LAB 4: UNDERSTANDING DIFFRACTION GRATING

During this laboratory session, students will

✔1 manipulate discharge tubes, diffraction grating, and light source with continuous spectrum,

✔2 consider light as an electromagnetic wave,

✔3 observe and quantify interference patterns,

✔4 measure the number of lines per millimeter of a diffraction grating,

✔5 measure different wavelengths using a diffraction grating,

✔6 consult the National Institute of Standards and Technology (NIST) data online.

Student Learning Outcome: Successful students will

✔1 know how to analyze an interference pattern in order to extract different physical quantities such as wavelength and slits parameters from it,

✔2 find out that a color element (blue, for example) corresponds to a range of wavelengths,

✔3 ultimately understand the difference between unicolor and multicolor,

✔4 get acquainted with discrete spectra and continuous spectra.

INTRODUCTION

Diffraction grating is a thin transparent object, usually a macromolecule, that has a certain number of lines per millimeter as if it was scratched (French verb “grater” means to scratch). These lines are opaque, that is to say, light cannot get straight through them, and can be parallel and equidistant to each other as well. Diffraction is a word that is used to describe the ability of light waves to avoid obstacles by taking a detour. According to the Huygens–Fresnel principle, which states that any point of the front of a wave (including light wave) is by itself a new source of wave, each line of the grating system acts as a light source bearing similar characteristics as the first incoming light wave. Therefore, the grating system creates new light sources that will interfere. Skipping all details that you should see in the lecture, let us just say that the successions of bright and dark fringes follow the same rules as for the double-slit interference:

$$d * \sin(\theta) = m * \lambda$$

where, d is the distance between two consecutive lines, λ the wavelength, θ the angle relative to the original incoming light, and “m” is the order of interference. For the entirety of this lab, $m = 1$.

We will use a diffraction grating that is expected to have 1,000 parallel and equidistant lines per millimeter. Therefore, the expected value of d is (1/1,000) mm = 1,000 nm. The lab will have three distinct activities: the first one consists of measuring *d* and the number of lines/mm, the second involves the analysis of He I line spectrum, and the last is looking at the continuous spectrum of your cell phone flashlight.

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General step-by-step instructions on the use of the discharge tube power supply

1. Before plugging anything, make sure that the power supply is off (see the following figure).

The discharge tube power supply is safe if handled correctly. The instruction is simple and easy to follow. Yet, beware that these power supplies use high voltage (up to 5,000 V) and run electric currents that are high enough to cause death. Before plugging anything, make sure that the switch of the power supply is in its off position.

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2. Notice that the power supply has two nozzles that can host the ends of the discharge tubes. Inside each nozzle, a spring ensures the stability of the tube and the electric contact between the power supply and the tube. Open carefully the box that contains the mercury tube—avoid shaking it. Insert carefully one end of the tube into the lower nozzle—which end you insert does not matter (see the following figure).

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3. Push the tube gently and deep enough into the lower nozzle so that the other end of the tube clears the opening of the upper nozzle. Release the

tube slowly; you should feel the springs at work. The spring will not fasten the tube, yet you will notice that the tube is secured in and by the nozzles (see the following figure).

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4. Slide the diffraction grating into its holder, which is a homemade slit on the PASCO lens holder. Put the lens holder slit into the optical bench—it should just latch in. Set up the power supply, tube, meter stick, optical bench, and diffraction grating according to the following figure. Then turn on the power supply switch.

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Activity #1: Measuring *d* with the mercury I lines

1. Put one of your eyes close to the diffraction grating and look sidewise to the right. You should see spectral lines similar to the ones in the following

figure. Then list out the colors of the lines that you see.

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2. Now look to the left, then list out again the colors of the lines that you see. You should be able to see a list of the lines in the following figure.

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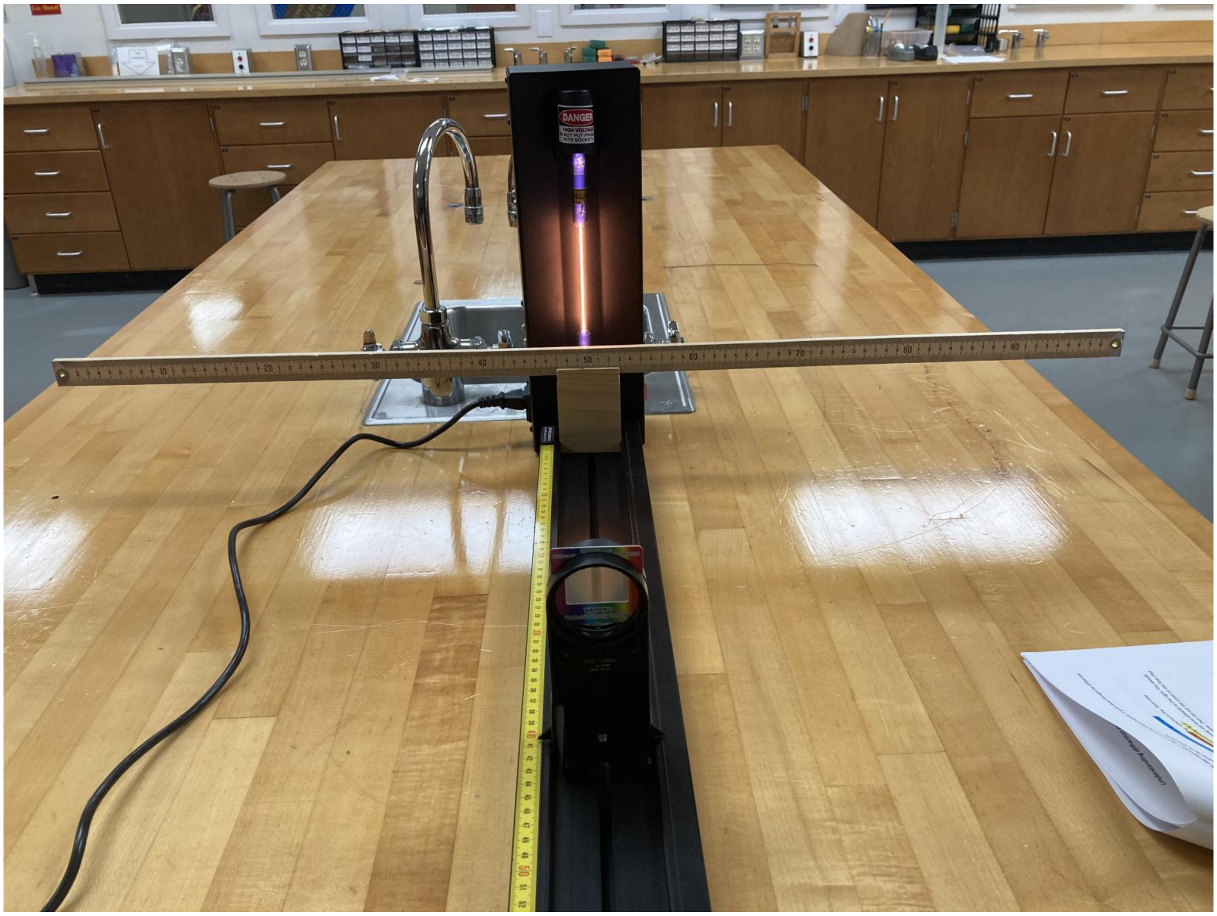
3. Compare the two lists you got from the right and left views in steps #1 and #2. They should be the same, but if not, look again at the line spectrum because some lines might be really faint. It is worth that each lab partner views the lines and the lists. Let your lab partner know if you are color blind.
4. Identify the corresponding wavelength of each color using your answers to preliminary works #2 and #3.
5. For each color (or line), measure the distance between its position on the left side and its position on the right using the meter stick. That distance divided by two is the side opposite of the right triangle defining θ. The side adjacent is the distance from the meter stick to the diffraction grating. It might be convenient to create an Excel spreadsheet, in which the first column is the wavelength (see question #4), then the distance, followed by tan(θ). The last column should be sin(θ)
6. Turn off the power supply then start analyzing your chart. Use LINEST FIT in

Excel to analyze your data and extract “*d*,” which should be the slope. You may watch **Using LINEST in Excel (https://www.youtube.com/watch?v=6wbcPbYbq6M)** or **How to use Linest Function in Excel || Linest Formula (https://www.youtube.com/watch?v=ZxfvWJpb8lU)** if you need help with the LINEST FIT. Do not forget to report your results in your conclusion.

Activity #2: Retrieving the strong helium I lines

1. The purpose of this activity is to measure the wavelengths of He I using the value of *d* measured in the previous activity. Use the NIST data as known values in order to evaluate the errors. Basically, you will have to repeat most of the operations you did in activity #1.
2. Remove the Hg tube after it had time to cool down to the point your fingers are comfortable with its temperature. Then replace it with the helium tube. Follow the same steps #2 and #3 in the “step-by-step instructions.” Then turn on the power supply. A quick look at the diffraction grating and helium lamp should be like the following figure.



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3. Put one of your eyes close to the diffraction grating and look sidewise to the right. You should see spectral lines similar to the ones in the following figure. Then list out the colors of the lines that you see.

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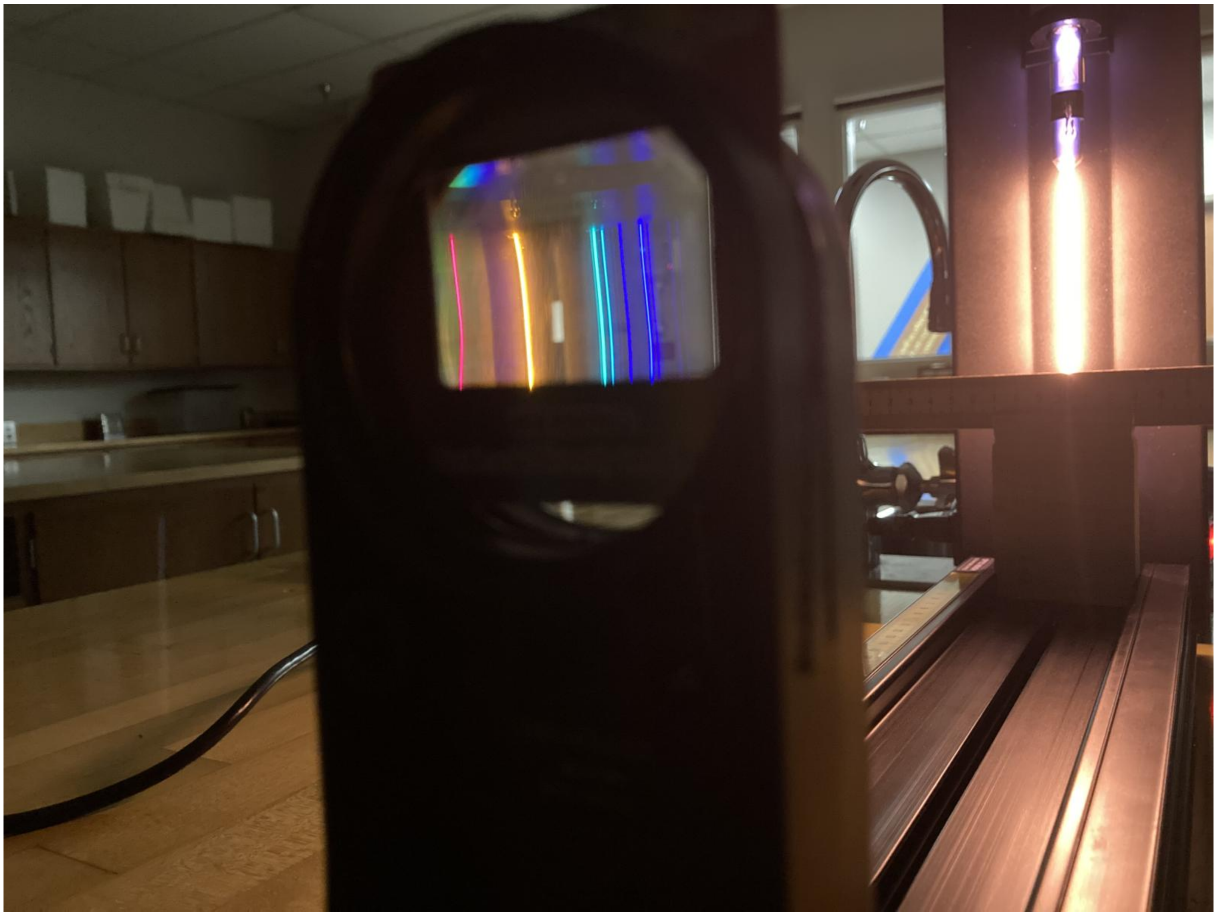
4. Now look to the left, then list out again the colors of the lines that you see. You should be able to see at least the lines in the following figure.



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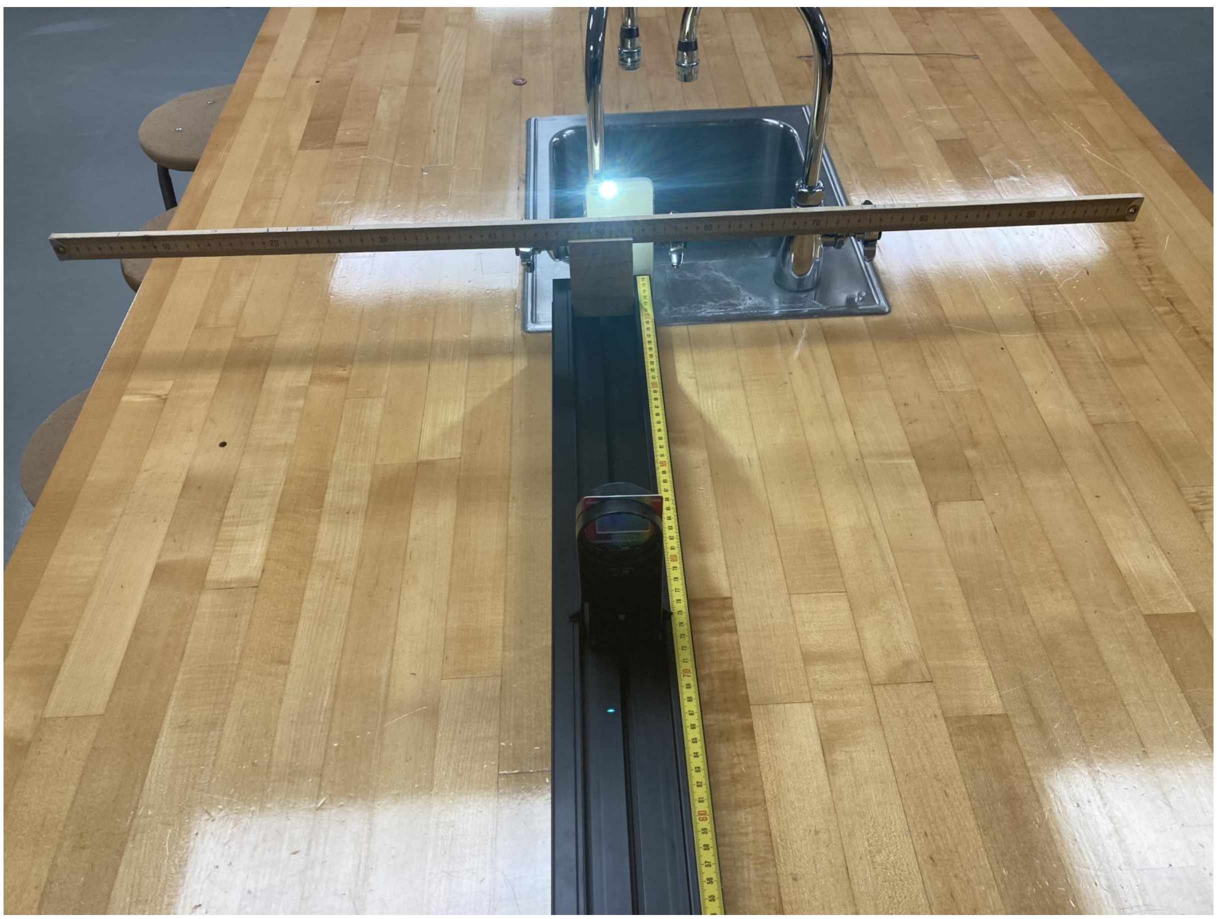
5. Compare the two lists you got from the right and left views in steps #3 and #4. They should be the same, but if not, look again at the line spectrum because some lines might be really faint. It is worth that each lab partner views the lines and the lists.
6. Identify the corresponding wavelength of each color using your answers to preliminary works #4 and #5.
7. For each color (or line), measure the distance between its position on the left side and its position on the right using the meter stick. Once again, that distance divided by two is the side opposite of the right triangle defining θ. The side adjacent is the distance from the meter stick to the diffraction grating. Suggestion: create another Excel spreadsheet, in which the first column is the distance, then tan(θ) followed by θ and sin(θ). The last three columns should be the measured value of wavelength ($d * \sin(\theta) = \lambda$), the known value of wavelength from NIST (see step #6), and the percentage error on the measured wavelength.

8. Turn off the power supply, move it out of the way, and lay it down in a safe place. Avoid attempting to remove the discharge tube from the power supply nozzles because it might still be really hot.

Activity #3: Analyzing continuum spectrum from your cell phone flashlight

1. Place your cell phone where the power supply was according to the following figure.



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2. Turn on your flashlight, then look left and right as you did in the previous

activities. The right-side view should be similar to the following figure.

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3. Using the same technique as in the previous activities, determine the wavelengths that define the border of each elementary color. Report your results in a chart. Discuss whether these values are correct or not using the previous activity results (consistency, discrepancy, etc.).