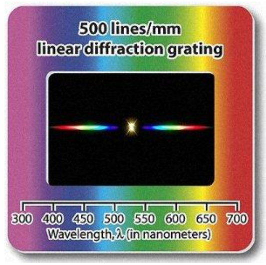
Lasers & Diffraction Grating Project
MAT 277, Spring 2018

For this project you will need the following:

- Laser pointers (at least 3 colours/wavelengths)

- Diffraction gratings (at least 3 different widths or number-of-lines-per-unit length)



- Safety glasses (sunglasses will work in a pinch)

- Yards sticks, tape measures (or other measuring device)

- A wall or screen
- Masking tape or other removable adhesive
- Marker or writing utensil

Warning!

Laser light can damage the eyes, even in reflection. Please use shaded safety glasses if staring at reflections for long periods, and DO NOT shine light into anyone's eyes.

We will be working on this project in class for one week (4 clock hours). You will need to collect all the data in that time. If necessary, you may complete the analysis at home. Students will need to break into three or four groups to collect data on each variable. If necessary, students can get necessary data from other groups to complete the assignment. You should try to collect data on at least two variables in your own group. Please don't ignore the "check with your instructor" signposts. These are there to ensure everyone is on the same page and gets good data.

A. Pick up one laser (any color) and one diffraction grating. Shine it at a wall or screen (and away from any people). Why do you think you have bright spots on the wall, but no light anywhere else? How do you think the bright spots were formed?

B. Below, draw a diagram showing your experimental set-up. Make sure you identify where the laser is, where the diffraction grating is, and where the "screen" is.

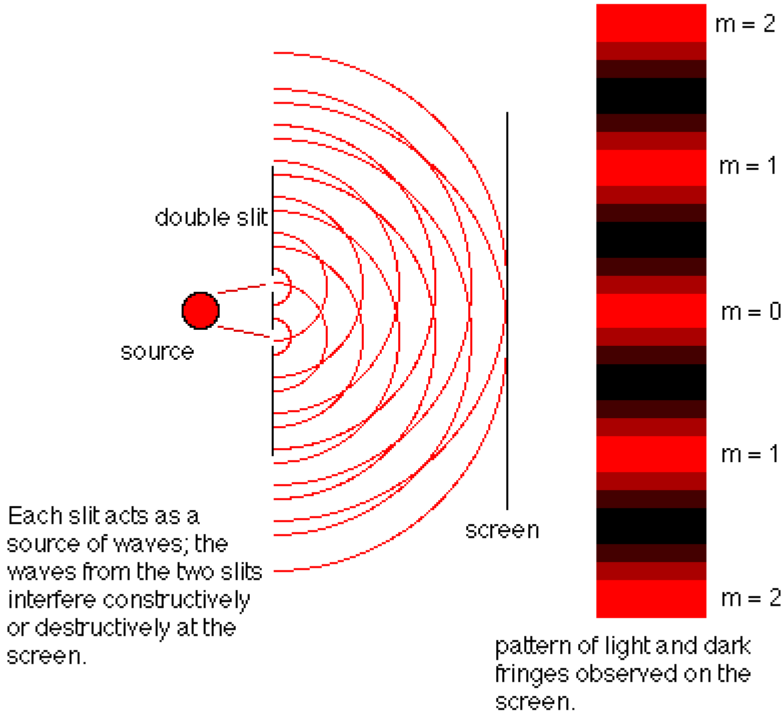
C. Experiment with the equipment and determine which variables seem to influence the pattern (the distance to bright spots and where the laser is shone) that you get on the wall. Were there any variables that did NOT affect the distance from the center to the spots? Write the variables below. Feel free to experiment with the materials available to you.

Variables that affect distance to bright spots	***Variables that do NOT affect distance to bright spots***

D. Do you think that the color of the laser would affect the distance between the center maximum and other maxima (bright spots)? Why? Use a second laser color to check your conclusion.

Check with your instructor

E. One of the variables you identified is the "grating". A diffraction grating is made by making many small slits or lines in an opaque material. When light shines on these slits, each slit then acts as a source of light waves. You will see an interference pattern with maxima (bright spots) and minima (dark areas) where light from different slits interferes constructively or destructively.



You might think that the number of lines/mm of the grating is a good variable. However, this can cause problems during data analysis. For instance, if you use "300" as a value, it is not easy to see if it is 300 slits/ mm, or 300 slits/mile. Instead of using the number of lines/slits, you will use the ***distance between the slits*** *(d).* Then this variable is just a distance, which is much easier to interpret.

F. To figure out the distance between the lines/slits, do the following: to get the distance between slits, you need to take the total distance and divide by the number of slits.

i. Observe the numbers of the diffraction gratings that you were given. For instance, one grating has 300 lines/ mm. This means that there are 300 slits cut in the distance of a millimeter. What is the distance between the slits?

ii. Change your units so that the distance between the slits is in units of meters.

iii. For each of the diffraction gratings you have, figure out the distance between the slits **in units of meters** and write below. [Note: you will use these values later in the analysis when working with the gradients.]

Number of slits	***Distance between the slits, d in meters***

Check with your instructor

G. The variables that you identified above influence the distance to bright spots (y). Design experiments to test how each of these variables affects the distance to the bright spots. Fill in the chart below to help you organize these experiments.

- Write a question about each of the variables that can be experimentally tested.
- Briefly describe the associated experiment to answer each question.
- Identify the independent variable, the dependent variable, and the controlled variables, along with the units of each.

You will have access to four different colors of lasers, as well as a penlight.

	Question	***Brief Description of Experiment***	***Independent variable & units***	***Dependent variable & units***	***Controls & units***
Experiment 1	If you change _______________ (independent variable) how does the <u>distance to bright spots</u> (dependent variable) change?	The ______________________________ (independent variable) will be varied to see how the _____________________________________ (dependent variable) changes. The ______________________and ________________________, and _______________________ will stay the same.			
Experiment 2	If you change _______________ how does the _________________________ _________________________ change?	The ______________________________ will be varied to see how the _____________________________________ changes. The _______________________and ________________________ , and _______________________will stay the same.			

	Question	***Brief Description of Experiment***	***Independent variable & units***	***Dependent variable & units***	***Controls & units***
Experiment 3	If you change				
Experiment 4 (optional)	If you change				

H. For each experiment, determine what the values of the independent variable will be and what the values of the controlled variables will be. Fill these values into the tables for each experiment below. Fill in the rest of the information that you know in the tables below, also. Check each laser for what wavelengths are written on the lasers for each color. A nanometer is 10^{-9} meters. An Ångstrom (which is often used in astronomy and spectroscopy) is 10^{-10} meters.

Laser Colour	Wavelength as reported on laser	Wavelength in meters

Check with your instructor.

I. Carry out your experiments, filling your data into the corresponding tables below.
   - Make sure all lengths or distances are in units of meters.
   - There is only one yellow laser, and limited number of gratings for particular slit sizes. Check with your instructor when you are ready for those items.

Experiment 1 *How does ______________________________ depend on _________________________________?*	
Controls and Units ____	
IV ______________________________________ ***Units*** _____________________________________	***DV*** ______________________________________ ***Units*** _____________________________________

Experiment 2 *How does ______________________________ depend on _________________________________?*	
Controls and Units ____	
IV ______________________________________ ***Units*** ____________________________________	***DV*** ______________________________________ ***Units*** ____________________________________

Experiment 3 *How does ______________________________ depend on _________________________________?*	
Controls and Units ____	
IV ______________________________________ ***Units*** ____________________________________	***DV*** ______________________________________ ***Units*** ____________________________________

Experiment 4 (Optional) *How does* ______________________________ *depend on* _________________________________*?*	
Controls and Units ____	
IV ____ ***Units*** ____	***DV*** ____ ***Units*** ____

Check with your instructor

J. Develop mathematical models for each experiment that describe the relationship between each independent variable and the distance to the bright spots. Include
- brief statement of what the experiment tested;
- a plot of the data and the best-fit regression equation, making sure to label the axes;
- the regression equation you found and reasons why it is the best-fit; be sure to consider long-run behavior, least # of variables, as well as correlation (closer to 1 is better);
- a verbal description of how the distance to the bright spots changed when the independent variable of the experiment changed.

K. To obtain a regression equation, follow these steps. (Handouts for the calculator steps are available.)

1. Enter data into the calculator by typing STAT and selecting **Edit**. Put the independent variable in **L1** and the dependent variable in **L2** (for the first data set, but you may want to use other lists for the next set of graphs so you still keep all the data).

   When finished entering data, 2nd MODE is the **Quit** function to escape back to the main screen.

2. To draw a scatterplot of the data, select 2nd Y= to enter **StatPlot**. To turn on **Plot1**, select it. Highlight **ON** and select it. Select the scatterplot option. Select the sources for your data (L1, L2, or whatever is appropriate). When all the fields are

completed, press ZOOM 9 for **ZoomStat** to automatically reset the axes to match your data.

3. To obtain regression equations, select STAT and scroll over to **Calc** menu. Select the appropriate regression equation. Options for linear, quadratic, cubic, quartic, exponential, power, natural logarithm, logistic and sine regression equations. Each function solves for coefficients and specifies what each represents in the equation. (Linear regression is modeled in one handout.) In each case, a correlation (r) or (R^2) value should be output along with the coefficients. Record this value along with the equation. You will want to experiment with different types of equations to model the data before choosing the best one (based on correlation and end behavior.

Experiment 1 tested the affect that changing the ___________________________had on the

__________________________________, while controlling the ______________________________

and _________________________________, and _______________________________.

Regression equation type	**Regression equation obtained**	**r^2 or R^2 (4 decimal places)**

Regression Equation and why best fit

Verbal Description of how the distance to bright spots (y) changed as the independent variable was changed.

Experiment 2 tested ____

____

Regression equation type	Regression equation obtained	r^2 or R^2 (4 decimal places)

Regression Equation and why best fit

Verbal Description of how variables are related

Experiment 3 tested ____

____

Regression equation type	Regression equation obtained	r^2 or R^2 (4 decimal places)

Regression Equation and why best fit

Verbal Description of how variables are related

Experiment 4 tested ____

____

Regression equation type	Regression equation obtained	r^2 or R^2 (4 decimal places)

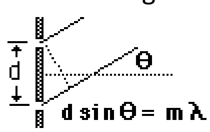
Regression Equation and why best fit

Verbal Description of how variables are related

Check with your instructor

L. You found relationships between each independent variable and the same dependent variable. You have three mathematical models describing how the dependent variable is related to each independent variable separately. However, we would like **one** math model that describes how the dependent variable depends on all of the variables (e.g. one equation involving all the variables).

First, let's use symbols that are closer to the names of the variables**-** otherwise, you have too many x's in your equations that represent different variables.

- L is distance from diffraction grating to the screen.
- λ is the wavelength, or color, of the laser.
- d is the distance between the slits of the grating
- y is the distance to the bright dots.
- θ is the angle 

- m is the order of the bright spot (the central one is 0, and then m=1, 2, 3… as you move away from the center)

Below, re-write each of your regression equations using these symbols.

M. To develop one equation with all the variables, think about doing several changes in a row to your experimental set-up and how the distance to bright spots would change after each. Then, figure out how the distance to the bright spots would change overall.

- Suppose you doubled the distance to the screen, then doubled the wavelength, then doubled the distance between the slits. For each change, how would the distance y to the bright dots change?
    - if you double the distance to the screen, the distance y to bright spots would

______________ because y and L are ___________________ to each other.

- If you double the wavelength λ, the distance y to the bright spots would

______________ because y and λ are ___________________ to each other.

- If you double the distance between slits d, the distance y to the bright spots would

______________ because y and d are ___________________________________ to each other.

- If you double the angle θ, the distance y to the bright spots would

______________ because y and θ are ___________________________________ to each other.

- If you double the order m, the distance y to the bright spots would

______________ because y and m are ___________________________________ to each other.

- Now, put all these changes together. How would distance to bright spots y change if you made all three changes to your experimental set-up? Show your reasoning.

Check with your instructor

N. Now think about making the distance to the screen L six times as big, then making the distance between the slits d four times as big, and then making the wavelength λ eight times as big.
- What would happen to the distance y to the bright spots for each change?

- What would the total change in the distance y to the bright spots be? Show your work.

O. Think about what you did above and write an equation that shows how the distance y to the bright spots depends on the other variables L, λ, θ, m and d (use only the variables you measured). Incorporate as many variables as you can. You may not need them all.

P. Check that the equation above works with the data from each experiment. You don't need to check every data point, just several in each experiment.

Check with your instructor

Q. Use your equation relating all the variables to answer the following.

i. If the distance to the screen L is halved, the wavelength λ is ¼ as big, and the distance between slits is 4 times as big, what happens to the distance to bright spots, y? Explain and show your reasoning.

ii. If the distance to the screen L is three times as big, the wavelength is one-sixth as big, and the distance between the slits is 1/12 as big, what happens to the distance y to bright spots? Explain and show your reasoning.

Check with your instructor

R. You are given a 1200 lines/ mm diffraction grating. Predict the distance to green laser bright spots if the screen is 2 meters from the grating. Explain and show your reasoning.

S. The distance to bright spots is 0.675 m when a blue laser with wavelength 450 nm is shined on a diffraction grating that is 1.5 m from a screen.
   - What is the distance between the slits of the diffraction grating?
   - What is the number of slits that the diffraction grating has in each meter? In each mm?

Check with your instructor

T. Find the linear approximation for y in terms of the remaining variables (use differentials). Suppose that you wanted to use the linear approximation at the point of the red laser at 1.5 m from the wall with 100 lines/mm to estimate where to place an infrared detector at if the grating is 140 lines/mm, placed 1.6 m from the detector and using a wavelength of 760 nanometers.

U. How similar is your estimate using the linear approximation to the "true" value obtained from the equation we found?

V. Redo your linear approximation to estimate from 1.5 m from the wall, with 800 lines/mm and a blue wavelength of 450 nanometers. Use your linear approximation to obtain where you should place an ultraviolet light detector if the wavelength of the ultraviolet laser is 320 nanometers, 830 lines/mm grating is used 1.4 m from the wall.

W. How similar is your estimate using the linear approximation to the "true" value obtained from the equation we found?

X. What do you expect would happen if you shone a white light on the diffraction grating? Use the equation we found to explain what you think you would see.

Y. Humans can see wavelengths between 390 and about 700 nanometers. What is the range of y at the distance of the length of a football field using a grating with 2000 lines/mm if our equation holds?

Z. In our diffraction gratings, the lines only go in one direction, but one can find gratings that are bidirectional (horizontal and vertical lines, for instance). Based on what you've seen, describe the results you'd expect to see from a bidirectional gradient. Could we continue to use a rectangular coordinate system, or would we need to convert to a polar system to measure the distance from the center point?