Lab Journal

PH2233 - Physics Lab II

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Lab Journal

Pune, March 2025

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Lee's Method

Date of Experiment: 11 January 2025

Introduction

In this experiment, we are trying to find the the thermal conductivity of the material. We will place a brass disc with different materials and we will try to find the thermal conductivity of the given material placed in contact with brass disc and let it cool. We will try to do it different materials and will compare their thermal conductivity.

Theory

In the first part of the experiment, we will heat the the brass disc by placing the material disc between the bottom brass disc and the upper disc connected to steam. Steam will cross through the upper disc hence heating it, thereon heating the bottom disc by conducting through the material in between.We will wait for the point where the temperature for the upper disc and lower disc reach to a steady state(constant for at least 10 minutes). Then we will heat the lower disc directly without placing the material disc in between. We will raise the lower disc temperature by 7° celsius. After which we will again put back the material on it but without having steam connected upper disc. Hence it will cool down, and by analyzing the cooling pattern we will determine the instantaneous rate of cooling.
Thermal Conductivity: Watt per unit Kelvin
So, it is the heat per unit time per unit length for per unit temperature difference.
So, we will see the thermal conductivity at its peak while cooling from its highest attainable temperature (steady state) with particular material in between the heating disc and bottom disc.

Figure 1.1: *Image of different materials*

Observations

Here is presented the table for diameter and thickness readings:

Material	Main Scale	Vernier Scale	Reading	Mean D	Area ($\times 10^{-3}\ m^2$)
Material 1	11.1	9	11.19	11.03	9.555
	11	0	11.00		
	10.9	7	10.97		
	10.9	5	10.95		
Material 2	11.1	0	11.10	11.09	9.664
	11.1	3	11.13		
	11	8	11.08		
	11	6	11.06		
Material 3	11	8	11.08	11.07	9.620
	11	9	11.09		
	11	3	11.03		
	11	7	11.07		
Material 4	10	0	10.00	9.97	7.803
	10	0	10.00		
	9.9	0	9.90		
	9.9	7	9.97		

Table 1.1: *Diameter of Materials: Mean Values (in cm) and least count of Vernier Scale is 0.01 mm with no error.*

Material	Main Scale	Circular Scale	Reading + 0.10	Mean Thickness (mm)
Material 1	2	25	2.25+0.10	2.4167
	2	33	2.33+0.10	
	2	41	2.41+0.10	
	2	24	2.24+0.10	
	2	41	2.41+0.10	
	2	26	2.26+0.10	
Material 2	4	19	4.19+0.10	4.286
	4	23	4.23+0.10	
	4	18	4.18+0.10	
	4	16	4.16+0.10	
	4	17	4.17+0.10	
Material 3	4	54	4.54+0.10	4.528
	4	09	4.09+0.10	
	4	49	4.49+0.10	
	4	36	4.36+0.10	
	4	33	4.33+0.10	
	4	76	4.76+0.10	
Material 4	3	47	3.47+0.10	3.612
	3	40	3.40+0.10	
	3	54	3.54+0.10	
	3	59	3.59+0.10	
	3	56	3.56+0.10	

Table 1.2: *Thickness of Materials (in mm). Least count of the screw gauge is 0.01 mm with 10 circular scale divisions of negative error.*

Time(Seconds)	Material 1	Material 2	Material 3	Material 4
30	83.0	91.0	74.5	86.0
60	81.5	90.0	72.5	83.5
80	79.5	89.0	71.0	81.5
120	78.5	87.5	70.0	79.5
150	77.0	86.5	69.0	78.5
180	76.0	85.0	68.0	77.5
210	75.0	84.0	67.0	76.0
240	74.0	83.0	66.5	75.0
270	73.0	82.0	65.5	74.0
300	72.0	81.0	64.5	73.5

Table 1.3: *Cooling Pattern of different material and temperature is in degree celsius*

Analysis

We are going to use some relations:

1)Fourier's Law of Heat Conductance: Rate at which transfer of heat between two objects at temperatures T_2 and T_1 connected by a conductor with conductivity k and cross-sectional area A (assumed uniform) and length l.

$$\frac{\Delta Q}{\Delta t} = k\frac{A}{l}(T_2 - T_1) \tag{1.1}$$

2)The rate at which heat is lost by the disc, if m is the mass of the disk and s is the specific heat of the material:

$$\frac{\Delta Q}{\Delta t} = ms\left(\frac{dT_1}{dt}\right) \tag{1.2}$$

3) Heat Balance in the experiment is given by combining (1.1) and (1.2):

$$k = ms\frac{(dT/dt)l}{A(T_2 - T_1)} \tag{1.3}$$

Material	dT/dt	$T_2 - T_1$	Area ($\times 10^{-3}\ m^2$)	Thickness (mm)	Thermal Conductivity($W/(m \cdot K)$)
1	-0.03541	22.0	9.555	2.4167	0.14014
2	-0.04039	7.0	9.664	4.286	0.88092
3	-0.02384	31	9.620	4.528	0.12461
4	-0.06836	14	7.803	3.612	0.77808

Table 1.4: *Value of Thermal Conductivity, Mass of disc = 0.9059 kg, s= 380 J/kg K*
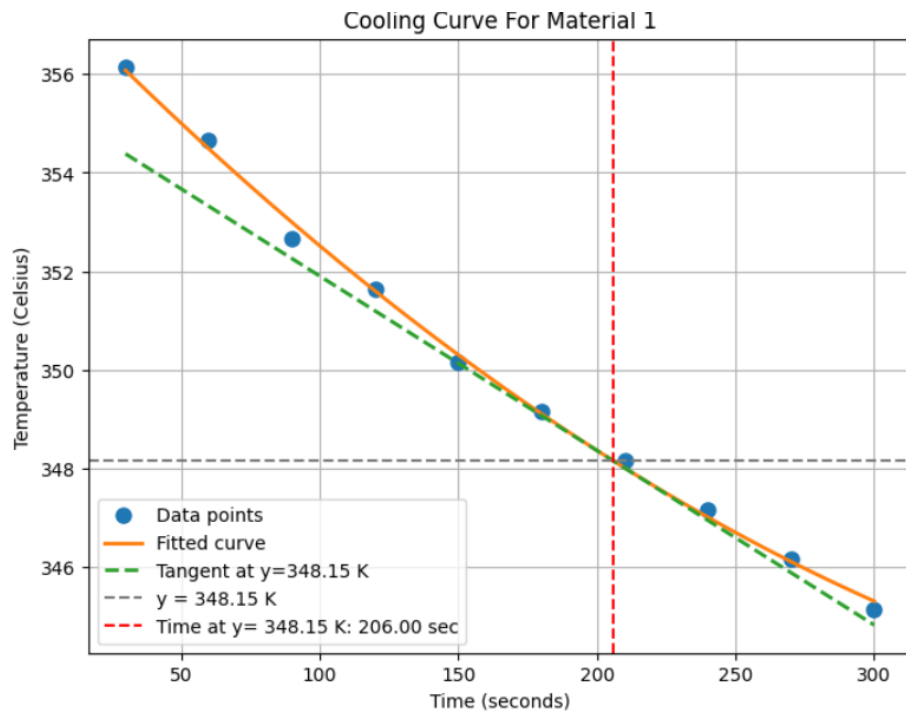
```
The fitted polynomial equation is: 0.0001x^2 + -0.0580x + 357.7667
Slope: -0.03541287526950219, Intercept: 355.4449175323403
Fitted parameters: [ 5.47138025e-05 -5.79545455e-02  3.57766667e+02]
Slope at time 206.00 sec: -0.0354 ± 0.0048
```

Figure 1.2: *Material 1*
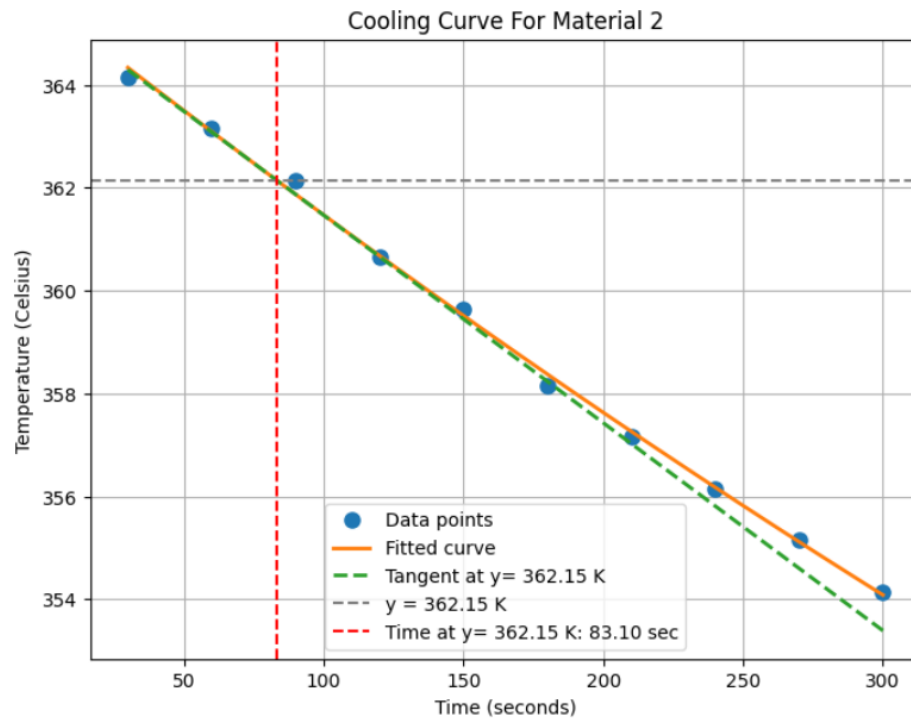

```
The fitted polynomial equation is: 0.0000147306x^2 + -0.0428x + 365.6083
Slope: -0.04039269330509305, Intercept: 365.50661064009745
Fitted parameters: [ 1.47306375e-05 -4.28409091e-02  3.65608333e+02]
Slope at time 206.00 sec: -0.0368 ± 0.0044
```

Figure 1.3: *Material 2*

The fitted polynomial equation is: 0.0001x^2 + -0.0510x + 348.7167
Slope: -0.023840312270160723, Intercept: 345.0625894369925
Fitted parameters: [5.05050364e-05 -5.10100959e-02 3.48716666e+02]
Slope at time 206.00 sec: -0.0302 ± 0.0083

Figure 1.4: *Material 3*

The fitted polynomial equation is: 0.0001x^2 + -0.0798x + 361.1667
Slope: -0.06836060309475207, Intercept: 360.8572245869426
Fitted parameters: [1.05218867e-04 -7.97727309e-02 3.61166667e+02]
Slope at time 206.00 sec: -0.0364 ± 0.0074

Figure 1.5: *Material 4*

Error Analysis

For finding the uncertainty in k, we will use the below given expression:

$$\frac{\Delta k}{k} = \sqrt{\left(\frac{\Delta(\frac{dT}{dt})}{\frac{dT}{dt}}\right)^2 + \left(2 \cdot \frac{\Delta d}{d}\right)^2 + \left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta T_2 + \Delta T_1}{T_2 - T_1}\right)^2} \tag{1.4}$$

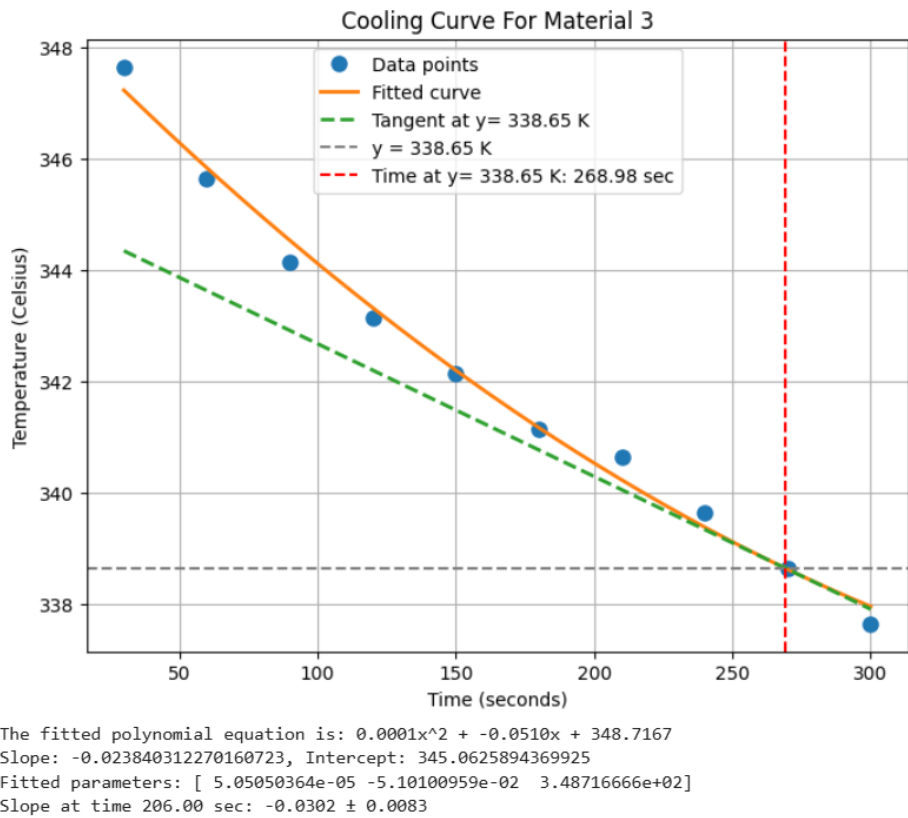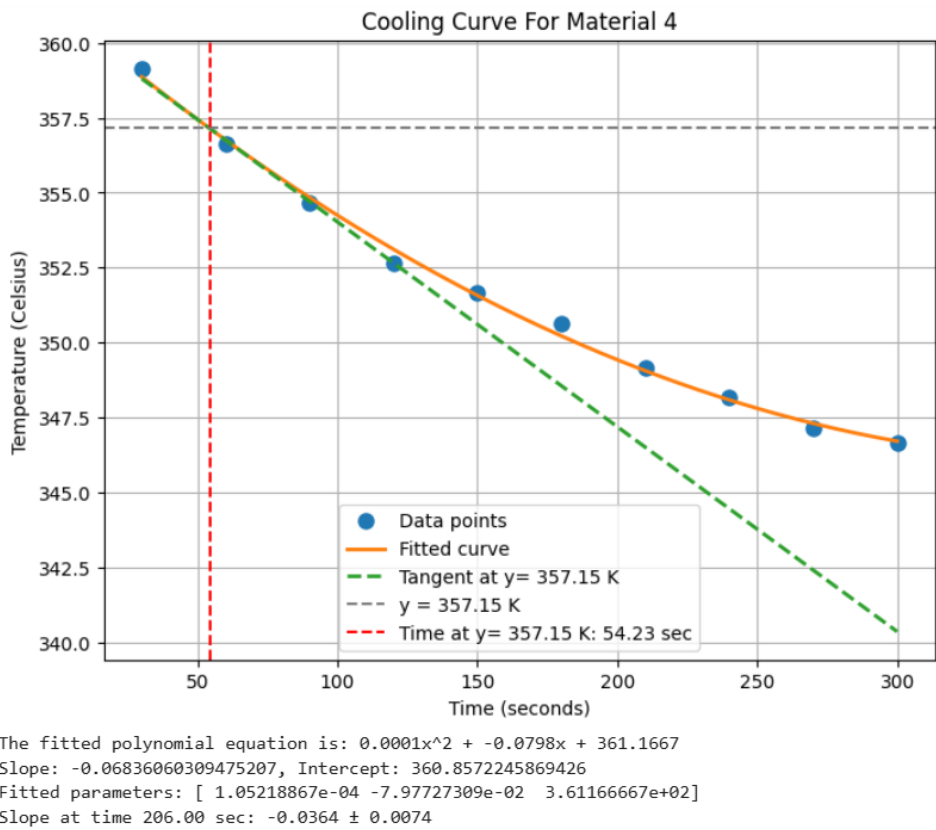For one material , if we try to do it multiple times for multiple values for T_2 and T_1, but it is time consuming. So, we we take ΔT_2 and ΔT_1 as 0.5 because it is least count in the digital thermometer. And for $\Delta\frac{dT}{dt}$, we could have done the heating and cooling multiple times, then plotting multiple cooling plot and then finding $\Delta\frac{dT}{dt}$ from multiple values of $\frac{dT}{dt}$. But again, it is time consuming. So for $\Delta\frac{dT}{dt}$, I am using *curve fit* from *scipy.optimize*. And used *param errors* for finding the uncertainty in the slope.

Material	Δd	Δx	$\Delta\frac{dT}{dt}$	$\Delta k/k$	Δk
1	0.11	0.0789	0.0048	0.148	0.02074
2	0.02986	0.027	0.0044	0.17986	0.1584
3	0.0263	0.2259	0.0083	0.3532	0.04401
4	0.0472	0.0766	0.0074	0.1318	0.1025

Table 1.5: $\Delta k/k$ *values for different materials.*

Probable errors and precautions:

- There are some big gaps in T_1 and T_2 and I also checked the data of other trials(by different students) , may be I assumed steady state before the actual one. That's why i got value less than actual maximum thermal conductivity (as available on the internet).
- There are some losses from the edges. Therefore, the thickness should be sufficiently less than its diameter as it won't contribute more.

Results

Thermal Conductivity of the materials:

$$2 > 4 > 1 > 3$$

As I have used curve fit function from scipy.optimize, also used param errors for finding error in

Material	$k(W/(m \cdot K))$	% error
1	0.14014 ± 0.02074	14.8
2	0.88092 ± 0.1584	17.986
3	0.12461 ± 0.04401	35.32
4	0.77808 ± 0.1025	13.18

Table 1.6: k *values for different materials.*

slope. So Errors obtained in k is mostly because of uncertainty in slope.

Points to Ponder

1. **Why is it necessary to have a thin disk in the experiment?**
   Because we are trying to find thermal conductivity of bad conductors so we have to take thin disk otherwise (the difference of T_2 and T_1 will be higher) the heating and cooling time will be more. But it will also increase the circular area of the edge due to thickness and then it will cause the heat loss to the ambient environment and as the area other than contact increase , the heat loss will play significant role and hence will result into wrong thermal conductivity value because significant value of heat is lost through other than the material's contact for which we are trying to find the value of k.

2. **Would this method work for measuring the conductivity of a good conductor?** Obviously it will work but as the conductivity is very high due to which the the difference of T_2 and T_1 will be lower so we need instruments with precision and least count and less errors. And also it will also radiate heat to ambient temperature so we need to have good controls on instruments.

3. **In the cooling part of the experiment, why is the brass disc D1 covered by the glass disc? Is it crucial to do so?** While heating with the glass disc, we reached to a steady state and then for cooling we used same glass disc to see the cooling by the thermal conductivity through the same material. In the heating part, we figured out the steady state where the heating by the material's conductivity and heat radiated is same. And while cooling at the same steady state temperature, we observed the heat loss that will be only through the glass disc. If we will not put the glass disc then the dT/dt at the steady state, will not be because of the glass disc , so we can't use it in (1.2) .

4. **Why do we take the cooling data asymmetrically around T1 in the second half of the experiment?** Because we have interest in finding thermal conductivity of the disc placed in between and we have to make the heat flow from the lower brass disc to the material at the steady state temperature.

Michelson's Interferometer

Date of Experiment: 18 January 2025

Introduction

In this experiment, we are taking a coherent light source, and because of same phase, we pass it to a beam splitter and then using two mirror to have the focus the laser on single point on the screen. Then using divergence lens in front of lens. Now because of the light interfering at the screen will behave at it is coming from two sources having little difference between their distance, causing the interference of light from coherent source.

Theory

Here, we will see the constructive and destructive interference of lights coming from Mirror 1 and 2. We are placing the Mirror 1 and 2 as the distance traveled from laser to mirror then from mirror to screen are equal for both beams interfering at the screen. Otherwise their amplitude will differ and won't give perfect constructive (bright fringes) or destructive (dark fringes) interference.

In the first part we are shifting the mirror 2 position and it is kind of same effect as in the double slit experiment, as by moving the micrometer , we are changing the distance between the slits (analogy). By doing it with green laser, we figured the value of Calibration constant.So in second part we did it with red laser and used the calibration constant obtained from the first part to calculate the wavelength for red laser.

In the third part, by placing the glass slide before the screen we are making the light to pass through the glass. But for calculating the refractive index of the glass, we will calculate the fringes moved by moving the slide by some angle. Actually by moving the slide by some angle , the incident angle is decreasing(or, increasing) lead to shift of bright and dark fringes.

In the fourth part, we are passing the light through air with different pressures, and due to changing the pressure waves shift and due to which the fringes will shift.
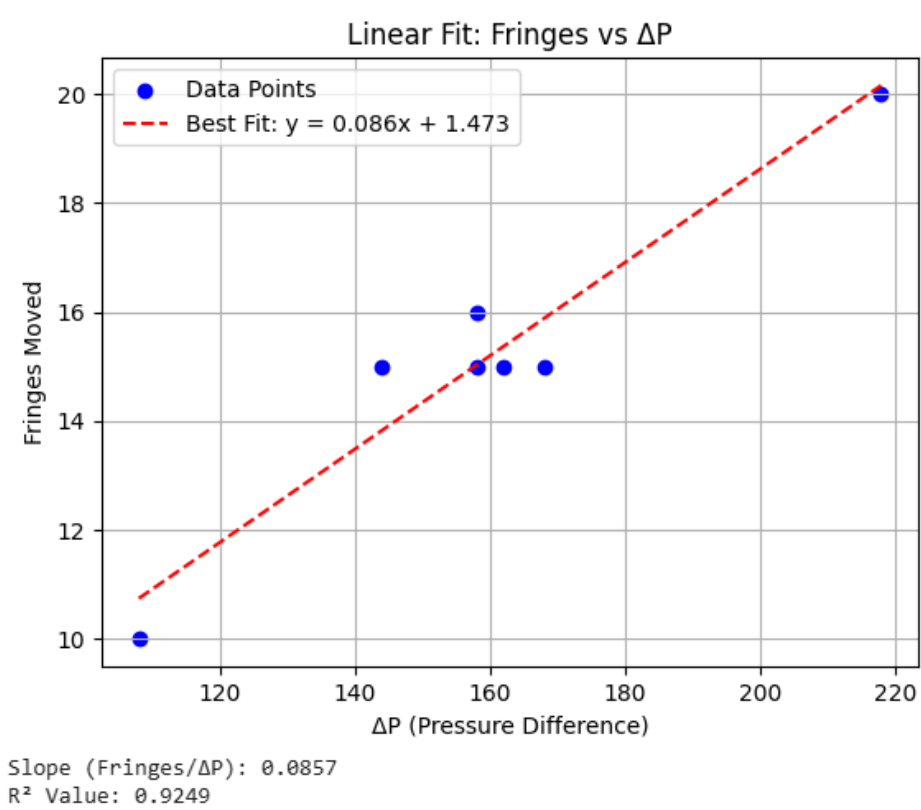
Figure 2.1: *Fringes observed by us*

Figure 2.2: *Slope of graph* $(m_{\Delta P}/\Delta P)$

Observations

Here is presented the table for readings and evaluated calibration constant:

S. No.	No. of Fringes	Difference (in mm)	Calibration Constant (Δ)
1	18	0.23	0.0208
2	20	0.24	0.022167
3	20	0.21	0.02533
4	20	0.23	0.02313
5	20	0.20	0.0266
6	20	0.21	0.02533
7	20	0.22	0.02418
8	20	0.21	0.02533

Table 2.1: *Using Green laser (532nm) to find the calibration constant*

S. No.	No. of Fringes	Difference (in mm)	Wavelength (λ in nm)
1	20	0.25	602.709
2	20	0.24	578.601
3	20	0.24	578.601
4	20	0.25	602.709
5	25	0.32	617.174
6	25	0.33	636.461
7	25	0.33	636.461
8	25	0.32	617.174

Table 2.2: *Calculating wavelength of red laser using the calibration constant obtained by using the green laser(532nm)*

S. No.	Fringes Moved	Angles Moved	Refractive Index
1	20	11	1.36
2	20	10	1.47
3	20	11	1.36
4	20	10	1.47
5	25	14	1.25
6	25	15	1.21
7	30	16	1.23
8	30	13	1.39

Table 2.3: *Finding refractive index from the third part*

S. No.	Fringes Moved	P_1	P_2	ΔP
1	10	200	92	108
2	15	220	62	158
3	20	258	40	218
4	15	256	112	144
5	15	252	84	168
6	15	252	90	162
7	16	238	80	158

Table 2.4: *Finding refractive index for air, pressure is in mm Hg, Refractive index obtained by this data is 1.002165*

Analysis

1) The wavelength of laser is calculated by:

$$\lambda = \frac{2d}{N} \cdot \Delta \tag{2.1}$$

We used the Δ (Calibration Constant) obtained by the green laser for finding λ for red laser.

2) **For the refractive index of glass slide:**

$$n = \frac{(2t - N\lambda)(1 - cos\theta)}{2t(1 - cos\theta) - N\lambda} \tag{2.2}$$

t = thickness of the glass slide
N = the number of fringes counted
λ = the wavelength of light used
θ = the angle turned for N fringes

3) **Refractive Index of air**

$$m_{\Delta P} = \frac{2d(n-1)}{\lambda} \cdot \frac{\Delta P}{P_{atm}}$$

$$n - 1 = \frac{m_{\Delta P}}{\Delta P} \cdot \frac{\lambda}{2d} \tag{2.3}$$

d = length of the pressure cell
$\frac{m_{\Delta P}}{\Delta P}$ = slope obtained by graph

Results

1) **Calibration Constant:**

$\Delta = 0.02411 \pm 0.001941$
There is 8% error in wavelength because of σ of calibration constant.
Wavelength calculated with our data is $608.736 \pm (3.71 + 8)$ % nm.
$\lambda = 608.736 \pm 71.283$ nm

2) **Refractive of glass obtained**

n = $1.3425 \pm 0.1029(\sigma)$

3) **Slope$(m_{\Delta P}/\Delta P)$ = 0.0857**

n = $1 + 0.002165 = 1.002165$

Error Analysis

1. While calculating the angle moved, it was hard to accurately measure the angle. We can have better way to move and measure the angle.
2. While moving micrometer, even little disturbance causes flickering. When we started moving the micrometer, initially the 2-3 fringes moved inward and then suddenly started moving outward for rest pf micrometer movement.
3. While stopping the micrometer and placing your hand off from it, 2-3 fringes will move inward. Again we have to take care while having any movement on apparatus.
4. Human error is very obvious here, it is more better if we can film the micrometer movement and the number of fringes moved and then analyzing it for avoiding human error.

5. We counted for only 10-30 fringes and some small micrometer distance. So, we can't get near to correct value , if we are not considering high number of fringes. It is almost like applying Central Limit Theorem. We are doing it multiple but each time the sample space should be enough big, then we can only get more correct values. But it needs more time for it.

Points to Ponder

1. What do you understand by interference of light?
   When two light waves come and overlap, combine to produce a resultant wave of greater,lower, or the same amplitude. This occurs due to the superposition principle. Even two waves of same amplitude are in opposite phase, and then it will cancel out each other will give dark fringes because of destructive interference. While superposition in same phase will give constructive interference, makes bright fringes.
2. What is a coherent light source?
   A coherent light source emits light waves of constant phase difference (over time), and it emits light of a single or narrow range of wavelength.
3. What is the role of coherence of the light source in the Michelson interferometer?
   For clear interference patterns, we need to have light waves with constant phase, while incoherent light sources produce blurred fringes. The path different is also fixed because of the coherent length of of the light source. That's why we are getting flickering waves.

Brewster's Angle

Date of Experiment: 25 January 2025

Introduction

We are going to find the Brewster's angle and the refractive index of the material used to measure the Brewster's angle.

The Fresnel equation*s (or Fresnel coefficients) describe the reflection and transmission of light (or electromagnetic radiation in general) when incident on an interface between different optical media. They were deduced by French engineer and physicist Fresnel who was the first to understand that light is a transverse wave, when no one realized that the waves were electric and magnetic fields. For the first time, polarization could be understood quantitatively, as Fresnel's equation*s correctly predicted the differing behaviour of waves of the s and p polarizations incident upon a material interface.

Theory

Fresnel's equation*s for Reflection and Transmission:

For s-polarized light (Electric field perpendicular to the plane of incidence):

$$\frac{E_R}{E_I} = \frac{\cos\theta_I - \mu\cos\theta_T}{\cos\theta_I + \mu\cos\theta_T} \qquad \frac{E_T}{E_I} = \frac{2\cos\theta_I}{\cos\theta_I + \mu\cos\theta_T}$$

For p-polarized light (Electric field parallel to the plane of incidence):

$$\frac{E_R}{E_I} = \frac{\cos\theta_T - \mu\cos\theta_I}{\cos\theta_T + \mu\cos\theta_I} \qquad \frac{E_T}{E_I} = \frac{2\cos\theta_I}{\cos\theta_T + \mu\cos\theta_I}$$

Snell's Law:

$$\sin\theta_I = \mu\sin\theta_T$$

where θ_I is the angle of incidence and θ_T is the angle of transmission, both measured with respect to the surface normal.

Fresnel's Sine and Tangent Laws:

$$r_s = -\frac{\sin(\theta_i - \theta_t)}{\sin(\theta_i + \theta_T)} \quad \text{(Fresnel's sine law)}$$

$$r_p = \frac{\tan(\theta_i - \theta_t)}{\tan(\theta_i + \theta_T)} \quad \text{(Fresnel's tangent law)}$$

Electric Field Strength and Intensity: The electric field strengths (E_x) are related to intensity using:

$$I = \frac{1}{2}\epsilon_0 |E|^2 c$$

where ϵ_0 is the permittivity of free space and c is the speed of light.

Brewster's Law: For p-polarized light, the intensity of the reflected ray becomes zero when:

$$\cos \theta_T = \mu \cos \theta_I$$

Using Snell's law ($\sin \theta_I = \mu \sin \theta_T$), these two conditions are simultaneously satisfied only when:

$$\theta_I + \theta_T = \frac{\pi}{2}$$

which implies:

$$\tan \theta_I = \mu$$

This is known as **Brewster's Law**. It states that when light is incident at an angle equal to $\tan^{-1} \mu$, the intensity of the p-polarized reflected light becomes zero. This property is useful for determining the refractive index of a material by measuring the angle at which no p-polarized light is reflected.
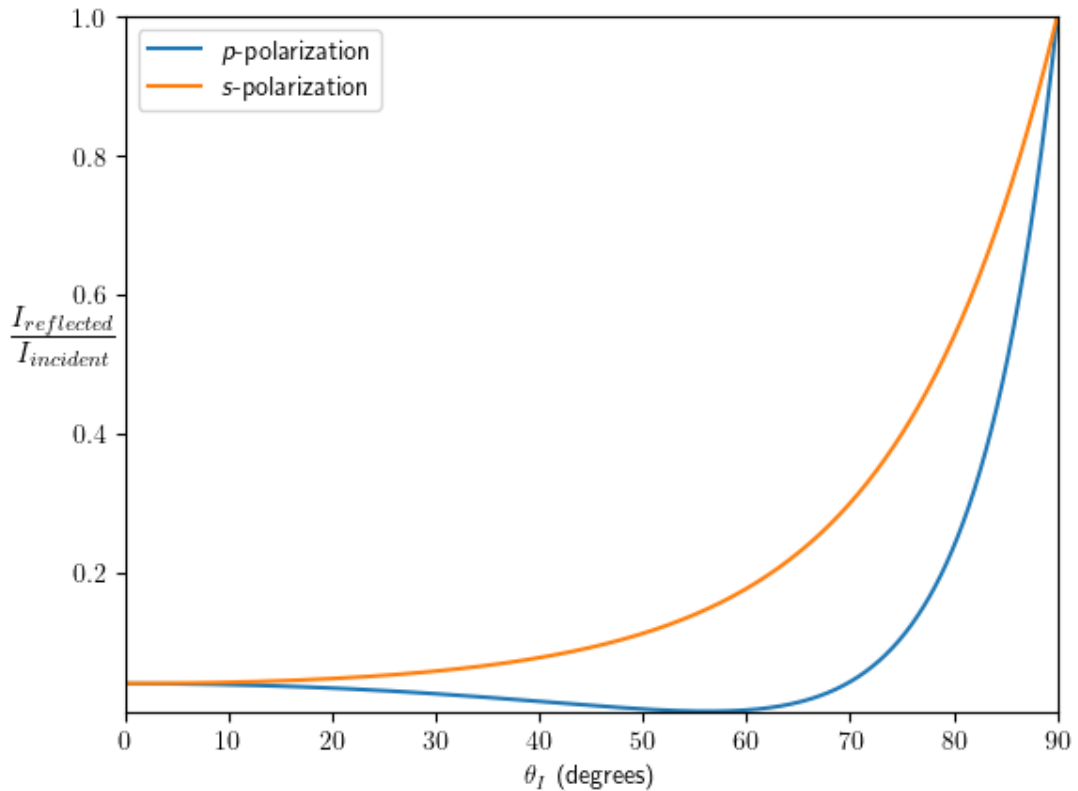
Observations

Table 3.1: *Reflected intensity measurements for different angles of incidence. The uncertainty in intensity measurements for all datasets is ±0.005. All values are in mA.*

	Set 1		Set 2		Set 3
$\theta°$	Value (mA)	$\theta°$	Value (mA)	$\theta°$	Value (mA)
-	-	10	1.3	-	-
-	-	15	1.2	15	0.5
20	1.1	20	1.2	20	0.9
25	1.0	25	1.0	25	0.8
30	1.1	30	0.8	30	0.6
35	0.8	35	0.7	35	0.5
40	0.6	40	0.7	40	0.6
45	0.2	45	0.6	45	0.4
50	0.097	50	0.6	50	0.3
55	0.053	54	0.6	51	0.2
60	0.2	55	0.4	52	0.1
65	0.5	56	0.6	53	0.4
70	1.0	57	0.5	54	0.4
75	5.5	58	0.8	55	0.6
-	-	59	0.8	60	0.7
-	-	60	0.9	65	1.6
-	-	65	1.3	70	2.6
-	-	70	2.4	75	4.9
-	-	75	5.7	-	-

Analysis

We can see that we haven't observed zero anywhere, it may be because of instrument error or imperfect polarisation. As instrument was showing zero without any intensity, then probably some s polarised component was also there that's why the even at the brewster's angle we haven't observed 0 current(intensity). So, we will try to fit the curve by removing the s component from that.

S and P polarisation

We can detect the transmittance and reflectivity of the laser simultaneously then we can able to detect the problem with polariser and can fit with the transmittance and reflectivity with fresnel equation, can verify it more explicitly.

Brewster's Angle and Fitting Issues

Our theoretical fit did not align with the experimental data, primarily because the reflected intensity at Brewster's angle should ideally drop to zero but did not in our measurements.I am considering s component and removing from it then trying to fit it.
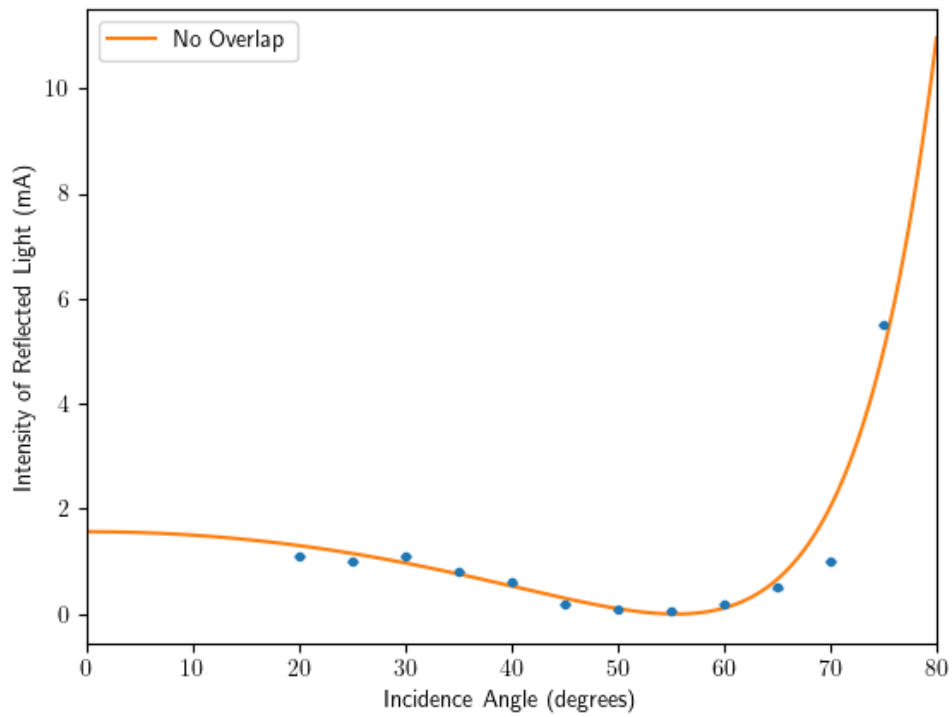
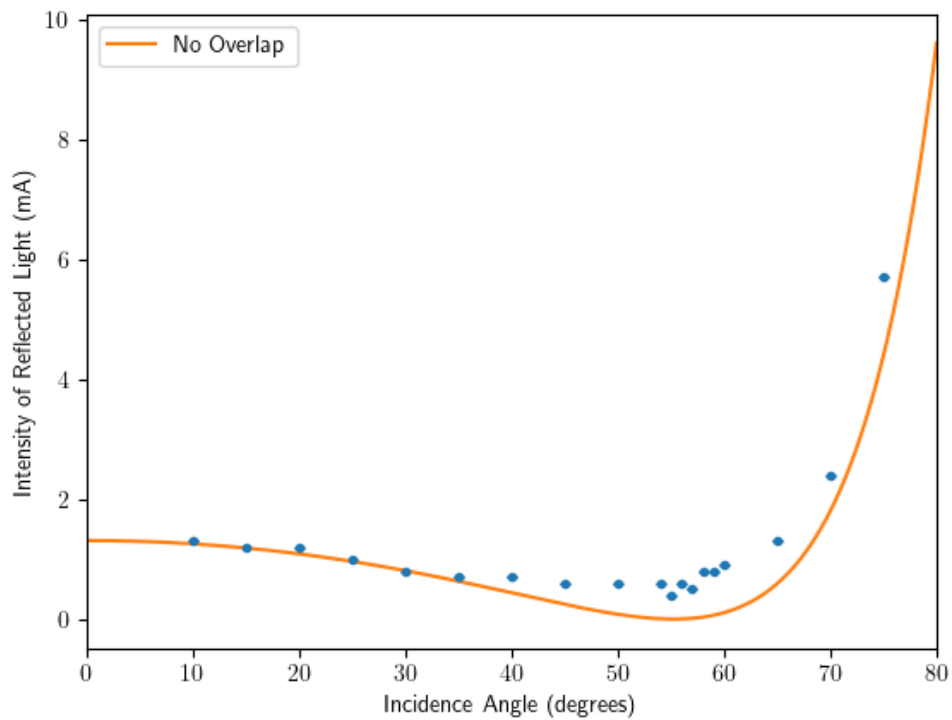**Figure 3.1:** (*Set 1*)*Without considering s- polarised mixing*

Figure 3.2: (*Set 2*)*Without considering s- polarised mixing*
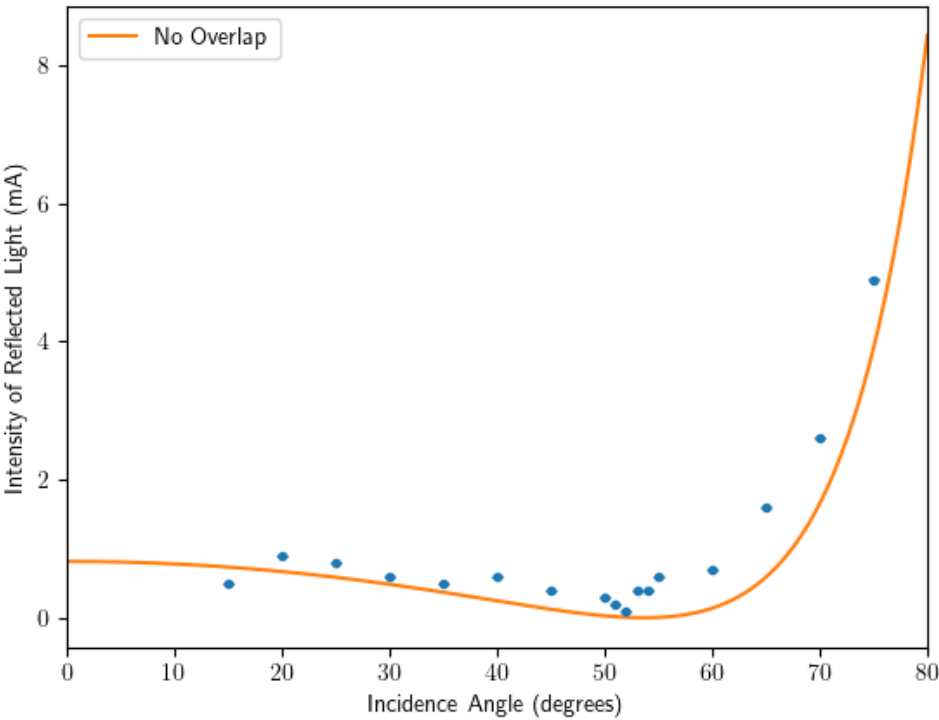
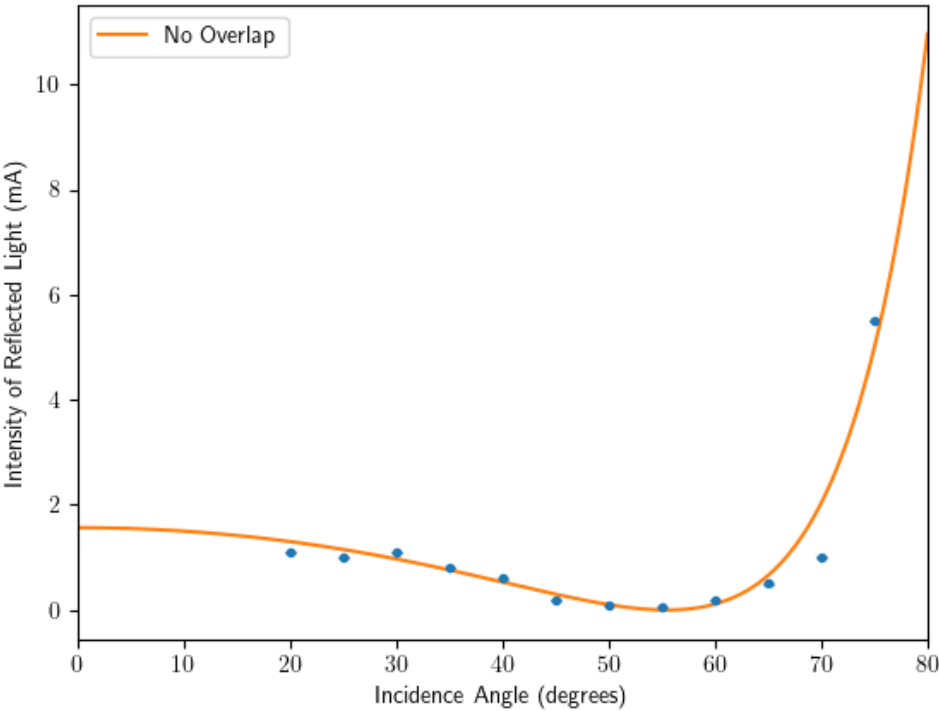**Figure 3.3:** (*Set 3*)*Without considering s- polarised mixing*

Figure 3.4: (*Set 1*)*With considering s- polarised mixing and fitting*
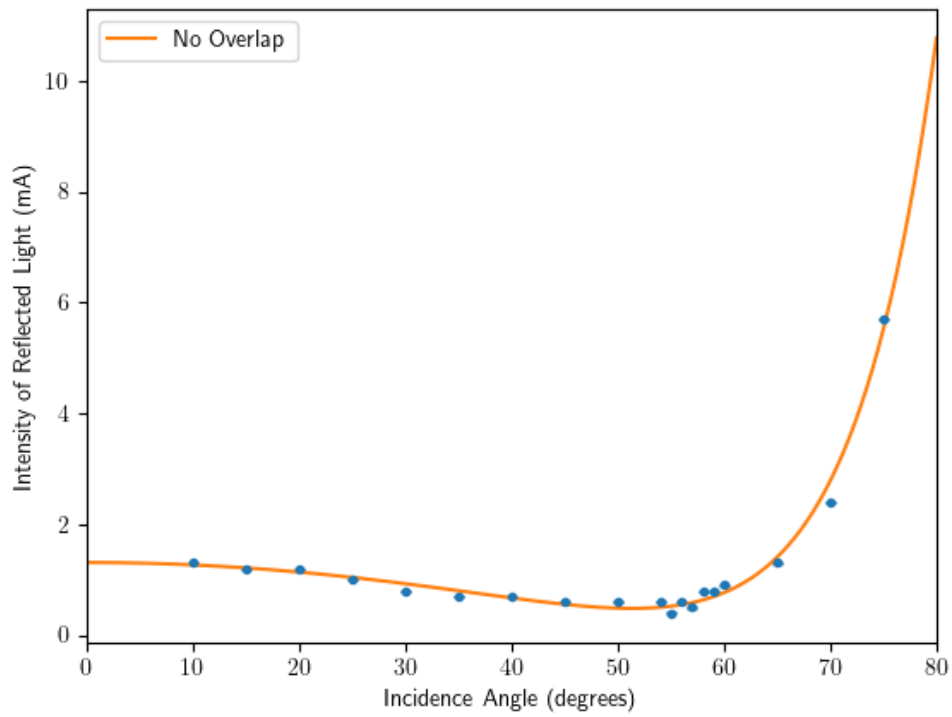
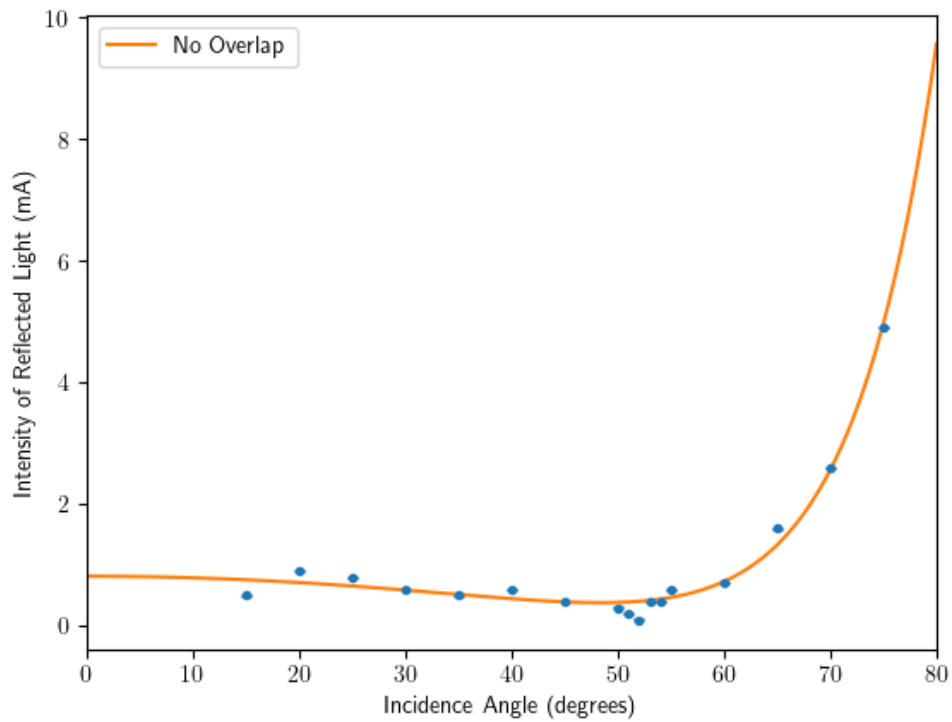**Figure 3.5:** (*Set 2*)*With considering s- polarised mixing and fitting*

Figure 3.6: (*Set 3*)*With considering s- polarised mixing and fitting*

Results

This refractive index and polarisation angle is obtained by curve fit of scipy.optimize.

Set	Refractive Index	Polarization Angle (°)	Intensity (mA)
1	1.45 ± 0.00	0.00	45.84 ± 0.04
2	1.44 ± 0.00	19.12 ± 0.04	40.04 ± 0.05
3	1.36 ± 0.00	21.85 ± 0.06	35.14 ± 0.06

Table 3.2

Error

One of the primary sources of uncertainty in our experiment arises from the fact that the laser beams are not idealized point sources. Due to their finite spread, we had to manually scan the illuminated area on the detector apparatus to locate the highest intensity, introducing potential manual errors. Additionally, the detector apparatus itself may have inherent measurement errors, though these appear to be minimal in our case.

Results and Conclusion

We have a lot of discrepancies in our data and we also tried to take it into account.As we tried to remove s component from the reflected part and tried to remove it also. Ultimately, we determined the refractive index of glass to be:

$$\mu = 1.44 \pm 0.01$$

which is quiet close to the accepted value of 1.5.

I am not considering the third set not for now, as it way off the value and kind of accepting that it wrong with the apparatus and i did it with red beam for red beam and it was showing beam splitting due to which minimum values were not acceptable at 52-53 degrees. Beam splitting happens because of the double reflection phenomenon. Our analysis suggests that the failure of a naive fit can be attributed to two key factors:

(i) Imperfect polarization of the incident beam, and

(ii) The double reflection phenomenon, which significantly impacts measurements at both low and high incidence angles.

Achieving a completely polarized incident beam may not be feasible. However, the issue of double reflection can be mitigated by employing a thicker glass slab. A thicker slab ensures that the beam splitting remains sufficiently large, preventing the overlap of the two reflected rays on the detector. Furthermore, it would absorb much of the transmitted beam, thereby reducing the intensity of the secondary reflected ray, leading to more accurate measurements.
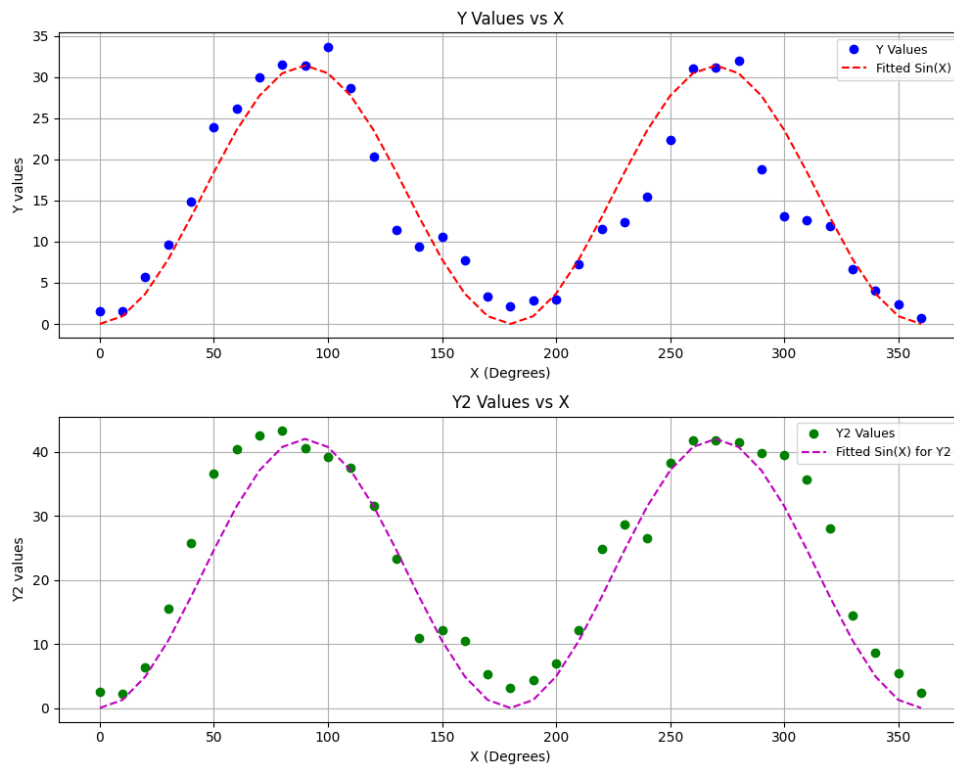
Verification of Malus's Law
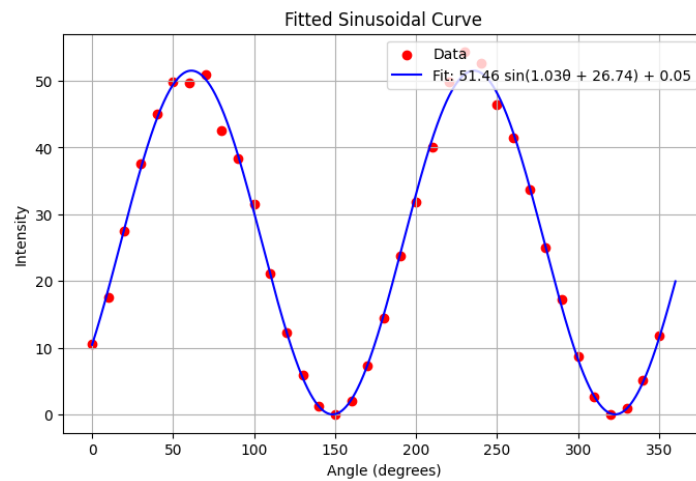

Figure 3.7: *Verification of Malus Law*

Figure 3.8: *Data: From Sankar, Verification of Malus Law*

Balmer Series and Rydberg Constant

Date of Experiment: 01 February 2025

Introduction

In a discharge lamp,hydrogen atoms emits a series of lines in the visible part of the spectrum. Balmer found this series, by trial and error a formula. The formula is given by

$$\frac{1}{\lambda} = R \left[\frac{1}{2^2} - \frac{1}{n^2} \right]$$

Rydberg found several series of spectra that would fit a more general relationship, similar to Balmer's empirical formula. This general relationship is known as the Rydberg formula and is given by

$$\frac{1}{\lambda} = R \left[\frac{1}{n_f^2} - \frac{1}{n_i^2} \right]$$

where n_i and n_f are integers 1,2,3,4,5... up to infinity, with $n_i > n_f$. For the H atoms, $n_i = 2$ corresponds to the Balmer series.

Theory

Energy of photon = -[Energy of final state - Energy of initial state]

$$\Delta E = E_i - E_f = hv = h\frac{c}{\lambda}$$

Bohr further postulated that the magnitude of the orbiting electron's angular momentum would be quantized and that must be an integral multiple of the quantity $h/2\pi$.

$$L = m_e v_n r_n = \frac{nh}{2\pi}$$

and n = 1,2,3...
The electron in a hydrogen atom orbits the proton under the influence of the Coulomb force, which provides the centripetal force. The forces are balanced as:

$$\frac{e^2}{4\pi\epsilon_0 r_n^2} = \frac{m_e v_n^2}{r_n}$$

The angular momentum is quantized:

$$m_e v_n r_n = n\hbar$$

Solving these equations simultaneously gives the radius and speed of the electron:

$$r_n = \frac{4\pi\epsilon_0 \hbar^2 n^2}{m_e e^2}, \quad v_n = \frac{e^2}{4\pi\epsilon_0 \hbar n}$$

The total energy of the electron is the sum of its kinetic and potential energy:

$$E_n = \frac{1}{2} m_e v_n^2 - \frac{e^2}{4\pi\epsilon_0 r_n}$$

Substituting r_n and v_n gives:

$$E_n = -\frac{m_e e^4}{8\epsilon_0^2 h^2 n^2}$$

For a transition from n_i to n_f, the energy change is:

$$\Delta E = E_f - E_i = \frac{m_e e^4}{8\epsilon_0^2 h^2} \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

The wavelength of the emitted photon is:

$$\frac{1}{\lambda} = \frac{\Delta E}{hc} = R \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

where the Rydberg constant R is:

$$R = \frac{m_e e^4}{8\epsilon_0^2 h^3 c}$$

Observations

We did the experiment with Hydrogen and Mercury Discharge tube. We have to calibrate it first. We have 15000 lines per inch as grating value, and wavelength values observed are not calibrated with the actual values, i will calibrate it and will use the calibration constant to correct the wavelength. In the below table, $Values$ are taken from Internet from National Institute of Standards and Technology (NIST). https://www.physics.nist.gov/PhysRefData/Handbook/Tables/mercurytable2.htm

Now we will use it to find out actual wavelength values for the hydrogen spectral lines.

Analysis

Table 4.1: *Mercury Lamp Spectral Data*

Colour	θ_R	θ_L	$Cor\theta_R$	θ_R (rad)	θ_L (rad)	λ_R (nm)	λ_L (nm)	*Values*	*Calibration*
Violet	192.4	12.350	12.400	0.216	0.216	363.612	362.160	435.833	1.197
Light green	194.0	13.983	14.000	0.244	0.244	409.648	409.160	Ignored	
Green	195.65	15.500	15.650	0.273	0.271	456.786	452.516	546.074	1.195
Yellow 1	196.47	16.446	16.465	0.287	0.287	479.961	479.961	576.960	1.202
Yellow 2	196.58	16.483	16.583	0.289	0.288	482.276	480.443	570.066	1.193
Faded orange 1	197.05	16.783	17.050	0.298	0.293	496.488	488.938	587.128	1.183
Faded orange 2	197.47	17.250	17.466	0.305	0.301	508.228	502.135	Ignored	
Faded orange 3	197.65	17.400	17.650	0.300	0.304	513.413	506.367	614.644	1.197
Red 1	197.75	17.583	17.750	0.310	0.309	516.223	511.526	614.948	1.191
Violet(m=2)	205.2	25.000	25.200	0.440	0.436	360.487	357.811	435.833	1.209
Green(m=2)	211.98	31.900	31.983	0.558	0.557	448.445	447.404	546.074	1.218
Yellow 1(m=2)	213.97	33.750	33.967	0.593	0.589	473.078	470.376	576.960	1.220
Yellow 2(m=2)	214.0	34.000	34.000	0.593	0.593	473.443	473.443	570.066	1.223

Table 4.2: *Calibration Constants*

Calibration Constant Mean	Standard Deviation	Standard Deviation (%)
1.203	0.017	1.056

Table 4.3: *Hydrogen Lamp Spectral Data*

Colour	n	m	θ_R	θ_L	$Cor\theta_R$	θ_R (rad)	θ_L (rad)	λ_R (nm)	λ_L (nm)
Violet	5	1	192.233	12.283	12.233	0.214	0.214	358.791	300.235
Turquoise	4	1	193.833	13.816	13.833	0.241	0.241	404.857	404.369
Red	3	1	198.850	18.800	18.850	0.329	0.328	547.093	545.694
Violet	5	2	205.316	25.330	25.316	0.442	0.442	362.038	362.225
Turquoise	4	2	208.583	28.500	28.583	0.499	0.497	405.066	403.988
Red	3	2	220.216	40.330	40.216	0.702	0.704	546.660	547.946
Violet	5	1	167.600	12.517	12.400	0.216	0.218	363.612	366.989
Turquoise	4	1	166.083	14.017	13.917	0.248	0.245	407.267	410.135
Red	3	1	161.000	19.200	19.000	0.332	0.334	551.286	556.872

Table 4.4: *Calibrated Spectral Data*

Colour	n	m	λ_R (nm)	λ_L (nm)	$\frac{1}{4} - \frac{1}{n^2}$	$\frac{1}{\lambda_R(nm)}$	$\frac{1}{\lambda_L(nm)}$
Violet	5	1	431.687	433.424	0.210	0.002316	0.002307
Turquoise	4	1	487.113	486.526	0.188	0.002053	0.002055
Red	3	1	658.247	656.564	0.139	0.001519	0.001523
Violet	5	2	435.594	435.819	0.210	0.002296	0.002295
Turquoise	4	2	487.364	486.067	0.188	0.002052	0.002057
Red	3	2	657.726	659.273	0.139	0.001520	0.001517
Violet	5	1	437.488	441.551	0.210	0.002286	0.002265
Turquoise	4	1	490.012	493.463	0.188	0.002041	0.002026
Red	3	1	663.292	670.012	0.139	0.001508	0.001493

(**a**) *From Left Scale*   (**b**) *From Right Scacle*
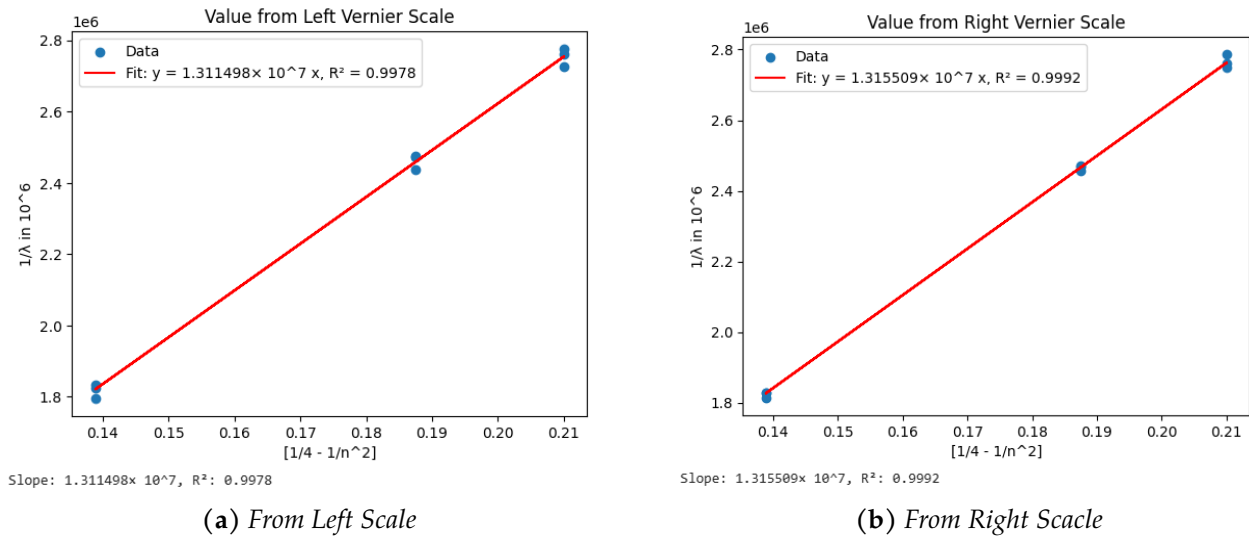
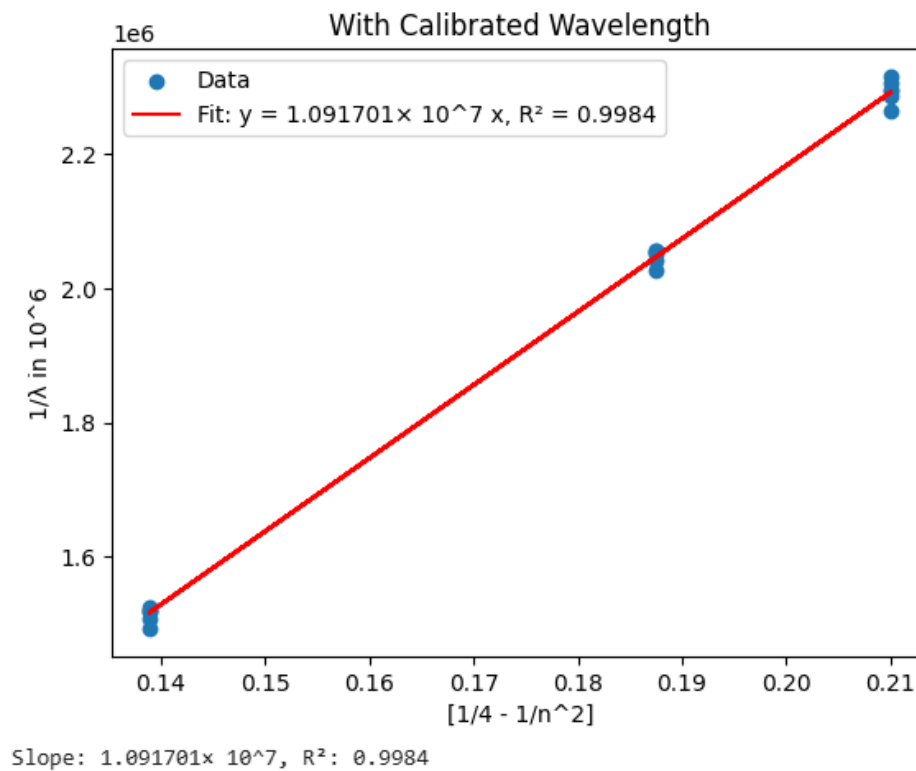**Figure 4.1:** *R calculated by without calibrated wavelength*

Figure 4.2: *R calculated by with calibrated wavelength*

Error Analysis

- Labeling of Spectrometer table and slit should be adjusted.
- Changes in temperature cause expansion/contraction of the diffraction grating, slightly altering spacing.
- Incorrect calibration of the spectrometer or diffraction grating leads to systematic shifts in wavelength measurements.

Results

Table 4.5: *Hydrogen Emission Lines: Calculated vs Actual Wavelengths*

Colour	n	λ_{Uncal} (nm)	λ_{Cal} (nm)	λ_{Actual} (nm)	% Diff (Uncal)	% Diff (Cal)
Violet	5	362.56	436.19	434.00	16.47	0.50
Turquoise	4	406.04	488.41	486.10	16.47	0.48
Red	3	548.41	659.44	656.30	16.47	0.48

Percent Difference Calculation

The percent difference is calculated using the formula:

$$\%\text{Difference} = \frac{|\text{Accepted Value} - \text{Measured Value}|}{\text{Accepted Value}} \times 100\%$$

Rydberg Constant Comparison

- Uncalibrated Rydberg Constant: $R_{\text{Uncal}} = 1.3135035 \times 10^7 \, \text{m}^{-1}$
- Calibrated Rydberg Constant: $R_{\text{Cal}} = 1.091701 \times 10^7 \, \text{m}^{-1}$
- Accepted Rydberg Constant: $R_{\text{Accepted}} = 1.097373 \times 10^7 \, \text{m}^{-1}$

The percent differences for the Rydberg constants are:

$$\%\text{Difference (Uncal)} = \frac{|1.097373 \times 10^7 - 1.3135035 \times 10^7|}{1.097373 \times 10^7} \times 100\% = 19.69\%$$

$$\%\text{Difference (Cal)} = \frac{|1.097373 \times 10^7 - 1.091701 \times 10^7|}{1.097373 \times 10^7} \times 100\% = 0.52\%$$

Thermistor

Date of Experiment: 08 February 2025

Introduction

In this experiment, basically we are trying to find out change in the resistance of the thermistor with change in the temperature. For certain semiconductors, the change in resistivity with temperature can be very rapid. Such materials can be used to make resistors with high temperature sensitivity,and are called thermistors. They can be used as temperature sensors.

Theory

The change in resistivity of a thermistor due to temperature variations is primarily due to the underlying physics of charge carriers in semiconductors. Basically thermistor behavior depend on the material either it is a Negative Temperature Coefficient or Positive Temperature Coefficient type. In case of NTC Thermistors, the resistivity decreases as temperature increases. This is because of excitement of electrons from valence band to conduction band. While in PTC Thermistors, resistivity increases with temperature due to lattice vibration(phonon scattering) or phase transitions in some case.

Observation

While doing the experiment, the way at which the temperature is changing also decides the change in resistivity. I will show the the part where i tried rapid cooling (forced by adding ice or directly taking out of the medium to normal room temperature).Sudden change causes different effects in resistance so, it affects the way we are cooling or heating it.
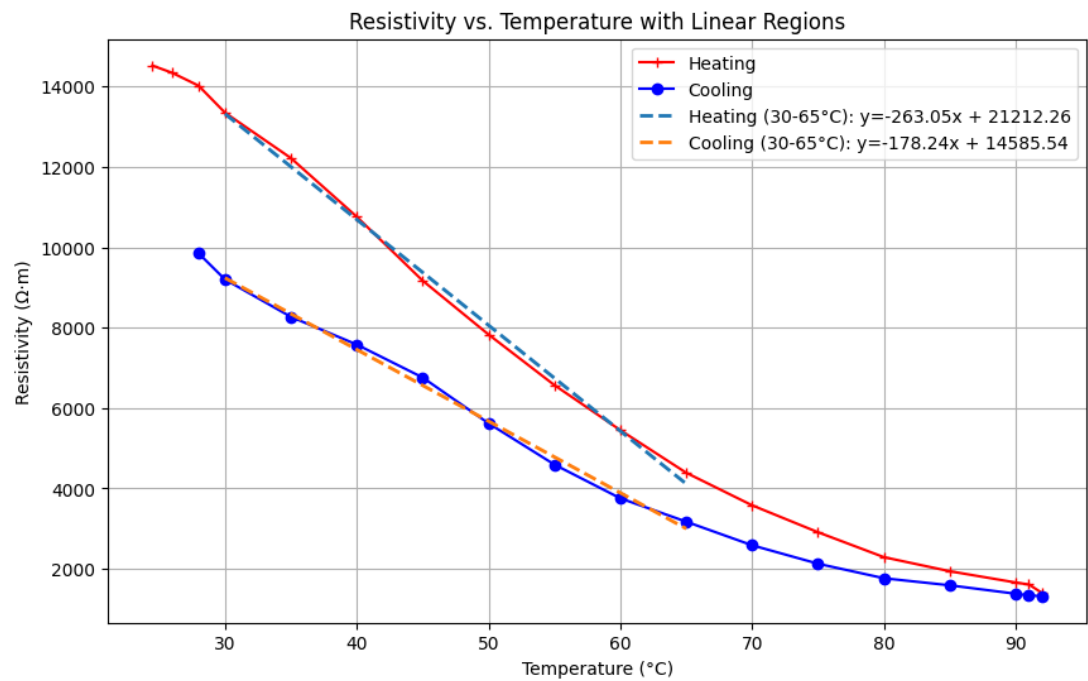
Analysis

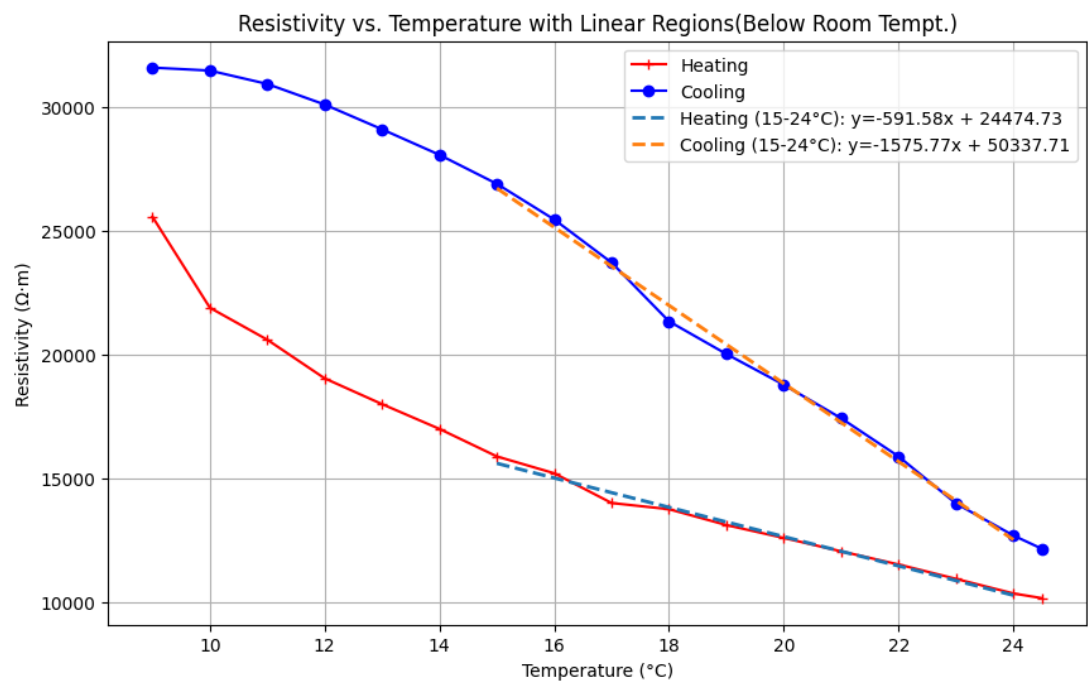**Figure 5.1:** *Heating and Cooling without forcing it to accelerate*

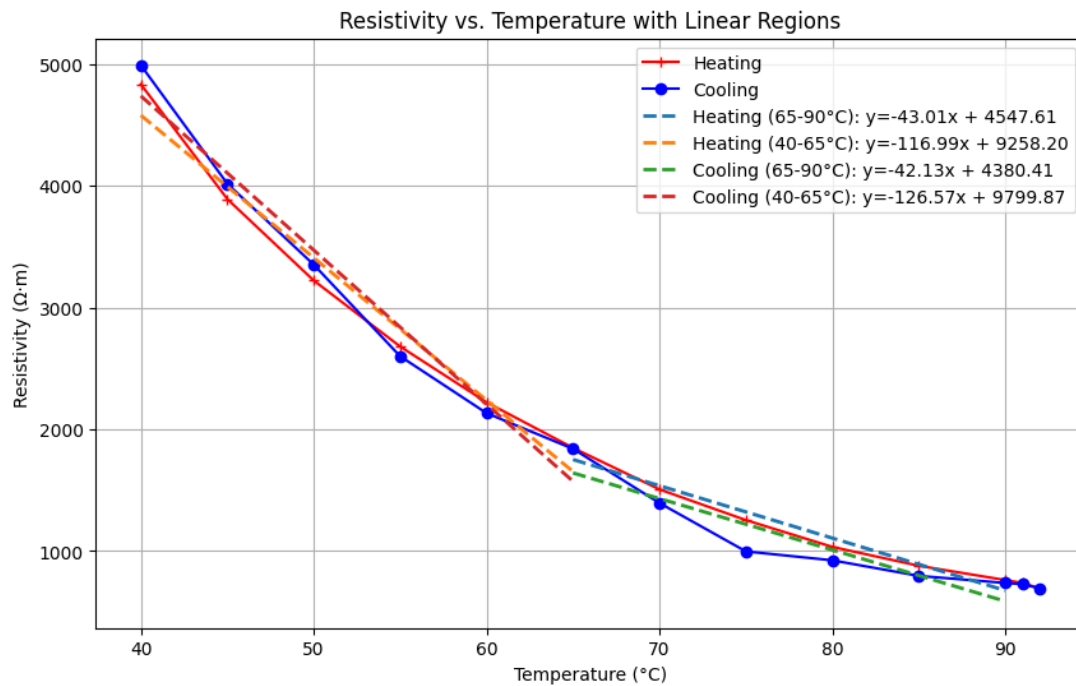**Figure 5.2:** *Cooling and heating below room temperature without sudden forcing*

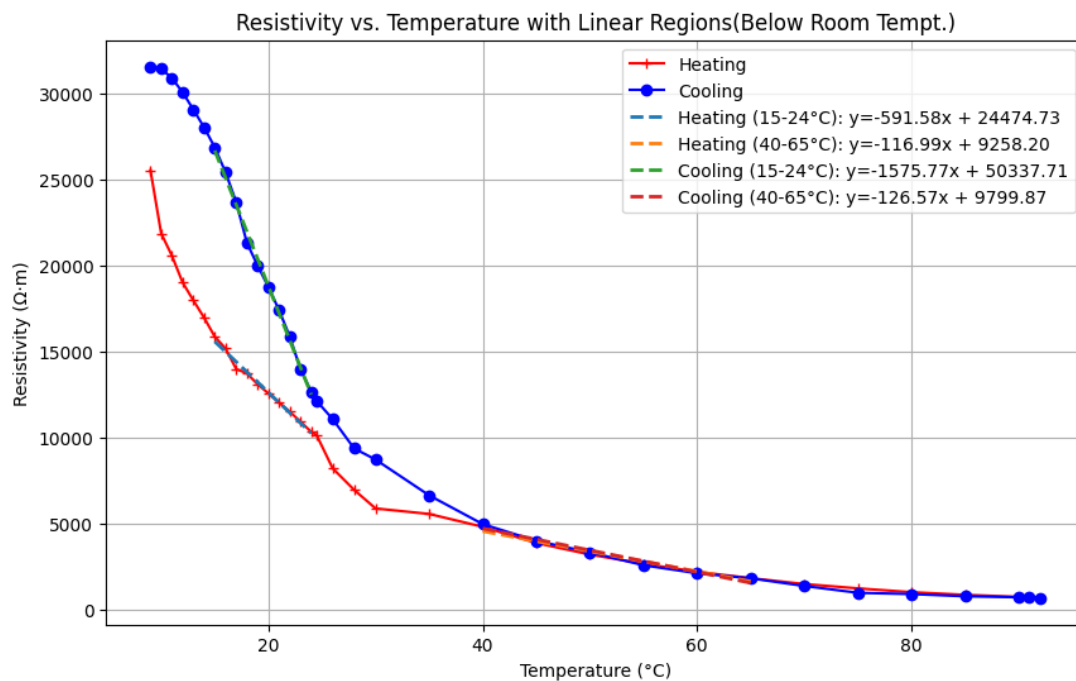**Figure 5.3:** *Heating and Cooling without forcing it to accelerate (Apparatus 2)*

Figure 5.4: *Cooling and heating below and above room temperature and perturbation at the room temperature because changing water to ice suddenly lifted resistance change*

Using the Analysis based on the temperature dependence of the resistance of a semiconductor can be modeled as

$$\frac{1}{T} = A + B[\ln R] + C[\ln R]^3$$

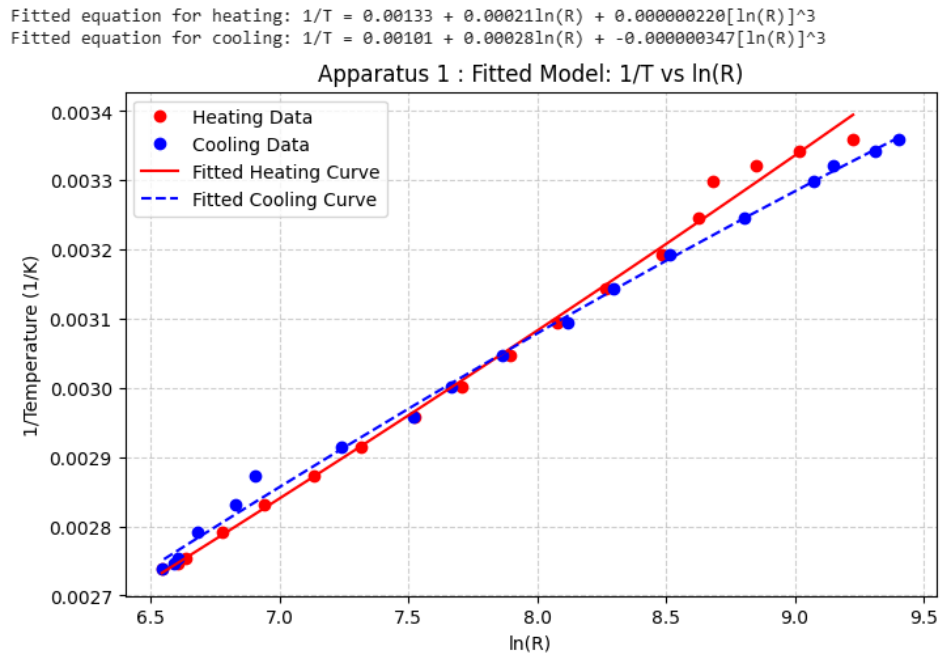By plotting a graph of $1/T$ vs $\ln(R)$, the coefficients can be determined by a cubic fit to the data.

Figure 5.5: *Cooling and heating below and above room temperature and perturbation at the room temperature because changing water to ice suddenly lifted resistance change*
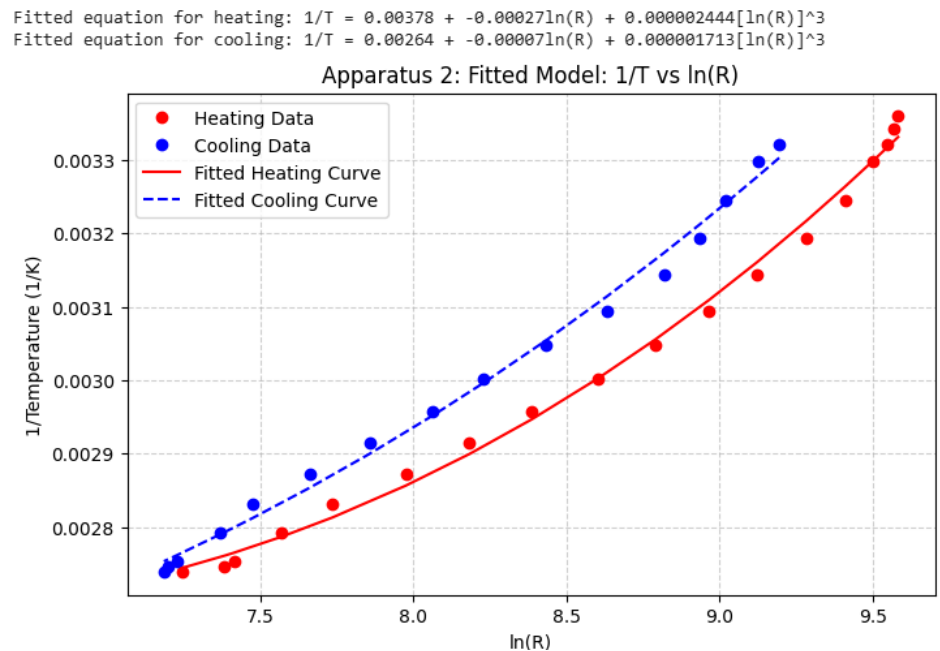

Figure 5.6: *Heating and Cooling without forcing it to accelerate (Apparatus 2)*

Even we tried to plot it using Power Law Fit:

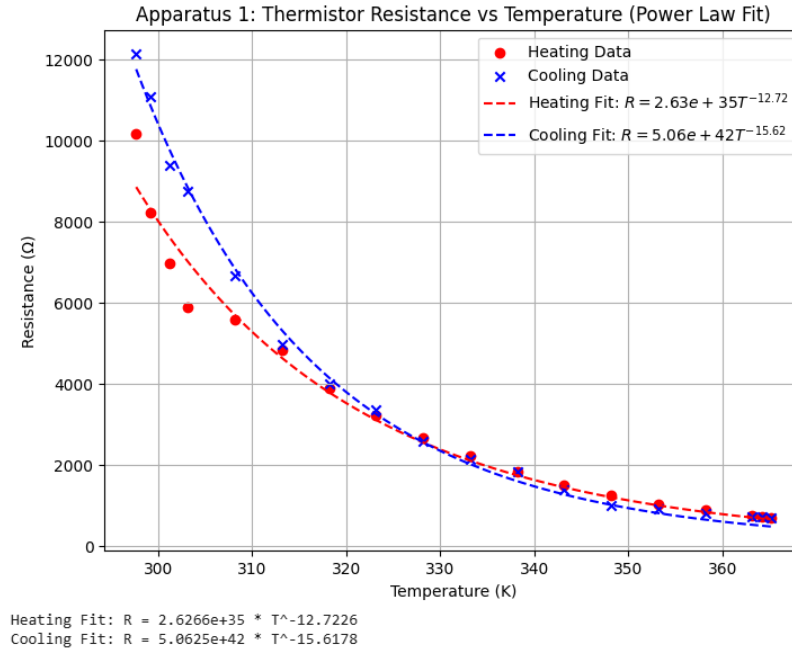$$R(T) = aT^b$$

$$\ln R = \ln a + b \ln T$$

Heating Fit: R = 2.6266e+35 * T^-12.7226
Cooling Fit: R = 5.0625e+42 * T^-15.6178

Figure 5.7: *Apparatus 1 : Power Law Fit*

Heating Fit: R = 1.3080e+28 * T^-9.6699
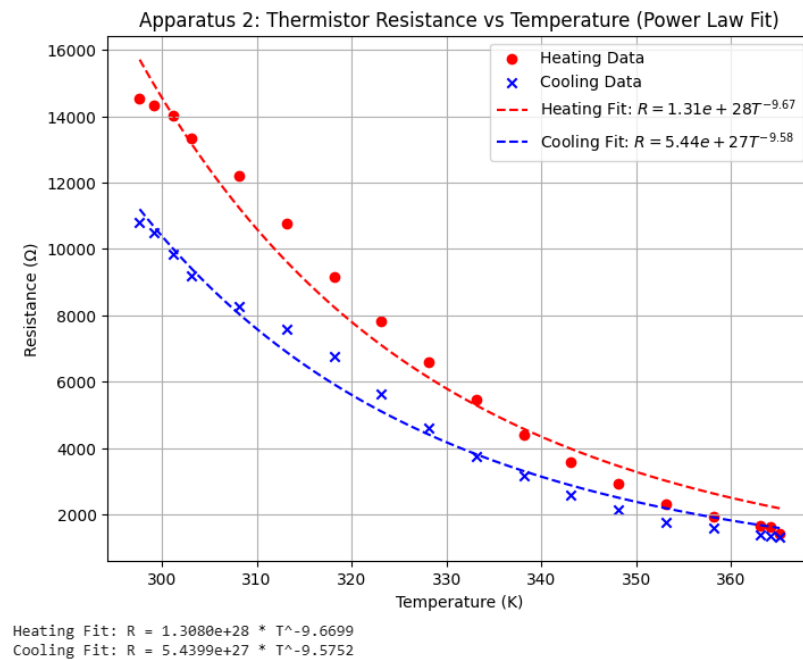Cooling Fit: R = 5.4399e+27 * T^-9.5752

Figure 5.8: *Apparatus 2 : Power Law Fit*

Results

Using Steinhart-Hart Equation, we plotted and figured out the coefficient of those:

- For Apparatus 1:
  -Heating ($R^2 = 0.99487$)

$$\frac{1}{T} = 0.00133 + 0.00021[\ln R] + 0.000000220[\ln R]^3$$

  - Cooling ($R^2 = 0.99678$)

$$\frac{1}{T} = 0.00101 + 0.00028[\ln R] + 0.000000347[\ln R]^3$$

- For Apparatus 2:
  -Heating ($R^2 = 0.99528$)

$$\frac{1}{T} = 0.00378 + 0.00027[\ln R] + 0.000002444[\ln R]^3$$

  - Cooling ($R^2 = 0.99379$)

$$\frac{1}{T} = 0.00264 + 0.00007[\ln R] + 0.000001713[\ln R]^3$$

Resistance is highly sensitive to temperature in case of thermistor, and even increase linearly in some temperature range.

-Hysteresis (Heating vs Cooling Behavior)
Cooling and heating curves are differing, hysteresis exists.This means the resistance at a given temperature depends on whether the thermistor was heated or cooled.There can be different reasons for this like internal heating effects, material response lag and slow thermal equilibration.
-Cooling curve is under the heating curve if heating first while heating curve is under the cooling curve if cooling is done first.

Points to Ponder

1. **On the basis of observations, can you find a range in which a thermistor behaves linearly?**
- Yes, under slow changes in temperature, the thermistor appears to behave approximately linear in the range of 30–65°C. The exact range may vary slightly depending on the thermistor type, but within this interval, the relationship between resistance and temperature follows a nearly straight-line trend.
2. **Is a thermistor more useful for measuring small or large temperature changes accurately?**
- A thermistor is more useful for detecting small temperature changes because its resistance varies rapidly with temperature, allowing for high sensitivity. For large temperature changes, its response becomes nonlinear, making accurate measurements more challenging. Therefore, thermistors are ideal for applications where precise detection of minor fluctuations is needed.

6

THERMAL EXPANSION

7

Stefan's Law

Specific Heat of Solids

Photoelectric Effect

Millikan's Oil Drop

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