The Wave Nature of Light

Physics 126L Spring 2025

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Lab report due **Saturday, May 3, at 11:55 P.M.**

Introduction

The coherence length of sunlight, and similarly artificial white lights, is only about 1 μm. In addition, typical light sources have significant angular extent. As one example, the sun subtends about 0.5°. Because of these two characteristics of the most commonly encountered illumination, we rarely see direct manifestations of the wave nature of light in everyday experience. When they do appear, for example in reflections from soap bubbles or diffraction from a CD or DVD, the result is often a striking display of color.

Because there are so few common situations in which the behavior of light cannot be explained completely by reflection, refraction, and straight-line travel, it took scientists well over a hundred years of careful study before the wave theory was accepted and physical optics was given a firm foundation. Although both diffraction and interference were demonstrated by Francesco Grimaldi in the mid 1600s, Isaac Newton was not convinced by the wave theories of the time, and in his 1704 book *Opticks*, he advanced a "corpuscular" theory of light particles.

It took another hundred years before Thomas Young (as in Young's Modulus) made, carefully documented, explained, and presented a series of measurements during the first decade of the 1800s that firmly established the wave character of light.[1] Nevertheless, Newton's incomparable reputation and several prominent skeptics in the scientific community delayed acceptance of the wave theory until a decade later when Augustin-Jean Fresnel gave a complete and convincing explanation of diffraction and interference. His work finally convinced the remaining skeptics that the wave explanations were correct.

In this lab we will see how coherence determines when we can and cannot see interference and diffraction patterns, and we will replicate the original experiments that convinced the world that light acts as a wave.

Assembling and testing the equipment

You should have the following equipment:

[1] Some of Young's writings can be found in a handout on the web page for this experiment.

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1. 405 mm drilled PVC pipe
2. Copper wire: 32, 36, and 40 AWG
3. Laser printed slits
4. Aluminum foil
5. A pin
6. Plastic mesh #1
7. Plastic mesh #2

Many of the items are small and easy to lose, especially the wire, pin, and plastic mesh, so be careful.

1. Cut a 75 mm length of each copper wire.
2. Pass one of the wires through both of the radial holes near one end of the pipe so that it is recessed by about 5 mm from the end. Center the wire so that equal amounts stick out from the two holes.
3. Tape one end of the wire to the outside of the pipe. Pull it gently so that it is stretched across the inside of the pipe, then tape the other end to the opposite side of the outside of the pipe.
4. In this experiment you will measure a number of different apertures, each of which can be taped to one end of the pipe. Except for the wires this is not required, but you might find it convenient.
5. Using a pin, make several small holes in the aluminum foil. Leave at least 1 cm between each pinhole and the edge, and practice until you get a very small, round hole. It will probably help to rotate the needle as you push it into the foil.
6. We will use two light sources for this experiment, a 635 nm laser diode and an LED. You should try these test exercises before you attempt to do quantitative measurements:
   - Shine the laser on a distant (> 2 m) light-colored non-reflective surface. **Do not shine the laser toward your eye.** Focus the laser to the smallest possible spot by turning the output end of the case. Then place the end of the pipe with the wire directly in front of your eye and observe the laser spot through the pipe. As you pass the wire in front of the spot, you should see a diffraction pattern perpendicular to the wire.
   - Once you are able to see the diffraction pattern with the laser, place the LED several meters from where you will be observing and turn it on. Find the diffraction pattern as you did with the laser. It is helpful to have a dark background. See the pictures below.

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Measuring angles

We will be measuring the light patterns produced by diffraction and interference. Typically these patterns are described by the angular variation of irradiance and color in the "far field," many wavelengths away from the source and aperture. Here are three methods you can use to measure maxima and minima in diffraction and interference patterns:

1. To get a rough estimate of an angle in the pattern, you can compare the feature of interest with the angle subtended by the aperture at the far end of the pipe. In radians, this angle is approximately 34.5 mm/405 mm.

2. Place a piece of paper with distance markings on a wall, then put the source at the center of the paper. Observe the pattern at a known distance from the wall, and measure the pattern using the markings on the paper. Convert distance on the paper and distance from the wall to an angle.

3. Obtain a camera app for your phone or tablet that has manual focus, or use the Raspberry Pi camera. With either the manufacturer's specifications or a calibration of your own design, determine the plate scale of your camera (the angle in the field of view that corresponds to a single pixel on the sensor). Set up the source at least a few meters away, then manually focus the camera so that the source appears sharp in the image. Photograph a diffraction pattern by holding the aperture, for example the pipe with wire, in front of the camera lens. This may require some practice. Using Gimp (free) or another image analysis program, measure the size of the diffraction pattern in pixels and convert to an angle. Save your photos. If done correctly, this is far and away the most precise and accurate of the three suggested methods.

Measuring diffraction, interference, and spatial coherence

Here are the measurements you should make:

1. Using the diffraction patterns from the three wires, determine the average wavelength of the light from the LED. You can practice with the laser, since you already know its wavelength. In keeping with *Babinet's Principle,* the diffraction pattern produced by a wire is the same as the pattern you would get from a single slit of the same width.

2. Measure the spectral width of visible light using the LED and the best of the three wire diffraction patterns. You may have large uncertainties here, so don't forget to estimate them.

3. Laser-printed aperture A is a single slit. With the focused laser spot as your source (see above), use diffraction to measure the width of slit A. To see the pattern, look directly at the laser spot (**NOT into the beam!**), for example on a wall. Put the slit between your eye and the spot, and move the slit as close to your eye as necessary to see the pattern. You must have the slit exactly on the line between your eye and the spot to see the pattern. Once you have found the pattern with your eye, manually focus your camera on the spot. Put the slit between the camera lens and the spot, then use the screen or viewfinder to find the pattern and take a photo. Slit B has the easiest pattern to see if you are having trouble.

4. With a focused laser spot as your source, measure the two-slit interference patterns from laser-printed apertures B and C. Compare with theory and determine the slit spacings.

5. The two pieces of plastic mesh consist of nylon wire woven into very fine square grids. This is equivalent to having two perpendicular diffraction gratings. With a focused laser spot as your source, use diffraction to determine the wire spacing for both pieces of mesh.

6. With a focused laser spot as your source, observe the Airy disk diffraction pattern from your foil pinhole. Measure the pattern to determine the diameter of your pinhole.

7. Starting close to the LED, observe and describe how the diffraction pattern from one of the pieces of plastic mesh changes as you move away from the LED, its angular size gets smaller, and its spatial coherence width increases.

8. With one of the laser printed double slits and an LED, determine the distance r from the slits to the LED at which the interference pattern vanishes (the fringe visibility goes to zero). Using the diameter of the LED and r, determine the angle θ subtended by the LED at distance r. Review the discussion on pages 238–241 of the *Pedrotti* textbook excerpt, especially Eq. (38) and Example 3. Using what you have measured, determine the spacing for the double slit you used. Assume the source wavelength λ is the average value for visible light, 550 nm. How does this measurement of the slit spacing compare with your previous one using interference?

9. With your measured slit spacing and the LED behind the pinhole as your source, use spatial coherence to determine the size of the pinhole. Compare with your Airy disk measurement of the pinhole.

10. **Extra credit:** measure the width of a human hair using diffraction. What do you expect to see if you look at sunlight reflecting off of someone's hair?

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Report suggestions

1. The illumination patterns produced in the far field ("Fraunhofer diffraction") by various apertures are typically described by giving irradiance as a function of angle. The angle is measured between the optical axis and the light heading *away* from the aperture. You could measure this angle directly, for example by shining your laser through the plastic mesh onto a wall. Instead, however, the three suggested methods of measurement above all have the observer looking back *toward* the aperture. Can you explain why this gives the same result?

2. What are the sources of uncertainty when measuring a diffraction or interference pattern with a cell phone camera? Is the mapping from angle as seen by the lens to pixel position perfect?

3. If you were to use an LED as the light source for a Michelson Interferometer, what would you need to do to obtain fringes that is not necessary with a laser?

4. Include as many pictures as possible in your report. It is very helpful when reporting this type of measurement to annotate the photo, for example with angle markings. This can be done in Gimp or another image editor.

5. **Extra credit:** explain the spikes radiating from the central maxima in the photos above with black backgrounds.

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