GRATING SPECTROMETER

IDEA TO REMEMBER!

Each element has its own spectral fingerprint!

OBJECTIVE:

Understand how the wavelength of light is measured using the interference pattern from a grating spectrometer.

MATERIALS:

Spectroscope

Diffraction grating

Hydrogen tube

Helium tube

Spectral lamp

Flashlight

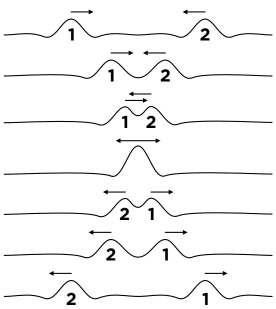
Gloves

CONCEPT:

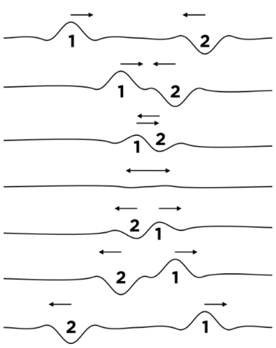
Have you noticed the common thread?… ***Waves!*** This is the big idea of everything we have been learning in this course. Waves are simple harmonic motions with a constant, periodic oscillation. Waves are exchanging energies with an amplitude, frequency, and equilibrium; <u>they are not physical objects but are still a phenomenon of motion</u> (see FUN FACT). Refraction, diffraction, and interference phenomena characterize both mechanical and electromagnetic waves. Every idea this semester has built our understanding of what waves are. We encourage you to go back and look at the *Real World Applications* sections of each lab manual as a springboard to dive deeper into the foundations! In this lab we will think about diffraction with *polychromatic* light.

FUN FACT: The Universe (that word meaning "many in one") consists as 3-in-1: **time**, **space**, and **matter**. With Einstein's theory of relativity, it can be proved that *nothing* inside the Universe can exist without each component… By their governing laws each component can also be seen as 3-in-1: time as past, proceeding from future, through the present; space as length, width, and height; and matter as energy, manifesting motion, manifesting phenomena—light, sound, scent, heat, hardness, pressure, weather, etc.

THINK: How does interference work? Do the waves collide with each other? How do two or more waves occupy the same space at the same time?



(a) *Progression of constructive interference, starting at top*



(b) *Progression of destructive interference, starting at top*

Figure 1

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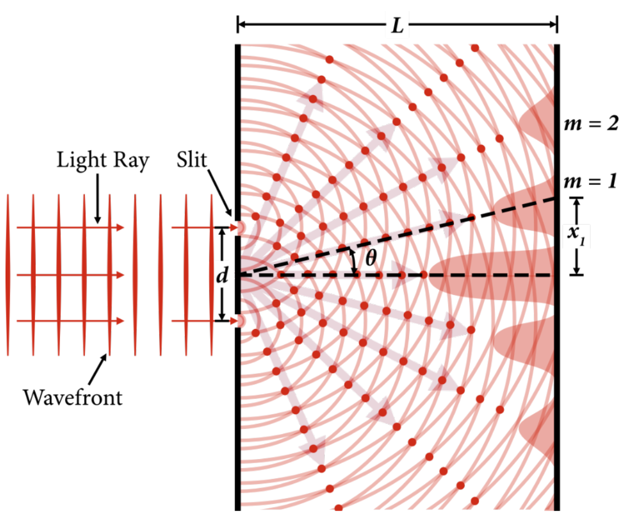
Recall the **principle of superposition**, which indicates that <u>waves travel as if other waves were not present</u>; since waves are not really "objects" they do not collide with each other but they do interfere with one another. When two or more waves occupy the same place their amplitudes combine—<u>yet their energies are not destroyed</u>—and the waves continue to travel. Figure (1) visualizes the wave displacement aspect of superposition ([this video]) displays the concept in action).

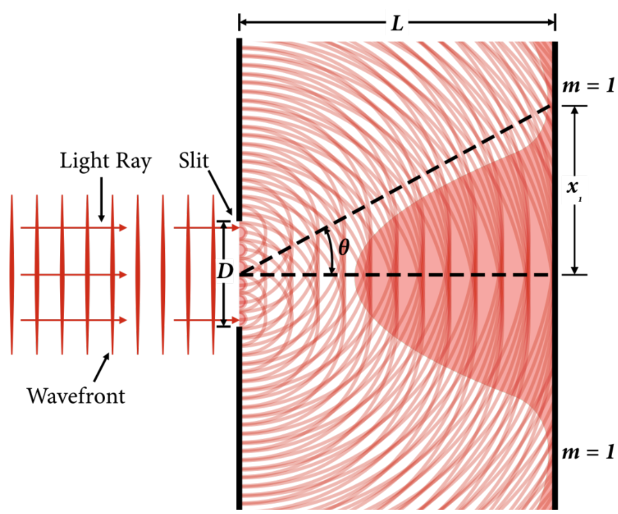
Superposition helps us understand the interference pattern against a screen for *monochromatic* light sources through two small slits, as shown in Figure (2a). Furthermore, think of each wavefront divided into an infinite number of "wavelets" with the same wavelength (frequency), according to Huygen's principle of waves. Figure (2b) shows this concept, called **diffraction**, through a single slit. Consider the interference patterns from both slits.

When we introduce *polychromatic* light, meaning that it is made of several wavelengths, we see that the effect is compounded. A prismatic separation of wavelengths occurs in the pattern! See Figure (3). This effect is most visible with a double slit apparatus and sunlight (see the video in the *Real World Applications*), but we will explore this with discharge tubes with specific emission frequencies.

A **diffraction grating** is a device with a large number of parallel slits. When a *polychromatic* light source is incident (perpendicular) to a diffraction grating, <u>each slit acts as a new light source</u>, and each wavelength of the light source can be observed as a bright fringe (line) at a particular angle. However, in any direction other than straight ahead, each wavelength has to travel an additional distance, which differs from each adjacent slit-source traveling in the same direction (see Figure 3); thus <u>each beam arrives at a different time</u>. <u>**If this time is exactly equal to the time for one full vibration or**</u>



(a) *double slit*



(b) *single slit*

Figure 2

<u>some multiple thereof, the waves are completely in phase</u>. In other words, the longer the wavelength, the bigger the angle needed for constructive interference.

Since we know the diffraction grating density (slits/mm), we can find the space between the slits d (mm). Then we can solve for the wavelength λ (nm) for each first order maxima/fringe $m = 1$ after we find the angle θ from a spectrometer:

$$m\lambda = d sin\theta \quad (1)$$

THINK: How does the interference pattern change when the number of slits increases, like in a diffraction grating?

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Increasing the number of slits increases the number of secondary sources of light, which translates to an increased number of interferences. So, what does that look like? When more light waves interfere constructively, <u>the resultant wave has an amplitude equal to the sum of all the waves</u>. So, while the overall light does increase, the maximas become dimmer/sharper and spread out; this is why we will see mostly darkness and thin color lines, see Figure (4). Plus, our view "zooms in" as the slit distance grows closer together with higher grating densities.

THINK: Can you explain why? Hint: See Figure (3) again.

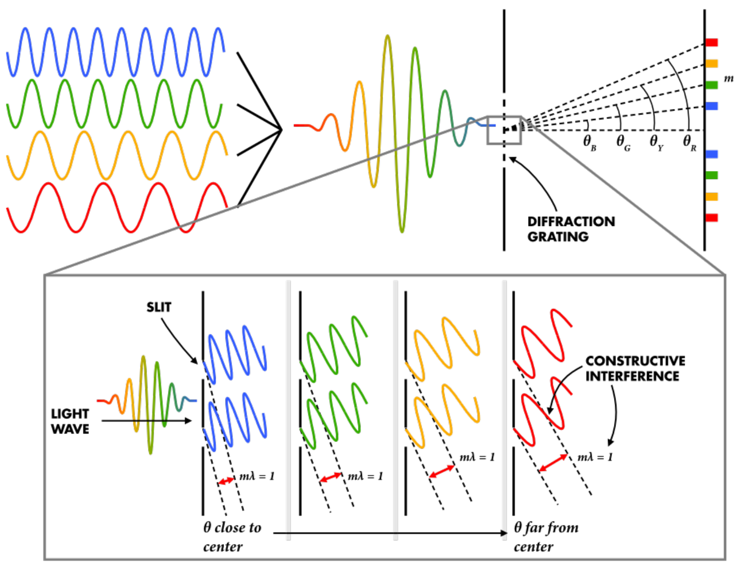

Figure 3

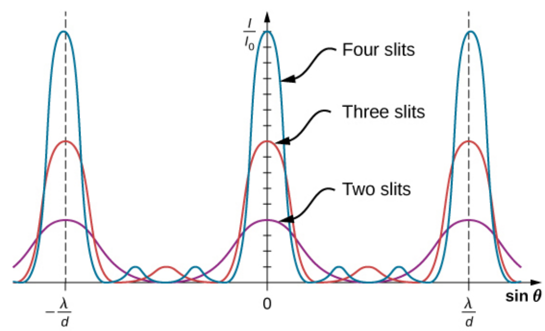

Figure 4 [OpenStax]

Real World Applications

- Researchers in various fields use **laboratory spectrometers** to identify and characterize the electromagnetic signatures emanating from unknown materials; the signature peaks in frequency provide a clue about the material. **Bruce Banner in *Avengers*** alluded to this fact when he asked for labs to "put [their] spectrometers on the roof and calibrate them for gamma rays."
- When designing the **James Webb Space Telescope**, scientists chose to separate light wavelengths using **diffraction gratings** for high and medium resolution and a **prism** for low resolution!

1) The original double-slit experiment!
2) Spectroscopy explained!

PRECAUTIONS:

This lab demonstration requires working in the ***dark****, move slowly and carefully. The discharge tubes get very* ***hot****—wear the provided gloves when handling.*

PROCEDURE:

Figure (5) provides a diagram of the spectroscope you will use in this lab.

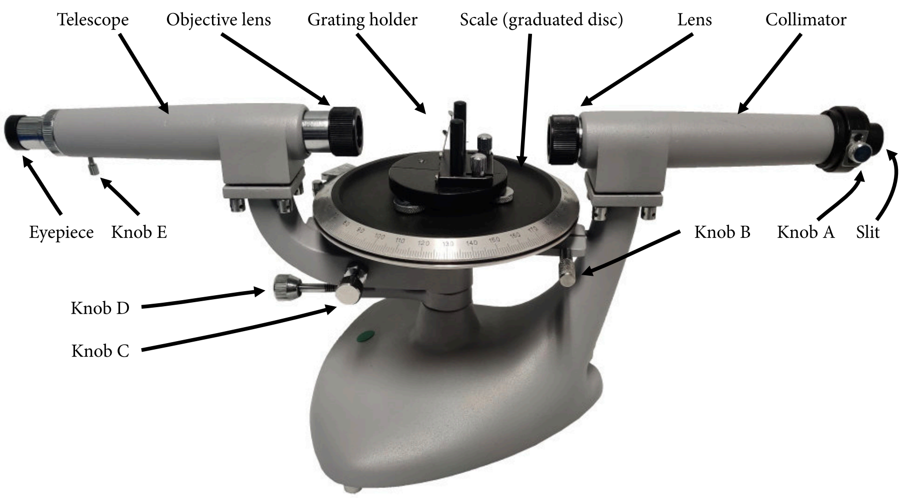

Figure 5 Diagram of spectroscope

1. ☐ Fill out the top information on the worksheet **and** complete the memory exercise—Questions M1–M3.

2. ☐ Read the *Concept* section.

3. ☐ Assemble the setup as shown in Figure (6).
   - 3.1. Adjust the *telescope* to be in line with the *collimator*.
   - 3.2. Ensure the *slit* is a narrow opening, see Figure (6a). Adjust the opening using *Knob A*.
   - 3.3. Place a discharge tube in the lamp holder of the high voltage (HV) power supply and turn it on. **WARNING: The bulbs are designed to operate 30 seconds ON - 30 seconds OFF.**
   - 3.4. Position the *slit* close to the discharge tube by 3mm or a 1/8in. Figure (6b) shows this.
   - 3.5. Place a diffraction grating in the *grating holder*.
   - 3.6. Looking through the *eyepiece*, you should see a bright light, which is the bright fringe at n = 0. Adjust the telescope so that the crosshairs are centered in the bright fringe, as in Figure (6c), and use the focus knob on the collimator to make the image sharp.
   - 3.7. Using *Knob B*, lock the *Scale* to *0*, as in Figure (6d).

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CONCEPT & PROCEDURE VIDEOS:

4. ☐ Rotate the telescope away from center, you should see a spectrum of colors, as in Figure (7). (If the position of the spectrum is up and down from the view of the telescope, the grating is not well aligned. Ask your TA to help you with aligning the grating.)

5. ☐ Rotate the telescope till you see each of the colors in Table 1 on the worksheet. Use *Knob D* to lock the telescope in place and then use *Knob C* to micro-adjust from the locked position. Record the diffraction order, and record the angle at the exact center of each color.

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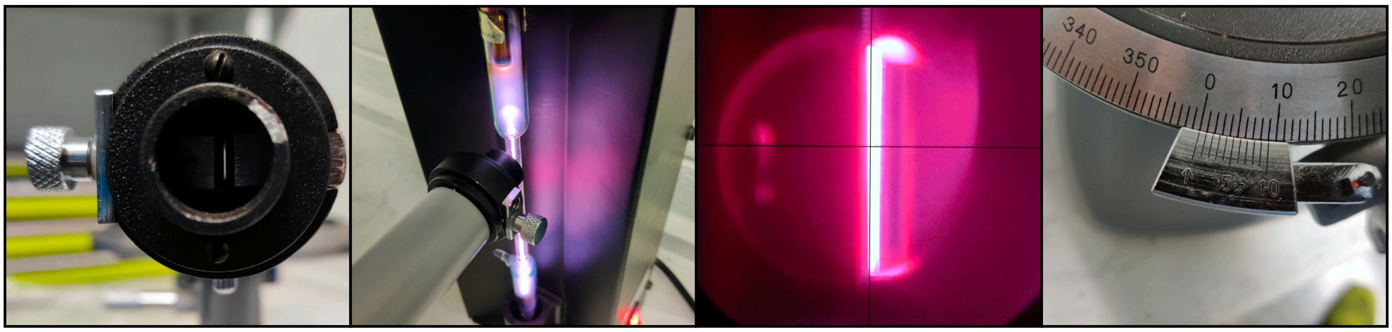
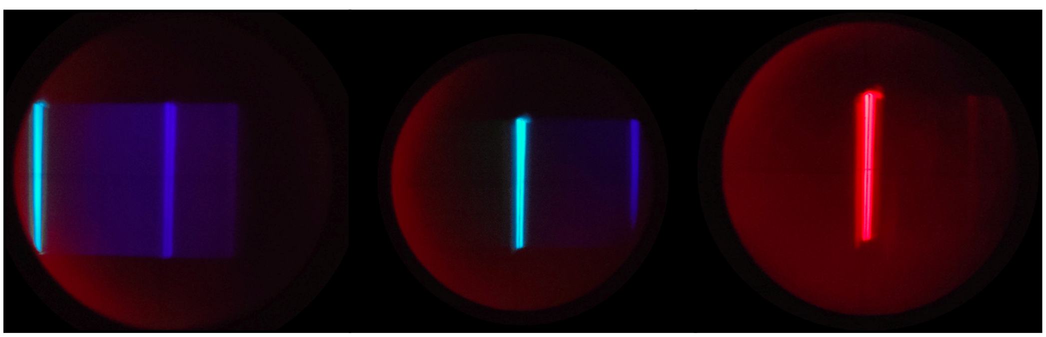


(a) (b) (c) (d)

Figure 6



(a) (b) (c)

Figure 7

6. ☐ Complete Table 1 and answer Question 1–4 on the worksheet.

7. ☐ Turn off the HV and take out the helium discharge tube, wearing the safety gloves while doing this since the discharge tube will be hot.

8. ☐ Reset the spectroscope, step 3, and repeat steps 4–5 with the hydrogen discharge tube.

9. ☐ Complete Table 2 and answer Question 5 on the worksheet.

10. ☐ Turn off the HV and take out the hydrogen discharge tube, wearing the safety gloves while doing this since the discharge tube will be hot.

11. ☐ Follow the **Let's THINK!** instructions on the next page.

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Let's THINK!

- **Ask questions**: What are you learning here?... Why is this Physics concept important and how can it be used?... What do you not understand?... (For more information on this Physics topic, scan the QR codes in the *Real World Applications* and at the start of the *Procedure* section.)
- **Discuss** the concept and demonstration with your partner to help each other understand better. Discussion makes learning active instead of passive!
- For **FULL PARTICIPATION [15 points]** you must call on the TA when you have finished your group discussion to answer some comprehensive questions. If you do not fully understand and the TA asks you to discuss more, you must call on them one more time to be dismissed with full marks.
- **CONCLUSION [10 points]**: In the Conclusion section at the end of the worksheet, write 3 or more sentences summarizing this concept, how this lab helped you understand the concept better, and the real world implications you see. Do you still have questions? If so, write those as well.

Updated Date	Personnel	Notes
2023.03	Chase Boone, Bernard Osei	2022 Summer Improvement: Created new format.

Name: ______________________________ *PH2233* Section #:__________

Name: ______________________________ TA Name:____________________

GRATING SPECTROMETER
WORKSHEET [70 points]

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Memory exercise [each 2 extra credit points]**:**

M1) Light rays are the individual ____________ of a light wave.

M2) All waves can ____________ and _______________

M3) Standing waves are the result of _______________ between two waves.

Table 1: Helium spectrum [24 points; 1 point per cell]

Color	Expected Wavelength λ_E (nm)	Order m	Angle θ (°)	Calculated Wavelength λ_C (nm)
Violet	438.8			
Blue-violet	447.1			
Blue	471.3			
Blue-green	492.2			
Green	501.6			
Green	504.8			
Yellow	587.6			
Red	667.8			

1) Show all of the steps for the calculation of wavelength from the angle you obtained for Blue. [5 points]

2) Calculate the angle of the second order (m = 2) violet spectral line. Can you see it at that angle? [4 points]

3) Does the density of the diffraction grating (300 lines/mm, 400 lines/mm, etc) affect the angle of the spectral lines? Why or why not? [5 points]

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4) How does the density of the diffraction grating affect the *apparent* brightness of the spectral lines? This is tricky... [5 points]

Table 2: Hydrogen spectrum [12 points; 1 point per cell]

Color	Expected Wavelength λ_E (nm)	Order m	Angle θ (°)	Calculated Wavelength λ_C (nm)
Violet	410.2			
Blue-violet	434.0			
Blue-green	486.1			
Red	656.3			

5) Why do the blue-ish spectral lines appear at smaller angles and the red-ish spectral lines appear at larger angles? [5 points]

Conclusion

Write 3 or more sentences summarizing this concept, how this lab helped you understand the concept better, and the real world implications you see. Do you still have questions? If so, write those here as well. [10 points]

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