What's so special about the laser?

A guide for taking LaserFest into the classroom.

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Activity 1: Exploring laser light

Students view various light sources, with and without diffraction glasses, to see the different rainbows (visible spectra) they create. By looking at reflected light from laser pointers, students explore how laser light is different from other kinds of light.

Objectives

- Learn to identify the colors that make up a particular light source using diffraction glasses
- Recognize that all light sources produce rainbows with colors in a specific order
- Determine the difference between “regular” light and laser light
- Introduce the concept of the wavelike behavior of light (see appendix)
- Introduce the phenomenon of the interference of light waves

Materials Included

- Laser pointer
- White, red, and blue LEDs (Light-Emitting Diodes)
- Three binder clips
- Rainbow diffraction glasses

Materials Needed

- Tape
- Large piece of cardboard (approximately 1x2 feet or so)

Advanced Preparation

- Bend the cardboard into a tri-fold, as shown in the picture.
- Remove the chains from the white, red, and blue LEDs and attach a binder clip to each as shown below.
- Tape the LEDs vertically (in a stoplight arrangement) to the cardboard, as shown. This will be referred to as the “light board” for the rest of this activity.

In the Classroom:

WARNING

Lasers can cause serious damage to one's eyesight. **Do not look directly into any laser beam and do not shine one at any student's eyes or onto shiny reflective surfaces.** Do not allow children to use a laser pointer unless supervised by a responsible adult. In particular the laser pointers used in these activities are less than 5 mW and are class IIIA---dangerous, but safe if used properly.

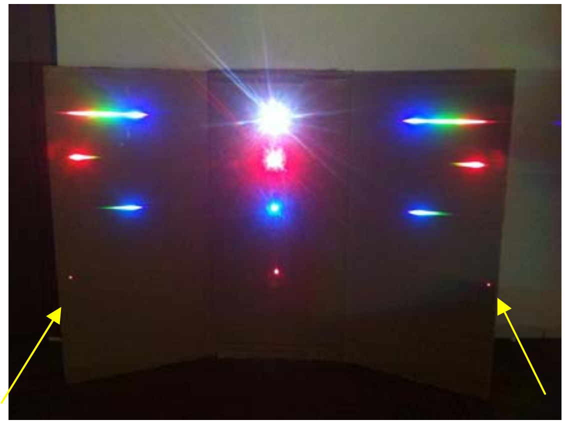
1. Have each student put on a pair of rainbow glasses (make sure to have yours on too!). Many blurry rainbows are likely to be visible from the myriad light sources around the room. Dim or turn off the room lights and shut the blinds on the windows if possible.

2. Place the light board at the front of the room and turn on the white LED. Ask the students what they see through the glasses. The LED's white light should now be flanked by rainbow "fringes" on either side. Clarify that white light contains all of the colors of the visible spectrum (or Newton's famous 7 colors known by ROY G BIV). Note that in India the acronym is memorized as VIBGYOR!

3. Ask for predictions of what will happen when a red LED is turned on, and then turn on the red LED. Notice it contains red, orange, and yellow light and that they appear directly under the corresponding colors in the white LED fringes.

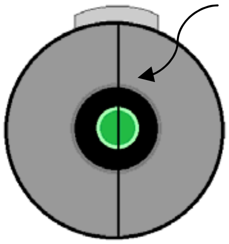
4. Repeat with the blue LED and notice the (mostly) blue, green, and violet colors.

5. Now ask for predictions of what will appear when one shines a red laser just below the other three lights. Upon doing so, show that the laser's rainbow is only one color and appears as a single dot (as indicated by the arrows in the photo; the dot is very dim in the photo), as opposed to a "smear" of colors from the LEDs. **Note: Do not shine the laser at the students, stand behind them and shine it onto the cardboard so they can see the reflection off of the light board.**



6. Shine the laser pointer directly on top of the other LEDs central spots to show that it appears in the red part of the spectrum on each. **Conclusion: lasers produce a single color of light.**

Activity 2: Measuring a hair's width with lasers


Hair taped across front of laser head

Put a single hair in the path of the laser beam and students can view the diffraction pattern produced by the hair. This activity allows for comparative measurements of hairs' widths; if one desires to estimate the numerical value for the width of the hairs from the fringe spacing, see the Appendix.

Objectives

- Show that small objects, like a hair, can cause light to diffract around it and this makes a distinctive "fringe" pattern.
- Help students recognize that the spacing between the fringes reveals the comparative size of the object in the path of the beam
- Show that lasers can be used for practical things, like measuring the size of small objects.
- Introduce the concept of the wavelike behavior of light (see appendix)
- Introduce the phenomenon of the interference of light waves

Materials included

- Red laser pointer (the activity also works well with a green laser, which is used in the images)

Material Needed

- Tape
- Clay
- A hair from a volunteer or leader

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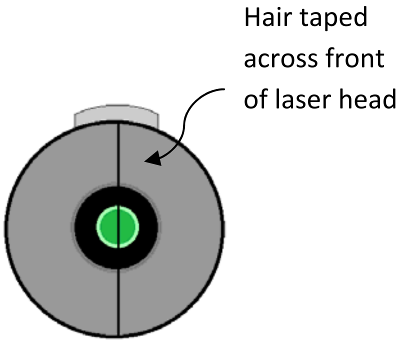
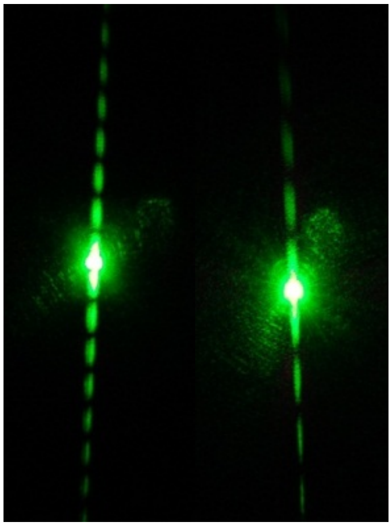


In the Classroom:

1. Obtain a piece of hair at least 1-inch long and place it across the center of the hole at the end of the green laser **while the laser is turned off** (see the drawing looking down the barrel of the laser shown at right). Then tape it down on the sides of the laser to hold it in place. When done, the hair should be secured at the end of the laser through the center of the beam.

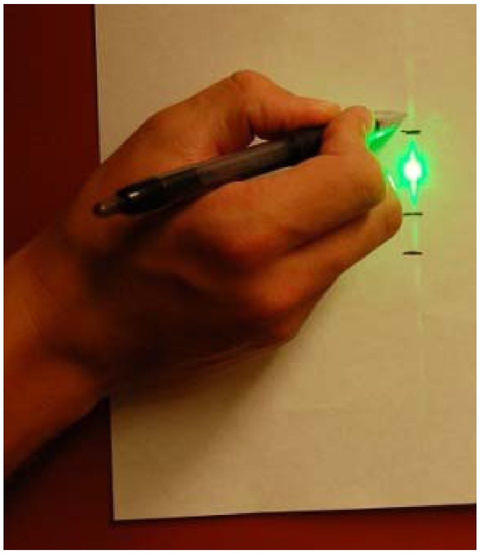
2. Tape the button on the laser down and use some clay to secure the laser in place such that when the laser light is viewed on a distant wall, it has a vertical or horizontal diffraction "fringe" pattern. Dim the lights, if possible.Vertical patterns from two different hairs are shown to the right.

3. Tape a piece of white paper to a somewhat dark wall such that the laser setup can be aimed at its center.



4. Aim the laser at the paper to reveal the diffraction pattern on the paper. Take note of the color of the hair and the spacing between the fringes. The purpose of this exercise is to show how the laser can be used to measure small things, but depending on the class's level of understanding of light and waves, you may want to remark upon what is causing the pattern. In particular, note that when the hair is horizontally oriented, the fringe pattern is vertical, and vice versa.

5. Mark the centers of the first few dark spots on the paper.



6. Repeat steps 4 and 5 with several different color hairs to demonstrate the relationship between hair color and hair thickness. Dark hairs are generally thicker, and therefore they will have a finer diffraction pattern. ***You may want to skip drawing on the paper and just use two lasers simultaneously to compare two different hairs if you happen to have another laser with the <u>same wavelength</u>.***

7. Note that often lasers are used in this manner for quality control in measuring the thickness of wires as they are manufactured.

Going Farther, Making an Actual Measurement of a Hair:

1. Measure the distance from the hair to the paper on which the "fringes" appear and record this number as D.

2. Without moving the laser or the paper, mark the center of the central bright spot on the paper. Now, mark the center of the first 4 dark spots on the upper side of the pattern. Note: using both sides could be boring and redundant, but will give a better measurement.

3. Remove the paper from the wall. Using a ruler, measure the distance between each adjacent marking (the distance from the center to the first dark spot, from the first to the second, etc) and record it in the corresponding part of the table provided (y_1).

4. Average the values for y_1 and calculate the diameter using the formula in the appendix.

Activity 3: Transmitting sound with a laser

Rewire the red laser pointer so that it can send a music signal across the room to be detected by a solar cell, which in turn can drive a speaker to hear the music.

Objectives

- Demonstrate that a laser light signal can carry the information needed to produce music
- Introduce some basic elements of electronics: batteries, solar cells, circuits.
- Show that lasers can be used for practical things like communication through a fun example.

Materials included

- Red laser pointer
- Spectra Sound kit
- Amplified Speaker
- Fiber optic cable
- Comb

Material Needed

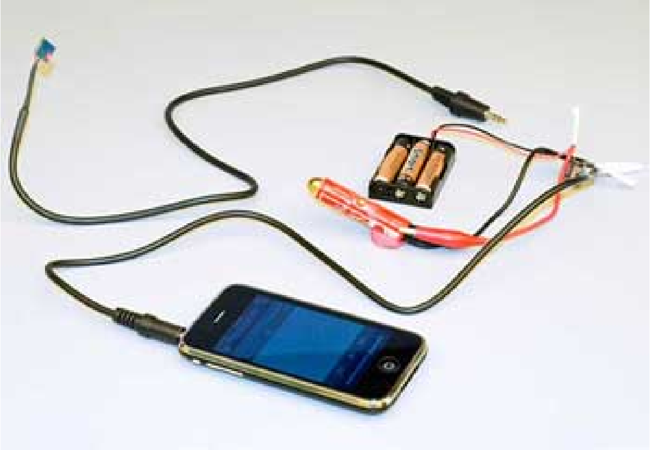
- Clay
- Tape
- Music player (like an iPod)

Advance preparation

- Follow the directions provided in the Spectra Sound kit to set it up. Note: Pay special attention to steps 3-6 instead of relying on the circuit diagram alone.
- Plug the solar cell into the speaker and tape it to a side of the speaker with the "blue" side of the cell facing out.
- Use the clay to properly align the laser to hit the solar cell.
- The setup should look like the pictures on the next page. Note: this kit was soldered together instead of using the B connectors provided.

Prefacing Remarks

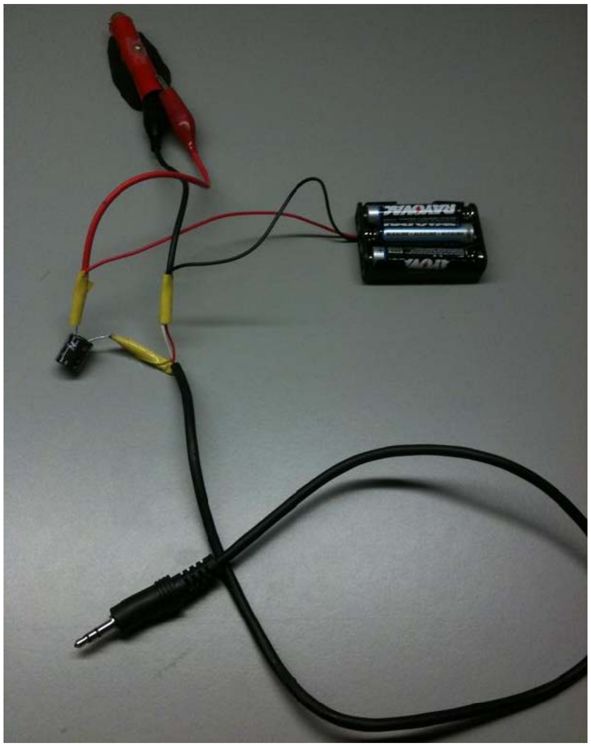
Another use for lasers is transferring the sound signal from a music player to speakers. This may be done with a little simple, but clever, wiring. The concept is to have a solar cell pick up the small changes in intensity from the laser when it's modified by a music signal, and have them amplified with a speaker. When the laser is incident on the solar cell, a constant voltage is produced and no sound is heard (other than the sound produced when the laser initially hits the cell). However, when the laser is wired in parallel with a capacitor and a music player as shown in the Spectra Sound kit, the intensity of the laser varies slightly according to the signal sent out by the music player. This same signal is then picked up by the solar cell and amplified by the speaker for surprisingly good results.



Blocking and unblocking the laser results in large voltage changes through the speaker which create a somewhat loud sound every time the laser hits the cell. Doing this fast enough (by using the comb provided) can result in different pitches and effects. The laser may also be reflected off of mirrors or other surfaces to reach the solar cell without disturbing the signal. It may even be sent through the piece of fiber optic cable provided to arrive at the solar cell. In this situation, the light undergoes total internal reflection through the cable until it reaches the other end and comes out.

In the photo at left below, we show the speaker with a solar cell input (taped to front of speaker at lower right of photo).

In the photo at right below we show a red laser pointer (at the top of the photo), wired with a capacitor, batteries, and a jack to be plugged into your favorite music source. The idea is to shine the laser pointer on the solar cell so that you can hear the sound from your player emitted from the speaker across the room—music carried by the light fantastic!



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In the Classroom:

- Comment on how lasers are used in everyday life: fiber optics, transmitting signals for internet and cable, etc.

- With the speaker turned on and the Spectra Sound kit set up, play some class appropriate music and talk about what is happening. Or, you may want to leave the source of the music a mystery and ask a volunteer to sit in a cleverly placed chair, so that when the student sits down he/she will block the laser beam and cause the music to stop**. Note: Do not have the student sit such that the laser could hit his/her face**. Ask the student to stand up and the music plays again (repeat if necessary). See if anyone can guess what is happening.

- Block the laser with your hand to show that the music turns off and angle your hand so that everyone can see the spot from the laser. Chalk dust or dry ice vapors are also good for revealing the path of the laser beam.

- Move the comb through the laser to create different sound effects, and encourage students to try it themselves. Moving the entire comb back and forth very fast through the laser makes some pretty cool sounds.

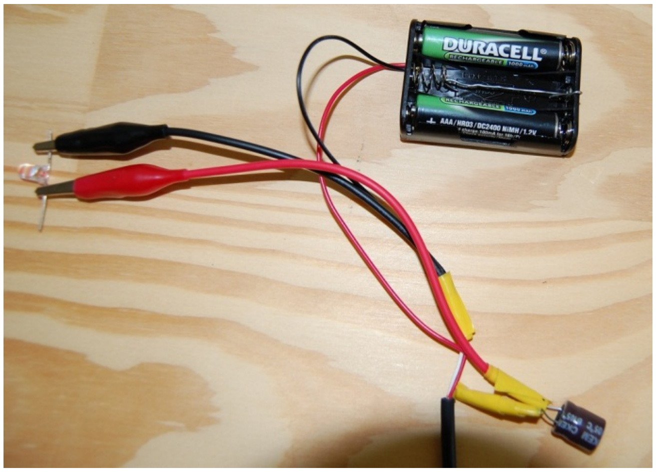
- Put the speaker behind or above the laser and use the fiber optic cable to bend the light back to the solar cell, so that the music starts again. Relate this to data transfer used in everyday life.

Extra Demonstrations with Spectra Sound:

1. Let students predict what will happen when you…
   - Place a bottle of water between the laser and the solar cell?
   - Reflect the laser off a piece of white paper and onto the solar cell?
   - Put a piece of hair in front of the laser and shine the diffraction pattern on the solar cell?

   In all cases the music should still play just fine. This is because the solar cell only picks up the changes in intensity of the light, and is not affected by different patterns and interference. This may be shown with the next step.

1. Take the LED out of a keychain light. And remove the batteries from the Spectra Sound kit. Attach the black alligator clip to the short lead of the LED and the red alligator clip to the longer lead. Since the LED only uses 3V, short one of the battery terminals from the kit with a wire or piece of solder and **only use two AAA batteries** (2 x 1.5V = 3V).



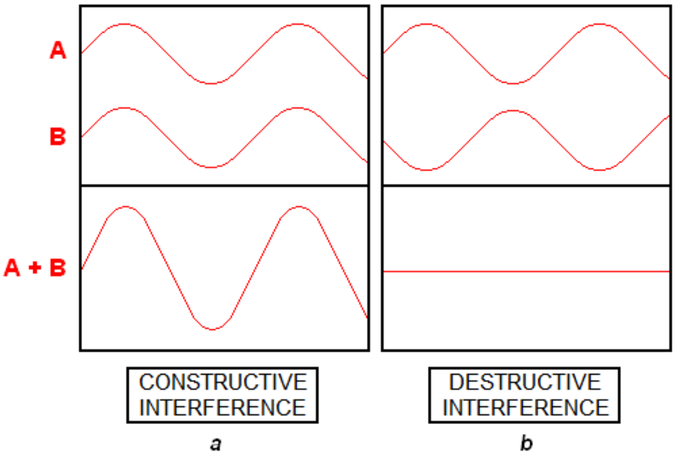
   Use the new setup as you did with the laser and note that it still works (when within range). Move the LED very close to the solar cell and then back it away. The advantage of a laser is that you can transmit the signal from close range or much farther away without disturbing the signal.

Appendix: Introduction to light as a wave

As you might know, light acts as a wave in many settings. Certain waves, such as the light waves produced by lasers, are considered **coherent**. Generally speaking, this means that all of the light waves in a laser beam have nearly the same wavelength, are approximately in phase with each other, and have nearly the same direction of propagation (though there are exceptions).* The light produced by a light bulb or the Sun is not coherent, as it is made up of light waves that contain several different wavelengths (thus, they exhibit rainbows), that are not in phase, and that are not limited to a small set of directions. For example, the light from the white LED (Light-Emitting Diode) provided to you in this kit contains all the wavelengths (colors) of the visible spectrum. As a side note, you might be interested to know that the word "laser" is an acronym: **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation.

Two light waves that are coherent may interfere with each other either constructively or destructively when they overlap. Constructive interference occurs when the two waves are in phase with one another, producing a wave with larger amplitude than either individual wave (shown in Figure 1a). Destructive interference occurs when the two are out of phase and a wave with smaller (or even zero) amplitude is produced (Figure 1b).

Figure 1

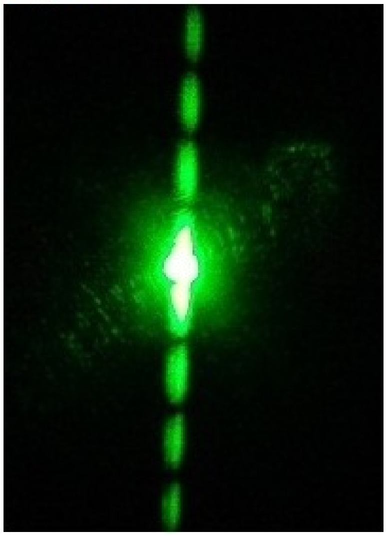


http://www.vectorsite.net/tpecp_11.html

An interference pattern is created when a coherent light source, such as a laser, is incident on a narrow slit of width *d* (narrow, but still many times larger than the light's wavelength).

This pattern can be observed by placing a screen at a set distance *D* behind the slit. A horizontally-oriented slit with a laser beam incident will produce a central bright dot on the screen along with vertically-oriented, alternating bright and dark spots above and below it, shown in Figure 2. These bright spots are known as fringes.

Figure 2



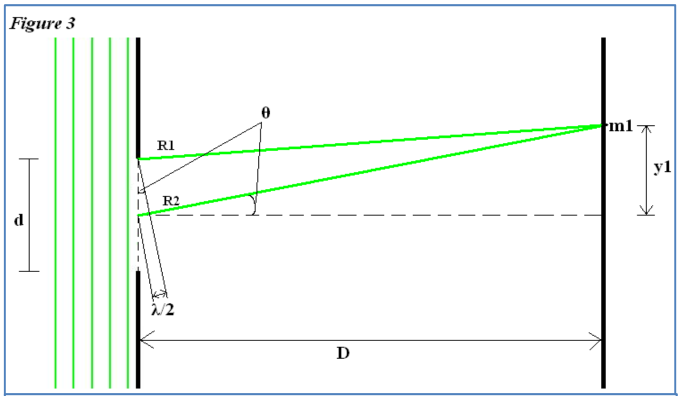


Figure 3

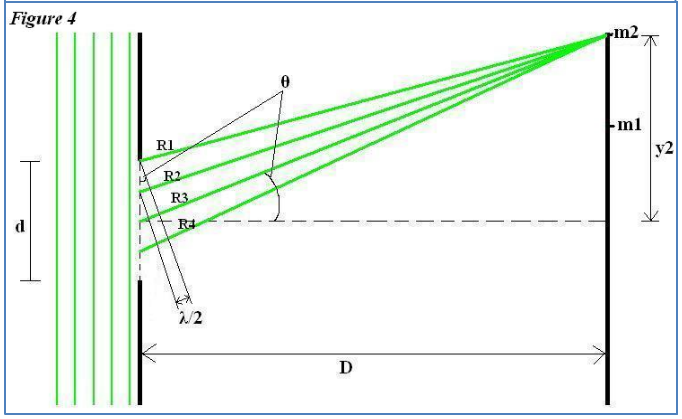


Figure 4

At the dark spots, or minima, destructive interference is occurring. This means that at a dark spot, each ray (R) shown in Figure 3 must be canceled out by another that is 180° out of phase. For this to happen, the second ray's path to the screen must be an odd integral number of *half wavelengths* longer (or shorter) than the first ray's path. So when the origins of two rays are separated by $d/2$ and with the assumption $D >> d$, the path of ray R_2 is one half wavelength longer than the path of ray R_1 and results in a minimum at point $\mathbf{m_1}$. So the condition is as follows:

$$\frac{d}{2} sin\theta = \frac{\lambda}{2} \text{ or } d sin\theta = \lambda \qquad (1)$$

where λ is the wavelength.

Similarly, in Figure 4 when the rays are separated by $d/4$, the path of ray R_2 is one half wavelength longer than the path of ray R_1 and results in a minimum at $\mathbf{m_2}$. So, the condition is:

$$\frac{d}{4} sin\theta = \frac{\lambda}{2} \text{ or } d sin\theta = 2\lambda \qquad (2)$$

Note that this differs from Eq. 1 by just a coefficient of 2. Had there been 6 rays drawn, the coefficient that would correspond to the 3rd minimum would have been 3, and so on. Now let the path length of a ray be L. Since $D >> y$ for this experiment, $L \approx D$ and therefore $\sin\theta \approx y / D$. So, generalizing the previous 2 equations, the distance from the central bright spot to the next minimum is given by:

$$y_m = \frac{\lambda D}{d} m \qquad (3)$$

where m corresponds to the fringe number (1st: m=1, 2nd: m=2, etc.). Since all the minima will be equidistant from one another, one may just use m=1 and average the distances between the adjacent minima.

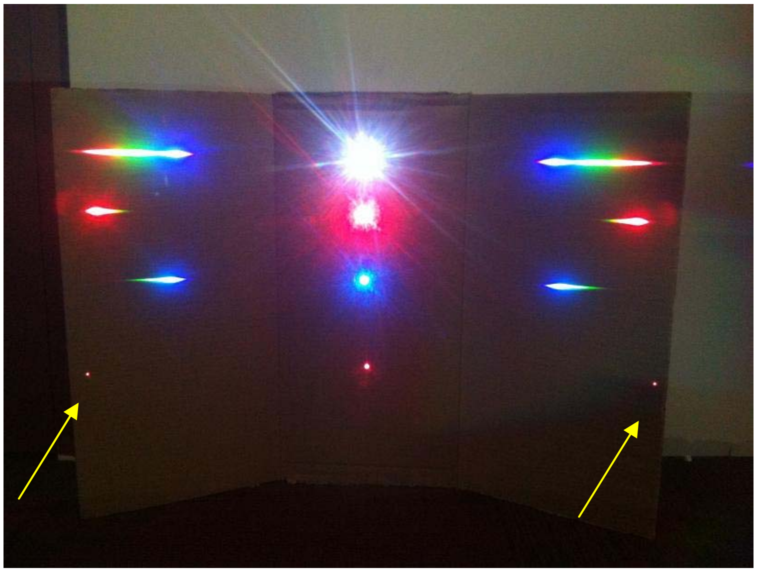
Interestingly, using the "negative" of this experiment (a narrow barrier instead of a slit) produces similar results, at least in the region away from the bright central spot. This is known as *Babinet's Principle* and may be referenced in a number of popular textbooks. A human hair works very well for this barrier. The diameter of the hair would correspond with the distance d. As stated earlier, one would then find the diameter of a hair by averaging the distances between adjacent minima on the interference pattern displayed on the screen. This averaged number would correspond to y_1. Now the diameter of the hair may be calculated by rearranging Eq. 3 (with m=1) as:

$$d = \frac{\lambda D}{y_1} \qquad (4)$$

The wavelength of the green laser pointer is about 532×10^{-9} meters, while the red laser has $\lambda \sim 660\times10^{-9}$ meters. It can be seen from Eq. 3 that a hair with a smaller diameter will produce more widely separated fringes. Likewise, thicker hair will produce more closely spaced fringes. It turns out that hair color generally corresponds with hair thickness, with lighter hairs being thin and darker hairs being thick. Qualitatively, this can clearly be observed from the activity when using different color hairs.

The diffraction glasses used in this activity create a similar interference pattern. The diffraction in this case, however, is due to multiple slits instead just a single slit. In fact, these glasses have hundreds of tiny, closely-spaced, vertical scratches that act as slits (500 lines per millimeter). Thus when shining a laser through the glasses onto a far screen, one sees bright fringes oriented horizontally that are much further spaced than in the single-slit case (see the two tiny dots indicated by the arrows at the bottom of the figure below). Other higher order interference fringes from the laser are not seen because they are outside the boundary of the photo (and likely too small and dim, anyway).

The picture at right was snapped with one lens of the rainbow glasses covering the camera lens, so the image duplicates what is seen when looking at the light sources through the rainbow glasses. The image shows four light sources arranged vertically down the center of the picture, along with the interference patterns produces on either side of each of the four light sources. At the top center is the central spot from a white LED, beneath that is the central spot of a red LED, then the central spot from a blue LED, and at the bottom is a dim dot of light from a laser pointer someone is shining on the screen.



When white light (with many different wavelengths) is incident on the rainbow glasses, as in the top center of the photo, the result is a similar set of bright spots or interference fringes. Since each wavelength of light is diffracted at different angles, when viewed through the glasses each color of light produces its own fringe, with the blue fringe appearing somewhat closer to the central spot than green or red, which accounts for the rainbow effect. Note that the red LED produces a smear of red and orange-ish colors, and the blue LED a smear of blue and greenish colors, while the red laser dot produces essentially a single dot of red color. Note also that the colored fringes from each source are aligned vertically on each side of the central spots—red with red, blue with blue, etc. The red laser pointer is thus seen to be different from the red LED in that its spectrum only includes a small window of red light (single-frequency), while the red LED is seen in the photo to have a much broader spread of red and orange-ish colors.

*For a contrasting experts' view about what lasers are, check out the talk by Warren S. Warren of Duke University at the 2010 Summer Meeting of the American Association of Physics Teachers. Start at the 5:30 mark, www.ustream.tv/recorded/8382372.