Dumpster Optics

THE COLORS OF LIGHT

DO ALL RED LIGHTS CONTAIN THE SAME COLORS? BUILD A SPECTROSCOPE FROM A CARDBOARD TUBE AND AN OLD CD AND LEARN ABOUT THE COLORS IN THE LIGHTS AROUND YOU.

MATERIALS

Activity 1 – Make a Rainbow

- Flashlight – the old fashioned kind with a single incandescent bulb or single LED bulb. Flashlights with multiple LEDs won't work for this experiment.
- Recordable CD with coating removed (or purchased linear diffraction grating)

Activity 2 – Making Waves

- Rope or Slinky® (spring) toy
- Meter stick

Activity 3 – Make a Spectroscope

- Cardboard tube 15-20 cm long (like a toilet paper tube)
- Piece of CD or diffraction grating from activity 1
- Square of aluminum foil to wrap over end of tube
- Craft knife or pencil to make a slit or hole in the foil
- Tape
- Rubber band

Activities 4-5 – Spectra of Light Sources/Mystery Spectrum

- Assorted sources of light. Several types of light that appear to be the same color to the eye are interesting, for example Christmas tree lights, colored bulbs, LEDs all in the same color. Incandescent versus fluorescent is an interesting comparison also. A physics laboratory may have gas spectrum tubes with high voltage power supplies, for example H or He gas in a sealed tube. Any lights around you can be used – lighted signs (especially "neon" lights), street lamps, the moon – but do NOT look at the sun or into a laser! Very bright lights can damage your eyes!

Optional Activity – Measuring Spectra

- This requires a camera to record the spectrum.

Where to find materials: A toilet paper or paper towel tube (cut in half) work well for the spectroscope. The CD must be the kind you record yourself; commercially made CDs have labels that are difficult to remove. If you want to purchase diffraction gratings, they are available in many science supply stores (such as Educational Innovations, www.teachersource.com) and can be purchased in bulk from Rainbow Symphony Store (www.rainbowsymphonystore.com). Be sure to get "linear" gratings, not two-dimensional gratings. These are sold both as mounted slides and sheets of material. Two-dimensional gratings create interesting starburst effects, but it's more difficult to identify the colors in the spectra.

VOCABULARY:

- Wavelength
- Spectroscope
- Spectroscopy
- "ROYGBIV"
- Plasma
- Emit
- Absorb
- Scatter
- Spectrum (plural Spectra)

TEACHER NOTES:
In this lesson students will create a *spectroscope* and use it to do elementary *spectroscopy* by identifying light sources from the colors appearing in their spectra. Spectroscopy is important in many areas of science and technology, for example, for identifying plant diseases (light reflected from leaves), studying the universe (light given off by stars, galaxies, and absorbed by dust clouds), matching paint colors, identifying unknown substances at a crime scene, environmental investigations and more. The example from NASA on Slide #4 shows a laser vaporizing a small piece of rock. The vapor is called *plasma*, a very hot gas of atomic nuclei and free electrons. As the electrons return to the nuclei to form atoms, light is given off. This light is analyzed to determine what elements make up the rock.

In these activities, students will look at visible light spectra but spectroscopy also includes other parts of the electromagnetic spectrum (radio, microwave, infrared, ultraviolet, x-ray and gamma ray).

BREAKING LIGHT INTO A SPECTRUM OF COLORS: White light is composed of all the colors of the rainbow- red, orange, yellow, green, blue, (indigo, if included) and violet - ROY G B(I)V. A light source's spectrum depends on the type of light source, that is, how the light is produced. It is not possible to tell with the naked eye what colors are in the spectrum of a given light source. Instruments used to study the color makeup of a light source may be very complex but there are some features common to all:

- An element to take the incoming light and spread it into a spectrum of colors
- Some kind of structure to block out stray light from the surroundings
- A thin entrance slit that lets in a sample of the light being studied
- A sensor to detect the spectrum

You probably know that you can spread white light into a rainbow spectrum using a prism. While a prism is the most obvious method of separating light into its spectral components, prisms are difficult to align. A diffraction grating (or just grating) is a series of very closely spaced grooves that bend light and cause it to spread out into its spectral components. Gratings are easy to use and more difficult to damage than a glass prism (although the gratings in a precision spectrometer are expensive and require careful handling). The CD used in this lesson acts like a grating. Before the label is removed it reflects white light as a rainbow (*reflective grating)* and after the label is removed light passing through is spread into a spectrum (*transmission grating*). Although the fine parallel grooves of a CD are circular, this won't affect the experiment.

The simple spectroscope in this lesson uses a cardboard tube to exclude room light and a slit cut in a piece of aluminum foil to allow only a thin line of light to enter and be examined. Your eye is the sensor! In the optional activity, a camera is the sensor.

A note on indigo: Many sources place the color "indigo" between blue and violet. Since indigo dye is closer to blue than to violet, students who are familiar with indigo as a textile color (blue jeans for example) might find this confusing. We sometimes omit indigo, although BIV makes an easier to pronounce acronym than BV.

ACTIVITY 1 – MAKE A RAINBOW

It is usually very easy to remove the label from a recordable CD. Lightly scratch the shiny label with a pair of scissors, place a piece of sticky tape over the scratch and pull the tape off sharply. The CD can be cut with sturdy scissors. Be careful of sharp edges! If you use a purchased diffraction grating, be sure to handle it by the edges to avoid finger smudges.

Old-fashioned (single bulb) incandescent flashlights work best for projecting a rainbow, or you can use a keychain (single bulb) white LED light. Flashlights with multiple LED bulbs don't work because the individual beams overlap too much. If that's all you have you can cover the end of the flashlight with aluminum foil and poke a very small (2-3 mm) hole over just one of the bulbs.

If you look through a grating (CD piece) at a light source you will see overlapping images of the source in different colors. This is especially evident if you look at a compact fluorescent. You might ask students to try this and then to brainstorm ideas for separating the colors so they can be seen more clearly, which they will do in Activity 3. Remind them they should NEVER look at the sun or into a laser, which can damage the sensitive retina of the eye.

ACTIVITY 2 – MAKING WAVES

Slinky® (spring) toys make easily measured waves. You can also use rope (which needs more vigorous shaking). You need to hold a slinky at both ends to make good waves; the rope can be stretched along the floor and wiggled at one end. The faster you shake one end the shorter the distance between the wave peaks (wavelength).

With a Slinky® held at both ends you can make *standing waves* if you shake one end at a constant rate. Standing waves occur because the wave is reflected from the end that is held tight, and reach the shaken end just in time to be reinforced with another shake. Standing waves look like loops (the light gray "reflection" in the drawing on the slide). Standing waves are easier to measure than moving waves along a rope. Measure from one wave crest to the next. The measurement takes cooperation among students.

The Slinky® or rope waves have wavelengths in the centimeter range. The wavelengths of light are much, much smaller- less than 1/100th the diameter of a human hair! Visible light ranges fromut abo 400 nanometers to 700 nanometers and a hair is about 50 to 100 micrometers across. One nanometer is one billionth of a meter, 10^{-9} meters, and one micrometer is one millionth of a meter, 10^{-6} meters.

ACTIVITY 3 – MAKE A SPECTROSCOPE

If students looked through the grating at a small light source they probably noticed many overlapping images of the bulb in a rainbow of colors. Using a slit will make studying the spectrum easier since they will now see an image of the slit. If students did not try this in Activity 1, have them now look at a compact fluorescent bulb with and without the slit. With the slit, lines of color are observed. Without the slit, overlapping colored bulb images make it difficult to see separate colors.

The narrower the slit, the more the colors are separated. But if the slit is too narrow, the light is too dim to see. For this activity, the slit should be about 1 cm long and as wide as the blade of a craft knife. Alternatively, you can poke a small hole in the center of the foil with a pencil point. The spectrum in this case will be a series of dots.

It is important to remind students not to look at the sun or into a laser beam. Students often don't know why this is dangerous so it is a good opportunity to talk about safety. You can look at the solar (or laser) spectrum by looking at the light reflected from white paper, that is, put the white paper in the sunlight and look at the paper with the spectroscope. For a laser, turn down the room lights and shine the laser on a piece of white paper. Look at the laser reflection with the spectroscope. We usually provide stickers for the spectroscope tubes stating: DO NOT LOOK AT THE SUN OR INTO A LASER!

ACTIVITY 4 – USE THE SPECTROSCOPE TO STUDY LIGHT SPECTRA

It is sometimes difficult for students to locate the spectra inside the tube. As the photo on the slide shows, the slit is illuminated by the source (it is the same color as the source) and the spectra appear on the sides of the tube. Depending on the grating used, there may be one or two spectra on each side of the slit. A CD will produce only one spectrum on each side.

The colors in the spectrum depend on how light is produced by the light source. Consider several light sources that look red to the eye. Each will produce a different light spectrum. For example, a red laser pointer is a very pure red light because of the way laser light is produced. The spectrum will consist of a red line only on each side of the tube. A red LED will be nearly all red but there may be some orange or green especially in a low cost LED. A red incandescent bulb (a white light with a red bulb coating) will produce a complete rainbow with the blue and violet end dimmed or missing. Computer monitors use three colors, red, green and blue, so you will see mostly red depending on the shade of red. And a red-coated fluorescent bulb has specific bands of color depending on the coating on the bulb.

Experiment with different types of bulbs, both white light and colored. "Neon" lights are particularly interesting since they contain glowing gases, each with its own spectral "fingerprint". What are commonly called neon lights are actually filled with low-pressure gas subject to a high voltage, causing them to glow. Neon gas produces orange-red light, with mixtures of other gases used to produce different colors.

ACTIVITY 5 – MYSTERY SPECTRUM

After students have examined the spectra of several different types of lights you can present some "mystery spectra" and see if they can identify the source. You can hide a bulb inside a box, with a slit to let light emerge, or use photos of spectra found on the internet.

The slide shows a photograph of a green-coated incandescent bulb. The green and blue portions of the spectrum are bright but orange and yellow are missing and red is dull. What other lights can you look at? Try streetlights at night, candle flames (be careful!), exit signs- anything that emits light.

OPTIONAL ACTIVITY – MEASURING SPECTRA

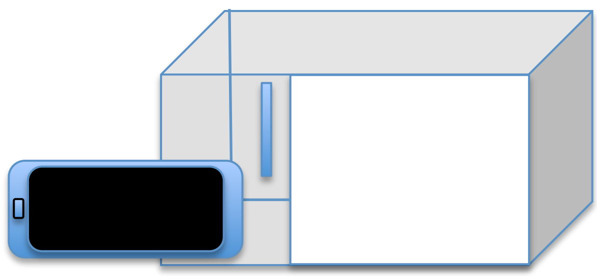
Commercial spectroscopes can measure wavelengths to within a fraction of a nanometer. In this optional activity students measure approximate wavelengths by constructing a calibrated spectrometer system. (See diagram on the next page.)

Some points to consider:

- To calibrate your spectrometer you need a standard wavelength scale that you use to compare other spectra. Think of this as the markings on a thermometer. You can create an approximate calibration by assuming the purple end of a full (rainbow) spectrum is 400 nm and the red end is 700 nm.
- You need a way to record the calibration spectrum and also those you want to compare. The simplest way is a camera. If the camera has a flash, shut it off.
- Take a photo of the spectrum of an incandescent bulb or sunlight. (You need a source of light that produces a spectrum from violet to red.) More precise calibration requires the use of spectra that consists of sharp lines at known wavelengths, like the spectra of tubes of low-pressure gas subject to high voltage.
- To make the calibration spectrum print the full spectrum and label the violet end 400 nm and the red end 700 nm. Draw a line between these points and use a ruler to subdivide it into convenient divisions. You can then line up the other

spectrum photos with this chart and determine wavelengths in other spectra.

- In order for the calibration to work you need to keep the camera and light source (slit) in the same relative position from spectrum to spectrum. Instead of the tube, use a small box. Make a narrow slit in one side and mount the camera opposite. Instead of trying to make a slit in a box, you can also make a larger hole in the box and cover it with aluminum foil. Make a narrow slit in the foil, as you did with the spectrometer tube. Note that the side where the camera is located is partially blocked to minimize room lighting.
  In the drawing the light source is behind the slit in the box (not shown) and the grating is taped over the phone's camera lens (also not shown). The photo will show the spectrum spread out to the side of the slit, on the inside of the box. Use whatever supports you need to keep everything in place.
- Replace the full spectrum source by other light sources and see how accurately you can measure wavelengths.



SOME BASIC SPECTROSCOPY REFERENCES

For more information, including a video showing how to make the spectroscope of Activities 3 and 4, see "Exploring Light Spectra" here: http://bit.ly/1ZMQ0rg. Also see the references below for easy-to-understand sources of information on spectroscopy.

Astronomers Toolbox (NASA) http://imagine.gsfc.nasa.gov/science/toolbox/spectra1.html

Alien Vision, Exploring the Electromagnetic Spectrum by Austin Richards, SPIE Press

ONE MORE TECHNICAL REFERENCE

Ocean Optics Applications Notes- Spectroscopy for a Better World
http://oceanoptics.com/product/application-notes-brochure/