SOMEWHERE OVER THE RAINBOW

Facilitator's Guide • Section 2.1

STOP for science

SCIENCE TOPIC OUTREACH POSTERS

INTRODUCTION

Most students have encountered rainbows, either spotting them directly on those special days when the raindrops fall while the Sun still finds cloudless regions to peek through, or at least seeing pictures of them in books or movies. Many have also seen "rainbows" formed in the spray of water from a garden hose on a sunny day. Although most students thus make the connection between water droplets and sunlight in the formation of these colorful arcs, few think about how this actually happens, or about the special geometry required for a rainbow to be visible. "Somewhere Over The Rainbow" introduces key ideas about light—and sunlight in particular—to explain its behavior when it travels through a raindrop, and how this results in the formation of rainbows. The concepts of refraction and dispersion are introduced, with an example to explain how the direction of a wave is changed when it enters a medium in which its speed is reduced. This is extended to the case where white light enters a drop of water, and the geometry of the resulting light path is illustrated to explain how the colors in a rainbow are formed, and why they come from the directions we observe to form these familiar arcs.

The primary points covered in the poster are:

- Light is a wave. Like waves in water, it can be characterized by a wavelength.
- The wavelength of light determines its color. Blue light has a shorter wavelength than red light.
- Sunlight is made up of many colors. When the different colors are merged together, they look white. But there are ways of isolating the different colors that make up sunlight.
- When a wave goes from one medium (like air) to another in which it slows down (like water), its direction changes. This effect, called refraction, occurs when the wave enters the new medium at an angle; it ends up traveling in a new direction in the new medium.
- When a wave is refracted, the change in its direction depends on its wavelength. Blue light (short wavelength) is deflected more than red light (long wavelength). This is called dispersion.
- A rainbow is formed when sunlight enters a water droplet, with refraction and dispersion changing the direction of the light. The light is refracted as it enters the droplet, with the colors spreading out (dispersion). There is also an internal reflection in the droplet, and then more dispersion as the light exits the droplet.
- We only see rainbows in particular directions relative to the Sun. The angle at which the light exits the water droplet is 42 degrees from the direction back to the sun. For the light to get to our eye, the sun thus needs to be behind us. Our shadow marks the direction opposite of the sun position, and the rainbow will appear 42 degrees above this.
- The rainbow is actually a double-arc. With particularly bright rainbows, one can sometimes see a faint second arc above the primary rainbow. If you look closely, you'll notice that the colors are reversed.

BACKGROUND SCIENCE

Light is a form of electromagnetic energy. It behaves like a wave, with blue light having a shorter wavelength than red light. The wavelength of both blue and red light is very, very small—about 40 millionths of a centimeter for blue light, and a bit less than twice this value for red light. The human eye is sensitive to light with wavelengths from about 390 nm to 750 nm (a nanometer, abbreviated nm, is one-billionth of a meter)—the so-called "visible" part of the electromagnetic spectrum. Sunlight contains light of every wavelength in this range (and, thus, all colors), and when combined together the light appears white. Other forms of electromagnetic energy have exactly the same properties as light, and differ only in wavelength, with radio waves having very long wavelengths (as long as a meter) and gamma-rays having incredibly short wavelengths (smaller than atoms).

Light travels at a speed of about 186,000 miles per second (300,000 km per second) in space. This is the fastest anything can travel. (See the poster "That's Fast!" in the Stop for Science series.) But light travels more slowly when it goes through something other than a vacuum. It slows down when it enters our atmosphere, for example, though not by much. It travels even more slowly in water, glass, or other transparent media. When light enters a medium in which its speed changes, its direction changes; the path is "bent" to a new direction. (The exception is when it enters exactly perpendicular to the surface of the new medium, in which case it is not bent.) This effect, called refraction, is actually quite common. It is the reason that a stick appears to bend when placed into the water, and it is instrumental in the design of eyeglasses, which delicately redirect light in directions that compensate for flaws in the focusing properties of some people's eyes (an interesting topic for another poster!).

Refraction is a wave property, and it knows all about wavelength; waves of different wavelengths refract by different amounts as then enter the new medium—an effect called dispersion. This effect is most commonly known from seeing the results of having white light go through a prism. The light path is bent, and different colors are bent by different amounts. The angle by which the path is changed is greater for blue light (short wavelength) than for red light (long wavelength), allowing us to separate the light into its multicolored spectrum. The same thing happens when light enters a raindrop. When it exits the raindrop, the colors have spread out. The light can also reflect from the inside of the raindrop and then exit (see the diagram on the poster). Light that doesn't undergo that reflection will form a rainbow too, but since the direction of the light hasn't changed much, you would have to look in the direction of the sun to see it. And, since the sun is so bright, this is just too faint to notice. The light that undergoes that extra reflection comes back out from a direction far away from the direction to the sun, and is easy to see. The light is turned around by about 318 degrees, or 42 degrees away from the direction back to the sun. Since the line from our own shadow to our eyes marks the direction back to the sun, we will see the rainbow about 42 degrees away from our shadow. Blue light is bent more than red light, so we see the blue light coming back from a direction lower in the sky.

FUN FACTS

- Light can undergo a second reflection within a raindrop, and then exit in a completely different direction. If the light enters the raindrop at the right location, the ray that exits after two reflections will be directed toward the ground. The angle away from the sun is somewhat different from that of the primary rainbow; it appears higher in the sky. This is the nature of a double rainbow.

- Visible light isn't special in terms of forming a rainbow. Infrared radiation does the same thing, for example, but our eyes can't see it. However, infrared-sensitive cameras have indeed taken pictures of the "infrared rainbow."

- Raindrops are not the only things that can cause sunlight to be refracted and/or dispersed. Ice crystals in the upper atmosphere can do the same thing. Because the crystals are not spherical (but do have regular, well-defined shapes) the light comes back to us at angles different from that of the rainbow. These are sometimes seen as "sundogs"—colorful arcs of light seen about 22 degrees from the sun, generally on cold sunny days.

- The ice crystals responsible for sundogs can also form a "halo" around the sun at a radius of 22 degrees. But the sun is much too bright for this to be seen unless it is blocked out by some object along the line of sight. Thus, it isn't a good idea to look for this (and it is important to never look close to the direction of the sun; it is so bright that it is dangerous to our eyes!). However, this halo can often be seen around the full moon on cold winter nights.

- The wavelength of radio waves that carry the music to your car radio is about 3 m (about 10 ft). You can actually notice this at times. Have you ever had the radio station fade out a bit when you stop your car? Try rolling forward (or backward) a couple of feet. Often the reception improves. This is the result of what we call interference. You can move from a region of "destructive interference," where the signal is bad, to one of "constructive interference," where the signal is good, by moving a distance equal to half of the wavelength.

- Scientists use special instruments that disperse the spectrum of stars and other objects that they view through telescopes. The spectrum tells them a lot about the temperature and structure of these objects.

COMMON QUESTIONS OR MISCONCEPTIONS

- Don't be surprised if some students have never seen a rainbow! If you live where there isn't much rain, this can be a rare sight. If some have never seen one, it is well worth doing a demonstration with a garden hose. The first time, it is like seeing magic…

COMMON QUESTIONS OR MISCONCEPTIONS (continued)

- The position of the rainbow in the sky depends on where the sun is. If the sun is too high in the sky (for example, if it is near noon), the raindrops needed to get light back to your eye have to be on the ground!
- Why is the second arc of a double rainbow so faint? This is simply because by the time light has gotten to the point in the raindrop where a second reflection would occur, most of the light has already come back out of the raindrop.
- How do I remember the colors of the rainbow? Remember the name of a fictional kid named Roy G. Biv; the colors are Red, Orange, Yellow, Green, Blue, Indigo, and Violet.
- Is it really my own rainbow? Yes, it is. The droplets that act to get the sunlight back to your eyes are not the same ones that get the light to the eyes of someone standing somewhere else. Each person sees their own personal rainbow!
- Is it really worth standing in the rain to see a rainbow? Absolutely! Positively!

DEMONSTRATIONS AND ACTIVITIES

- **Rainbows in the yard.** It is simple to create your own rainbow on a sunny day. All that is required is a garden hose with a nozzle that can create a fine mist. This is a great way to actually demonstrate the geometry involved because you can place the source of droplets almost anywhere you want relative to the observer. Thus, you can make rainbows at high noon, for example. Have kids mark the direction to their shadows (the shadow of their heads, specifically, since it is the light directed back at their heads that they see). Move the spray from the hose around until they see a rainbow. Have them mark the direction to the rainbow. Now estimate the angle between those two directions. Note that the student will need to be between the sun and the mist to be able to see a rainbow; they will need to look in a direction away from the sun.

- **The color of sunlight.** It is always worth doing a simple demonstration of light dispersion with a prism. This can be done with a white light source, of course, but it is potentially more interesting to use light directly from the sun. (This is how Isaac Newton first discovered that light was composed of multiple colors.) This is tricky, because the refracted light, dispersed into its colors, is faint compared with bright daylight. One option is to wait for a time when sunlight shines directly into the windows of a classroom, and to then close the shades except for someplace where you can mask out everything but a small (preferably circular) opening. Use that light beam to send through the prism and you should get a dispersed spectrum in a dark room—just what you want.

- **Demonstrate dispersion.** Another way to demonstrate dispersion is to use a round fishbowl or similar container filled with water. Use a flashlight with a bright, narrow beam and shine it through the container at a slight angle. The beam coming out the side will be split into different colors. (Note that this effect may be somewhat subtle.)

DEMONSTRATIONS AND ACTIVITIES (continued)

- **Investigate refraction.** The bending of light rays can be demonstrated easily with a ruler and a wide tank of water. Fill the tank to a depth about two-thirds the length of the ruler. Now insert the ruler into the water at an angle and look at this from above. It appears that the ruler bends. Actually, light coming from the part of the ruler that is in the water is bent as it comes out, making it look like it came from a different position in the water.

RESOURCES

http://www.nasa.gov/audience/forstudents/k-4/dictionary/Rainbow.html

Rainbows, Halos, and Glories (Robert Greenler: Peanut Butter Publishing; Milwaukee, WI)