Measurement of Wavelengths of Light

Goal of this lab

- **measure the wave length of light with a diffraction grating.**

Overview

A diffraction grating of the transmission type consists of a thin plate of transparent material on which are ruled many closely-spaced parallel lines. This arrangement may be very roughly compared to a sheet of metal with many parallel slits cut in it through which light may pass. When a parallel beam of monochromatic light (light of a single wave length or, roughly, a single color) is incident upon a diffraction grating, part of the light passes straight through the grating (in the direction of the incident light) and part of the light is *diffracted* by the grating into different propagation directions.

The situation is illustrated in the figure below. A parallel beam of monochromatic light strikes the grating at normal incidence from the left. The rulings are very narrow (less than a wavelength) and each re-radiates the light incident on it in all directions; the fraction of the incident light propagating in a given direction is the sum of the light emitted in that direction by the many rulings.

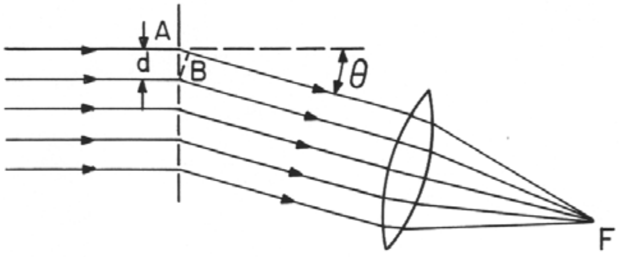

Figure 1: The Diffraction Grating

The rays emitted by the individual slits at the angle θ will all be focused by the lens at its focal point *F*. But if the light arriving at the grating from the left is in phase, then the light reaching *F* will in general not be in phase, since each ray travels a different distance from the particular ruling producing it to the focal point of the lens. The many rays will interfere constructively or destructively and the actual intensity of the light striking *F* depends upon the path differences. If the difference in path length traveled by adjacent rays is a whole number of wave lengths all of the rays will be in phase and will add constructively to produce a bright spot of light at *F*. From the figure above it can be seen that the difference between two adjacent paths is the segment $\overline{AB}$, whose size is related to the spacing between adjacent slits and the deflection angle by

$$\overline{AB} = d\sin\theta$$

Maximum light intensity will be produced at F if $\overline{AB}$ is an integral number of wave lengths:

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

The value of n is called the *order* of the diffracted beam. In general the intensity of the diffracted beam decreases as the order increases. Since the sine of an angle cannot exceed unity the order n cannot exceed d/λ

If the beam of light incident upon the grating contains a number of wavelengths (i.e, colors) each wave length will have its own angle of deviation in each order. This results in a complete spectrum of the source for each diffraction order.

In this experiment the grating is placed close to the eye and the eye lens serves to collect the light. An aperture through which light from the source may pass is mounted at S on a meter stick. A diffraction grating is placed at a distance L from the source aperture along the perpendicular to the meter stick through S. Looking through the grating you will see diffracted images of the aperture on both sides of the undiffracted image. A different set of images will be present for each color in the incident light. For a given color and order there will be two images on opposite sides and at equal distances D from the aperture, as shown in the figure. Measurements of D and L will give $\tan\theta$ from which $\sin\theta$ and λ may be computed. Although both first and second order images will be visible, we will not study the second order ones because they are not bright and are difficult to locate precisely.

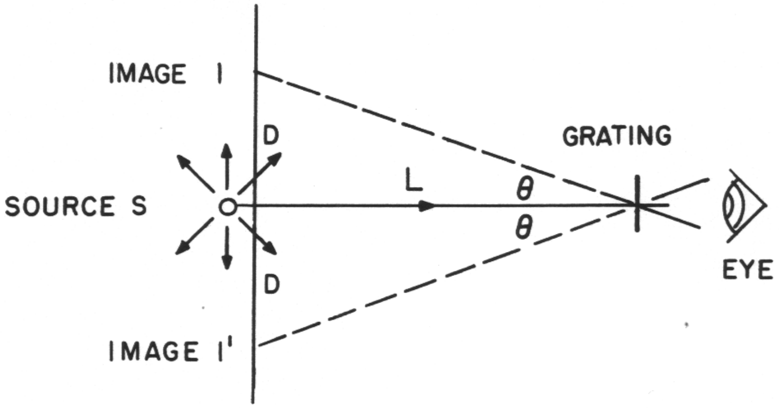

Figure 2: Basic Apparatus

Prelab Question 1: Due to its ability to store a large amount of information easily, the compact disc (CD) has become a very common object. The digital information is stored as a series of microscopic dimples that form a spiral around the surface of the CD. The spiral is so tight that if the radius of the CD were 1 meter, there would be 6.25×10^5 lines crossing it. The CD is smaller than a meter, but we still describe the line density as 6.25×10^5 lines/meter. You will find a number like this on the diffraction grating in the lab.

(a) It will be necessary to convert the number of lines per meter to "d", the distance separating any two lines from each other. Practice this by determining "d" for the CD using the line density given above.

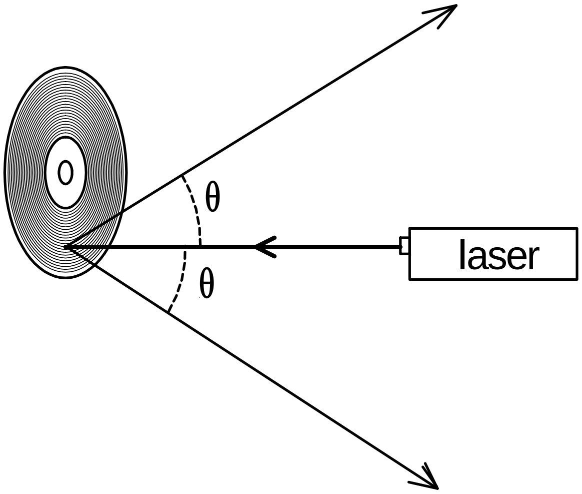

Figure Prelab 1

(b) A laser is aimed at the bottom of a CD, and strikes it at the "6 o'clock" position on the round face, as shown above. Because a CD has a reflective surface behind the spiral track, the diffraction pattern that we might expect to see on the opposite side of the light source is reflected back to the same side as the light source. Other than this exception, a reflecting grating (like a CD) follows the same rules as a transmission (clear) grating, like the one you will use in the lab. If the diffracted beams from the laser go off at $\theta = 24.8°$, what is the wavelength of the laser?

Prelab Question 2: Although they look like CDs, DVDs can hold nearly 7 times as much data. This is done with a combination of smaller dimples and a tighter spiral track. The line density of a DVD is 1.35×10^6 lines/meter. How could you use this information and a laser pointer to help your frantic younger sister find her DVD of Britney Spears' movie <u>Crossroads</u> which has been lost in a stack of Britney's audio CDs? (Of course they have all been used so much that the labels are worn off.)

Description of the Light Sources

The light source consists of a sliding holder with different discharge tubes that can be positioned to place any of the tubes behind the aperture. The power supply and Variac (used to adjust the voltage) are separate units wired to the discharge tubes. A push button on the Variac box completes the circuit and causes the connected tube to light. Each tube is labeled with its chemical symbol.

To change from one discharge tube to another,

1. turn the Variac down to zero
2. move the high voltage plug on the back of the source to connect the desired tube
3. press the push button and turn the Variac knob clockwise until the tube glows steadily.

Procedure

1) Verify that the slotted meter stick is in the clamps on the framework around the light source. The stick should be positioned so that its mid-point (50 cm mark) is exactly aligned with the light source to facilitate your measurement.

2) Adjust the height of the grating so that it is at the same height as the aperture. The flat side of the grating holder must face the light source aperture. Position the grating at a perpendicular distance of about 1 meter from the aperture, and measure (using a regular meter stick) and record the perpendicular distance L between the grating and the nearest surface of the slotted-meter stick.

3) Turn off the room lights. Connect and turn on the He source (pink). Look through the grating for images of the light source in the different colors emitted by the source. For each color a line will appear on each side of the actual aperture. The sets of lines may repeat on each side; this is a higher order (n=2) of diffraction which we do not use in this experiment. Rotate the grating until two lines of a given color are equidistant (within one-half cm) from the center of the meter stick.

4) For each color you observe measure and record the position of the image on both sides of the light source. The separation is $2D$, as illustrated in **Figure 2**. Estimate the uncertainty in D. If the distances on the two sides are not nearly the same (within 0.5 cm) the alignment of the grating must be adjusted. When determining the position of the images it is important that you keep your head in a single, fixed position as you view the images.

5) Repeat the above with the mercury source (blue-green). Also measure the separation of the two yellow lines if they are resolved in your apparatus.

6) For neon (red) just observe the spectrum on both sides of the aperture.

7) Record the number N of grating lines per meter as marked on the grating.

Analysis

1. For each color observed compute sinθ (and its uncertainty), and then λ and its uncertainty. Compare the values of λ with those in the table below. Within the uncertainty of your measurements, your results and the values in the table should agree.

2. What is the effect on the spectrum of increasing the number of grating lines per inch?

Table of Wavelengths

Mercury		**Helium**	
Color	**Wavelength (x10^{-10} m)**	**Color**	**Wavelength (x10^{-10} m)**
Yellow	5791	Red	7065
Yellow	5770	Red	6678
Green	5461	Yellow	5876
Blue-Green(Weak)	4916	Green	5047
Blue-Violet	4358	Blue-Green	4922
Violet(Weak)	4078	Blue	4713
Violet	4047	Blue-Violet	4471

The Balmer Series

Note: This experiment is a relatively simple measurement of the spectral lines of the Balmer Series of hydrogen. It is intended as an optional addendum to the experiment **Measurements of the Wavelengths of Light**.

Goals of this lab

- **use the diffraction grating to study the Balmer series of hydrogen**
- **measure the Rydberg constant.**

Overview

In 1885, a Swiss school teacher, Johann Balmer, published an empirical equation which predicted, within the limits of experimental error, the wavelengths of the known hydrogen lines. Balmer's equation is:

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \quad \text{where } n = 3,4,5,\ldots \qquad (1)$$

and R is an empirical constant. One might suspect that other sequences of spectral lines could be found which would correspond to wavelengths predicted by a generalized form of the above equation:

$$\frac{1}{\lambda} = R\left(\frac{1}{m^2} - \frac{1}{n^2}\right) \quad \text{where } n,m = 1, 2, 3, \ldots \qquad (2)$$

and investigations in the far ultraviolet and infrared regions confirm this suggestion. The constant R (known as the Rydberg constant) is

$$R = 1096.78 \text{ x } 10^4 \text{ m}^{-1}$$

The important point that Balmer established empirically was that the inverse wavelength, $1/\lambda$, of each spectral line could be expressed as the *difference* between two terms. However, many years were to elapse before the significance of Balmer's result was completely appreciated. In 1913 Niels Bohr carried the understanding of the spectrum of atomic hydrogen a step further. From his theory he was able to derive Equation (2) and to express the Rydberg constant in terms of other fundamental constants.

Procedure

Follow the procedure of **Measurement of Wavelengths of Light**. Connect the hydrogen tube and place it behind the source aperture. The spectrum will not be as "clean" as those for helium and mercury, but three distinct lines should be observable. Repeat step 3 of **Measurement of Wavelengths of Light**.

Analysis

Calculate the wavelength for each color you observe. Be sure to use the distance from the *slit* to the grating in making your calculation. Do you know why it is this distance (and not the distance from the source) that is important?

Plot the reciprocal of the wavelength as a function of the square of the reciprocal of the appropriate integer for each color. In principle you should experiment with different integers to find the right set. However, since it took Balmer a while to find them, we'll spoil the game by suggesting you use 3 for red, 4 for blue-green, and 5 for blue-violet.

The slope of the graph should be the Rydberg constant *R*, while the "y" intercept $n = \infty$ should be $R/4$. Compare the value of *R* you obtain from your graph (and its associated error) with the accepted value.