Calculation of Coherent Light Wavelength Through Diffraction

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Introduction

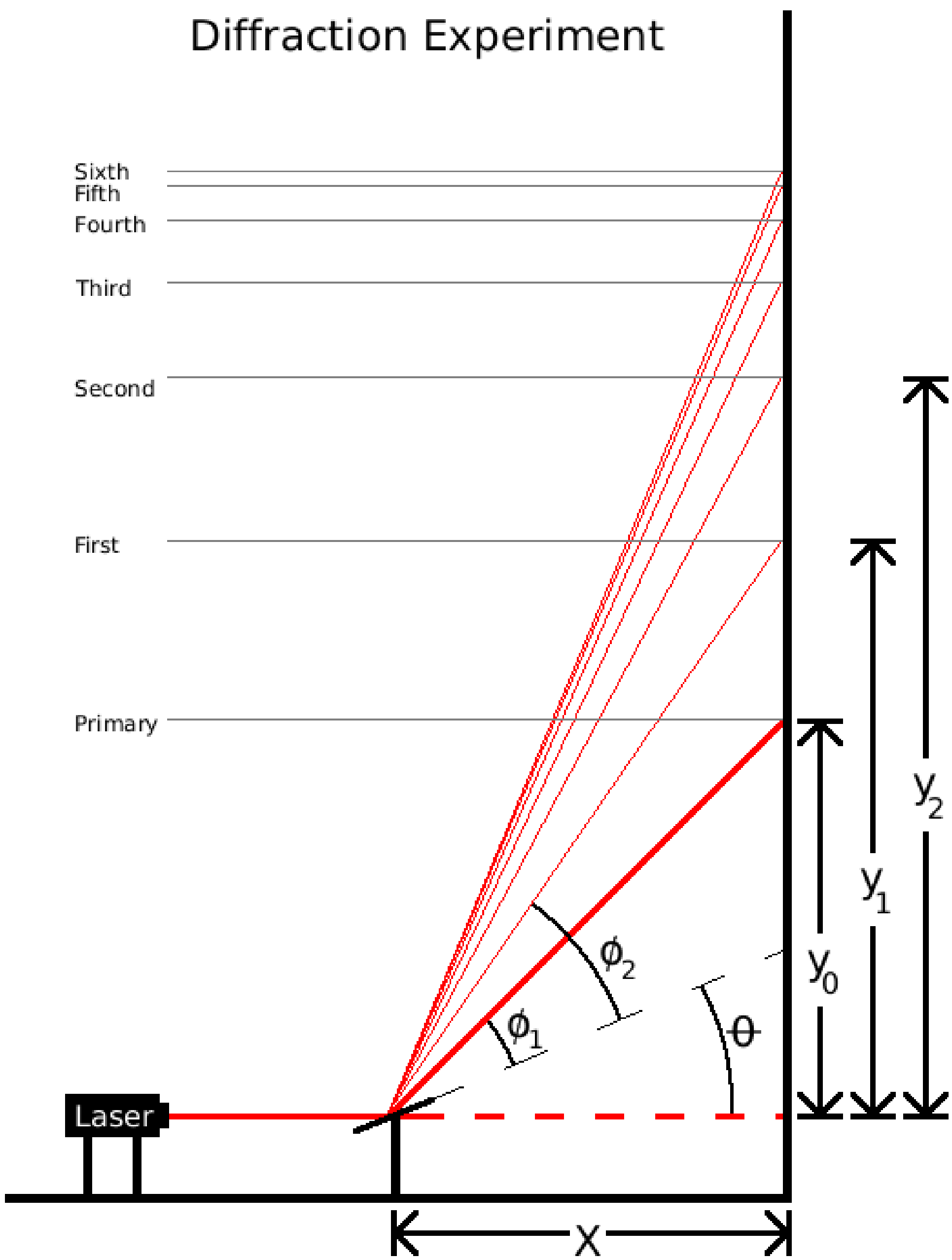
In this experiment we will investigate a procedure to determine the wavelength of laser light. Our method is to reflect this laser light off a ruler towards a wall. Using basic principles of the wave properties of light, and the behavior of constructive and destructive interference, we can deduce the wavelength of the original light. When the laser is aimed at the ruler, set at a slight angle, it produces a vertical series of spots on the wall, in decreasing intensity vertically, with the brightest spot as the lowest spot.

Predictions

We predict that by measuring the vertical position of the spots, along with the horizontal distance from the ruler to the wall, we can calculate the wavelength of the laser light.

Description of Experiment

Our experiment consisted of one standard HeNe laser, a small metal ruler, a standard track to mount the laser and ruler on, and a tape measure. The ruler had rulings of 1/64th inch, and was set at approximately the same vertical height as the laser, but at a slight angle of inclination. Initially, we removed the ruler from the laser's path, in order to find the height on the wall directly across from the laser. This became our vertical reference height. When we placed the ruler into the path of the laser, a series of spots of light appeared on the wall. Each spot is an order of diffraction. They are labeled the first order, second order, etc. Our experiment consists of measuring the pertinent lengths, both the horizontal distance, as well as the vertical heights. A diagram of this experiment is located on the next page. Please note that not all of the y-values are indicated. Some have been left off for space reasons. The same can be said for some of the φ values.


Diffraction Experiment
Sixth
Fifth
Fourth
Third
Second
First
Primary
Laser
ϕ_1
ϕ_2
θ
y_0
y_1
y_2
X

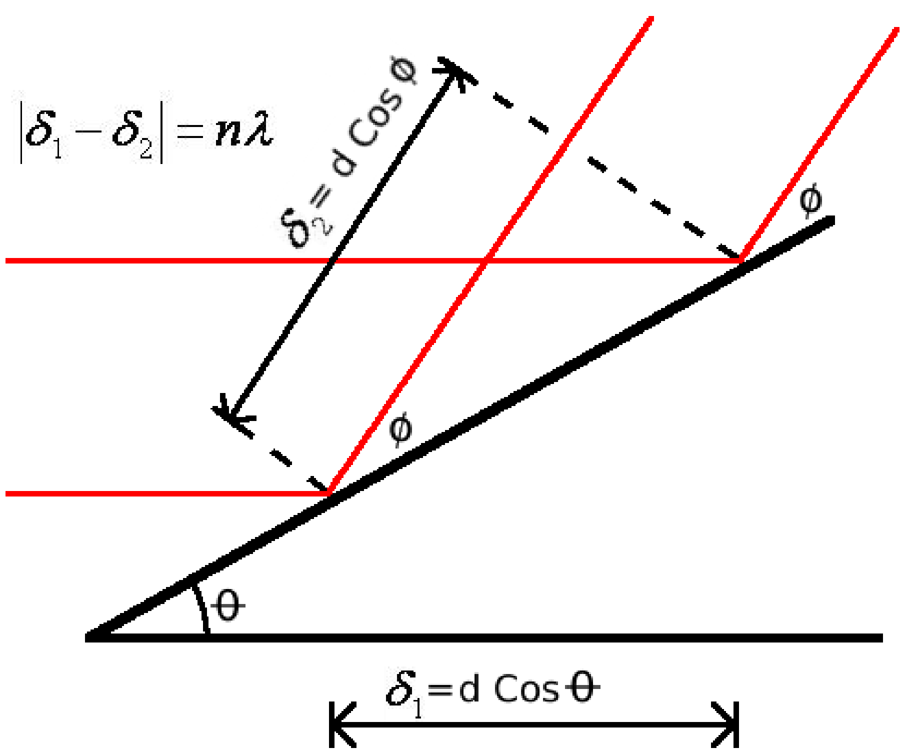
Data

Distance between rulings on ruler: d = 0.0396875 cm
Distance to wall: x = 358.1 cm
Here is a table of y-values:

Order of Diffraction	Vertical Distance (cm)
0	20.9
1	33.3
2	41.2
3	47.4
4	52.2
5	57.3

Results & Analysis

One of the initial problems we encountered was the difficulty of measuring the angle of the ruler. We solved this by measuring the height of the first stop on the wall, which is called the primary ray. This ray is formed by the combined reflections of the laser off of the shiny parts of the ruler. By geometry, the angle that the primary ray makes with the horizontal is twice the angle of the ruler. This is the angle θ in the diagram. We calculated θ = 1.67°. Here is a diagram of a close-up of two rays striking the ruler:



This diagram is used to illustrate what happens when two parallel rays hit non-shiny parts of the ruler. They will diffract off the marks, sending a small amount of light in all directions. In the diagram, δ_1 is the extra horizontal distance traveled by the upper ray, and δ_2 is the extra angular distance traveled by the lower ray. When you take the absolute value of the difference between these two values, you get the total difference in path length. A spot is formed on the wall only when the difference in path length is an integer multiple of the wavelength of the laser's light. That multiple is the same number as the associated order of diffraction. This relationship is quite important, in that it allows us to relate the vertical distances between the spots on the wall, and the wavelength of the light.

The first step in the derivation is to calculate the value of $\theta + \varphi$ for each order of diffraction:

Order of Diffraction	θ + φ (degrees)
0	3.34
1	5.31
2	6.56
3	7.54
4	8.29
5	9.09

To obtain the value for just φ, you merely have to subtract the value of θ:

Order of Diffraction	Φ (degrees)
0	1.67
1	3.64
2	4.89
3	5.87
4	6.62
5	7.42

Now that we have the values for theta and phi, we can calculate the values of δ_1 and δ_2. $\delta_1 = d \cos(\theta)$ and $\delta_2 = d \cos(\varphi)$:

Order of Diffraction	δ_1	δ_2
0	0.0396706430	0.0396706390
1	0.0396706430	0.0396073176
2	0.0396706430	0.0395428609
3	0.0396706430	0.0394793889
4	0.0396706430	0.0394226030
5	0.0396706430	0.0393550820

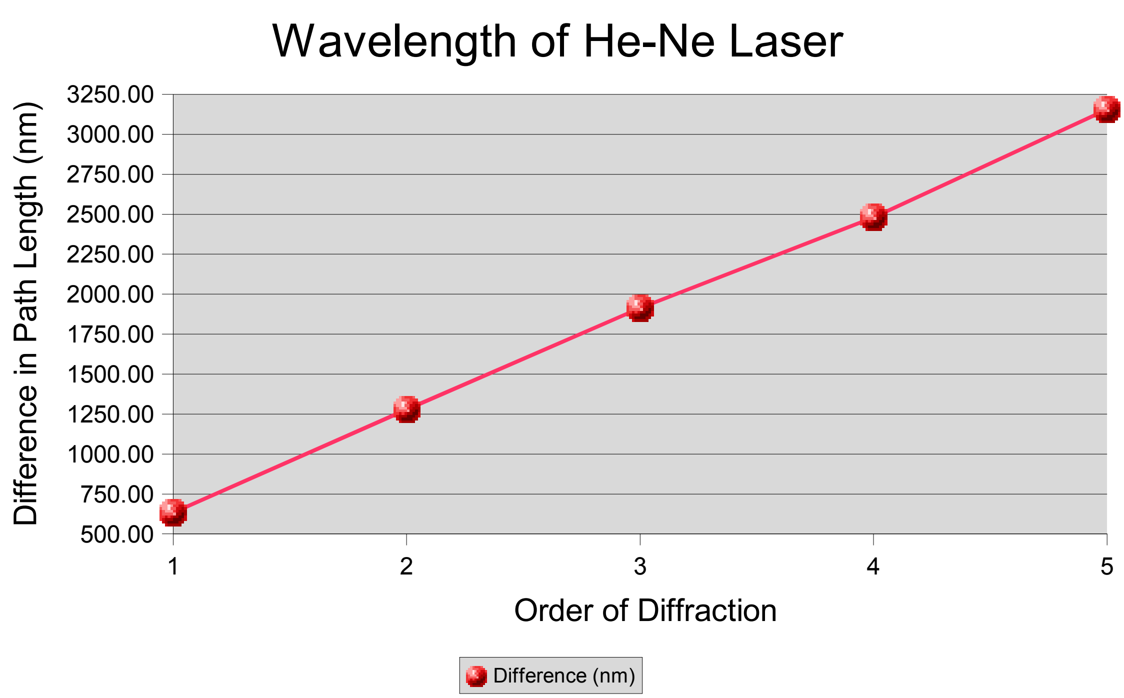
Using the expression from above, we can calculate the difference in path lengths:

Order of Diffraction	Path Length Difference (nm)
0	n/a
1	633.25
2	1277.82
3	1912.54
4	2480.4
5	3155.61

Since the spots observed were all locations of constructive interference, we know that the difference in path length must be the number of the order of diffraction multiplied by the wavelength. We can divide the path length difference by the order of diffraction to calculate a wavelength for each spot:

Order of Diffraction	Wavelength (nm)
0	n/a
1	633.25
2	638.91
3	637.51
4	620.1
5	631.12

These calculations give us five different values for the wavelength. If we take a chart of the path length differences vs. the order of diffraction, we can use the slope of the calculated regression curve to better approximate the value of the wavelength. Here is a chart of the values:



The slope of the linear regression to these points of data is approximately 627.26 nm. This is very close to the known value of 632.8 nm. We were quite fortunate to obtain results so close to the accepted value.

Error Attribution

There are many possible sources of error in this lab. One of the largest sources of error is using a standard wooden meter stick to measure the vertical distances, and a a plastic tape measure for the horizontal distance. It is really exciting that we were able to obtain such accurate results using simple tools. We avoided having to measure the angles directly by using right triangle trigonometry to calculate the angles.