

The Shoebox spectrograph construction and lab investigations

By

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Part 1. Build your own spectrograph from flat cardboard

Tools and materials:



Necessary items

Scrap cardboard (You will need a 46cm by 44cm piece, a 12cm by 5cm, and a 5cm by 5cm piece)

Box cutter or utility knife

Duct tape

School glue

Meter stick

Shears

Marking pen

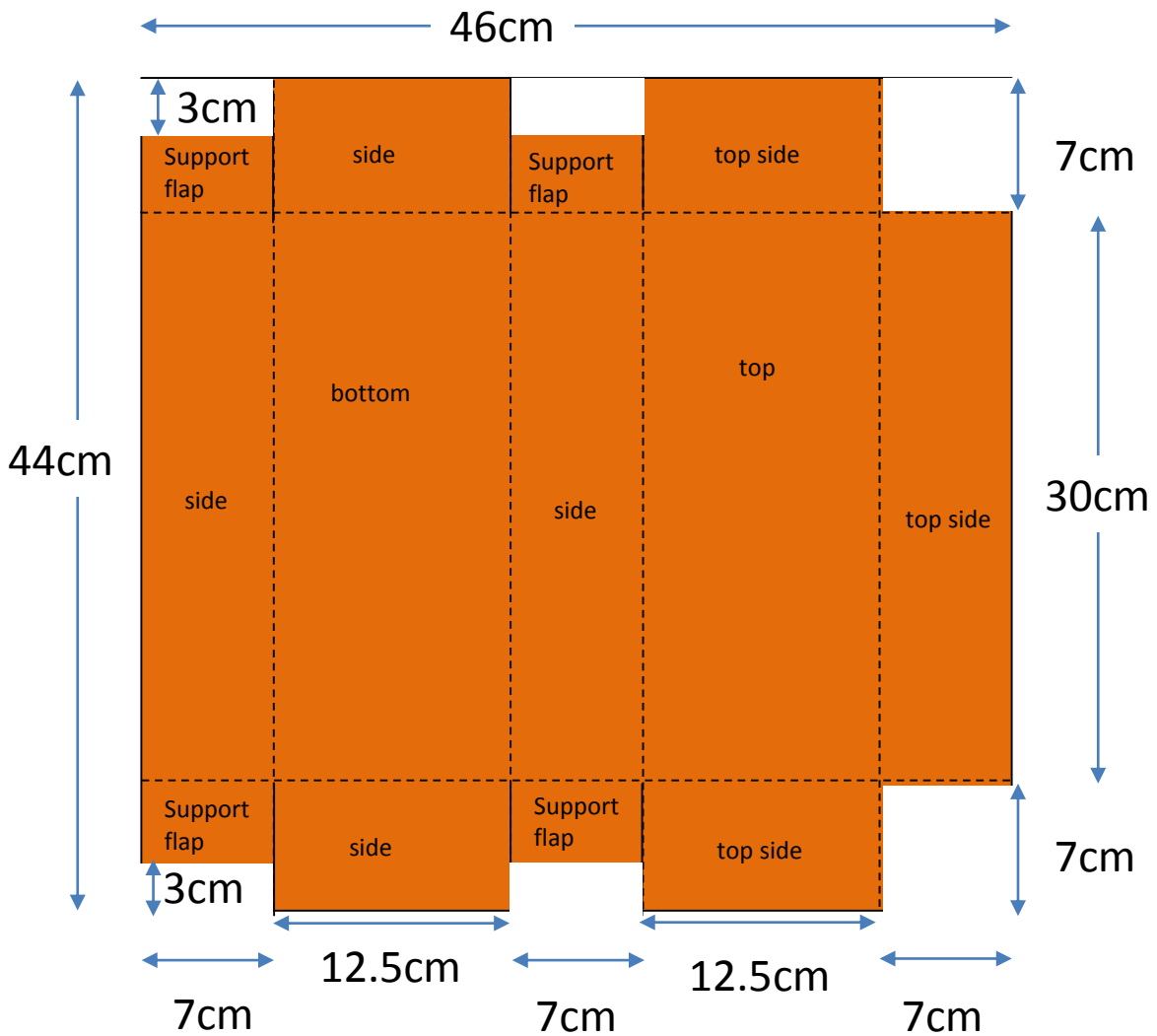
DVD or piece of a DVD (blank read/write disks are fine)

Useful additions

Heating gun (steam from a pot of boiling water can replace this item)

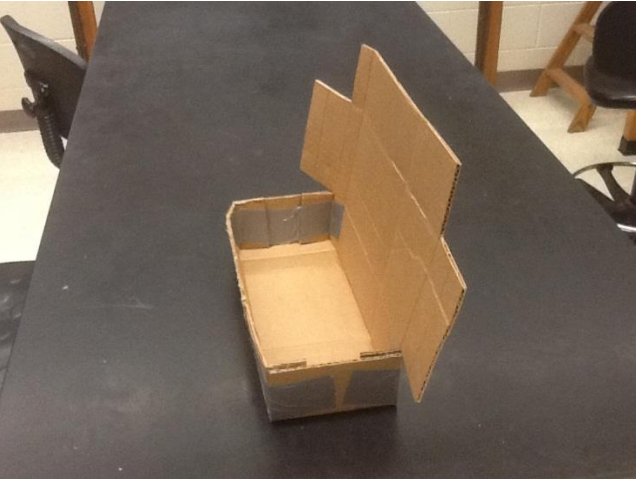
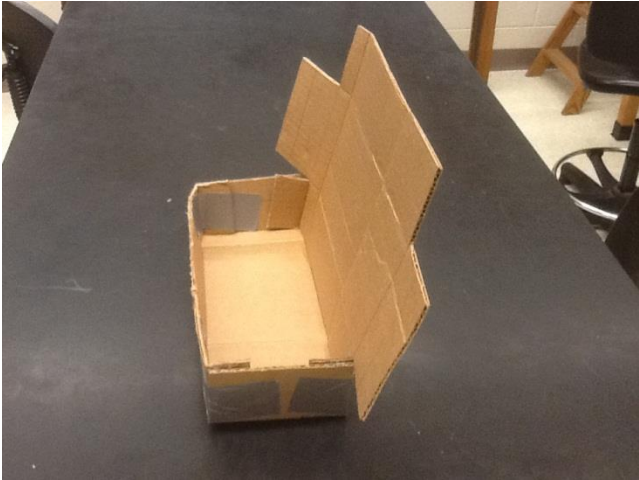
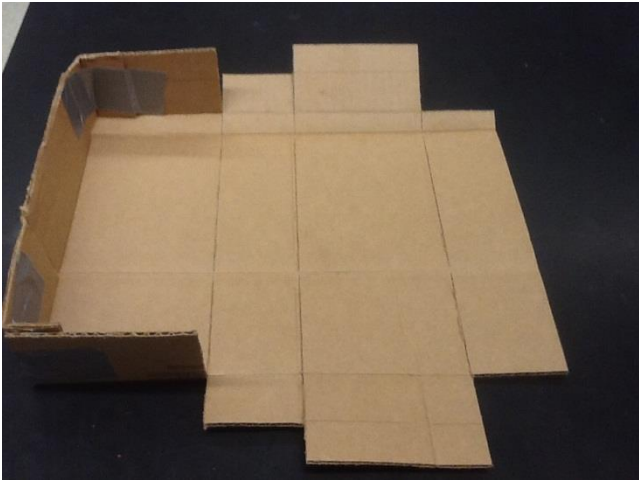
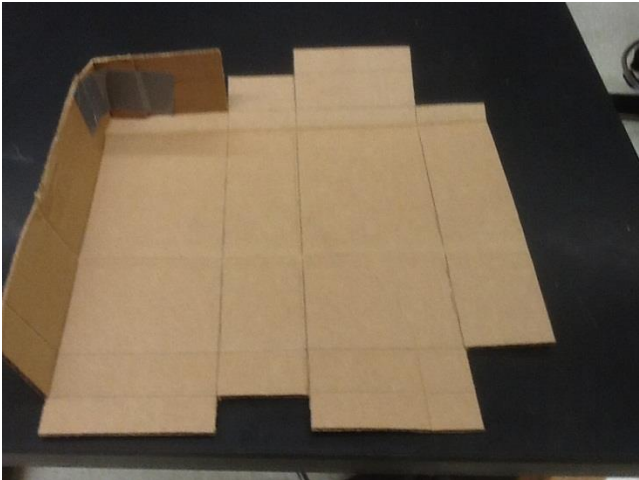
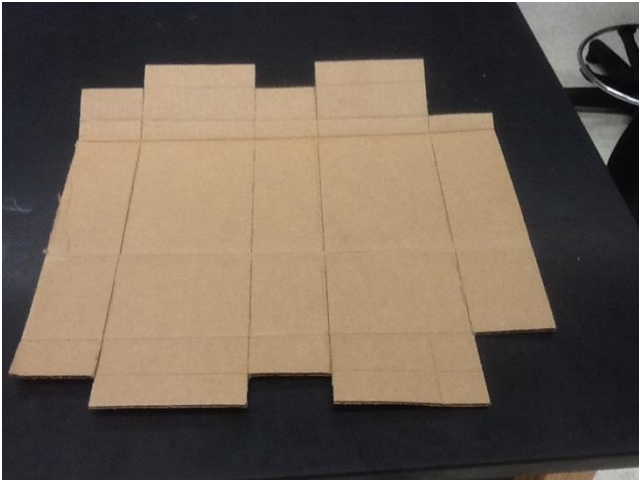
T-square (to ensure right angles, but careful measurements can be used instead)
 Cutting board (to eliminate gauging your work table)
 Rubber stopper hole cutter- 0.6cm diameter (to get a more neat round view port hole)
 Glass cutter (used to scribe lines for folding, but carefully cutting with a box cutter through one layer will work)

Step 1: Cut out the following shape using flat cardboard. The solid lines indicate cut slots. The dotted lines indicate scribed indentures for easier folding. This should be ONE PIECE of cardboard.



Step 2: Fold the cardboard into a box shape and use duct tape and school glue to hold the cardboard in place. The duct tape simply holds the box in shape while the glue dries. See the following assembly photos.

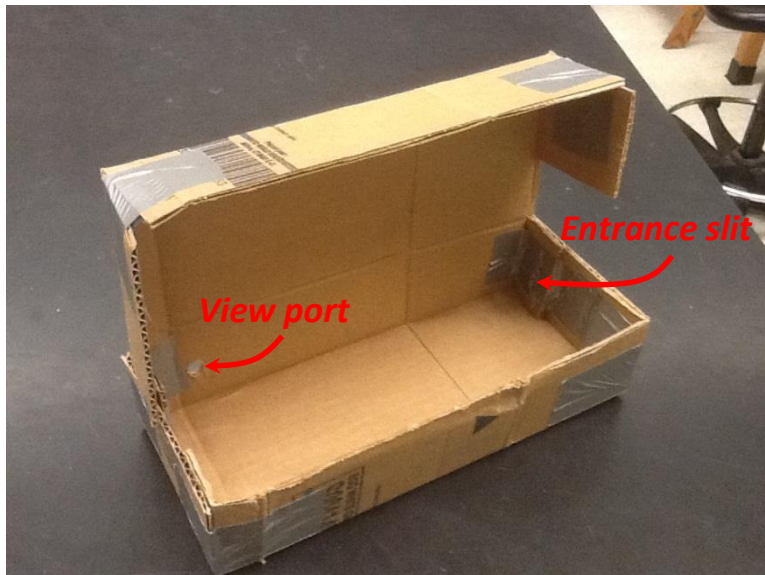
Pictures during assembly



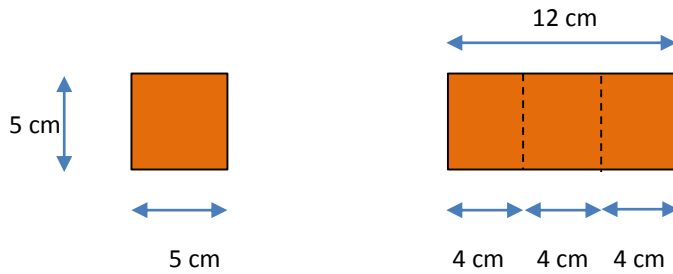
Step 3: Cut off a portion of the side flap. Otherwise when you try to make a slit, you would have to cut through 3 layers of cardboard. Then cut a light entrance slit. The slit should be approximately 4cm long and 0.2cm wide and be approximately 2.5cm from the side of the box (see the following photos).



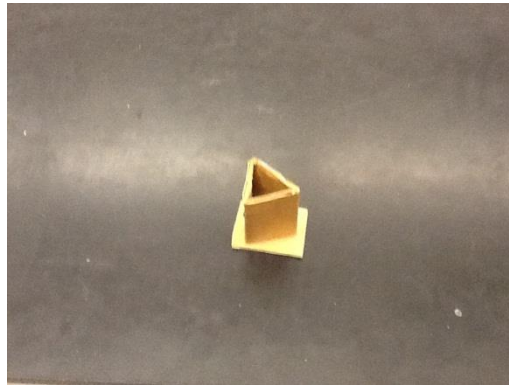
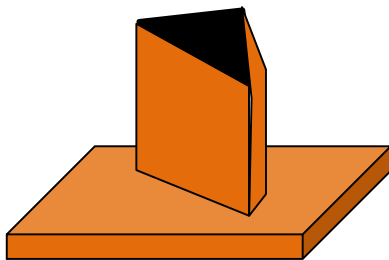
Step 4: Cut the view port into the side of the box (about 4cm from the box's edge). The easiest way to get a round view port is to use the same tools that make holes in rubber stoppers.



Step 5: Prepare the grating holder. You will need a 12cm by 5cm piece of flat cardboard and an approximate 5cm by 5cm piece of flat cardboard. Scribe the 12cm by 5cm piece as shown below.

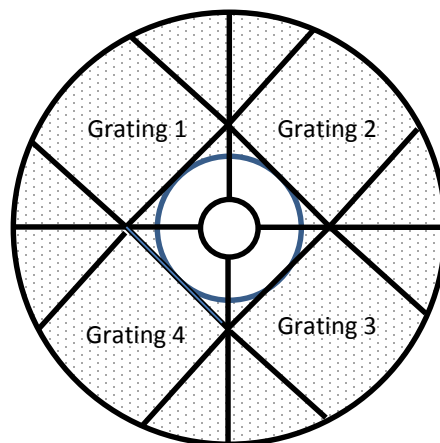
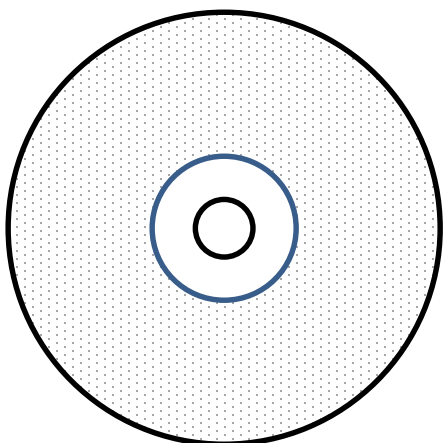


Step 6: Fold the 12cm by 5cm cardboard piece into a triangle and secure the shape with tape. Then attach the triangle to the 5cm by 5cm piece (see below) using tape.

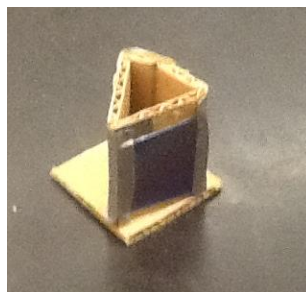
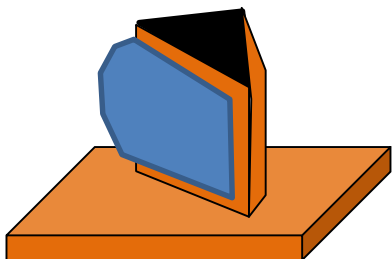


Step 7: Now you need to make your grating from a DVD. Be aware that if you try to cut a room temperature DVD, it will crack, flake, and/or fracture. To avoid this problem, you must first heat the DVD. Heating it for about a minute with a heat gun will work or boiling it in water. You want the disk to be a little hotter than you could hold, but not so hot the plastic deforms.

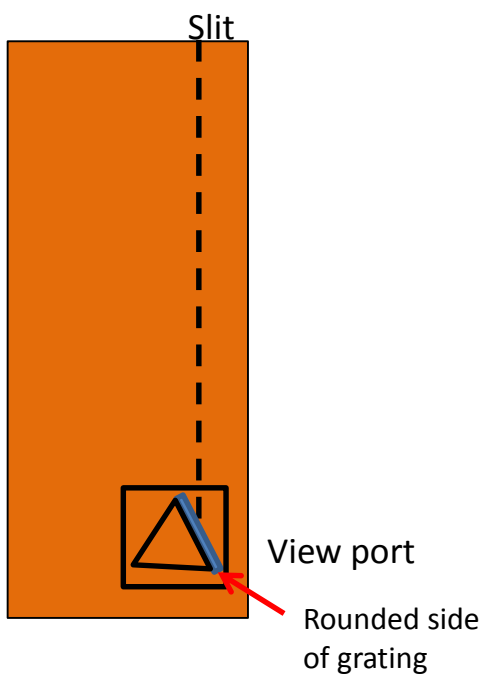
Step 8: Cut the DVD with shears or strong scissors to get your grating. Trying to cut it with a knife or saw (even when heated) can cause flaking, cracking, and/or fractures. Each DVD can provide up to 4 usable gratings (see the sketch shown below).



Step 9: Attach your grating to your grating holder using tape. Make sure that most of the grating is not covered by tape.



Step 10: Open your spectrometer box and place the grating assembly inside. The center of the grating should be aligned with the slit (see sketch).



Step 11: Hold the slit upwards toward a light source like fluorescent lights. Carefully rotate the grating assembly until the diffraction pattern (bands of different colors of light in the same order as a rainbow) is seen through the view port. You may find it necessary to cut off pieces of the grating holder base for optimal viewing. Make sure the light you are using is coming through the slit (putting your finger over the slit should make the diffraction pattern go away). Once you have the grating assembly in the correct position, hold it in place until you can secure the position with tape and glue.



Step 12: Close the box and view different light sources. Keep in mind that you can also use light that is reflected off non-luminous object.

Part 1 alternate: Build your own spectrograph from a pre-existing cardboard box (an alternate way of creating a spectrograph)

Tools and materials:



Necessary items

A box (ideally 30cm by 12.5cm by 7cm, but there is a lot of leeway in these dimensions)

Scrap cardboard (You will need a 12cm by 5cm and 5cm by 5cm piece)

Box cutter or utility knife

Duct tape

School glue

Meter stick

Shears

Marking pen

DVD or piece of a DVD (blank read/write disks are fine)

Useful additions

Heating gun (a pot of boiling water can replace this item)

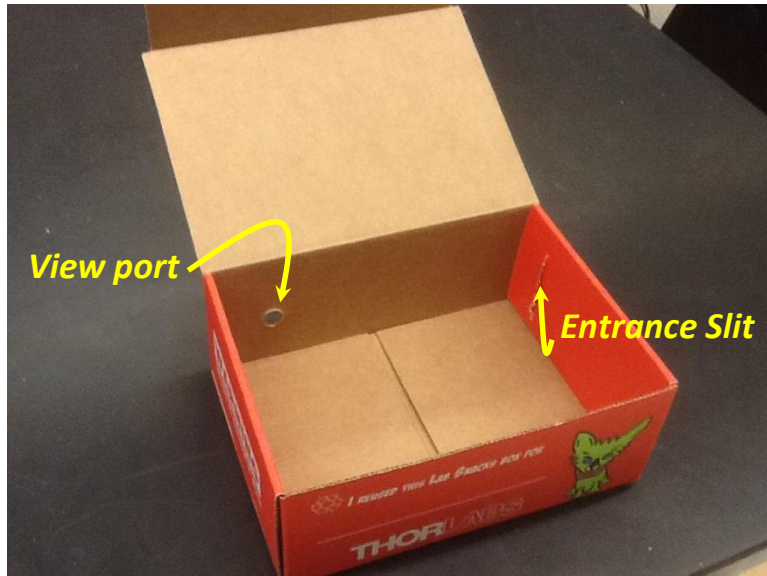
Cutting board (to eliminate gauging your work table)

Rubber stopper hole cutter- 0.6cm diameter (to get a more neat round view port hole)

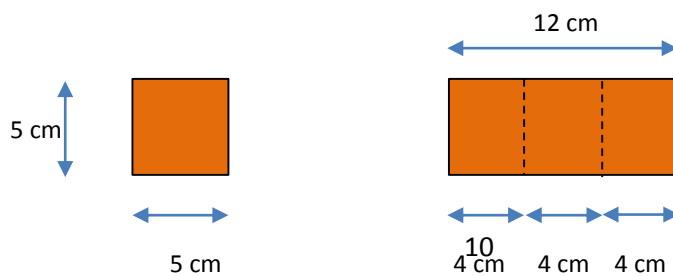
Step 1: Cut a light entrance slit into a side of the box. The slit should be approximately 4cm long and 0.2cm wide and be approximately 2.5cm from the side of the box (see the following photo).



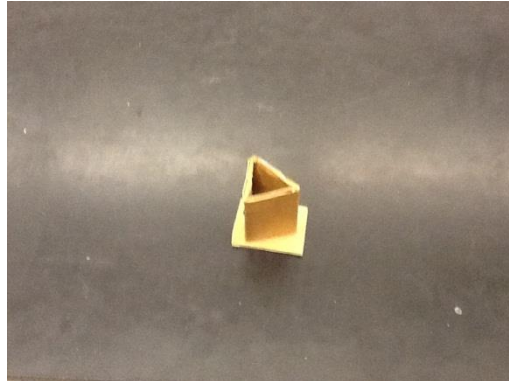
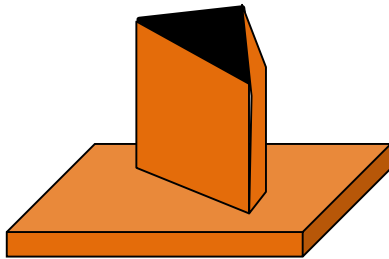
Step 2: Cut the view port into the side of the box (about 4cm from the box's edge). The easiest way to get a round view port is to use the same tools that make holes in rubber stoppers.



Step 3: Prepare the grating holder. You will need a 12cm by 5cm piece of flat cardboard and an approximate 5cm by 5cm piece of flat cardboard. Scribe the 12cm by 5cm piece as shown below.

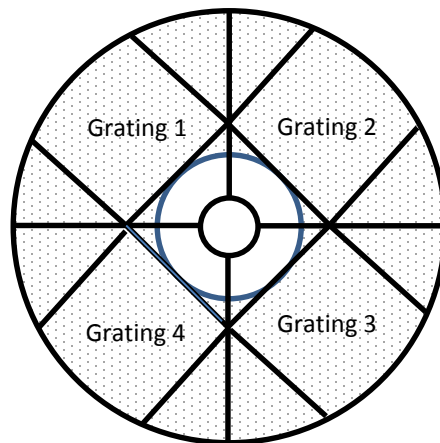
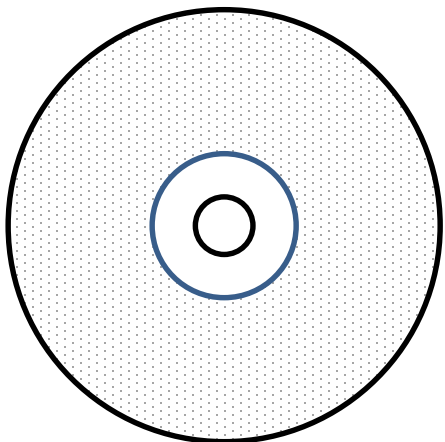


Step 4: Fold the 12cm by 5cm cardboard piece into a triangle and secure the shape with tape. Then attach the triangle to the 5cm by 5cm piece (see below) using tape.

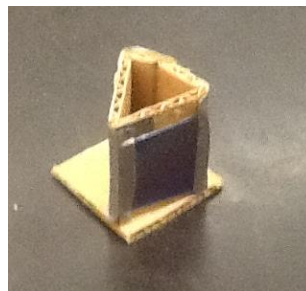
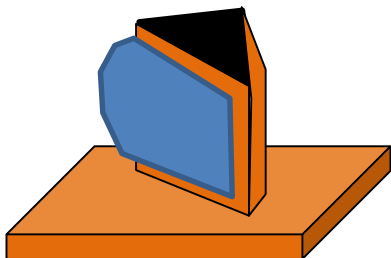


Step 5: Now you need to make your grating from a DVD. Be aware that if you try to cut a room temperature DVD, it will crack and fracture. To avoid this problem, you must first heat the DVD. Heating it for a about a minute with a heat gun will work.

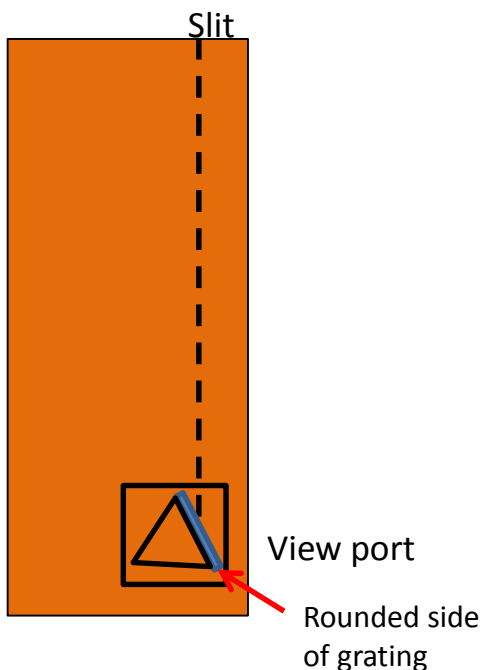
Step 6: Cut the DVD to get your grating. Each DVD can provide up to 4 usable gratings (see the sketch shown below).



Step 7: Attach your grating to your grating holder using tape. Make sure that most of the grating is not covered by tape.



Step 8: Open your spectrometer box and place the grating assembly inside. The center of the grating should be aligned with the slit (see sketch).



Step 9: Hold the slit upwards toward a light source like fluorescent lights. Carefully rotate the grating assembly until the diffraction pattern (bands of different colors of light in the same order as a rainbow) is seen through the view port. Make sure the light you are using is coming through the slit (putting your finger over the slit should make the diffraction pattern go away). Once you have the grating assembly in the correct position, hold it in place until you can secure the position with tape and glue.



Step 10: Close the box and view different light sources. Keep in mind that you can also use light that is reflected off non-luminous object.

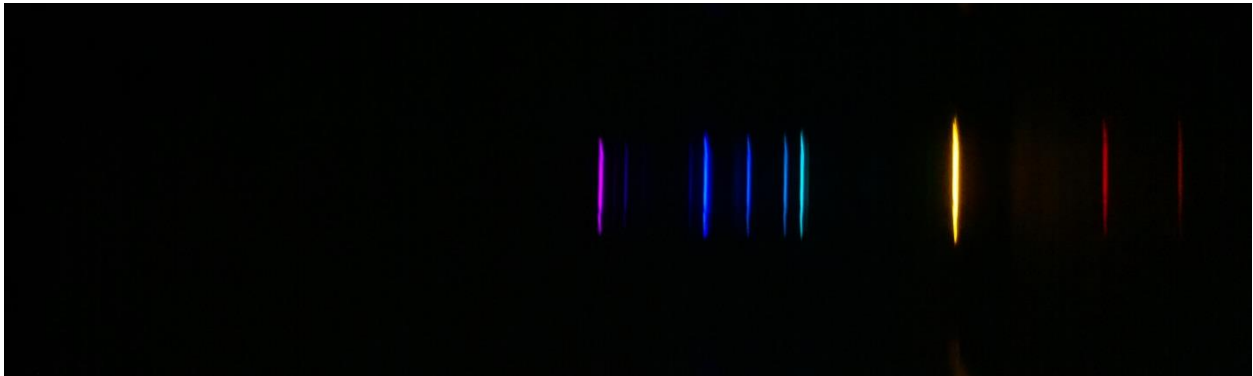
Part 2. Webcam placement and Calibration

Objectives: In this section, you will first attach a webcam (or some other photo taking device to your spectrograph). Next you will be introduced to an open source program called imageJ to analyze pictures taken with your spectrograph. Then after a calibration process, you will be able to perform a variety of later investigations.

Step 1: Aim your spectrograph towards a light source. This light source could be the overhead fluorescent lights or gas discharge tube (like a helium source). Ideally, this light source should have discrete lines. Then try to lightly attach your spectrograph to a table top or desk (masking tape can help) so that you can see the spectra through the viewing port **WITHOUT MOVING THE SPECTROGRAPH.**

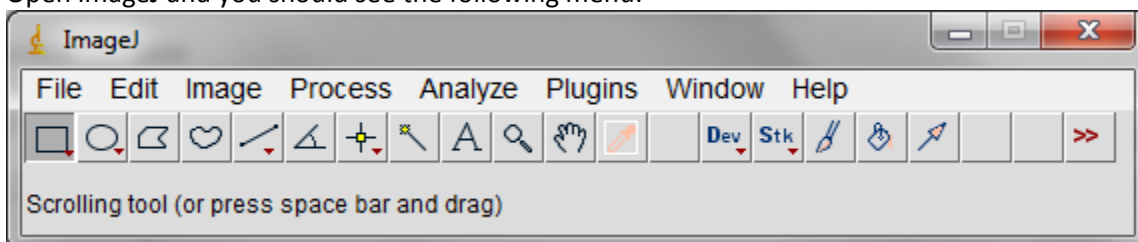
Step 2: Now bring the webcam (or photo taking device) to the spectrograph's viewport. The webcam should be attached to a computer so that you can see how the spectral lines are oriented. Try to orient the webcam such that the discrete lines are **VERTICAL** and one can see red through violet lines simultaneously on the screen. Once you have this orientation, secure the webcam to the spectrograph with tape (you can carefully use glue if you are trying to make a more permanent spectrograph). Getting help from a second person can greatly aid this process so don't be shy in asking for help. **IT IS VITAL THAT THE WEBCAM IS SECURELY ATTACHED AND WELL ALIGNED. IF THE WEBCAM MOVES YOU WILL LOSE A GREAT DEAL OF ACCURACY.** Use lots of tape and/or glue.

Step 3: Now that the webcam is securely attached to the spectrograph, we will use a helium gas discharge tube to calibrate the spectrograph. Turn on the lamp and orient the spectrograph to get the brightest spectral lines possible. Take a picture of these lines.



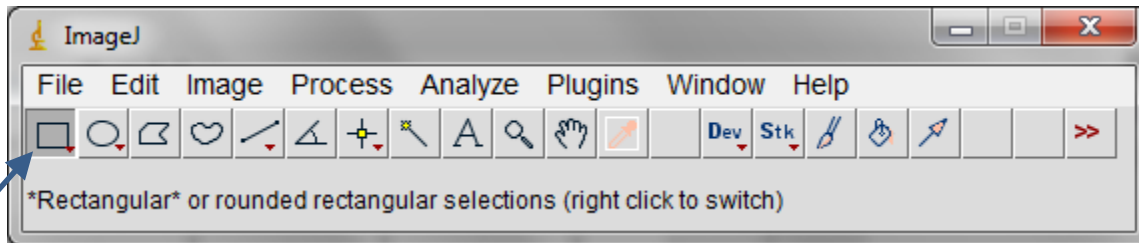
Where the lines appear in the photograph is irrelevant. All you need is bright, vertical lines going from red to violet (or violet to red).

Step 4: If you haven't already done so, download imageJ to your computer (go to imagej.nih.gov/ij/). Open imageJ and you should see the following menu:



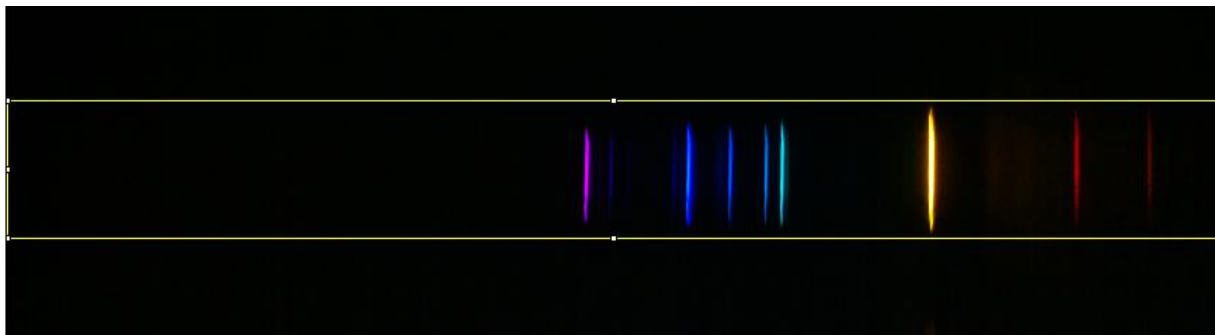
Use the mouse and go to File → Open... This should open a browsing window. You now need to locate (and then open) the photograph you took in step 3.

Once the photograph is opened (you should see a window that contains your photograph) use the rectangle tool to define a region of interest. First click on the rectangle tool.

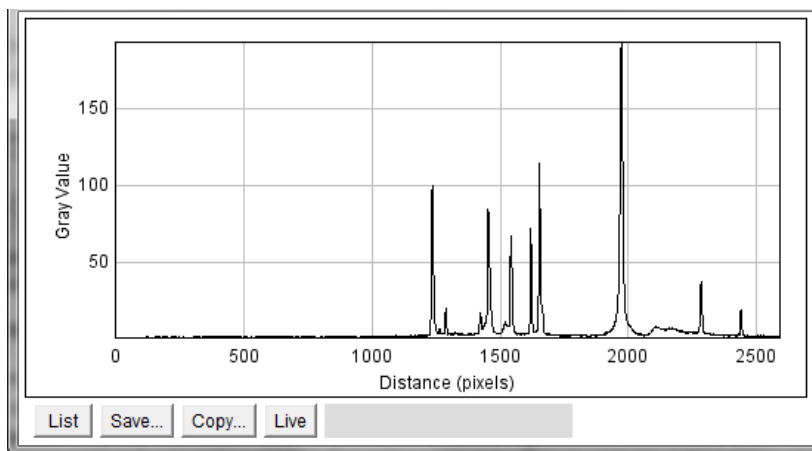


Rectangle tool

Then move the mouse to the window with your photograph. Left click and drag the mouse to select a region of interest. **THIS REGION OF INTEREST SHOULD EXTEND FROM THE FAR LEFT SIDE OF YOUR PHOTOGRAPH TO THE FAR RIGHT SIDE.** If you didn't draw the region of interest to your exact liking, there are small squares on the yellow box that allow you to modify it after it was drawn.



Now go to Analyze → Plot Profile. This should open another window that displays an intensity vs. distance graph.



Step 5: Now open a spreadsheet program like Excel. On the window that shows the intensity vs. distance graph there is a button called "Copy..." Press the button by left clicking it with the mouse. Then go to the spreadsheet program and paste in the values.

Step 6: One must now determine the pixel locations for peak intensities. For the example shown above, we find peak intensities at pixel locations ...

1238
1267
1291
1426
1456
1524
1545
1622
1656
1668
1975
2286
2442

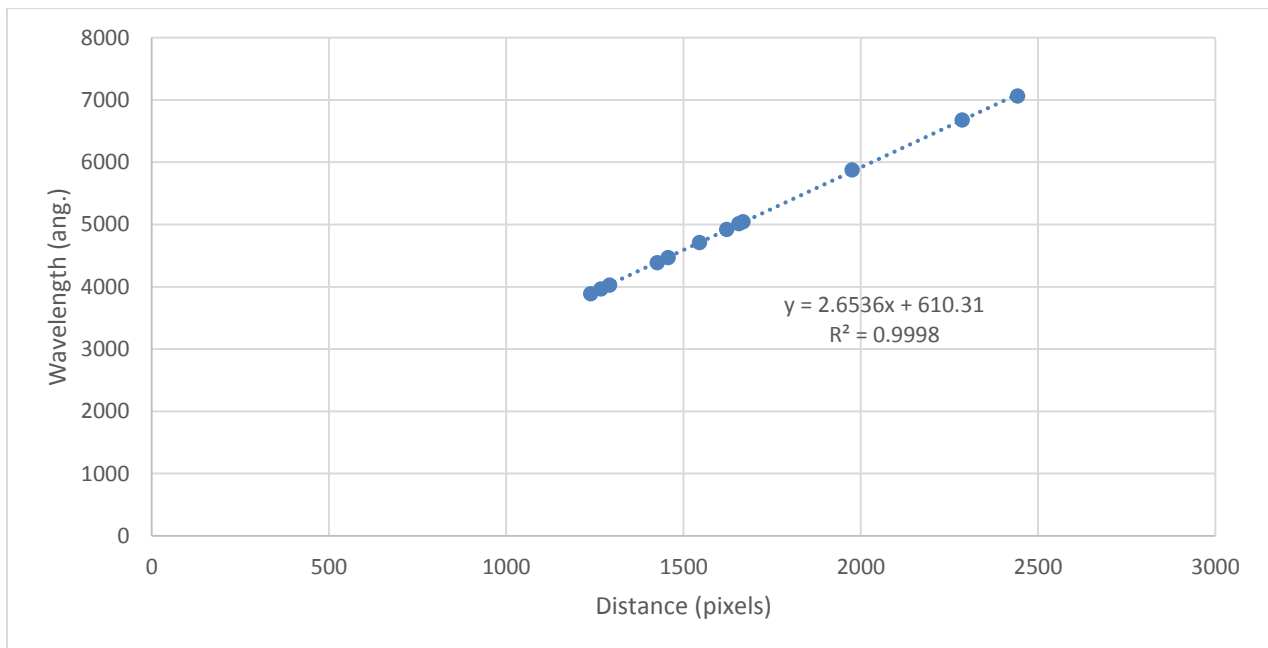
Step 7: Now we need to look up the known wavelengths of helium. The National Institute of Standards and Technology (NIST) maintains this information on line. The easiest way of finding any element is to do a google search of "strong lines of element name". By googling "strong lines of helium" we can find the appropriate table for helium. These tables are over-complete for our purposes and one can ignore any wavelength that is less than 3500 angstroms and any wavelength greater than 7500 angstroms (these are beyond the range of human vision as well as beyond the range of most photographic devices).

Step 8: We now need to match the peak intensity pixel locations with known wavelengths. If we do this correctly, there should be a linear relationship between our pixel locations and the known wavelengths. This sounds easy but there are multiple distractors. For example, there are "strong lines" that are rarely seen such as those listed as He II. These are lines associated with He-He molecules and they produce far weaker lines than atomic helium (He I). It is also not uncommon to see peak intensity locations that do not match listed wavelengths. This happens for two reasons: NIST may not have called that emission a strong line or there may be a contaminating substance in the tube. Finally, it is not uncommon to see listed wavelengths as strong lines with no corresponding peak intensity in the photograph. This occurs because some gas discharge tubes do not populate the energy levels that correspond to those lines or that these lines are too weak to be seen with our apparatus.

In the example shown above, we found the following correlations between pixel location and wavelength:

Pixel	Wavelength (ang.)
1238	3888.6489
1267	3964.729
1291	4026.191
1426	4387.929
1456	4471.479
1524	
1545	4713.146
1622	4921.931
1656	5015.678
1668	5047.74
1975	5875.6148
2286	6678.1517
2442	7065.1771

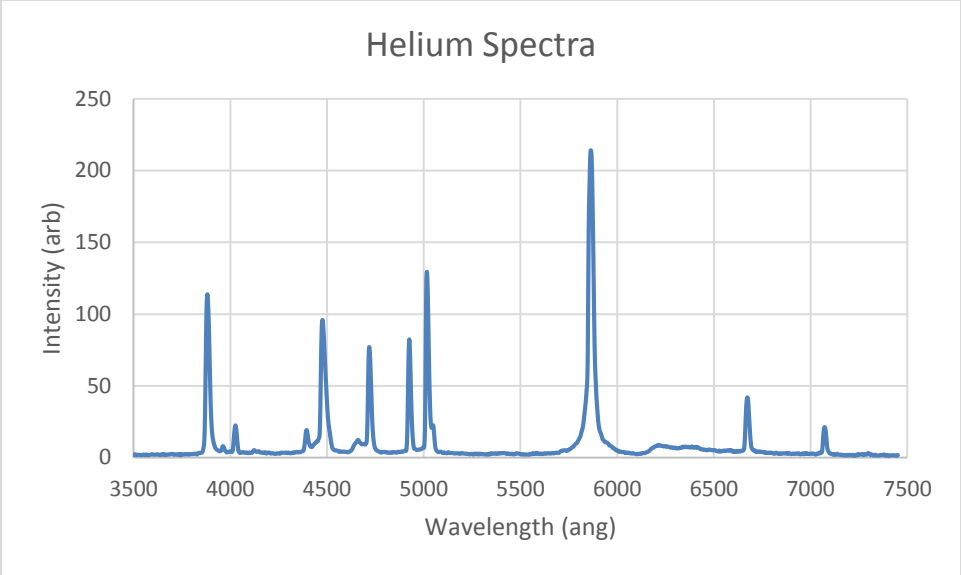
Which when plotted form a linear relationship:



This would indicate that the calibration is:

$$\text{Wavelength} = 2.6536 \frac{\text{ang}}{\text{pixel}} \times \text{Distance} + 610.31 \text{ ang}$$

By using Excel to create a wavelength column we can produce helium tube intensity vs. wavelength graph.



Part 3. Measurement of “unknown” spectra

Objectives: The purpose of these measurements is to determine the relative accuracy of your particular spectrograph as well as demonstrate how one can use spectrographs to determine substances that emit light.

You have been given four different gas discharge tubes. One of which is labeled as Helium. The other three have masking tape covering their labels and could be Hydrogen, Neon, or Mercury gas tubes. **DO NOT REMOVE THE MASKING TAPE OR YOU WILL LOSE ALL CREDIT FOR THIS SECTION.**

Place each tube in the power supply and observe the color light they produce (as seen with the human eye). Write a short description of the color for each tube based on human eyesight and color vision. (This does NOT involve your spectrograph).

Now use your spectrograph. First take a picture of helium spectra. Ensure yourself that the peak locations are the same as before. If they have all consistently moved by similar numbers of pixels, your webcam might have moved. Make a list of the pixel locations for the peak intensities and compare them to your previous values.

Do you need to recalibrate the spectrograph based on your results? Make an argument for/against based upon your data. If you do need to recalibrate, write down your new calibration equation.

Now select one of your unknown tubes. Use the spectrograph to determine multiple strong line wavelengths. From these measurements, can you determine the gas in the tube? (Don't forget that you can go on line to look up the strong lines for each of the given gases)

Now select a different unknown tube. Use the spectrograph to determine multiple strong line wavelengths. From these measurements, can you determine the gas in the tube?

Now select the final unknown tube. Use the spectrograph to determine multiple strong line wavelengths. From these measurements, can you determine the gas in the tube?

Based upon what you have seen so far, how accurate is your particular spectrograph? That is, how close does your spectrograph's measurements correspond to the measurements given by NIST? Make actual numerical comparisons in the space below.

To test how well you understand your spectrograph, try the following. Aim your spectrograph upwards at the fluorescent lights and take a spectral picture. Use imageJ to analyze the results and determine the strong line wavelengths. (NOTE: because of the cardboard design and different angle of operation, the spectra could slightly shift, but the separation in wavelength between features should remain consistent).

Is there any evidence that there is Helium, Hydrogen, Mercury, or Neon in the fluorescent lights based upon your data? Fully explain your reasoning as to whether you believe each gas is present or absent in fluorescent light tubes.

Part 4. Human color vision and spectral colors

Objective: How is human color vision related (if at all) to spectral colors? This investigation examines the relationship between spectral color and human color vision.

To begin with we will weakly define human color vision as the colors one would use to describe crayons. Spectral colors are the colors we see in rainbows and on our spectrograph pictures.

Are all human vision colors located at some point in the visible spectra (colors in the rainbow)? What is your initial guess without doing this investigation?

How does the color white (as seen by humans) relate to spectral colors (the colors in the rainbow)? What is your best guess?

Consider the color brown (as seen by humans). Is there a location in the rainbow spectrum that can be described as being brown? If not, what is your best guess to how the color brown is related to the spectral colors?

MAKE SURE THAT YOUR ANSWERS ON THIS PAGE ARE CONSISTENT WITH EACH OTHER!!!

We will begin by examining white light in three different forms (incandescent bulb, fluorescent light, and white from a computer screen). **This will be somewhat complicated by the fact that the DVD fragment in the spectrograph does NOT equally reflect all colors of visible light.**

To ensure consistent pictures go into the settings (advanced settings) and turn off automatic white balance, right light, and any other automatic light correction controls.

NOTE: It is now assumed that you have calibrated your spectrograph and that this calibration is still valid.

Using your spectrograph, take a picture of light from an incandescent bulb. How would you describe the spectral features of this light using words and values from you analyzed spectral photograph?

Using your spectrograph, take a picture of light from a fluorescent light tube. How would you describe the spectral features of this light using words and values from you analyzed spectral photograph?

To examine white light produced by a computer monitor open the program PowerPoint. Do not allow the PowerPoint window to occupy the full screen (you will need to have the webcam program also available on the screen). On PowerPoint, draw a large white rectangle. Place the spectrograph entry slit on top of the white rectangle that you drew and take a photograph. Analyze this photograph using imageJ. How would you describe the spectral features of this light using words and values from you analyzed spectral photograph?

Previously, you were asked, “How does the color white relate to spectral colors (the colors in the rainbow)? “ Now that you collected data, does your previous answer agree with your experimental results? If not, how would you change your response to that question given what you know now?

Do you need all spectral colors to give humans the sensation of white light? If not, what colors do you need to make people see white?

Go back to the PowerPoint window. Change the color of the rectangle you drew to blue. **Before you take any measurements with your spectrograph**, predict how your spectra colors will change (compared to the white light picture taken before)?

Now take a picture of the blue rectangle using your spectrograph and analyze it using imageJ. Give a description of the spectral light intensities as seen through the spectrograph. Make sure that your answer is detailed enough to differentiate it from previous answers.

Resolve any differences between your last two answers. NOTE: Resolve does not mean just noting differences. You are expected to attempt to figure out what is going on.

Change the color of the rectangle you drew to green. **Before you take any measurements with your spectrograph**, predict how your spectra colors will change (compared to the white light picture taken before)?

Now take a picture of the green rectangle using your spectrograph and analyze it using imageJ. Give a description of the spectral light intensities as seen through the spectrograph. Make sure that your answer is detailed enough to differentiate it from previous answers.

Resolve any differences between your last two answers. NOTE: Resolve does not mean just noting differences. You are expected to attempt to figure out what is going on.

Change the color of the rectangle you drew to yellow. **Before you take any measurements with your spectrograph**, predict how your spectra colors will change (compared to the white light picture taken before)?

Now take a picture of the yellow rectangle using your spectrograph and analyze it using imageJ. Give a description of the spectral light intensities as seen through the spectrograph. Make sure that your answer is detailed enough to differentiate it from previous answers.

Resolve any differences between your last two answers. NOTE: Resolve does not mean just noting differences. You are expected to attempt to figure out what is going on.

Now try to summarize your results of the white, blue, green, and yellow rectangles. How do the spectral colors produced by the monitor change as we go from white to blue to green to yellow?

Reconsider the much earlier question about the color brown. How (if at all) would your answer to that question change given what you have seen so far?

Change the color of the rectangle you drew to brown. **Before you take any measurements with your spectrograph**, predict how your spectra colors will change (compared to the white light picture taken before)?

Now take a picture of the brown rectangle using your spectrograph and analyze it using imageJ. Give a description of the spectral light intensities as seen through the spectrograph. Make sure that your answer is detailed enough to differentiate it from previous answers.

Resolve any differences between your last two answers. NOTE: Resolve does not mean just noting differences. You are expected to attempt to figure out what is going on.

Your instructor is going to give you a color for your PowerPoint rectangle. Write down this color and predict what the monitor will do to produce that color.

Show your answer to the instructor.

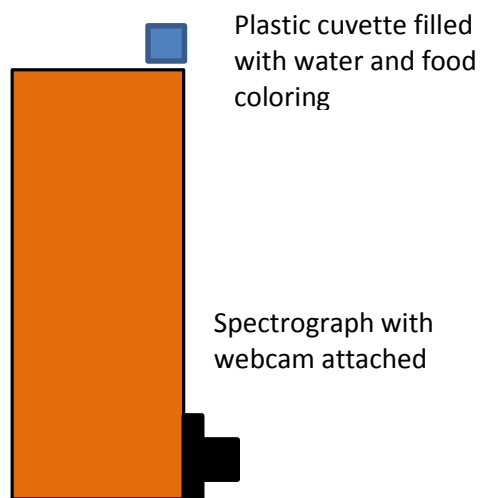
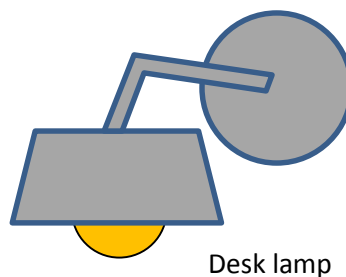
Now take a picture of this new rectangle using your spectrograph and analyze it using imageJ. How does your result compare to your prediction?

Part 5. Absorption of light

Objective: Consider the action of adding food coloring to water in an aquarium. Is the food coloring adding color to the light that passes through the water or is it doing something different? This investigation will reveal the results.

Describe white light from an incandescent light bulb. Hint: You really should have a spectral picture of it from your last investigation.

Now consider the following investigation (you aren't doing it yet). White light from an incandescent light bulb is directed through a small container (cuvette) containing a mixture of green food coloring dye and water. How would the light spectra change (if at all) from your previous answer? Explain your reasoning!



To ensure consistent pictures go into the settings (advanced settings) and turn off automatic white balance, right light, and any other automatic light correction controls.

NOTE: It is now assumed that you have calibrated your spectrograph and that this calibration is still valid.

Measure 100mL of water in a beaker. Pour some of this water into a cuvette. Set up the experiment as shown on the previous page and take a picture.

Now pour the water back into the beaker and add ONE drop of green food coloring. Mix it until the color is consistent and pour some of the water back into the cuvette. Place the cuvette in front of the spectrograph's entrance slit and take another picture.

Now pour the water back into the beaker and add TWO drops of green food coloring. This mixture now has a total of THREE drops of food coloring. Mix it until the color is consistent and pour some of the water back into the cuvette. Place the cuvette in front of the spectrograph's entrance slit and take another picture.

Now pour the water back into the beaker and add THREE drops of green food coloring. This mixture now has a total of SIX drops of food coloring. Mix it until the color is consistent and pour some of the water back into the cuvette. Place the cuvette in front of the spectrograph's entrance slit and take another picture.

Now pour the water back into the beaker and add FOUR drops of green food coloring. This mixture now has a total of TEN drops of food coloring. Mix it until the color is consistent and pour some of the water back into the cuvette. Place the cuvette in front of the spectrograph's entrance slit and take another picture.

Now examine each dye mixture picture using imageJ and get the intensity vs. wavelength graph for each picture.

Transmittance is defined as the intensity of the light after passing through a substance divided by the intensity of light before it entered the substance. In this case, the substance is the food coloring. The intensity of the light (before the food coloring) is represented by water only picture.

Use the imageJ data to produce a four trace graph (one drop, three drops, six drops, and 10 drops) of transmittance vs. wavelength for a range of 450nm to 600nm. **Attach this graph to this report.**

Based upon this graph, is the green dye adding color to the light that transmits through the water? Explain your reasoning.

Recall your prediction. How well did your prediction correspond to the experimental results? Make sure you use experimental values in your WELL EXPLAINED response.

Now consider the following investigation (you aren't doing it yet). White light from an incandescent light bulb is directed through a small container (cuvette) containing a mixture of yellow food coloring dye and water. How would the light spectra change (if at all) from your previous answer? Explain your reasoning!

You are now going to repeat the process with yellow food coloring using a fresh cuvette. That is you are going to produce transmittance graph traces for one drop, three drops, six drops, and 10 drops of yellow food coloring. **Attach this graph to this report.**

Finally, to test your knowledge, you should now be able to predict the transmittance if we have a mixture of 100mL + 10 drops of green + 10 drops of yellow. Your prediction should be in the form of a graph and you need to supply a written explanation as to how you came up with your prediction.

SHOW YOUR ANSWER TO YOUR INSTRUCTOR BEFORE PROCEEDING.

Make a mixture of 100mL water + 10 drops of green + 10 drops of yellow. Mix well and fill a fresh cuvette. **Measure the transmittance of this mixture vs. wavelength and attach a graph of it to this report.**

How accurate was your prediction compared to the results? Be specific and make direct numerical comparisons.

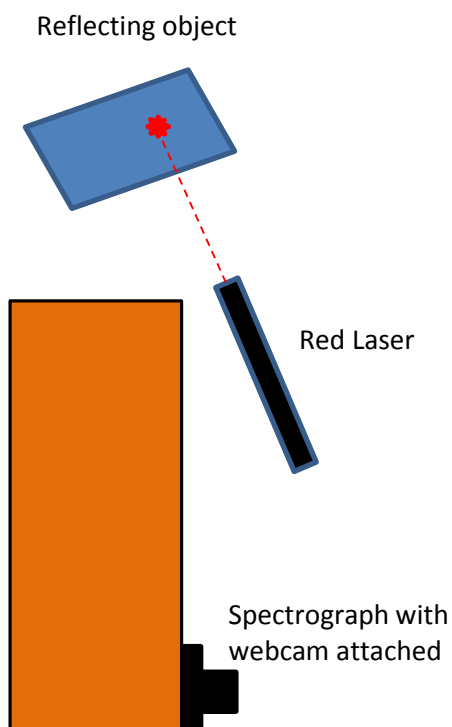
If you could re-do the green-yellow prediction or experiment, what would you do differently?

Part 6. Reflection of light

Objective: What causes some objects to look red and other objects yellow? How does reflected spectral colors differ between two differently colored objects? This investigation explores these relationships among others.

Based upon what you think you know, consider the following question. If an object is only illuminated by red light (620nm to 750nm), is it possible for the object to reflect green light (495nm to 570nm)? Explain your reasoning.

Consider the experiment shown to the right (don't set it up yet). A red laser is reflected off an object and the reflected light is directed into the spectrograph. A laser produces a very narrow range of wavelengths. Would the wavelengths of the reflected light that enter the spectrograph depend on the color of the reflecting object? Explain your reasoning.



Now try the experiment (shown on this page) using at least 5 different colors of construction paper as your reflecting object. Collect photographs and analyze them using imageJ and your calibration equation. **Attach this information to your paper.**

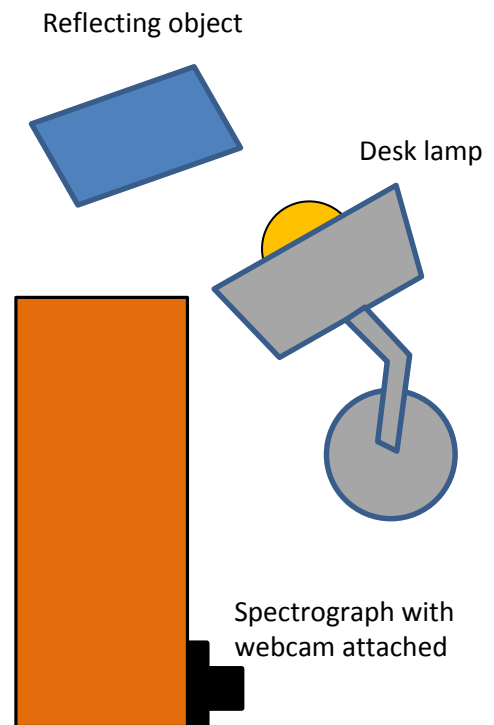
Based upon your collected evidence with the construction paper, what changes (if any) did you see from color of construction paper to the next? Explain your reasoning using collected numerical values.

How (if at all) would you change your answers to the questions that were asked before the experiment? Does the experiment support what you said earlier or should you revise your thinking? **EXPLAIN.**

Based upon what you think you know, consider an object that looks white under an incandescent light bulb. If the white object is only illuminated by red light (620nm to 750nm), what color would we see this object (human sight vision)? Explain your reasoning.

Based upon what you think you know, consider an object that looks dark blue under an incandescent light bulb. If the dark blue object is only illuminated by red light (620nm to 750nm), what color would we see this object (human sight vision)? Explain your reasoning.

Consider the experiment shown to the right (don't set it up yet). A light from an incandescent bulb is reflected off an object and the reflected light is directed into the spectrograph. Would the wavelengths of the reflected light that enter the spectrograph depend on the color of the reflecting object? Explain your reasoning.



Now try the experiment (shown on this page) using at least 5 different colors of construction paper as your reflecting object (they can be the same ones you used before). Collect photographs and analyze them using imageJ and your calibration equation. **Attach this information to your paper.**

Based upon your collected evidence with the construction paper, what changes (if any) did you see from color of construction paper to the next? Explain your reasoning using collected numerical values.

For the final experiment in this investigation, you will need to go outside and collect a small piece of some brightly colored object (for example, a dandelion flower). If this object was used as your reflecting object (illuminated with an incandescent bulb), **PREDICT** the spectra you would expect to see. Explain your reasoning.

Show your object and prediction to your instructor.

Now try the experiment with your sample. Collect a photograph and analyze it using imageJ and your calibration equation. **Attach this information to your paper.**

Recall your prediction. How well did your prediction correspond to the experimental results? Make sure you use experimental values in your WELL EXPLAINED response.

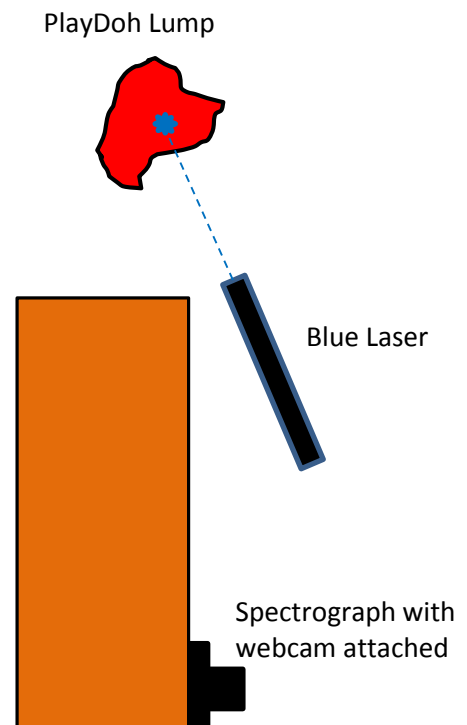
Now that you have run the experiment, how if at all would you change your prediction and/or the experiment?

Part 7. Laser induced PlayDoh Fluorescence

Objective: What is the difference between fluorescence and reflection? Given the spectra for input light, could we look at light coming off an object and deduce whether that light is due to reflection or fluorescence?

Based upon what you think you know, consider the following question. If an object is only illuminated by blue laser light (405nm), is it possible for the object to emit red light (620nm to 750nm)? Explain your reasoning.

Consider the experiment shown to the right (don't set it up yet). A blue laser beam is incident upon a lump of PlayDoh. Would the wavelengths of the light that enter the spectrograph match those of the laser beam? Explain your reasoning.



Now try the experiment using red, yellow, green, and blue lumps of PlayDoh with a blue laser (405nm). Collect photographs (one for each color of PlayDoh) and analyze them using imageJ and your calibration equation. **Attach this information to your paper.**

Fluorescence differs from reflection in that the wavelength emitted from an illuminated object does not match the wavelength of the incident light. Have you seen any evidence of fluorescence?

Repeat the experiment using a green laser (532nm) instead of a blue laser. Collect photographs (one for each color of PlayDoh) and analyze them using imageJ and your calibration equation. **Attach this information to your paper.**

Green light is approximately in the middle of the visible spectrum. Is there any evidence that green light can produce fluorescence with a higher wavelength (greater than 532nm)? Explain using numerical values from your data.

Is there any evidence that green light can produce fluorescence with a lower wavelength (less than 532nm)? Explain using numerical values from your data.

Reconsider the fluorescence from blue laser light. Is there any evidence that blue light can produce fluorescence with a lower wavelength (less than 405nm)? Explain using numerical values from your data.

Repeat the experiment using a red laser (~650nm) instead of a blue laser. Collect photographs (one for each color of PlayDoh) and analyze them using imageJ and your calibration equation. **Attach this information to your paper.**

Is there any evidence that the red light is producing fluorescence in any color of PlayDoh? Explain using numerical values from your data.

Based upon your entire set of data, which color of laser light seemed to most effectively produce fluorescence? Explain your reasoning.

Do you have any fluorescence experiment that resulted in a lower wavelength being emitted than the laser beam? Explain your reasoning and use numerical data when possible.

Photons are the smallest whole part of light. A single photon's energy is given by $\frac{hc}{\lambda}$ where h is Planck's constant, c is the speed of light in vacuum, and λ is wavelength. Which color laser had the most energetic photons?

Based upon your limited data, is there any indication that fluorescence may depend on photon energy?