Introduction to WebTOP

John T. Foley and Taha Mzoughi
Department of Physics and Astronomy
Mississippi State University

David C. Banks
Department of Computer Science
Florida State University

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URL: http://webtop.msstate.edu/

Email: jtf1@ra.msstate.edu, mzoughi@ra.msstate.edu and banks@wkkxt5.csit.fsu.edu
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1. Introduction

When you log on to webtop.msstate.edu or run WebTOP from your computer’s cd player or hard drive, you will get the “Welcome to WebTOP” page pictured below.

In order to run WebTOP, the VRML plug-in should be Blaxxun Contact 5.0 (the manual download version). Therefore, if your computer does not have this plug-in installed, you need to do so. A link to the Contact page on the blaxxun website is provided on the Welcome to WebTOP page (see Figure 1 above). When you go to that page, click on the “free download” tab at the top of the page. Next, click on the link provided there for the operating system of your computer. You will then be given the choice between an “Automatic” or “Manual” download. Choose the latter, and use it to install the plugin.

Please click on the “Run WebTOP” link that is appropriate for your computer. You will then get the “About WebTOP” page pictured in Figure 2 below.
Figure 2  The About WebTOP page

The sixteen WebTOP modules can be accessed from the About WebTOP page either by clicking on the appropriate thumbnail image in the center of the page, or by clicking on the WebTOP Modules link at the top of the page. Please click on this link.

Figure 3  The About WebTOP Page with the WebTOP Modules menu displayed.
A menu providing links to all the modules is now displayed (See Figure 3). Please click on the Fresnel Single Slit link.

2. The WebTOP Window

Your window should now look like Figure 4 below.

![Figure 4](image)

**Figure 4** The WebTOP window for the Fresnel Single Slit Module.

The WebTOP window for each module has five basic parts: the Scene, the Navigation Icons, the Console, the Recording Panel, and the Activities Menu (see Figure 4).

2.1 The Scene

The Scene is the interactive 3D simulation itself and occupies the largest part of the Web page. It usually consists of a light source, a variety of optical elements, and an observation screen. The parameters of these items can be modified either by direct manipulation of the “widgets” in the scene, or by typing the desired parameter values into the appropriate keyboard entry boxes on the Console.

For example, in the Fresnel Single Slit module (see Figure 4) the scene consists of a single slit, an observation screen, and three kinds of widgets that allow the user to change the parameters of the simulation. In this module a monochromatic plane wave of wavelength $\lambda$ is normally incident upon a slit of width $w$. The resulting diffraction pattern is observed on an observation screen that is a distance $z$ from the plane that contains the slit.

The parameters $\lambda$, $w$, and $z$ can be changed either by typing the desired values into the appropriate keyboard entry box on the Console, or by manipulating the appropriate widget in the Scene. Spinning the Wavelength widget (the wheel that is located in front of the aperture) changes the wavelength. Pulling on the Width widget (the red double
cone on the edge of the slit) changes the width of the aperture. Pulling on the Screen widget (the red double cone on the top of the observation screen) changes \( z \). These widgets are labeled in Figure 4.

Let’s learn how to use a widget, for example the Width widget. Place your mouse cursor over the red double cone widget on the right edge of the slit. The cursor will change “modes” from its normal mode, which looks like \( \text{Select Control mode, which looks like } \). If you now depress the left mouse button and hold it down, the widget will get brighter, signifying that it is ready to be moved. With the left mouse button held down, drag the widget to the right to open the slit more, then release the widget. Note that down in the Console at the bottom of the window, the value of Width (the slit width) automatically updates when you use the widget to change the slit width.

**Exercise 2.1**

(a) Try changing the position of the observation screen by using the Screen widget.

(b) Try changing the wavelength of the light by spinning the Wavelength widget.

### 2.2 The Navigation Icons

WebTOP uses a Virtual Reality Modeling Language (VRML) file to display and allow manipulation of the 3D Scene. In order to run WebTOP you must have a VRML browser plug-in associated with your regular Web browser. We strongly recommend the Blaxxun Contact 5.0 VRML browser.

The five navigation icons shown below in Figure 5 allow you to control the appearance of the scene.

<table>
<thead>
<tr>
<th>Viewpoint</th>
<th>Zoom</th>
<th>Pan</th>
<th>Rotate</th>
<th>Hide Icons</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Viewpoint Icon" /></td>
<td><img src="image" alt="Zoom Icon" /></td>
<td><img src="image" alt="Pan Icon" /></td>
<td><img src="image" alt="Rotate Icon" /></td>
<td><img src="image" alt="Hide Icons Icon" /></td>
</tr>
</tbody>
</table>

Figure 5  The Navigation Icons.

A Viewpoint icon (the Fresnel Single Slit module has three) returns the scene to a predefined position when you click on it. The Zoom icon allows you to zoom into or out of the scene. To use it, place the cursor over the icon, depress and hold down the left mouse button, and push into (pull out of) to zoom into (out of) the scene. The Pan icon allows you to translate the scene left/right or up/down. To use it, place the cursor over the icon, depress and hold down the left mouse button, and move the cursor in the desired direction. The Rotate icon allows you to rotate the scene. To use it, place the cursor over the icon, depress and hold down the left mouse button, and rotate the checkered ball in the desired direction. The Hide Icons icon allows you to hide all the other navigation icons. When you click on it, they all disappear, and the Hide Icons button gets very dim. If you click on this button again, the other navigation icons will reappear, and the Hide Icons button becomes bright again.

Let’s try these controls.

**Exercise 2.2**

(a) With the cursor over the Rotate icon, depress and hold down your left mouse button, and slide the cursor to the right. The scene will rotate in the appropriate manner.

(b) Try Pan, and then Zoom. With Pan, you may translate the scene in any direction by dragging the cursor in the desired direction. With Zoom you can zoom in by “pushing” the cursor into the scene, or zoom out by pulling it out of the scene.

(c) Click on the second Viewpoint icon, then the third, and then the first. These give you three “home” positions to which you may return with a single mouse click.
(d) Click on the Hide Icons icon. Click on it again.

2.3 The Console

The Console is near the bottom of the window (see Figure 4). It has three functions. First, it tells the user the current values of the input parameters, and the values of other important parameters. For example, in Figure 4, the Console is reporting that the values of the input parameters are wavelength = 550 nm, slit width = 0.40 mm, and z = 50 mm, and that the value of the Fresnel number,

$$N_F = \frac{w^2}{4\lambda z},$$

(2.1)

is 1.45.

The second purpose of the console is that it allows us to change the input parameters. Let’s change the wavelength from it’s current value to 700 nm. To do this, highlight (or delete) the number shown in the Wavelength box in the Console. Now type in 700 and hit the Enter key (or the Tab key). WebTOP will now recalculate everything, and change the Scene to correspond to the new wavelength.

The third thing the Console does is that it gives the user help messages and the readout of the module’s touch sensor (if it has one). For example, when you place the cursor over a widget, a help message concerning the use of the widget appears in the lower left hand corner of the Console. To see this, place the cursor over Wavelength widget. When you do this, a message (in yellow letters) appears at the bottom of the Console that says, “The wheel modifies the wavelength of the light – clockwise increases the wavelength.” To see what a touch sensor does, place the cursor on the observation screen. When you do this, a message (in yellow letters) appears at the bottom of the Console that says, “Position = current value, intensity = current value.”

2.4 The Recording Panel

The Recording Panel is at the bottom of the window. It contains VCR-like controls that allow you to record a WebTOP session, store it in the form of a script, and then play the script back at any later time. The names of the buttons in the Recording panel are, from left to right: Rewind, Record, Play, Pause, Stop, and Open. These items will be discussed in Section 17. In order to save scripts to your hard drive, you must grant WebTOP permission. To do this, click on the “Setting Up the Recording Feature” link on the Welcome to WebTOP page (see Figure 1 above), and follow the instructions.

2.5 The Activities Menu

The Activities Menu is at the top of the window. It lists the five activities available in WebTOP: the module we are presently in (Fresnel Single Slit in this case), Directions, Theory, Examples, and Exercises. It also provides a link to the Other Modules. To access any activity, click on its name in the menu. The module activity, the one we are in now, contains the interactive simulation itself. The Directions activity contains documentation on how to interact with a WebTOP module: (a) how to change its parameters by using the widgets in the Scene or the keyboard entry boxes on the Console, (b) how to use the Navigation icons to manipulate the scene, and (c) how to record, save, and play back WebTOP sessions using the features on the Recording panel.

The Theory section presents an overview of the physics being simulated in the module. The Examples section is a Web page that contains descriptions of and links to previously recorded WebTOP sessions in the form of scripts (very small files). The scripts are loaded by clicking on the name of the example, and then played by clicking on the Play button on the Recording Panel. Currently WebTOP has sixty-four such examples. The Exercises section provides exercises for the user to try. These are inquiry-based exercises in that the user is asked to interact with the software, observe how the simulation changes, and then come up with an explanation for what is happening. Clicking on Other Modules displays a list of the other modules that the user can access.
3. The Fresnel Single Slit Module

Let’s now use the Fresnel Single Slit Module to do some physics. This module simulates a monochromatic plane wave of light normally incident upon a single slit. The observed intensity pattern is displayed on the observation screen, and is plotted (see the white curve) above the observation screen. The user can vary the following parameters: (a) the wavelength of the light, (b) the width of the slit, and (c) the distance, call it $z$, from the plane containing the slit to the observation plane.

Let’s do an exercise with this module

Exercise 3.1 Changing the Width of the Slit: Odd Fresnel Numbers

Use the Wavelength box on the Console to set the wavelength equal to 500 nm, and the $z$ box to set the distance to the screen to be 50 mm. Remember to hit the Enter key (or the Tab key) after you type in a parameter value for each value you change.

(a) Use the Width widget to make the width of the slit such that the Fresnel number is approximately 7.0. Is the intensity on axis a maximum or a minimum? Starting at one edge of the intensity pattern and proceeding across it through the origin to the other edge, how many “major” maxima do you encounter?

What you should see is

![Figure 6 Fresnel diffraction from a single slit. Fresnel number of 7.0.](image_url)

The intensity in the center is a maximum, and there are seven major maxima across the pattern.

(b) Use the Width widget to make the width of the slit such that the Fresnel number is approximately 5.0. Is the intensity on axis a maximum or a minimum? Starting at one edge of the intensity pattern and proceeding across it through the origin to the other edge, how many “major” maxima do you encounter?

What you should see is shown below.
Figure 7  Fresnel diffraction from a single slit. Fresnel number of 5.0.

The intensity in the center is a maximum, and there are five major maxima across the pattern.

(c) What rule of thumb can be deduced from the results seen in (a) and (b) above, as regards the intensity on axis when the Fresnel number is odd?

When the Fresnel number is an odd integer, a maximum occurs on-axis.

(d) What rule of thumb can be deduced from the results seen in (a) and (b) above, as regards the number of major maxima seen across the intensity pattern when the Fresnel number is odd?

When the Fresnel number is an odd integer, the number of major maxima across the pattern is equal to the Fresnel number.

Exercise 3.2  Transition from the Fresnel Region to the Fraunhofer Region

The observation plane is said to be in the Fraunhofer region when the Fresnel number is much less than 1, in which case we see the familiar Fraunhofer diffraction pattern on the observation screen. Set the value of the wavelength to be 500 nm, the value of the slit width to be 0.2 mm, and the value of $z$ to be 10 mm. The Fresnel number should be 2.0.

(a) Change the value of $z$ to be 20 mm. Are we in the Fraunhofer region yet?
(b) Change the value of $z$ to be 40 mm. Are we in the Fraunhofer region yet?
(c) Change the value of $z$ to be 100 mm. Are we in the Fraunhofer region yet?

Please click on the Other Modules link in the Activities menu, then click on Fraunhofer Rayleigh Resolution.
4. The Rayleigh Resolution Module

The Rayleigh Resolution module is pictured below. In this module monochromatic light of wavelength $\lambda$ from two distant point sources separated by an angle $\theta$ is incident upon a lens of focal length $f$ and diameter $D$. The resulting intensity pattern is viewed on an observation screen positioned in the focal plane of the lens.

The parameters $\lambda$, $D$, and $\theta$ can be changed either by typing the desired parameter values into the appropriate keyboard entry box on the Console, or by using the appropriate widget in the Scene. (The focal length $f$ can only be changed by using its widget.) Spinning Wavelength widget (the wheel which is located in front of the lens) changes the wavelength. Pulling on the Diameter widget (the red double cone on rim of the lens) changes the diameter of the lens. Pulling on the Angle widget (either of the two gray bars through the center of the lens) changes the angle between the sources. Pulling on the Focal Length widget (the red double cone on the top of the observation screen) changes the focal length of the lens.

The white line above the observation screen is a plot of the intensity of the light at observation points across the center of the screen.

The Console displays, in addition to the values of $\lambda$, $D$, and $\theta_{\text{min}}$, the value of the minimum angle for which (according to Rayleigh) the two images can be resolved,

$$\theta_{\text{min}} = \frac{1.22\lambda}{D}. \quad (4.1)$$
One comment is in order regarding Figure 8. Upon comparing it to Figure 4, notice that the Hide Icons button has been used to hide the navigation icons.

**Exercise 4.1 The Resolution of Two Distant Sources: Changing Angular Separation of the Sources**

(a) Use the keyboard entry boxes on the Console to enter the following parameter values: Wavelength = 550 nm, Diameter = 3.355 cm, and Angle = 4.0E-5 rad. The minimum angle predicted by Rayleigh is 2.0E-5. Are the images on the observation screen resolved?

(b) Use the Angle keyboard entry box to change the angle between the two sources to 2.0E-5. Are the images on the observation screen resolved?

(c) Use the Angle keyboard entry box to change the angle between the two sources to 1.0E-5. Are the images on the observation screen resolved?

**Exercise 4.2 The Resolution of Two Distant Sources: Changing the Wavelength of the Light**

Start with the parameter values the same as they were in part (b) of the Exercise 4.1 (Wavelength = 550 nm, Diameter = 3.355 cm, and Angle 2.0E-5).

(a) Change the wavelength to 700 nm. Are the two sources resolved now?
(b) Change the wavelength to 400 nm. Are the two sources resolved now?

**Exercise 4.3 The Resolution of Two Distant Sources: Changing the Diameter of the Lens**

Start with the parameter values the same as they were in part (b) of the Exercise 4.1 (Wavelength = 550 nm, Diameter = 3.355 cm, and Angle 2.0E-5).

(a) Change the diameter of the lens to 2 cm. Are the two images resolved now?
(b) Change the diameter of the lens to 6 cm. Are the two images resolved now?

Please click on the Other Modules link in the Activities menu, then click on Fraunhofer N-Slit.

**5. The Fraunhofer N-Slit Module**

The Fraunhofer N-Slit module is pictured below. In this module monochromatic light of wavelength $\lambda$ is normally incident upon a plane that contains $N$ slits of width $w$ and center-to-center separation $d$. The resulting intensity pattern is viewed on an observation screen which is a distance $z$ from the aperture plane.

The parameter $N$ can be changed by typing in the desired value into the Slits keyboard entry box on the Console. The parameters $\lambda$, $w$, $d$, and $z$ can be changed either by typing the desired parameter values into the appropriate keyboard entry box on the Console, or by using the appropriate widget in the Scene. Spinning the Wavelength widget (the wheel which is located in front of the aperture plane) changes the wavelength. Pulling on the Width widget (the red double cone on the side of one of the slits) changes the slit width. Pulling on the Distance widget (the blue cone on the top of a slit) changes the distance between consecutive slits. Pulling on the Screen widget (the red double cone on the top of the observation screen) changes $z$. This module has a touch sensor – when you place the cursor over a position on the observation screen, the position and the intensity at that position are displayed in the lower left-hand corner of the console.
Figure 9  The Fraunhofer N-Slit module.

Exercise 5.1  Single Slit - Effect of Changing the Slit Width or the Wavelength

Set the number of slits to be 1, the wavelength to be 500 nm, the slit width to be 0.10 mm, and \( z \) to be 1000 mm. “Distance” is irrelevant since there is only one slit.

(a) Use one of the red cone widgets on the slit to increase the width of the slit. Does the intensity pattern on the observation screen get wider or narrower? Justify this using the equation that describes the angular position of the first off-axis minimum of the pattern.

(b) Use the wheel widget to increase the wavelength of the light. Does the intensity pattern on the observation screen get wider or narrower? Justify this using the equation that describes the angular position of the first off-axis minimum of the pattern.

Exercise 5.2  Double Slit - Effect of Changing the Distance Between the Slits, or the Slit Width

Set the number of slits to be 2, the wavelength to be 500 nm, the slit width to be 0.005 mm, the distance between slits to be 0.20 mm, and \( z \) to be 1000 mm.

(a) Use the blue cone widget on one of the slits to decrease the distance between the slits to about 0.4 mm. Do the off-axis maxima move towards the axis or away from it? Justify this using the equation that describes the angular position of the first order maximum of the pattern.
(b) Use the appropriate keyboard entry boxes to set the distance between slits to 0.40. Use one of the red cone widgets on a slit to increase the width of the slits to approximately 0.10 mm. Do the positions of the maxima change? Do the peak intensities of the maxima change? Comment upon any similarities between this intensity pattern and the single slit intensity pattern you saw in Exercise 5.1 (a). (Hint: Use the Slits keyboard entry box to change the number of slits to 1, then back to 2 and watch what happens.)

**Exercise 5.3 More than 2 Slits - Effect of Changing the Number of Slits**

Set the number of slits to be 2, the wavelength to be 500 nm, the slit width to be 0.005 mm, the distance between slits to be 0.10 mm, and z to be 1000 mm. Let us refer to the maxima we observe now as “major maxima.”

(a) Use the “Slits” keyboard entry box to change the number of slits to 3.
   (i) Did the positions of the major maxima change?
   (ii) How many “secondary” maxima occur between every two consecutive major maxima?
   (iii) Did the major maxima become wider or narrower?
   (iv) Did the peak intensities of the major maxima change? (You will need to consult the scale on the white intensity graph above the observation screen to determine this.)

(b) Use the “Slits” keyboard entry box to change the number of slits to 5.
   (i) Did the positions of the major maxima change?
   (ii) How many “secondary” maxima occur between every two consecutive major maxima?
   (iii) Did the major maxima become wider or narrower?
   (iv) Did the peak intensities of the major maxima change?

(c) Based on what you have seen in (a) and (b) above, if the number of slits is \( N \), how many “secondary” maxima will occur between every two consecutive major maxima? How does the peak intensity of a major maximum vary with \( N \)?

(d) Use the “Slits” keyboard entry box to change the number of slits to 10. Is what you see consistent with your answers to part (c)?

Please click on the Other Modules link in the Activities menu, then click on Polarization.

**6. The Polarization Module**

The Polarization module is pictured in Figure 10. In this module the propagation of a monochromatic, completely polarized plane wave of light (or an unpolarized plane wave of light) and the effect of various optical elements (polarizers and wave plates) on the corresponding electric field vector are simulated.

First the user chooses the incident field to be either completely polarized or unpolarized. If the former is chosen, the electric field simulated is of the form

\[
E(z,t) = E_{0x} \cos(kz - \omega t) \hat{x} + E_{0y} \cos(kz - \omega t + \epsilon) \hat{y}
\]

(6.1)

where \( \hat{x} \) and \( \hat{y} \) are, respectively, unit vectors in the positive x and positive y directions, \( k = \frac{2\pi}{\lambda} \), and \( \lambda \) is the wavelength of the light. The parameters \( E_{0x}, E_{0y}, \epsilon, \) and \( \lambda \) can be changed either by typing the desired parameter values into the appropriate keyboard entry box on the Console, or by using the appropriate widget in the Scene. Pulling on the E0x widget (the gray collar on the x-axis) changes \( E_{0x} \). Pulling on the E0y widget (the gray collar on the y-axis) changes \( E_{0y} \). Pulling on the Phase Difference widget (the blue cone over the orthogonal yellow waves just to the right of the x-axis) changes \( \epsilon \), the phase difference between the two components. Spinning the Wavelength widget (the wheel which is located just in front of the Phase Difference widget) changes the wavelength \( \lambda \).
Figure 10 The Polarization module

Once the incident field has been chosen two different kinds of filters, linear polarizers and wave plates, may be inserted into the path of the incident field. These are inserted by choosing the desired filter from the pull-down menu on the left-hand side of the Console and then hitting the Add button right next to the menu. To change the parameters of a filter, the filter must be “selected.” When a filter is added it is automatically selected, so that its parameters can be modified. If a filter added previously is not selected and needs to be, it may be selected by putting the cursor over it.

For a linear polarizer there are two parameters that can be varied: its position, \( z \), and the angle, \( \phi \) that is its transmission axis (TA) makes with the positive x-axis. These two parameters can be changed either by typing the desired parameter values into the appropriate keyboard entry box on the Console, or by using the appropriate widget in the Scene. Pulling on the Position widget (the gray double cone on the top of the linear polarizer) changes \( z \). Grabbing the Angle widget (the small gray cylinder on the end of the TA) and rotating it changes \( \phi \).

For a wave plate there are three parameters that can be varied: its position \( z \), the angle \( \phi \) that its fast axis makes with the positive x-axis, and \( N \), the number of waves of path length difference (between the two electric field components) that the wave plate provides. For example, for a half-wave plate \( N = 0.5 \). These three parameters can be changed either by typing the desired parameter values into the appropriate keyboard entry box on the Console, or by using the appropriate widget in the Scene. Pulling on the Position widget (the gray double cone on the top of the wave plate) changes \( z \). Grabbing the Angle widget (the small gray cylinder on the end of the fast axis) and rotating it changes \( \phi \). Pulling on the Thickness widget (the two gray boxes near the upper right-hand corner of the wave plate) changes \( N \).
Exercise 6.1 Various Kinds of Polarized Light and Unpolarized Light

(a) Let the parameter values be the default values (Tab = Polarized, Wavelength = 550 nm, $E_{0x} = 1$, $E_{0y} = 1$, and Phase Diff = 90 degrees). What kind of polarized light is this? Linearly polarized? Left circularly polarized? Right circularly polarized? Elliptically polarized?

(b) Change the x-component value to 0.5. What kind of polarized light is this? Linearly polarized? Left circularly polarized? Right circularly polarized? Elliptically polarized?

(c) Change the value of the phase difference between the x and y components to be 0. What kind of polarized light is this? Linearly polarized? Left circularly polarized? Right circularly polarized? Elliptically polarized?

(d) Click on the Unpolarized tab in the console. Comment on the pattern formed by the dots in the input plane.

Exercise 6.2 Linear Polarizer – Linearly Polarized Light Incident

Choose the Polarized option for the incident electric field. Set the x-component of the incident electric field to 1, the y-component to 1, and the phase difference between the components to 0. This light is linearly polarized at 45 degrees with respect to the positive x-axis. Rotate the scene up a bit to get a better view.

(a) Click on the Add button to add a polarizer. Position it at $z$ =10. Rotate the scene to get a good view of the field exiting the polarizer. What is the polarization of the light exiting the polarizer? Is this is consistent with the way a linear polarizer works?

(b) Use the Angle keyboard entry box to change the angle that the TA makes with the positive x-axis to 45 degrees. What is the polarization of the light exiting the polarizer?

(c) Use the Angle keyboard entry box to change the angle that the TA makes with the positive x-axis to 90 degrees. What is the polarization of the light exiting the polarizer?

(d) Use the Angle keyboard entry box to change the angle that the TA makes with the positive x-axis to 135 degrees. What is happening here?

Exercise 6.3 Linear Polarizer – Unpolarized Light Incident

(a) Let the polarizer of Exercise 6.2 remain in position, and set the Angle variable to zero. Choose the Unpolarized option for the incident electric field. What is the polarization of the light exiting the polarizer? Verify that this is consistent with the way a linear polarizer works.

(b) Use the Angle widget to rotate the transmission axis of the polarizer to a few different angular values. Is there any difference in the polarization of the light that exits the polarizer?

Exercise 6.4 Half-Wave Plate – Linearly Polarized Light Incident

Click on the Remove button to remove the polarizer used in Example 6.3. Choose the Polarized option for the incident electric field. Set the x component of the field to 1.00, the y-component to be 1.00, and the phase difference between the components to 0. Click on the pull-down menu on the left-hand side of the Console, choose Waveplate, and then click on the Add button. Set the $z$ value to 10. The Thickness value should be its default value, 0.50.

The light incident upon the wave plate is linearly polarized at 45 degrees to the positive x-axis. What is the polarization of the light exiting the waveplate? (You may want to rotate the Scene so that the wave is coming directly towards you.) Verify that this is consistent with the way a half-wave plate works.
Exercise 6.5 Quarter-Wave Plate – Linearly Polarized Light Incident

Let the incident field and position of the wave plate remain the same as in Exercise 6.4. Change the Thickness value to 0.25. What is the polarization of the light exiting the waveplate? Verify that this is consistent with the way a quarter-wave plate works.

Please click on the Other Modules link in the Activities menu, then click on Scattering.

7. The Scattering Module

The Scattering module is pictured below.

![The Scattering Module](image)

Figure 11 The Scattering Module

This module simulates the non-resonant scattering of light from an atom. The atom is located at the origin, and the incident light is traveling along the negative y-axis in the positive y-direction. The oscillated pink arrow depicts the induced dipole moment of the atom. The scattered electric field is depicted along three different axes: the positive x-axis, the positive z-axis, and movable axis that whose angular position the user can vary. The spherical polar angles \( \theta \) and \( \phi \) are used to specify the position of the movable axis.

The module has two options for the incident field: Polarized (linearly) and Unpolarized. When the former option is chosen, the incident electric field is given by the expression

\[
\frac{16}{45}
\]
\( E_0(t) = E_0 \cos(kt - \omega t) \), \hspace{1cm} (7.1)

where \( k = \frac{2\pi}{\lambda} \) is the angular wave number of the incident light, \( \lambda \) is its wavelength, \( \omega = kv \) (\( v \) being the wave speed) is its angular frequency, and

\[ E_0 = E_{0x} \hat{i} + E_{0z} \hat{k} . \] \hspace{1cm} (7.2)

Here \( E_{0x} \) is the amplitude of the x-component of the incident electric field, and \( E_{0z} \) is the amplitude of its z-component.

When the incident field is polarized, there are five parameters that the user can vary: \( E_{0x}, E_{0z}, \lambda, \theta, \) and \( \phi \). Each of these parameters can be varied either by using the appropriate keyboard entry box on the Console, or by using the appropriate widget in the scene.

The \( E_{0x} \) widget is the small white cylinder on the left-hand side of the plane where the incident field enters, and the \( E_{0z} \) widget is the small white cylinder on the top part of that same plane. The wavelength widget is the blue wheel. The \( \theta \) widget is the red cube on the top of the movable screen, and the \( \phi \) widget is the blue cube on the top of the movable screen. The domains of these parameters are: \( 0 \leq E_{0x} \leq 1 \), \( 0 \leq E_{0z} \leq 1 \), \( 400 \text{ nm} < \lambda < 700 \text{ nm} \), \( 0 < \theta < 180 \text{ degrees} \), and \( 0 < \phi < 360 \text{ degrees} \).

When the incident field is unpolarized, there are no incident field parameters for the user to vary. The variables \( \theta \) and \( \phi \) may still be varied.

**Example 7.1 Scattering of Linearly Polarized Light**

Let the parameter values be the default values.

(a) Set the value of \( E_{0x} \) to 1 and the value of \( E_{0z} \) to zero. Describe the polarization of the light for observation points on the positive z-axis. (Is it linearly polarized? If so, in what direction?) You may have to rotate the scene to get a better view. Describe the electric field for observation points along the x-axis.

(b) Set the value of \( E_{0x} \) to zero and the value of \( E_{0z} \) to 1. Describe the polarization of the light for observation points on the positive x-axis. Describe the electric field for observation points along the z-axis.

(c) Move the movable screen around and investigate the polarization of the electric field at other locations.

(d) Change the value of the wavelength from 700 nm to 400 nm. Do the amplitudes of the scattered fields get smaller or larger? Use your results to explain why the sky is blue.

**Example 7.2 Polarization by Scattering.**

Choose the Unpolarized option by clicking on its tab.

(a) Describe the polarization of the light for observation points on the positive x-axis. Describe the polarization of the light for observation points along the z-axis. Describe the polarization of the light for observation points along the y-axis.

(b) Set \( \theta \) to be 90 degrees and \( \phi \) to be 15 degrees. Rotate the scene so that the field is coming towards you. Why is this called “partially” polarized light?

Please click on the Stop button before you leave the module. Please click on the Other Modules link in the Activities menu, then click on Waves.
8. The Waves Module

The Waves module is pictured below.

![The Waves module](image)

Figure 12 The Waves module

The module simulates a “ripple tank” with the surface of the water being the x-y plane. The user may place one or more monochromatic point sources (which create circular waves), or monochromatic line sources (which create waves with straight-line wavefronts, let’s call them “linear waves”) on the water surface. The module shows the resultant disturbance, either in a static form (a still picture) or as traveling waves.

For each point source the user controls the amplitude, wavelength, and initial phase of the wave it generates, as well as the x and y coordinates of the position of the source. These parameters may be changed either by typing them into the appropriate keyboard entry box on the Console, or by interacting with the multi-element Point Source widget. The various features of the Point Source widget will be discussed in Exercise 8.2 below.

Each line source creates a wave of amplitude $A$, wavelength $\lambda$, angle of propagation $\theta$, and initial phase $\phi$. The wave function for the wave is given by the formula

$$
\psi(x, y, t) = A \cos(k_x x + k_y y - \omega t + \phi)
$$

where $k_x$ and $k_y$ are, respectively, the x- and y- components of the wave vector of the wave,
\[ k_x = k \cos \theta, \]
\[ k_y = k \sin \theta. \tag{8.2} \]

Here, \( k = 2\pi/\lambda \) is the wave number of the wave, \( \omega = k/v \) is the angular frequency of the wave, and \( v \) is the wave speed. For each line source the user controls the \( A, \lambda, \theta, \) and \( \phi \). The parameter values may be changed either by typing them into the appropriate keyboard entry box on the Console, or by interacting with the multi-element Line Wave widget. The various features of the Line Wave widget will be discussed in Exercise 8.3 below.

The default setting for the module is two point sources (Point Source 1 and Point Source 2), each generating circular waves of amplitude 4.0, wavelength 8.0, and initial phase 0; the first source is located at the position \((0, 16)\) and the second at \((0, -16)\).

Exercise 8.1  Interference of Two Point Sources

(a) Click on the second Viewpoint icon (the one on the right). Are you seeing what you expected in terms of the angular locations of the maxima?

(b) Use the Y keyboard entry box to change the y-coordinate of source Point Source 1 from 16.0 to 8.0. From the Select Source pull down menu, choose Point Source 2. Use the Y keyboard entry box to change its y value to from –16.0 to –8.0. Are you seeing what you expected in terms of the angular locations of the maxima? Click on the first viewpoint icon. Click on the Play button to see the waves moving outwards. Click on the Stop button before proceeding to the next exercise.

Exercise 8.2 Features of the Point Source Widget

Click on the Remove button to remove one of the point sources of the last exercise. Use the appropriate keyboard entry boxes to set the parameter values of the source to: Amplitude = 6.0, Wavelength = 12.0, Phase = 0.0, X = 0.0, and Y = 0.0. Rotate the Scene upwards a little bit. What you should see depicted is something like Figure 13 below.

![Figure 13](image)

Figure 13  The Point Source Widget.

(a) First, let us change the initial phase of the wave created by the point source. Place the cursor over the gold “collar” on the blue pole. Engage the widget by depressing the left mouse button, and then pull the collar downwards until the value of the initial phase is equal to 180 degrees.
(b) Next, let us change the amplitude of the wave created by the point source. Place the cursor over the gold cone on the top of the widget. Engage the widget by depressing the left mouse button, and then pull upwards until the amplitude is equal to 10 (the maximum value).

(c) Next, let us change the wavelength of the wave created by the point source. Place the cursor over any part of the blue ring which surrounds the source. Engage the widget by depressing the left mouse button, and then pull the ring outwards until the value of the wavelength is approximately 16.0.

(d) Next, let us change the position of the point source. Place the cursor over any blue part of the pole. Engage the widget by depressing the left mouse button, and then drag the point source to a new position.

**Exercise 8.3 Features of the Linear Wave Widget**

Click on the Remove button to remove the circular wave of Exercise 8.2 Click on the Add button to add a linear wave. What you should see is pictured in Figure 14 below.

![Figure 14 The Line Wave Widget.](image)

(a) First, let us change the initial phase of the wave created by the line source. Place the cursor over left red ball on the widget. Engage the widget by depressing the left mouse button, and then pull the ball to the left until the value of the phase is 180 degrees.

(b) Next, let us change the amplitude of the linear wave. Place the cursor over the cone on the top of the Linear Wave widget. Engage the widget by depressing the left mouse button, and then pull upwards until the amplitude is equal to 6.

(c) Next, let us change the wavelength. Place the cursor over the cone on the widget that is pointed in the horizontal direction (the x-direction). Engage the widget by depressing the left mouse button, and then pull the cone to the right until the value of the wavelength is approximately 16.0.

(d) Next, let us change the direction in which the wave travels. Place the cursor over either of the two arrowheads (currently pointed in the positive and negative y-directions) on the widget. Engage the widget by depressing the left mouse button, and then turn the arrowhead counterclockwise to rotate the wave until the Angle variable is 45 degrees. Click on the Play button to see the wave move. Click on the Stop button before proceeding to the next exercise.
Exercise 8.4 Beats

Click on the Remove button to remove the linear wave of the last exercise. Add a linear wave whose amplitude is 3.0, wavelength is 6.0, phase is 0, and angle is 0. Add a second linear wave that is identical to the first one, except that its wavelength is 6.75. Rotate the scene up a little, then click on the Play button. You should be able to identify traveling wave packets by looking at the edge of the water surface. Please click on the Stop button before you leave the module.

Please click on the Stop button before you leave the module. Please click on the Other Modules link in the Activities menu, then click on Reflection/Refraction - Waves.

9. The Reflection and Refraction - Waves Two Media Module

The Reflection and Refraction - Waves Two Media module is pictured below.

Figure 15  The Reflection and Refraction - Waves Two Media module.

In this module a monochromatic, plane electromagnetic wave of wavelength $\lambda_1$ and angular frequency $\omega$ is incident from medium 1 onto medium 2 in the manner depicted in Figure 15. The incident electric field is linearly polarized in the z-direction. The two media occupy the half-spaces $x < 0$ and $x > 0$, respectively, and have indices of refraction $n_1$ and $n_2$. The plane of incidence is the x-y plane and the angle of incidence is $\theta$. The module shows a plot of the z-component of the electric field as a function of position in the plane of incidence. The three white vectors above the scene indicate the directions of the incident, reflected, and transmitted plane waves.
The amplitude, wavelength, and angle of incidence of the incident plane wave can be changed either by interacting with the line wave widget on the left of the scene, or by typing in the desired values into the appropriate keyboard entry boxes on the Console. The indices of refraction of the two media can be varied by using the appropriate keyboard entry boxes on the Console. The user may toggle between displaying, in medium 1, either the total field, the incident field only, or the reflected field only by clicking on the button marked “Incident Only” in Figure 15. For example, in that figure the total field is being displayed, and if the user clicks on the “Incident Only” button, the incident field will be displayed instead of the total field.

Exercise 9.1 Air to Glass: Varying the Angle of Incidence

Starting from the default settings, first click on the second viewpoint icon to get an overhead view.
(a) Use the mouse cursor to grab the bottom of the long bar on the line wave widget, and rotate it clockwise to decrease the angle of incidence. Does the angle of refraction increase or decrease?
(b) Now rotate the bar in the counterclockwise direction and increase the angle of incidence to approximately 60 degrees. Did the angle of refraction increase or decrease? Click on the Incident Only button to display only the incident wave in medium 1. Next, click on Reflected Only button to display only the reflected wave in medium 2. Finally, click on the Both button to display the total disturbance again.

Exercise 9.2 Glass to Air: Varying the Angle of Incidence

Use the keyboard entry boxes to change the angle of incidence to 10 degrees, \( n_1 \) to 1.50, and \( n_2 \) to 1.00. The critical angle for this situation is 41.82 degrees. If you do not currently have an overhead view, please click on the second viewpoint icon.
(a) Use the keyboard entry box to change the angle of incidence to 20 degrees, and then to 40 degrees. Does the angle of refraction increases or decrease?
(b) Use the keyboard entry box to change the angle of incidence to 41 degrees, then to 41.5 degrees, and then to 41.8 degrees. What value is the angle of refraction approaching? Click on the Animation button, and then the Play button to see these waves in motion.
(c) Click on the first viewpoint icon to get a non-overhead view. Use the keyboard entry box to change the angle of incidence to 42 degrees. The wave in the air, i.e., on the right of the interface, is an evanescent wave. It travels parallel to the interface, and decays in the direction perpendicular to the interface.
(d) The “penetration depth” of the evanescent wave depends on the angle of incidence. Use the keyboard entry box to change the angle of incidence to 45 degrees, then to 50 degrees, then to 60 degrees. Does the penetration depth of the evanescent wave increase or decrease as the angle of incidence is increased?

Please click on the Other Modules link in the Activities menu, then click on Reflection/Refraction - Vectorial
10. The Reflection and Refraction - Vectorial Module

The Reflection and Refraction - Vectorial module is pictured below.

![The Reflection and Refraction - Vectorial module.](image)

In this module a plane wave of light is incident from a homogeneous medium of index of refraction $n_i$ onto a planar interface with a homogeneous medium of index of refraction $n_t$. The user can vary either of these indices via the appropriate keyboard entry box on the Console.

The user can make the incident light either completely polarized or unpolarized, by selecting either the Polarized or Unpolarized tab on the upper left hand corner of the Console. If the Polarized option is selected, the user can vary the wavelength ($\lambda$), the amplitude of its component perpendicular to the plane of incidence ($E_{\perp}$), the amplitude of its component parallel to the plane of incidence ($E_{\parallel}$), the phase difference between the two components (Phase Diff.), and the angle of incidence (Incident Angle). If the user selects the Unpolarized option, a simulated unpolarized electric field is sent in, and the angle of incidence can be varied. In both cases, the user can use the middle button on the bottom of the console to display which electric field component or components are being displayed: the perpendicular component, the parallel component, both components, or the composite (the actual electric field vector itself).

The values of the angle of refraction, the critical angle (if any), and Brewster’s angle for the specified indices of refraction and angle of incidence are displayed in the center-right portion of the Console.
Exercise 10.1 s-Polarized Light Incident from Air onto Glass

(a) Click on the Hide Widgets button and the Hide Coefficients button. Let the parameter values be the default values (\(\text{Lambd}_i = 550\,\text{nm},\, E_{\text{perp}} = 2.4,\, E_{\text{par}} = 2.4,\, \text{Phase Diff} = 0,\, n_i = 1.0,\, n_t = 1.50,\, \text{Incident Angle} = 45\,\text{degrees}\)), and set the display mode Perpendicular.

(i) Is there a \(\pi\) phase change upon reflection? (You may want to slow the play speed down and Zoom in to get a closer look.) Is there a \(\pi\) phase change upon transmission?

(ii) Which field, the reflected or the transmitted, has the larger amplitude?

(iii) Is the wavelength of the light in the second medium smaller than or larger than the wavelength in the first medium?

(b) Set value of the angle of incidence to 89.9 degrees.

(i) Is there a \(\pi\) phase change upon reflection?

(ii) Approximately what percentage of the incident intensity is reflected, and what percentage is transmitted?

Exercise 10.2 p-Polarized Light Incident from Air onto Glass

Set the display mode to Parallel.

(a) Set value of the angle of incidence to 45 degrees.

(i) Is there a \(\pi\) phase change upon reflection? Is there a \(\pi\) phase change upon transmission?

(ii) Which field, the reflected or the transmitted, has the larger amplitude?

(b) Set value of the angle of incidence to 56.31 degrees. What is the intensity of the reflected light?

(c) Set value of the angle of incidence to 89.9 degrees.

(i) Is there a \(\pi\) phase change upon reflection?

(ii) Approximately what percentage of the incident intensity is reflected, and what percentage is transmitted?

Exercise 10.3 Total Internal Reflection

Set the angle of incidence to 45 degrees. Choose the Composite option for the display type. Set the index of refraction of the incident medium to be 1.50 and the index of refraction of the transmitting medium to be 1.00. The critical angle for this situation is 41.81 degrees. (Comment: the module does not depict the evanescent wave that occurs in the transmitting medium when the angle of incidence is greater than or equal to the critical angle.) Why is the reflected light elliptically polarized instead of linearly polarized?

Exercise 10.4 Unpolarized Light Incident from Air to Glass at Brewster’s Angle

Click the Stop button to stop the animation. Set the index of refraction of the first medium to 1.00, and the index of refraction of the second medium to 1.50. Click on the Unpolarized tab on the Console, and set the angle of incidence to be 56.31 degrees. What is the polarization of the reflected light? Click on the Play button.

Please click on the Other Modules link in the Activities menu, then click on Michelson Interferometer.
11. The Michelson Interferometer Module

The Michelson interferometer module is pictured below.

![The Michelson Interferometer module](image)

Figure 17 The Michelson Interferometer module

In this module light from a monochromatic point source is incident upon the interferometer. The user can vary the wavelength of the incident light by using the Wavelength keyboard entry box or the Wavelength widget (the wheel on the far right of the scene). The interferometer has four components: the beam splitter, the compensator plate, the tilt mirror, and the translation mirror. The first two items are fixed in place and cannot be accessed by the user. The tilt mirror is the mirror on the far left of the scene. It can be tilted (about its vertical axis) an angle $\phi$ by the user either by using the phi keyboard entry box on the Console, or by using the Phi widget, the pink ball that sits on the semicircular track to the left of the tilt mirror. The translation mirror is in the foreground on the right hand side of the scene. It controls the path length difference, $d$, between the paths traveled by two beams. The path length difference $d$ can be varied by using the $d$ keyboard entry box on the Console, or by rotating the Translation Mirror widget (the vertical wheel on the right hand side of the translation mirror).

Exercise 11.1 Changing the Path Length Difference

Set the value of the wavelength to be 500 nm, the value of the path length difference $d$ to 0.005 cm, and the tilt angle $\phi$ to zero.
(a) Is the intensity at the center of the intensity pattern a maximum or a minimum? Is this what you expected? If not, did you consider the $\pi$ phase difference between the two beams introduced at the beam splitter due to the fact that the two beams reflect from it differently?

(b) Use the cursor to engage the Translation Mirror widget, and slowly rotate the wheel clockwise to increase $d$. How does the intensity pattern change? Do the rings move outwards or inwards? Is this what you expected?

Exercise 11.2 Rotation of the Tilt Mirror
Use the mouse cursor to move the Phi widget’s red ball towards the observation screen. How does the observation pattern on the screen change?

Exercise 11.3 Change of the Wavelength
Set the value of the wavelength to be 400 nm, the value of the the Path Length difference to be 0.005 cm, and the tilt angle $\phi$ to be zero. Use the keyboard entry box to increase the wavelength to 500 nm, 600 nm, and 700 nm. How does the observation pattern on the screen change? Is this what you expected?

Please click on the Stop button before you leave the module. Please click on the Other Modules link in the Activities menu, then click on Fabry-Perot Etalon.

12. The Fabry-Perot Etalon Module

The Fabry-Perot Etalon module is pictured below.

![Image of Fabry-Perot Etalon module]

Figure 18 The Fabry-Perot Etalon module.

In this module light from a monochromatic point source (on the left of the scene) is incident upon the “interferometer”. The user can vary the wavelength of the incident light by using the Wavelength keyboard entry
box or the Wavelength widget (the wheel on the far left of the scene). The interferometer is a circularly-faced slab of material of index of refraction \( n \) and thickness \( d \). The faces of the slab are coated and have reflectivity \( R \). \( n \) can be varied by using the Index of Refraction keyboard entry box on the Console, or the wheel widget on the side of the slab. \( d \) can be varied by using the \( d \) keyboard entry box, or the \( d \) widget (the yellow cylindrically shaped slider on the right of the slab). \( R \) can be varied by using the \( R \) keyboard entry box, or the \( R \) widget (the blue-green cylindrically shaped slider just below the slab).

Exercise 12.1 Changing the Reflectivity

Set the value of the wavelength to be 550 nm, the value of the thickness of the slab, \( d \), to be 1.0 cm, the index of refraction of the slab to be 1.5, and the reflectivity to be 0.3. Use the \( R \) keyboard entry box to change the reflectivity to 0.5, then 0.7, and then 0.9. How does the intensity pattern on the screen change as the reflectivity is increased? Is this what you expected?

Exercise 12.2 Changing the Thickness of the Slab

Set the value of the wavelength to be 550 nm, the value of the thickness of the slab to be 0.5 cm, the index of refraction of the slab to be 1.5, and the reflectivity to be 0.7. Use the \( d \) keyboard entry box to change the thickness of the slab to 1.0, and then to 1.5. How does the intensity pattern on the screen change? Is this what you expected?

Please click on the Other Modules link in the Activities menu, then click on Geometrical Optics - Eye.

13. The Eye Module

![The Eye module](image)

Figure 19 The Eye module.
The Eye module is pictured in Figure 19.

The length of the eye can be changed by interacting with the red cone widget on the retina, or by typing the desired value into the Eye Length keyboard entry box on the Console. The yellow object arrow is a widget. The object distance can be varied by pulling on this widget with the mouse cursor, or by typing the desired value into the Object Distance keyboard entry box on the Console. The minimum and maximum focal length for the eye can be varied by interacting with the widgets marked “Min” and “Max,” or by typing the desired values into the appropriate keyboard entry boxes.

The default state of the eye is that it is “normal,” i.e., its far point, when it is relaxed, is infinity, and its near point is 25 cm from the eye. As long as the object is in the range of clear vision, the eye accommodates, and the image of the object forms on the retina. The characteristics of the eye can be changed by changing the eye length or its min or max focal length, or by clicking on any one of the following three buttons: “Near-Sighted (Myopic)”, “Far-Sighted (Hyperopic)”, or “Far-Sighted (Presbyopic)”.

If the eye is farsighted or nearsighted, this can be corrected by going to the Corrective Optics Panel and adding eyeglasses or contact lenses. Figure 20 shows the Eye module with the Corrective Optics panel showing, after corrective lenses added to a myopic eye.

![Figure 20 A myopic eye with a corrective lens.](image)

**Exercise 13.1: Corrective Lens for a Myopic Eye**

On the Setup panel on the Set vision line, click on the Near-Sighted (Myopic) button. This makes the eye myopic, and its far point is 60.00 cm from the eye. Click on the Corrective Optics tab, then click on the Add button, and then click on the Set button. This adds a lens with the proper power to correct the myopia. Move the object away from the eye and convince yourself that the new near point is at infinity (or at least very far away).
Exercise 13.2: Contact Lens for a Myopic Eye

Go to the Setup panel, click the reset button, and then click the Near-Sighted (Myopic) button. This makes the eye myopic, and its far point is 60.00 cm from the eye. Click on the Corrective Optics tab, then click on the Add button, then click on the Contacts button, and then click on the Set button. This adds a lens with the proper power to correct the myopia. Move the object away from the eye and convince yourself that the new near point is at infinity (or at least very far away).

Exercise 13.3: Corrective Lens for a Presbyopic Eye

Go to the Setup panel, click the reset button, and then click the Far-Sighted (Presbyopic) button. This makes the eye presbyopic, and its far point is 45.02 cm from the eye. Click on the Corrective Optics tab, then click on the Add button, and then click on the Set button. This adds a lens with the proper power to correct the presbyopia. Move the object towards the eye and convince yourself that the new near point is 25 cm from the eye.

Please click on the Other Modules link in the Activities menu, then click on Diffraction – Transmission Grating.

14. The Transmission Grating Module

The Transmission Grating module is shown below.
In this module a plane wave of light from a source is incident upon the grating. The Source pull down menu on the left of the Console allows the user to choose amongst the following possibilities: a hydrogen lamp, a helium lamp, a mercury lamp, a sodium lamp, or “user defined.” If the latter is chosen The user can type a wavelength into the Wavelength keyboard entry box, enter it, and then keep adding wavelengths until the incident beam has the desired set of spectral lines. The number of grooves, groove width, and the distance between grooves can be varied by using the appropriate keyboard entry boxes.

**Exercise 14.1 Measuring the Angular Position of a Diffracted Order**

The wavelength of the Hα Balmer line in hydrogen is 656.3 nm. Suppose that light from a hydrogen lamp is incident upon a transmission diffraction grating whose grooves are spaced 2.00 microns apart. At what angles do the various diffracted orders of the Hα line occur?

Let’s use WebTOP to find out. From the Source pull down menu, choose Hydrogen. Click on the second viewpoint icon, so that the screen is closer to you than the grating. The central order \((m = 0)\) is in the center of the scene. Use the Rotate icon to position the first order Hα line (the first off-axis red line) in the center of the scene. Place the mouse cursor over this line. The numerical value of the angle at which this line occurs is displayed in yellow text on the bottom left corner of the Console. Repeat this for the other Hα diffracted orders.

**Exercise 14.2 Creating Your Own Spectrum**

Click on the second viewpoint icon. From the Source pull down menu, choose User Defined. Enter the value 400 in the Wavelength keyboard entry box, and hit Enter (or click on the Add Line button). Enter the value 500 in the Wavelength keyboard entry box, and hit Enter (or click on the Add Line button). You now have created your own spectrum. It should be noted that all the lines added in this way are of equal strength; you do not have a way of changing the strengths. Use WebTOP to determine the angular positions of the various orders of the two lines.
15. The Lasers Module

The Lasers module simulates the behavior of an optical resonator oscillating in a TEM\textsubscript{00} mode. This module consists of a cavity of length $L$ that has concave spherical mirrors on each end, and an observation screen. This is pictured below. The mirror on the left has radius of curvature $R_1$ and the mirror on the right has radius of curvature $R_2$. The wavelength of the light is $\lambda$. The observation screen is a distance $s$ from the mirror on the left.

Exercise 15.1 Confocal Resonator

Set the wavelength to be 700 nm, the radius of curvature of each mirror to be 1000 mm, the length of the cavity to be 1000 mm, Screen to be 2000 mm, and the transverse mode to be TEM\textsubscript{00}.

(a) Use the Wavelength keyboard entry box to change the wavelength from 700 to 400 and back twice. For which wavelength is the beam wider? Why is it wider?

(b) Use the Rotate widget to get a more “head-on” view of the observation screen. Use the Screen widget to move the screen towards the laser to Screen = 1200 mm. How many times larger is the intensity at the center of the beam at this position, as compared to the original position?
(c) Use the Screen widget to move the back to the position Screen = 2000 mm. Select TEM\textsubscript{10} in the Transverse Mode Menu. This inserts a vertical wire into the cavity that forces the laser to lase in its TEM\textsubscript{10} mode. How many intensity nodes (locations of zero intensity) are there on the horizontal axis on the observation screen? How many are there on the vertical axis?

(d) Select TEM\textsubscript{01} in the Transverse Mode Menu. This inserts a horizontal wire into the cavity that forces the laser to lase in its TEM\textsubscript{01} mode. How many intensity nodes are there on the horizontal axis on the observation screen? How many are there on the vertical axis?

(e) Select TEM\textsubscript{11} in the Transverse Mode Menu. This inserts crossed wires into the cavity that forces the laser to lase in its TEM\textsubscript{11} mode. How many intensity nodes are there on the horizontal axis on the observation screen? How many are there on the vertical axis?

Exercise 15.2 Near-Concentric Resonator

Click on the first viewpoint icon. Set the wavelength to be 550 nm, the radius of curvature of each mirror to be 540 mm, the length of the cavity to be 1000 mm, Screen to be 2000 mm, and the transverse mode to be TEM\textsubscript{00}.

(a) Use the Beam brightness slider to make the beam inside the cavity brighter. The location in the center of the cavity where the beam width is the smallest is called the beam waist.

(b) Use the Rotate widget to get a more “head-on” view of the observation screen. Use the Screen widget to move the screen towards the laser to Screen = 1200. How many times larger is the intensity at the center of the beam at this position, as compared to the original position?

(c) Change the two radii of curvatures to 1000 mm. This makes the resonator a confocal resonator. Which resonator produces a more collimated beam, the near-concentric or the confocal?

Please click on the Other Modules link in the Activities menu, then click on Diffraction – Fresnel Circular.
16. The Fresnel Circular Module

The Fresnel Single Slit module is pictured below. In this module a monochromatic plane wave of wavelength $\lambda$ is normally incident upon a circular aperture or obstacle of diameter $D$. The resulting diffraction pattern is observed on an observation screen that is a distance $z$ from the aperture plane.

![Image](image.png)

Figure 23 The Fresnel Circular Aperture module

The parameters $\lambda$, $D$, and $z$ can be changed either by typing the desired values into the appropriate keyboard entry box on the Console, or by manipulating the appropriate widget in the Scene. Spinning the Wavelength widget (the wheel which is located in front of the aperture) changes the wavelength. Pulling on the Diameter widget (the red double cone on the top of the aperture plane) changes the diameter of the aperture. Pulling on the Screen widget (the red double cone on the top of the observation screen) changes $z$.

The current value of the Fresnel number, which is defined as

$$N_f = \frac{D^2}{\lambda z},$$

(16.1)
is displayed on the Console (see Figure 23).

**Exercise 16.1 Changing \( z \): Even Fresnel Numbers**

Use the Wavelength box on the Console to set the wavelength equal to 500 nm, and the Diameter box to set the diameter to 1.00 mm. Remember to hit the Enter key each time after you type in a parameter value.

(a) Use the \( z \) keyboard entry box to set the value of \( z \) to 50 mm. The Fresnel number should now be 10.0. Is the intensity on axis a maximum or a minimum? Starting at one edge of the intensity pattern and proceeding across it through the origin to the other edge, how many “major” maxima do you encounter?

(b) Use the Width widget to make the width of the slit such that the Fresnel number is approximately 8.0. Is the intensity on axis a maximum or a minimum? Starting at one edge of the intensity pattern and proceeding across it through the origin to the other edge, how many “major” maxima do you encounter?

(c) What rule of thumb can be deduced from the results seen in (a) and (b) above, as regards the intensity on axis when the Fresnel number is even?

(d) What rule of thumb can be deduced from the results seen in (a) and (b) above, as regards the number of major maxima seen across the intensity pattern when the Fresnel number is even?

Please click on the Stop button before you leave the module. Please click on the Other Modules link in the Activities menu, then click on Scattering.
17. The Lenses Module

The default configuration of the Lenses module is pictured below.

In this module light rays from a source propagate through a system of lenses and stops according to the laws of paraxial geometrical optics. The rays that hit the observation screen cause a white dot to be displayed there.

In Figure 24 the source is five small circular sources in the shape of a T. We call this the Small T source. The other source options are: Single On-Axis Point, Single Off-Axis Point, Medium T, Large T, Point at Infinity, the T at Infinity, and the Rotation. The source is always fixed in place, it does not move.

In Figure 24 the optical system is a single converging lens of focal length $f = 20$ cm and diameter 5 cm that is 30 cm to the right of the source, and the observation screen is located at the image plane of the lens. In Figure 24 the lens is “selected.” This means that its widgets are displayed and available for the user to interact with, and that the lens parameter keyboard entry boxes (Position, Focal length, and Diameter) are displayed on the module’s console. Pulling on the red double cone on the top of the lens changes the position of the lens, and pulling on the red double cone on its side changes its diameter. Pulling on the green double cone changes the focal length of the lens. Alternatively, these parameters can be changed by typing the desired values into the keyboard entry boxes on the console. Other optical elements (converging lenses, diverging lenses, and stops) can be added by choosing the type of optical element from the pull down menu in the center of the console, and then clicking on the Add button next to it.
In Figure 24 the image quality parameter value is Very High. The other possible values for this parameter are Fastest, Fast, High, Very High, and Custom. They are accessible from the Image Quality pull-down menu on the module’s console.

Figure 25 below corresponds to the same situation, except the now the observation screen is selected. This means that its widgets are displayed and available for the user to interact with, and that its parameter keyboard entry boxes (Position, Width, and Height) are displayed on the module’s console. Pulling on the red double cone on the top of the observation screen changes its position. Pulling on the blue cube on upper left hand corner of the screen changes its height and/or width. Alternatively, typing the desired values into the keyboard entry boxes on the console can also change these parameters.

An optical element (lens, stop or the observation screen) can either be selected by passing the mouse cursor over it, or by using the Selected pull down menu on the console.

Example 17.1 Converging Lens: Object Outside the Focal Point

Starting from the default situation, grab the observation screen Position widget (the red cone on its top) and pull the screen towards the lens (but not past it). Now pull the screen back towards the image plane position, and then past it. How does the ray pattern on the screen change as you pass through the image plane?

Example 17.2 Image Formation by a Two Lens System: Real Intermediate Image

(a) Click the reset button to return to the default situation. Use the Position keyboard entry box to set the position of the lens to 20 cm and the Focal Length keyboard entry box to set its focal length to 10 cm. Click the Add button to add a second converging lens. Use its keyboard entry boxes to set its position to 60 cm and focal length to 10 cm. Select the Observation screen and set its position to be 80 cm. Choose the image quality to be Very High. You should see the situation depicted in Figure 26 below.
Figure 26  The final image for the two lens system of Example 17.2.

(b) Use the mouse cursor to grab the red cone widget on the top of the observation screen and pull the screen to the left until you find the real image formed between the two lenses.

Example 17.3 Image Formation by a Two Lens System: Virtual Object for the Second Lens
Click the reset button to return to the default situation. Set the image quality to Very High. Add a converging lens. Set its position to 50 cm. Set its focal length to 40 cm. Select the observation screen and set its position to 70 cm. You should see the scene depicted in Figure below.

Figure 27  The final image for the two lens system of Example 17.3.

Example 17.4 Astronomical Telescope
Click the reset button to return to the default situation. From the Source pull-down menu choose T at Infinity. Set the position of the converging lens to be 1 cm and its focal length to be 50 cm. From the pull down menu in the center of the console, choose Converging Lens, then click on the Add button. Set the position of this lens to be 56 cm and its focal length to 5 cm. Move the observation screen to the left until it almost touches the first lens, and then
18. How to Record and Play a Session

The fourth portion of WebTOP screen is the recording panel. It contains VCR-like controls that allow you to record a WebTOP session, store it in the form of a script, and then play the script back at any later time.

There are two modes of operation of the recording feature of WebTOP, the RAM-Mode and the Disk Mode.

17.1 RAM-Mode
This mode does not require setting up the recording feature of WebTOP but allows you to save sessions only to the computer RAM memory. Under this mode, you can record a session and replay it but you cannot save it to disk and cannot replay it again after you run another session or after you close the browser. This mode does not allow you to run the provided examples.

17.2 Disk-Mode
This mode allows you to save sessions to computer hard disk, play sessions that are stored on disk and run the provided examples. Figure 27 provides a description of the buttons available at the recording panel. You can use only the highlighted keys.

![Figure 27 Default start-up setting for the recording panel.](image)

The default start-up setting for the Disk-Mode has only two highlighted buttons: the 'record' and the 'open Script.' You can use the 'record' button to record a new script and the 'Open Script' button to retrieve a previously saved script.

To record a script, first press the record button. The Recording panel will then look like Figure 28.

![Figure 28 The status of the recording panel when in recording mode.](image)

Next, make the desired changes to the scene, and then press the stop button when you are through. A file save dialog box will appear, prompting you for a name of the script. Once you give it a name and save it to disk, you may replay the script at any later time. You may now run the script you just recorded, or click on the Open Script button to open an old script.

Suppose that you either just recorded, or just opened a file named 'ex2.wsl'. The recording panel will now look as it does in Figure 29.

![Figure 29 The recording panel after a script has been opened.](image)
To play the script, you must hit the Play button. The Script Status display shows the progress of the running script. Figure 30 shows an example of a running script. The Script Status display then shows the progress of a running script. Figure 30 shows an example of a running script.

Figure 30  The recording panel showing the running script.

19. How to Edit a Script

A WebTOP script has two major parts: initialization tag, and script tag. The initialization tag contains the state of a module when recording started; the script tag records all user interactions. You may use your favorite text editor to edit the script. We recommend the shareware editor Ultraedit (ultraedit.com) and the freeware “Programmer’s File Editor: PFE” (available on our site at: http://webtop.org/tutorialdev/download/pfe101i.zip and is available in the download folder of the WebTOP CDROM.) We do not recommend using Microsoft Windows Notepad since it does not translate carriage returns properly. Figure 31 provides an example script:

```xml
<wsl>
    <singleslit wavelength="550.0" slitWidth="0.4" z="50.0" widgets="visible" action="reset">
        <view value="0.0 0.0 0.0 -2.0 2.0 -10.0" />
    </singleslit>
    <script>
        <actionPerformed param="slitWidth" value="0.3" timeStamp="7480" />
        <viewpointChanged value="-0.0954957 -0.031241298 0.0 -2.0 2.0311637 -26.090597" timeStamp="0" />
        <viewpointChanged value="-0.0954957 -0.031241298 0.0 -2.0 2.0311637 -26.090597" timeStamp="60" />
        <viewpointChanged value="-0.0954957 -0.031241298 0.0 -2.0 2.0623274 -26.090597" timeStamp="0" />
        <viewpointChanged value="-0.0954957 -0.031241298 0.0 -2.0 2.0623274 -26.090597" timeStamp="20" />
        <viewpointChanged value="-0.0954957 -0.031241298 0.0 -2.0 2.0934916 -26.090597" timeStamp="0" />
        <viewpointChanged value="-0.0954957 -0.031241298 0.0 -2.0 2.0934916 -26.090597" timeStamp="30" />
        <viewpointChanged value="-0.0954957 -0.031241298 0.0 -2.0 2.1246548 -26.090597" timeStamp="0" />
        <viewpointChanged value="-0.0954957 -0.031241298 0.0 -2.0 2.1246548 -26.090597" timeStamp="31" />
        <viewpointChanged value="-0.0954957 -0.031241298 0.0 -2.0 2.166983 -26.090597" timeStamp="0" />
        <viewpointChanged value="-0.0954957 -0.031241298 0.0 -2.0 2.166983 -26.090597" timeStamp="30" />
        <viewpointChanged value="-0.0954957 -0.031241298 0.0 -2.0 2.249311 -26.090597" timeStamp="0" />
        <actionPerformed param="wavelength" value="450.0" timeStamp="9143" />
        <actionPerformed param="z" value="25.0" timeStamp="8061" />
        <actionPerformed param="widgets" value="hidden" timeStamp="2183" />
        <actionPerformed param="widgets" value="visible" timeStamp="2244" />
    </script>
    <scriptEnded timeStamp="2684" />
</wsl>
```

Figure 31 A script recorded by the Fresnel Single Slit module

The script starts with the “<wsl>” tag. This is required and should be kept unchanged. The Initialization Tag starts in the following line. The name of the tag (in this case “singleslit”) is determined by the module and should not be changed. The values of the different parameters are embedded within the same tag. You may change the parameter values to whatever you desire as long as you use the same number format (an integer should remain an integer, etc.)

Within the Initialization Tag are the viewpoint “view” parameters. The six numbers are three angles in radians and the three coordinates of the module.

You may only change parameter values from within the Initialization Tag; you should not remove any.

The script starts after the “<script>” tag and ends at the “</script>” tag. It is where user interactions are recorded. Each interaction is defined in terms of an “action tag” with these attributes:

- target: ID of the object involved
- param: parameter affected
- value: new value of param
- timeStamp: time elapsed in milliseconds since the previous action (required)

The type of interactions recorded are mouse interactions on VRML widgets, value entries in module console, and viewpoint changes. The corresponding action tags are:
• objectAdded
• objectRemoved
• mouseEntered
• mouseExited
• mousePressed
• mouseReleased
• mouseDragged
• actionPerformed
• viewpointChanged
• viewpointSelected

Each interaction is recorded as the symbol “<” followed by the action tag name (for example: “viewpointChanged”) and the ending tag “/>”. You may delete a tag if you delete everything from the “<” symbol to the “/>” symbol. You may also change the value for an interaction or the “timestamp” value. Figure 32 shows an edited version of the script in Figure 31.

```wsl
<singleslit wavelength="550.0" slitWidth="0.4" z="50.0" widgets="visible" action="reset">
  <view value="0.0 0.0 0.0 0.0 0.0 -10.0" />
</singleslit>
<script>
  <actionPerformed param="slitWidth" value="0.3" timeStamp="7480" />
  <viewpointChanged value="-0.0954957 -0.031241298 0.0 -2.0 2.249311 -26.090597" timeStamp="500" />
  <actionPerformed param="wavelength" value="450.0" timeStamp="500" />
  <actionDate param="z" value="25.0" timeStamp="500" />
  <actionDate param="widgets" value="hidden" timeStamp="500" />
  <actionDate param="widgets" value="visible" timeStamp="500" />
</script>
<scriptEnded timeStamp="1000" />
</wsl>

Figure 32  An edited version of the script in Figure 31

20. How to Set Up a Web Page That Uses WebTOP

Except for the Reflection/Refraction Vectorial module, all WebTOP modules can be included in a web page by including the code in Figure 33. The bold underlined items are module specific and are provided in tables 1 and 2. The code assumes that you are placing the html file in the same folder as the vrml (extension “.wrl”) file. It also assumes that the “jars” folder is at the same level as the folder you are using for your html, and that the script is placed in a subfolder of the “jars” folder called “wsl”. Information about the tree structure is provided below. Note that you might download each of the files listed in Tables 1 and 2 individually by going to the following URLs: http://webtop.org/tutorialdev/vrmlist.html and http://webtop.org/tutorialdev/classlist.html. The common files used by all modules can be downloaded from http://webtop.org/tutorialdev/webtophtmltags.html. You may choose any name for the scripts you record “scriptname.wsl” as long as you use the “.wsl” extension.
Figure 33  html code used to include a WebTOP module

Table 1 Parameters to use for the various WebTOP modules. These parameters are marked in bold and underlined in Figure 33.

Table 2 Additional Parameters to use for the various WebTOP modules. These parameters are marked in bold and underlined in Figure 33.
The Reflection/Refraction Vectorial module requires the use of an additional applet. The code for this applet should be placed just after the "</OBJECT>" tag shown in Figure 33. The additional code needed for the module is shown in Figure 34.

```html
<applet codebase='../jars/' code='webtop.reflection.Coefficients.class' alt='Coefficients' name='Coefficients' id='Coefficients' width="205" height="281" mayscript archive='component.jar,numberbox.jar,adlmath.jar,util.jar,wsl.jar,parser.jar,reflection.jar' />
</applet>
```

Figure 34 html code to add to the code shown in Figure 28 when using the Reflection/Refraction Vectorial module. The bolded and underlined items may be customized.

### 20.1 Building the Tree Structure Used In the Example Discussed Above

To build the tree structure described above, please follow these steps:

- Create a folder called: webtop
- Enter that folder and create the following three folders (which are subfolders to the "webtop" folder): images, jars, and html
- Enter the folder "jars" and create a folder called wsl.
- All html files that you create should be placed in the folder called "html"
- All vrm files (extension wrl) should be placed in the folder called "html"
- All the jar files should be placed in the folder called "jars"
- All script files (extension wsl) should be placed in the folder called "wsl"
- The "checker.jpg" image file should be placed in the images folder.

![Directory Structure](https://via.placeholder.com/150)

Figure 35 An example of the directory structure discussed.
More help on how to set up WebTOP-based web pages is available at the tutorial development URL: http://webtop.org/tutorialdev/

21. Conclusion and Acknowledgment

WebTOP is not yet a finished product. Some Theory, Examples, and Exercises sections need to be finished, and other modules are under development. We would appreciate any comments or suggestions on any of the modules you may have.

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Appendix: WebTOP Team Members and Alumni

Members

Dr. David C. Banks  
Department of Computer Science  
Florida State University  
Tallahassee, FL 32306  
banks@csit.fsu.edu

Dr. John T. Foley  
Department of Physics and Astronomy  
Mississippi State University  
Mississippi State, MS 39762  
jtf1@ra.msstate.edu

Peter Gilbert  
Department of Computer Science  
Mississippi State University  
Mississippi State, MS 39762  
pig19@msstate.edu

S. Davis Herring  
Department of Physics and Astronomy  
Mississippi State University  
Mississippi State, MS 39762  
sdh6@ra.msstate.edu

David Moore  
Department of Computer Science  
Mississippi State University  
Mississippi State, MS 39762  
dtm3@ra.msstate.edu

Matt Morris  
Department of Computer Science  
Mississippi State University  
Mississippi State, MS 39762  
mjm9@cs.msstate.edu

Dr. Taha Mzoughi  
Department of Physics and Astronomy  
Mississippi State University  
Mississippi State, MS 39762  
mzoughi@ra.msstate.edu

Brian Thomas  
Department of Computer Science  
Mississippi State University  
Mississippi State, MS 39762  
bth32@msstate.edu

Alumni

Yong-Tze Chi  
Sparco.Com  
500 Russell St.  
Starkville, MS 39759  
tze@sparco.com

Kiril Vidimce  
Pixar Animation Studios  
1001 W. Cutting Blvd.  
Richmond, CA 94804  
vkire@pixar.com

Rhett Maxwell  
Rhett.Maxwell@BroadVision.com

Sara Smolensky  
Microsoft Corporation  
One Microsoft Way  
Redmond, WA 98052-6399  
sarasmol@microsoft.com

Ben Wyser  
Data-Tronics Corp.  
Fort Smith, Arkansas  
bwyser@cox-internet.com
Notes