Lab # 8
Measuring the Wavelength of Light Using a Ruler
(Formal Report)

I. Introduction

In this lab you will measure the wavelengths of the light emitted by two different He-Ne lasers, one emitting in the red part of the visible spectrum, the other in the green. The measurement will be carried out by observing the interference pattern produced by having the laser light incident on a metal ruler. By having the laser beam hit the ruler near "grazing incidence," you can observe several different orders of constructive interference. You will then use a least-squares fit of the distances between maxima in the interference pattern to find the wavelength of the light. With some care in your procedures you should be able to have an experimental uncertainty of less than 1% in your wavelength determination.

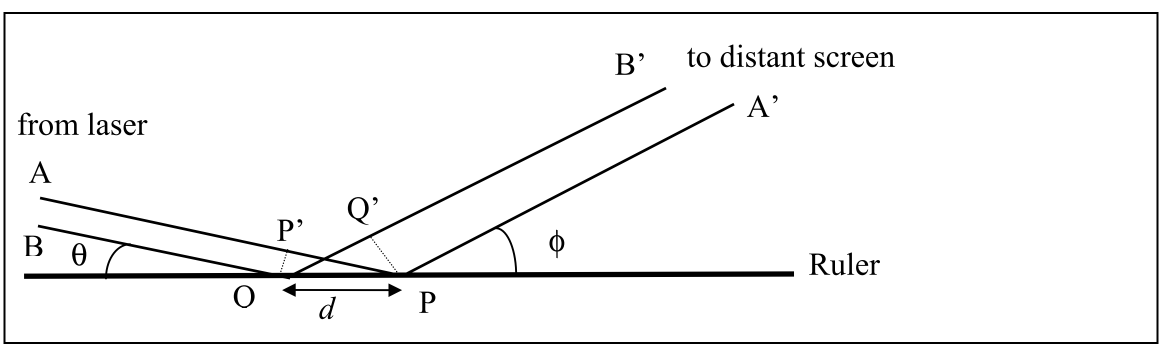
II. Theory

The light diffracted from the ruler forms an interference pattern, which is in essence a pattern due to many sources in a regular array with a spacing d = 1mm or so. In this case, the condition of a maximum in the intensity pattern is the same as that for two slit interference, but between successive maxima are a number of much weaker local maxima and minima.

In the diagram below two rays AP'PA' and BQQ'B' are shown hitting successive markings P and Q separated by a distance d (1 mm or 0.5 mm, depending on your ruler). Let θ be the incident angle and ϕ the emergent angle (both measured between the rays and the ruler surface). From the diagram you can see that the path difference between the two rays is given by

$$PP' - QQ' = d(\cos\theta - \cos\phi) \qquad (1)$$

If the two rays are to interfere constructively to produce a bright spot, the path difference must be $n\lambda$, where n is some integer. n = 0 corresponds to ordinary specular reflection with $\theta = \phi$. Note that n > 0 corresponds to bright spots on one side of the specular reflection spot, and n < 0 to bright spots on the other side.



In the attached article, Nobel laureate A. L. Schawlow shows that Eq. (1) can be written as

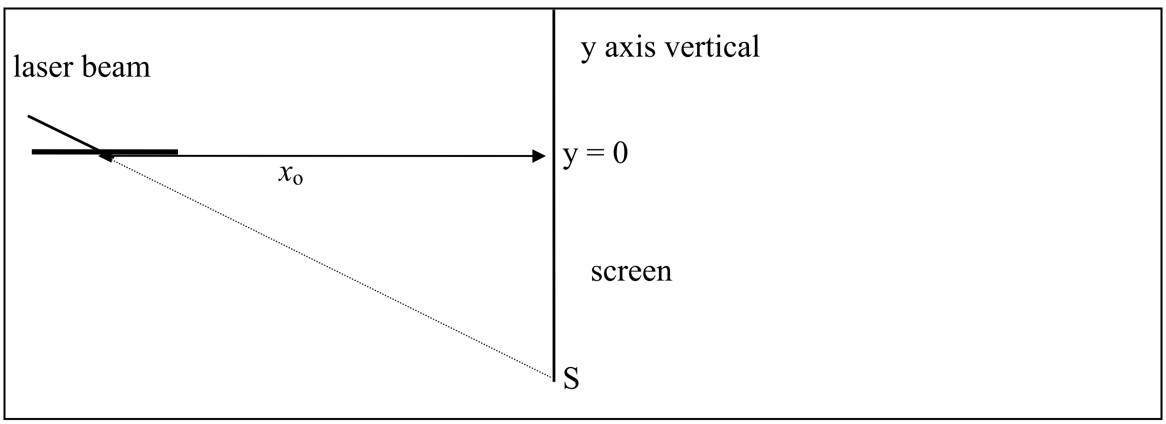
$$n\lambda = d(y_n^2 - y_0^2)/2x_0^2 \qquad (2)$$

where x_0 is the distance from the screen to where the laser beam hits the ruler. The ys are measured from the point on the screen hit by the extension of the ruler. Eq. (2) will be the working equation for this lab. Read and understand this derivation.

III. Experimental Procedure

Before you are ready to measure distances and angles, you must observe the following precautions:

- Make sure that the screen (a clean sheet of white paper taped to the wall) is perpendicular to the edge of the ruler. (How can you check this reliably and to what accuracy?)
- Make certain that the screen is about 3 m or more from the ruler.
- Position one of the red-emitting He-Ne lasers near the ruler.



Alignment and Measurement Procedures:

- Be sure that point S will be on the screen: Without disturbing the laser remove the ruler and note where the laser beam strikes the screen. This last observation is necessary to obtain the origin of your y axis, the point where the ruler, if extended would meet the screen. (See the figure above.)
- Align the laser and ruler so that you see on the screen the best defined set of dots you can obtain. Spend some time playing with the alignment to ensure that you do as well as you can.
- Once you have a satisfactory pattern, mark each dot carefully with a fine pencil.
- Note the position of the specular reflection for n = 0. You may slide the ruler so the laser beam strikes a smooth part of the ruler to see which maximum corresponds to n = 0.
- Measure the distance x_0 from the spot where the laser beam hits the ruler to the screen.
- Repeat the preceding steps with a different value of x_0 to provide a consistency check.

IV. Analysis

Determine the origin of the y axis as the point on the screen where the imaginary extension of the ruler would intersect the screen. As indicated in the Schawlow article, this point is halfway between the point S and the $n = 0$ interference maximum. Then determine each of the y_n values for each of the maxima as carefully as possible.

Use a spreadsheet program (linear regression) to fit Eq. (2) to your data for the red He-Ne laser to determine the wavelength of the emitted light. The handbook value for this wavelength is 632.817 nm. Compare your estimate of the experimental uncertainty (based on your evaluation of the uncertainty in distance measurements) with the uncertainty given by the spreadsheet program. Discuss any discrepancies with the instructor.

V. The Green He-Ne Wavelength.

Repeat your procedures to determine the wavelength of the green He-Ne laser.

VI. The Report.

Your report should include a derivation of Eq. (2) from Eq. (1) and a complete discussion of experimental uncertainties. Which of the measured quantities has the greatest effect on the final experimental uncertainty? How might the measurement of that quantity be improved?

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