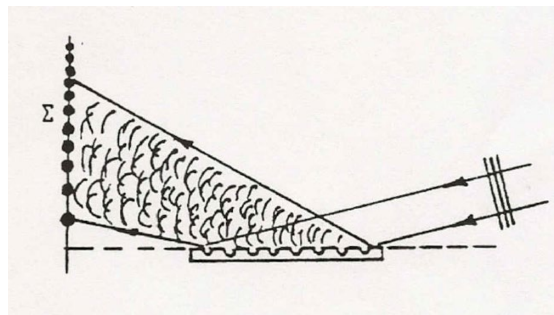
Interference of light: Schawlow's Ruler

The goal of this lab is to observe interference effects in light reflected by a crude diffraction grating and to determine from the resulting interference pattern the wavelength of the laser source.

References. A. L. Schawlow, *Am. J. Phys.* **33**, 922 (1975) and
https://www.nobelprize.org/prizes/physics/1981/schawlow/biographical/

I. Introduction



A reflection grating is compose of a large, uniform array of reflecting surfaces. Figure 1 depicts a flat reflection grating viewed side-on; in the present context one can think of the device as a flat array of highly reflecting plateaus separated by thin grooves. When illuminated by laser light, these plateaus behave like a collection of identical, coherent, monochromatic sources. The resulting superposition of light on the screen shows a dramatic sequence of interference maxima (bright spots) separated by darkness (where destructive interference prevails). The purpose of this experiment is to infer from the locations of the maxima the wavelength of the incident light. Since you will be using a finely-ruled steel ruler as a grating, you will be measuring the wavelength of light with (of all things) a ruler!

II. Learning goals

At the end of this lab you should know how to

- Observe interference using a reflection grating division of wavefront.
- Connect underlying theory of wave addition to intensity profile observed.
- Distinguish when the small angle approximation can be used in a large data set.
- Convert from the original Schawlow description to a small angle valid description of the experiment.
- Properly perform linear fit to determine a measured wavelength.
- Properly perform non-linear fit to appropriate form of theory
- Understand how this effect can apply to higher resolution spectroscopy with diffraction gratings (more rulings)

III. Procedure

1. Place the ruler on provided supports so that the laser beam hits at wide angle (almost parallel to the ruler), with the center of the laser spot approximately 5 to 10 meters from the wall.
    a. The laser spot on the ruler should be about 1-3 inches in size.
    b. The ruler supports should already be adjusted so that the ruler pretty well leveled and is square to the wall.
    c. The laser must hit only one well defined set of rulings.

2. The laser is typically about 1 meter from the ruler, and is on a table slightly tilted to create the shallow entry angle incident upon the ruler.
3. The ruler supports should not need adjusting. Instead, you might need to adjust the height of the laser using the large lab jack the laser is mounted upon. This controls the vertical position of the laser relative to the ruler.
4. The laser is also mounted on a horizontal fine adjust translator, so you can control its lateral position. Allow part of the laser beam to pass undeflected alongside the ruler to establish a reference point.
5. The reference point is the "straight through" path of the laser on the wall.
6. Translate the laser onto the ruler so that you can see the interference pattern.
7. Hang paper from the wall (a long narrow strip or several pages taped together) where you will record positions of the laser pattern (constructive intereference fringe positions).
8. First mark the position the laser hits the wall as a "straight through" path.
9. Next mark the position of a simple specular (mirror like) reflection upon the wall. This position is the zero order (n=0) maximum. You must find the "zeroth-order" maximum (corresponding to n = 0) located at y_o. This particular maximum is the red spot where a purely reflected beam hits the wall. Since the identification of this maximum can be confusing, it helps to momentarily slide the ruler sideways so that the laser beam reflects off a perfectly smooth portion of the ruler. Under these conditions one gets only the zeroth-order maximum (no interference); carefully mark its location on the wall, and then move the ruler back to its proper position.
10. The midpoint between the "reference point" and the "zeroth-order" maximum must lie on the plane of the ruler. All measurements of the y_n should be made from this midpoint. THIS IS NOT WHERE THE ZERO ORDER FRINGE IS LOCATED. NO NO NO!
11. We recommend that you start with y_o and not worry about the few "negative-order" maxima below it.
    a. It may or may not be possible to see negative order fringes for your setup angle.
    b. This depends in a very sensitive manner upon the initial setup angles and positions.
12. Adjust the laser beam and ruler in order to optimize the sharpness of the maxima.
    a. The laser should be reflecting off a specific set of rulings (markings on the ruler) and you must know which ones.
    b. You will need to measure the distance from the center of the laser spot on the ruler to the wall.
13. Carefully mark off the positions for fringes ordering n=0,1,2,3,…. for as many maxima as you can distinguish. When you take your paper down, you can measure the positions from the center plane y_o, y_1, y_2,….
    a. You may notice that for each order, there is a bright spot and then stripes of subsidiary bright lines. You want to mark the center of the big bright spot.
    b. In general you can ignore the secondary fringes within a single order and stick to the primary.
14. After you measure the y_n for all your data, you will need to establish a method for fitting and decide if all your data satisfies the small angle approximation.

15. I AM ONLY GOING TO HAVE YOU PERFORM THE NON LINEAR FIT. You may use Origin, Matlab, or Python, or other. I give you in my "Schawlow Ruler Discussion" notes---most of the way to solving for y^2 . Your fit should have y^2 on the vertical and n on the horizontal axis. The open ended parameter to determine MUST be the wavelength. We hypothetically know things like the wall distance, the marking spacing, and the location of "zero" (not zero order fringe). I leave it to your judgement to see if you need to fit one or several parameters.

    If you wish to also check fit with small angle approximation, you may do so---but our data goes beyond small angle, so you will need to justify carefully where to cut off (what n).

    We are not doing the underlined linear fit small angle approx. (what for), but I have left in the discussion. You may want to know how to do the small angle fit anyway—since I will ask you to do that with two data points on your "hands on lab skills".

    Using the least squared method, determine the wavelength of the laser source (with uncertainty) and compare it with its theoretical value (632.81646 nm in air). Schawlow's paper use a small angle approximation and keeps only data points adhering to a "small angle". Your data will take you further than a small angle, also the initial angle your laser hits the ruler with will determine smallness of angles. It is strongly suggested on this lab that you detail what is meant by "small angle"—and that you validate this with your data. When does making the small angle approximation introduce more error than the uncertainties in the data point measurements themselves? Answering that last question should be an indicator as to when the small angle approximation is not valid. To determine an answer to "how many data points should I keep and analyze with small angle" you may need to simulate data both with and without making the small angle approximation and see how far off the results are, and compare that to your predicted uncertainty (point by point).

    a. Your data analysis ….. include a linear fit with a small number of "n" up to some max. To determine the wavelength.
    b. DO THIS HERE----Your data analysis must include a non-linear fit (I use origin, but matlab, or other are fine). You will need to cartesian up the theory and fit accordingly to determine the wavelength. NO SMALL ANGLE APPROX.

16. Repeat all the process for a different set of ruler markings. Make sure you record the markings used for each set of "dots" on your paper.
17. Make sure you measure the distance from the center of your laser spot to the wall.
18. This lab is often a "redo" on data, so be careful the first time.
19. The most important data point to find is where is y=0 (THIS IS NOT THE n=0 FRINGE). All data is measured from y=0, so if it is off, everything is off---REDO. BUMMER.