PHY 252 Fall 2010 Practical Lab 2
The Diffraction Grating

OBJECTIVES:

1) Observe the interference pattern produced when laser light passes through multiple-slit grating (a diffraction grating).

2) Graphically verify the wavelength of the laser light using the data collected from the interference pattern produced when the light passes through a diffraction grating.

CAUTION!

The laser is a device that can produce an intense, narrow beam of light at one wavelength. <u>NEVER</u> look directly into the laser beam or its reflection from a mirror, etc.

<u>INTRODUCTION</u>

Interference occurs when two or more coherent waves overlap. (Coherent means that the waves have a fixed phase relationship.) Constructive interference takes place at certain locations where two waves are in phase (for example, both waves have maximum). Destructive interference takes place where two waves are out of phase (for example, one wave has maximum, the other has minimum).

The simplest interference patterns involve plane waves (collimated or parallel light beams). In this experiment, we will use a laser as our light source.   A laser produces collimated and coherent light beams at one wavelength.

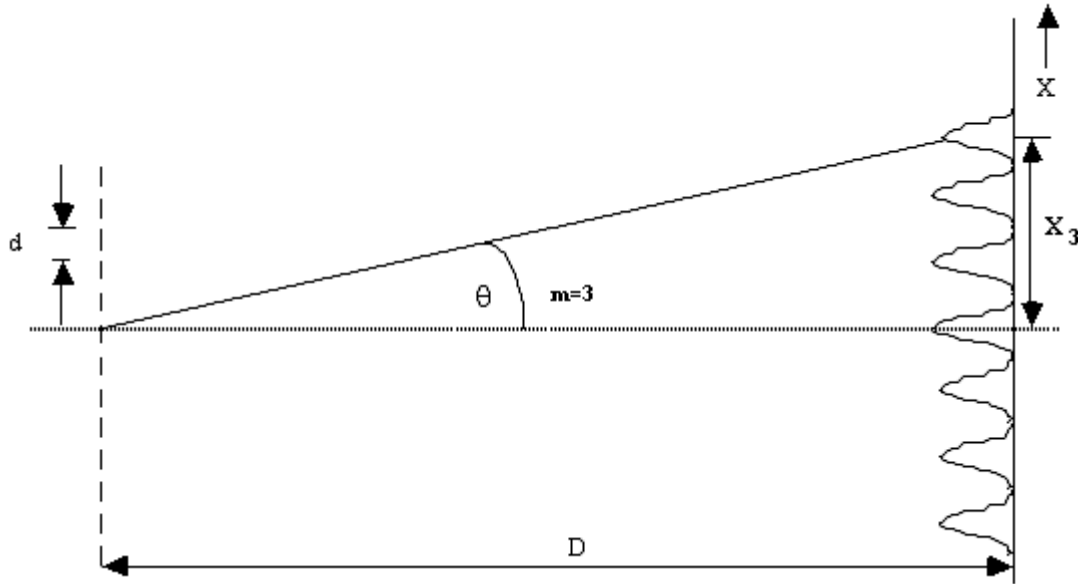Multiple-slit interference (a diffraction grating)

Figure 1: Intensity distribution of a diffraction grating

Although a multi-slit grating is commonly referred to as a diffraction grating, a more appropriate name for it is an interference grating. The phenomenon that is observed is interference and not as its name suggests diffraction. The condition here for interference maximum is the same as for double-slits, but the pattern may be very different because d (the slit spacing) for gratings is very small.

$$d \sin \theta_m = m\lambda$$

or

$$\sin \theta = \frac{m\lambda}{d} \qquad (1)$$

If a graph of $\sin \theta_m$ vs. m is constructed, it has the form of a straight line with m playing the role of x and $\sin \theta_m$ playing the role of y. The line should have an intercept of zero and a slope of $\frac{\lambda}{d}$. Note: $\frac{1}{d}$ is the ruling density which will be given in lines/mm. Using the slope of the line and the ruling density, the wavelength of the laser light can be calculated.

The angles involved when using the diffraction grating are large; therefore you cannot use the small angle approximation here. In Figure 1 above, $\sin\theta$ (for m = 3) is expressed as the ratio of the opposite side of the right triangle (x_3) to the hypotenuse of the right triangle $\left(\sqrt{D^2 + x_3^2}\right)$. The distances x_m are measured from the location of the central maximum, x_0. Equation 1 can be expressed as:

$$\frac{x}{\sqrt{D^2 + x^2}} = \frac{m\lambda}{d} \qquad (2)$$

The distances x_m are positive for positive values of m and are negative for negative values of m. The order of the maxima can take on the values of m=0, ±1, ±2, …

PROCEDURE

The wavelength (λ) of the green diode laser used in this experiment is $532 \pm 10\,nm = (5.32 \pm .10) \times 10^{-4}\,mm$. The screen to diffraction grating distance D and the ruling density $\frac{1}{d}$ you will use will be given to your answer sheet of the practical lab.

1. Place the grating in the laser beam at the distance D specified on your answer sheet in front of the screen and record this distance in your Excel spreadsheet.
2. Record the labeled ruling density (grooves/mm) in your Excel spreadsheet.
3. Tape a piece of paper across the screen. Mark carefully the positions of the principal maximum and the <u>interference maxima</u>. You should mark and record the location of the central maximum, both first order maxima and both second order maxima. Remove the paper from the screen and attach it to your lab report.
4. Measure the distance of each interference maximum from the principal maximum (x_m) and record them in your Excel spreadsheet. Have Excel calculate $\left(\sqrt{D^2 + x_m^2}\right)$ and $\sin\theta = \dfrac{x_m}{\sqrt{D^2 + x_m^2}}$ for each of the maxima.
5. Transfer your data table into Kaleidagraph and make a plot of $\sin\theta_m$ vs. m. Fit your plot with a best-fit line and have Kaleidagraph display the equation of the line along with the uncertainties in the slope and intercept.

QUESTIONS
1. Sketch the pattern you observed when the laser light passed through a diffraction grating (i.e. attach the piece of paper from your screen). Label each of the interference maxima.
2. What is the slope of your graph?

3. From the slope of your graph and the ruling density, calculate the wavelength of the laser light and its uncertainty (show calculations). $\delta\lambda = \lambda\left(\dfrac{\delta\,slope}{slope} + \dfrac{\delta\left(\frac{1}{d}\right)}{\left(\frac{1}{d}\right)}\right)$

4. Discuss the consistency of your measured value of the wavelength from question 3 with the accepted value of $532 \pm 10\,nm$.

5. If the grating density, $\dfrac{1}{d}$ were halved what would be the highest possible order of the resulting interference maxima?

Comparing Data

It is often necessary to compare two different pieces of data or results of two different calculations and determine if they are compatible (or consistent). **In just about every experiment in this course you will be asked if two quantities are compatible or consistent.** The following describes how to determine if two pieces of data are consistent (or compatible). Use this procedure to answer the question at the end and use it as a reference whenever you are asked if two pieces of data are compatible or consistent. Let's denote the pieces of data by d_1 and d_2. If $d_1 = d_2$ or $d_1 - d_2 = 0$, clearly they are compatible. We often use Δ (pronounced "Delta") to denote the difference between two quantities:

$$\Delta = d_1 - d_2 \tag{8}$$

This comparison must take into account the uncertainties in the observation of both measurements. The data values are $d_1 \pm \delta d_1$ and $d_2 \pm \delta d_2$. To perform the comparison, we need to find $\delta\Delta$. The addition/subtraction rule for uncertainties is:

$$\delta\Delta = \delta d_1 + \delta\,d_2 \tag{9}$$

Our comparison becomes, "is zero within the uncertainty of the difference Δ?" This is the same thing as asking if:

$$|\Delta| \leq \delta\Delta \tag{10}$$

Equation (9) and (10) express in algebra the statement "d_1 and d_2 are compatible if their error bars touch or overlap." The combined length of the error bars is given by (9). $|\Delta|$ is the separation of d_1 and d_2. The error bars will overlap if d_1 and d_2 are separated by less than the combined length of their error bars, which is what (10) says. Sometimes rather than a second measured value you are comparing your data to an expected value. If this is the case, replace $d_2 \pm \delta d_2$ with $e \pm \delta e$, where $e \pm \delta e$ is the expected value including its uncertainty.

Excel Commands

Operation or Function	Mathematical description	Excel command
Addition	11 + 12	=11 + 12
Subtraction	29 - 21	=29 – 21
Multiplication	30×15	=30 * 15
Division	44/12	=44/22
Example	$3 + \dfrac{4}{5 \times 2} - 3 \times 7$	=3 + 4/(5*2) – (3*7)
Square root	$\sqrt{5}$ or $\sqrt{7 \times (5/3)}$	=sqrt(5) or =sqrt(7*5/3)
Power	6^3 or $7^{0.5}$	=6^3 or 7^(0.5)
Pi	π	=pi()
Sum of numbers	$\sum a_i$	=sum(a_i) where a_i can be a list of cells
Examples	A1+A2+A3+A4+A5	=sum(A1,A2,A3,A4,A5) or* =sum(A1:A5)
Mean value	$\dfrac{A1 + A2 + A3 + A4 + A5}{5}$	=average(A1:A5)
Standard deviation	$\sqrt{\dfrac{\sum (x_i - \bar{x})^2}{N-1}}$	=stdev(series of cells)
Sine	Sin (x) or Sin(2 πx)	=sin(x) or =sin(2*pi()*x)
Cosine	Cosine (x)	=cos(x)

*- This second option can be used when the Excel command references cells in the same column and adjacent rows, or in the same row and adjacent columns. You can also combine methods of defining cells. For example, if you wanted to find the sum of the contents of cells B3 through B28, B32 and B40 through B100 the Excel command you would use is: =sum(B3:B28,B32,B40:B100)

Some other useful hints:
- If in doubt, use parentheses to make sure things get calculated in the right order. For example, =3+5/2 results in 5.5. But, =(3+5)/2 results in 4. In the first case, it would be better to use =3+(5/2) in Excel.
- Pushing the Ctrl + ~ keys will display the formulas for the entire spreadsheet. Pressing these two keys again reverts back to the calculated numbers.

Spreadsheet for Practical Lab:

Diffraction Grating Practical Lab

Double Slit Interference

Distance from the slit to the screen D			mm
Ruling density			mm^{-1}

order of interference m	distance from principle maximum x_m (mm)	$\sqrt{D^2 + x_m^2}$	$\sin(\theta_m) = \dfrac{x_m}{\sqrt{D^2 + x_m^2}}$
0	0		
1			
2			
-1			
-2			

slope		uncertainty		
wavelength from slope		uncertainty		mm
wavelength from slope		uncertainty		nm