

## LABORATORY VII: WAVE OPTICS

In this lab, you will solve problems in ways that take advantage of light interference, a phenomenon most easily understood in terms of the wave nature of light. Like waves, light can interfere constructively and destructively with itself. Under some conditions, this causes distinctive patterns of light and dark fringes that would not be seen if light had no wave-like behavior. These conditions may be less familiar to you than the conditions for which geometrical optics is useful. The results of interference can, however, be seen in common situations such as the colored fringes that form in parking lot puddles where a thin layer of oil floats on the water, or the colored light patterns that reflect from a compact disc.

### OBJECTIVES:

After successfully completing this laboratory, you should be able to:

- Describe interference patterns in terms of constructive and destructive interference.
- Predict how changes in the size of an object or slit, or the wavelength of the light, will affect interference patterns.

### PREPARATION:

Before coming to lab, read Sections 2 and 3 of Chapter 13, Sections 1 and 2 of Chapter 14, and Sections 1-3 and 6-9 of Chapter 27 in Serway & Jewett. Keep the objectives of the laboratory in mind as you read the text. It is likely that you will do these laboratory problems before your lecturer addresses this material; the purpose of this laboratory is to introduce you to the material.

Before coming to lab you should be able to:

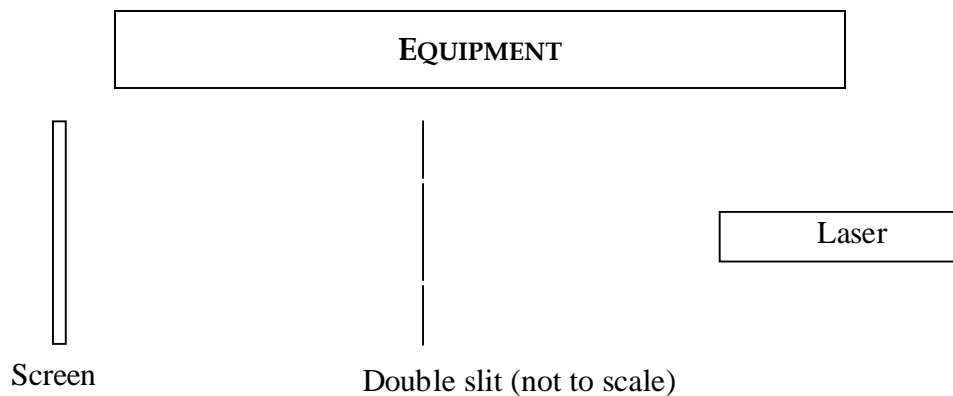
- Find unknown quantities using trigonometric relationships.
- Relate constructive and destructive interference of two waves to phase differences between the two waves.
- Describe why laser light is described as coherent.
- Create graphs of measured quantities and determine the equation describing linear relationships between graphed quantities.

## PROBLEM #1: INTERFERENCE DUE TO A DOUBLE SLIT

Your group is involved in a project investigating some properties of viruses. You need to categorize viruses by size, but have found that they are too small to view with any microscope that uses visible light. You know, however, that for a small object illuminated by coherent light, a diffraction pattern will be formed rather than an image. The size of an object can be determined from its diffraction pattern, and you would like to try a diffraction technique with viruses.

Two issues occur to you. The first issue is, of course, how to determine the size of an object from its diffraction pattern. The second issue has to do with the form in which the viruses will be studied. Your group can isolate a single *type* of virus, but cannot isolate a single *example* of the virus. As a result, you will be forced to study the pattern produced by several viruses in very close proximity to one another. You hope that some information about the size of a single virus can be extracted from the pattern formed by many viruses. If the technique is to be useful, you must be able to distinguish the diffraction pattern due to a *single virus* from the pattern that results from *several copies* of the same type of virus.

In this problem and the next one, you will study light interference in a simplified system to explore how these two issues can be dealt with. You will deal with the second issue first. In this lab problem, you will investigate the interference pattern due to more than one object. In the next lab problem, you will develop a technique for determining the size of an object from its diffraction pattern. In this lab problem, a Helium Neon laser will be the light source, and pairs of closely spaced slits will represent the viruses. In this model you are interested in what pattern is formed on a screen by coherent light that passes through a pair of narrow slits and how that pattern depends on the separation of the slits.



For this problem, you will be provided with a Helium Neon laser, a slide with four sets of double slits, a magnetic slide holder, a screen, an optical bench, and a ruler.

**PREDICTION**

Write an expression describing the double-slit interference pattern that relates the vertical positions of interference maxima on the screen to: the distance between the slits, the distance between the slide and the screen, and the wavelength of the laser's radiation. (For this prediction, do not include the effects of single slit diffraction. You will deal with those effects in the next lab problem.)

**WARM-UP**

Read Serway & Jewett: sections 27.1, 27.2, 27.3.

1. Draw a sketch of the arrangement you will use to project an interference pattern on the screen. Include laser, laser beam, slits, and screen.
2. Draw another diagram with an enlarged view of the slits and the screen. Show a laser beam wave front reaching the slide. Are the parts of the wave front that reach the two slits in phase? If they are out of phase, determine the phase difference between them.
3. Indicate the point on the screen that is equidistant from the two slits. Label this as  $O$ . Are the parts of the wave front that reach  $O$  from the bottom slit and the top slit in phase? If they are out of phase, determine by how much. Choose another point  $P$  on the screen. Are the parts of the wave front that reach  $P$  from the two slits in phase? If they are out of phase, determine the relative phase difference. Is this determination simplified if you assume that the distance between the slide and the screen is much larger than the distance between the slits? If so, explain.
4. What condition must the phase difference meet to produce a bright spot in the interference pattern? Use your diagram to write an expression for the vertical distances (above or below  $O$ ) to the points where interference maxima should be produced. What condition must the phase difference meet to produce a dark spot in the interference pattern? Write an expression for the distances to interference minima.
5. Should the minima (or maxima) be equally spaced from one another? Write an expression for the wavelength of the incident light, in terms of the spacing between minima (maxima).
6. Sketch a graph, showing light *intensity vs. position* on the screen. Identify positions of interference maxima and minima.
7. What should happen to the distances between bright spots if the spacing between the slits is doubled? What should happen if the distance from the slits to the screen is doubled?
8. What pattern would you expect to see on the screen if light from the two slits did not interfere? Could you distinguish between this pattern and the one shown in your graph?

### EXPLORATION

**Warning:** *Laser beams may cause permanent vision impairment or blindness.*

**Do NOT allow the laser beam (or its reflection) to point into anybody's eye. To avoid stray beams in the laboratory, make sure beams from your laser terminate on a screen at all times.**

Laser beams are extremely intense compared to light from any common light source (even compared to sunlight, as viewed from earth). While it might seem that the beam is not very bright, it is well parallel. Your eye lens will focus all of the beam's power into a small spot on your eye's retina. Before your blink reflex functions, enough energy will be absorbed to temporarily damage the spot. Permanent blindness may result from prolonged exposure to any laser beam, even those from small laser pointers.

Turn on the laser and open the shutter. Let it warm up for a few minutes to achieve a stable beam. Arrange the laser and the slide with double slits on the optics bench. The laser should be parallel to the optics bench and perpendicular to the slide, and its beam should be aimed at one of the pairs of slits. The screen should be vertical and perpendicular to the optics bench.

By inspection, make sure both slits are illuminated approximately equally. Adjust the positions so that you clearly observe an interference pattern on the screen.

How does the interference pattern compare with your predictions? Which features did you predict, and which ones did you not predict?

Some of the features you see may be the effect of light from one slit interfering with light from the other slit. Other features may be the effect of light from one part of a slit interfering with light from another part of the same slit. There are four pairs of slits on the slide, with different slit widths and different separations between the slits. Use these to make a judgment about which features of the interference pattern are due to each type of interference.

How does the interference pattern change for different slit separations? How does the pattern change when you adjust the distance from the slits to the screen? Do your observations match your predictions?

How important do you think is laser light for this problem? If possible, try illuminating the slits with an alternative light source. Do you still see the interference/diffraction picture? Record your results.

<b>MEASUREMENT</b>
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Continuing your exploration, sketch the interference patterns for two pairs of slits with the same slit widths and different slit separations.

Place a sheet of paper on the screen as a recording device. On the paper, label positions of the maxima you can observe. Be sure to record the distance from the slits to the screen. Repeat this operation, for the two pairs of slits, for at least two different distances between the screen and the slits. (Be sure to record the distance from the slits to the screen each time, and the widths and separations of the slits reported on the slide.)

Measure the positions of the interference maxima for each trial.

<b>ANALYSIS</b>
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Compare the sketches you prepared during measurement to the graphs from your warm-up questions answers. Do the patterns match?

Use your measurements from each trial and your predicted relationships to determine the wavelength of the laser light. Do you obtain a consistent value across different trials? If so, is it comparable to the accepted value for the wavelength of light produced by a Helium Neon laser?

CONCLUSION
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Can you tell which features of a two-slit interference pattern are caused by light from one slit interfering with light from the other slit? Can you distinguish them from the features due to light from part of one slit interfering with light from another part of the same slit? Explain.

Do your results allow you to *rule out* the possibility of determining the size of a single virus from the pattern due to several copies of the same virus in close proximity to one another? Explain.

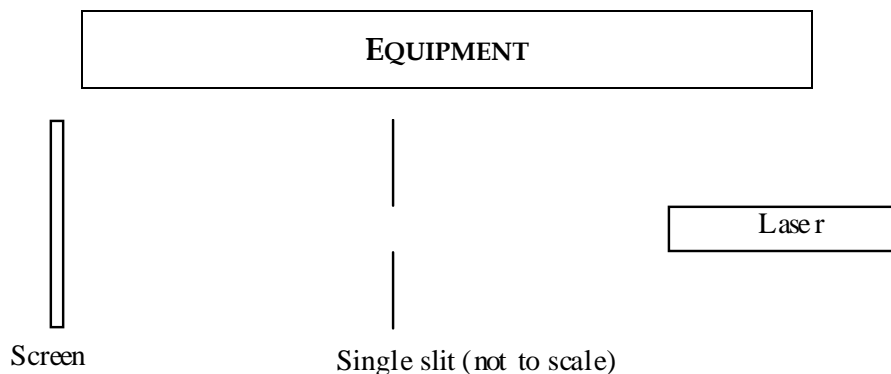
The size of common viruses is on the order of  $10^{-6}$  m to  $10^{-8}$  m. When determining virus size with an interference technique, would it be helpful to use light with a different wavelength from the one you used for this problem? If so, explain why.

## PROBLEM #2: INTERFERENCE DUE TO A SINGLE SLIT

Your group is involved in a project investigating some properties of viruses. You need to categorize viruses by size, but have found that they are too small to view with any microscope that uses visible light. You know, however, that for a small object illuminated by coherent light, a diffraction pattern will be formed rather than an image. The size of an object can be determined from its diffraction pattern, and you would like to try an interference technique with viruses.

Two issues occur to you. The first issue is, of course, how to determine the size of an object from its diffraction pattern. The second issue has to do with the form in which the viruses will be studied. Your group can isolate a single *type* of virus, but cannot isolate a single *example* of the virus. As a result, you will be forced to study the pattern produced by several viruses in very close proximity to one another. You hope that some information about the size of a single virus can be extracted from the pattern formed by many viruses. If the technique is to be useful, you must be able to distinguish the diffraction pattern due to a *single virus* from the pattern that results from *several copies* of the same type of virus.

In the previous problem and this one, you study light interference in a simplified system to explore how these two issues can be dealt with. You dealt with the second issue first, in the previous problem. In the present lab problem, you will develop a technique for determining the size of a single object from its diffraction pattern. A Helium Neon laser will be the light source, and a narrow slit will represent a virus. You are interested in what type of diffraction pattern is formed and how the pattern depends on the width of the slit.



For this problem, you will be provided with a Helium Neon laser, a slide with four individual slits of different widths a second slide with four pairs of double slits, a magnetic slide holder, a screen, an optical bench, and a ruler.

**PREDICTION**

Write an equation describing the single slit diffraction pattern that relate the positions of diffraction maxima on the screen to: the width of the slit, the distance between the slide and the screen, and the wavelength of the laser's radiation.

**WARM-UP**

Read Serway & Jewett: 27.1, 27.2, 27.3, 27.6, 27.7.

1. Draw a sketch of the arrangement you will use to project a diffraction pattern on the screen. Include laser, laser beam, slit, and screen.
2. Draw another diagram with an enlarged view of the slit and the screen. Show a laser beam wave front reaching the slide. Are the parts of the wave front that reach different parts of the slit in phase? If they are out of phase, determine the phase difference between them.
3. What condition must be met for a maximum to occur in the diffraction pattern for a single slit? What condition must be met for a minimum to occur? How can these conditions be understood in terms of the situation's geometry and the properties of light waves?
4. Indicate the point on the screen that is equidistant from the two slits. Label this as  $O$ . Is  $O$  a diffraction maximum or minimum? Choose another point  $P$  on the screen. Indicate on your diagram how you would determine if  $P$  were a diffraction maximum or minimum. Is this determination simplified if you assume that distance from the slide to the screen is much larger than the slit width? If so, explain.
5. Use your diagram to write an expression for the distances (above or below  $O$ ) to the points where diffraction maxima should be produced. Write another expression for the distances to diffraction minima. Write a third expression for the wavelength of the incident light, based on positions of maxima or minima.
6. Sketch a graph, showing *light intensity vs. position* on the screen. Identify positions of diffraction maxima and minima.
7. What should happen to the distances between bright spots if the width of the slit were doubled? What should happen if the distance from the slits to the screen is doubled?
8. Does the width of the slit place a restriction on the maximum amplitude or wavelength of a light wave that could pass through the slit? If so, illustrate the limits below your diagram, and describe how you expect this might affect the observed diffraction pattern.

### EXPLORATION

**Warning:** *Laser beams may cause permanent vision impairment or blindness.*

**Do NOT allow the laser beam (or its reflection) to point into anybody's eye. To avoid stray beams in the laboratory, make sure beams from your laser terminate on a screen at all times.**

**Laser beams are extremely intense compared to light from any common light source (even compared to sunlight, as viewed from earth). While it might seem that the beam is not very bright, it is well parallel. Your eye lens will focus all of the beam's power into a small spot on your eye's retina. Before your blink reflex functions, enough energy will be absorbed to temporarily damage the spot. Permanent blindness may result from prolonged exposure to any laser beam, including those from small laser pointers.**

Turn on the laser and open the shutter. Let it warm up for a few minutes to achieve a stable beam.

Arrange the laser and the slide with single slits on the optics bench. The laser should be parallel to the optics bench and perpendicular to the slide, and its beam should be aimed at one slit. The screen should be vertical and perpendicular to the optics bench. Adjust the positions so that you clearly observe a diffraction pattern on the screen.

How does the diffraction pattern compare with your predictions? Which features did you predict, and which ones did you not predict?

How does the diffraction pattern change for different slit widths? How does the pattern change when you adjust the distance from the slit to the screen? What happens if you rotate the slit from a vertical to a horizontal position? Do your observations match your predictions?

How does the diffraction pattern of a single slit compare with the diffraction pattern of a pair of slits with the same width? Does this bode well for the virus project? Do you think the laser is important for this problem? Do you have any other sources of light to try instead of laser? What do you see?

### MEASUREMENT

Continuing your exploration, sketch the diffraction patterns for two different slit widths.

Fix a sheet of paper on the screen. Mark maxima of diffraction pattern on the screen. (If the maxima are difficult to locate visually, mark some positions so that the central part of each spot can be precisely determined from the marks.) Be sure to record the slit width and the distance from the slit to the screen.

Repeat this operation for at least two different distances and at least two different slit widths.

Remove the slit from the system, and observe the pattern produced when laser light shines on a human hair. Do you see a diffraction pattern? Measure and record the distance from the hair to the screen, as well as the positions of the diffraction maxima.

### ANALYSIS

Compare the sketches you prepared during measurement to the graphs from your warm-up questions answers. Do the patterns match?

Use your measurements and the relationships from the prediction to determine the wavelength of the laser light from each trial. Do you obtain a consistent value across different trials? If so, is it comparable to the accepted value for the wavelength of light produced by a Helium Neon laser?

The diffraction pattern due to a solid object (a hair, for example) is the same as that due to a hole of the same shape. Use your measurements to determine the width of your hair.

### CONCLUSION

Do the expressions you predicted match the diffraction patterns you observed? If they do not match perfectly, identify some sources of error, and explain how they could result in the observed errors.



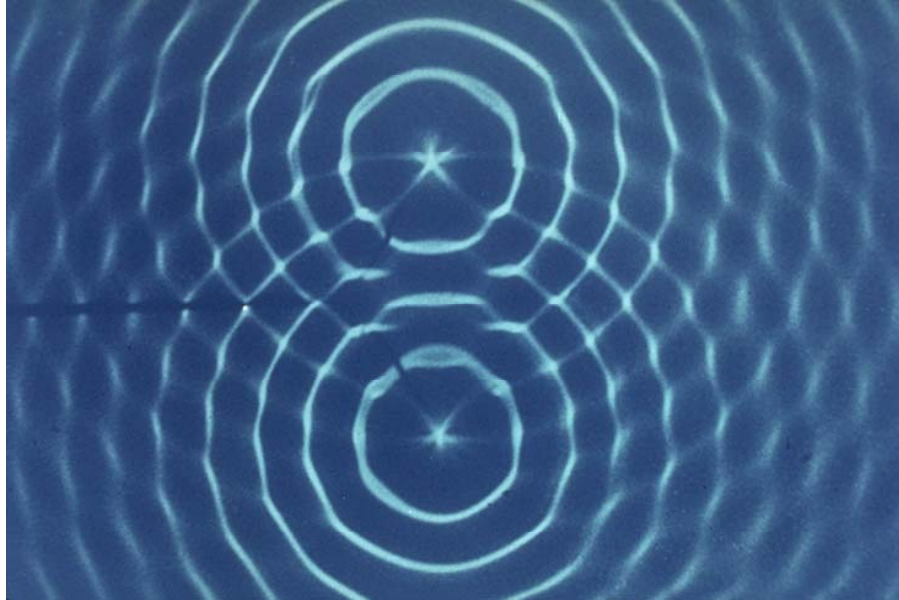
Do your observations provide evidence for the wave nature of light?

Does your measurement of hair thickness match an order-of-magnitude estimate of hair thickness based on direct observation? Explain your estimate.

What do you need to know to determine an object's size from the diffraction pattern it produces?

Compare the results of this problem to the results of the previous problem. How closely connected are the features of a single slit diffraction pattern to those of a double slit interference pattern?

CHECK YOUR UNDERSTANDING



The picture above shows a series of circular water waves emanating outward from two points. The waves interfere with one another. Refer to the picture for questions 1-5 below.

1. On the picture, indicate the wavelength of these waves.
2. Draw lines to show where the waves are *constructively* and *destructively* interfering. How many interference *maxima* are there along the right edge of the picture?
3. What are the phase-difference requirements for constructive or destructive interference? Demonstrate at several points how these requirements are met in the picture above.
4. How would the interference pattern change if the wavelength were shortened?
5. How would the interference pattern change if the wave sources were moved closer together? What would happen if the wave sources were located on top of each other – at a single point?

# PHYSICS 1202 LABORATORY REPORT

## Laboratory VII

Name and ID#: \_\_\_\_\_

Date performed: \_\_\_\_\_ Day/Time section meets: \_\_\_\_\_

Lab Partners' Names: \_\_\_\_\_

\_\_\_\_\_

Problem # and Title: \_\_\_\_\_

Lab Instructor's Initials: \_\_\_\_\_

Grading Checklist	Points
<b>LABORATORY JOURNAL:</b>	
<b>PREDICTIONS</b> (individual predictions and warm-up completed in journal before each lab session)	
<b>LAB PROCEDURE</b> (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
<b>PROBLEM REPORT:*</b>	
<b>ORGANIZATION</b> (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
<b>DATA AND DATA TABLES</b> (clear and readable; units and assigned uncertainties clearly stated)	
<b>RESULTS</b> (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
<b>CONCLUSIONS</b> (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
<b>TOTAL</b> (incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
<b>BONUS POINTS FOR TEAMWORK</b> (as specified by course policy)	

\* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.

