

UCD: PHYSICS 9HC LAB



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UCD: Physics 9HC Lab

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Licensing

A detailed breakdown of this resource's licensing can be found in [Back Matter/Detailed Licensing](#).

CHAPTER OVERVIEW

1: Traveling Waves on Strings

[1.1: Background Material](#)

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1.1: Background Material

Text References

- [waves on strings](#)
- [wave reflection](#)

The Simulator

This activity uses a simulator to generate data what we would normally get in a laboratory setting with real devices. This simulator runs in HTML and it should work fine in all browsers.

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1.2: Activities

Things You Will Need

All you will need for this lab is [this PhET simulator](#). **Go ahead and run this simulator now in another window for use in the activities below.**

Using the Simulator

This software simulates transverse wave motion along a one-dimensional medium (a string of beads). We'll start by configuring the simulator to start this lab...

- select the "Pulse" radio button in the upper-left corner
- leave the "Fixed End" radio button selected in the upper-right corner
- select the "Rulers" and "Timer" check boxes in the lower-right corner
- set the "Amplitude" equal to 1.00cm
- set the "Pulse Width" equal to 1.00s (the maximum)
- set "Damping" to "None" (the minimum)
- set "Tension" to "Low" (the minimum)

There are several features available that may help you with your tasks:

- The rulers and timer can be dragged-and-dropped around the screen for more accurate measuring (we will not need the vertical ruler, however).
- The "Slow Motion" radio button may come in handy if the wave is moving too fast for your purposes.
- You can set the apparatus so that the timer starts at the same moment as the pulse as follows:
 - From a fresh restart, press the pause simulation button  (this will reveal the play simulation button .
 - Press the start timer button  (this will reveal the stop timer button ). Notice that the timer does not start with this click.
 - Now clicking the pulse button will start the simulation, initiating a pulse and starting the timer at the same time.
- Pausing the simulation at any moment allows for easy length measurements and time stamps.
- You may want to advance the wave incrementally, to make measurements easier. You can step the simulator from a paused state using the step simulator button .

A Simple Observation

We'll start the experiment with nothing more than an observation:

1. Describe a feature that distinguishes the reflection of a wave pulse (a bump in the spring) off a fixed end from a reflection off a loose end.
2. Does this reflection rule apply to waves that are more complicated than a simple bump? (You can switch the mode to "Manual" for this.) Provide a basic before/after reflection sketch (please don't submit a picture or a screen capture) of a wave you tried in the simulator that demonstrates your answer.

Computing the Tension

Playing with the tension slide bar reveals that there are only three settings – the "Low" and "High" labeled, and one unmarked setting between them. One might be inclined to assume that these are evenly-spaced (i.e. that the middle setting is the average of the low and high tensions), but it is dangerous to do so when the settings are not labeled. Your task will be to actually *calculate* the tension in the string for each of these three settings. You do this using measurements on the ruler and timer for a simulated pulse that you generate, as well as the following piece of data not available from the simulator:

every bead has a mass of 0.10 grams

3. Use what you know about the physics of waves on strings to compute the three tensions (yes, they are very small numbers).
4. Are the three tension settings evenly-spaced? That is, is the increase in tension from "Low" to the middle setting the same as the increase from the middle setting to "High"? If not, can you discern any pattern to these two jumps?

Lab Report

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CHAPTER OVERVIEW

2: Standing Waves on Strings

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2.1: Background Material

Text References

- [standing wave mathematics](#)
- [standing wave harmonics](#)

Creating a Standing Wave with the Simulator

For this lab, we will be using the same string wave simulator that we used in the previous lab. Our goal is to study standing waves, which requires a great deal more precision than existed in the previous lab. What follows is a careful step-by-step procedure for creating a standing wave, which you will need to follow for parts of this lab. Start by [running the simulator](#) now in another window.

A standing wave requires two identical periodic waves traveling in opposite directions, generally achieved by reflections off two boundaries. In our simulator, we have one boundary (which we can choose to be fixed or loose), but the other end drives the wave (i.e. puts energy into the system). So the trick to forming a standing wave here is to drive a wave into the string for just the right amount of time, then stop the driver and hold it fixed (there is no way to make it loose, but that is fine). The waves will then bounce back-and-forth between the two ends, and a standing wave will be the result. So we'll do one together here, so that you have the process down. We won't go through the math – we have to save something for your lab activity!

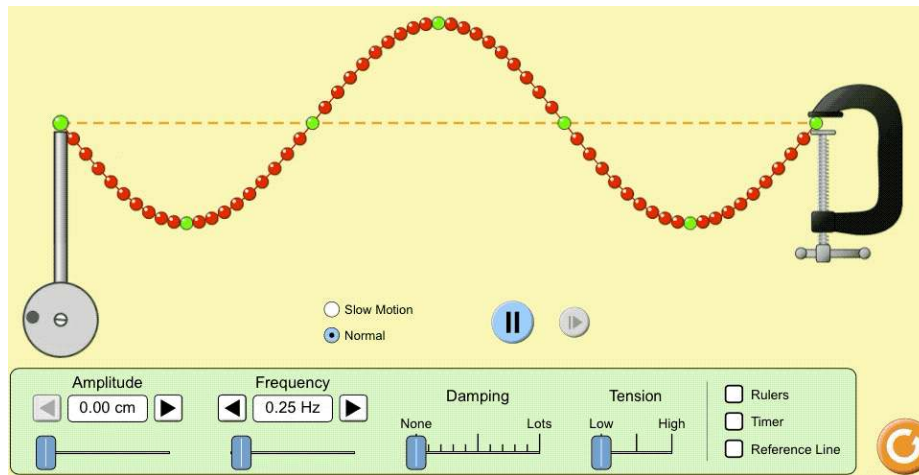
1. Configure the simulator as follows:

- click the pause simulation button 
- click the "Oscillate" radio button selected in the upper-left corner
- leave the "Fixed End" radio button selected in the upper-right corner
- set the "Amplitude" equal to 0.50cm
- set the "Frequency" equal to 0.25Hz
- set "Damping" to "None" (the minimum)
- set "Tension" to "Low" (the minimum)

2. Click the play simulation button , starting the driver. A wave will begin to propagate across the string. Allow this to continue until after it reflects, but click the pause simulation button  before it gets all the way back to the driver.

3. We want to stop the driver at the moment the wave completes exactly one round-trip, so use the step simulator button  to increment the return trip of the wave, and leave the simulation paused when the round-trip is complete. You will know this has occurred when the green bead at the top of the driver has returned to the dashed line from below it. Instead of watching the wave, you can just watch the driver – you want to freeze the simulation when it completes exactly three full cycles. [*Note: This "three cycle shortcut" only works for this specific case – you can't use this for more general cases you will do in the lab activities.*] Besides looking at the green bead's position, you can also confirm that the cycle is complete when the black dot on the driver wheel is at exactly 9 o'clock.

4. With the simulator frozen in the perfect position, it's time to turn off the driver. Set the amplitude to zero, and click the play simulator button again... Voilà, a standing wave!



If you did not follow the above steps precisely, you may achieve something that *resembles* a standing wave – at least for awhile – but it will have a few small imperfections that will show up in the motion of the string. Try this procedure until you are able to make it work before going on to your lab. Note that it is important that the damping is set to "none" for this to work properly, but in principle it should be doable (with the correct frequency setting) for fixed or loose ends, and for all three tension settings. Indeed we will explore these very changes in the lab activity.

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2.2: Activities

Things You Will Need

All you will need for this lab is [this PhET simulator](#). **Go ahead and run this simulator now in another window for use in the activities below.**

Creating Harmonics

In the previous lab, you may have calculated the traveling wave velocities for the three tension settings in this simulator. There is no need to do these again, or to go back and look them up – here they are for you to use:

Low tension setting: $v_{wave} = 1.25 \frac{cm}{s}$

Medium tension setting: $v_{wave} = 3.75 \frac{cm}{s}$

High tension setting: $v_{wave} = 6.25 \frac{cm}{s}$

1. The [Background Material](#) shows a step-by step method for creating a standing wave with three antinodes between two fixed ends. Your first task is to repeat this process to create a standing wave with the same number of antinodes for each of the other two tensions. For each of these two tensions, do the following:
 - a. Provide a screen capture (or a photo, if you are unable to do this) of the standing wave in the simulator. Be sure to include the control panel at the bottom of the screen that shows the frequency you used for the standing wave, and the tension setting.
 - b. In your lab report, show the calculations you performed to determine how to create the standing wave.
2. **Select the "Rulers" box in the lower-right corner**, and use the vertical ruler to measure the amplitude of one of the standing waves you created (you don't need to do both of them). It will of course help to freeze the simulator, and step it until the maximum displacement of the antinode is achieved (recall you can also move the ruler where you like). Record the measurement (no screen capture necessary), and explain how this value is the correct one according to the standing wave mathematics we have seen.
3. Create a standing wave with any tension that *keeps all of the green beads stationary*. As before:
 - a. Provide a screen capture of the standing wave in the simulator.
 - b. In your lab report, show the calculations you performed to determine how to create the standing wave.

One End Free

In principle we can also create standing waves with the string having a free end. **Select the "Loose End" radio button in the top-right corner.**

4. It turns out that we can only approximate such a standing wave with this simulator, because the frequency setting only goes to two decimal places. Explain why at least 3 decimal places are required to get a precise standing wave on this simulator.
5. Try *approximating* a standing wave with a loose end with a rounded-off frequency that should get you close. Submit a screen capture of your attempt.

Lab Report

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3: Two-Source Interference

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3.1: Background Material

Text References

- [double-slit interference](#)

A New Simulator

This activity uses a new PhET simulator, but like the previous one, it runs in HTML.

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3.2: Activities

Things You Will Need

All you will need for this lab is [this PhET simulator](#). **Go ahead and run this simulator now in another window for use in the activities below.**

Using the Simulator

This software simulates wave interference of various types. We will be focusing on interference of light passing through a double slit. We therefore configure the simulator as follows:

- select the window "Slits"
- click the light source button 
- select the "Screen" check box, and the "Intensity" sub check box
- select "No Barrier" in the drop-down menu
- set the "Frequency" slider somewhere near the middle of the red portion of the spectrum
- leave the "Amplitude" slider at its "max" setting

The green button on the Light Generator starts a plane wave, represented by alternating bright and dark regions that represent the crests and troughs of the waves, respectively. [Note that these do not represent bright and dark regions! That is, if you were in the simulator, and you looked at the Light Generator, you would see constant, uniformly-bright red light coming from it. If you run the simulator, this is in fact what you see on the screen.]

As with the simulators we have seen already, the pause button  halts the simulator, allowing you to more easily take measurements. In this lab, we will be taking only two types of measurements:

- distances with the tape measure , which can be dragged to anywhere it is needed – the base of the roll of tape will remain in place as you drag the other end (the length units for this tape measure is *nanometers*, which is $10^{-9}m$).
- times with the timer , which can also be dragged around (the time units in this timer is *femtoseconds*, which is $10^{-15}s$).

As we saw with a previous simulator, a powerful tool for precise time measurements is to pause the simulation, start the timer (it will not run until the simulation is restarted), and then continue the simulation one step at a time with the step simulator button.

Computing the Light Frequency

You will notice that the slider for frequency of the light does not include a numerical output. Our task will therefore be to compute the frequency of the red light that you have chosen. We will do this in several ways...

[Note: Our level of precision is such that if you use it in your calculations, you will want to use $2.998 \times 10^8 \frac{m}{s}$ for the speed of light.]

1. Measure the frequency of the light in two ways. In each case, explain what you measure and how you determine the frequency from it.
 - a. using only the timer (note the "step simulator" trick given above)
 - b. using only the tape measure (clicking the "Graph" check box for the purposes of this measurement may be helpful).
2. These two calculations are not likely to agree exactly, so let's estimate some uncertainty.
 - a. The timer measures in hundredths of femtoseconds, but when the simulator is stepped, it doesn't increment the timer by one unit in this decimal place, so the real time elapsed falls somewhere in a range. Compute the percentage uncertainty of your time measurement using the appropriate range.
 - b. The tape measure measures down to tenths of nanometers, but dragging the tape measure the tiniest amount will jump the reading by more than this degree of precision, which means the actual length measurement falls somewhere in a range. Compute the percentage uncertainty of your length measurement using the appropriate range.
 - c. Determine whether your two calculations of the frequency of the light land within the uncertainty bounds.
 - d. Suppose that we want the most accurate measurement possible, using either of the two methods above. This means reducing the percentage uncertainty as much as possible. Explain how you would do this, and (assuming you didn't do this already), do so now for both methods, and determine the associated percentage uncertainties.

Next we will measure the frequency of the red light yet again (so don't change the frequency slider setting!), this time using what we know about double slit interference. This requires a few adjustments to the simulator:

- **select "Two Slits" in the drop-down menu**
- **set the slit width to 500nm**
- **set the slit separation at 2000nm**
- **drag the double slit barrier as far left as possible, so that you mostly light after it passes through the double slit**

Before freezing the simulator to take data, make sure it runs long enough to form an interference pattern on the screen.

[Helpful hint for making two length measurements with a common point involved: Place the base of the tape measure at the common point – it will stay put as you drag the open end of the tape measure to each of the other points in turn.]

3. Use the interference pattern to determine the light frequency by directly measuring the path length difference of the two interfering waves from the slits...
 - a. ... to a point of total destructive interference
 - b. ... to a point of maximal constructive interference
4. Determine the light frequency one more time, this time using [Equation 3.2.3](#) derived in the LibreText for 9B (you can use either a dark or bright fringe). This requires a bit of work on your part, as there is no protractor provided by the simulator to measure angles.

Fringe Spacing

You are probably finding that the calculations of the frequency are getting progressively worse. For question 3, this is because it is harder to make the measurement as accurately as in question 1. This is also true for question 4, but in that case the equation also drags in an approximation (see the text reference given in the [Background Material](#) for more details). We will conclude by looking at another approximation discussed in that text reference. If the angle of deflection is "small," then the separation of fringes (from dark to dark or from bright to bright) is given by a simple formula involving the wavelength λ , the distance to the screen from the slits L , and the slit separation d :

$$\Delta y = \frac{\lambda L}{d}$$

5. Check this formula for the following conditions given (note that you have the wavelength of the light, as you are using the same light as in question 1), and comment on what these measurements say about the validity of this fringe-spacing formula. [Note: It is easier to measure the distances between the fringes in the simulator accurately using the intensity graph than the screen display.]
 - a. the settings you have currently (double slit barrier as close to the Light Generator as possible)
 - b. with the double slit barrier dragged closer to the screen (say at about the halfway point)

Lab Report

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CHAPTER OVERVIEW

4: Diffraction

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4.1: Background Material

Text References

- [single slit diffraction](#)
- [Babinet's principle](#)
- [interference of many sources in phase](#)

Interference After Reflection

In the previous lab, we explored interference of light waves coming through two slits. The two waves emerged from the slits in phase, so difference in distances they traveled accounted for the interference pattern observed. In the reading above, we see that if we use many more slits (a diffraction grating), then we get a much more sharply-defined pattern, with very intense bright fringes separated with the same $d \sin \theta = m\lambda$ relationship as for the double-slit, but separated by broad regions of darkness.

We are going to explore this phenomenon in this lab, but rather than pass the laser light through the many slits of a diffraction grating, we are going to *reflect it* off a surface with many grooves – a compact disk. The light that strikes the raised ridges of the disk are reflected diffusely (i.e. not in phase), which effectively means that these ridges act like the spaces between slits in a diffraction grating. Meanwhile, the interior of the grooves are highly reflective, so the light reflected from them remains in phase, and the grooves behave like the slits of a diffraction grating.

Our Favorite Simulator is Back!

We will once again use the wave interference PhET simulator, this time as a tool for getting a result from data we obtained in a "real world" lab. Don't worry, we'll also obtain the result from mathematics!

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4.2: Activities

Things You Will Need

Go ahead and run [the PhET simulator](#) in another window, as you have twice before. You will also need a small ruler (this part of the simulator doesn't come with a virtual tape measure!).

While it is certainly not required that you do so, you may find this entire lab (or maybe part of it) to be fun to do yourself at home! You can do these if you happen to have a laser pointer, and have a way to look up its wavelength. You will also need a compact disk or DVD, a tape measure, some tape, and bit of space to work with. Notes on doing this lab at home are in red for your convenience.

Using the Simulator

Here is the configuration of the simulator you will need:

- **select the window "Diffraction"**

The large black square on the left with a white circle in it is the barrier to the light, and the white circle is the aperture through which the light passes. The other black square is the screen onto which the diffraction pattern is projected. We will want to simulate a thin rectangular aperture (actually a thin rectangular barrier, but we'll get to that later), so:

- **click the rectangular aperture button** 
- **elongate the aperture to its maximum by dragging the "Height" slider to 0.40mm**
- **turn on the laser**  **by clicking the circle**

The wavelength of the laser and the width of the gap are left as variables for use to play with. Note that the scale lengths for both the slit and the screen are given on their upper-left corners, and *they are not the same*. Measurements of the slit are unnecessary, as the gap width is given in the "Width" slider, but measurements of the diffraction pattern will require a ruler and the scaling provided.

In order to use the simulator to mimic the case of our real-world physical experiment, we will need to make sure every dimension matches. We can adjust the gap width and make measurements of the diffraction pattern, but the distance from the slit to the screen is also important, and that is not given (we are not given a scale for the top of the diagram, so we can't measure it with a ruler). So to that end...

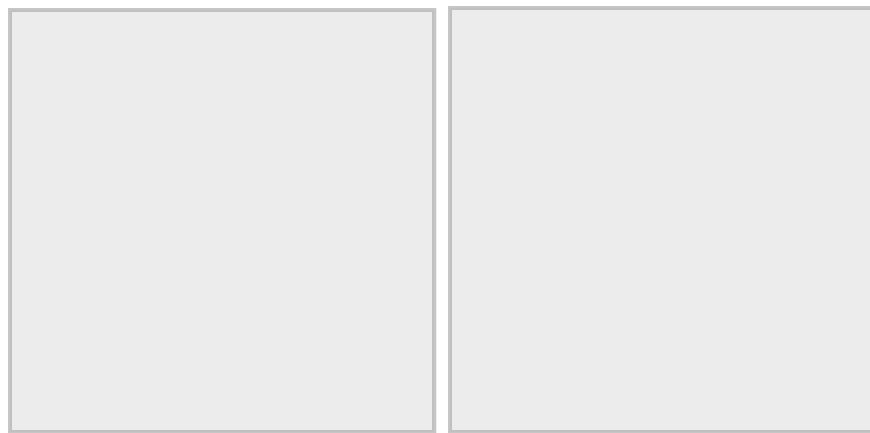
1. Use any wavelength and gap width you like to find the distance from the slit to the screen, then confirm your calculation with a new wavelength and gap width.

The Thickness of a Human Hair

In the text references for the [Background Material](#) is a discussion of Babinet's principle, which essentially states that under the right conditions, a thin barrier to a laser beam results in the same diffraction pattern as a slit of the same width. We will exploit this to measure the thickness of a human hair.

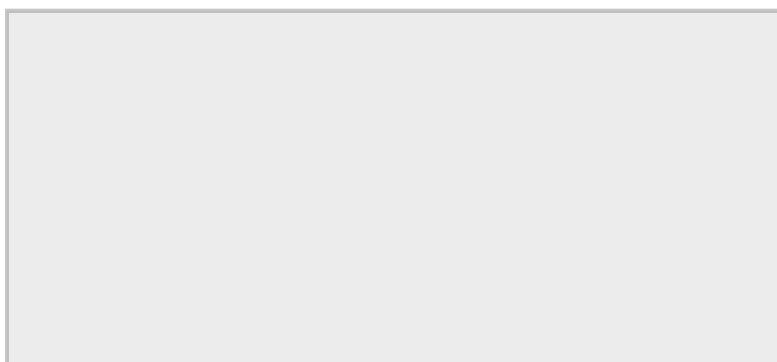
If you are doing this at home, you will of course need a hair that you can place into the path of the laser beam. The simplest way to do this is to tape it across the hole in the laser pointer where the beam emerges. **BE CAREFUL NOT TO LOOK INTO THE LASER WHEN DOING THIS, AS ACCIDENTALLY TURNING ON THE LASER CAN DAMAGE YOUR EYE.** You'll know the hair is in the beam when looking at it from the side, you see a bright "bead" where the hair is (see the pictures below). Then point the pointer at the wall from the distance that you computed in question #1 above. You should see a diffraction pattern similar to the (horizontal) pattern shown in the simulator, and you can make direct measurements of the diffraction pattern.

Figure 5.2.1 – Hair in Laser Beam



The hair in the pictures above has been taped across the hole of a compact disk (which, efficiently, is used for another purpose later in this lab), but any manner of getting the hair into the beam is sufficient. The hair is vertical, like the rectangle in the simulator, providing a horizontal diffraction pattern:

Figure 5.2.2 – Diffraction Pattern



There is a lot of stray light here, but the "speckles" can be ignored, and we need focus our attention on the bright horizontal bands that constitute the hair's diffraction pattern.

Taping the hair across the opening of a laser pointer may or may not exhibit this much "noise" in the diffraction pattern, but much will depend upon the quality of the laser.

The distance to the screen from the hair was adjusted to be the same as that of the simulator, and a measurement was made of the distance between the two dark fringes that bracket the central bright band. The wavelength of the laser is also known:

- **distance between first-order dark fringes** = 1.6cm
- **laser wavelength:** $\lambda = 633\text{nm}$

2. Use the simulator to approximate the thickness of the hair. This may require a bit of trial-and-error to get the dark fringe spacing to the correct value. Perhaps meticulously placing some tape on your monitor with the proper spacing will help? Take a screen shot of the simulator when you feel you have reached the correct value and attach it to your lab report.
3. Mathematically compute the hair width using single-slit diffraction formulas. Justify any approximations you might use.

If you check the thickness you get at home against what is computed in the "packaged lab" here, don't be discouraged if they diverge from each other substantially – hairs come in a pretty wide variety of thicknesses!

The Groove Density of a Compact Disk

Next we will use our laser and the parallel that we drew between diffraction gratings and reflections off surfaces with regularly-spaced grooves to determine the density of grooves (number of groove per centimeter) on a compact disk. To do this, we need to set up the laser to reflect off the CD, and have the reflection illuminate a wall a distance away.

Figure 5.2.3 – Reflecting Laser Light Off a Compact Disk

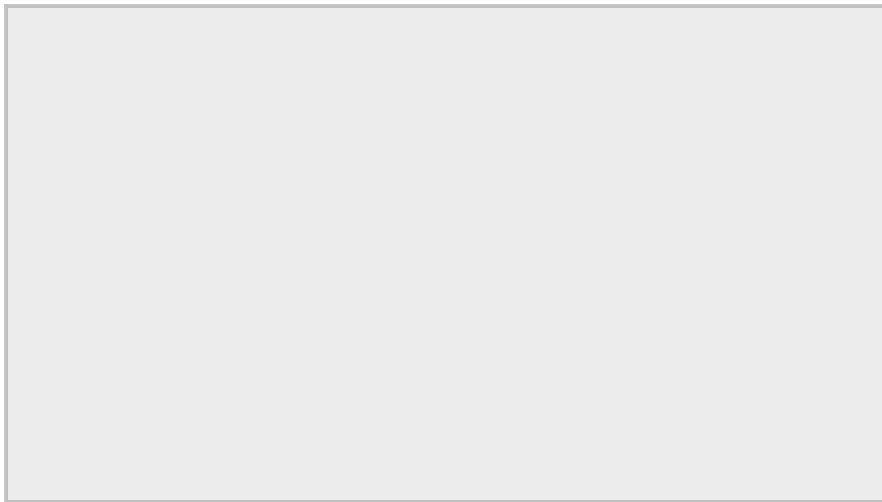


Figure 5.2.4 – Bright Fringes Off Compact Disk



Note that the laser strikes the CD on the grooved side (naturally), at a point located horizontally from its center. In this region, the grooves will be oriented vertically, so the fringes will spread horizontally. You *may* be able to see the second-order fringes as well – if so, this can reduce the overall uncertainty in your result.

Now for the measurements made in the lab:

- **distance from CD to wall** = 230cm
- **distance from central bright fringe to:**
 - **left bright fringe** = 98cm
 - **right bright fringe** = 100cm

4. Compute the density of grooves in the compact disk, measured in grooves per millimeter. [*Make a note that these bright fringes do **not** occur at small angles, so you need to take care not to use any approximations that assume this!*]

Lab Report

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