Group 5: Final Report

Part 1: Measuring the Wavelength of Light with Diffraction

The experiment on measuring the wavelength of light with diffraction explores the wave nature of light by investigating its diffraction patterns. The diffraction grating equation forms the basis for this study, relating the angle of diffraction, wavelength of light, and spacing between diffracting elements. Accurate knowledge of light's wavelength is crucial in various scientific and technological applications. The report focuses on the experimental setup, methodology, and data analysis to extract information about light's nature through diffraction. The outcomes aim to enhance our understanding of optical phenomena and contribute to precise wavelength determination in scientific disciplines.

Key Words:

Diffraction . Wavelength of Light . Diffraction Grating Equation . Interference Patterns . Wave-Particle Duality . Optics

APPROXIMATE PERFORMANCE TIME: 5 hours

1. Conceptual Objectives

- Understanding Diffraction
- Applying Diffraction Grating Equation
- Relating Theory to Experiment
- Recognizing Interference Patterns
- Exploring Practical Applications

2. Experimental Objectives:

In this experiment, the diffraction of light is examined to determine its wavelength, utilizing the diffraction grating equation.

3. Theoretical Introduction

1. The Wave Nature of Light: Light is a phenomenon that defies easy categorization, revealing both particle-like and wave-like behaviors. The wave nature of light becomes particularly apparent when it interacts with obstacles, leading to a fascinating phenomenon known as diffraction. In diffraction, light waves undergo bending and interference as they encounter barriers or apertures, creating intricate patterns that provide valuable insights into the nature of light.

2. The Diffraction Grating Equation: At the heart of our experimental endeavor lies the diffraction grating equation, a cornerstone in the field of optics.

$$d\sin(\theta)=n\lambda$$

- d represents the distance between adjacent diffracting elements in the diffraction grating, such as slits or rulings.
- ϑ is the angle of diffraction, which is the angle between the incident light direction and the direction of the diffracted light.
- n is the order of the diffraction maximum. It is an integer that represents the number of the diffraction maximum being observed.
- λ is the wavelength of the incident light.

This equation establishes a fundamental relationship between the angle of diffraction, the wavelength of light, and the characteristics of diffracting elements such as gratings or slits. The diffraction grating equation serves as a powerful tool for quantifying the wave properties of light, allowing us to extract precise information about its wavelength.

3. Exploring Diffraction Patterns: Central to the experiment is the exploration and analysis of diffraction patterns. When light waves encounter obstacles or slits, they create distinctive interference patterns that can be observed and measured. These patterns serve as a visual representation of the wave nature of light, showcasing the constructive and destructive interference that occurs as light waves interact with the diffracting elements.

4. Precision Wavelength Measurement: Our primary goal is to measure the wavelength of light with precision. This involves a meticulous application of the diffraction grating equation, utilizing the observed angles of diffraction and the known characteristics of the diffracting elements. By carefully analyzing these measurements, we can derive accurate values for the wavelength of light, emphasizing the importance of precision in scientific measurements.

4. Apparatus:

1. Green Laser (532 nm)
2. Screen
3. Diffraction Gratings:
    a. 60 micrometers
    b. 2 micrometers
4. White screen
5. Light Filter
6. Marker
7. Ruler

5 Experimental Method:

5.1 Preparation:

Setup Preparation:

- We began by setting up the experiment as shown below.

Light Source Alignment:

- We aligned the laser to ensure a stable and well-defined wavelength for the incident light.

Diffraction Grating Installation:

- We carefully installed a diffraction grating with a slit spacing (d) of 60 micrometers in the path of the incident light.

Screen Placement:

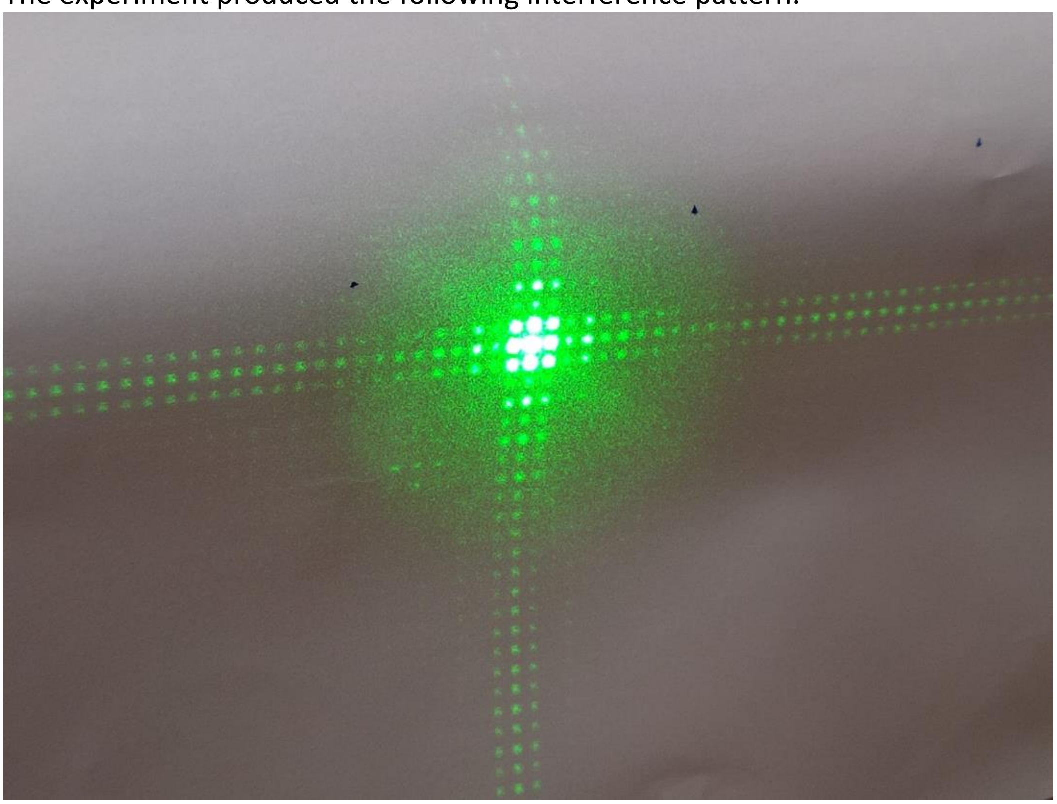
- We placed a screen at a distance of 51 cm from the diffraction grating to capture and observe the resulting diffraction patterns.
- We attached white sheet on the screen.

Safety Precaution:

- We used a light filter to reduce the intensity of the laser light to prevent eye damage.
- We also made use of protective eye wear.
- We turned the laser off after small time intervals, to prevent overheating.
- We also placed obstacles behind the laser to prevent the reflected beams from damaging other students' eyes.

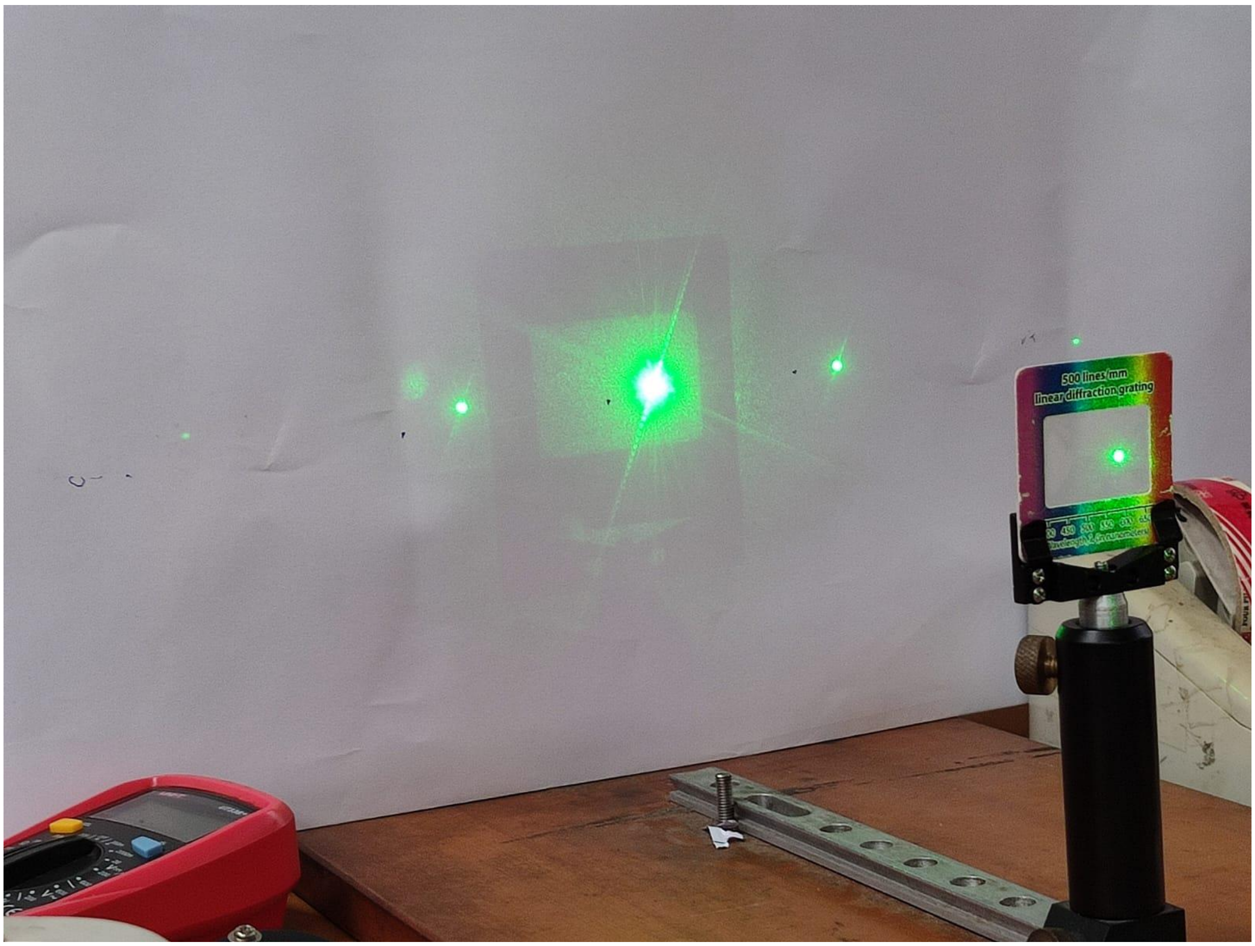
5.2 Data Collection:

- Once our apparatus was completely set up, we turned on the laser and observed an interference pattern on the white sheet.
- We carefully marked the bright fringes on both horizontal and vertical axis using a marker and we took extra precaution not to move the white sheet during this process.
- Once we had successfully marked the position of bright fringes of the first, second, and third order, we switched off the laser and cautiously removed the white sheet from the screen.
- We proceeded to take measurements of the distance between the bright fringes of first order, and second order respectively using a Vernier caliper to increase the precision of our readings
- The experiment produced the following interference pattern.



- We repeated the experiment using a diffraction grating of 2 micrometers. We changed the distance between the diffraction grating and the screen to 48cm,30 cm, and 16cm and recorded the positions of the first and second order fringes respectively. (As this experiment did not produce vertical fringes, we only measured positions for the horizontal fringes.). We used different colored markers to mark the position of the fringes on the same sheet.

- This experiment produced the following interference pattern:



5.3 Data Analysis:

- We proceeded to find the wavelength of the laser light for each set of values obtained for the distance between fringes of the same order on the same axis using the following formulas:
  - To obtain the angle between zeroth order and the required order: x=Tan^{-1}(distance between corresponding fringes/2)/ (distance between screen . and diffraction grating)
  - To obtain wavelength: Wavelength= ((line spacing of diffraction grating) *(sin(x)))/(order of the bright fringe)
- We obtained the results shown in the table below:

Results table #1

Line spacing of Grating #1 = 60 micrometers					
Distance between the screen and grating= 51.0 cm					
Distance between the two spots of orders:					
First Order		**Second Order**		**Third order**	
Vertical spots	**Horizontal spots**	**Vertical spots**	**Horizontal spots**	**Vertical spots**	**Horizontal spots**
1.040 cm	0.970 cm	1.925 cm	1.860 cm	3.200 cm	2.800 cm
Wavelength values from these raw measurements					
W1a	W2a	W3a	W4a	W5a	W6a
612 nm	571 nm	566 nm	547 nm	627 nm	548 nm

Average value of wavelength using grating #1= 579 nm

Results Table #2

Line spacing of Grating #2 = 2 micrometers					
Distance between grating and screen					
48 cm		**30 cm**		**16 cm**	
First Order	**Second Order**	**First Order**	**Second Order**	**First Order**	**Second Order**
26.5 cm	60.8 cm	16.5 cm	37.5 cm	8.6 cm	19.3 cm
Wavelength values from these raw measurements					
W1b	W2b	W3b	W4b	W5b	W6b
532 nm	535 nm	530 nm	529 nm	519 nm	516 nm

Average value of wavelength using grating #2 = 527 nm

- By further averaging the two values of average wavelength obtained, we obtain the final experimental value of wavelength: **553 nm**

Possible causes for error:

- Difficulty in making spots on the white sheet, the white sheet was not of an appropriate size and completely without bends for it to be attached to the screen properly. This caused slight inaccuracy in our measurements.
- The laser and the grating were not completely perpendicular to screen, as the grating was not fully fixed or aligned so it swayed slightly every time the laser was activated, which caused inaccurate results.
- We didn’t have a grid available to attach on screen, which made it difficult for us to accurately measure the fringe distances.
- The diffraction grating might have collected dust or dirt which may have affected the interference pattern.

5.4 Conclusion:

- To find percentage error, we used the following formula: Percentage Error = ((Experimental Number – Actual Number)/ Actual number) x 100 and obtained a value of **4%** for the percentage error.
- In conclusion, our experiment utilizing diffraction gratings to measure the wavelength of a green light laser yielded a precise value of 553 nm. This result aligns with the expected wavelength range for green light, typically falling within the 495 to 570 nm range. The success of our experiment can be attributed to the meticulous alignment of the monochromatic light source, the careful calibration of the diffraction grating, and the systematic measurement of diffraction angles. The incorporation of a light filter not only ensured monochromatic conditions but also prioritized safety by reducing light intensity, with safety goggles worn throughout. The accuracy of our findings underscores the reliability of the diffraction grating equation and the effectiveness of our experimental setup.

Part 2: Investigating Optical Rotation of Light

The investigation of optical rotation delves into the captivating phenomenon where the plane of polarized light undergoes rotation as it traverses through certain substances. Rooted in the fundamental principles of chirality, this optical property has been a subject of scientific exploration for centuries.

This experiment investigates the interplay of polarized light and optically active solutions. Polarizers are combined with substances capable of rotating the plane of polarized light. The study aims to understand the principles of optical polarization, examine the impact of optically active solutions on light polarization, and uncover the molecular mechanisms at play.

Key words:

Optical polarization. Polarizers. Optically Active Solutions. Chiral Molecules. Achiral Molecules. Plane of Polarization. Rotation

1. Theoretical introduction:

1.1 Key Definitions:

1. **Optical Rotation:**
   Optical rotation refers to the rotation of the plane of polarization of linearly polarized light as it passes through an optically active substance. This rotation is caused by the interaction between the electric field of the light wave and the asymmetric molecular structure of the substance. The degree of rotation is often measured in degrees and is specific to the substance, concentration, wavelength, and the path length of the sample.
2. **Specific Rotation:**
   Specific rotation ([θ]) is a property of optically active substances that quantifies their ability to rotate polarized light. It can also be defined as the change in orientation of monochromatic plane-polarized light, per unit distance–concentration product, as the light passes through a sample of a compound in solution.
   Values for specific rotation are reported in units of deg·mL·g−1 ·dm^{-1}, which may be shortened to just deg.
   The formula for calculating specific rotation is: $[\theta]= \theta/(C*L)$
   Where Θ=Phase difference
   C= concentration in g/mL
   L= path length in decimeters
3. **Optically Active Substances:**
   Optically active substances are compounds that have the ability to rotate the plane of polarized light. These substances are typically chiral, meaning they lack a superimposable mirror image due to their asymmetric molecular arrangement. Common examples include sugars, amino acids, and certain organic molecules. The direction and magnitude of optical rotation depend on the specific molecular structure of the substance.

4. **Polarized Light:**
   Light consists of electromagnetic waves oscillating in various directions. Polarized light is light in which the vibrations occur predominantly in a single plane. This can be achieved by using polarizers, which selectively transmit light waves vibrating in a particular direction while blocking others. Linearly polarized light is often used in experiments involving optical rotation.

1.2 Conceptual Objectives:

1. Understanding optical polarization
2. Studying optically active solutions
3. Quantifying polarization changes

1.3 Experimental Objectives:

1. Characterizing optically active solutions
2. Measuring rotation angles
3. Comparing different optically active substances

2 Apparatus:

1. Laser
2. Solution tubes
3. Optically active solutions
    a. Glucose
    b. Tartaric acid
4. Optically inactive solutions
    a. Distilled Water
    b. NaCl
5. Polarizers
6. Photodetector
7. Light filter

2 Experimental method:

2.1 Preparation:

Set up the apparatus as shown below.

Next, we formed solutions for NaCl, Glucose and Tartaric Acid. We added 4g powder of each substance into 20 ml of water. These solutions were then added to a glass jar, like the one shown in the diagram above. There was also a tube containing distilled water.

2.2 Procedure:

The angle of the first polarizer was set to 0 degrees and not changed throughout the whole experiment.

The distances between the apparatus were also kept constant.

Initially, there was no solution placed between the polarizers.

The angle on the second polarizer was initially set to 240 degrees (beta), and then changed gradually by 20 degrees.

Resistance was measured in kilo ohms by a multimeter for all the values of beta angle.

Intensity was calculated by taking the reciprocal of resistance.

The procedure was repeated with Glucose solution, Tartaric acid and Sodium Chloride solution.

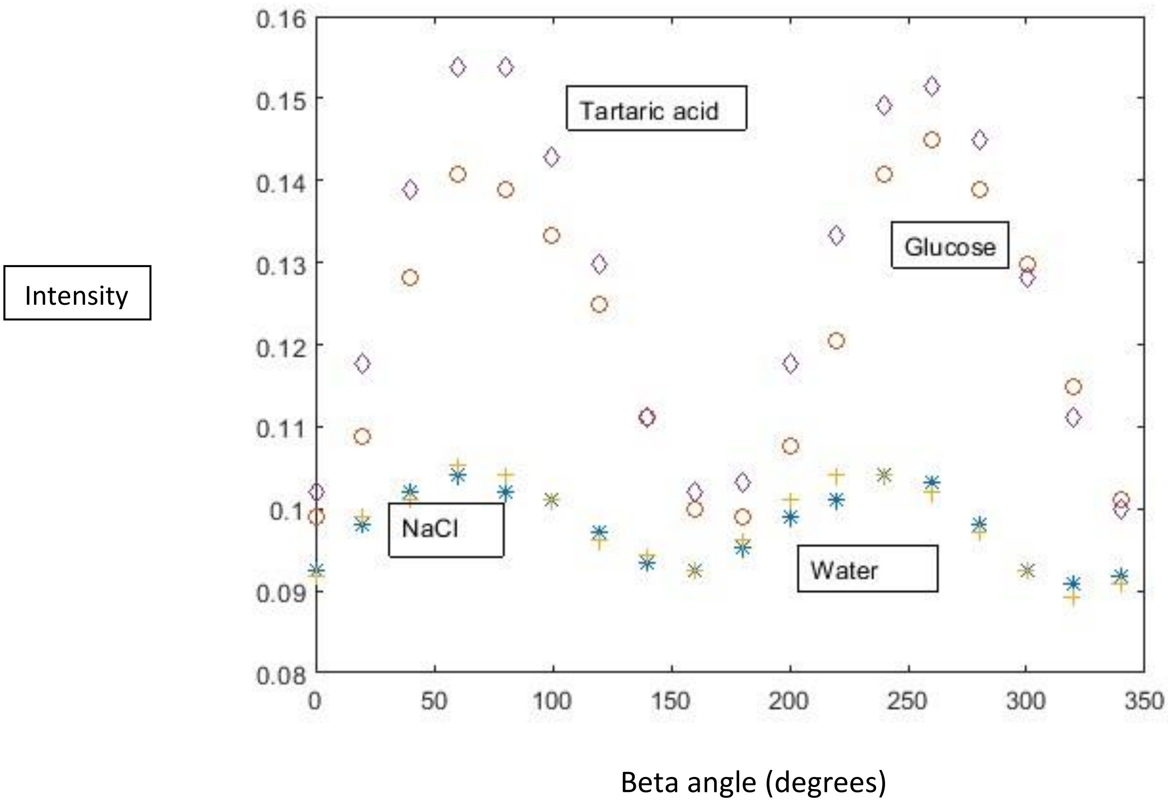
2.3 Data Collection:

The following data was collected:

Beta angle (degrees)	Intensity				
	No Solution		Glucose (20g/100ml)	NaCl (20g/100ml)	Tartaric Acid (20g/100ml)
	No jar	Jar + water			
240	0.19	0.10	0.14	0.10	0.15
260	0.20	0.10	0.14	0.10	0.15
280	0.19	0.10	0.14	0.10	0.14
300	0.17	0.09	0.13	0.09	0.13
320	0.14	0.09	0.11	0.09	0.11
340	0.12	0.09	0.10	0.09	0.10
0	0.11	0.09	0.10	0.09	0.10
20	0.14	0.10	0.11	0.10	0.12
40	0.18	0.11	0.13	0.10	0.14
60	0.20	0.10	0.14	0.11	0.15
80	0.21	0.10	0.14	0.10	0.15
100	0.19	0.10	0.13	0.10	0.14
120	0.17	0.10	0.13	0.10	0.13
140	0.13	0.09	0.11	0.09	0.11
160	0.11	0.09	0.10	0.09	0.10
180	0.12	0.10	0.10	0.10	0.10
200	0.14	0.10	0.11	0.10	0.12
220	0.18	0.10	0.12	0.10	0.13

2.4 Data Plotting:

Using Matlab, the intensities were plotted against the angle beta (x):

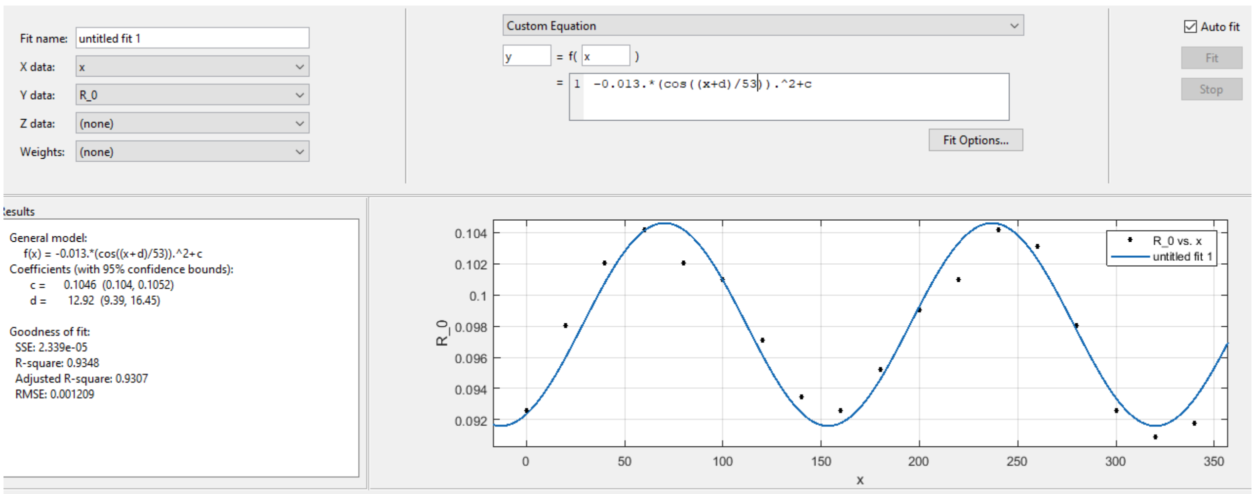


Note: When we measured the intensities of light without any jar in between, they came out to be greater than when a jar with distilled water was placed in between. This is because the glass of jar itself also refracts light.

2.5 Results/Calculation of Specific Rotation:

We take the values of Intensities through water as reference values, to calculate the phase difference.

a. Water:



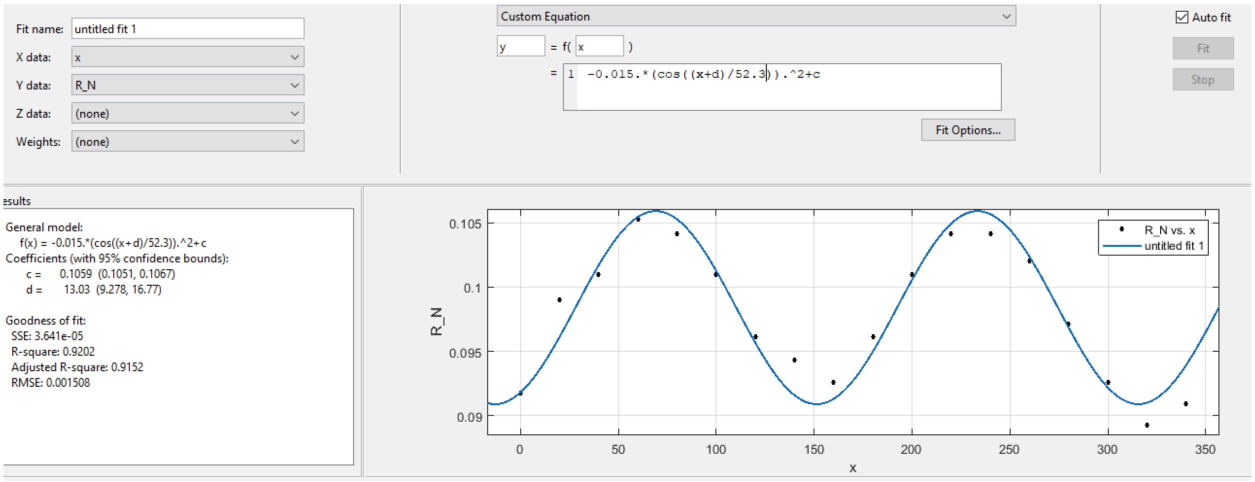
We used curve fitting tool to fit a custom equation graph on the values, with the help of Maluss's law.

The variable 'd' here represents the phase.

So the phase of distilled water is 12.92.

We will use this value to calculate the phase difference of the optically active solutions.

b. NaCl:



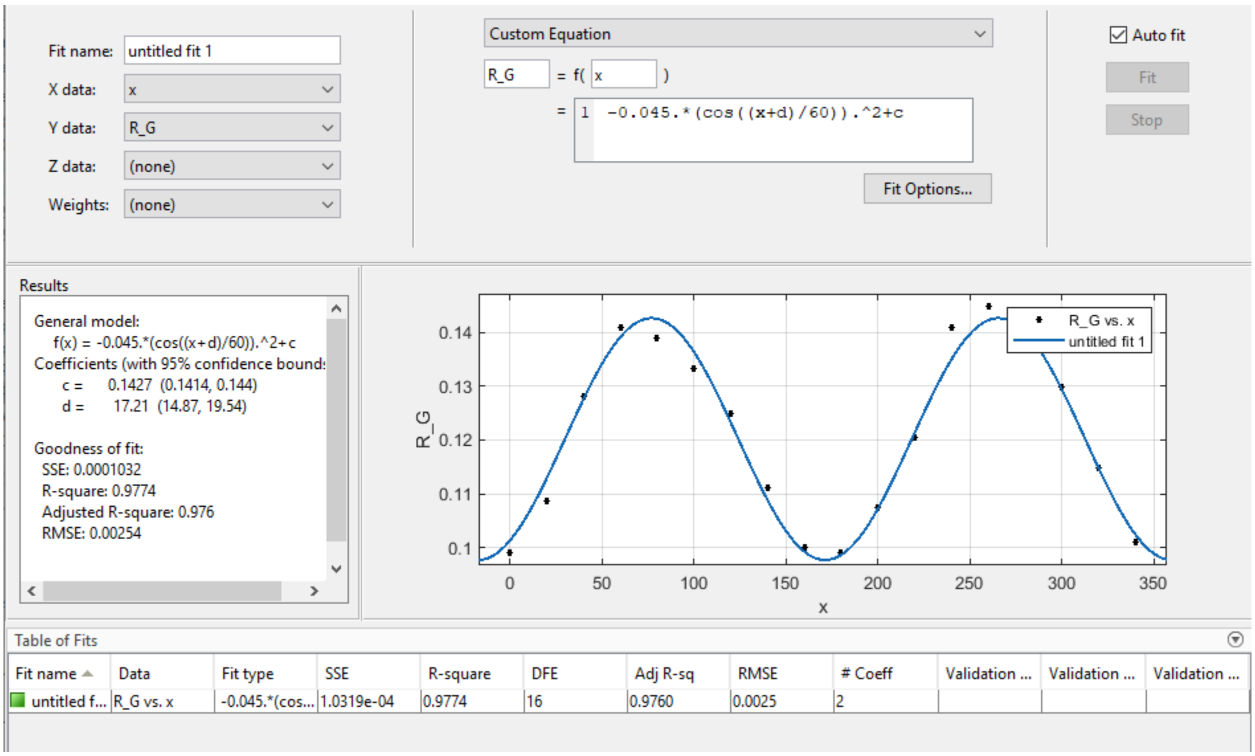
After fitting the curve with custom equation the variable ‘d’ represents the phase of the NaCl Solution.

So phase is 13.03

Phase difference= 13.03-12.92= 0.11
Concentration is 0.2g/mL
The path length is 0.2845 dm

Using the formula:
Specific rotation value= 0.11/(0.2*0.2845)
= +2 degrees

c. Glucose:



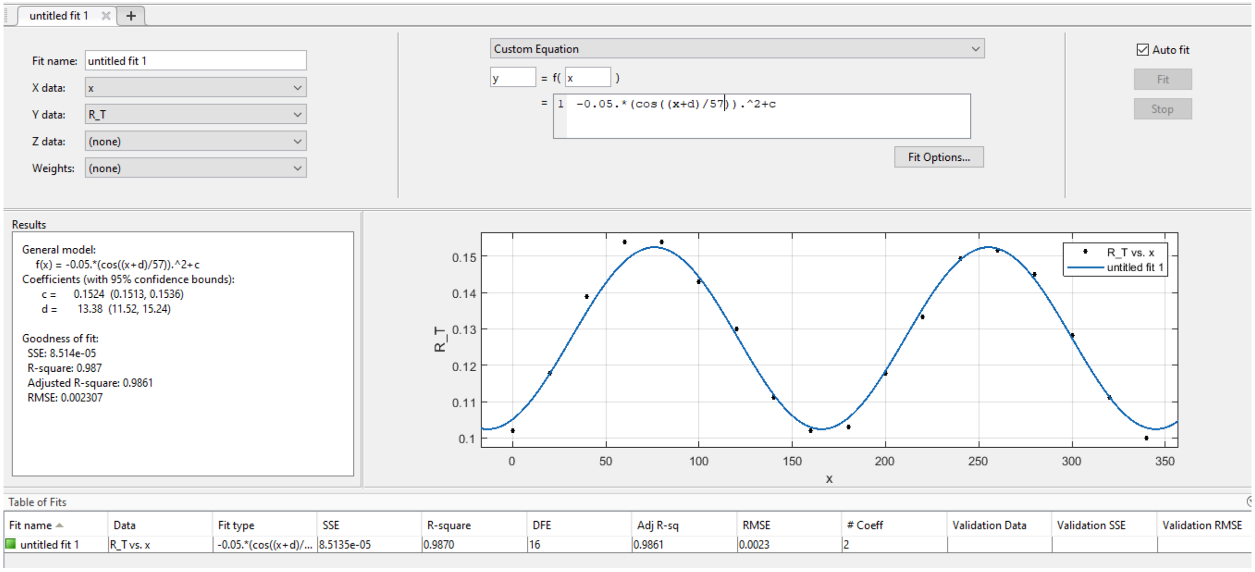
After fitting the curve with custom equation the variable ‘d’ represents the phase of the Glucose Solution.

So phase is 17.21.

Phase difference= 17.21-12.92= 4.29
Concentration is 0.2g/mL
The path length is 0.2845 dm

Using the formula:
Specific rotation value= 4.29/(0.2*0.2845)
= +75 degrees

d. Tartaric acid:



After fitting the curve with custom equation the variable ‘d’ represents the phase of the Tartaric acid.

So phase is 13.38.

Phase difference= 13.38-12.92= 0.46
Concentration is 0.2g/mL
The path length is 0.2845 dm

Using the formula:
Specific rotation value= 0.46/(0.2*0.2845)
= +9 degrees

2.6 Analysis of data:

1. **Glucose:** The calculated specific rotation value for Glucose was determined to be +75 degrees. However, the expected value for Glucose's specific rotation is commonly known to be approximately +52 degrees. The observed deviation from the expected value suggests a potential source of error in the experimental procedure or variations in the concentration or purity of the Glucose solution used.

2. **Tartaric Acid:** The specific rotation value for Tartaric Acid was found to be +9 degrees. Remarkably, this falls within the expected range for Tartaric Acid, demonstrating the accuracy and reliability of the experimental procedure for this particular substance. The agreement between the calculated and expected values lends credibility to the experimental approach and affirms the validity of the results obtained for Tartaric Acid.

3. **NaCl (Sodium Chloride):** Surprisingly, the calculated specific rotation value for NaCl was determined to be +2 degrees. However, NaCl is a well-known optically inactive substance, and its specific rotation should theoretically be zero. The non-zero value obtained could signify an experimental error, calibration issues, or potential contamination.

Potential Sources of error in the experiment:

1. The top pan balance was precise only to 0.1g. This might have led to an inaccurate mass amount measured.
2. A beaker was used to measure volume of water instead of more precise apparatus like pipette.
3. The laser and polarizers were not fitted tightly and so they moved, and had to be readjusted many times.
4. The polarized light would be rotated after exiting the second polarizer in a way that the light would not enter the photodetector and so the detector had to be realigned multiple times throughout the experiment.
5. The material of the solution tube also affected the rotation of light.
6. Not all of the solute was dissolved inside the solvent.
7. The tube may not have been linearly aligned with the polarized light which may have caused some initial refraction of the polarized light.
8. Some of the light may also have been reflected from the surface of the tube.

Conclusion:

In conclusion, the experiment demonstrated the clear connection between the chirality and the observed optical rotation. Path length and the concentration of solutions were identified as critical factors influencing the magnitude and direction of the rotation. These findings enhance our understanding of the principles governing optical rotation and contribute to the broader knowledge of chiral interactions with polarized light.