8} m/s}{500 \times 10^{3} eV} = 2.481 \times 10^{-12} m \tag{2}$$

Angle of scattering will be

$$\theta = \cos^{-1}(1 - \frac{\Delta\lambda}{\wedge}) \tag{3}$$

where

$$\Delta\lambda = 2.481 \times 10^{-12} - 1.873 \times 10^{-12} = 6.08 \times 10^{-13} m \tag{4}$$

and $\wedge = 2.36 \times 10^{-13} m$. Therefore, angle of scattering will be

$$\theta = \cos^{-1}(1 - \frac{6.08 \times 10^{-13} m}{2.36 \times 10^{-13} m}) = \cos^{-1}(0.743) = 42^{\circ} \tag{5}$$

If we scatter photon with an angle of 42°, we get 500 keV photons.

6. Must Compton scattering take place only between X- or γ-rays and free electrons? Can blue light undergo Compton scattering with a free electron?

The wavelength of blue light is varies between 450 nm to 495 nm which is much larger than the Compton wavelength of the electron. For visible light, the Compton shift is negligibly small compared with its wavelength. So the change in wavelength of the visible light due to the Compton scattering would be too small to be measured.

Discussion and Conclusion

This experiment shows a crucial topic in Physics which is Compton effect. Normally, we must took data between 0 and 90 degree but we only measured the angle of 30 degree. That is why we could not compare experimental data whether it is decreases or increases due to increasing in angle. Since we have only one data, we cannot calculate a standard deviation error. However, we can calculate a percentage error. At 30°, energy of a scattered photon 564 keV [1]. Therefore

$$PercentageError = \frac{|TheoreticalValue - ExperimentalValue|}{TheoreticalValue} \times 100 \tag{6}$$

$$PercentageError = \frac{|564 - 538.5|}{564} \times 100 = 4.52\% \tag{7}$$

As we can see, we have very low percentage error. It is because, we measured this data in 300 seconds. In the lab, we set two different point for measurement. We had some background reading while taking data it is because our radiation source was radiating at all angles. We have seen a graph like below All

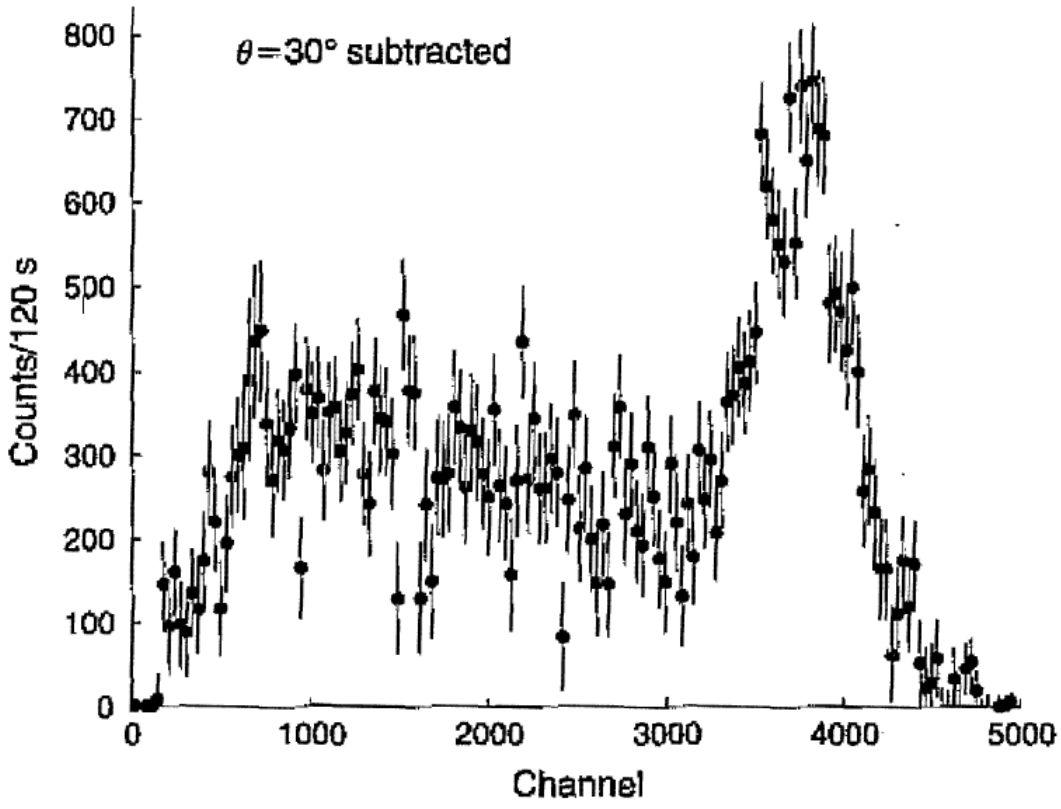
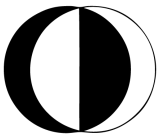


Figure 1: Plot of γ-rays at 30° for 120 secs

in all, we can say that this experiment is successful. We have very low percentage error which caused probably by instrumentation error.

References

[1] Melissinos, Adrian C. *Experiments in Modern Physics*,. New York: Academic Press, 1966. 382.



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Exp. MP-ED The Diffraction of Electrons by Graphite

Group Members: Cem MADEN, İrem KÜL, Deniz AKYÜREK
Experiment Date: December 18, 2015
Report Submit Date: December 25, 2015

			First Ring			Second Ring		
Measured Anode Voltage [V]	Converted Anode Voltage [V]	Wavelength [Å]	Inner Radius [m]	Outer Radius [m]	Average Radius [m]	Inner Radius [m]	Outer Radius [m]	Average Radius [m]
2	4000	0,19364917	0,011	0,0125	0,01175	0,0195	0,0215	0,0205
2,1	4200	0,18898224	0,0105	0,012	0,01125	0,0185	0,021	0,01975
2,2	4400	0,18463724	0,0105	0,012	0,01125	0,0185	0,0205	0,0195
2,3	4600	0,18057878	0,01	0,0115	0,01075	0,018	0,0195	0,01875
2,4	4800	0,1767767	0,01	0,0115	0,01075	0,0175	0,02	0,01875
2,5	5000	0,17320508	0,01	0,011	0,0105	0,0175	0,02	0,01875
2,6	5200	0,16984156	0,01	0,011	0,0105	0,017	0,019	0,018
2,7	5400	0,16666667	0,0095	0,011	0,01025	0,0165	0,0185	0,0175
2,8	5600	0,16366342	0,0095	0,0105	0,01	0,0165	0,018	0,01725
2,9	5800	0,16081688	0,009	0,0105	0,00975	0,016	0,0175	0,01675
3	6000	0,15811388	0,009	0,0105	0,00975	0,0155	0,0175	0,0165

Figure 1: Data for the first two interference rings on the diffraction pattern

Lattice Constants:

$$d_1 = 2.09 \pm 0.012 \mathring{A}$$
$$d_2 = 1.20 \pm 0.048 \mathring{A}$$

In the laboratory manual graphite planes for the first two interference rings is given below:

$$d_1 = 2.13 \mathring{A}$$
$$d_2 = 1.23 \mathring{A}$$

Voltage [V]	d_1 [m]	d_2 [m]	d_1 [Å]	d_2 [Å]
4000	2,0931E-10	1,1997E-10	2,09305908	1,19968021
4200	2,1334E-10	1,2152E-10	2,13339947	1,21522755
4400	2,0843E-10	1,2025E-10	2,08434925	1,20250918
4600	2,1333E-10	1,2231E-10	2,1333493	1,22312027
4800	2,0884E-10	1,1974E-10	2,08843166	1,19736748
5000	2,095E-10	1,1732E-10	2,09495669	1,17317575
5200	2,0543E-10	1,1983E-10	2,05427405	1,19832653
5400	2,065E-10	1,2095E-10	2,06504065	1,20952381
5600	2,0785E-10	1,2049E-10	2,0785254	1,20494226
5800	2,0947E-10	1,2193E-10	2,09474295	1,21932799
6000	2,0595E-10	1,217E-10	2,05953468	1,21699777
Sum	2,298E-09	1,326E-09	22,9796632	13,2601988
Average	**2,0891E-10**	**1,2055E-10**	**2,08906029**	**1,20547262**

Figure 2: Latice constants for each voltage value

1. What is the implication of the diffraction pattern on the screen in the experiment you have carried out?

We targeted an electron gun to graphite planes as we mentioned in manual. When an electron strikes to graphite planes, it scatters an electron from this plate. After passing through from collimators we can see these electrons as a pattern on the screen. Theoretically we could have seen more than two circular line on the screen but we observed an electron beam at the center and two circular lines around this beam. Below figure illustrates the experiment. On the right figure, after second ring, circles started to blurred.

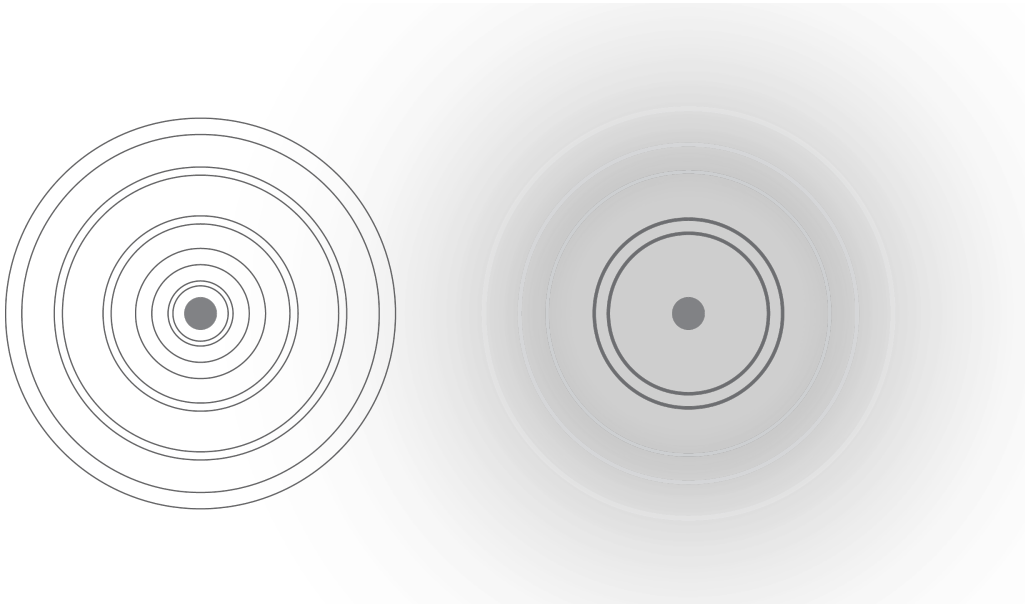


Figure 3: **Left:** Predicted screen resolution for diffraction pattern. **Right:** Observed screen resolution for diffraction pattern.

2. What properties of a material can be determined from the experiment you have carried out?

We can determine the wavelength of electrons, verify the de Broglie's equation, determine the lattice place spacing of graphite and structure of crystal. If we have some solid state physics knowledge we can determine the type of crystals whether simple cubic, face-centered cubic or body-centered cubic. Since we measure the wavelength of material, we can also calculate mass, momentum and some other basic properties of related material.

Discussion and Conclusion

As we know, light can behave both particle and wave like. In this experiment we studied the wave behaviour of electrons. The wave aspect of particle first demonstrated by C. H. Davisson and L.H. Gerner. After this experiment, hypothesis of L. de Broglie is corrected he was awarded the Nobel Prize in Physics in 1929. In 1937, Davisson and Gerner received Nobel Prize for their experiment. In this experiment we used a crystal graphite to scatter electrons. As seen in Figure 3, we observed only two rings on the screen. Since this is not enough to determine a correct wavelength, we changed voltage and measured the differences in those rings. This difference can be seen in Figure 1. Theoretical values for lattice constants are mentioned above. By using them we can calculate a percentage error for this experiment:

$$PercentageError = \frac{|TheoretialValue - ExperimentalValue|}{TheoretialValue} \times 100 \tag{1}$$

For d_1

$$PercentageError = \frac{|2.13 - 2.09|}{2.13} \times 100 = \boxed{1.9\%} \tag{2}$$

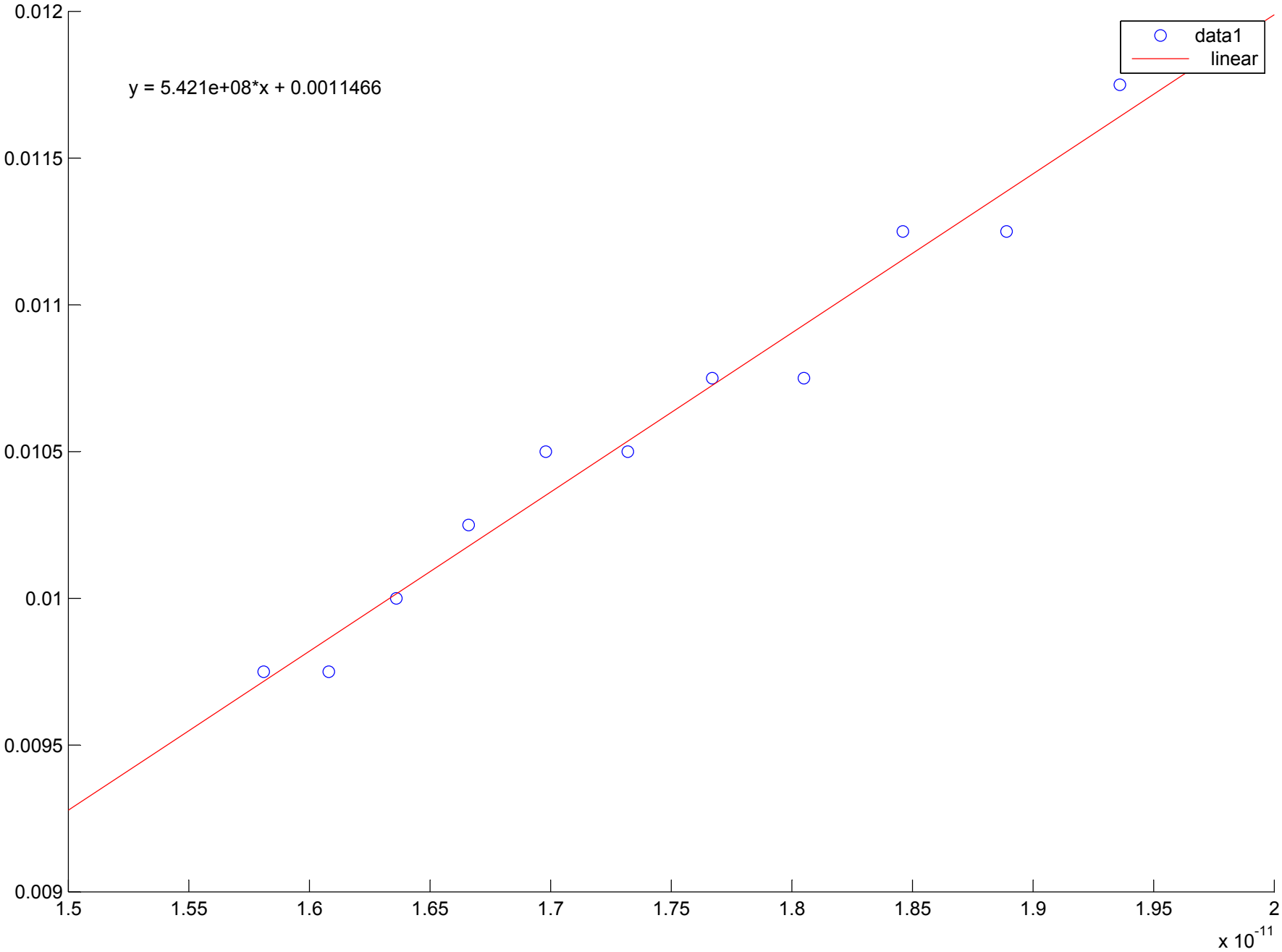
For d_2

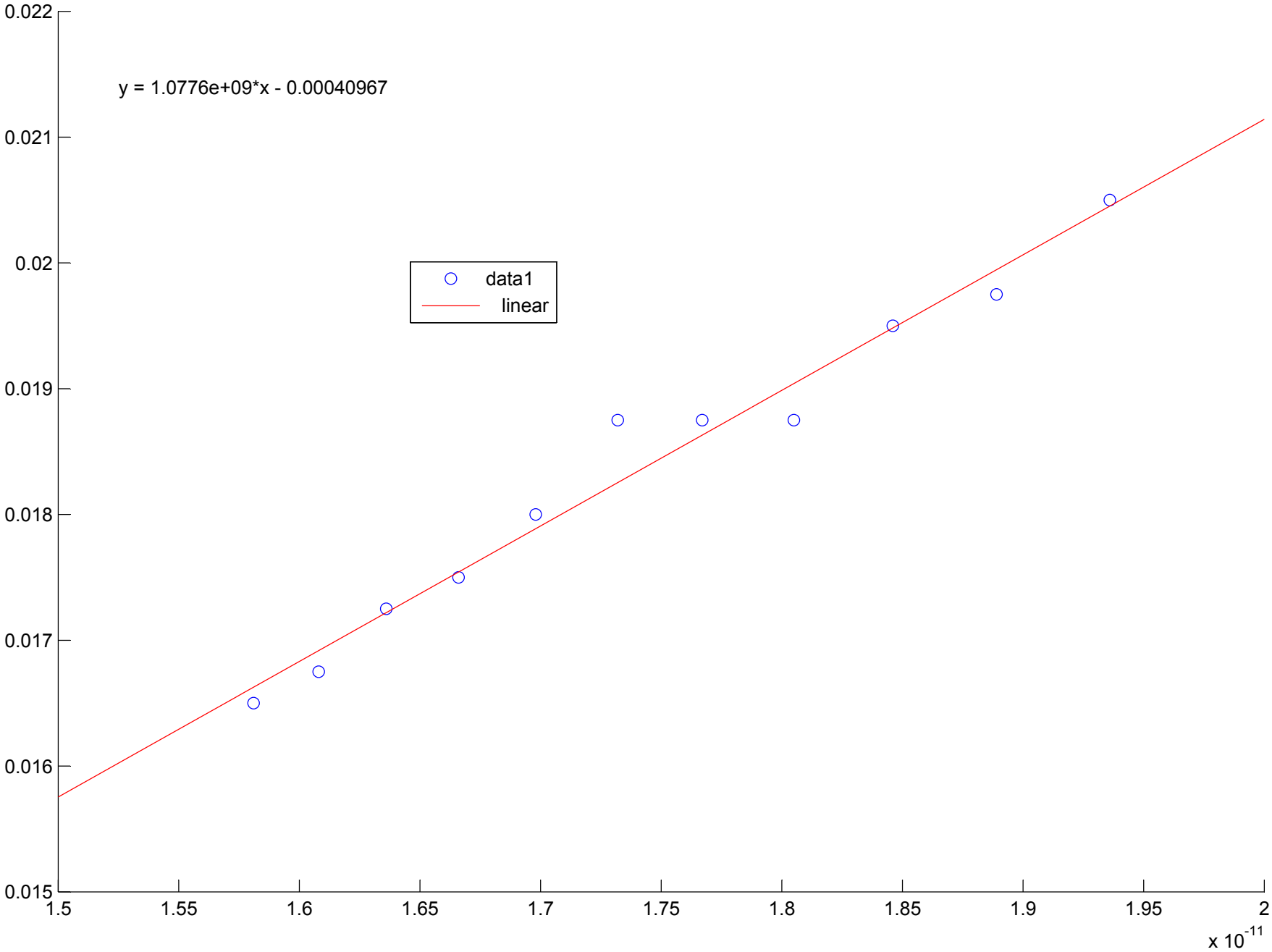
$$PercentageError = \frac{|1.23 - 1.20|}{1.23} \times 100 = \boxed{2.4\%} \tag{3}$$

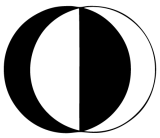
There is an extra table in this report as seen in Figure 2. Since we have different d_1 and d_2 values for each voltage and wavelength, I calculated an average value for them. These lattice constants are calculated according to following equation:

$$d = n\frac{2R}{r}\lambda \tag{4}$$

where $R = 0.0635$ m, $n = 1$, r and d are varies according to Figure 1. We can say that this experiment is accomplished it is because we have very low percentage errors and we observed what we predict before the experiment. These errors caused by human falses and setup falses. For instance, as stated in manual setup reduces the voltage ratio 100:2.


y = 5.421e+08*x + 0.0011466
data1
linear
0.012
0.0115
0.011
0.0105
0.01
0.0095
0.009
1.5
1.55
1.6
1.65
1.7
1.75
1.8
1.85
1.9
1.95
2
x 10^-11


y = 1.0776e+09*x - 0.00040967
data1
linear
0.022
0.021
0.02
0.019
0.018
0.017
0.016
0.015
1.5
1.55
1.6
1.65
1.7
1.75
1.8
1.85
1.9
1.95
2
x 10^-11



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Exp. MP-HE The Hall Effect

Group Members: Cem MADEN, İrem KÜL, Deniz AKYÜREK
Experiment Date: December 4, 2015
Report Submit Date: December 11, 2015

Sample Current - I_p (mA)	Hall Voltage - U_H (mV)
-30	-39.6
-25	-32.1
-20	-23.7
-15	-15.2
-10	-8.3
-5	0.7
0	7.7
5	15.7
10	24.8
15	32.4
20	39.7
25	48
30	55.6

Table 1: Hall Voltage as a function of Sample Current

Slope m=1.6 mV/mA

•The charge carrier concentration from (U_H versus I_p) =8.1×10^{20} m^{-3}
•Type of Germanium semiconductor used = *p-type*

Flux Denstiy - B (mT)	Hall Voltage - U_H (mV)	Sample Voltage - U_p (mV)
0	-1.3	1.80
15	2.5	1.80
30	6.0	1.80
45	10.2	1.81
60	13.4	1.81
75	17.0	1.81
90	20.6	1.81
105	24.3	1.81
120	27.4	1.81
135	30.6	1.81
150	34.7	1.82
165	37.9	1.82
180	41.5	1.83
195	44.3	1.83
210	48.0	1.83
225	50.7	1.83
240	54.0	1.84
255	57.3	1.84
270	60.3	1.84
285	63.4	1.85
300	66.1	1.85

Table 2: Hall Voltage and the Sample Voltage as a function of Flux Density

Slope m=0.2 mV/mT

	x	y	(x-x̄)	(x-x̄)²	x²	y²	ŷ	xy	(y-ŷ)	(y-ŷ)²
	0	-1,3	-150	22500	0	1,69	0	0	-1,3	1,69
	15	2,5	-135	18225	225	6,25	3,3	37,5	-0,8	0,64
	30	6	-120	14400	900	36	6,6	180	-0,6	0,36
	45	10,2	-105	11025	2025	104,04	9,9	459	0,3	0,09
	60	13,4	-90	8100	3600	179,56	13,2	804	0,2	0,04
	75	17	-75	5625	5625	289	16,5	1275	0,5	0,25
	90	20,6	-60	3600	8100	424,36	19,8	1854	0,8	0,64
	105	24,3	-45	2025	11025	590,49	23,2	2551,5	1,1	1,21
	120	27,4	-30	900	14400	750,76	26,5	3288	0,9	0,81
	135	30,6	-15	225	18225	936,36	29,8	4131	0,8	0,64
	150	34,7	0	0	22500	1204,1	33,1	5205	1,6	2,56
	165	37,9	15	225	27225	1436,4	36,4	6253,5	1,5	2,25
	180	41,5	30	900	32400	1722,3	39,7	7470	1,8	3,24
	195	44,3	45	2025	38025	1962,5	43,1	8638,5	1,2	1,44
	210	48	60	3600	44100	2304	46,4	10080	1,6	2,56
	225	50,7	75	5625	50625	2570,5	49,7	11408	1	1
	240	54	90	8100	57600	2916	53	12960	1	1
	255	57,3	105	11025	65025	3283,3	56,3	14612	1	1
	270	60,3	120	14400	72900	3636,1	59,6	16281	0,7	0,49
	285	63,4	135	18225	81225	4019,6	63	18069	0,4	0,16
	300	66,1	150	22500	90000	4369,2	66,3	19830	-0,2	0,04
Σ	3150	708,9	0	173250	645750	32742	695,4	145386	13,5	22,11

Figure 1: Terms calculate the slope and error in the slope of Hall Voltage versus Field Strength ($x = B$, $y = U_H$)

Sum of some important values:
$\sum x = 3150$
$\sum y = 708.9$
$\sum x^2 = 645750$
$\sum y^2 = 32742$
$\sum xy = 145386$
$\sum (y - \hat{y})^2 = 22.11$
$\sum (x - \bar{x})^2 = 173250$

e. Find slope by the use of following formula

$$m = \frac{145386 - \frac{\sum x \sum y}{n}}{\sum x^2 - \frac{(\sum x)^2}{n}} \tag{1}$$

$$m = \frac{\sum xy - \frac{3150 \times 708.9}{21}}{645750 - \frac{(3150)^2}{21}} \tag{2}$$

$$m = \frac{39051}{173250} \tag{3}$$

$$\boxed{\text{m=0.225}}$$

Then find the charge carrier concentration n by the use of following formula

$$n = \frac{I}{mqd} \tag{4}$$

where I=0.03 A, d=0.001 m and q=1.602×10^{-19}

$$n = \frac{0.03}{0.001 \cdot 1.602 \times 10^{-19} \cdot 0.225} \tag{5}$$

$$\boxed{n = 8.32 \times 10^{20}}$$

f. Find Δm (standard error in the original slope) by the use of following formula

$$\Delta m = \sqrt{\frac{\frac{1}{n-2} \sum (y - \hat{y})^2}{\sum (x - \bar{x})^2}} \tag{6}$$

$$\Delta m = \sqrt{\frac{\frac{1}{19} 22.11}{173250}} \tag{7}$$

$$\boxed{\Delta m = 0.00259}$$

The standard error in carrier concentration is

$$\Delta n = \frac{n^2}{K} \times \Delta m \tag{8}$$

where $K = \frac{I}{qd}$ which is equal to 1.87×10^{20} in this case

$$\Delta n = \frac{(8.32 \times 10^{20})^2}{1.87 \times 10^{20}} \times 0.00259 \tag{9}$$

$$\boxed{\Delta n = 9.58 \times 10^{18}}$$

So,

$$\boxed{\text{n} = 8.32 \times 10^{20} \pm 9.58 \times 10^{18}\ \text{m}^{-3}}$$

1. Explain how did you find out the type of semiconductor.

As we can see in Table 1, slope is positive (m=1.6). Since slope is positive, we can say that this is a p-type semiconductor.

2. a) A piece of semiconductor with the Hall coefficient 6.3×10^{-4} $\mathbf{m^3C^{-1}}$ is used to make a Hall probe. A current of 2.0 mA is passed along the 10 mm length of the probe. The width of the face to be placed perpendicular to the uniform magnetic field measures 5 mm and the thickness is 1 mm. Estimate the Hall potential difference which would be obtained when B is 0.3 T.

As we know, Hall coefficient R_H is equal to $\frac{1}{nq}$. Hall potential V_H

$$V_H = \frac{1}{nq}\frac{IB}{d} \tag{10}$$

Therefore Hall potential V_H will be

$$V_H = 6.3 \times 10^{-4}\frac{0.3 \cdot 2.0 \times 10^{-3}}{1.0 \times 10^{-3}} \tag{11}$$

$$\boxed{V_H = 3.78 \times 10^{-4}\ \text{V}}$$

b) Find the speed of the charge carriers in the semiconductor given above.

$$v = \frac{1}{nq}\frac{I}{A} \tag{12}$$

where A is cross-sectional area of semiconductor

$$v = 6.3 \times 10^{-4}\frac{2.0 \times 10^{-3}}{5 \times 10^{-5}} \tag{13}$$

$$\boxed{v = 0.0252\ \text{m/s}}$$

3. Explain how and why does the sample voltage change with magnetic field strength ($U_P - B$).

The resistance of the sample increases with the increase of magnetic. Ohm's Law stated the relation between resistance and voltage clearly as

$$V = IR \tag{14}$$

Since resistance R increase, voltage V also increases. This phenomenon is known as magnetoresistance which is due to the fact that the drift velocity of all carriers is not the same.

4. Explain how and why does the Hall voltage change with magnetic field strength ($V_H - B$).

The Hall Voltage is a linear function of the applied magnetic field. This relation can be expressed mathematically as

$$V_H = -wvB \tag{15}$$

where B is the magnetic field strength. When a magnetic field is applied to across the semiconductor or any material which is perpendicular to the current path, Lorentz forces cause a slight shift in the current path because they do in traditional Hall effect. This is causes a voltage differential. As we mentioned above, Hall voltage is proportional to the magnetic field and also related with the drift velocity. In a known magnetic field, drift velocity can be calculated by using Hall voltage.

Discussion and Conclusion

In this experiment we carried out a crucial topic in physics which is Hall Effect. Hall effect is widely using in some like Solid State Physics. When we put a conductor in a magnetic field then a voltage difference can be observed across the conductor. By using Hall Effect, today, we can detect the type of a semiconductor wheter is a p-type or n-type. While talking about Hall effect, we should explain the Hall Coefficient R_H which is equal to $1/nq$. In this experiment we used a Germanium semiconductor which is the intrinsic semiconductor. We applied different voltage and current to our semiconductor and we observed that each one can effect the magnetic field stregth. Obviously, changing in magnetic field stregth also effect voltage and current. There is one issue that we did not studied in the experiment that is the behaviour of voltage and current in different temperature. As we state in Table 2, slope is 0.2 mV/mT. After calculations whose are stated in Figure 1 we can see that slope m is equal to 0.225 mV/mT. In Figure 3 and 4 we stated theoretical and experimental values for Hall Voltage. Since there is a small difference between them we can calculate a percentage error as follows

$$PercentageError = \frac{|0.22 - 0.23|}{0.22} \times 100\% = 4.5\% \tag{16}$$

To sum up, we can say that this experiment was successful and data that we took in experiment is acceptable.

Plots

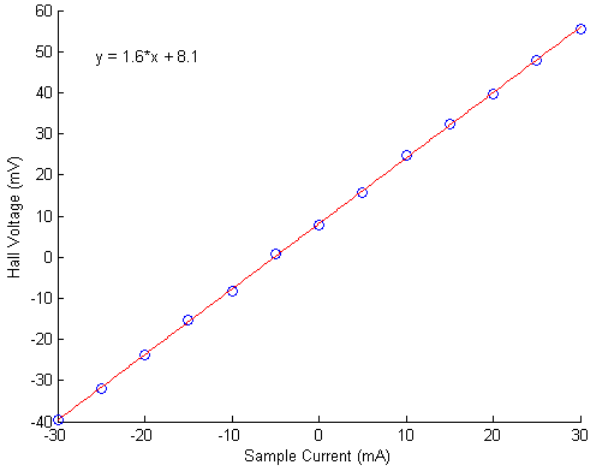


Figure 2: Hall Voltage versus Sample Current

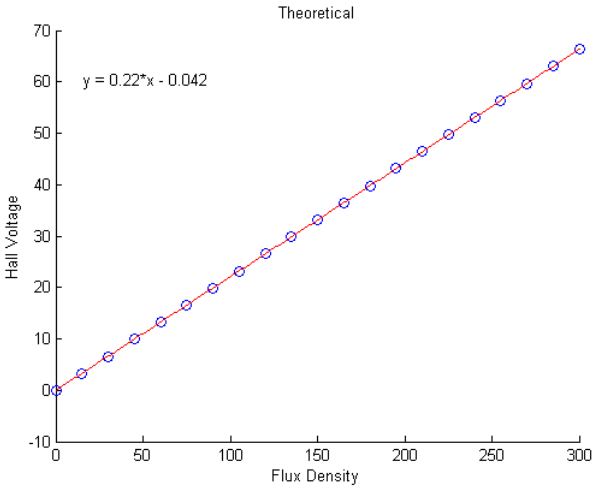


Figure 3: Hall Voltage versus Flux Density Theoretical Value

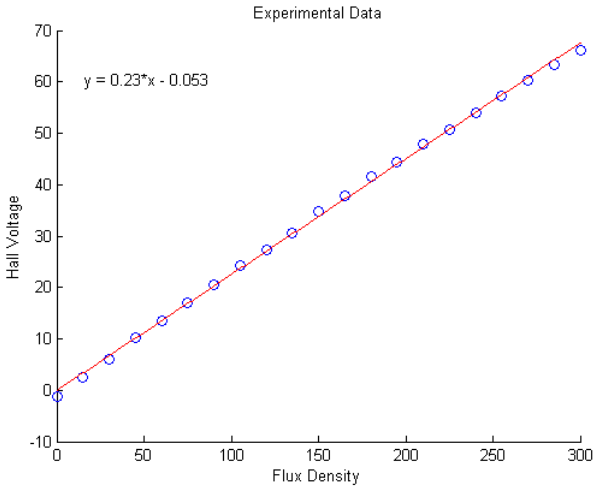
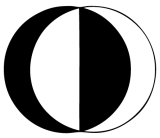


Figure 4: Hall Voltage versus Flux Density Experimental Value



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Exp. MP-SA The Energy Spectra of Alpha Particles

Group Members: Cem MADEN, İrem KÜL, Deniz AKYÜREK
Experiment Date: November 27, 2015
Report Submit Date: December 4, 2015

Peak (channel no)	Source of α-particles	Energy (in keV)
76	^{226}Ra	4780
118	^{222}Rn	5551
146	^{218}Po	6065
234	^{214}Po	7680

Table 1: The resolved peaks in the spectrum of ^{226}Ra in the vacuum

Peak (channel no)	Energy (in keV)
52	4340
100	5221
140	5954
230	7606

Table 2: The resolved peaks in the spectrum of ^{226}Ra in the air

Peak (channel no)	Total Pulses	Energy (in keV)	Source of α-particle
151	4280	6156	^{244}Cm

Table 3: Data for unknown α-source in the vacuum

1. Calculate the activity of the unknown α-source.

$$Activity(\alpha/s) = (\frac{\sum \alpha}{t})(\frac{4\pi S^2}{A}) \tag{1}$$

where S=0.02 m, A=4.0×10^{-6}m^2, $\sum \alpha = 4280$ and t=300 secs.

$$Activity(\alpha/s) = (\frac{4280}{300})(\frac{4 \cdot \pi \cdot 0.02^2}{4.0 \times 10^{-6}}) \tag{2}$$

$$Activity(\alpha/s) = 17928 decay/s \tag{3}$$

$$Activity(\alpha/s) = 0.48 \mu Ci \tag{4}$$

2. Write at least five different reasons for observing only a few peaks rather than nine peaks in the spectrum of ^{226}Ra in the vacuum and make suggestions to improve the resolving of the peaks in the spectrum with the present system.

1- We could not vacuumed the detector 100%.
2- Noise and vibration
3- ^{216}At, ^{218}Rn, ^{210}Tl and ^{206}Tl in the decay sequence of ^{226}Ra only occur with very low activities.
4- Loss of radon daughters [1].
5- The detector does not have high sensivity.
6- In the experiment we used five different experimental setups and each one have it's own calculation error.
To be more accurate in the experiment my suggestion is splitting vacuum chamber and other experiment setups because noise and vibration are very effective to distort the data. Using an high tech detector will give more accurate solutions. In laboratory, other radioactive decays may cause to distortion in data. Some researchers state that a calibration before the experiment may reduce to error in experiment. ^{210}Po, ^{238}U, ^{238}Pu, ^{239}Pu and ^{241}Am is strongly preferred over pulser-calibration techniques [2].

3. Describe the physical significance of any peak on energy spectra of α-particles.

Each peak is a α decay of ^{226}Ra. In each peak ^{226}Ra is turned to his isotopes in the order of as stated in Table 1. By using these peaks we can calculate the energy of α decays, we can detect the type of radioactive isotopes.

Discussion and Conclusion

In this experiment we observe the α decay of ^{226}Ra in both vacuum and air. After this experiment we can realize the behaviour of α decays in different environment. Another significant observation in this experiment is the decays of unknown sample. By using decay rate of unknown sample we tried to predict that name of radioactive isotope. In this experiment we have very low percantage error. For instance for ^{222}Rn which is took in vacuumed chamber:

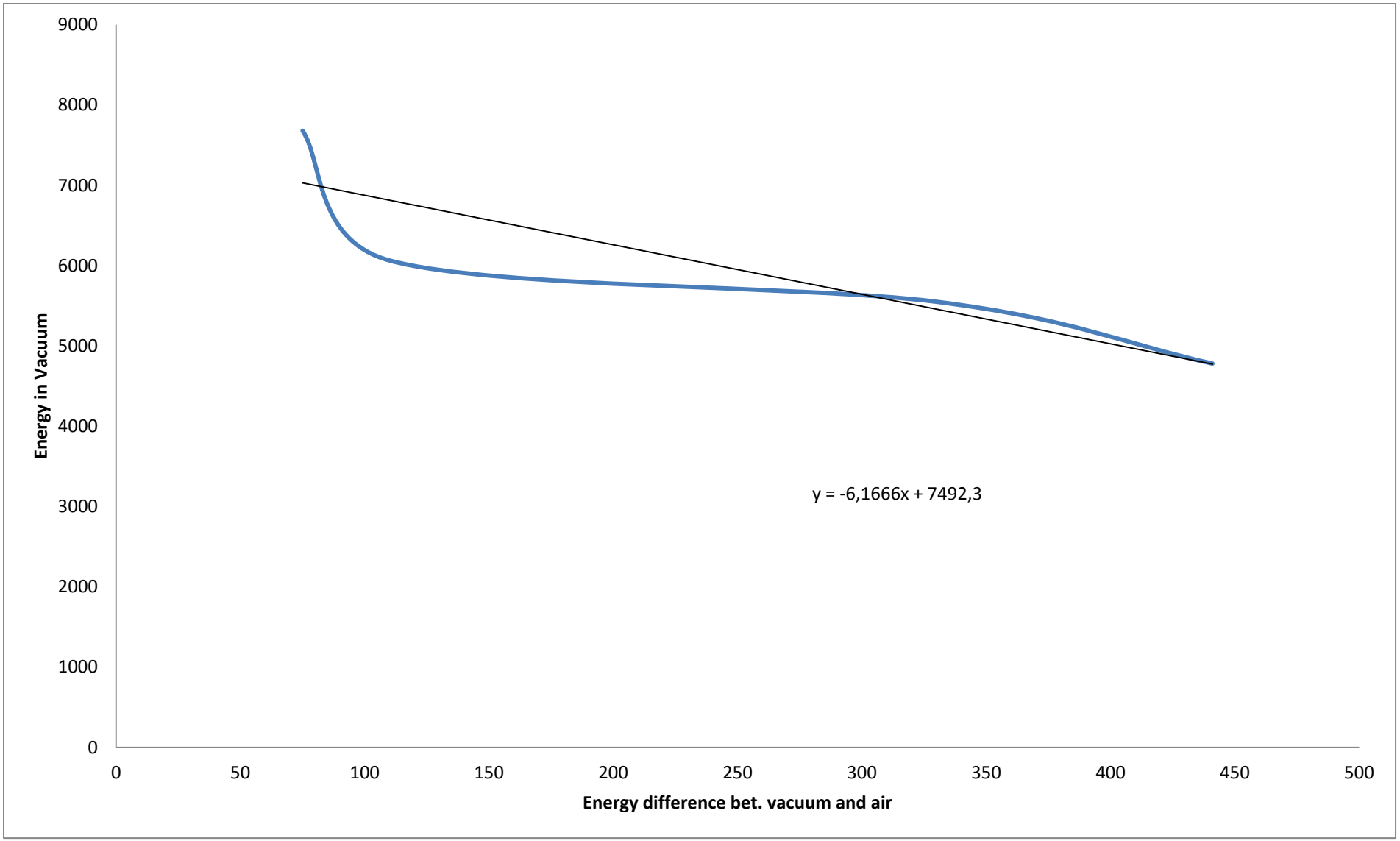
$$Per.Error = \frac{|5480 - 5550|}{5480} \times 100\% \tag{5}$$

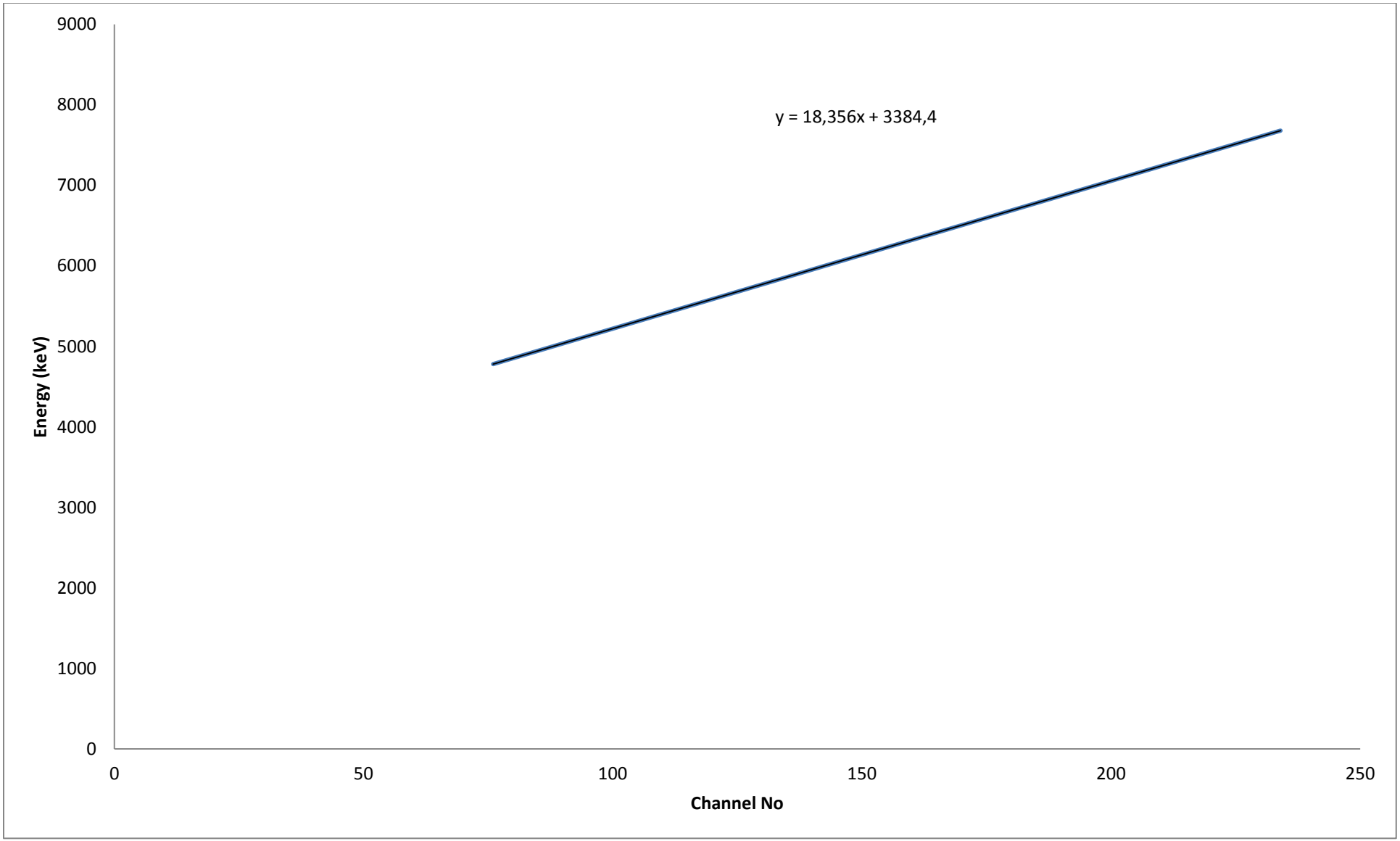
$$Per.Error = 1.3\% \tag{6}$$

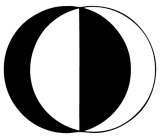
References

[1] *Alpha-, Beta-, and Gamma-Ray Spectroscopy*, Ed.: Kai Siegbahn, Vol. 1, North-Holland Publ. Co., Amsterdam, New York (1968)

[2] *Nuclear Spectroscopy and Reactions,* Ed.: J. Cerny, Academic Press, New York and London (1974)


9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Energy in Vacuum
y = -6,1666x + 7492,3
0
50
100
150
200
250
300
350
400
450
500
Energy difference bet. vacuum and air


y = 18,356x + 3384,4
Energy (keV)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
50
100
150
200
250
Channel No



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Exp. MP-SB The Spectroscopy of Beta β Particles

Group Members: Cem MADEN, İrem KÜL, Deniz AKYÜREK
Experiment Date: November 13, 2015
Report Submit Date: November 20, 2015

Trial 1	Trial 2	Trial 3	Average Counts
4	5	7	5.33

Table 1: Counts at zero magnetic field *(B=0)* strength for ^{90}Sr

We need to calculate kinetic energy of each particle in different magnetic fields. The kinetic energy K of a particle is

$$K = \sqrt{(eBrc)^2 + m_0^2c^4} - m_0c^2 \tag{1}$$

where e is charge of an electron, r is radius of given orbital, c is speed of light, B is magnetic field and m_0 is rest mass of particle. As an example for a kinetic energy of a β^--particle, we can take a particle which is in B=100 mT magnetic field. We are going to use following values:

- $e = 1.60217662 \times 10^{-19}$ C
- $m_0 = 9.10938215 \times 10^{-31}$ kg
- $r = 0.05$ m
- $c = 3.0 \times 10^8$ m/s
- $B = 0.1$ T

$$K = \sqrt{(1.60217662 \times 10^{-19} \times 0.1 \times 0.05 \times 3.0 \times 10^8)^2 + (9.10938215 \times 10^{-31})^2(3.0 \times 10^8)^4} - (9.10938215 \times 10^{-31})(3.0 \times 10^8)^2 \tag{2}$$

$$K = \sqrt{6.45 \times 10^{-26}} - 8.20 \times 10^{-14} \tag{3}$$

$$K = 2.53923 \times 10^{-13} - 8.20 \times 10^{-14} \tag{4}$$

$$K = 1.72 \times 10^{-13} Joule \tag{5}$$

As we can see, this equation gives result in Joules unit. However, we need to convert it to keV. Therefore we are going to use following equation:

$$1J = 6.2415096471204 \times 10^{15} keV \tag{6}$$

B [mT]	Trial 1	Trial 2	Trial 3	Average	Corrected Average	Energy [keV]
10	11	9	5	8.33	3	21.48
20	16	16	13	15	9.67	81.41
30	14	19	21	18	12.67	169.16
40	27	19	21	22.33	17	276.83
50	52	37	45	44.67	39.34	396.20
60	52	62	55	56.33	51	523.57
70	66	69	67	67.33	62	656.32
80	64	90	75	76.33	71	792.82
90	85	71	83	79.66	74.33	932.02
100	86	66	78	76.66	71.33	1073.16
110	98	59	85	80.66	75.33	1215.80
120	59	70	69	66	60.67	1359.60
130	58	58	60	58.66	53.33	1504.3
140	35	49	32	38.66	33.33	1649.73
150	34	26	27	29	23.67	1795.74
160	32	29	20	27	21.67	1942.23
170	19	14	12	15	9.67	2089.12
180	12	10	9	10.33	5	2236.15
190	6	9	11	8.66	3.33	2383.86
199.5	6	7	7	6.66	1.33	2531.61

Table 2: Counts of β^--particles for different values of magnetic field strength

Finally, we see that at 100 mT magnetic field, a β^--particle has a kinetic energy of 1073.16 keV.

Experimental end-point energy of β^--particles = 2531.61 keV

Accepted end-point energy of β^--particles = 2270 keV

Percentage error in end-point energy of β^--particles = 3.59%

$$PercentageError = \frac{|ExperimentalValue - TheoreticalValue|}{TheoreticalValue} \times 100\% \tag{7}$$

1. Explain the high counting readings when the magnetic field strength is equal to zero.

Background counting is caused by different types of radiation and their penetrating ability. These may be natural sources such as cosmic rays and radioactive elements found in the surrounding air and building materials, or artificial sources such as unshielded radioactive chemicals stocked nearby or the luminous paint of a wristwatch [1]. For instance, in our lab we have Cs-137 and it can cause some radiation. The background radiation count rate should always be measured as part of any radiation experiment. It should then be subtracted from the count rate data taken for the experimental source like as we did while calculating corrected average. In fact, there is a way to reduce background radiation. C-14 is a good beta emitter but in our experiment it does not work because its beta particles have low energy and are deflected out of the magnetic field before they can reach the Geiger tube [2].

Another possible background counting cause may be Bremsstrahlung *(also known as braking radiation or deceleration radiation)*. Bremsstrahlung is a electromagnetic radiation which is produced by the deceleration of charged particles when these particles deflected by another particle [3]. Since I am not familiar with this topic, I will not move deeper.

2. Comment on the graph that you have plotted.

This graph demonstrate the spectrum of electrons emitted in the β^- decay of Sr-90. The last data

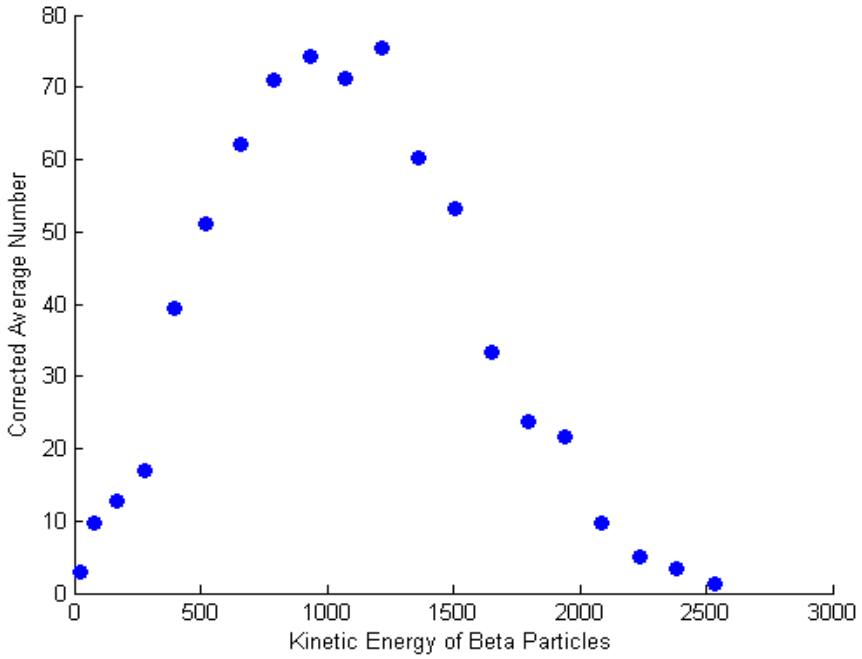

Figure 1: Corrected average number versus kinetic energy of β^--particles emitted from Sr-90 in keV

point shows us the endpoint of Sr-90. Since we have some experimental error our graph does not look like theoretical one. These graphs are mostly plotting in MeV unit but we plotted in keV. In this experiment we used only Sr-90. However, this experiment completed with other elements such as Cs-137, Co-60 and Am-241. Note that each one will give different graphs. For instance, we have only one peak but Cs-137 and Co-60 have more than two peaks (see Figure 2).

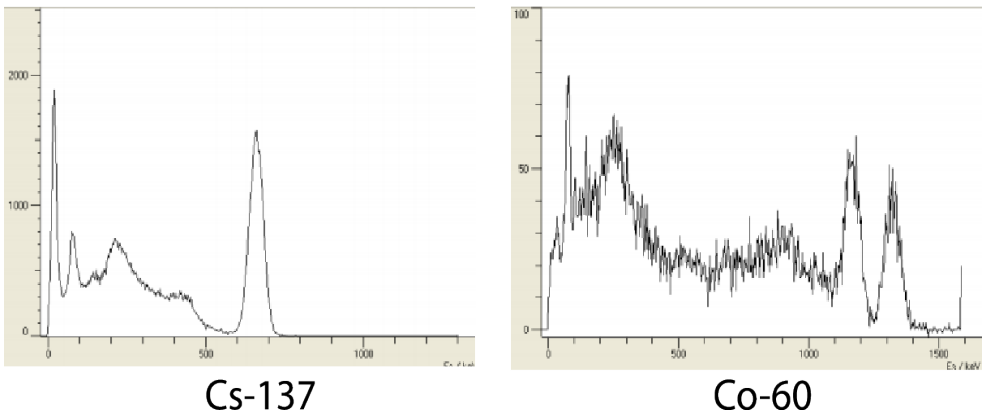

Figure 2: Spectrum for Cs-137 and Co-60 with Background Subtracted

Discussion and Conclusion

In this experiment, we studied the β^--particle decay which is very important topic in nuclear physics. This experiment shows that kinetic energy of β particles can effected by magnetic field. Besides, each radioactive isotopes have different kinetic energy values and different energy spectrum also. Another important fact that I learned in the experiment is that a radioactive isotope can transform another radioactive isotope at different kinetic energies. For instance, Sr-90 is a radioactive isotope of Strontium and Sr-90 becomes Yr-90 in 540 keV and then becomes Zr-90 in 2270 keV [4]. After this experiment I became more familiar with some topics such as neutrino, anti-neutrino, Kurie plot and Fermi Function. According to our results, end-point energy of β^--particles is 2531.61 keV. However, while I was searching this value stated as 546 keV [5]. I am still confused about this value. When examine our graph we can see that we have a peak at 1215 keV kinetic energy and I do not know what does it stands for? If we had more than one source, we would see different behaviours of radioactive isotopes and different energy spectrums. Overall, I think that this experiment was succesful and objective of experiment is reached.

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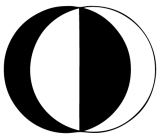

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Exp. MP-AG The Absorption of Gamma Rays

Group Members: Cem MADEN, İrem KÜL, Deniz AKYÜREK

Trial 1	Trial 2	Trial 3	Average
1932	1831	1914	1892

Table 1: Background Intensity [counts/min]

Mass per cross sectional area of Pb [g/cm²]	Trial 1	Trial 2	Trial 3	Average	Corrected Average
0	26780	27188	27063	27010,33	25118,33
3,5	18733	18874	19035	18880,67	16988,67
7	14028	14171	13979	14059,33	12167,33
10,5	10598	10644	1066	7436	5544
14	8576	8280	8334	8396,667	6504,667
17,5	6552	6728	6592	6624	4732
21	5413	5606	5479	5499,333	3607,333
24,5	4697	4566	4565	4609,333	2717,333

Figure 1: Counting rates of radiation from ^{137}Cs for different thickness of lead

Slope of the line = $21759e^{-0.088x}$
Mass absorption coefficient $\mu_m = 7.76\times10^{-3}$ cm^2/g
Linear absorption coefficient $\mu = 0.088$ cm^{-1}
Apparent energy value of γ-rays from ^{137}Cs = 667.0 keV
Accepted energy value of γ-rays from ^{137}Cs obtained from Fig.AG.1 = 661.6 keV
Percentage error in the energy of γ-rays from ^{137}Cs = 0.81 %

1. What is the half thickness of γ-rays from ^{137}Cs in lead?

The half thickness $d_{1/2}$ of a material is the thickness that decreases the incident radiation energy by one half. We can express this quantity as follows

$$d_{1/2} = \frac{\ln 2}{\mu} \tag{1}$$

As we stated above μ is 0.088 cm^{-1}. So

$$d_{1/2} = \frac{\ln 2}{0.088} \tag{2}$$

$$d_{1/2} = 7.87cm \tag{3}$$

2. Compute the percent of an incident beam of γ-rays from ^{137}Cs after passing through 2 mm of lead.

$$I = I_0 e^{-\mu x} \tag{4}$$

μ=0.088 cm^{-1}, x is 0.20 cm, $\rho_{Pb} = 11.3g/cm^3$

$$\frac{I}{I_0} = e^{-\mu x} = e^{-0.088\times 0.20} \tag{5}$$

$$\frac{I}{I_0} = e^{-0.0176} \tag{6}$$

$$\frac{I}{I_0} = 0.98 \tag{7}$$

above results show that the transmitted beam. Therefore %2 of the beams is absorbed.

3. Would the semilog graph of intensity versus thickness of the absorber be a straight line if the γ-radiation contained γ-rays of two different energies? Explain.

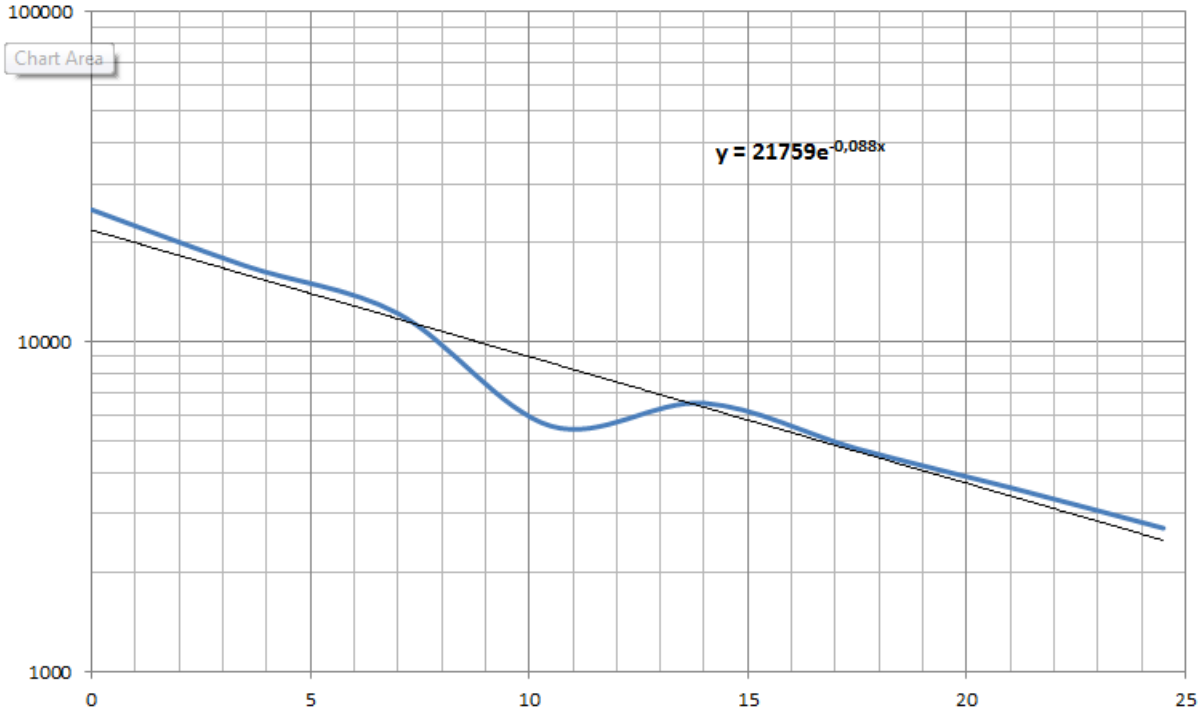


Figure 2: Graph of Intensity versus Thickness of the Absorber

No, if there were two absorption coefficients, Eq. 4 would have the form of

$$I = I_1 e^{-\mu_1 x} + I_2 e^{-\mu_2 x} \tag{8}$$

When the logarithms of both sides are taken, this does not reduce to a straight line.

4. The mass absorption coefficient of iron is 0.058 cm^2/g for 1.24 MeV γ-rays. What percentage of the beam of such γ-rays is transmitted (if any) through an iron plate 3 cm thick? (ρ_{Fe}=7.86g/cm^2)

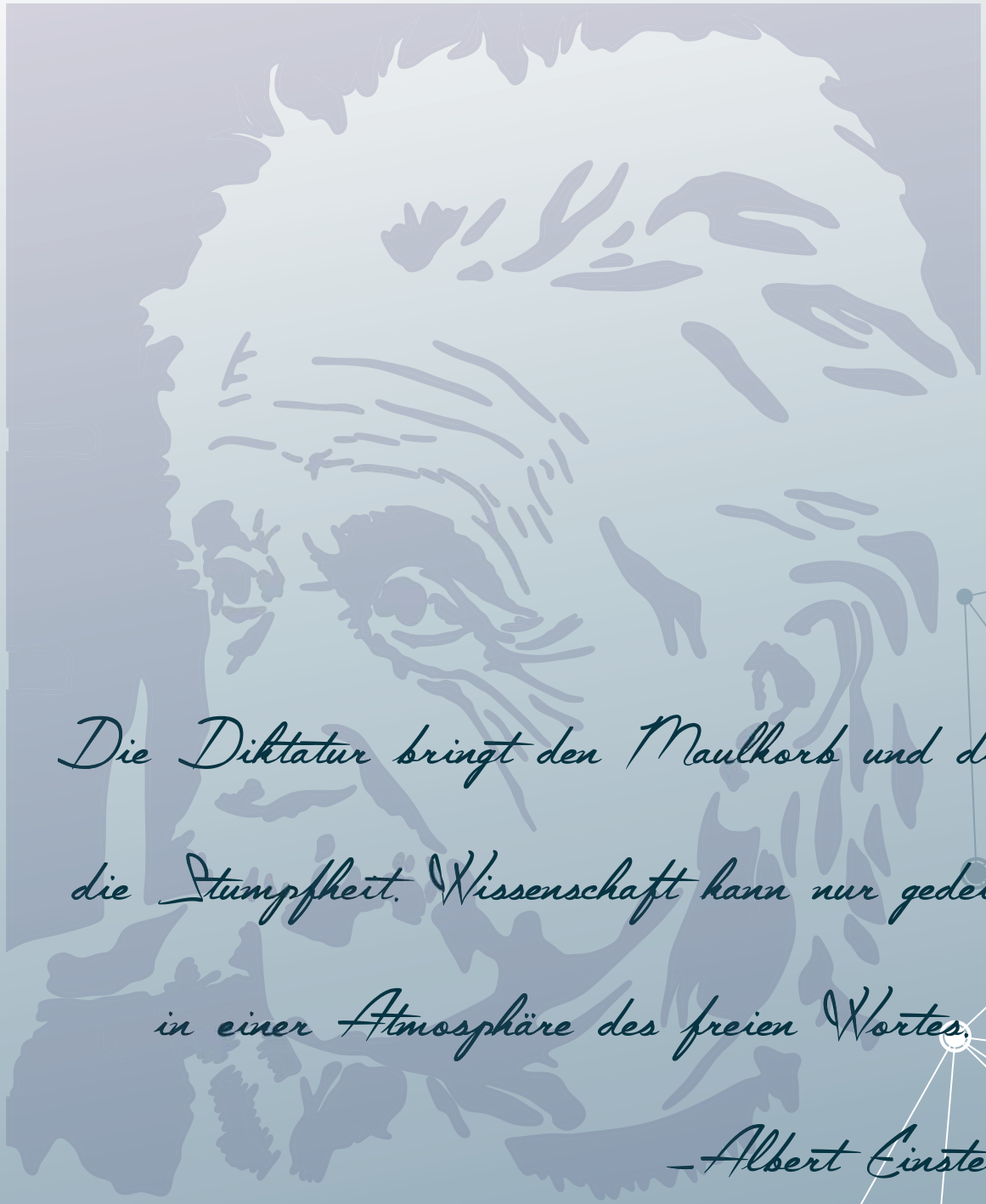
μ_m=0.058 cm^2/g, x=3 cm, ρ_{Fe} = 7.86 g/cm^3

$$\mu = \rho_{Fe}\mu_m = 7.86 \times 0.058 = 0.46 cm^{-1} \tag{9}$$

$$\frac{I}{I_0} = e^{-\mu x} = e^{0.46\times 3} = e^{-1.38} = 0.25 = 25\% \tag{10}$$

Discussion and Conclusion

The absorption of nuclear radiation is important in many applications. In this experiment we measured the gamma rays in different thickness. As we expect before the experiment, decreasing in thickness of lead causes to decrease in counting rates of gamma radiation. We used Cesium-137 (^{137}Cs) which is a good beta-gamma radiation source. According to our results, we can state that gamma ray intensity decays exponentially with the thickness of the material.



Die Diktatur bringt den Maulkorb und dieser die Stumpfheit. Wissenschaft kann nur gedeihen in einer Atmosphäre des freien Wortes.

–Albert Einstein