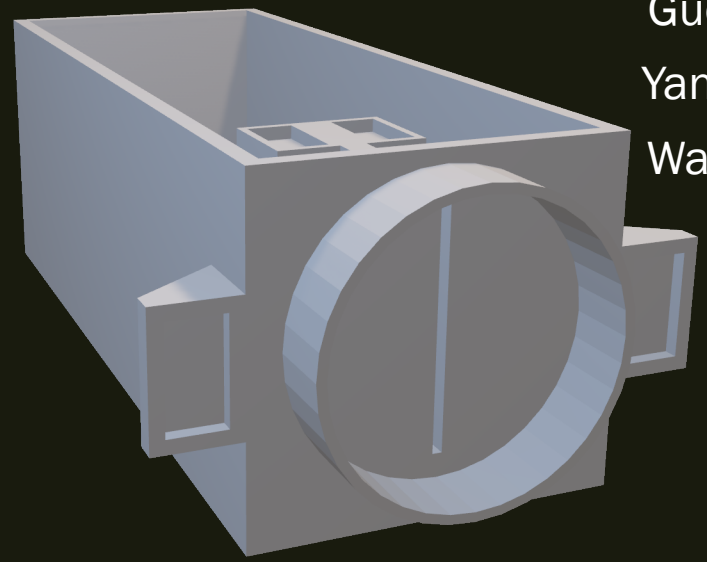
GROUP 4 FINAL PRESENTATION



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Outline

- Project Overview
  - *Member List*
  - *Distribution of Work*
  - *Experiment Objective*
  - *Milestone and Timeline*
  - *Budget*
- The Experiment of Diffraction Grating
- Make a Spectrometer
- Application 1: Measure the Plank's Constant with LEDs
- Application 2: Measure the Spectrum Absorption of Copper Sulfate Solution
- Reference etc.

(Every application has individual Methodology and Hypothesis)

DISTRIBUTION OF WORK

Work	Participants
Hardware Design	Guo Yiming
Software	Wang Yiran, Yang Ziou
Background Research/Literature Review	Wang Yiran, Yang Ziou
The Experiment of Diffraction Grating measurement	Guo Yiming
Plank's Constant with LEDs	Yang Ziou
Spectrum absorption of some solutions (for example, CuSO4)	Wang Yiran
Experiment plan design, setup and conduction	Guo Yiming, Wang Yiran, Yang Ziou
Planning project and Budget	Wang Yiran, Yang Ziou
Data analysis	Guo Yiming, Wang Yiran, Yang Ziou

Research Objective

- To determine and compare the grating constant for different brands of CD or DVD.
- To make a spectrometer
- Application:
  - *To measure and investigate Planck's constant with LED*
  - *To measure and investigate the spectrum absorption of some solutions (CuSO4)*

Milestone Timeline

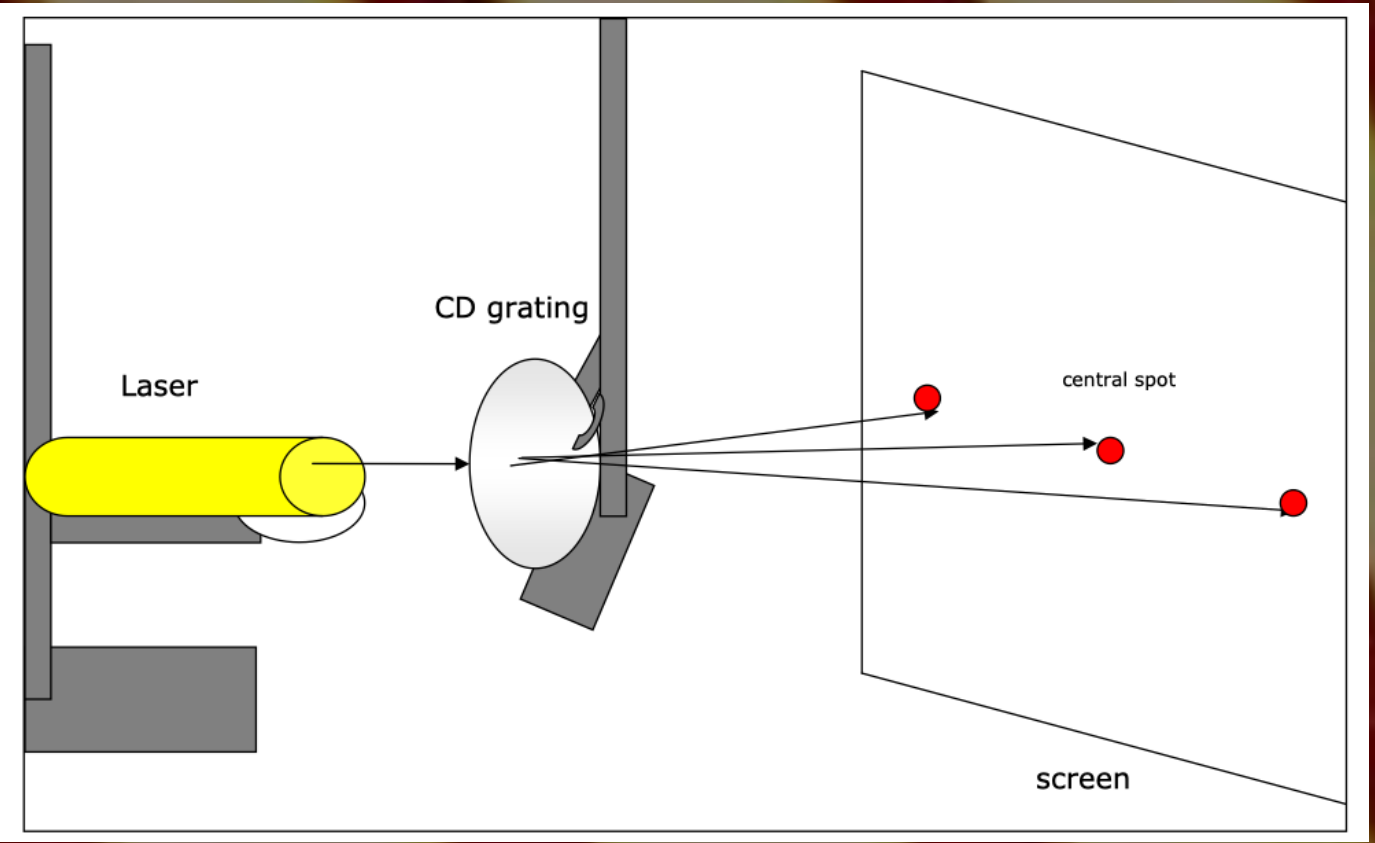
Milestone and Gantt Chart of Group 4 (2022/04)																
	Guo Yiming Yang Ziou Wang Yiran															
	25/04/2022	Week														
No	Milestone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	experimental plan, and background research															
2	prototype testing and software testing															
3	3D modeling, circuit design, assembly and performance testing															
4	Completed the experiment diffraction grating															
5	Completed the experiment Application 1															
6	Completed the experiment Application 2															
7	data collection and organization analyze															
8	Completed the experimental report															

Budget

Budget List of Lab Project 2022/04(Group 4)

Author	Guo Yiming	Update Date	24/4/2022						
Member	Guo Yiming, Yang Ziou, Wang Yiran								
exchange rate(RM-CNY)	1.5	Update Date	24/4/2022						
No	Item	Quanta	CNY Price	RM Price	Total (RM)	reimbursement(1/0)	Purchase Link	Shop Link	Memo
	Part 1: Experiment on Diffraction Grating								
1	CD	2	0.00	0.00	0.00	1			
2	DVD	5	2.68	1.79	8.93	1			
3	650nm red laser emitter	1	11.42	7.61	7.61	1			
					0.00				
	Part 2: Make a Spectrometer				0.00				
4	3D Model Printing Fee	1	200.00	133.33	133.33	1			
5	magnet	20	0.30	0.20	4.00	1			
6	Camera Module	1	20.80	13.87	13.87	1			
					0.00				
	Part 3: Application 1:Planck Constant				0.00				
7	LED light group(8 color)	1	13.80	9.20	9.20	0			
8	DuPont line	1	0.00	0.00	0.00	0			
9	Bread board	1	0.00	0.00	0.00	0			
10	Battery box	2	0.00	0.00	0.00	0			
11	Universal electric meter	1	0.00	0.00	0.00	0			
12	resistance	1	0.00	0.00	0.00	0			
13	switch	1	0.00	0.00	0.00	0			
					0.00				
	Part 4: Absorption spectrum of solution				0.00				
	Cuvette(10mm)	10	2.90	1.93	19.33	1			
	LED Light board	2	7.61	5.07	10.15	1			
					0.00				
	Others				0.00				
	Equipment damage(Unexpected expenditure)	1	50.00	33.33	33.33	1			
	Logistics price	1	20.00	13.33	13.33	1			
	Total				253.09				

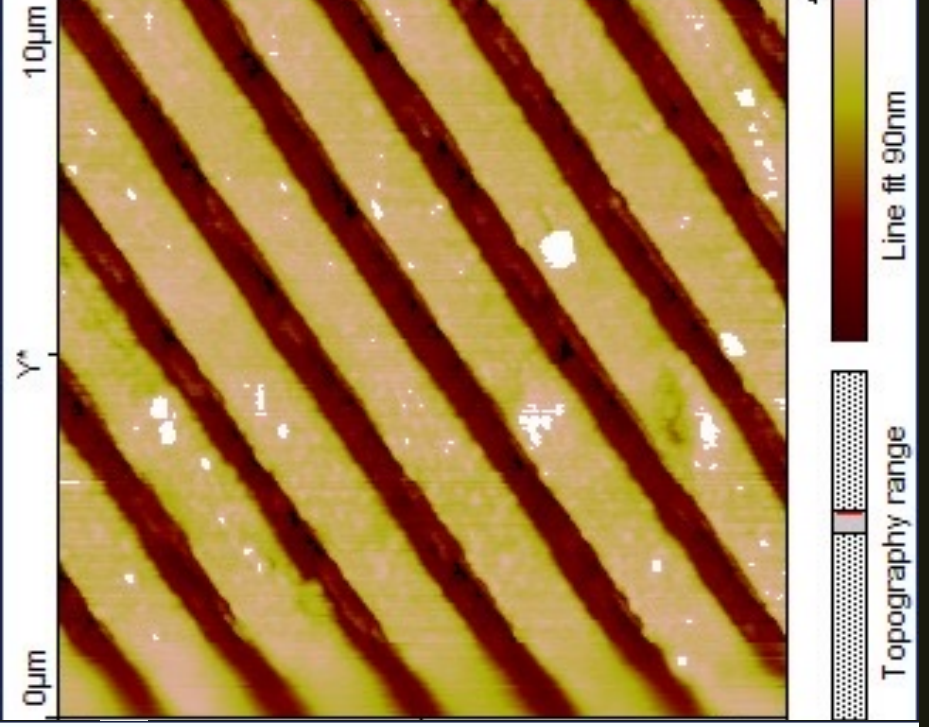
The experiment of Diffraction Grating measurement

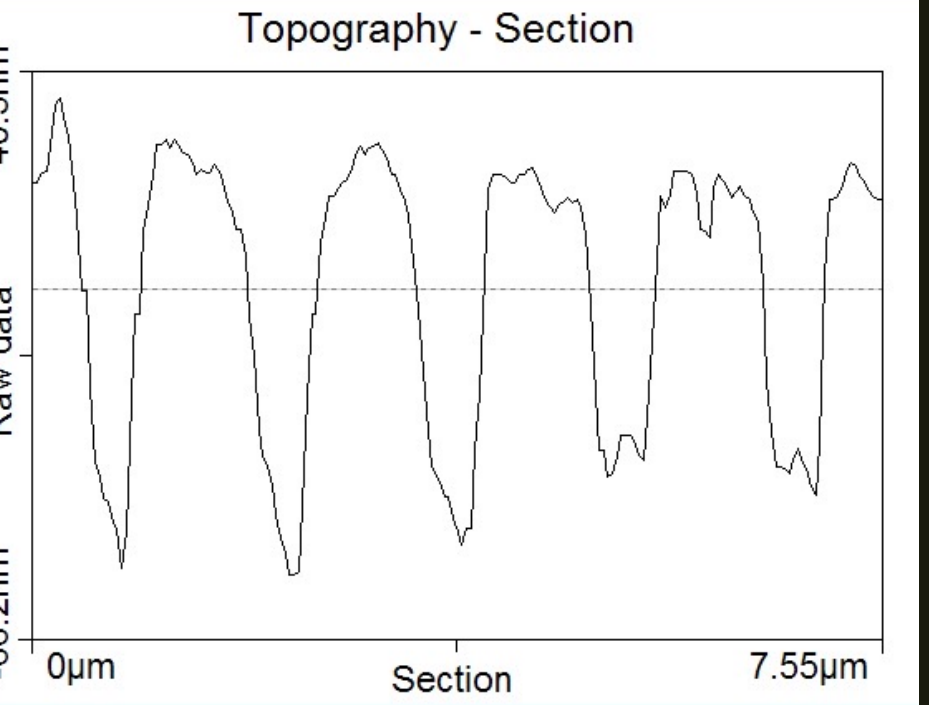


Experimental schematic(Image from Rama Balachandran)

- Experiment Objective:

To determine and compare the grating constant for different brands of CD or DVD.





Literature Review

- In a previous study, NNIN gave a detailed tutorial and experimental procedures as well as experimental data for reference. They used CDs and DVDs as diffraction grids, and also used lasers for their experiments, and gave a form for recording the experiments.
- They also measured the diffraction grating of CDs and DVDs using an AFM microscope. Detailed reference data are given.
- In this part of the experiment. We will try to reproduce the experiment using the tutorial provided by NNIN, and try to use different angles and different distance settings to get more insight into the experiment. This will be used in the subsequent design of the spectrometer.

Image left above: AFM image: CD 750MB

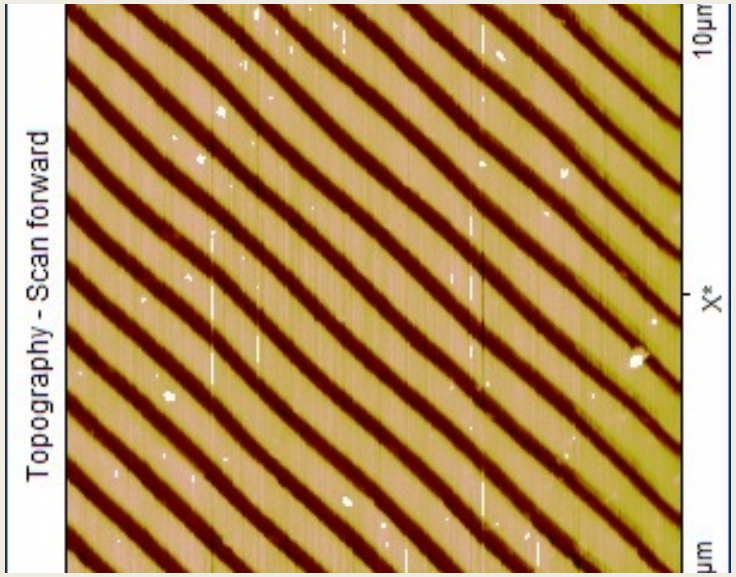
Image right above: AFM line scan of the image

Experiment Hypothesis

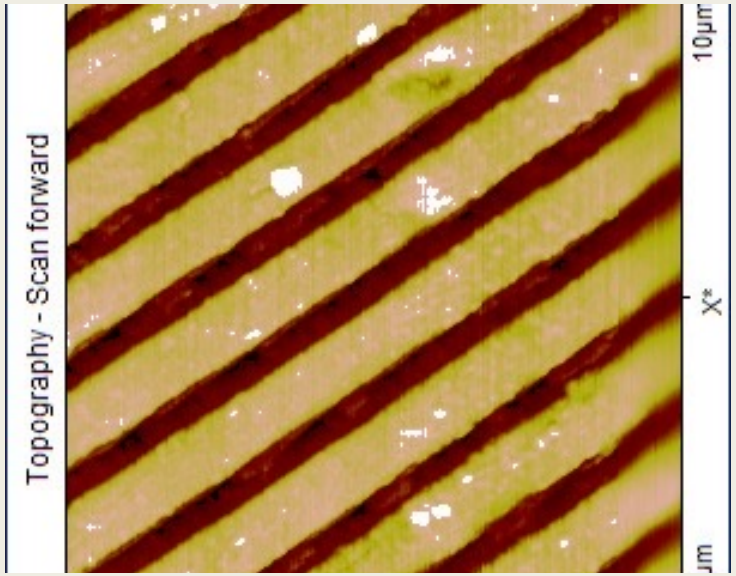
In this part of the experiment, we will try to measure and calculate different experimental parameters and investigate the relationship between the variables.

Hypothesis 1: The closer the laser irradiation position is to the center of the disc, the smaller the distance between the resulting light spots

Hypothesis 2: Other conditions are constant, the more dense the CD/DVD grating, the closer the distance between the generated spots



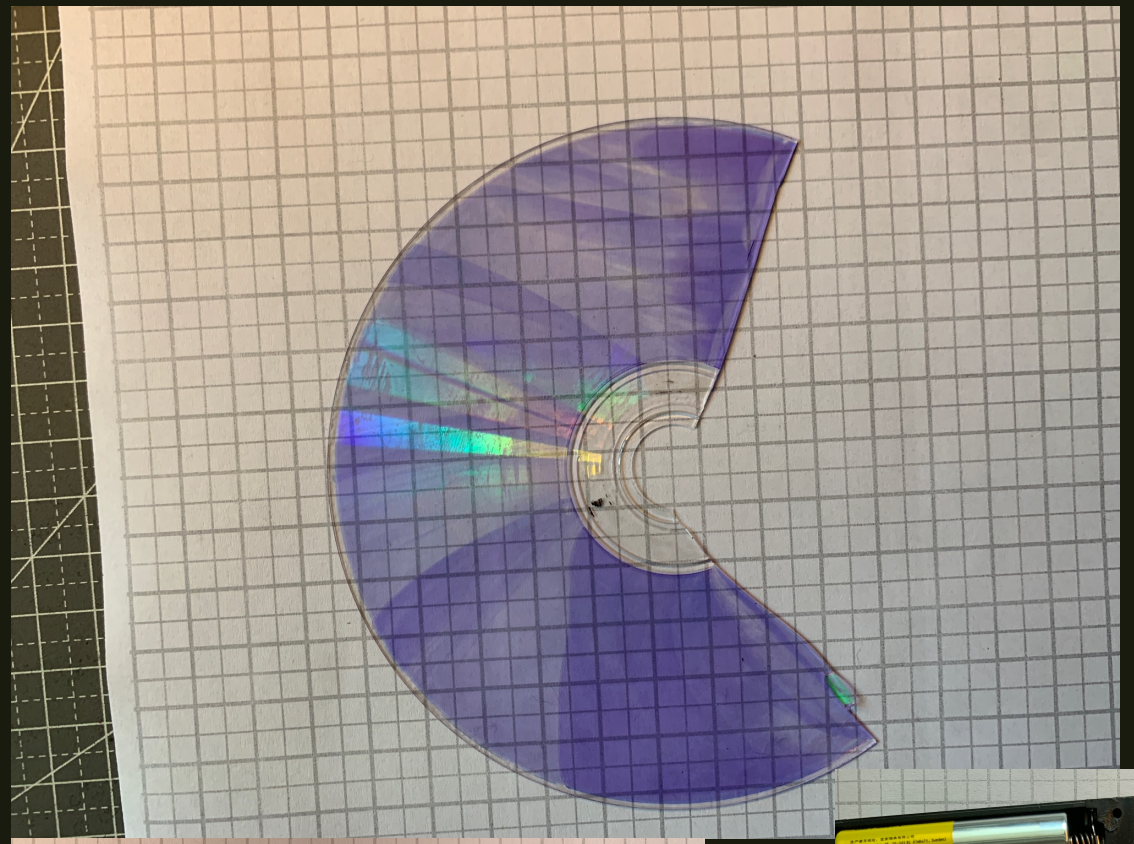
CD(700 MB)

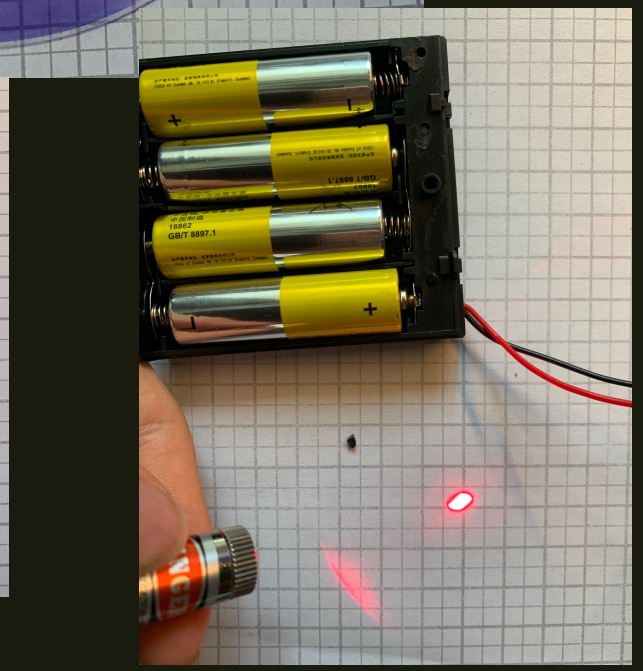


DVD(4.7GB)

Experiment Setup

1. 650nm Laser Emitter
2. CD/DVD(tear off the Sliver Layer)
3. Ruler
4. Several Support stand
5. Battery Case(to turn on the emitter)





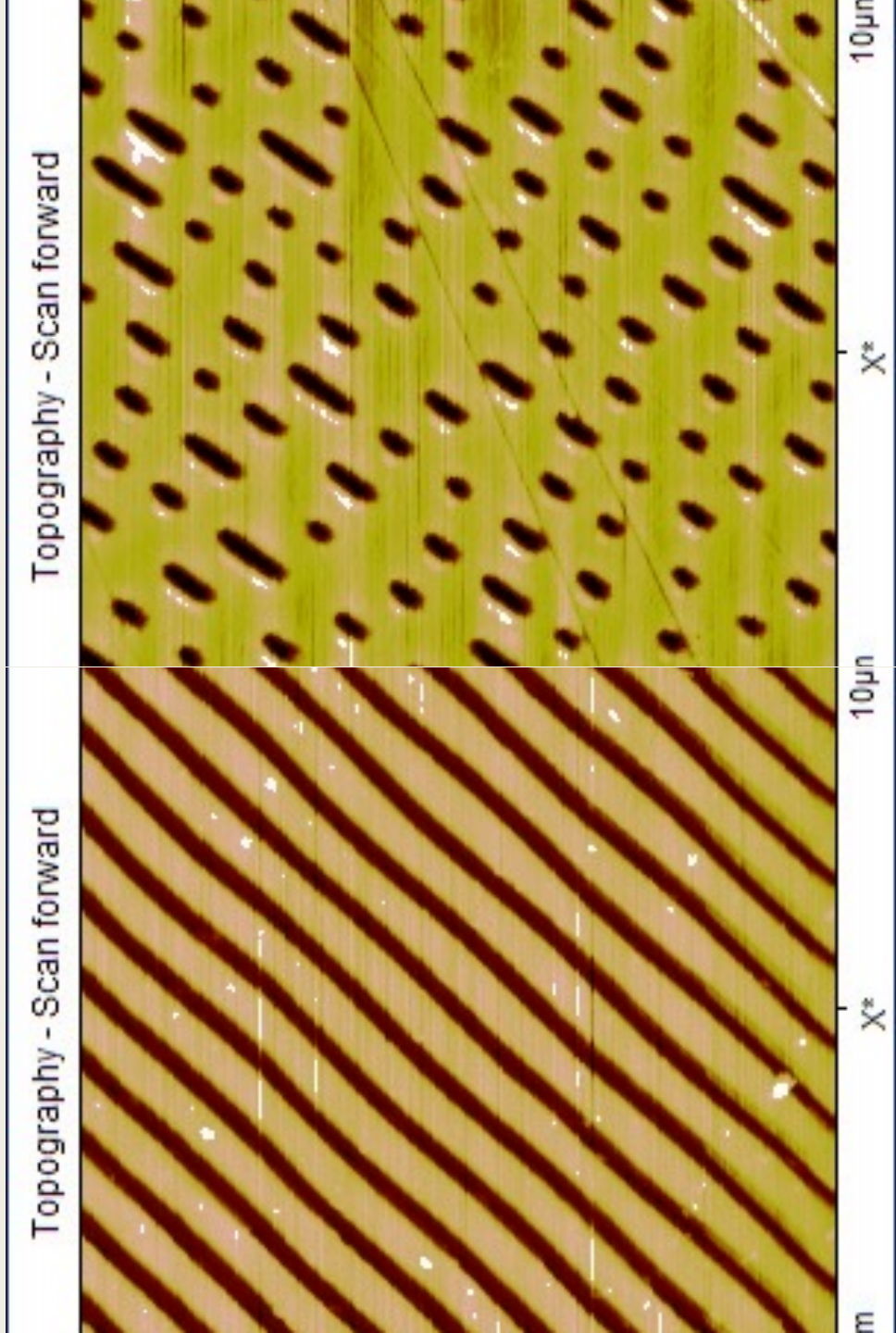
Experiment Methodology

- As previous studies have shown (NNIN) that unrecorded discs have better diffraction, in this experiment we used two unrecorded discs: CD (700MB), DVD (3.7GB) for the experiment.

1. The disc with the reflective layer removed was mounted on a stand and was placed on the table vertically.
2. Another projection plane will be mounted 5/10/15 cm in front of the disc (parameters from NNIN).
3. The 650nm red laser emitter/530nm green laser will be fixed at the same height as the center of the disc, illuminating the grating on both sides of the center horizontally.
4. During the experiment, the experimenter will record the two-dimensional coordinates (the most obvious 3-5 points) on the projection screen. Experiments with the same parameters will be performed several times

Image Above: AFM image of burned DVD

Image Below: AFM image of unburned DVD



Experiment analysis

- Here to determine the slit density of the disc, we can first turn out the distance of the slit(d).Here we apply the equation frequently used in double slit interference experiment
- Here by determine the distance between disk and screen and the distance between the light spot. Here we can derive the angle of diffraction

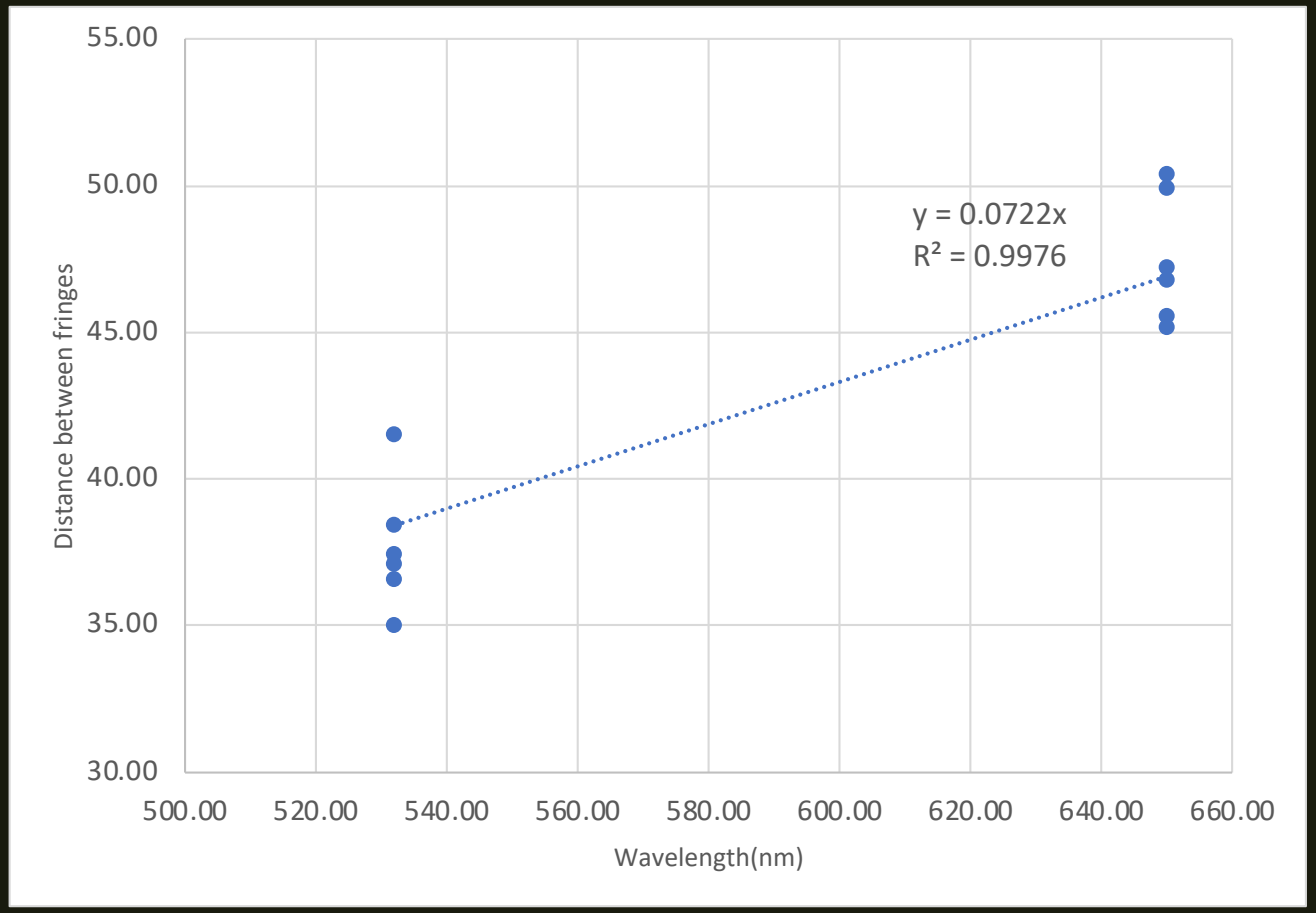
$$\theta = \arctan \frac{D}{x} \qquad d = \frac{m\lambda}{\sin\theta}$$

- After that we can derive the density of the slit and the diffraction grating constant

Result Analysis

- We organize the data get the result below, detailed graph could refer to the appendix or Github. And we can find that the measured average slit density as below, as can be seen that the average DVD is about 1250/mm compared to the actual result 1350. The error is small, within the acceptable range. As for CD the measured value is about 660/mm compared to the actual result 625. Also in acceptable range.

	DVD	real	CD	real(/mm)
av	1249.81246	1350	667.314071	625
stdev	69.90020042		-29.261238	

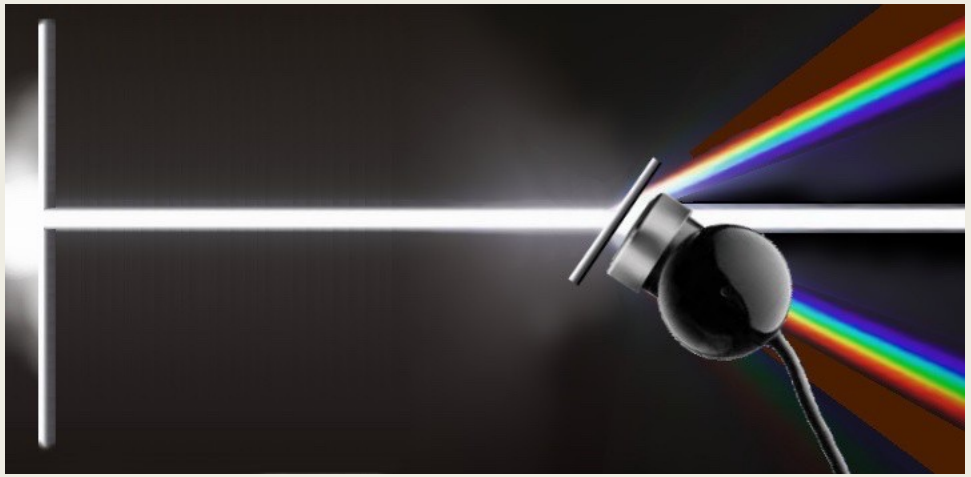


- Next, we can analyze the hypothesis, first, we compare the result with CD and distance at the same wavelength laser light. The result is below. Clearly that the disc-screen distance and the distance between spots is linear, and when the disc screen distance increase, the spots distance will increase linearly. The Hypothesis was proved

Make a Spectrometer

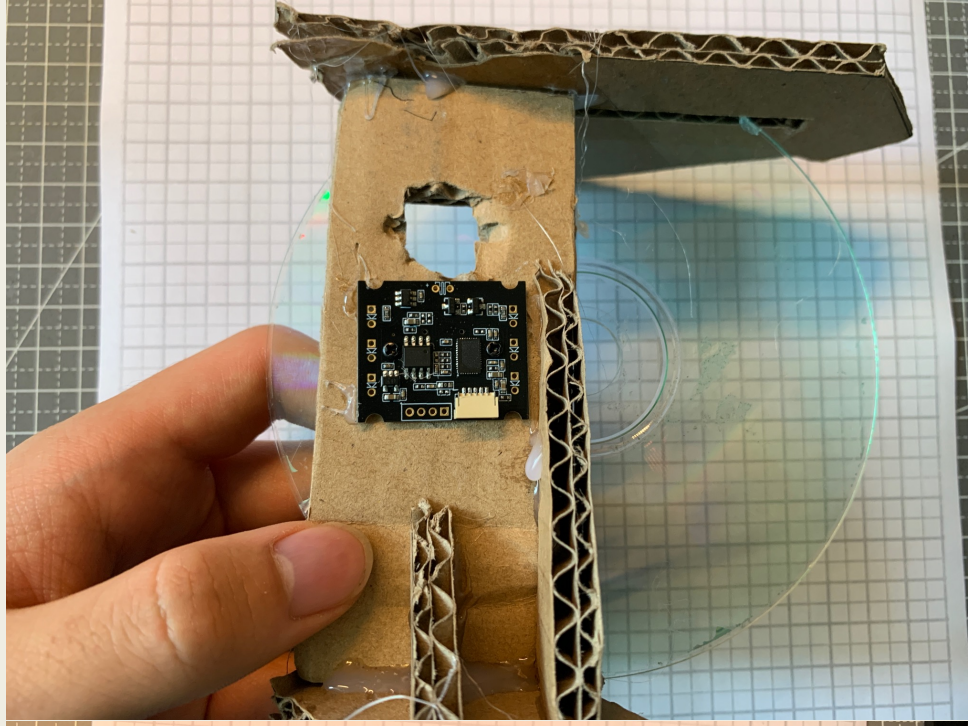
- This part is about the progress of the making a simple non-professional visible light spectrometer.
- Our progress could be separate as the prototype stage and formal stage
- We first used a cardboard box as the subject of the prototype to test the performance of the important components and to measure the relevant parameters to facilitate the design of the 3D model later.

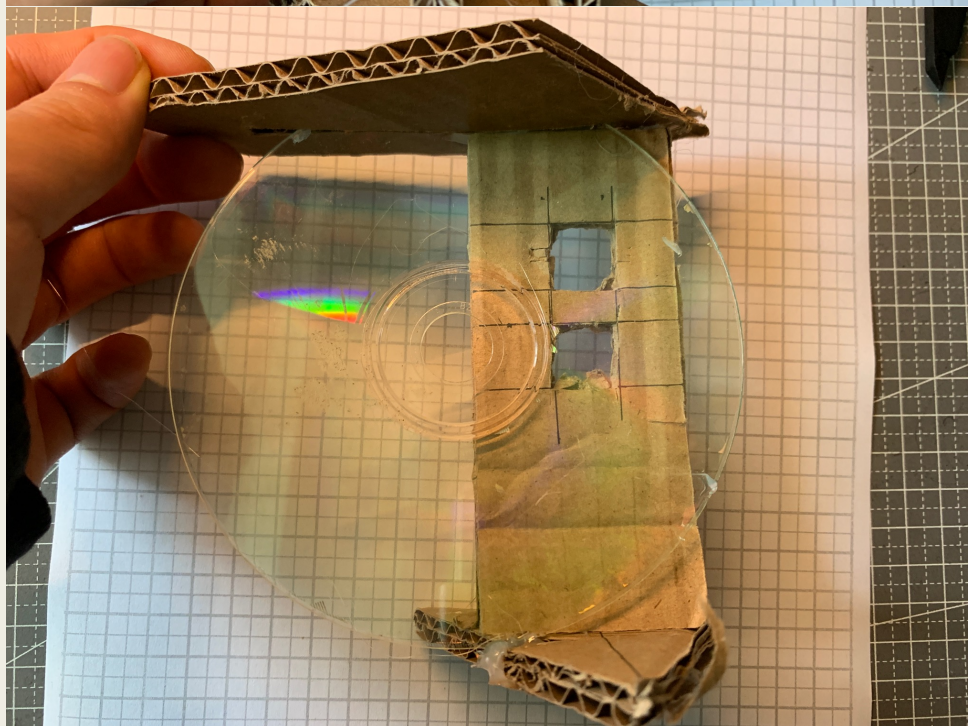
Optical Principle



Make a Spectrometer

- By the prototype of the spectrometer, we can determine several important parameter:
  - *The angle between DVD and CD as a grating and the light*
  - *the length and width of the slit*
  - *the height and angle of view of the camera installation*
  - *the focal length of the camera*
  - *etc*





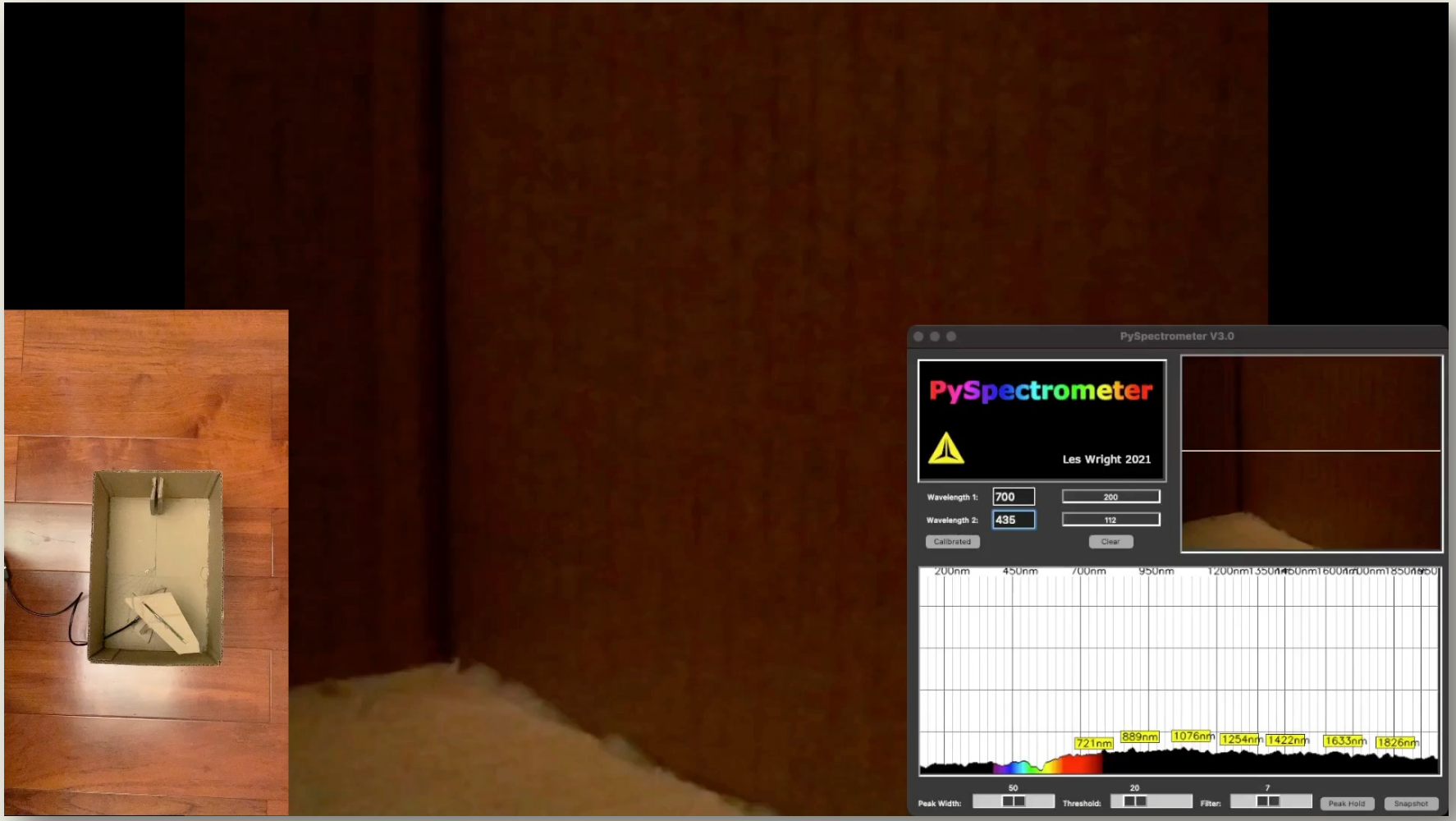
Demo Video of Prototype

Here is the demo video for the prototype spectrometer.

Here we have done a rough initial calibration by pointing the spectrometer to the display showing RGB.

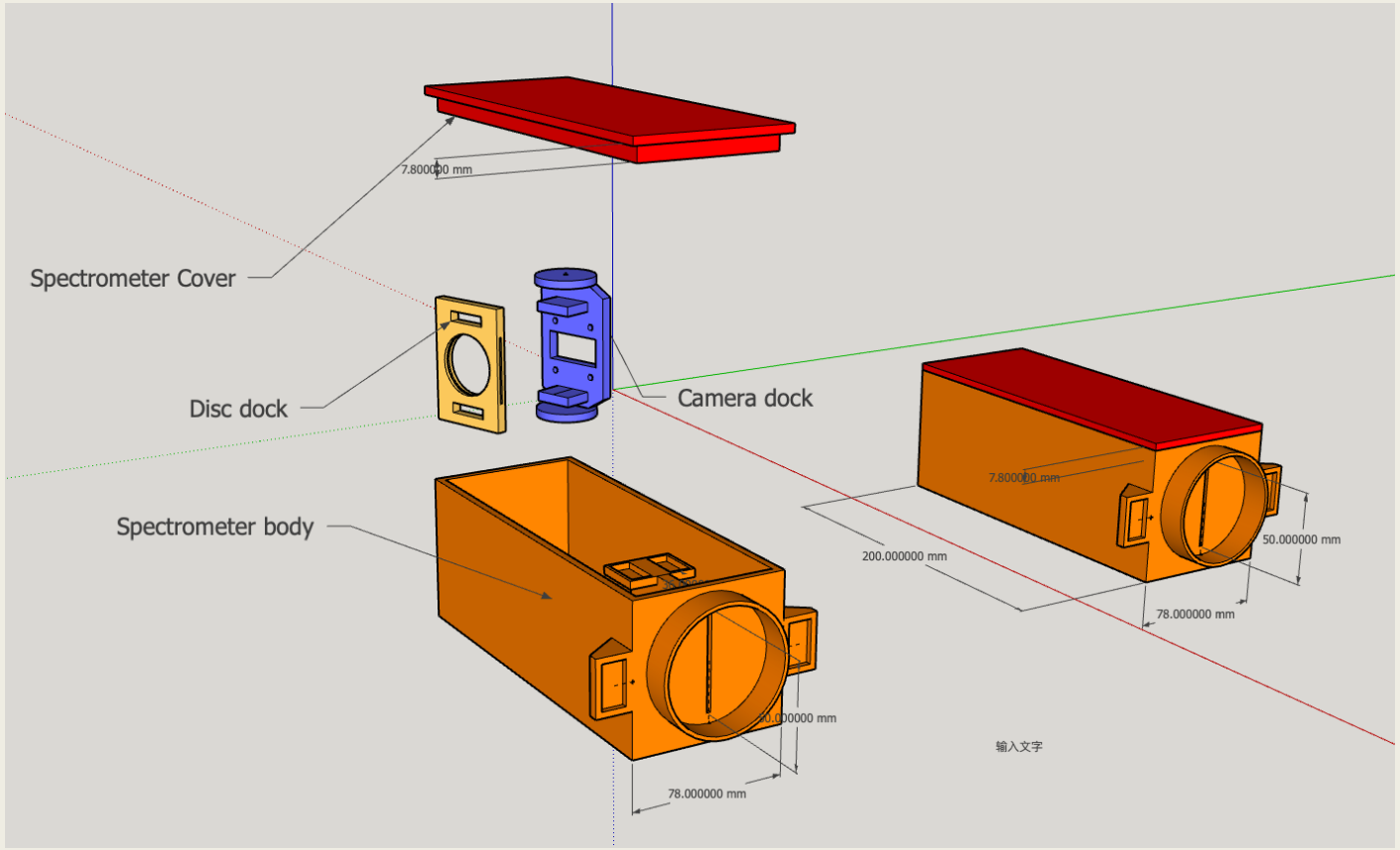
Here we can see the rough spectrum of LED lamp.

Next, we put a kettle between the light and the Spectrometer

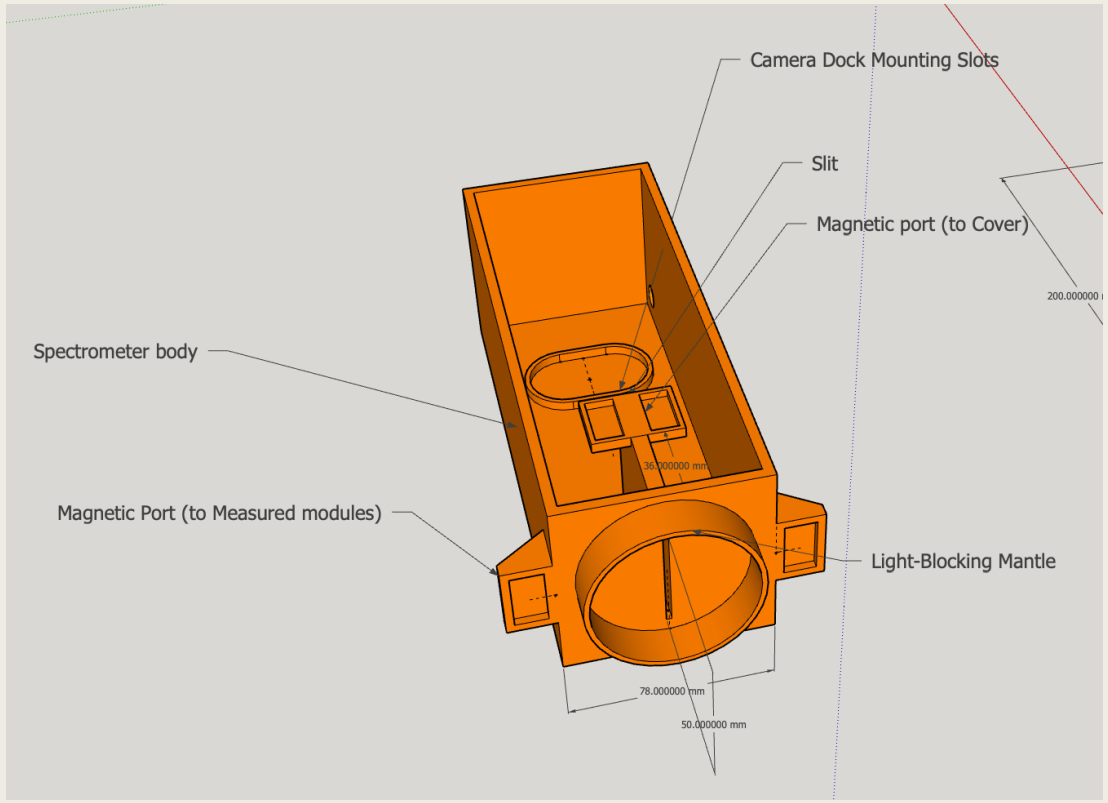


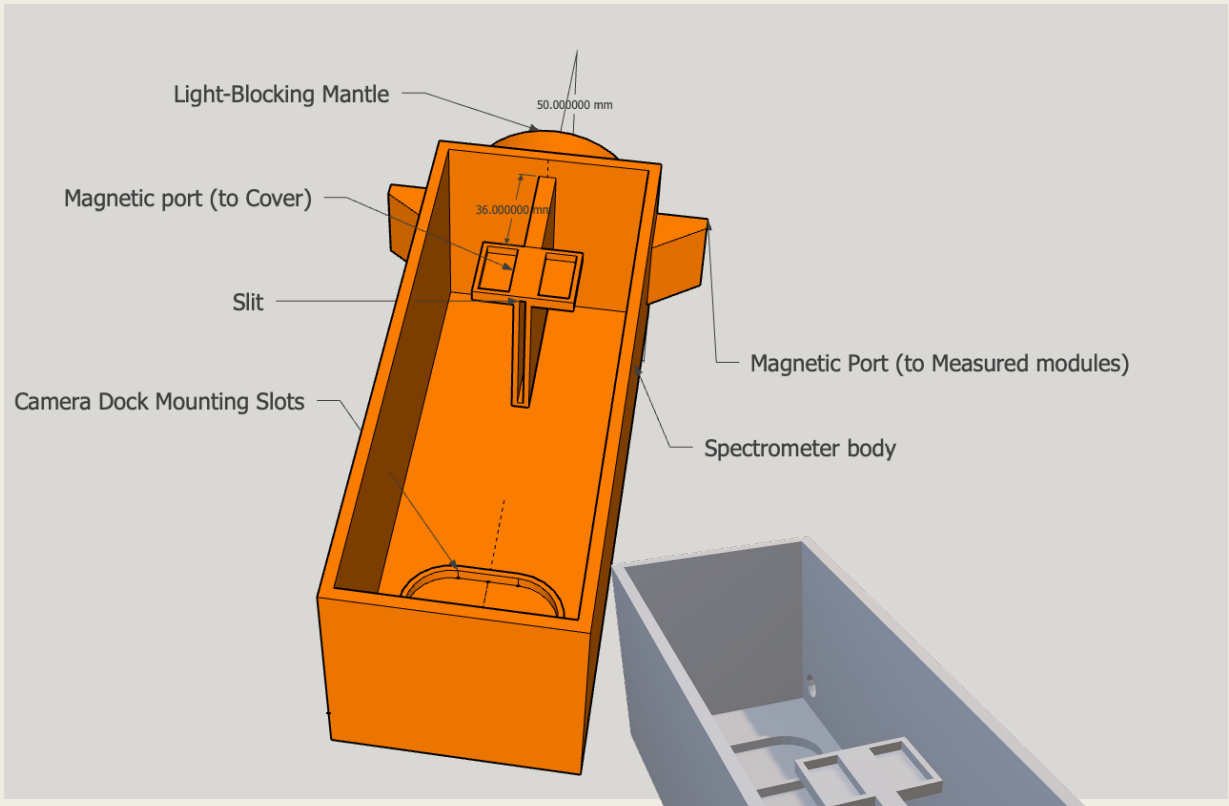
Formal Stage-3D model

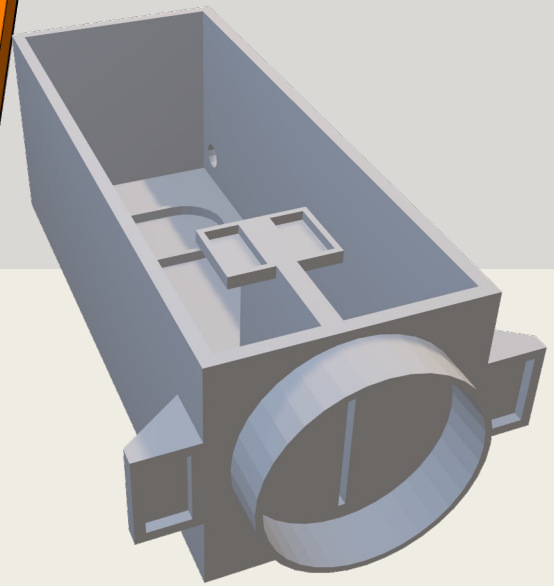
- Here is the design of the 3D model spectrometer, the major parts is:
  - *Spectrometer Cover*
  - *Disc Dock*
  - *Camera Dock*
  - *Spectrometer Body*



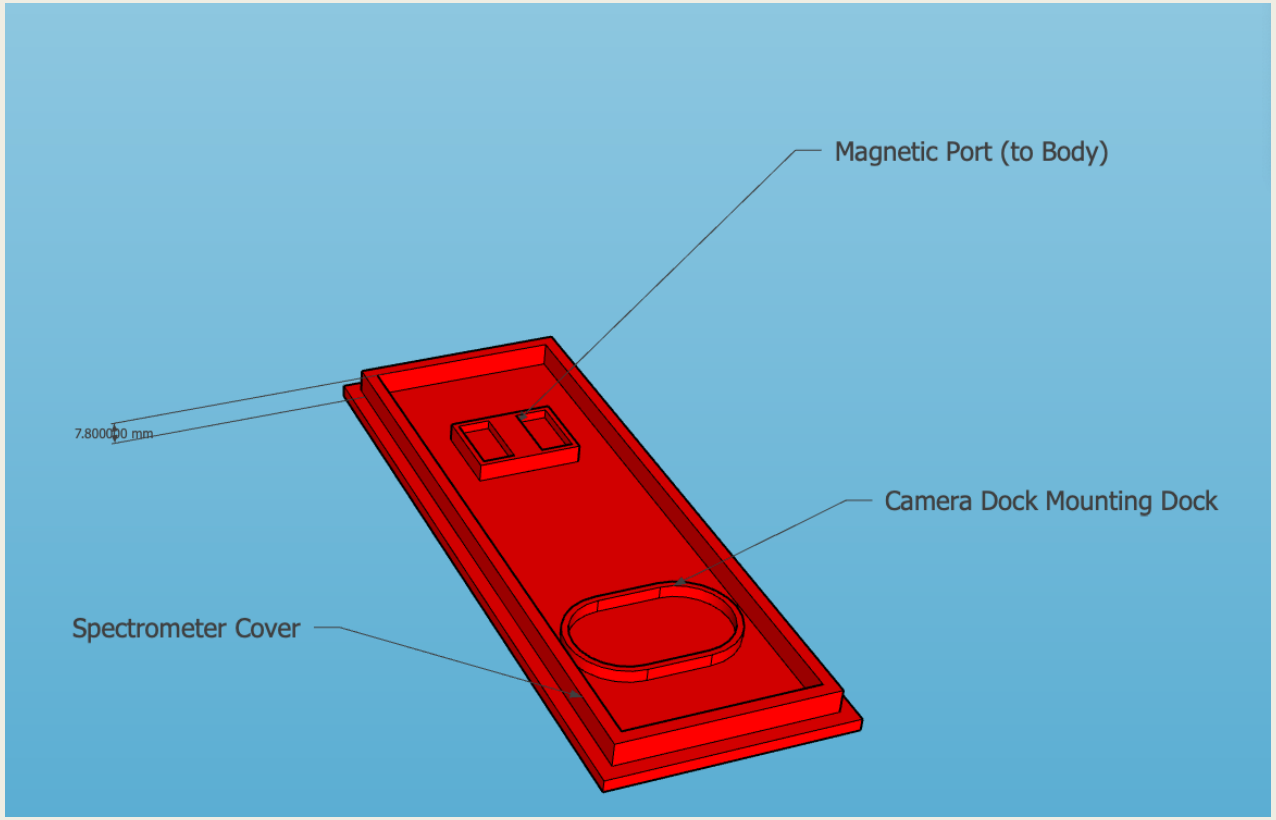
Spectrometer Body

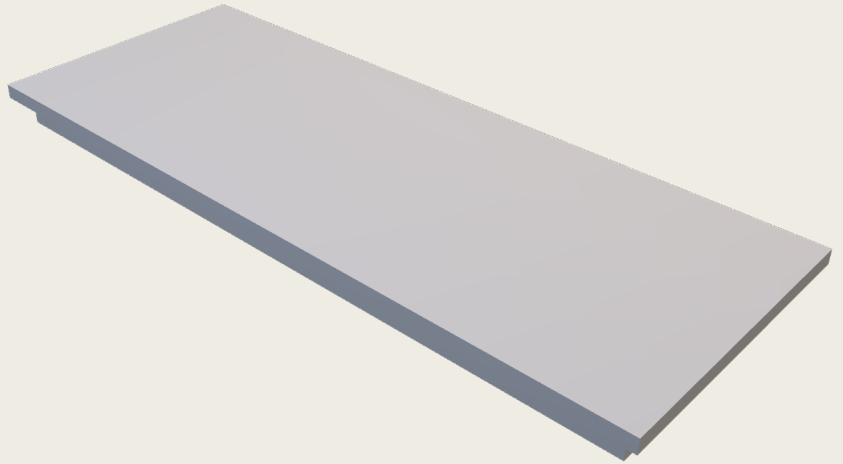




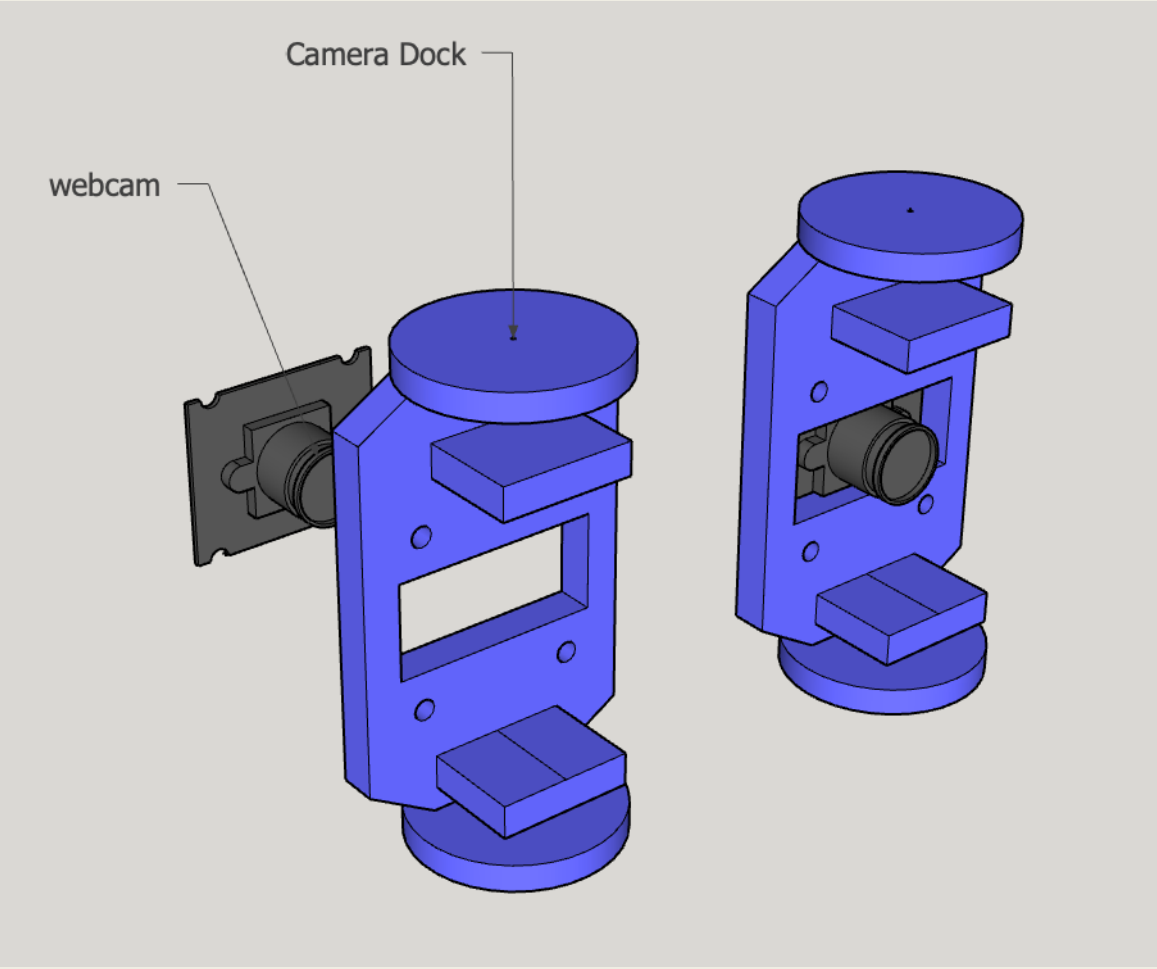


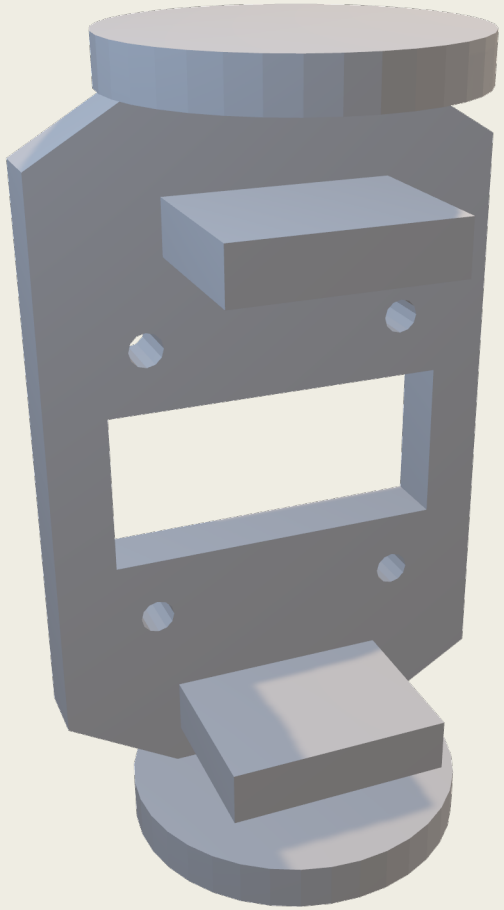
Spectrometer Cover





Camera Dock





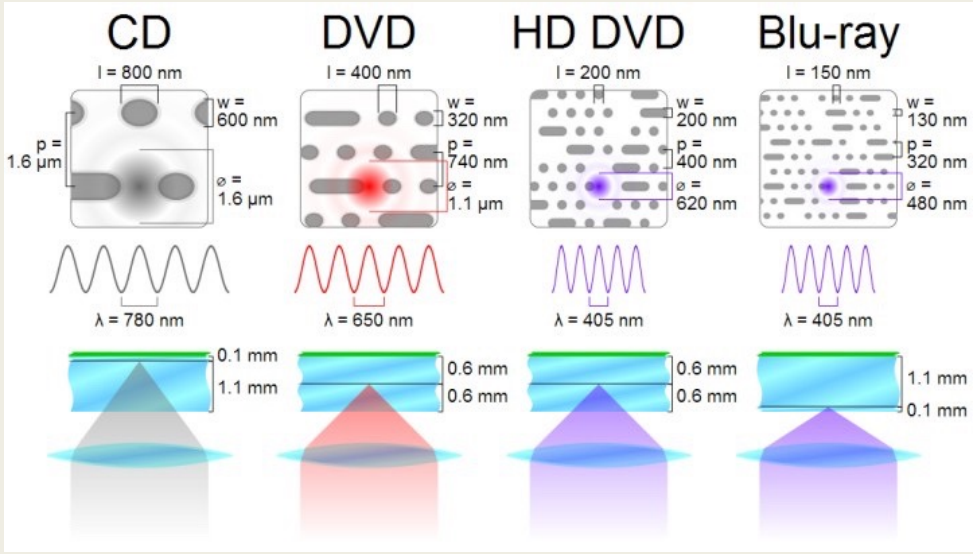
Here we use DVD

Information form theremino
According to our tests, the best patterns are derived from the DVDs and got better results by using them in transmission (no reflection)

The following pages present various useful possibilities for teaching and for extreme experimenters, commercial gratings, prisms, reflection methods...

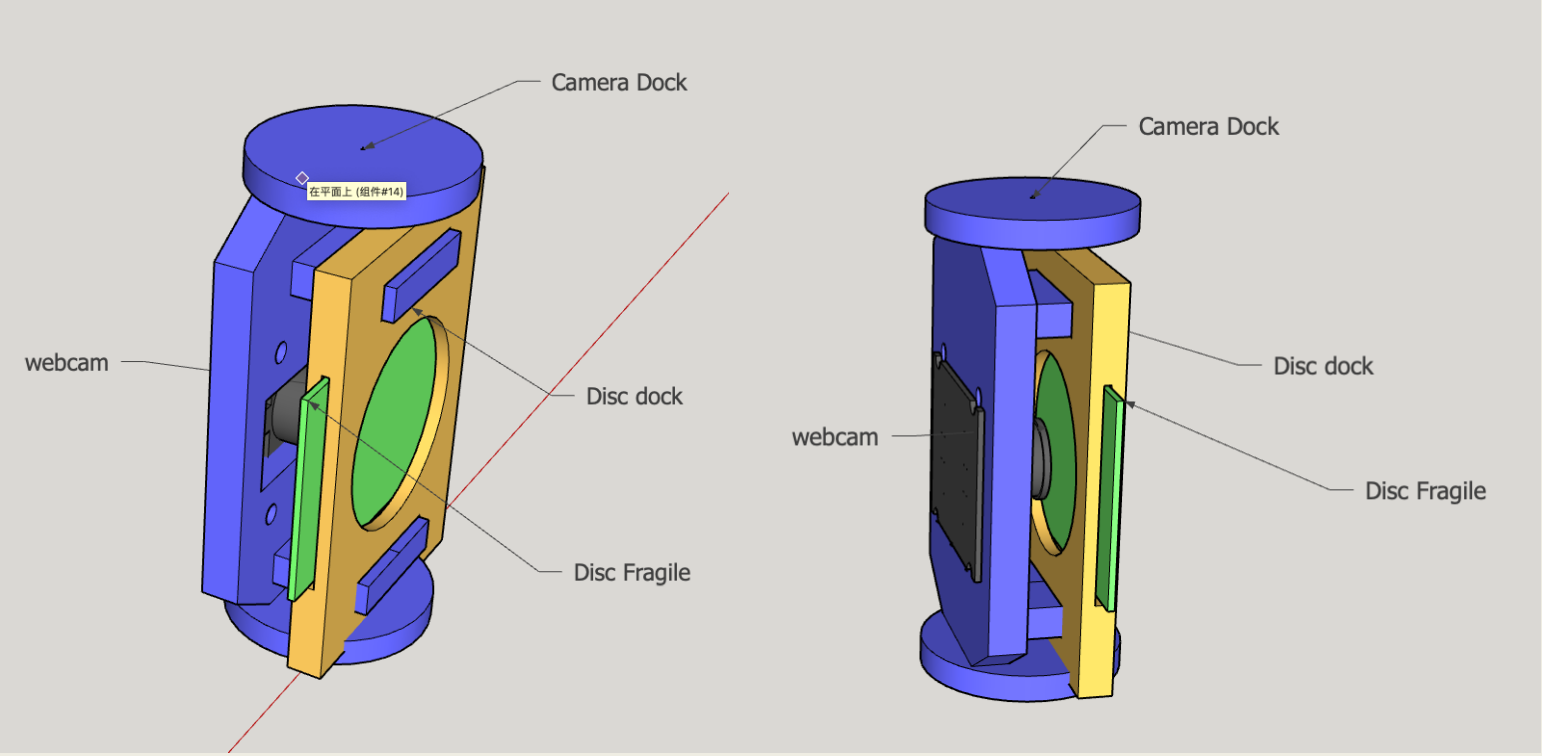
Who wants to build a simple spectrometer, without going into the theory, should cut a square of DVD and paste

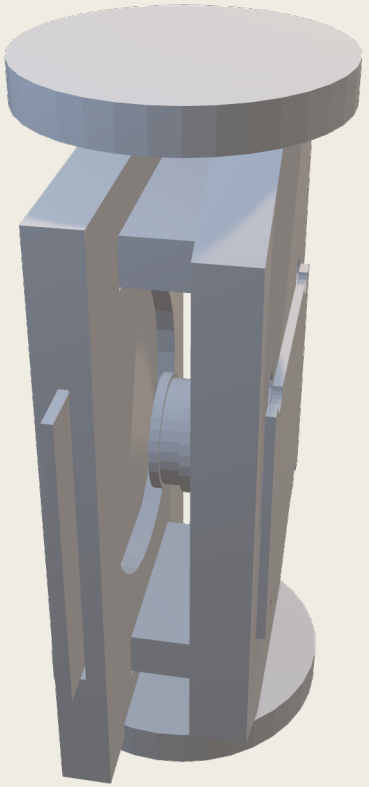
it on the tip of the lens of the camera, then skip directly to the file "Construction".



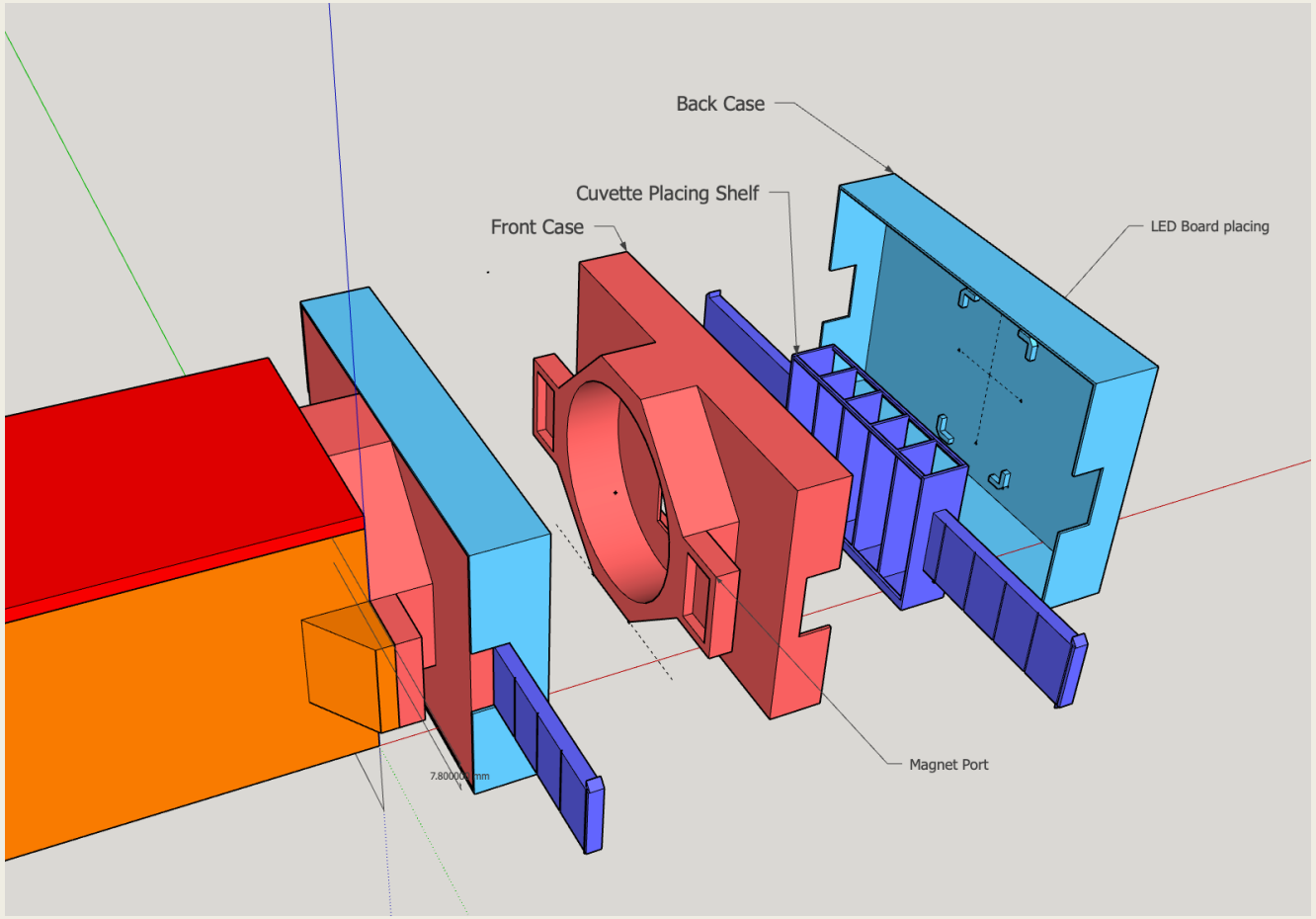
https://www.theremino.com/wp-content/uploads/files/Theremino_Spectrometer_Technology_ENG.pdf

Camera Dock and Disc Dock

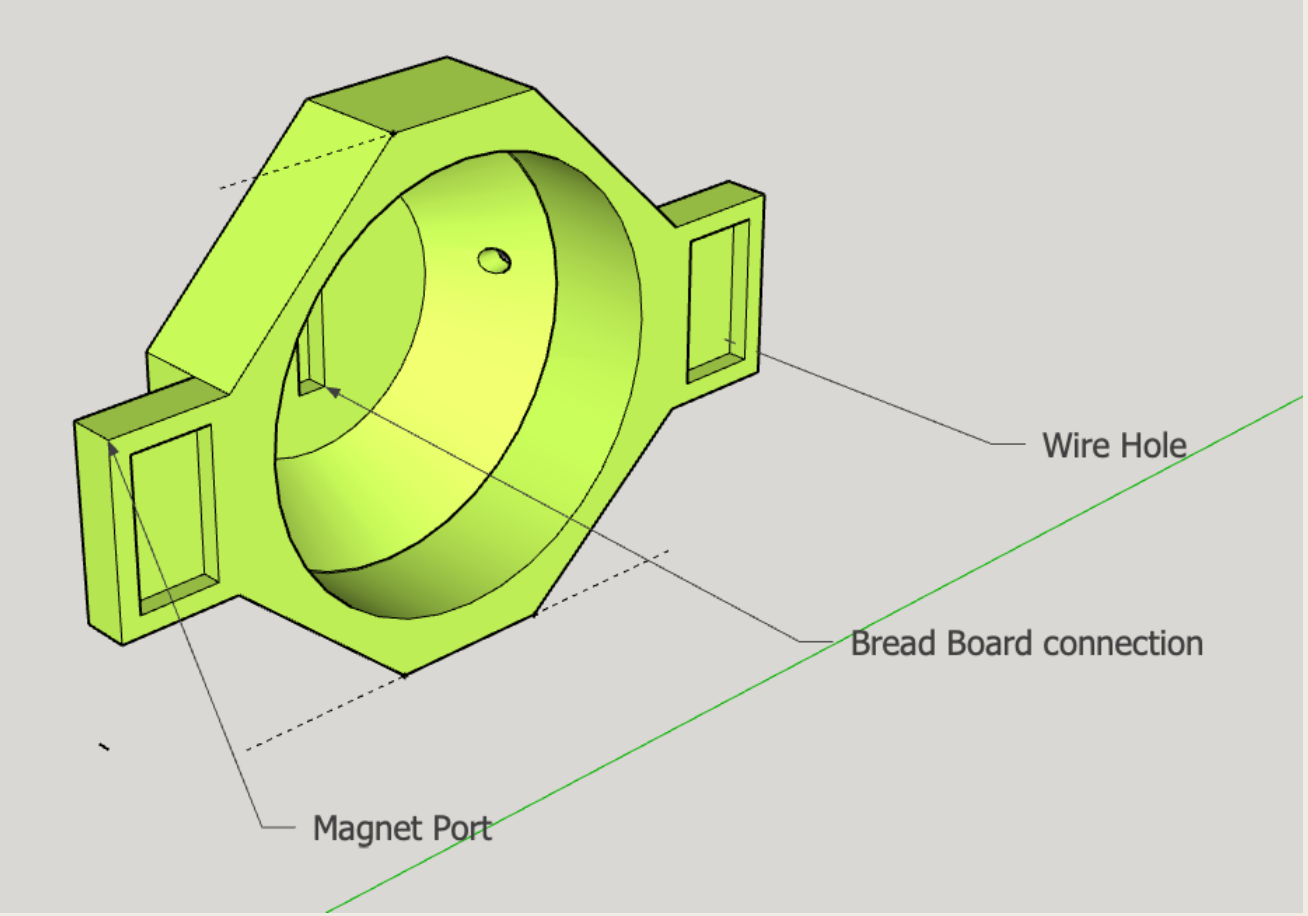




Cuvette Module



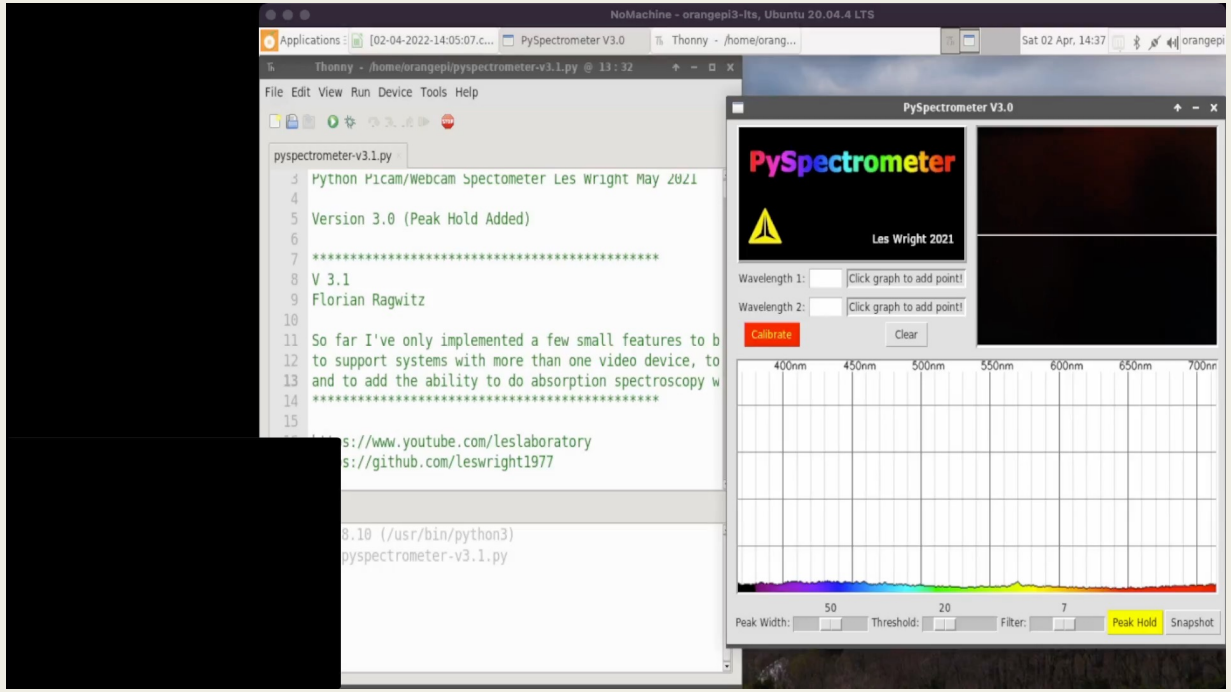
LED Module

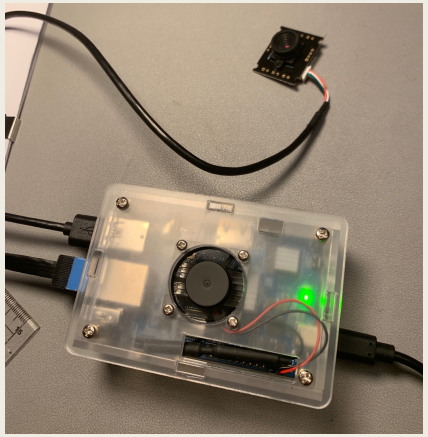


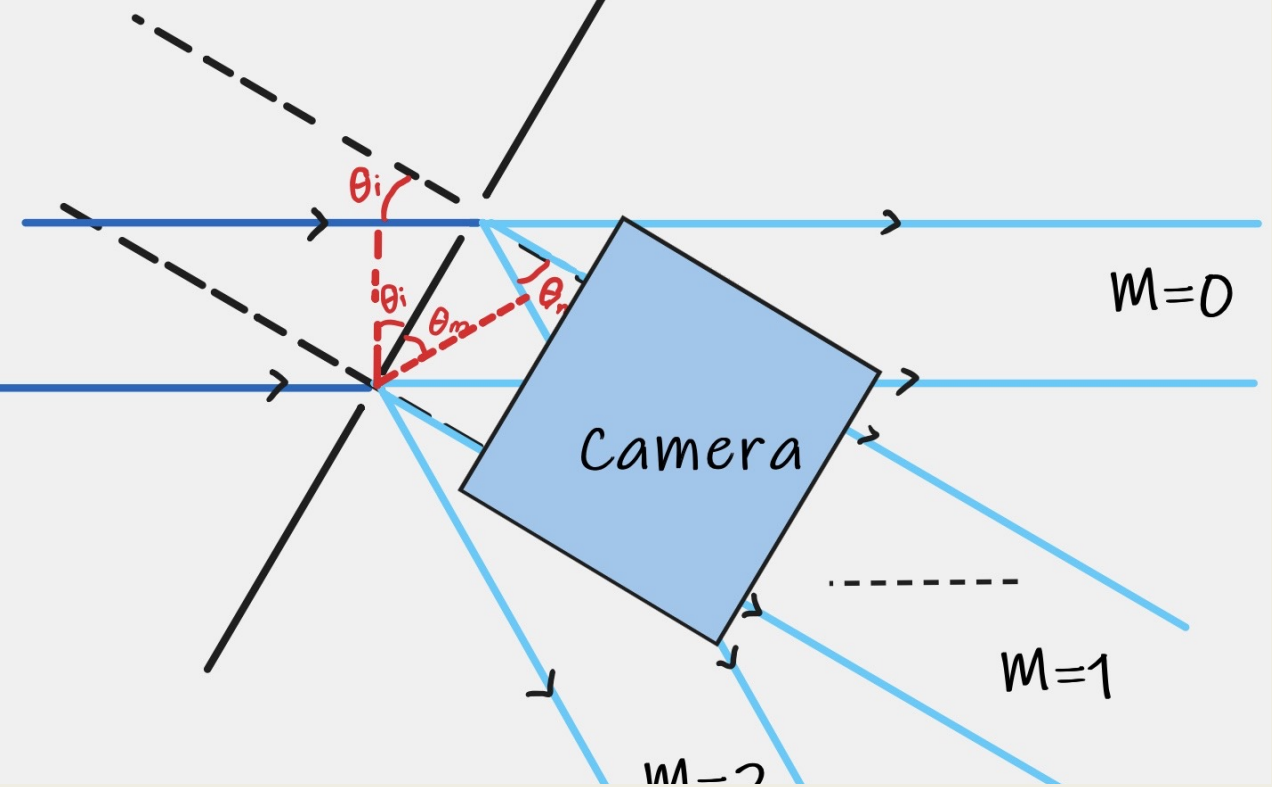
Setup and Calibrating

Software

- [leswright1977/PySpectrometer: Raspberry Pi Spectrometer (github.com)]
- The script run on any platform in Python environment
- It scan the brightness on the central horizontal line, and determine the intensity of light in different wavelength with the calibration data.







What is the best inclined angle between grating and input light.

In the application process we need to adjust the Camera Dock to an appropriate angle to the slit so that the dispersed spectrum can enter the camera lens vertically, so we can analyze it by the above schematic.

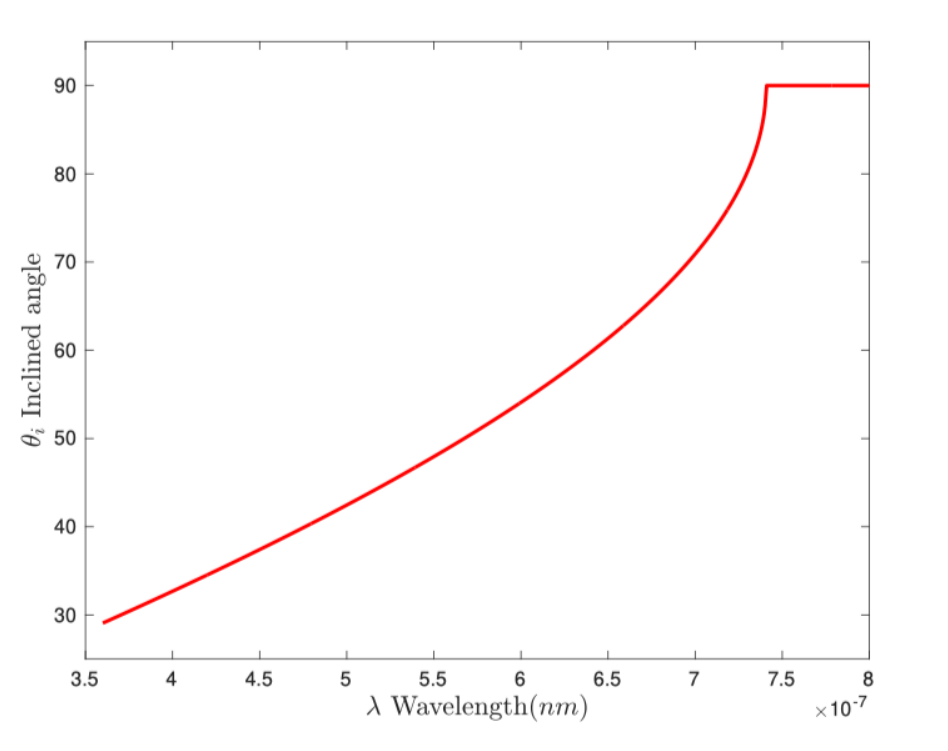
Best inclined angle theta_i

- Here we assume we using the laser light with wavelength λ = 650nm emitting into the spectrometer and we require the one of the diffraction light (m=1) of it perpendicularly shooting into the camera. Next we can calculate the incline angle between the incident light and the normal line of the grating. The equation could be list that:

$$a(\sin\theta_i + \sin\theta_m) = m\lambda$$

- Since there is a range in the spectrum, so that not all wavelengths of light can be directed perpendicularly into the center of the camera, but necessarily along different directions, we can plot the relationship between the images that can make different wavelengths of light emitted and the tilt angle.

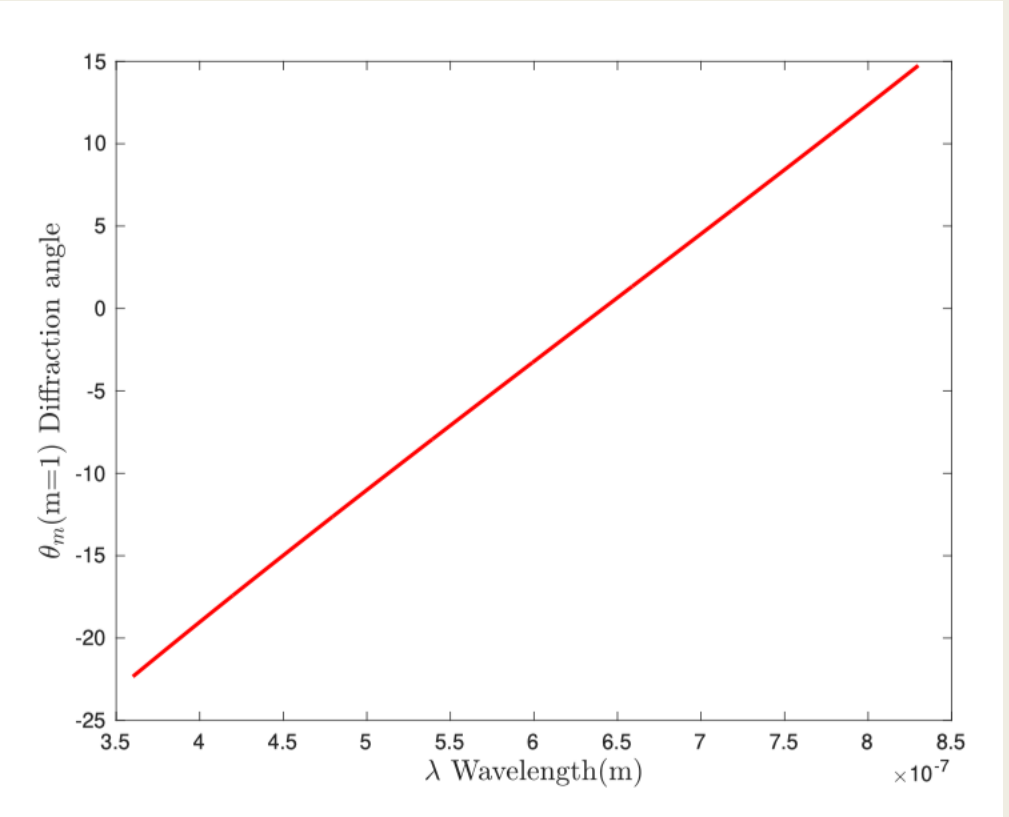
Best inclined angle theta_i



The corresponding incident angle(inclined angle between normal line of grating and incident light) to let the diffraction light(m = 1) normally out from grating.

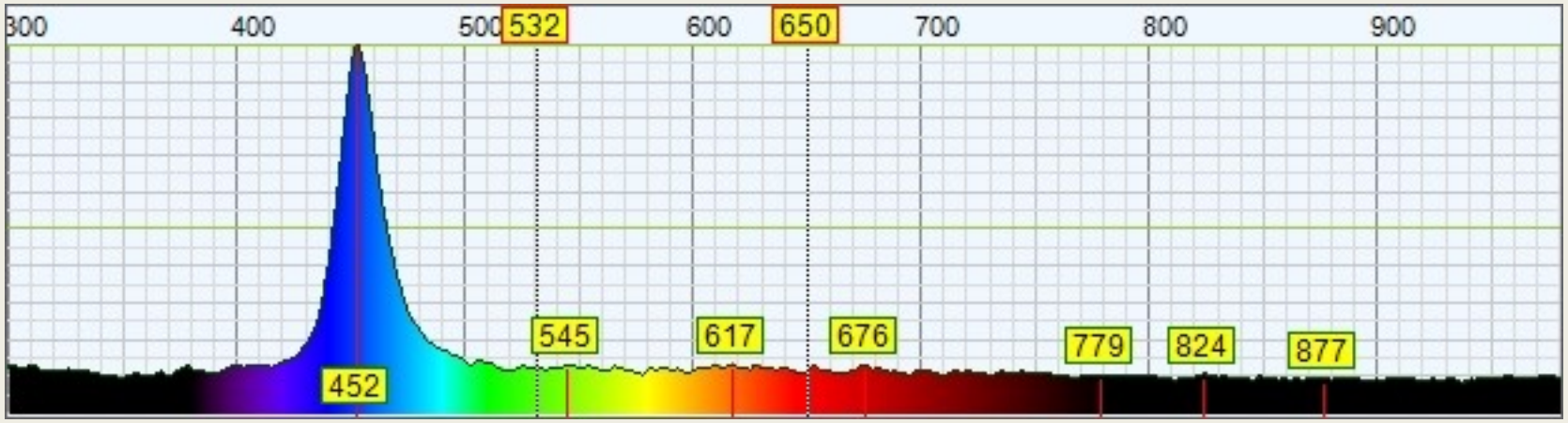
Distribution of the diffraction angle for different wavelength

- The visible spectrum is between about 400nm and 800nm, so here we can use the angle of 54 degrees of vertical intake at 600nm as the tilt angle, and here we can plot the corresponding angle change when the corresponding light is diffracted out. It can be seen that the two show a linear variation relationship, this is helpful for software to analyze the data.
- We can see that the two show a linear relationship, so the spectrum captured in the camera can directly correspond the intensity of light at each point position captured to the individual wavelengths.



What’s the resolution for the example

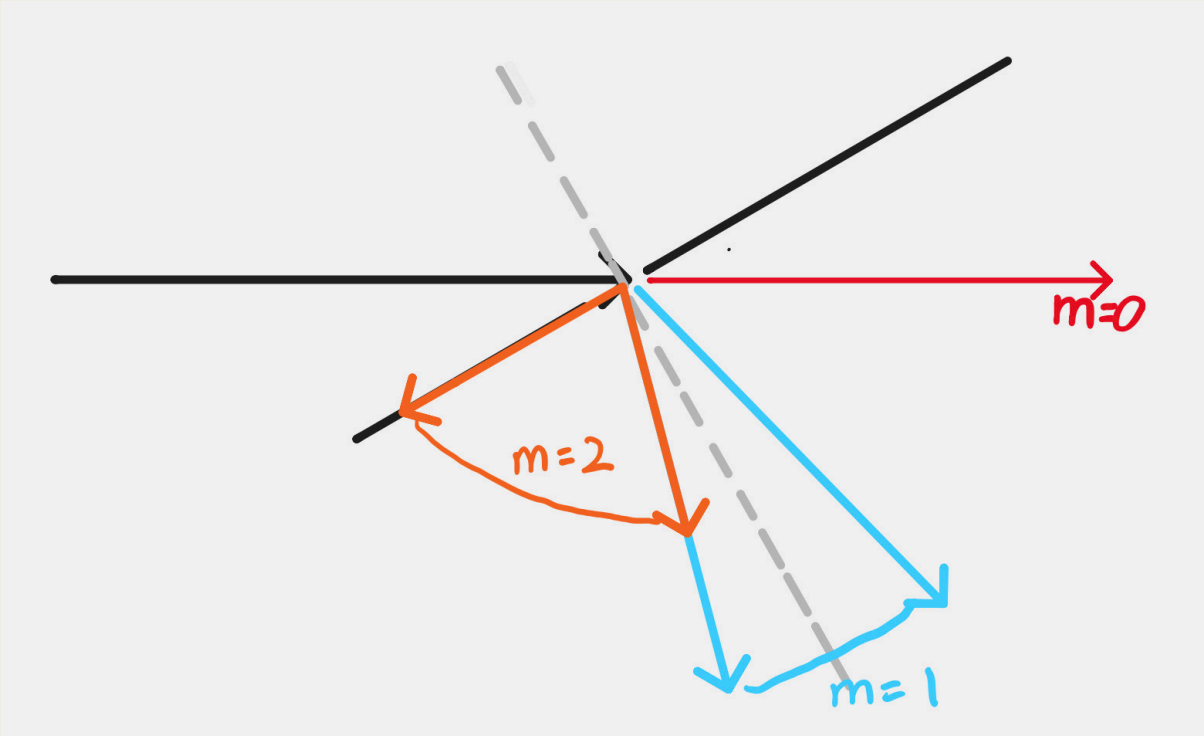
- Here we take the wavelength 440nm as example



$$\Delta\lambda_{\min} = 2\Delta\lambda_{1/2} = 20.90\ \text{nm}$$

$$\Re \equiv \frac{\lambda}{(\Delta\lambda)_{\min}} = 21.64$$

Will the diffraction light (m=1) overlap with others(m=2 or 0)?Can it cover the whole visible spectrum



Through the calculation we can find that the spectrometer can cover the entire visible interval, but at the same time there may be overlap at 400nm at m=2. However, since the intensity of diffraction decays sharply with angle, there is no need to worry about overlap here, which affects the experimental results.

m	800nm	400nm
0	-54	-54
1	15.7228	-15.6058
2	exceed(maximum at 670nm in 90)	15.7228

Uniqueness of our instrument

- **Low background noise**: The whole instrument is optically closed, so it is difficult for external light to enter the instrument .In out instrument the background noise could reduce to about 5% which provide very accuaruate result.
- **High resolution**: As been seen in the example our instrument can reach a high resolution
- **Easy to use**: Our equipment uses a lot of modular design, which can be easily adjusted through simple assembly and disassembly.
- **Multi function**: different measurement purposes can be carried out by installing different modules

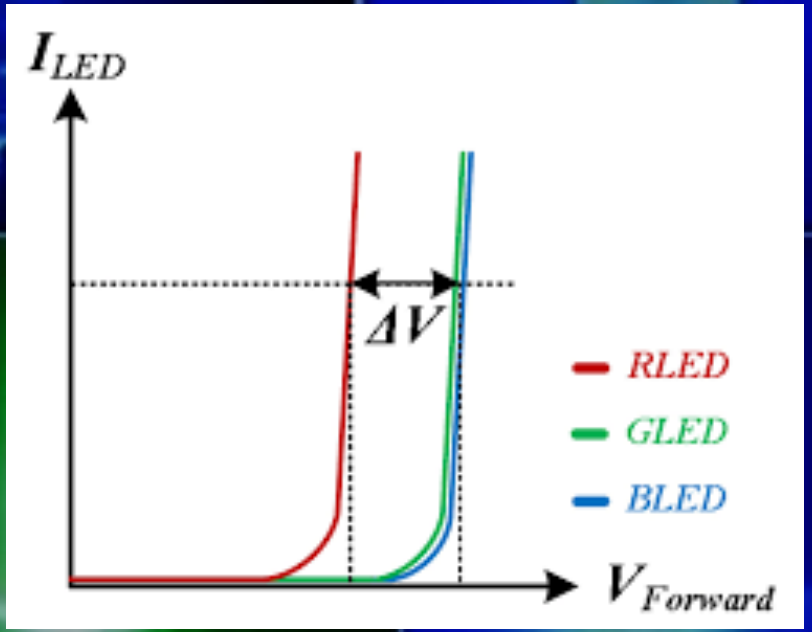
Application 1: Measure the Plank's Constant with LEDs

- Experiment Objective:

To measure the value of the Plank's constant with the LED bulb series and Spectrometer

- Experiment Hypothesis:

The shorter the wavelength of light, the greater the voltage across the LED (forward voltage)



Experiment Methodology:

- Background Information:

The Plank's constant 'h' is one of the most important constants in modern physics. Planck believed that matter could radiate only an integral multiple of some minimum energy, which he called a "quantum of energy," that is E=hv.

For the LEDs, when the P-N junction of the semiconductor material is applied to a forward voltage, the combination of injected minority and majority carriers releases excess energy as light, converting electrical energy directly into light energy.

$$E = hf = qU = 1.6 \times 10^{-19} C \times V_{Forward\ Voltage}$$

Color	Construction	Typical Forward Voltage (V)
Amber	AlInGaP	2.1
Blue	GaN	5.0
Green	GaP	2.2
Orange	GaAsP	2.0
Red	GaAsP	1.8
White	GaN	4.1
Yellow	AlInGaP	2.1

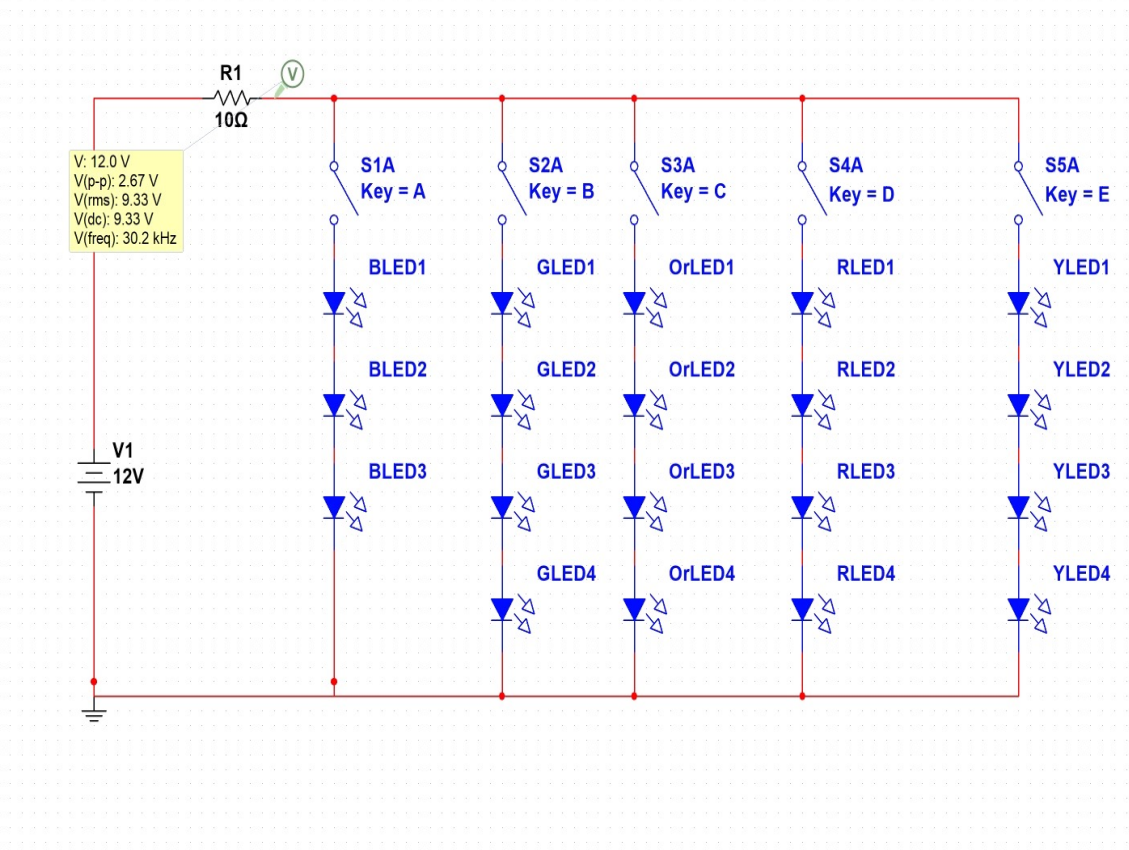
$$f = c/\lambda$$

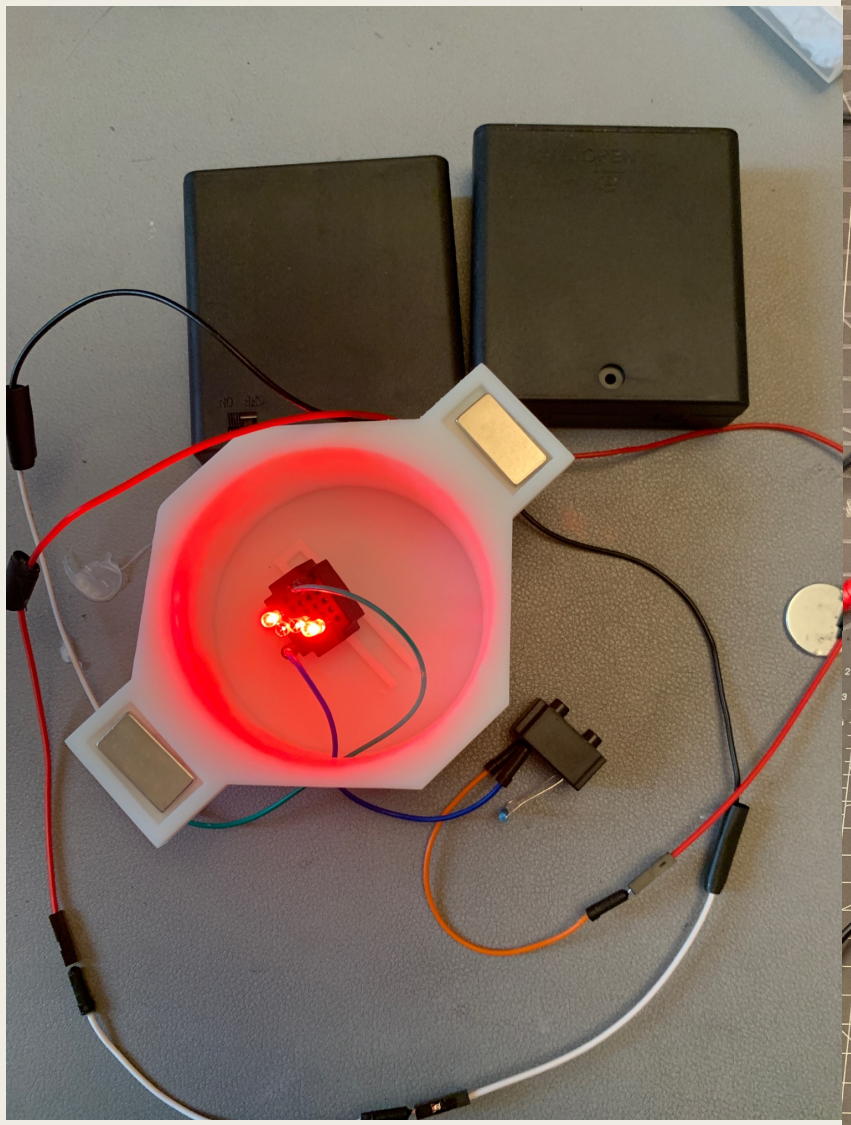
$$h = qf = qU\lambda/c$$

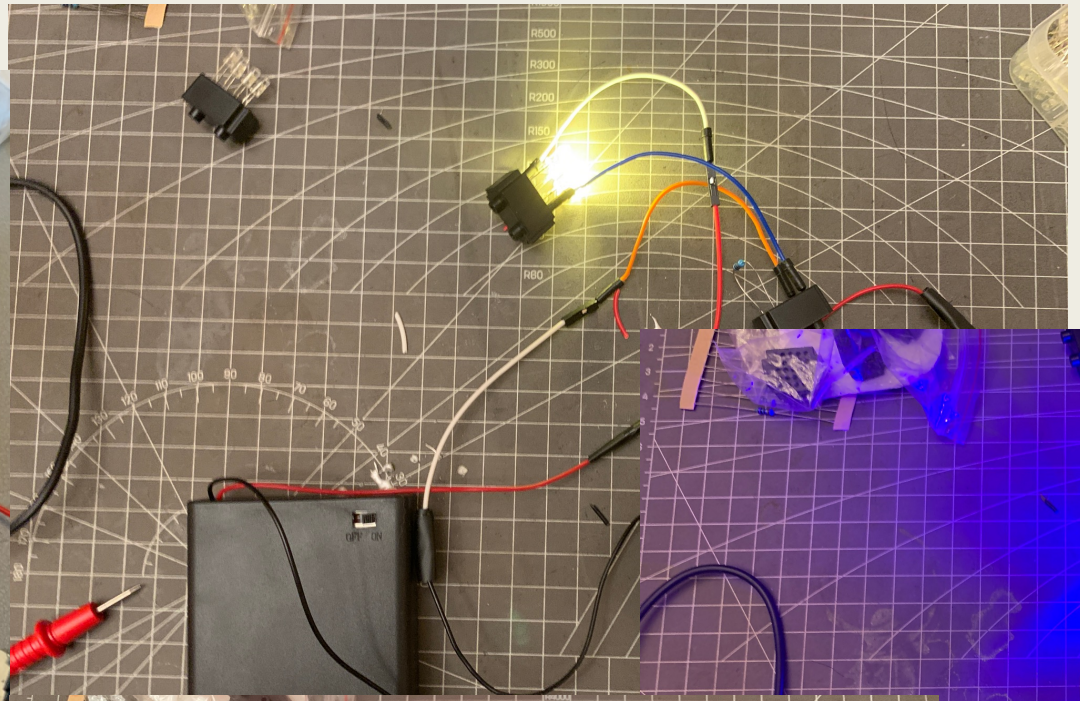
The forward Voltage of different Kinds of LED Bulb

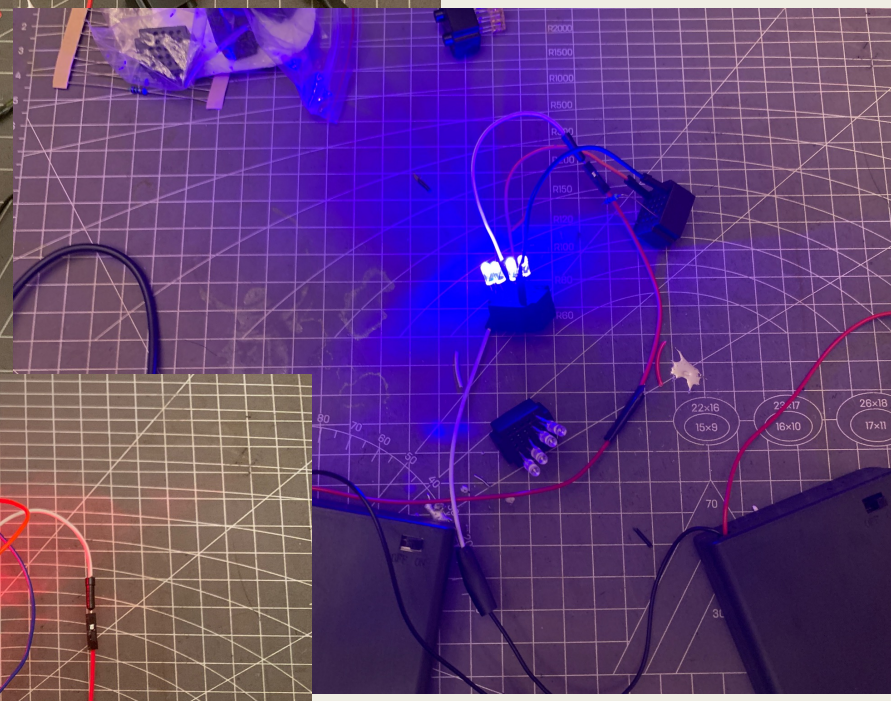
Experiment Methodology

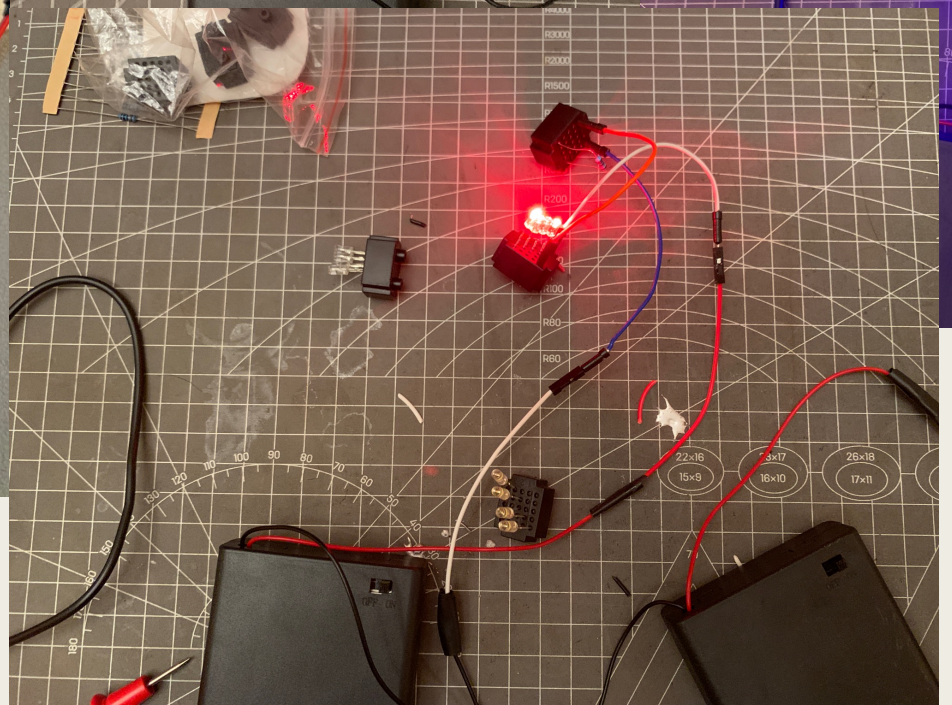
- In this part of the experiment, we will use multiple LEDs of the same type in series and measure their total potential to reduce the error due to.
- In this experiment, we use a multimeter as the measurement tool.
- The results in this part of the experiment will be used to calibrate the Spectrometer accurately.
- In order to save cost, here we use 8 household 1.5V batteries as the power supply, which constitute a 12V DC voltage
- On the right side is the circuit simulation in Multisim. You can see that when different switches are closed, different voltages can be obtained, which is the result of multiple LEDs sum

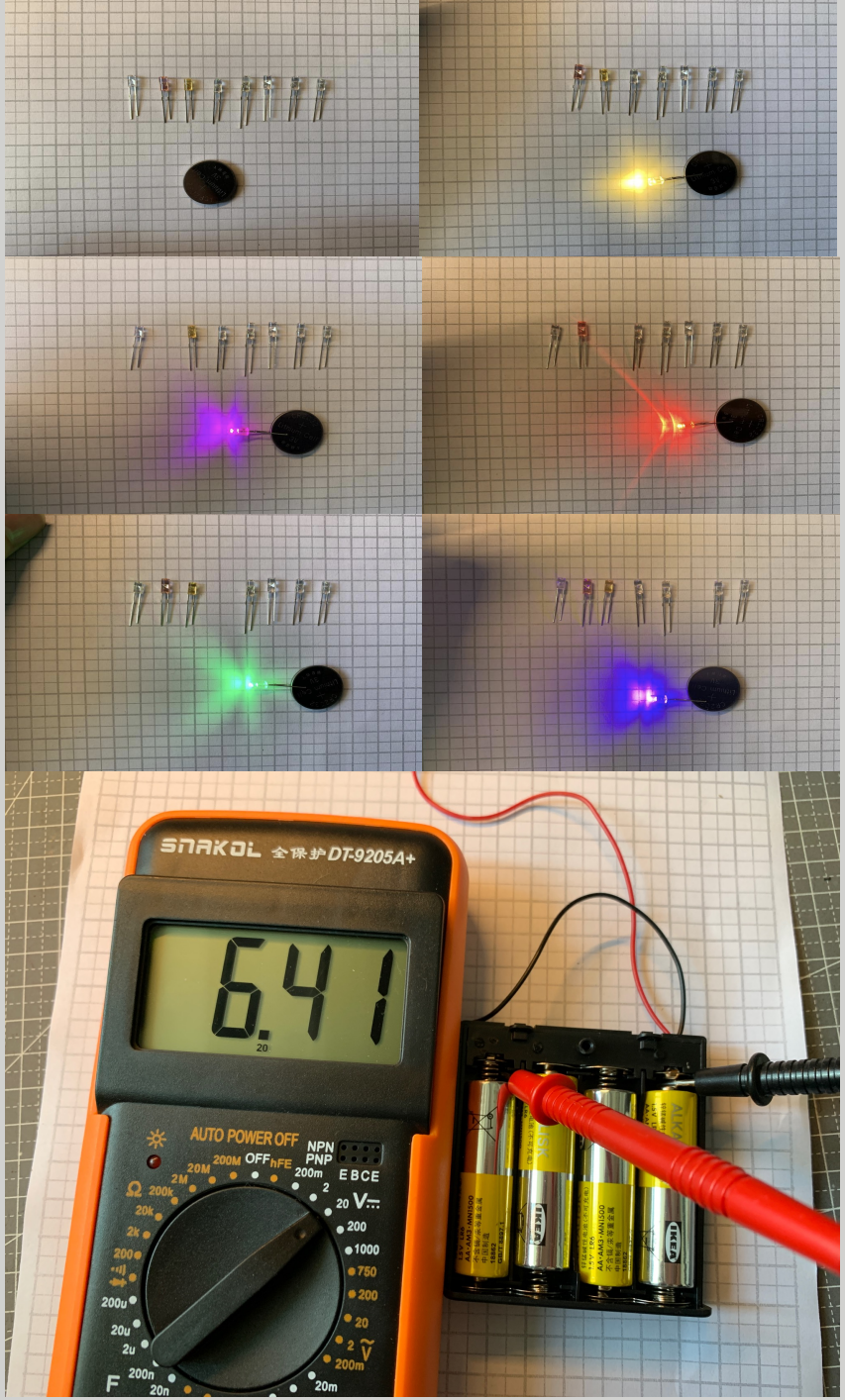








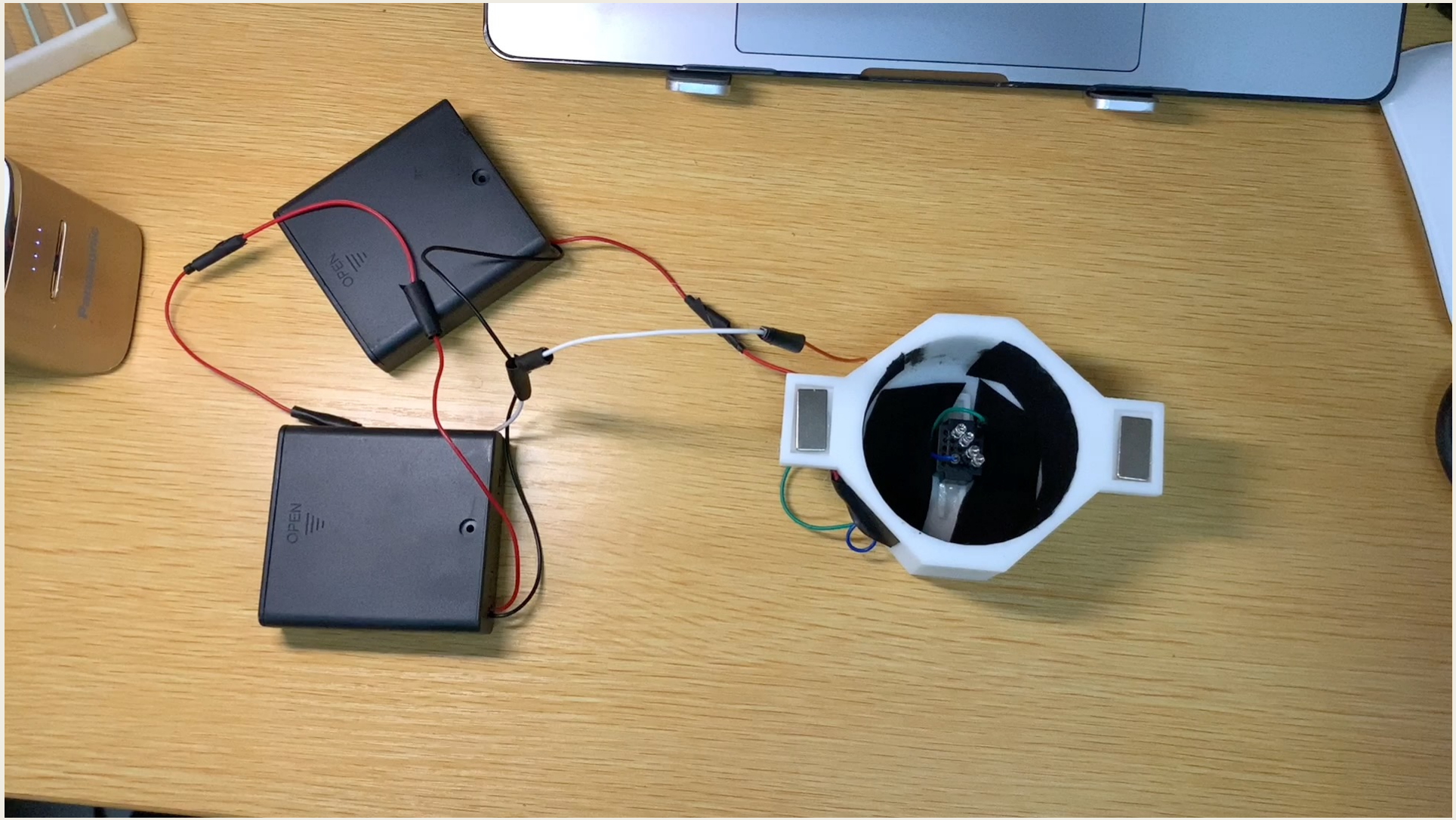




Material:

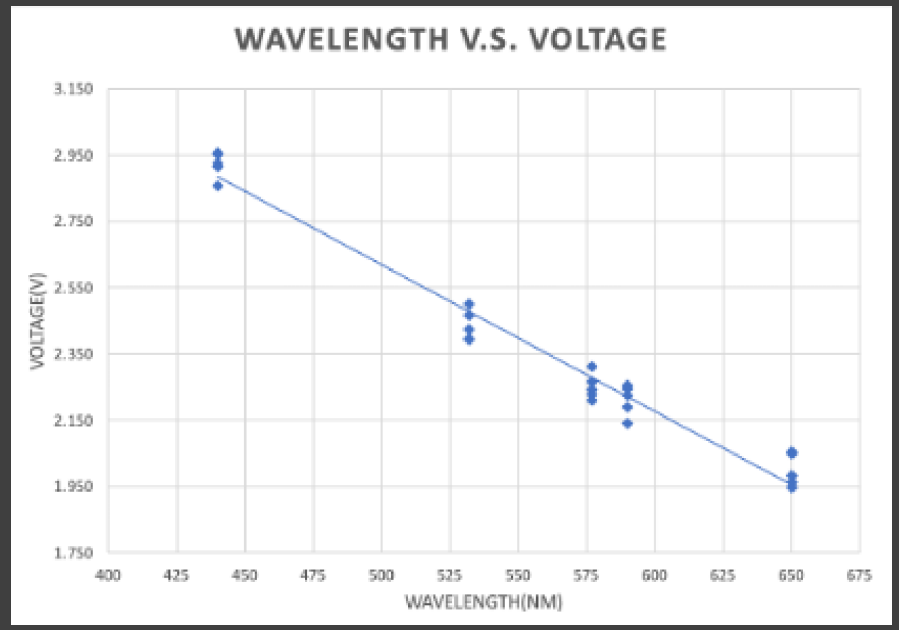
1. 8 kinds of the LED bulb
2. Resistor
3. Switch
4. Battery Case(about 12V)
5. 3D printed parts to construct the instrument

Experiment 2 Demo



Result

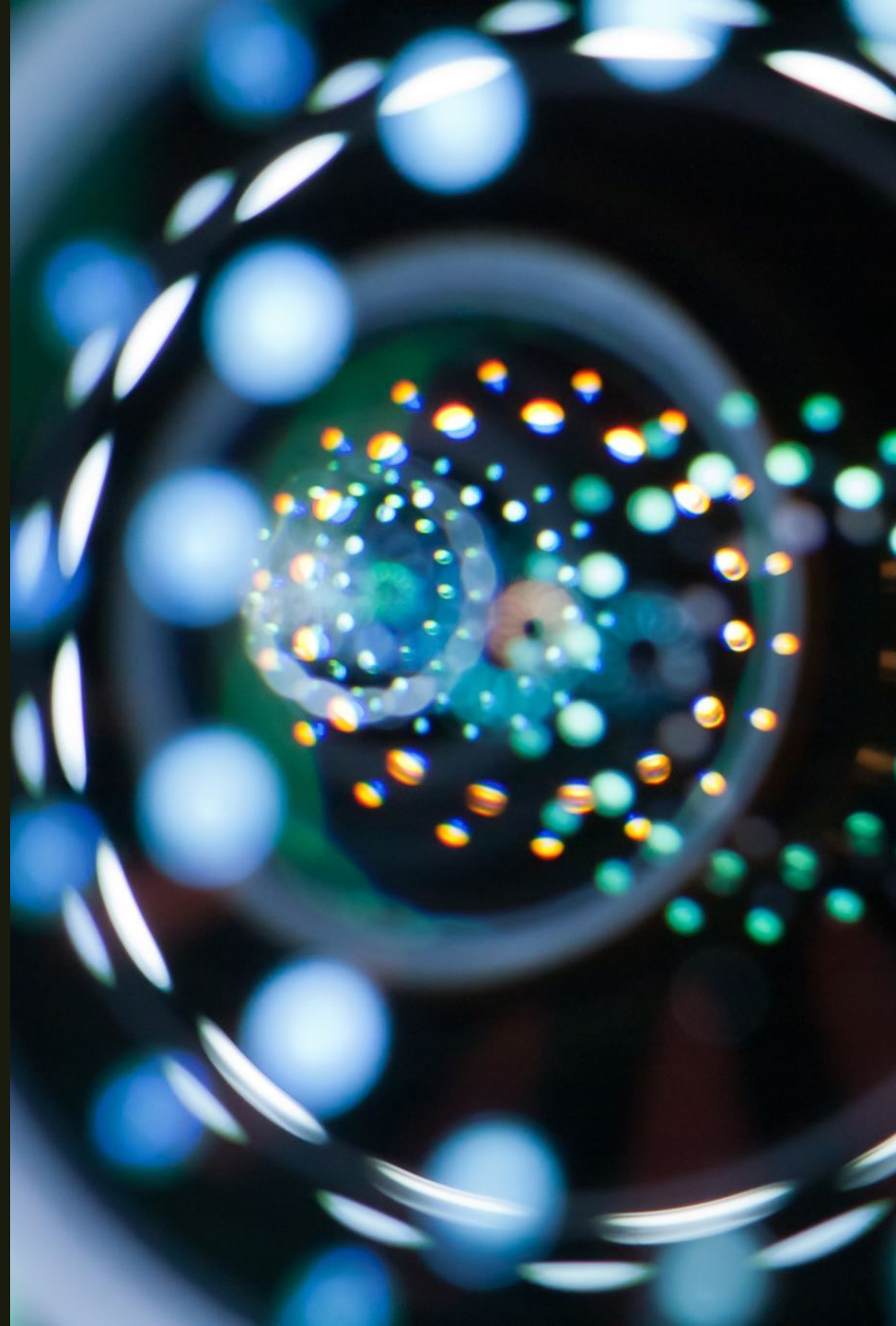
- First, we noticed that the voltage had a linear relationship with the wavelength, which proved the relationship between the two presented in the formula.
- We can through the observation of error in data evaluate the scientific rigor of the experiment, through calculation we can find in our final experiments, the standard deviation control within 5%, this shows that the experimental data is constant, the data is effective, we found that the relative theory of relative error is only 5% of the Planck constant, this proves that the experiment is scientific and accurate.
- At the same time, we can notice that in the experiment, the Planck constant result of the blue-purple lamp has a larger relative error than other lamps, which may be due to the internal defects of this type of bulb during production, such as resistance, leading to the measured voltage is greater than our theoretical calculation value. Finally, the Planck constant is larger.



Wavelength(nm)	Planck constant av	Planck constant stdev	Absolute Err	Relative Error
650	6.94143E-34	1.69397E-35	3.15359E-35	0.047593681
590	6.86417E-34	9.20313E-36	2.38099E-35	0.035933669
577	6.91954E-34	1.32358E-35	2.9347E-35	0.044290202
532	6.93844E-34	1.19651E-35	3.12367E-35	0.047142117
440	6.91051E-34	1.20435E-35	2.84435E-35	0.042926701
Total	6.94912E-34	1.36305E-35	3.23054E-35	0.048755027

Further Improvement

- we can use more LED beads in series and parallel at the same time to improve the sum of voltage and brightness and install an astigmatism plate at the front end of the spectrometer to make the incident light more uniform, so as to reduce the possible problem of distortion of experimental results caused by the uneven incident light in the experiment.
- At the same time, we can choose more LED beads and a wider wavelength range to conduct experiments, which will help improve the accuracy and universality of the experiment and also reduce the errors generated in the experiment by taking the average.



Application 2: Measure the Spectrum Absorption of Copper Sulfate Solution

- Background Information:
- In an experiment carried out by the Los Angeles City College, aimed at find out the relationship between concentration of the solution and the absorbance of solution, which draw out a colored solution's distribution of absorbance line is highly related to its color and the absorbance and concentration is of linear relationship.
- The experiment can be reduced by using spectrometer to determine the region of most significant absorbance happened and use two pair of data to calculate the maximum absorbance, and furthermore draw out the relationship between concentration and absorbance.

Hypothesis

- The more concentrated the solution is, the higher absorption of the solution is, the relation between absorption and concentration of the solution follows the Beer-Lambert Law.

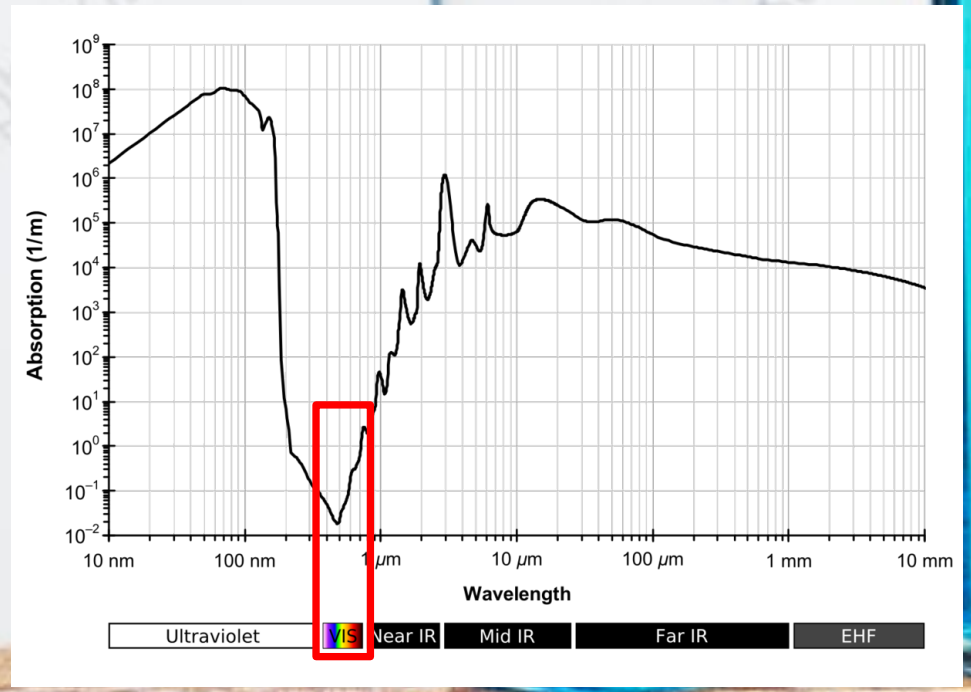
- The Copper Sulfate Solution's absorption of red light is less than the absorption of blue light, which corresponding to the blue color of the solution.

Application 2: Measure the Spectrum Absorption of Copper Sulfate Solution

- Background Information: Spectroscopy

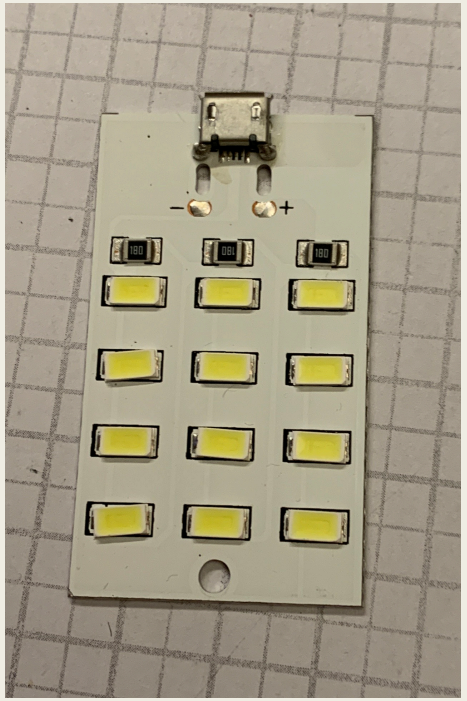
In this experiment we will only focus on the visible light spectrum of the solution.

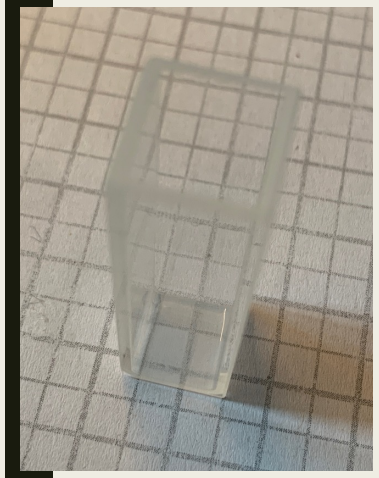
Reason: We use water as solvent.

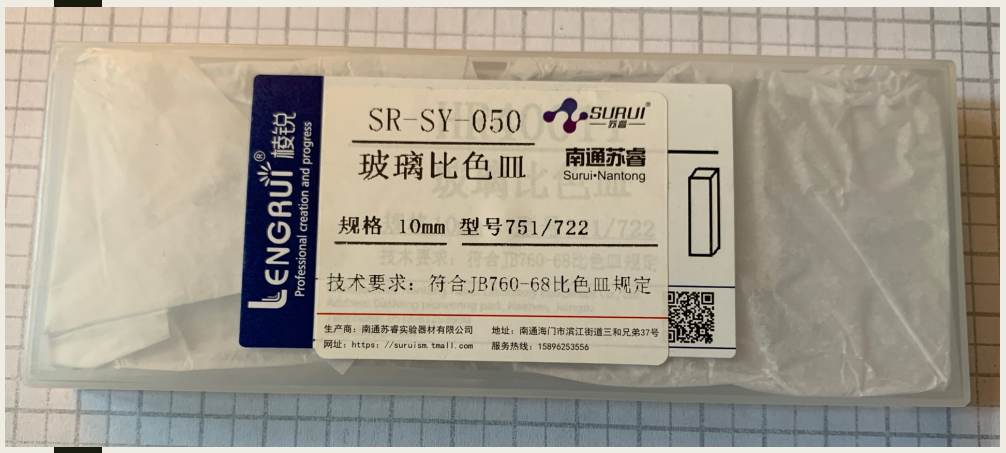


Obviously, the water has it's absorbtion reaches bottom in the visisble light region

And consider the water in the cuvette is very thin (less than 1cm), such absorption will be least visible.







- Material:

1. The solution used: Deionized water, $CuSO_4$ solution (deionized water + $CuSO_4$ crystal)

2. Light Used: 650nm red light source, 500nm blue light (Inspect whether the absorption is corresponding to the color)

3. $CuSO_4$ concentration: 0.1Mol/L, 0.2Mol/L, 0.5Mol/L and 1Mol/L

4. Amount of solution need: 5mL/each experiment

Light/Solution	Deionized water	0.1mol/L $CuSO_4$	0.2mol/L $CuSO_4$	0，5 mol/L $CuSO_4$	1mol/L $CuSO_4$
675nm (Red) wavelength light (optional)	Absorbance 1	Absorbance 2	Absorbance 3	Absorbance 4	Absorbance 5
500nm (Blue) wavelength light (optional)	Absorbance6	Absorbance 7	Absorbance 8	Absorbance 9	Absorbance 10

- Experiment Methodology:
- Experiment:

i. Turn on the spectrometer we make, use 500nm light (blue) with fixed intensity.

ii. Insert the cuvette with deionized water into the spectrometer, assure that no fingerprint or dirt on the cuvette, if there is, wipe them off with light duty wipe.

iii. Read and record the spectrum of the water.

iv. Change another cuvette with 0.1mol/L solution, repeat the experiment, record the spectrum.

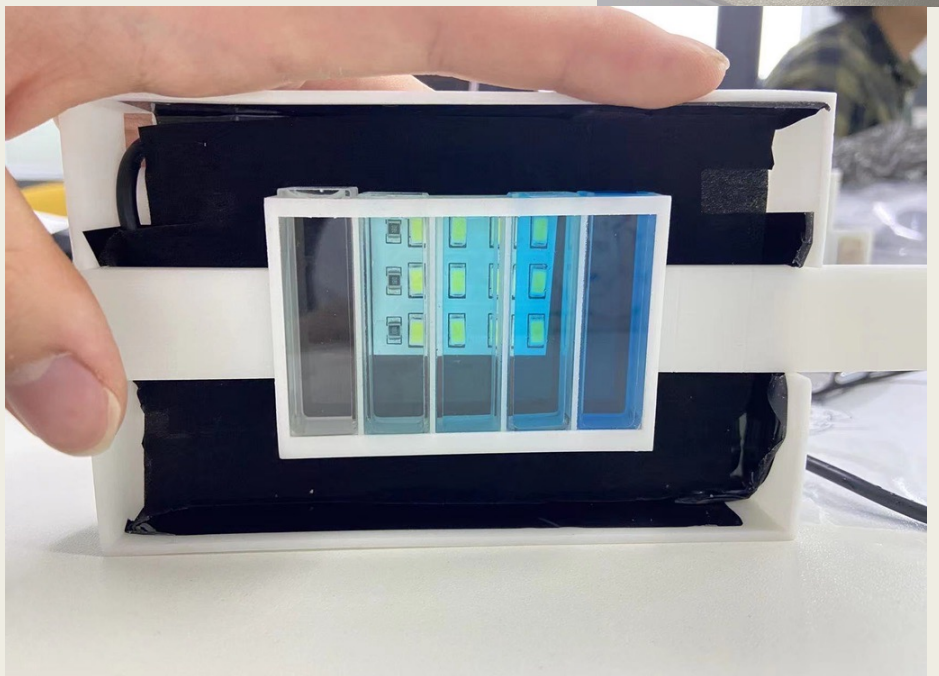
v. Repeat the process using 0.2, 0.5 and 1mol/L solution.

vi. Change the light source into 675nm (red) light source, repeat the step i to v again.

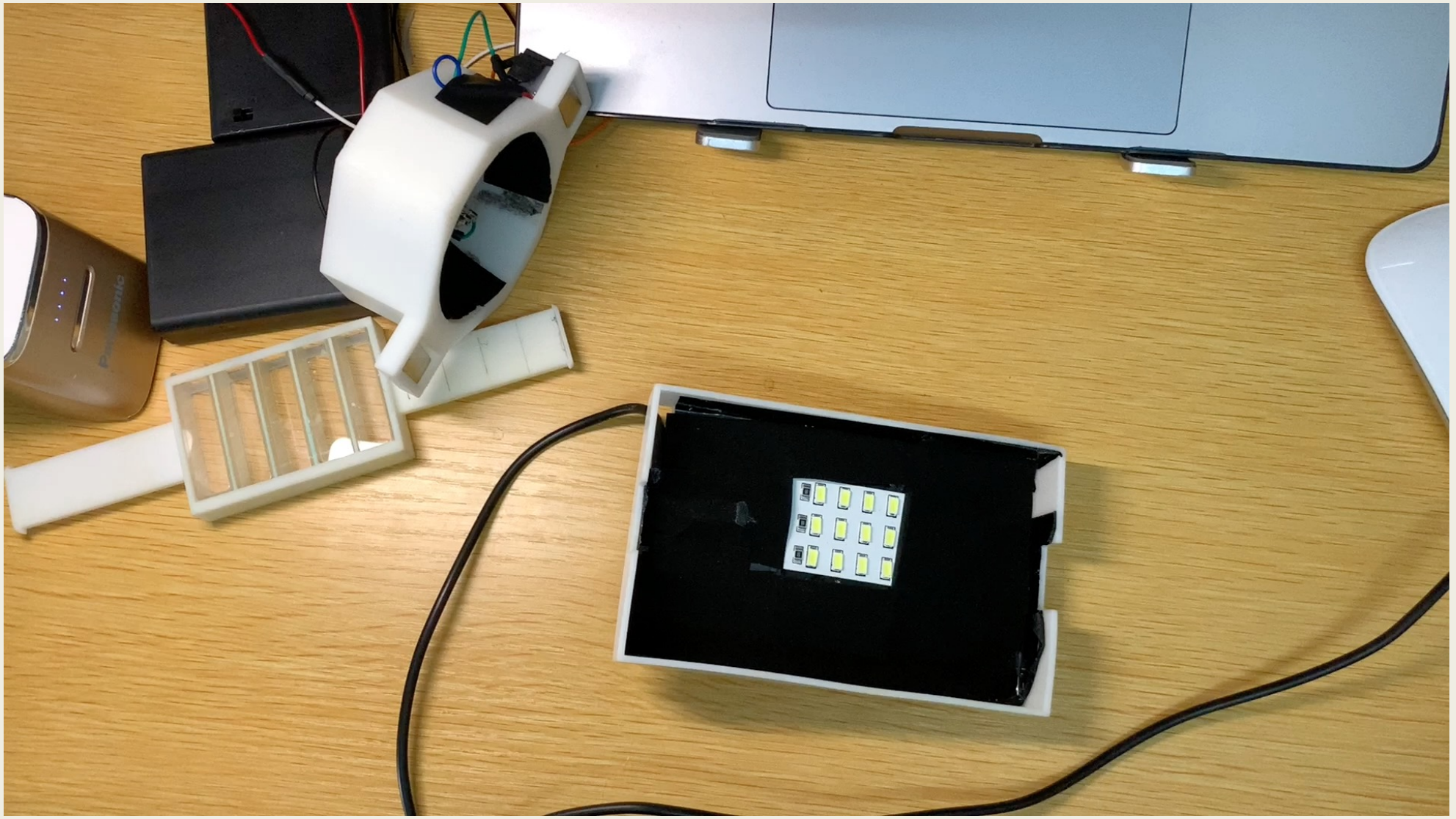
vii. Output the graph of different concentration and different light source and compare the data and graph to draw the conclusion.


开关
单位
495
计数
清零


0
0.1 mol/L
0.2 mol/L
0.5 mol/L
1 mol/L
XIAMEN
ADD:FUJIAN XIAMEN



Experiment 3 Demo



Result Analysis

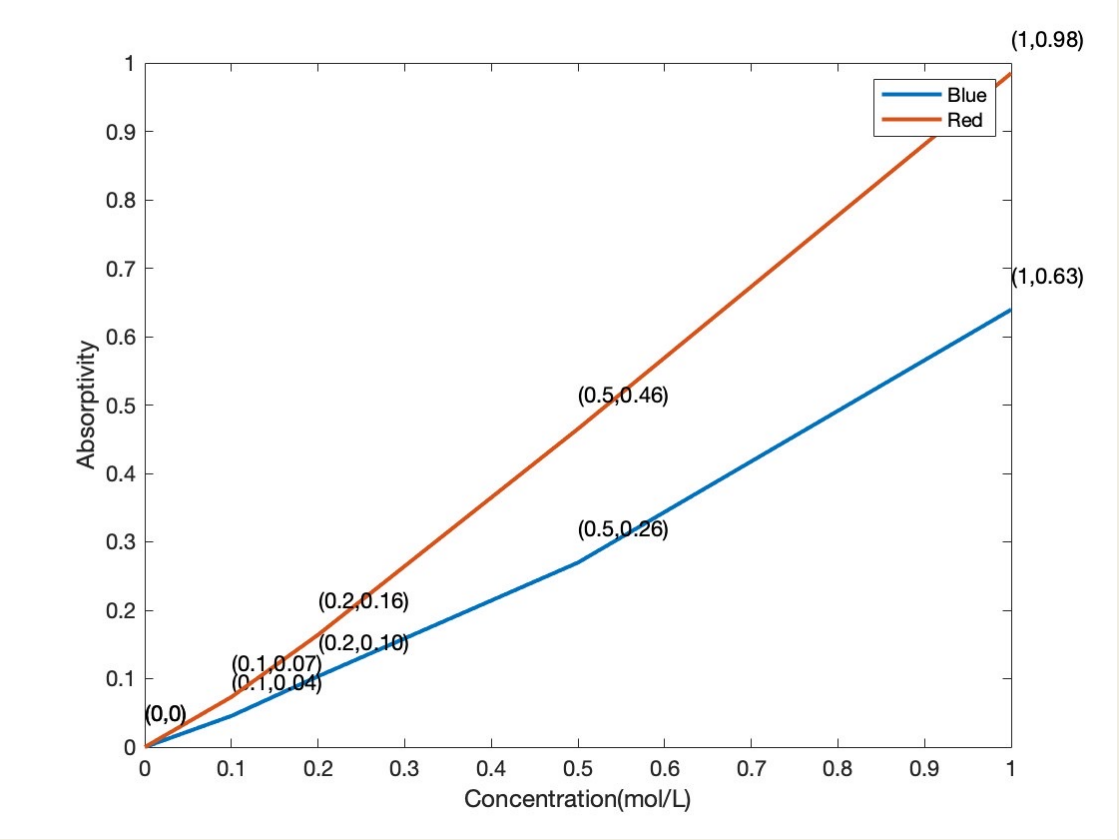
- In the experiment, we have

Fixed: optical path length l, molar absorptivity ε

Independent: Concentration c

Dependent: Absorptivity A

- According to Beer-Lambert's, $A=\varepsilon lc$ the absorptivity should be proportional to the concentration.
- The graph shows approximately linear relation, and the molar absorptivity of the red light is larger the the blue light.



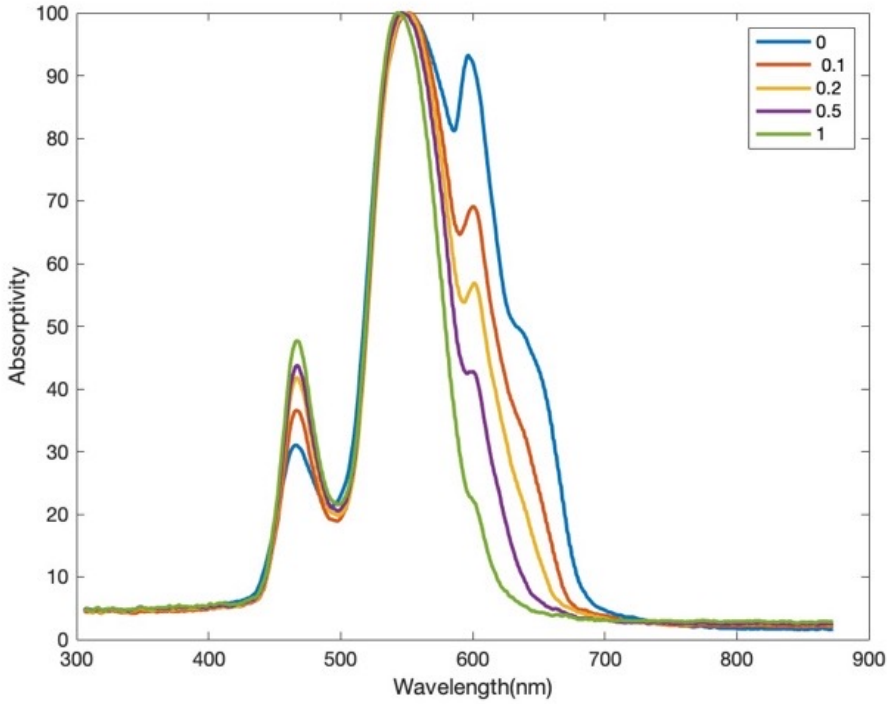
Conclusion

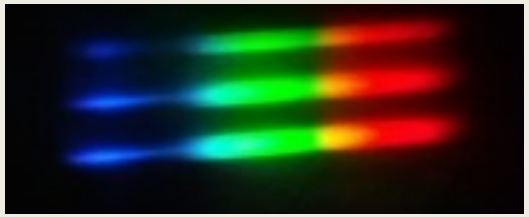
- The absorptivity of the Copper Sulfate solution follows the Beer-Lambert's Law, the absorptivity and concentration of the solution is of linear proportional relation.

- The solution's molar absorptivity of red light is significantly higher than the blue light, due to the steeper graph. This can be explained by the solution's blue colour and its transparency.

Further Improvement and Error Analysis

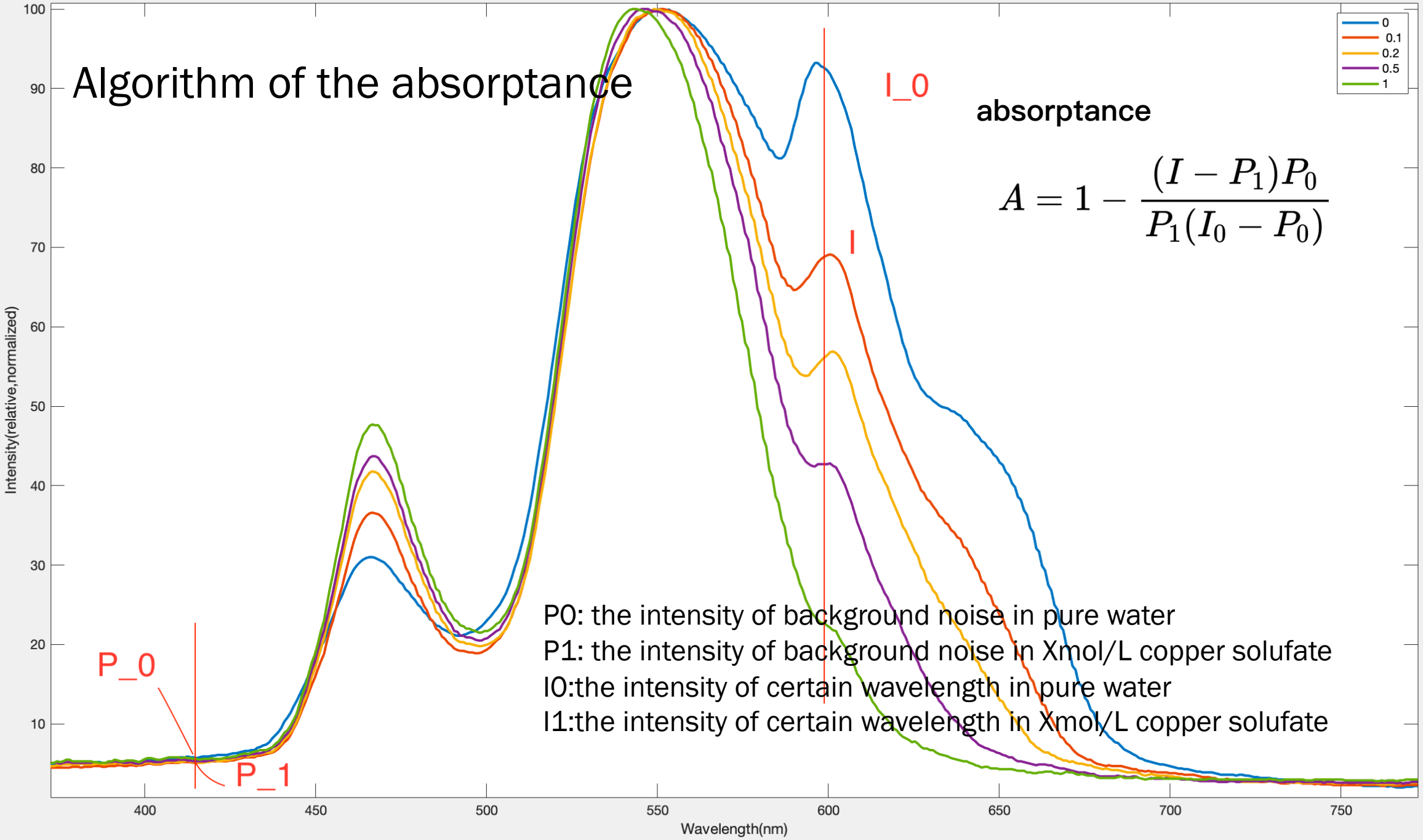
- In this experiment, we have been tested for many times. Due to the closeness of the instrument, the result error is generally kept at 1%. Therefore, in this process, we believe that there is no error due to measurement. The main error of the experiment lies in the uneven distribution of light intensity, the existence of **floodlight** and the **resolution** and the program and algorithm
- **Uneven light intensity distribution: Here LED light will have some wavelength with zero intensity which made the spectrum we plot has huge error**, therefore using more uniform light in each wavelength is required to improve the result.
- **Floodlight**: Some wavelength with high intensity will exist flood light
- **Few test groups**: We can increase the set of solute concentration again to verify the accuracy of Beer-Lambert Law at high concentrations.
- **Lack of the intensity data**: The software we using in the measurement doesn't perform well because **of lack of the function** to output the absolute intensity but relative intensity, which cause problem in data processing.





A little bit floodlight

Algorithm of the absorptance



absorptance

$$A = 1 - \frac{(I - P_1)P_0}{P_1(I_0 - P_0)}$$

P0: the intensity of background noise in pure water
P1: the intensity of background noise in Xmol/L copper solufate
I0:the intensity of certain wavelength in pure water
I1:the intensity of certain wavelength in Xmol/L copper solufate

Thank you!

Reference:

1. leswright1977/PySpectrometer: Raspberry Pi Spectrometer (github.com)
2. CDs and DVDs as Diffraction Gratings | NNCI
3. USING CDs AND DVDs AS DIFFRACTION GRATINGS | NNIN
4. https://www.theremino.com/wp-content/uploads/files/Theremino_Spectrometer_Technology_ENG.pdf
5. 利用发光二极管（LED）测定普朗克常数的实验设计 - 豆丁网 (docin.com)
6. https://www.lacitycollege.edu/Departments/Chemistry/documents/E07B-complexion-(1)

Any Technical Document relevant(Hardware Drawing, Circuit, Software) could be find in Github (MIT License): https://github.com/yimingio/Lab_IV_Spectrometer