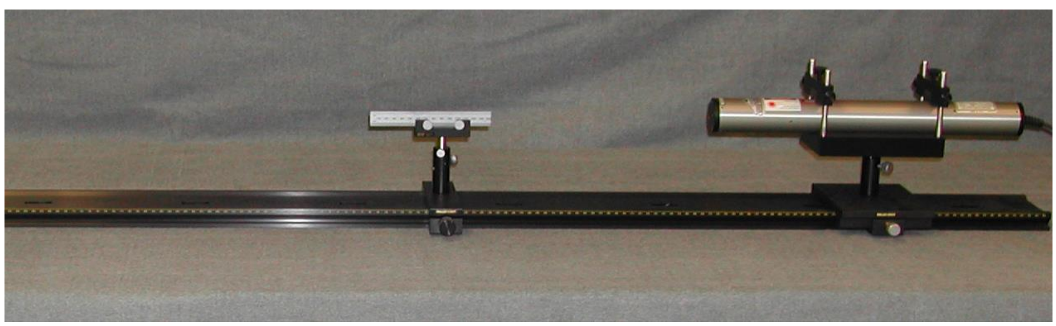
O14a: Measuring the Wavelength of Light using Diffraction

Introduction:

Diffraction of light refers to a phenomenon where light bends around an obstacle. The effect occurs when part of the light wave-front encounters a sharp barrier like a sharp edge or corner causing the wave to deviate from its otherwise straight-line behavior. Diffraction is a particular type of interference which is also a consequence of the superpositioning of waves. A coherent light source is required to obtain a diffraction effect. In this experiment a monochromatic light source (Helium Neon laser) is aligned at a grazing angle to a machinist rule that is being used as a reflection grating. The interference between the direct laser beam, the reflected light and the diffracted light from the rule will produce a diffraction pattern on a screen that can be measured. The collected data will be analyzed to determine the wavelength of the light emanating from the HeNe laser. Refer to any physics textbook for additional background on diffraction.

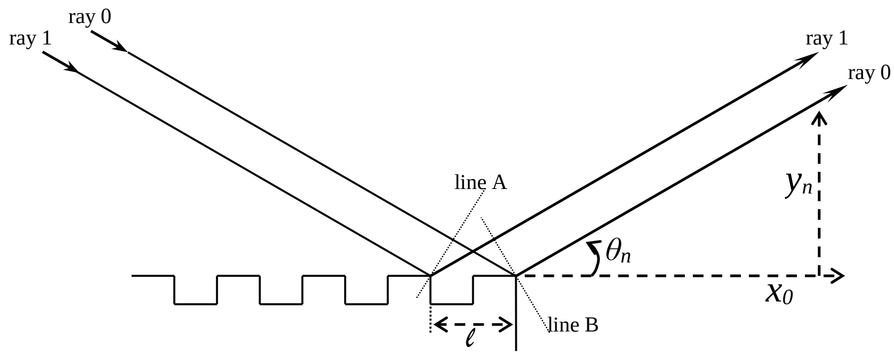
Apparatus:

➢ HeNe laser ➢ Machinist rule ➢ Optical holders & mounts ➢ Ruler accurate to .5mm	 **Figure 1**

Discussion:

Light originating at the laser (ray 0 & ray 1) travels an equal distance to line A. Light leaving the rule at line B travels an equal distance to arrive at the viewing screen. Since the two rays graze the rule at different positions the total distance they travel to the screen is different. The difference in this distance is called the difference in the optical path length. For the following refer to **Figure 2**. The rule scale being used as the grating has a repeated increment of ℓ. The distance from the end of the rule to the viewing screen is x_0. The distances from the origin line to each of the intensity points are represented by y_n. Notice that an expression is developed relating the grazing angle to the screen distance and intensity distances.

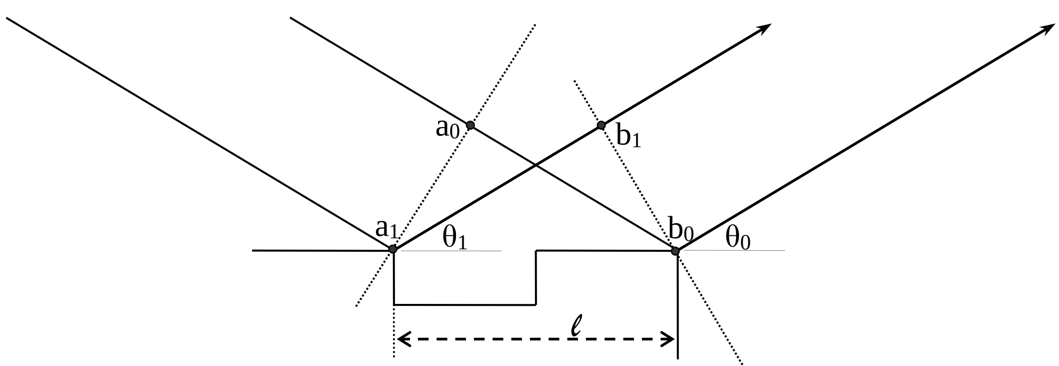
Figure 2



$$\cos\theta_n = \frac{x_0}{\sqrt{x_0^2 + y_n^2}}$$

Since the distance from the laser to line A and from line B to the viewing screen are equal, the difference in the optical path length must be equivalent to the different distance ray 0 travels from line A to line B versus ray 1 travels from line A to line B. This difference in optical path length (δ) must be equal to an integer multiple of the wavelength, otherwise constructive interference of the two waves would not occur. **Figure 3** develops an expression for this different distance (δ).

Figure 3



$\delta_{0n} = n\lambda$ also (for rays 0 & 1) $\delta_{01} = (a_0b_0 - a_1b_1)$

$$(a_0b_0 - a_1b_1) = \ell\cos\theta_0 - \ell\cos\theta_1$$

$$\therefore \quad n\lambda = \ell\cos\theta_0 - \ell\cos\theta_n$$

The expression developed in **Figure 3** for the difference in the optical path length is combined with the expression developed in **Figure 2**. This results in the following equation that can be used to solve for the wavelength of the HeNe laser light.

$$\lambda = \frac{\ell x_0}{n}\left(\frac{1}{\sqrt{x_0^2 + y_0^2}} - \frac{1}{\sqrt{x_0^2 + y_n^2}}\right)$$

Procedures:

The laser and machinist rule are mounted on optical holders and positioned as in **Figure 1**. The alignment between the laser and the rule is critical to obtaining a good diffraction pattern on the viewing screen similar to **Figure 4**. Do not adjust or change the laser & rule positions. If the alignment has been changed have lab personnel correct this.

Figure 4

1. Obtain from a lab instructor the distance from the end tip of the rule to the viewing screen. **Be extremely careful not to touch the rule at all, as this will disrupt the diffraction pattern.**
2. Also, obtain from a lab instructor the rule scale that is being used as the grating, the length of scale division.
3. Hold a long piece of paper to the viewing screen and duplicate the intensity pattern. Use a sharp tipped ink pen and dot in the center brightest location of each dot. Start with the direct ray and continue until 22 points have been collected. (It is important to note that the dots should be as small as possible, as it will be necessary to measure the distance between the dots to an accuracy of .5mm.
4. Correlate the reproduction of the diffraction pattern with **Figure 5**. Measure all of the distances from the origin to the intensity points (y_n).
5. Calculate the wavelength of the HeNe laser light.

Data Analysis:

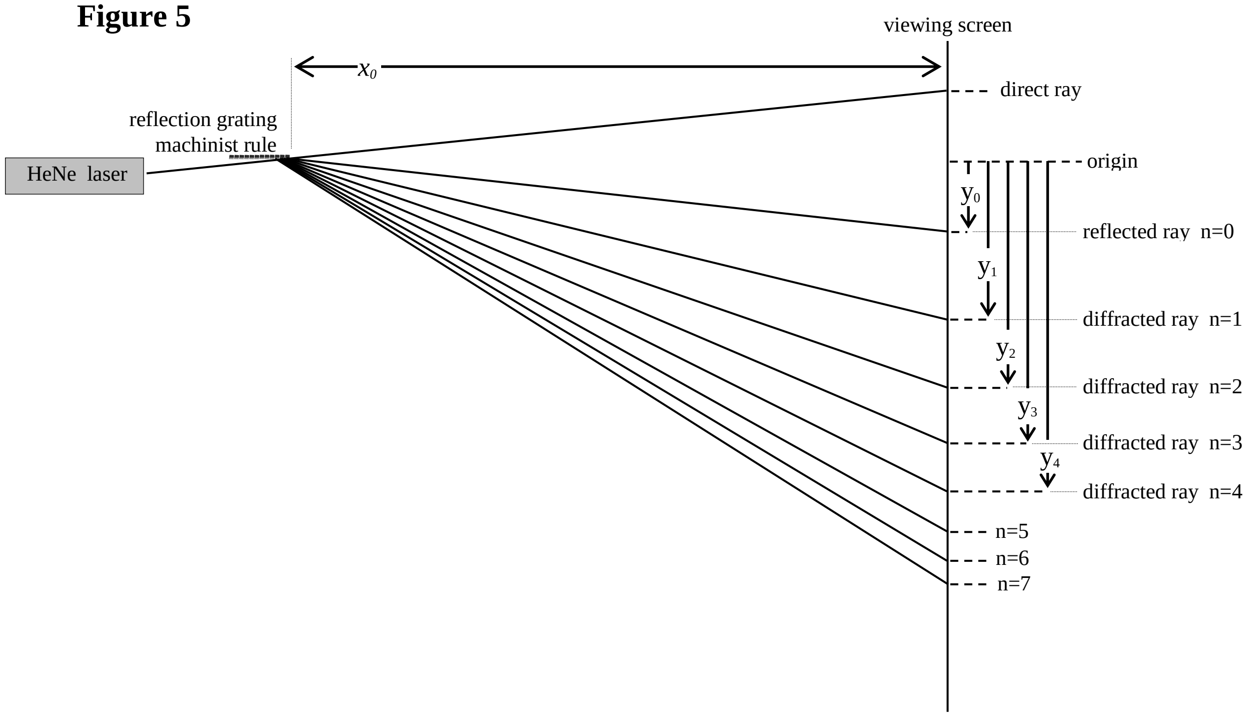
For the data analysis, it is necessary to measure the distances between the dots with respects to an origin that is established as half the distance between the direct ray and the reflected ray. Measure the distance between the first two dots (direct and reflected ray), and place the origin at half the distance. From this origin, measure the distance to the reflected ray (which should be exactly half the distance of the first measurement). This distance is y_0. The subsequent y_n measurements are also, all made from the origin.

The length of scale division represents the division between the marks on the machinist rule that created the diffraction pattern. This is **ℓ.** (*The machinist rule that creates the diffraction pattern has the same accuracy as the ruler used to make the measurements*). The distance x_0 is the distance from the end of the machinist rule, closest to the screen, to the viewing screen.

Make use of the picture provided below in **Figure 5** in comparison with the 22 data points collected previously. The two data points farthest apart (which should lie on either one end or the other of the data collected) represent the direct ray and the reflected ray.

As an important note: consider the relative accuracies of this experiment. In this experiment, the wavelength of laser light (***632.8 nanometers***) is trying to be determined experimentally to an accuracy of nanometers, 10^{-9} meters. This value is being determined via measurements made to an accuracy of .5mm, or 5 x 10^{-4} meters. This is equivalent to attempting to determine the speed a car travels as it drives between Orlando and Tampa having access to a measuring device able to only measure 100 miles at a time. **Because of this difficulty, it is extremely important to be careful when measuring the distance between the data points, as a half a millimeter can completely change the resulting calculation.**

Figure 5



Experiment O14a: Measuring the Wavelength of Light Using Diffraction

Student Name____

*Lab Partner Name*____

*Lab Partner Name*____

Physics Course____

Physics Professor______________________________________

Experiment Start Date__________________________________

Lab Assistant Name	*Date*	*Time In*	*Time Out*

Experiment Stamped Completed

Data Sheets: O14a: Measuring the Wavelength of Light Using Diffraction

NAME: ____________________________ **DATE: _________________**

Length of scale division (ℓ) ________________ meters

Distance from ruler tip to screen (x_0) ________________ meters

Distance from origin to reflected ray (y_0) ________________ meters

(n)	(y_n) (meters)	λ (nanometers)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

mean λ: _______________nm

standard deviation: _______________ nm