Experiment: Laser Characteristics as Observed through Diffraction and Interference of Light

Purpose: The purpose of this experiment is to learn about another property of waves called diffraction and to see the result of diffraction and interference of light. The most important conclusion we will make is that light from a laser has a single wavelength and frequency in air.

Obey all instructions regarding laser safety: you do not want to expose anyone's eye to direct light from the laser!

Stand whenever possible so that your eye level is well above the level of the laser light.

Turn off the laser when you are not using it.

The direct beam is most hazardous: always make a "block" out of poster board or heavy paper and block the laser beam before it leaves the lab table. (alternatively, use the six stations near the walls and point the laser toward the wall)

The reflected beam is less dangerous but should still be monitored. Keep track of reflections and make sure they do not shine in anyone's eye.

Introduction:

Diffraction gratings and prisms have long been used to investigate the properties of light. If light from a light bulb or from the sun is transmitted light through a prism or grating, the light is separated into its different colored components. This is a characteristic of "white" light. This light is made up of a mixture of all colors of light superimposed. This combination of light colors is inherent to the thermal method which generates the light. Various colors of light are diffracted differently by the grating and actually travels at different speeds through the glass prism creating the "rainbow" effect you observe.

In contrast a laser is a source of light that is not a combination of different colors of light. Instead, it is a single coherent light source of monochromatic light. The source of the light in a laser is a result of the discrete nature of electronic energy states in a gas or in a semiconducting material. This is schematically represented in figure 1. The electron

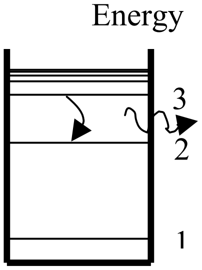


Figure 1: Schematic representation of the discrete energy levels available to an electron in an atom. As an electron transitions from energy state 3 to a lower energy state 2, it gives energy in the form of light called a photon. The wavelength of this photon is determined by the expression $\Delta E=hc/\lambda$ where h is a number equal to $6.6\text{x}10^{-34}$, c is the speed of light which is $3\text{x}10^{8}$m/s, and λ is the wavelength of the light emitted. Since all of the light generated in a laser is from transitions, it all has a single wavelength.

can only reside in an atom with discrete values or levels of energy. These energy levels are determined by the size of the atom and how many protons and other electrons exist in the atom.

We will now further investigate diffraction, the tool we will use to investigate laser light. A general schematic of light through a two-slit diffraction grating is shown in figure 2. The basic concept is that the light emerging from each slit must travel different distances to reach a projection screen, and therefore, are at different stages of their cycle, i.e. they reach their destination with different phases. This leads to interference when the two waves are superimposed. Several regions of constructive interference result in spots of light on the screen at symmetric about the initial direction of the light. We label these bright spots with an integer number 1, 2,3, etc which we represent as *m*. The criterion for constructive interference between two waves of the same wavelength λ, passing through two slits with separation *d* is the following:

$$d \sin\theta = m\lambda$$

If the distance to the viewing screen is much larger that the slit spacing, *sin θ* can be written as

$$\frac{y}{\sqrt{L^2 + y^2}},$$

where y is the distance from the center (where the light would be directed without the diffraction grating) to the bright spot. This is the same expression as is used for many slits in row such as is the case for a diffraction grating. Therefore we have a method for finding the wavelength of light or the distance between lines in a diffraction grating depending on which is known.

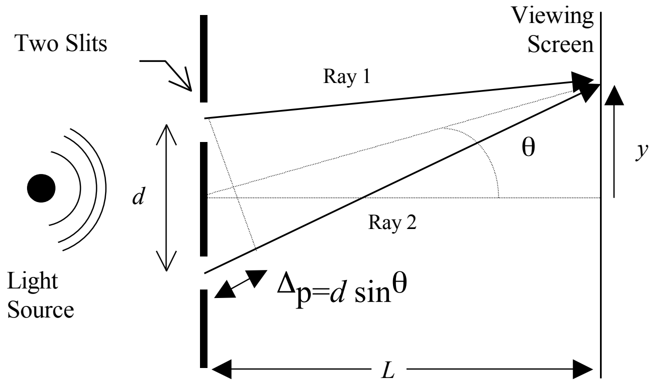
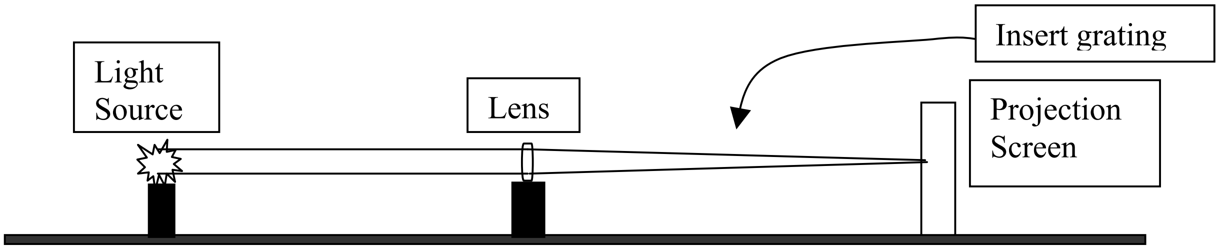


Figure 2: Interference of light from two slits. A maximum occurs when $\Delta p = m\lambda$ and a minimum when $\Delta p = (m+1/2)\lambda$, where *m*=0,1,2,…

Activity 1: Investigating the Composition of "White" Light

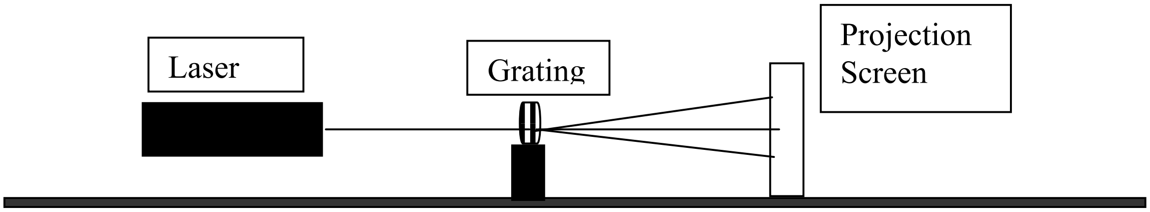
Using the optics bench, a projection screen, a white light source, a lens, and a diffraction grating, resolve white light into its components. To accomplish this focus the light coming from the source into a single line as seen on the projection screen. After accomplishing this, place the diffraction grating in the path of the light.



Describe what you observe on the projection screen. Using the expression $d \sin\theta = m\lambda$, describe the sequence of colors you observe.

Activity 2: Finding the Wavelength of Laser

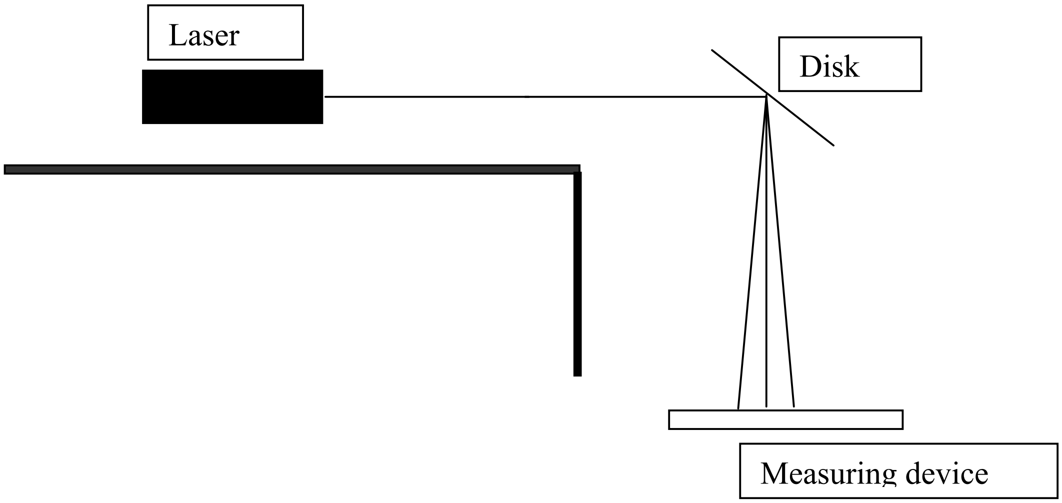
Using a diffraction grating of known line spacing and the theoretical background outlined above, determine the wavelength of a He-Ne red laser. Repeat this for a laser of green light. (Hint: You may want to clip a ruler to the projection screen to extend its width and to directly measure the positions of the points of constructive interference.



Describe what you observe on the projection screen. How is it different than in the white light experiment? Are your observations consistent with the expression $d \sin\theta = m\lambda$?

Activity 3: On the Construction of a Compact Disk

A compact disk has grooves which are used for tracking as information is read or written during the rotation of the disk. Find the spacing of this "diffraction grating". Do you get the same result for red and green light? (Hint: Lay a meter stick on the floor and reflect the laser light off the CD and project it toward the floor. Carefully measure the



separation and use this number to calculate the parameter *d* in the expression $d \sin\theta = m\lambda$.)

Repeat the above for a DVD.