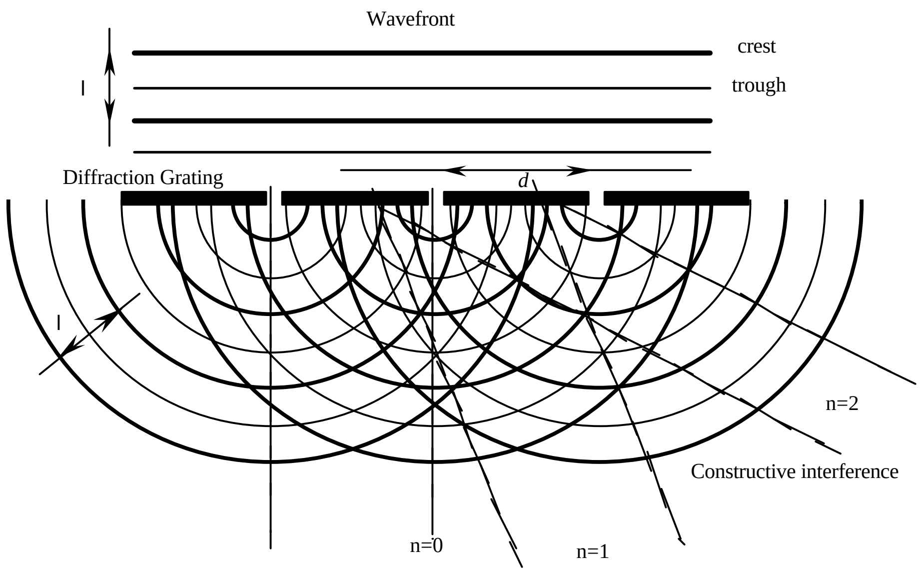
Diffraction

Introduction:

The phenomenon of *diffraction* results when a wave interacts with an object or aperture whose size is comparable to the wavelength of the wave interacting with it. Loosely speaking, the waves are bent and are capable of interacting with themselves. Today we will observe diffraction when we allow light waves to be incident on a series of apertures which are separated by a distance comparable to the wavelength of the light wave. Such a series of apertures is called a **diffraction grating**. When the wave's wavefront is incident upon the diffraction grating, parts of the wavefront are removed and each aperture serves as a virtual **source** for a new wavefront. Since each of these sources is driven by the initial wave front, all the sources are **in phase**, and the waves which emanate from the different apertures will all **interfere** with one another, creating regions of **constructive** and **destructive interference**. The following diagram illustrates the idea of a diffraction grating.



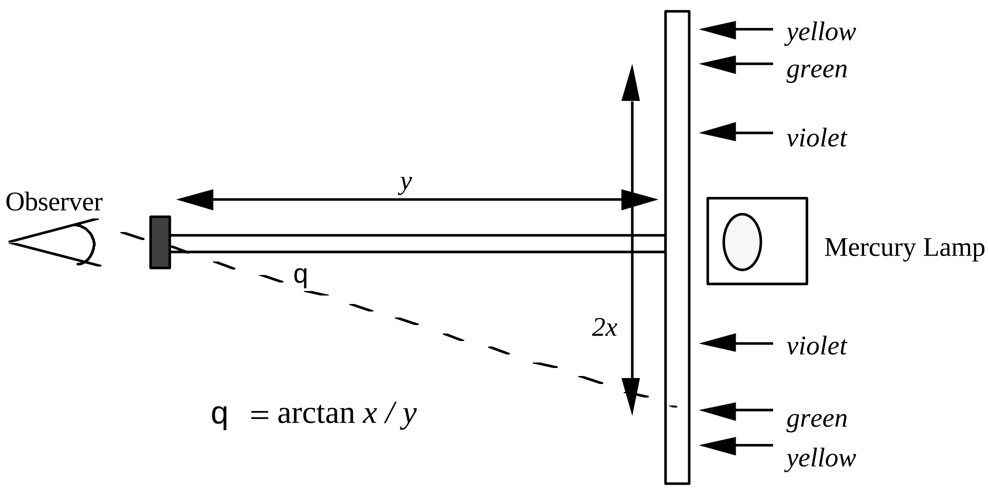
The above diagram gives a close up view of a portion of a diffraction grating. In practice, this grating will have thousands of apertures per centimeter. The dashed lines represent the directions of constructive interference. You will notice that these are the regions where the thick circles (crests) intersect with thick circles and the thin circles (troughs) intersect with thin circles. It is here that the fields of the different waves add, producing an enhanced field. In the regions of destructive interference, the fields cancel. These are the regions where thick rings (crests) intersect with thin ones (troughs), giving a total net field of zero.

If a screen is placed some distance away from the grating, one will notice that the light coming from the grating produces several spots or lines, each corresponding to a different **order** of interference or diffraction. The order is the way to describe which of the above lines is involved (n=0, n=1, n=2). In fact, for a large grating and a given wavelength of light, a mathematical relationship can be derived which relates the wavelength *(λ)*, the angle of the particular diffraction *(θ)*, the distance between two consecutive slits *(d)*, and the order of diffraction *(n)*. This is called the **diffraction** equation and is given below.

$$n\lambda = d \sin \theta$$

Due to the dependence of sin θ on the wavelength, for a given order *(n)* , the amount of diffraction will vary depending on the color of light. Generally, longer wavelengths will be diffracted more than shorter ones. This means that red light will be diffracted more than blue light. This equation is very useful experimentally. If the order of diffraction, the grating spacing *(d)*, and the angle of diffraction are known (can be measured), one can calculate the wavelength of the light diffracted. In this experiment, we will be observing the effect produced when light from a mercury lamp is passed through a diffraction grating. We will be recording the various orders and angles of diffraction for the various spectral lines (distinct colors) produced by the lamp, and we will use these along with the appropriate *d* for the diffraction grating to calculate the wavelengths of these spectral lines.

Procedure:



1. Place the meterstick flat on the table with the metric scale up. Let one end of the stick be flush with the table. Place a second meterstick on edge with the metric scale up, centered on and perpendicular to the other meterstick.

2. Insert the mercury vapor tube in the power supply. Notice how the tube is spring loaded. Place the power supply on end behind the second meterstick. The arrangement is shown in the diagram above.

3. **Caution!** The grating is a fragile photo-lithographic reproduction and should not be touched in any way. The diffraction grating is marked with a "down" side and should

be placed on the meterstick at the end of the table. The deep-recess side of the grating holder should be placed with its face away from the light source to avoid reflection of the light as it passes through the base material on which the grating is mounted. Use a piece of masking tape to secure the grating to the meterstick so that it is practically perpendicular to the rays of light from the source. The "spectrometer" is now ready for adjustments and use. The diagram illustrates the arrangement of the various components.

4. Place the eye on a level with the grating and look through it. Directly ahead, the light source should be visible. Viewing to the right should reveal at least three bright colored images of the tube. You should see the colors of violet, green, and yellow with violet closest to the center (diffracted the least). These compose the first order diffraction ($n = 1$). Looking farther to the right should reveal a second similar pattern. This is the second order diffraction ($n = 2$).

Analysis:

There may be other colors present due to contamination in the tube, but these colors are to be ignored. To find the wavelengths of the three observed colors, you will need to find the angle of diffraction of the colors. You already know the orders of the diffractions. To find the angle, measure x and y as shown in the diagram and then calculate the angle from the formula:

$$\theta = \arctan \frac{x}{y}$$

Arctan is the inverse of the tangent function and may also be written as $\tan^{-1}$. The best method of taking data is to find the distance between the diffraction line to the left and the diffraction line to the right, and taking this value as $2x$. Dividing by two will yield x. The above diagram illustrates this method.

The grating spacing *(d)* from the manufacturer is (1/6000) cm, or 1666 nm. Utilizing the order number *(n)* the grating spacing *(d)* and the diffraction angle (θ) in the diffraction equation to find the wavelengths (λ) of the different colors of the mercury spectrum. You may want to calculate the wavelengths for two different orders of diffraction and compare the values.

Caution: Units are very important in this lab! Your value for the wavelength will be in the same unit as your number for the grating spacing.

Conclusions:

1. Summarize your results for this experiment.

2. How was λ related to the angle of diffraction? How was λ related to the color of the line? Was the wavelength of a particular color different for different orders of diffraction? Why is one color diffracted more than another?
3. Would contamination in the tube affect your data? Explain.

4. What was unique about the light from the mercury tube?

Error Analysis:
What were the major sources for error in this experiment?
Calculate the actual percent errors for your wavelengths.
Actual Values:
violet: 435.9 nm 404.7 nm
green: 546.1 nm
yellow: 578.0 nm

1 nm = 10^{-9} meter 1 cm = 10^{-2} meter

Diffraction

Name:____________________Section:_________

Abstract:

Data: $d = (1/6000)$ cm = 1666 nm

Color	n	2x	x	y	θ	λ

Calculations: (Use back if necessary. Show units!)

Conclusions:

Error Analysis: (Compute actual percent errors, and describe sources of error.)