

An Undergraduate Guide into Experimental Physics:
Wave Mechanics and Optical Phenomena

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A special thanks to the editors of this book who performed each experiment and submitted corrections.

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Randy Smith.

Chapter 1

Wave Superposition

1.1 A Brief History

The superposition of waves is a common occurrence in every day life. Superposition is an overlay of one “thing” on another “thing”. Two or more waves can interfere with each other and cause a resultant wave. Interference is when two or more waves overlap each other such that the net amplitude at each point of the wave is the sum of the amplitudes of the individual waves. For instance, if we have a wave A and a wave B, the superposition of these waves is $A + B$. Today you will observe how waves add and subtract using the principle of superposition.

1.2 Notes

1. Always read the lab manual before coming to class. Daily quizzes will be given at the beginning of each class covering material in this manual.
2. This is the first laboratory for the PH 113 course. Unlike PH 114 and PH 115 the laboratory equipment will not be ready-to-go upon arrival into the classroom. Instead, the equipment will be placed at the front of the classroom and it will be the groups responsibility to assemble the apparatus.
3. It is always a good idea to bring a flash drive to class in case you may want to save images or data gathered during the experiment. I would recommend that each group member bring their own flash drive; relying on a single group member to email relevant data is never a good idea. This manual and your TA will remind you one class in advance if a flash drive is absolutely necessary.
4. Questions that are boxed in can be answered in class or outside of class. However, it is recommended that the questions be answered as approached during the laboratory. It is required that you answer all of the questions and discuss their results in the results section of your lab report.
5. Throughout the semester you will find that the necessary theory to solve some of the problems in the labs will be developed within the procedure. Read ahead!
6. All honors questions should be read before leaving the class each day. Some questions may require more work to be done in the lab. Honors question answers should be on a separate sheet of paper and stapled to your lab report each week.
7. If you find typos in the lab manual, or find that something should be re-written to be clearer you may email Mark at mws0002@alumni.uah.edu.
8. Most importantly, *have fun* and learn as much as possible!

1.3 Definitions

1. *Superposition*-The combination of two or more physical states, such as waves, to form a new physical state in accordance with the superposition principle¹.
2. *Interference*-The variation of wave amplitude that occurs from the superposition of two or more waves¹.

1.4 Laboratory Objectives

By the end of today's exercise it is in the hopes of this Author that you will understand how waves add and subtract.

1.5 Equipment

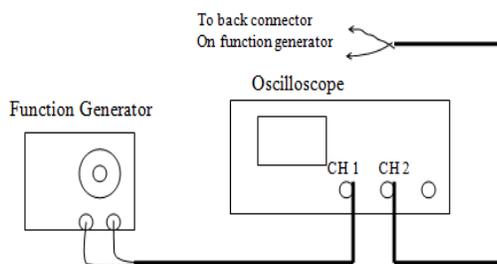
Two Function Generators, Oscilloscope, Two Loudspeakers, and Connector Wires.

1.6 In Class Lecture

1. The TA will give a brief review of the Superposition of Waves and the associated linear additive properties of waves. The TA will also cover a brief review of amplitude, period, wavelength, and frequency of waves.
2. The TA will give a short in class demonstration of the oscilloscope and all of the necessary functions to complete this lab. This includes how to measure the amplitude, period, wavelength, and frequency of the waves observed.

1.7 Procedure

1. Assemble the following apparatus.



2. Double check that the front outputs on the Function Generator are attached to Channel 1 of the Oscilloscope. Set the Function Generator to Sine Wave. Adjust the amplitude of the wave generated by the Function Generator to approximately $\frac{3}{4}$ maximum.
3. Adjust the frequency on the Function Generator to approximately 500 Hz. Now using *only* the Oscilloscope, adjust the settings until you discover the Sine Wave produced. Center it about an origin of your choice. Find the frequency f , period t , wavelength λ , and amplitude h . Note: Measure wavelength and amplitude in divisions. If you really want to torture yourself, convert into meters.

f : _____ Hz t : _____ s λ : _____ div h : _____ div

4. Connect Channel 2 on the Oscilloscope to the same leads that are connected to Channel 1. View Channel 2 only and find the frequency f , period t , wavelength λ , and amplitude h

f : _____ Hz t : _____ s λ : _____ div h : _____ div

5. Now set the Source switch to VERT MODE. Take note of the period of the wave with respect to the periods you measured above. Show both Channel 1 and Channel 2 on the Oscilloscope screen. Switch to ALT MODE. Adjust both waves such that they are both centered about the origin your group chose. Sketch the graph. Also include another sketch of this graph for your lab report due next week. It may be hand drawn and either attached on a separate sheet or included linearly in your lab report. ↓

6. Switch to ADD MODE and re-center the graphs if required. Measure the period t and the amplitude h of this graph.

t : _____ s h : _____ div

7. Sketch the graph. Also include another sketch of this graph for your lab report due next week. It may be hand drawn and either attached on a separate sheet or included linearly in your lab report. ↓

<p>Question 1: What happened when you switched the Oscilloscope to ADD MODE? Discuss this in the results section of your lab report.</p>

8. On the Function Generator, disconnect the wires leading to Channel 2. Connect these same wires to the Square wave on the Function Generator. Depending on which Function Generator you are using the input may be on the front or the back.
9. Confirm that Channel 2 has a Square Wave. Now set the Source switch to VERT MODE. Take note of the period of the wave with respect to the periods you measured above. Show both Channel 1 and Channel 2 on the Oscilloscope screen. Switch to ALT MODE. Adjust both waves such that they are

both centered about the origin your group chose. Sketch the graph. Also include another sketch of this graph for your lab report due next week. It may be hand drawn and either attached on a separate sheet or included linearly in your lab report. ↓

10. Switch to ADD MODE and re-center the graphs if required. Measure the period t and the amplitude h of this graph.

t : _____ s h : _____ div

11. Sketch the graph. Also include another sketch of this graph for your lab report due next week. It may be hand drawn and either attached on a separate sheet or included linearly in your lab report. ↓

Question 2: What happened when you switched the Oscilloscope to ADD MODE? Discuss this in the results section of your lab report.

12. Disconnect the wires that are attached to the back of the Function Generator Square Wave. Attach a second Function Generator to Channel 2 of the Oscilloscope. Set the second Function Generator to Sine Wave. Adjust the frequency of the second Function Generator to approximately 500 Hz. Set the Oscilloscope to ALT MODE. View both Channel 1 and Channel 2.
13. Using your circuit knowledge from PH 115, attach a loudspeaker to the output of each Function Generator while keeping the circuit fundamentally the same as it was. You may adjust the amplitude of the Function Generators such that the speakers are not too loud. Try and find the same amplitude for each wave. The purpose of the speakers is to give you some feeling as to what is happening physically with the system. It is recommended that you have a space of at least 0.03 m between the two speakers while facing each other.
14. Adjust the frequencies of the Function Generators such that the two waves appear to not move. After the waves are stationary switch the oscilloscope to ADD MODE. Adjust one of the Function Generators slowly and take note of what happens to the sound and waves.

Question 3: What happened when you switched the Oscilloscope to ADD MODE? Discuss this in the results section of your lab report.

15. Set the Oscilloscope to ALT MODE and set the time control to x-y. If you cannot find this setting your instructor will assist you. The figure you observe is called a Lissajous figure. Change the settings on the Function Generator until you have a firm grasp of what represents the x-axis and what represents the y-axis.

Question 4: With the Lissajous figure, what does the x-axis represent? With the Lissajous figure, what does the y-axis represent? What causes the figure to spin, what causes the figure to remain stationary? Why does it “rotate”? Discuss this in the results section of your lab report.

★**Honors Question A:** Does the theory of superposition only apply to linear systems? What is meant by linear?

★★**Honors Question B:** Show mathematically that the superposition of two waves , $\psi(x)$ and $\psi(y)$, is linear; where $\psi(x)=Ae^{-kx}$ and $\psi(y)=Be^{-ky}$ with A and B being arbitrary constants. i.e. Show $\psi(x) + \psi(y) = \psi(x + y)$.

★★ **Theory — Honors Question C:** Give an example of a superposition of waves that does not involve any gas or liquid.

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QUIZ 21 - Wave Superposition

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Chapter 2

Standing Waves

2.1 A Brief History

Standing Waves are also known as Stationary Waves. This means that the wave does not “travel” so-to-speak. A standing wave occurs when the wave hits a resonance frequency which may also be an integer multiple of the fundamental frequency. Standing waves have Nodes and Anti-Nodes. A Node is the point in which no oscillation occurs. An Anti-Node is the point where maximum oscillation occurs. In today’s laboratory you will create standing waves using a string and mass system.

2.2 Definitions

1. *Standing Wave*-A wave that oscillates in place and creates stable nodes of maximum and zero oscillation, produced whenever a wave is confined within boundaries, as in the vibrating string of a musical instrument¹.
2. *Resonance*-The increase in amplitude of oscillation of an electric or mechanical system exposed to a periodic force whose frequency is equal or very close to the natural undamped frequency of the system¹.
3. *Anti-Node*-For a standing wave, the region or point of maximum amplitude between adjacent nodes¹.
4. *Node*-A point or region of virtually zero amplitude in a wave or periodic system¹.

2.3 Laboratory Objectives

By the end of today’s exercise it is in the hopes of this Author that you will understand how Standing Waves behave and what constitutes a wave being classified as a Standing Wave.

2.4 Equipment

Mechanical Wave Driver (Thumper), Digital DC Voltmeter, String, Meter Stick, Digital Balance, Pulley, Mass Set, and Mass Hanger

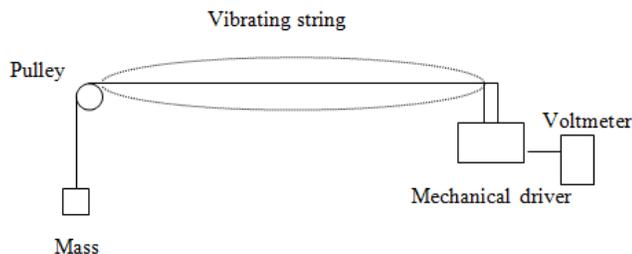
2.5 In Class Lecture

1. The TA will give a brief review of the Superposition of Waves and the associated linear additive properties of waves. The TA will also cover a brief review of amplitude, period, wavelength, and frequency of waves.

- The TA will give a short in class demonstration of the oscilloscope and all of the necessary functions to complete this lab. This includes how to measure the amplitude, period, wavelength, and frequency of the waves observed.

2.6 Procedure

- Assemble the following apparatus.



- Hang 0.03 kg on the Pulley end of the String. This will allow the String to have a large enough tension to allow periodic oscillation. Turn on the Thumper to test that it does indeed oscillate correctly.
- Increase the frequency until the string looks like the figure above (one maxima). Record the associated frequency (f_1).

Note: To determine the output frequency, just multiply the reading on the voltmeter by the selected range. For example, if the multiplier knob is set to 100 Hz, and the voltmeter reads 5.75 volts, the output frequency is 575 Hz. If the multiplier knob is set to 10 KHz, and the voltmeter reads 7.84 volts, the output frequency is 78.4 kHz.

f_1 : _____ Hz

Note that this is the fundamental frequency of the string. Also known as the 1st Harmonic.

- Increase the frequency until there are two maxima. Record the associated frequency (f_2).

f_2 : _____ Hz

Touch the string on a Node and then an Anti-Node.

Question 1: Was f_2 an integer multiple of f_1 ? Did the string continue to vibrate once the Node was touched? Did the string continue to vibrate once the Anti-Node was touched? Discuss this in the results section of your lab report.

- Find f_3 and f_4 by increasing the frequency.

f_3 : _____ Hz f_4 : _____ Hz

Question 2: Was f_3 and f_4 an integer multiple of f_1 ? Discuss this in the results section of your lab report.

Digressing from the experiment, recall that for a standing wave of length L we have

$$L = \frac{n\lambda}{2} \quad (2.1)$$

for $n=1,2,3,\dots$ λ is the wavelength. From your coursework, the velocity(v_1) on such a string was given by

$$v = \sqrt{\frac{T}{\mu}}. \quad (2.2)$$

where T is the tension of the string and μ is the mass per unit length of the string.

- Record the length and then calculate the velocity. Note: You will have to use your knowledge of physics to solve this problem. Your TA may give you a hand in solving it.

L : _____ Hz v_1 : _____ Hz

- Turn the Thumper off and then add 0.03 kg to the hanging mass. Find the first four harmonics and then calculate the velocity.

f_5 : _____ Hz f_6 : _____ Hz f_7 : _____ Hz f_8 : _____ Hz

v_2 : _____ Hz

Question 3: Are the velocities approximately the same? Explain. Does the Thumper act as a true node? Discuss this in the results section of your lab report.

★**Honors Question A:** Derive equation 22.2. You may use your textbook and the internet.

★**Honors Question B:** Describe why the string continues to vibrate unhindered when the Node is touched.

★ **Theory — Honors Question C:** What does it mean for a wave to be continuous?

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QUIZ 22 - Standing Waves

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Chapter 3

Sound in Air

3.1 A Brief History

Sound is a longitudinal wave. Sound travels as a compression radially outwards from a source. Some mediums resist the compression of sound waves and some allow the compression. This effect produces different speeds of sound in different mediums. In today's experiment, you will use a resonance tube apparatus to analyse how sound vibrates and compare it to the standing waves experiment completed in the previous chapter.

3.2 Notes

1. Review Brewster's Angle for the next chapter: Microwave Optics.

3.3 Definitions

1. *Sound*-Vibrations transmitted through an elastic solid or a liquid or gas, with frequencies in the approximate range of 20 to 20,000 hertz, capable of being detected by human organs of hearing¹.
2. *Longitudinal Wave*-A wave in which the direction of displacement is the same as the direction of propagation².
3. *Amplitude*-The maximum absolute value of a periodically varying quantity¹.
4. *Period*-The time interval between two successive occurrences of a recurrent event or phases of an event; a cycle¹.

3.4 Laboratory Objectives

By the end of today's exercise it is in the hopes of this Author that you will understand how Sound travels in air and what sort of properties it has while in air.

3.5 Equipment

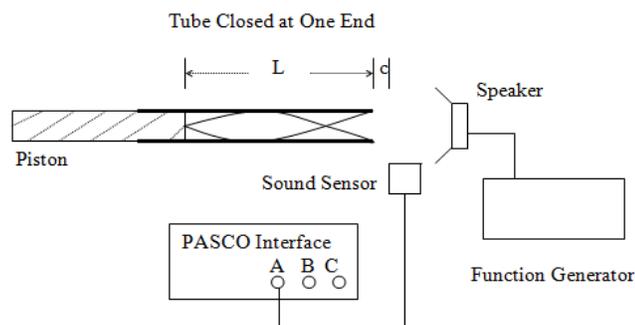
Resonance Tube Apparatus, Sound Sensor, DataStudio, Loudspeaker, Function generator, Digital DC voltmeter, and a Meter Stick

3.6 In Class Lecture

1. The TA will give a brief review of the Superposition of Waves and the associated linear additive properties of waves. The TA will also cover a brief review of amplitude, period, wavelength, and frequency of waves.
2. The TA will give a short in class demonstration of the oscilloscope and all of the necessary functions to complete this lab. This includes how to measure the amplitude, period, wavelength, and frequency of the waves observed.

3.7 Procedure

1. Assemble the following apparatus.



2. The experiment will need to be performed with the frequency of sound constant while adjusting the length of the apparatus. Place the loudspeaker at the open end of the resonance tube and raise the frequency of the Function Generator to 1.5 kHz; set on Sine Wave. Determine the observed frequency of the wave using the DC Voltmeter and the method discussed in the previous chapter.
3. In Datastudio, allocate the Sound Sensor icon to Channel 1. Drag the Scope icon that is located on the bottom left of the screen to Channel 1 also. This will give a real time wave display on the computer. On Datastudio, click the Start button to begin viewing the wave in real time.
4. Adjust the V/div and the ms/div to get a reasonable view of the wave. Note: You may need to adjust the Sound Sensor a few times to find the “sweet spot”. Using the piston, vary the length of the tube and note how the Scope changes with a few distances. When you find a resonant length the amplitude of the wave should double in size.
5. Starting with the longest possible tube find five resonant lengths. Try to be as accurate as possible.

L_1 : _____ m L_2 : _____ m L_3 : _____ m L_4 : _____ m L_5 : _____ m

6. Increase the frequency of the function generator to 3 kHz. Find five resonant lengths.

L_6 : _____ m L_7 : _____ m L_8 : _____ m L_9 : _____ m L_{10} : _____ m

7. Increase the frequency of the function generator to 4.5 kHz. Find five resonant lengths.

L_{11} : _____ m L_{12} : _____ m L_{13} : _____ m L_{14} : _____ m L_{15} : _____ m

A quick glance into your favorite introductory physics book will show that the velocity of sound in air is given by

$$v = \sqrt{\frac{\gamma RT}{M}} \quad (3.1)$$

where v is the velocity, γ (1.4) is the correction constant for air, R ($8.314 \frac{J}{Kmol}$) is the gas constant, T is the temperature in the room, and M ($28.7 \times 10^{-3} \frac{kg}{mol}$) is the average molecular weight of air.

Question 1: Find the average difference between resonances for each frequency calculated above. Calculate the wavelength associated to the three average frequencies. Next find the velocity of sound in the laboratory from this data. What is the percent difference between the accepted value of the speed of sound and your result? There is some room below to work in. Discuss this in the results section of your lab report.

8. If Datastudio is still recording, press the Stop button. Now remove the piston from the tube such that both ends are open. Now the length of the tube is constant, and the frequency will be altered to find the resonant frequencies. Record the length of the tube.

L : _____ m

9. Increase the frequency to 200 Hz. On Datastudio, press the Start button. You may need to adjust the V/div and ms/div to see the wave. Gently increase the frequency until you reach a resonance frequency. Recall from above that the resonance frequency will be roughly twice as high as the “normal” wave amplitude. Find five values of resonance.

f_1 : _____ Hz f_2 : _____ Hz f_3 : _____ Hz f_4 : _____ Hz f_5 : _____ Hz

Question 2: Find the average difference between resonances for each frequency found above. Calculate the wavelength associated to the average frequency. Note: You may need your result from Question 1. There is some room below to work in. Discuss this in the results section of your lab report.

★**Honors Question A:** Derive (23.1) using your textbook and the internet. Hint: Ideal gas law.

★**Honors Question B:** Explain why γ is required in (23.1).

★★ **Theory — Honors Question C:** We know that sound travels faster in water than in air. On a rainy day, would you expect the speed of sound in air to be appreciably faster, slower, or the same? Explain your reasoning.

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QUIZ 23 - Sound in Air

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Chapter 4

Microwave Optics

4.1 A Brief History

Microwaves travel as transverse waves. They do not require a medium to travel, instead it self oscillates perpendicular to the direction of propagation. Like all EM waves, microwaves have both geometrical and physical properties. Microwave's standard wavelength is taken to be approximately 3 cm with a frequency of around 10 GHz. In today's experiment, you will see the relationship between light and microwaves and what similar properties they hold even though microwave radiation is not in the visible spectrum.

4.2 Notes

1. Do not place your hands or electronics in the path of the microwaves or you are going to have a bad day.
2. Be warned, the drawings in this Chapter are poorly drawn and may take a sharp eye and a high level of patience to understand. Good luck young physicists...
3. Review Snell's Law for the next chapter: Geometric Optics.

4.3 Definitions

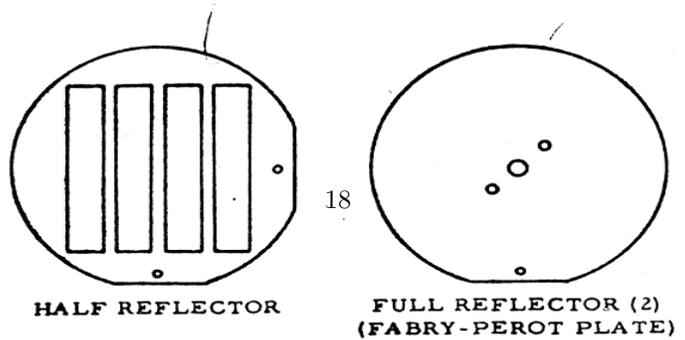
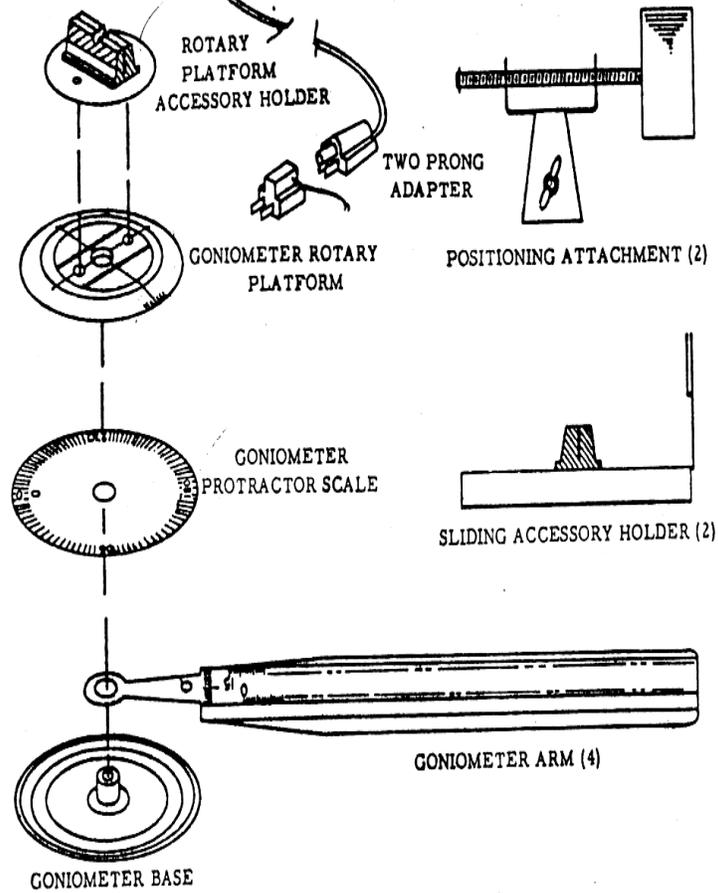
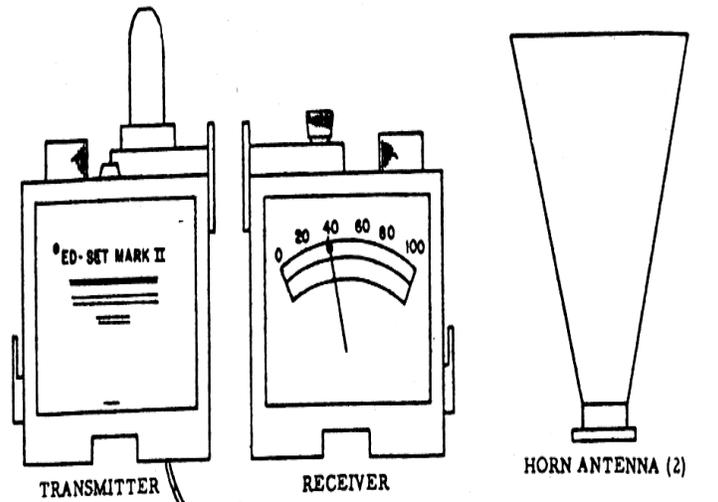
1. *Electromagnetic Radiation*-Radiation consisting of electromagnetic waves, including radio waves, infrared, visible light, ultraviolet, x-rays, and gamma rays².
2. *Microwave*-An electromagnetic wave of extremely high frequency, 1 GHz or more, and having wavelengths of from 1 mm to 30 cm².
3. *Transverse Wave*-A wave in which the direction of displacement is perpendicular to the direction of propagation².

4.4 Laboratory Objectives

By the end of today's exercise it is in the hopes of this Author that you will understand how microwaves behave and get a small glimpse into the behavior electromagnetic radiation.

4.5 Equipment

Microwave Emitter, Microwave Receiver, Metal Half-Transmission Grating, Metal Full-Transmission Grating, Metal Reflectors, and Emitter-Receiver Quadrant Apparatus. Dry Board Absorber, Rubber Absorber, 2 Plexiglass Sheets, and a Meter Stick. See the next two pages for poorly drawn pictorials of what the various items look like.



4.6 In Class Lecture

1. The TA will do a quick demonstration on how to set up the starting apparatus.
2. The TA will briefly describe the function of the Goniometer, Transmitter, and Receiver.

4.7 Procedure

1. Set up the following apparatus using the equipment the TA described during the introduction.

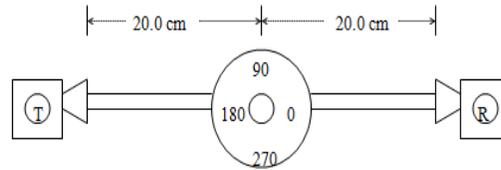


Figure 1

2. Plug the Transmitter into a power source and turn it on. Adjust the Gain on the Receiver to obtain a reading of approximately 100. Record this as the full power (P_0) and answer Question 1 before proceeding further.

Question 1: What units does the Receiver use? Be sure to include them below for your recorded values.

P_0 : _____

3. Find an easy method to your liking to place absorbers on the center of the apparatus as shown below.

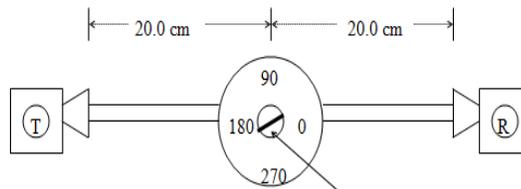


Figure 2

4. For the first absorber, use the dry board. Rotate the dry board 45° from the Transmitter. Record the reading on the receiver as the Attenuated Power (P_A).

P_A : _____

5. Rotate the Receiver 90° from the dry board without changing the orientation of the dry board. Note: Is the direction of rotation of the receiver important? Record the reading on the Receiver as the Reflected Power (P_R).

P_R : _____

From your coursework you should be familiar with the formula for Absorbed Power(P_{ABS}). If you are having a slight memory lapse here is a reminder:

$$P_0 = P_A + P_R + P_{ABS}. \quad (4.1)$$

Rearranging to solve for Absorbed Power we get

$$P_{ABS} = P_0 - (P_A + P_R). \quad (4.2)$$

6. Calculate the Absorbed Power.

P_{ABS} : _____

7. Find the Absorbed Power for Wet Foam. Note: Do not soak the foam, simply make sure that it is damp. If it is dripping, you did it wrong.

P_0 : _____ P_A : _____ P_R : _____ P_{ABS} : _____

8. Turn the Transmitter off and remove the Transmitter and Receiver from the apparatus. For this next part you will use the table as a reflector. Clear a space on the table such that the Transmitter and Receiver may sit facing each other with their “horns” being approximately 30 cm apart.
9. Turn the Transmitter on and adjust the Gain on the Receiver such that the Receiver reads 100. Turn the Receiver on its side and elevate it so that it is at the same height as the Transmitter. Note the reading on the Receiver.

Question 2: What reading did you get on the Receiver when it was placed on its side and elevated to the Transmitter’s height? What causes this? Hint: Ask your TA about linearly polarized waves. Discuss this in the results section of your lab report.

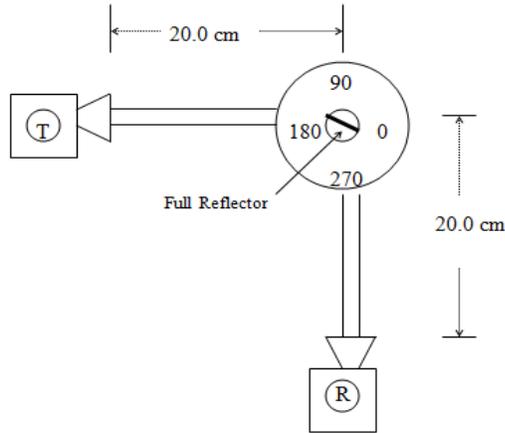
10. Even though this step more or less answers Question 2, I am going to ask you to find whether the beam the Receiver detects is Vertically Polarized or Horizontally Polarized. Chapter 23 asked that you review Brewster’s Angle in preparation for today’s experiment. Here is an even briefer review in case you were too busy during the week:

Brewster’s Angle is when light reflects off of a dielectric surface approximately between 50° and 70° which gives polarized light travelling parallel to the surface that reflected the incident light.

11. Maximize the Gain on the Receiver. Orient the Transmitter and Receiver such that they face each other and the edges of the “horns” are approximately 30 cm apart. Now tilt the Transmitter and the Receiver forward such that the “horn” on each device touches the table. Note: Discuss in your group what it means to be a dielectric surface. Does the table count as a dielectric surface?
12. Analyse, but do not record, the reading on the Receiver as your group slowly moves the devices slowly towards and away from each other. Make a note whether there was a dramatic change in reading during this process and briefly mention it in your lab report.
13. Now lay the devices on their sides and tilt them to approximately the same angle as in the previous step. Note whether you get a reading. Try moving the devices farther apart or closer together. Note whether the reading changes. Turn the Transmitter off while you answer Question 3.

Question 3: Is the wave vertically or horizontally polarized? What observations from this experiment did you use to come to this conclusion? On a separate piece of paper, draw what the wave looks like as it bounces off of the table for both orientations of the Transmitter and Receiver. Attach this sheet of paper to your typed lab report. Discuss this in the results section of your lab report.

14. Create the following apparatus.

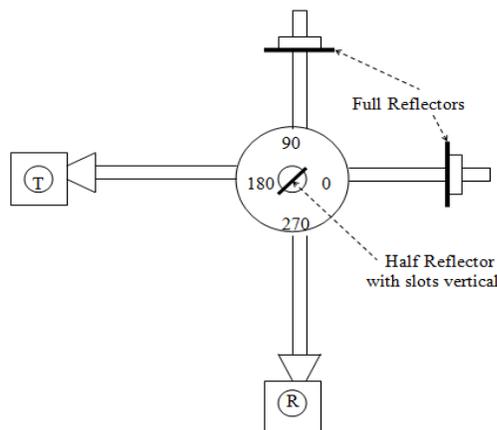


15. Turn the Transmitter on and then rotate the Full Metal Reflector until the Receiver reaches a maximum power. Record the Angle of Incidence (θ) and the Angle of Reflection (ψ).

θ : _____^o ψ : _____^o

Note whether the angles are equal or not in your lab report and explain why this is or is not the case.

16. Create the following apparatus. Use 20 cm spacing just like the previous apparatuses. For the moment, do not attach the Full Reflectors located at 90° and 0°.



17. Make sure the orientation of the Half Reflector is correct and then adjust the positions of the Transmitter and Receiver to find a maximum reading. Once the maximum reading has been found, place

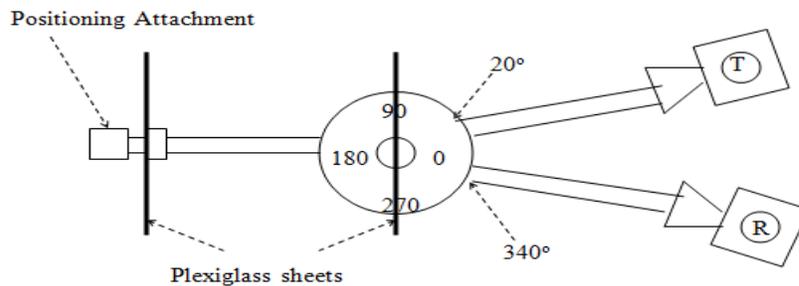
both Full Reflectors into the positions at 90° and 0° . Adjust the Full Reflector located at 90° to find a minimum reading on the Receiver. Finally, adjust the 0° Full Reflector to find a minimum reading on the Receiver. The system is now optimized to find the wavelength of the waves emitted by the Transmitter.

18. Carefully move the Full Reflector inwards towards the center using 0.1 cm increments. Record the change in power that the Receiver measures for each increment. The cycle should be periodic because you are measuring wavelength.

	Length (cm)		Power ()
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	
9		9	
10		10	

Question 4: Find a way to measure the wavelength of the Microwaves using the information recorded from the previous step. What is the wavelength? Search your text,(or ask your TA), to find the range of wavelengths for Microwaves. Does your answer fall into this range? Discuss this in the results section of your lab report.

19. Create the following apparatus. Adjust the positions of the Transmitter and the Receiver such that they are at 20° and 320° respectively. Note: You do not need to put the Transmitter and Receiver exactly at the angles mentioned, try to get a maximum reading on the receiver using approximately the orientation shown. The two plexiglass sheets should initially be 20 cm apart.



20. Carefully move the outer Plexiglass Sheet inwards towards the center using 0.1 cm increments. Record the change in power that the Receiver measures for each increment. Note: For Question 5, I would recommend combining with other groups to solve this problem and also to compare answers.

	Length (cm)		Power ()
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	
9		9	
10		10	

Question 5: Find the integer relationships between the wavelength and the spacing of the two plexiglass sheets. There will be two relationships relating to half wavelengths and quarter wavelengths respectively. It is recommended solving this question in class. Discuss this in the results section of your lab report.

★**Honors Question A:** Draw a diagram of the entire Electromagnetic Spectrum with labels depicting frequency, wavelength, type of wave, and amount of energy the waves generally carry.

★**Honors Question B:** How do microwave ovens work? Why is it that food generally loses some taste when you microwave it. What frequency does the microwave oven use? What molecule also has this frequency?

★★ **Theory — Honors Question C:** Explain what electromagnetic radiation is. What produces electromagnetic radiation?

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QUIZ 24 - Microwave Optics

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Chapter 5

Geometric Optics

5.1 A Brief History

Geometric optics is a branch in physics which generally covers the Euclidean nature of light rays. When light enters a medium its velocity will change (not so constant after all...). It is true that light generally takes the path of least time, and therefore the path upon entering the medium will change. How does light know to do this though? How does light know where the exit is so that it may find the path of least time? Think of these questions during today's experiment.

5.2 Notes

1. All experiment configurations should have the laser pointed away from all groups to prevent injuries. These lasers can and will injure your eyes should they be handled without care.
2. To create many of the different apparatuses you may find the creative use of wooden blocks, textbooks, and teamwork to be useful tools.

5.3 Laboratory Objectives

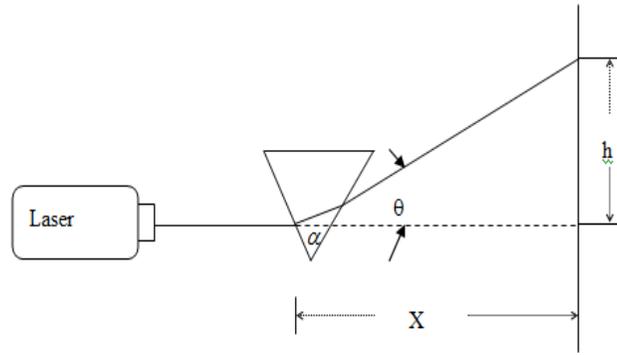
By the end of today's exercise it is in the hopes of this Author that you will understand how light travels in a medium.

5.4 Equipment

Helium Neon Laser, Laser Optics Box, Optical Protractor, Water Tank, Screen, Two Lenses, and a Meter Stick.

5.5 Procedure

1. Assemble the following configuration using the Helium Neon laser, a clear prism attached to the magnetic stand such that the laser beam may pass through it, and a screen in which the height(h) of the refracted laser light will be measured.



2. Find a way to align the Laser such that it passes through the Prism and hits the “wall” you are using. Record the distance X .

X : _____ m

3. Try to minimize the deviation of h by rotating the Prism. Briefly reviewing trigonometric properties of this system it can be easily observed that

$$\tan \theta = \frac{h}{X}. \quad (5.1)$$

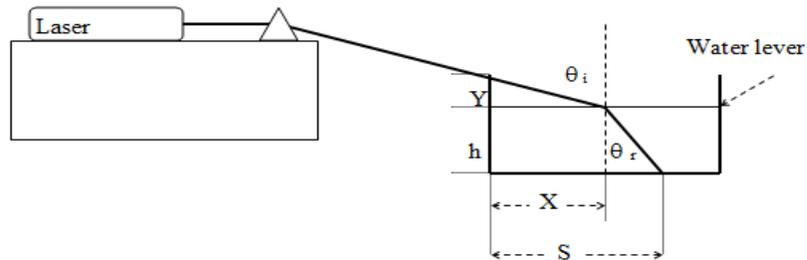
Calculate θ :

θ : _____ °

The Prism angles are also known because it is an equilateral triangle, therefore $\alpha = 60^\circ$. Using this information, and also a well known formula from your textbook, we can calculate the Index of Refraction (n) of the Prism.

$$n = \frac{\sin \frac{\theta + \alpha}{2}}{\sin \frac{\alpha}{2}} \quad (5.2)$$

4. Assemble the following configuration using the 3/4 filled Water Tank and the Prism.



5. Align the Water Tank with the incoming laser beam such that it just barely passes over the edge of the Water Tank and enters the water. Record all values listed below:

Y : _____ m X : _____ m h : _____ m S : _____ m

6. A quick glance at the figure yields the following relations to find the two angles of interest: Angle of Incidence(θ_i) and the Angle of Refraction(θ_r).

$$\tan \theta_i = \frac{X}{Y} \quad (5.3)$$

and

$$\tan \theta_r = \frac{S - X}{h}. \quad (5.4)$$

7. Calculate θ_i and θ_r .

θ_i : _____^o θ_r : _____^o.

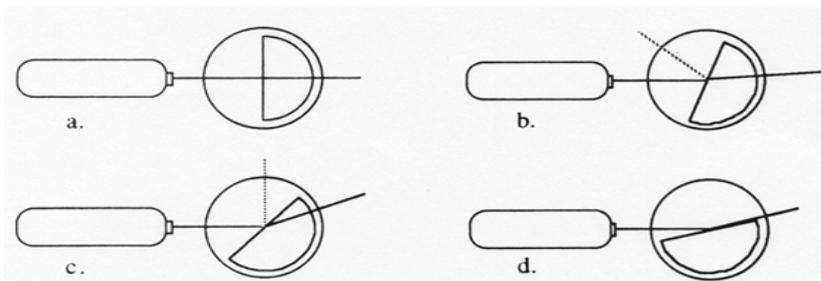
Finally we wish to find the Index of Refraction of the water(n_w) in the Water Tank. You should know that the Index of Refraction of Air is 1, so using this information and Snell's Law we get that

$$n_w = \frac{\sin \theta_i}{\sin \theta_r} \quad (5.5)$$

8. Calculate n_w .

n_w : _____

9. Set up the following apparatus such that the laser beam may pass through the center of the Optical Protractor. Take note of the orientation of the "hole" that is cut into the Optical Protractor. It is important that the hole is opposite the incident beam as shown below.



10. Rotate the Optical Protractor by 10° . This gives the Angle of Incidence(θ_i) to be 10° . Record the Angle of Reflection(θ_{ref}) by carefully inspecting the Optical Protractor's outgoing beam (the dotted line in the figure above is the reflected beam). Increment by 10° (up to 90°) and record the Angle of Reflection for each case.

θ_i	θ_{ref}
10°	
20°	
30°	
40°	
50°	
60°	
70°	
80°	
90°	

Question 1: Is there a reflected beam at 90° ? Explain. Discuss this in the results section of your lab report.

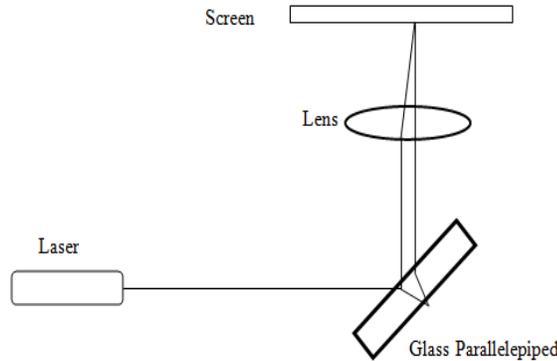
11. Rotate the Optical Protractor back to approximately 80° and slowly increase by 1° increments until the beam completely disappears. The Angle of Incidence that corresponds to this rotation is the Critical Angle (θ_c). Making use of the Critical Angle and Snell's Law we may easily calculate the Index of Refraction (n_p) for the Optical Protractor using

$$\sin \theta_c = \frac{1}{n_p} \quad (5.6)$$

12. Calculate n_p .

n_p : _____

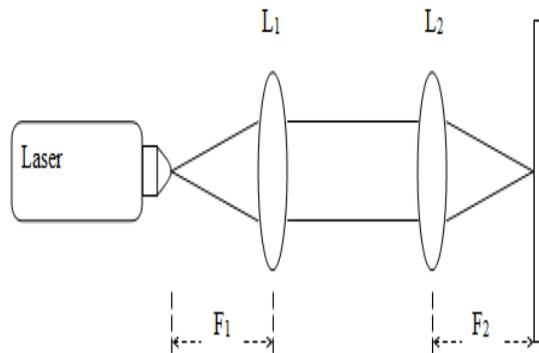
13. Assemble the following apparatus using the Laser, either Lens provided, a Parallelepiped (rectangular transparent prism type block included in the Optics Kit) glass beam splitter, and a Screen. Note: First confirm that you do indeed have two beams on the Screen. Then insert the Lens.



14. The Parallelepiped will allow you to split the laser beam into two separate beams. Try focusing the beams using the Lens. Notice whether the beams spread out or in as you alter the distance between the Lens and the Screen. To find the focal length (f) of the Lens you must find the point where both dots produced by the Parallelepiped focus to one point. Record the focal length of the Lens.

f_1 : _____ m

15. Assemble the following arrangement by attaching the small Diffuser to the Laser (your TA will show you which piece the Diffuser is and how to attach it). You will also need the second Lens and the Screen.



16. Place the Lens of known focal length(f_1) into the beam. Collimate the beam using the Lens. Now add the second Lens in front of the first Lens. Adjust the position of the second Lens and the Screen to collimate the beam again.

Question 2: Using the remainder of the class find a way to measure the focal length(f_2) of the second Lens using the collimated beams. Discuss this in the results section of your lab report.

f_2 : _____ m

★**Honors Question A:** Derive Snell's Law?

★★★**Honors Question B:** Does light always move in a straight line? What proof do you have?

★★★ **Theory — Honors Question C:** How does light “know” to take the path that gives it the least time upon entering a medium? This question is not trivial, so do not leave it to the last minute to solve.

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QUIZ 25 - Geometric Optics

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Chapter 6

Lenses

6.1 A Brief History

Lenses provide a means for most modern physics to progress. Almost all observations in astrophysics, particle physics, and even quantum mechanics are made using different types of lenses(not necessarily glass lenses). In your coursework you probably covered real and imaginary images. During today's experiment you will use optical instruments to create magnified images and also imaginary images.

6.2 Notes

1. Review Young's experiment for the next chapter: Physical Optics.

6.3 Laboratory Objectives

By the end of today's exercise it is in the hopes of this Author that you will understand how to ray trace and how real and imaginary images are formed.

6.4 Equipment

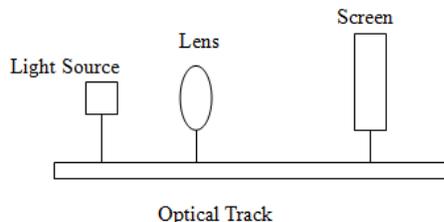
Optical Track, Light Source, Image Plate, Lens holders, and 3 Lenses of different focal lengths.

6.5 In Class Lecture

1. The TA will show the general theory of drawing ray diagrams of both real and imaginary images.

6.6 Procedure

1. Assemble the following apparatus using the Light Source, Optical Track, Screen, and a 18 cm Lens.



- Turn the Light Source on and make a mental note of the orientation of the image on the Light Source, it will be important later. Adjust the Lens(after it has been placed in a lens holder) and the Screen so that a clear and crisp image appears. Digressing briefly to review some concepts from your coursework, recall that the Thin Lens Formula is given by

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \quad (6.1)$$

where f is the focal length of the Lens, d_o is the object distance, and d_i is the image distance. The object distance is the distance from the Light Source to the Lens. The image distance is the distance from the Lens to the Screen.

- Record d_o and d_i and then Calculate f_{18} .

d_o : _____ m d_i : _____ m f_{18} : _____ m

- On a separate piece of paper, draw a Ray diagram depicting what you see. Label it as Diagram 1 and staple it to your lab report.
- Now calculate the magnification(m) of the Lens by using the familiar formula

$$m_{18} = -\frac{d_i}{d_o}. \quad (6.2)$$

m_{18} : _____

- Find another position for the Lens which gives another clear and crisp image. On the same separate piece of paper, draw another Ray diagram depicting what you see. Label it as Diagram 2.

Question 1: Is the image larger or small than before? Explain why. Discuss this in the results section of your lab report.

- Adjust the position of the Light Source so that it is 10 cm from the 18 cm Lens. Adjust the Screen distance to find an image.

Question 2: When the Light Source was within the focal length of the 18 cm Lens were you able to get an image on the screen? Was there an image somewhere? Was the image real or imaginary? Discuss this in the results section of your lab report.

- On the same separate piece of paper, draw another Ray diagram depicting what you found. Label it as Diagram 3.
- Repeat all steps(but not questions) for the 37 cm Lens and the 5 cm Lens (unless your TA says otherwise). Label all of the Ray Diagrams in ascending order(there should be 9 diagrams in total) and include them with your lab report. Note: Sometimes the images may be quite far away.

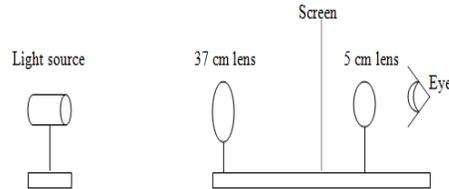
37 cm Lens:

$$d_o: \text{ ______ m} \quad d_i: \text{ ______ m} \quad f_{37}: \text{ ______ m} \quad m_{37}: \text{ ______}$$

5 cm Lens:

$$d_o: \text{ ______ m} \quad d_i: \text{ ______ m} \quad f_5: \text{ ______ m} \quad m_5: \text{ ______}$$

10. Assemble the following apparatus. The Screen is to be used to help find images and focal lengths and should be removed to view an image. Pay careful attention to the order of Lens with respect to the Light Source. It is possible to switch the two lenses however it would not work as easily or well.



11. This apparatus is analogous to a telescope. The 37 cm Lens is called the Objective Lens. The 5 cm Lens is called the Eyepiece. Place the Light Source approximately 3 meters away from the 37 cm Lens. Use the remainder of the class to find a clear and crisp image of the Light Source via the Eyepiece. Note: This part of the experiment may take quite a few adjustments to come up with the proper arrangement of distance for the Lenses. It is recommended that the Light Source and 37 cm Lens remain at constant distances.

Question 3: What is the angular magnification of the telescope? Should every group get the same answer? It might be a good idea to check the angular magnification that other groups calculated before leaving. The following formula below will be useful. Discuss this in the results section of your lab report.

The formula for angular magnification is

$$m_a = \frac{f_o}{f_e} \tag{6.3}$$

where f_o is the Objective Lens focal length and f_e is the Eyepiece focal length.

★**Honors Question A:** What does the negative sign in the magnification equation mean?

★**Honors Question B:** Why are you not upside down when you look into mirrors?

★ **Theory — Honors Question C:** How could an imaginary image be practical?

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QUIZ 26 - Lenses

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Chapter 7

Physical Optics

7.1 A Brief History

Light has a dual nature as described by the modern theory of Quantum Mechanics. It is both a particle and a wave depending on how you observe it. What does it mean to “observe” something though? One could define an observation as a measurement of a system, but then we are left with defining what a “measurement” constitutes. Young performed the double slit experiment which showed the dual nature of light. By introducing two slits for light to travel through he showed that the waves interfered with each other and produced an interference pattern. In contrast however, by shooting one photon at a time through the double slit experiment yielded the same pattern. If only one photon passes through the slits it may only take one path; then how does it produce an interference pattern? The only answer is if the photon interferes *with itself* and travels through both slits at the same time. In today’s experiment you will observe this dual nature of light in detail.

7.2 Notes

1. All experiment configurations should have the laser pointed away from all groups to prevent injuries. These lasers can and will injure your eyes should they be handled without care.
 2. To create many of the different apparatuses you may find the creative use of wooden blocks, textbooks, and teamwork to be useful tools.
1. Bring a flash drive for the next chapter: Polarization.

7.3 Definitions

1. *Diffraction*-The phenomenon exhibited by wave fronts that, passing the edge of an opaque body, are modulated, thereby causing a redistribution of energy within the front: it is detectable in light waves by the presence of a pattern of closely spaced dark and light bands at the edge of a shadow².
2. *Interference*-The process in which two or more light, sound, or electromagnetic waves of the same frequency combine to reinforce or cancel each other, the amplitude of the resulting wave being equal to the sum of the amplitudes of the combining waves².

7.4 Laboratory Objectives

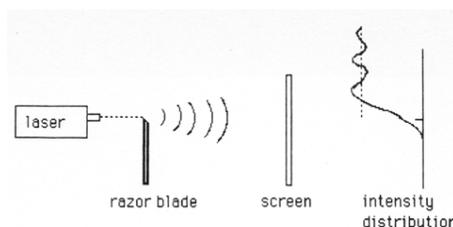
By the end of today's exercise it is in the hopes of this Author that you will understand how diffraction and interference works.

7.5 Equipment

Helium Neon Laser, Optics Kit, Screen, Normal Rulers, and a Meter Stick.

7.6 Procedure

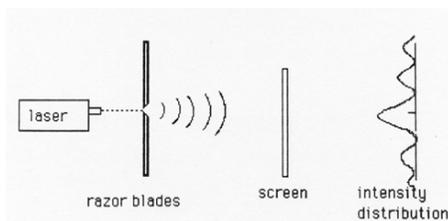
1. Assemble the following arrangement using the Laser, a Razer Blade edge, and a screen.



2. The Laser should be approximately 2 m away from the Screen. Using a magnetic holder, place the Razer Blade edge in the path of the laser beam. On a separate piece of paper, sketch what you see and label the sketch diagram 1. Turn this sheet in with your lab report due next week. Turn the Razor Blade sideways and notice what happens to the Diffraction pattern.

Question 1: Be so bold as to claim whether light is behaving as a wave or a particle in the above step. Explain. Explain what Diffraction is. Discuss this in the results section of your lab report.

3. Assemble the following apparatus using two Razor Blades instead of just one. The Laser should still be 2 m from the Screen.



4. Place the Razor Blade edges as close as possible without closing the gap. Notice what happens to the Diffraction pattern as the distance between the edges increases and decreases. In your coursework you probably discovered that the distance to the Screen must be incredibly large compared to the distance between the Razor Blade edges for Diffraction to be observable.
5. Lets get some practical use out of this and find the thickness of regular paper. You will need two matchbox size pieces of paper. Feel free to tear off the edges of this manual if you do not want to waste any paper or if you really just don't like this manual. Place the pieces of paper on top of one another and put them in between the Razor Blade edges. Close the Razor Blades around the two pieces of paper and remove the pieces of paper carefully while maintaining the distance between the Razor Blade edges.

6. Adjust the Laser such that the beam passes through the gap the paper created. Measure the distance(d) from the Razor Blades to the Screen.

d : _____ m

7. Using a Normal Ruler, measure the distance(x_L) from the center of the most central bright fringe to the center of the first minima on the left. Now measure the distance(x_R) from the center of the most central bright fringe to the center of the first minima on the right.

x_L : _____ m x_R : _____ m

Recall that for a single slit of width D we have

$$D \sin \theta = m\lambda. \quad (7.1)$$

Where θ is the angle measured from the triangle created by the central bright fringe and the minima. m is an integer, and λ is the wavelength of light. Find the mean(x_{mean}) of x_L and x_R and the observation that since $\theta \ll 1$ we have

$$\sin \theta \simeq \tan \theta = \frac{x_{mean}}{d} \quad (7.2)$$

x_{mean} : _____ m

Therefore we can solve for θ , and by extension solve for D .

8. Calculate D using $m=1$ and $\lambda = 6.3 \times 10^{-7}$ m.

D : _____ m

9. Find the width(w) of the piece of paper you used (be careful...it is easy to forget that you used two pieces of paper, not just one). In your lab report, compare this with the standard width of a piece of paper found via the internet.

w : _____ m Percent Difference: _____

Question 2: Why is $m=1$? Why is $\lambda = 6.3 \times 10^{-7}$ m? Discuss this in the results section of your lab report.

Unless your TA is feeling generous(which might be likely considering how long this experiment takes), repeat this experiment using only one sheet of paper and compare your answers.

Minima Distance:

x_L : _____ m x_R : _____ m

Mean Distance:

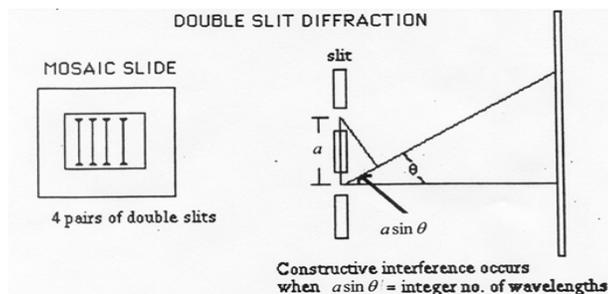
x_{mean} : _____ m

Slit Width:

D : _____ m

Paper Width:

w : _____ m Percent Difference: _____



10. **Double Slit Experiment:** The Mosaic slides provide narrow parallel slits. The ones on the bottom are the four pairs of double slits. Ask your TA to point them out if you are confused. The slits are so close together that Interference will occur(which is what we want!). The top three squares are Diffraction slits and will be used in the next part of this experiment. The formula

$$a \sin \theta = m\lambda \quad (7.3)$$

can be used to determine a .

11. Allow the Laser to pass through the 25×25 double slit. This distance(a) is approximately 4.5×10^{-5} m. On the same piece of paper as before, sketch the Diffraction pattern that is projected onto the Screen and label it diagram 2.
12. Measure the distance from the central bright fringe to the next maxima(not minima). Measure for both the left and right sides, x_L and x_R , respectively.

x_L : _____ m x_R : _____ m x_{mean} : _____ m

13. Calculate a for the 25×25 double slit

a : _____ m

14. Now allow the Laser to pass through the 25×35 double slit. This distance(a) is approximately 5.8×10^{-5} m. On the same piece of paper as before, sketch the Diffraction pattern that is projected onto the Screen and label it diagram 3.

15. Measure the distance from the central bright fringe to the next maxima(not minima). Measure for both the left and right sides, x_L and x_R , respectively.

x_L : _____ m x_R : _____ m x_{mean} : _____ m

16. Calculate a for the 25×35 double slit

a : _____ m

17. Now allow the Laser to pass through the 25×50 double slit. This distance(a) is approximately 7.5×10^{-5} m. On the same piece of paper as before, sketch the Diffraction pattern that is projected onto the Screen and label it diagram 4.

18. Measure the distance from the central bright fringe to the next maxima(not minima). Measure for both the left and right sides, x_L and x_R , respectively.

x_L : _____ m x_R : _____ m x_{mean} : _____ m

19. Calculate a for the 25×50 double slit

a : _____ m

Question 3: What do you notice happening to the Diffraction pattern? Make an educated guess as to what would happen to the pattern if the slit were to decrease in size. Make an educated guess as to what would happen to the pattern if the slit were to increase in size. Discuss this in the results section of your lab report.

20. **Diffraction Grating:** Now you will use the top three squares on the Mosaic grating. Allow the laser to pass through the 25 lines/mm grating. Notice the brightness compared to the previous parts of this experiment. On the same piece of paper as before, sketch the Diffraction pattern that is projected onto the Screen and label it diagram 5.

21. Measure the distance from the central bright fringe to the next maxima(not minima). Measure for both the left and right sides, x_L and x_R , respectively.

x_L : _____ m x_R : _____ m x_{mean} : _____ m

22. Now allow the laser to pass through the 50 lines/mm grating. On the same piece of paper as before, sketch the Diffraction pattern that is projected onto the Screen and label it diagram 6. Measure the distance from the central bright fringe to the next maxima(not minima). Measure for both the left and right sides, x_L and x_R , respectively.

x_L : _____ m x_R : _____ m x_{mean} : _____ m

23. Now allow the laser to pass through the 100 lines/mm grating. On the same piece of paper as before, sketch the Diffraction pattern that is projected onto the Screen and label it diagram 7. Measure the distance from the central bright fringe to the next maxima(not minima). Measure for both the left and right sides, x_L and x_R , respectively.

x_L : _____ m x_R : _____ m x_{mean} : _____ m

24. Use the remaining time in class to solve Question 4.

Question 4: Find a for each of the diffraction gratings. Reminder: a is now the separation of the lines on the grating and that $\#lines/mm = 1/a$. Discuss this in the results section of your lab report.

★**Honors Question A:** Why does diffraction occur?

★★**Honors Question B:** Why does the width of the slits need to be much less than the distance to the screen?

★★ **Theory — Honors Question C:** Saw you had an infinite line diffraction grating. Describe what you would see as you passed light through it. Would the light you see be continuous or would there be discontinuities?

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QUIZ 27 - Physical Optics

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Chapter 8

Polarization

8.1 A Brief History

Electromagnetic radiation that vibrates in an arbitrary plane will become polarized after passing through a polarizer. A polarizer restricts the vibration of the electromagnetic wave to a particular direction. Observing this often leads to the dimming of the light that passes through the polarizer. Sun glasses are often polarized. In today's experiment you will use polarizers to change the vibration plane of a light source.

8.2 Definitions

1. *Polarization*-A state, or the production of a state, in which rays of light or similar radiation exhibit different properties in different directions².

8.3 Laboratory Objectives

By the end of today's exercise you will understand how polarizers work and the relationship between intensity and angle difference of rotation between two polarizers.

8.4 Equipment

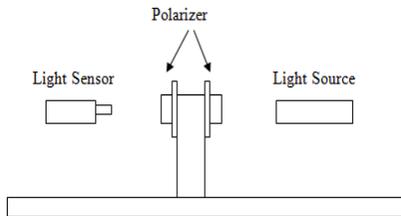
Polarization Apparatus, Datastudio

8.5 In Class Lecture

1. The TA will give a brief overview of polarization and how to set up the Polarization Apparatus.

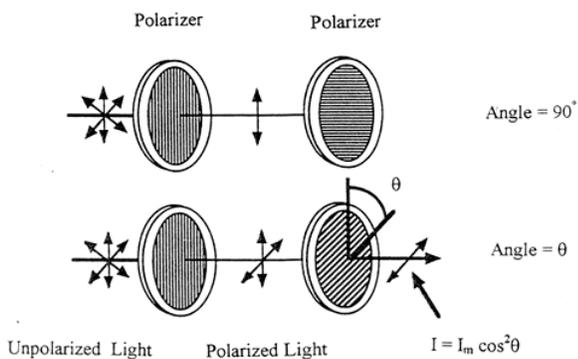
8.6 Procedure

1. The following figure gives the general idea of the setup of this experiment.



- Allocate the Polarizer apparatus to Channel A on the Datastudio physical interface. Allocate the Light Sensor icon to Channel A. Turn the light source on and place it close to one side of the double polarizer. Double click on the Light Sensor then click Calibrate. For the Low Value, rotate the two polarizers such that no light may pass through, type 0, and then click the Take Reading button. For the High Value, rotate the two polarizers such that a maximum amount of light may pass through, type 100, and then click the Take Reading button.
- Click the Options button to change the Sampling Options such that you may “Keep data values only when commanded” and give it the name Angle with Degrees for the units.
- On Datastudio, click the Start button. Click the Keep button and enter 0. Increment a polarizer of choice by 10° and then click the Keep button and enter 10. Continue to increment by 10° and Keep all values up to 180° . On Datastudio, click the Stop button.
- Drag the Run data to the Graph display. Verify that the graph displays Intensity vs Time. This is incorrect, we want Intensity vs Angle. Drag the Angle data to the Horizontal Axis in the graph display. If the graph is smooth, take a screenshot and paste the screenshot in Paint. Save the image to your flash drive and use it for your lab report. If the graph is not smooth, repeat the experiment. It is vital that the graph be smooth.
- Use the time remaining to calculate the $\cos^2 \theta$ of each angle above. Now using a graphing program of your choice, plot Intensity vs $\cos^2 \theta$ and put this graph in your lab report.

Question 1: When dealing with light intensity and polarizers, why is the $\cos^2 \theta$ important? Hint: See the image below and also review your coursework. Discuss this in the results section of your lab report.



★**Honors Question A:** A polarized sheet and an analyser are placed such that their transmission axes are co-linear. The analyser is then rotated by 22.5° . What is the irradiance of the transmitted light as a fraction of its previous value?

★★**Honors Question B:** You have three ideal linear polarizers. Light of irradiance 1500 W/m^2 is shone through two of the polarizers, with their transmission axes placed at a relative angle of 40° . What is the intensity of the transmitted light? Now place the third polarizer at an angle of 20° between the other two. What is the irradiance?

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QUIZ 28 - Polarization

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Chapter 9

Atomic Spectra

9.1 A Brief History

A spectral line of an element is the same as a human fingerprint. No two elements share the same series of spectral lines therefore if we chose to look at a star we could, in theory, determine the individual elements which made up the star. Ionizing an elemental gas will allow it to emit photons. Sending these photons through a prism or diffraction grating will separate the colors. Cataloguing the angular displacement of these lines will give the elemental signature.

9.2 Notes

1. This experiment will be done in the dark because the spectral lines are incredibly difficult to see. Allow your eyes to adjust before valiantly trying to find phantom spectral lines.

9.3 Definitions

1. *Spectra*-The entire range over which some measurable property of a physical system or phenomenon can vary, such as the frequency of sound, the wavelength of electromagnetic radiation, or the mass of specific kinds of particles.¹ ¹Definitions were provided by *The American Heritage Science Dictionary*

9.4 Laboratory Objectives

By the end of today's exercise you will understand that each element produces a different series of spectral lines and how we may observe these.

9.5 Equipment

Spectrometer, Transmission Diffraction Grating, Grating Holder, Mercury Light Source, Hydrogen Discharge Tube, and a Power Supply

9.6 In Class Lecture

1. The TA will give a brief overview of spectral lines and also a demonstration on how to set up the apparatus and pro-tips on where to look for spectral lines.

9.7 Procedure

1. Set up the Mercury lamp such that the light passes through the entrance slit of the collimator on the spectrometer. Adjust the eyepiece of the spectrometer such that you can view directly down the passage of the slit. Adjust the position of the source and the size of the slit to get maximum light while maintaining a knife edge narrow slit.
2. Once the light passing through has been optimized, place the given diffraction grating on the center of the spectrometer. Swing the eye piece to either side to find what is called the “first order” diffraction line; which consequently should be green. Record the angular position using the angle marks located on the bottom of the device.

θ_L : _____^o

3. Rotate to the opposite and equal angle to observe the “other” first order diffraction line. This part of the experiment is similar to experiment you completed in chapter 27 involving the double slits. Record this value.

θ_R : _____^o

4. Now find the average of θ_L and θ_R . The average of these two is θ .
5. The wavelength of the green light line you observed is **546.07 nm**. We know that the following relation holds for diffracted light:

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

where n is the order of light observed, λ is the usual wavelength, d is the grating constant, and θ is the average of the left and right angle deviations. Calculate the grating constant d .

d : _____ nm

6. Now turn off the Mercury lamp and replace it with the Hydrogen Lamp. Find three spectral lines and their respective colors.

First Order:

θ_1 : _____^o Color: _____

Second Order:

θ_2 : _____^o Color: _____

Third Order:

θ_3 : _____^o Color: _____

7. All of the lines that you observed are a part of the Balmer series. Calculate the wavelength associated for each color using a formula derived from your coursework:

$$\frac{1}{\lambda} = R \left(\frac{1}{2^2} - \frac{1}{n^2} \right) \quad (9.1)$$

where λ is the wavelength, R is the Rydberg Constant ($1.09 \times 10^7 \text{ m}^{-1}$), 2^2 is intrinsic of the Balmer series, and n is the order of the diffraction line.

λ_1 : _____ m λ_2 : _____ m λ_3 : _____ m

8. Use the remaining class time to experimentally calculate the Rydberg constant using the data you have gathered so far and then find the percent difference between your value and the theoretically accepted value. Show all work and staple this sheet to your lab report for next week.

★**Honors Question A:** Use the wavelength of mercury and methods developed previously to calculate a grating constant, d . d should be somewhere around 1640-1660 nm

★★★**Honors Question B:** Calculate an experimental value of the Rydberg Constant using your experimental data.

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QUIZ 29 - Atomic Spectra

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Chapter 10

Photoelectric Effect

10.1 Background

The photoelectric effect was observed in 1887 by Hertz and was first fully described by Albert Einstein in 1905. Quite simply, photons incident on a metal can induce a current. Determining why the photons can create a current is not a trivial task. It was so non-trivial that when Albert Einstein published his paper on the subject that he won the Nobel Prize. On a side note, Albert Einstein could have won the Nobel Prize for any of the three papers he published: Special Relativity, Brownian Motion, and the Photoelectric Effect.

10.2 Laboratory Objectives

By the end of today's exercise you will understand how it is the frequency of light that dictates emission-not the number of photons.

10.3 Equipment

Photoelectric Effect Current Inducer, Voltmeter, Mercury Arc Lamp, Helium Neon Laser, and Various Color Filters.

10.4 Procedure

1. Plug the Photoelectric Module in. Locate the opening hole in the Photoelectric Module. When light enters this hole and strike the semi-circle metal surface electrons will be emitted. Use a solid opaque cover to cover the hole and then calibrate the meter reading to 0. Make sure that the voltage has also been adjusted such that it reads 0 V in this state.
2. Plug the Mercury Arc Lamp in and align it so that it is facing the Photoelectric Module opening. The Mercury Arc Lamp should be about 13 cm from the Photoelectric Module opening. Replace the solid opaque cover with a Blue Filter. Adjust the positions of the devices such that you get a maximum reading. Record the reading.

I_b : _____ A

3. With the devices at their optimum distance, i.e. the maximum reading you took in the previous step, increase the anode voltage. Make note of the units of the photocurrent. Does this make sense? Measure the photocurrent as a function of the anode voltage. Once the photocurrent reaches zero, do not take

further measurements. Record five readings for the photocurrent and corresponding voltage:

I_1 : _____ I_2 : _____ I_3 : _____ I_4 : _____ I_5 : _____

V_1 : _____ V_2 : _____ V_3 : _____ V_4 : _____ V_5 : _____

4. Set the anode voltage to **0 V** manually and then place the lamp at a distance away such that the current is *half* of what it was previously. Repeat your measurements.

I_6 : _____ I_7 : _____ I_8 : _____ I_9 : _____ I_{10} : _____

V_6 : _____ V_7 : _____ V_8 : _____ V_9 : _____ V_{10} : _____

5. Replace the blue filter with a green filter and repeat the experiment.

I_1 : _____ I_2 : _____ I_3 : _____ I_4 : _____ I_5 : _____

V_1 : _____ V_2 : _____ V_3 : _____ V_4 : _____ V_5 : _____

6. Set the anode voltage to **0 V** manually and then place the lamp at a distance away such that the current is *half* of what it was previously. Repeat your measurements.

I_6 : _____ I_7 : _____ I_8 : _____ I_9 : _____ I_{10} : _____

V_6 : _____ V_7 : _____ V_8 : _____ V_9 : _____ V_{10} : _____

7. Replace the green filter with a red filter and repeat the experiment.

I_1 : _____ I_2 : _____ I_3 : _____ I_4 : _____ I_5 : _____

V_1 : _____ V_2 : _____ V_3 : _____ V_4 : _____ V_5 : _____

8. Set the anode voltage to **0 V** manually and then place the lamp at a distance away such that the current is *half* of what it was previously. Repeat your measurements.

I_6 : _____ I_7 : _____ I_8 : _____ I_9 : _____ I_{10} : _____

V_6 : _____ V_7 : _____ V_8 : _____ V_9 : _____ V_{10} : _____

9. Make note now that the following combinations will be used: Mercury with blue filter at **405 & 436 nm**, Mercury with green filter at **405 & 546 nm**, and finally the Laser with red filter at **632.8 nm**. (What is the wavelength of a red laser?)

10. Convert all meter readings to photocurrent. Recall that a **0 mA** meter reading equals **50 nA** photocurrent. You may use the space below.

Question 1: Plot and label photocurrent versus anode voltage for high level blue light, low level blue light, green filtered light, and red filtered light. Include these plots and discuss this in the results section of your lab report.

Question 2: For the three filtered measurements, estimate the stopping voltage. Discuss this in the results section of your lab report.

Question 3: The blue filter allows two wavelengths of the mercury spectrum to pass. Why? Calculate the average frequency for the blue light. Plot the three stopping voltages as a function of frequency of the colored light. Use the wavelengths and convert these to frequency. Include these plots and discuss this in the results section of your lab report.

For question 3, recall that you may use the equation for average frequency:

$$f_{avg} = \frac{f_1 + f_2}{2} = \frac{c}{2} \left(\frac{1}{\lambda_1} + \frac{1}{\lambda_2} \right)$$

Recall also that the equation for stopping voltage is given by

$$eV_s = hf - \phi$$

where e is the charge of an electron, V_s is the stopping voltage, h is planck's constant, f is the frequency of light, and ϕ is the work function.

Question 4: From the previous question, estimate the value for planck's constant and compare it to the accepted value. Show why the slope of the plots you made is equal to $\frac{h}{e}$. Using your value of planck's constant, determine the work function ϕ and determine the x-intercept on your plot. Don't panic, this is just an equation of a line. Discuss this in the results section of your lab report.

Question 5: Is stopping voltage independent of the intensity of incident light? Discuss this in the results section of your lab report.

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QUIZ 30 - Photoelectric Effect

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