Understanding the Wave Nature of Light by Observing Interference and Diffraction

Ethan Fahnestock

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Abstract

The wave nature of light is indirectly verified by matching collected data to an equation describing wave behavior. These wave properties are then used to find the width of a CD track. The first experiment has a small percent error but the second had a large amount, possibly hinting that the process is difficult to implement in practice.

1 Introduction

1.1 Purpose

The purpose of this lab is to verify the wave properties of light. Experimental data was collected and compared with formulas derived based on different wave properties. If the data matches predictions, this verifies light has wave like properties.

1.2 Background

In 1805 Thomas Young performed the double slit experiment, at the time confirming the wave nature of light. When light passed through two narrow slits, an interference pattern consisting of bars separated by constant distances appeared. To explain the interference pattern, Young concluded that light must be a wave that diffracts at the slits. This experiment overthrew the previous theory of light, which was Newton's corpuscle based theory.

Without this experiment the theory of light would not have evolved to where it is today. The change in the theory also played a key role in the introduction of quantum mechanics, which has had significant impacts in the worlds of physics and computer engineering.

1.3 Theory

Derived from the wave properties of light, a relation between variables for a double slit experiment is:

$$\lambda = \frac{hy}{nx} \tag{1}$$

- λ is the wavelength of light
- h is the distance between the centers of the slits.
- y is the distance between the centers of the bright spots in the interference pattern.
- n is the number of spots from the center bright spot (cbs) the measurement is made from.

2 Materials and Methods

2.1 Collecting Data to Calculate the Wavelength of the Laser

A helium neon laser was plugged in and turned on. The light emitted by the laser reflected off of a piece of paper taped on a distant wall. A grating with slits 0.3mm apart was positioned close to the laser and in it's path in such a way that an interference pattern was observed on the paper.

The center of the bright spots was approximately marked on the paper and the distance between the wall and the laser was measured. Later the distances between pencil markings on the paper were measured with a caliper.

2.2 Collecting Data to Calculate the Width of a CD Track.

The helium neon laser was pointed at a CD. The CD was positioned against a backing as to orient it orthogonality relative to the table plane on which the laser was also resting. A board was positioned between the laser and the CD as to catch the interference pattern created by the CD and laser. The distances between the dots and the point at which the laser reflected from the CD were recorded along with their respective uncertainties. See Figure 1 for more details.

3 Results and Analysis

3.1 Wavelength Calculations

3.1.1 Collected Data and Calculations

After the experiment was set up as described in Section 2, measurements were taken with a measuring tape and converted into meters. All of the collected data and uncertainties can be found in Table 1. The slit width was provided during the lab. The value for the interference distance is an average of six measured distances.

Measurement	Value	Uncertainty
Distance to wall (x)	2.898 m	$6.35x10^{-3}m$
Interference Pattern Distance (y)	$6.0x10^{-3}m$	$5.0x10^{-4}m$
Slit Distance (h)	$3.0x10^{-4}m$	$5.0x10^{-5}m$

Table 1: Collected Data.

The wavelength of the laser was calculated using Equation 1 as described below.

$$\lambda = \frac{3.0x10^{-4} * 6.0x10^{-3}}{1 * 2.898} = 621x10^{-9}m \tag{2}$$

The uncertainty was calculated using Equation 3. The uncertainty was not calculated on a weighted basis for the interference pattern because it was consistent throughout the measurements.

$$\delta\lambda = \sqrt{(\frac{\partial y}{\partial\lambda}\delta y)^2 + (\frac{\partial x}{\partial\lambda}\delta x)^2 + (\frac{\partial h}{\partial\lambda}\delta h)^2} = \sqrt{(\frac{h}{nx}\delta y)^2 + (\frac{-yh}{nx^2}\delta x)^2 + (\frac{y}{nx}\delta h)^2} \tag{3}$$

The calculated values and percent error are in Table 2

Measurement	Calculated Value	Actual Value	Percent Error	Uncertainty
Wavelength (λ)	621.1 nm	632.8 nm	1.85%	116 nm

Table 2: Calculated Data.

3.1.2 Analysis

The relation derived from wave characteristics (Equation 1) described the experimental results surprisingly accurately, with a small percent error. This is strong evidence that light has wave characteristics. In future experiments multiple trials should be completed, with one variable in Equation 1 changed each trial, to further verify the flexibility of this relation. Error in this lab, though small, likely derived from measurement errors. It is important to note that the uncertainty for this lab is large - roughly 10% of the calculated value. The most effective way to decrease this would be to measure the distance to the wall with a more accurate instrument, as this was the largest contribution to the overall uncertainty.

3.2 Track Width Calculations

3.2.1 Collected Data and Calculations

For the second part of the experiment the configuration described in 2.2 was set up. The measurements in Table 3 were collected.

Measurement	Value	Uncertainty
λ	621.1 nm	116 nm
Distance from CD to board	0.6604 m	$6.35x10^{-3}m$
Distance between Maximums	0.2125 m	$6.35x10^{-3}m$

Table 3: Collected Data for the CD Experiment

To calculate the width of the tracks on the CD, a formula similar to one used to describe interference on crystal latices was used.

$$hsin\theta = n\lambda \tag{4}$$

- h is the width of the track
- θ is the angle between the center bring spot and first maximum
- n is the number maximum being measured from
- λ is the wavelength of the light.

  Using trig to solve for θ, this equation was used to calculate the spacing on a CD as follows

$$h = \frac{n\lambda}{sin\theta} = \frac{1 * 621.1x10^{-9}}{sin(tan^{-1}(\frac{y}{x}))} \tag{5}$$

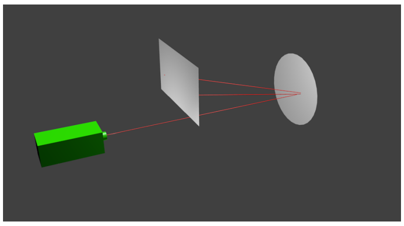
Assuming that one of the Maximums observed was the center bright spot (CBS) the data in Table 4 was calculated. A similar method to Equation 3 was used to calculate the uncertainty for h and θ.

Measurement	Value	Actual Value	Percent Error	Uncertainty
Distance between Tracks	$2.06\mu m$	$1.6\mu m$	28.75%	$3.81x10^{-7}m$

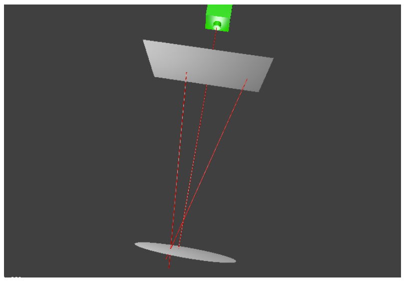
Table 4: Collected Data for the CD Experiment

3.2.2 Analysis

In this variant of the lab there was a significantly larger percent error and a slightly larger uncertainty. However the ratio of calculated value to uncertainty is vastly smaller. This would point to a physical inaccuracy in the lab setup. The likely cause of this error was the laser plane and laser background being non-orthogonal. During the lab, the distances between the reflection point on the CD and the observed maximum were measured to be significantly different values. An ideal setup of this lab is shown in Figure 1. This slant of the recording screen would have caused a drift in the y distance between the two points, causing error in the lab. As with the last lab, if this were to be performed again multiple independent variable trials should be performed to further verify the relation provided in Equation 4.



(a) Side View



(b) Top View

Figure 1: An Approximation of the Path of the Laser Reflecting on the CD

Regardless of the error, this part of the lab proved lights ability to diffract off of a different surface, as well as its application to measuring microscopic distances. The concepts tested in this lab could be applied to a manufacturing setting to test the quality of objects like CDs.

4 Conclusion

The level of accuracy in which Equation 1 explains the behavior of light diffracting and interfering indirectly verifies the wave theory of light. Applying similar principles, this lab proved that lasers can be used to measure microscopic distances. The calculated percent error for the second lab, 28.75%, hints that the process is difficult to implement, and should be improved.