FLEET ARC CENTRE OF EXCELLENCE IN FUTURE LOW-ENERGY ELECTRONICS TECHNOLOGIES

FLEET Schools. Activity 6: How to find a rainbow

Learning Intentions
To understand reflection and refraction and its role in the production of one of nature's wonders: the rainbow.

Extension: Students will learn about and apply Snell's Law to understand refraction and how understanding refraction was crucial to inventions such as the microscope, telescope and magnifying glass, and how it helped us understand how the eye works and the design of lenses to correct vision.

Before the activity:
Why are there so many songs about rainbows? In this activity students get to build Maunder and Hunt's Very Fabulous Rainbow Position Locator to find their rainbow using a bit of simple physics (reflection and refraction), maths and home-craft.

There's something fascinating about rainbows, which is why they feature in so many wonderful legends and myths, from the Bifrost bridge of Norse legend, to God's reassuring post-Flood sign, to the source of leprechauns' gold.

For scientists, rainbows are a beautiful, visible manifestation of relatively simple optical physics. With a couple of threaded steel bars and a poster tube you can construct a tool that at its simplest shows where a rainbow will form, but also 'opens your eyes' to hidden, lovely symmetries in every rainbow.

You probably know that a rainbow forms when the sun is behind you, and is low in the sky. And you may have inadvertently created rainbows when spraying a hose in bright sun in your backyard.

You may not know that the same precise mathematical relationship predicts where each rainbow forms, whether 'natural' rainbows in the sky or 'artificial' in your backyard. And that with the right tool you can precisely predict the location of both natural and artificial rainbows.

Here's the key: a rainbow forms at a position when the angle from your eyes to the rain and back to the Sun is precisely 41°. See Figure 1. below.

Note this activity requires the uses of tools such as a drill. Some supervision will be required.

Materials

- 1 Hoola hoop
- Poster tube
- 2×M6 steel rods (length longer than the diameter of the hoop)
- 12×M6 nuts
- Drill
- Tape measure
- Stanley knife

Extension

- scientific calculator

Teacher Notes	Teaching Notes: Running the activity
What is happening? Let's talk about math… With rainbows, it is the refraction that provides the colour and reflection is responsible for the shape – in this case a circle. Yes a circle. See 'Rainbows are Circles' below. When light from sun hits a raindrop, it does the following: (1) refracts (changes direction) as it enters the raindrop (2) reflects off the back of the raindrop (3) refracts again as it exits the raindrop. Together, that creates a reflecting ray at 41° ** to the incident ray. See Figure 2. Below. Therefore, if you're standing on the ground looking up at the sky, and there are raindrops at the right angle (41°) between you and the Sun, ka-pow! Rainbow-time. **This ignored the different angles of refraction of each of the colours in the visible spectrum. In fact, a rainbow's coloured bands cover a small range of angles, from 40° (red) to 42° (blue), but for simplicity we have referred to the centre of that band: 41°. **Extension – introduction to Snell's Law (Year 8+)** This extension will introduce students to Snell's Law, which describes how refraction works. There is some math to do here. First read, What is refraction, in Reflection, absorption, refraction. and see Figure 6 below. Snell's Law is the simple equation, $n_1\sin(\theta_1) = n_2\sin(\theta_2)$, where n_1 and n_2 are the angle of incidence and angle of refraction. See Figure 6 below There are online calculators you can access, but for students this is a simple enough equation. You just need the table of refractive indexes which you can also access online (one example here), and a calculator with the sin function key.	**Method** Using a poster tube and hoola-hoop you can create a viewing 'template' at the correct angle. To create a triangle with a viewing angle of 41°, measure the radius (R) of the hoola-hoop and calculate what horizontal length (H) is needed to create a ratio of 0.87 to one (tan 41° = 0.87). That is, H = R/0.87. [If your student is capable of doing the trigonometry, delete this from the instructions so they can calculate it themselves.] Our hoola-hoop radius (R) was 393mm so we needed a horizontal axis length (H) of 451mm. Measure the distance R from one end of the poster tube, drill four equally spaced holes of appropriate size to thread the steel rods (actually, offsetting alternate holes about half the width of the bar allows them to cross nicely). Thread your two steel rods through the holes at right angles. Secure with nuts. Drill four holes through your hoola-hoop, thread nuts on the steel rods, then the hoola-hoop, then secure with nuts. Check its central with a tape measure. Carefully cut a 'viewing window' at the end of the tube, so the hoola-hoop is visible with the tube pressed against your eye like a telescope. (Leave a narrow band of cardboard at the opening, for strength.) **Using the rainbow finder** With the Sun in the sky behind you, get a friend with a hose to spray water in the air, so you can form a rainbow to observe. (Get them to put one thumb over the end of the hose to create small droplets.) To align the tube with the Sun, look through the tube and align the 'cross hairs' of the two steel rods with the shadow of your own head.

Students can do a bit of algebra to solve for (θ_2). See the following:

$n_1 \sin(\theta_1) / n_2 = \sin(\theta_2)$

$1.00 \times \sin(35 \text{ degrees}) = 1.33 \times \sin(\theta_2)$

$\sin(\theta_2) = 1.00 \times \sin(35 \text{ degrees}) / 1.33$

Your angle of refraction (θ_2) should = 25.55 degrees.

Remember, if light enters any medium that has a *higher* refractive index, (such as from air into glass) it slows down and changes direction *towards* the normal line. If light enters into a substance with a *lower* refractive index (such as from water into air) it changes direction *away* from the normal line.

Rainbows are circles

The realization that rainbows are actually circles dashes any hope of a pot o' gold at the end of the rainbow. Rainbows are not actually arches, but circular and therefore no end of, and no pot o' gold. Of the light that is reflected/refracted to create the rainbow, we only see the portion that is above the horizon. But if you wait for the sun to be low on the horizon (which means the rainbow will be a bit higher in the sky) and get yourself up high – really high (which means you can see a bit further over the horizon) you may see the whole rainbow. And there needs to be rain, of course. Scientell and the ABC Education unit have a nice explanation.

Scientell

ABC

And for some insight into why we see all the colours of the rainbow see this article from the ABC

Without moving the tube, look up through the 'viewing window' to see that the hoop aligns with the rainbow formed by your friend with the hose.

As you move your eyes to look around the circumference of the hoola-hoop, you are maintaining the same 41° angle. This is why rainbows form a circle. As long as the angle between sun, raindrop and your eye is 41°, it works. See Figures 4 and 5.

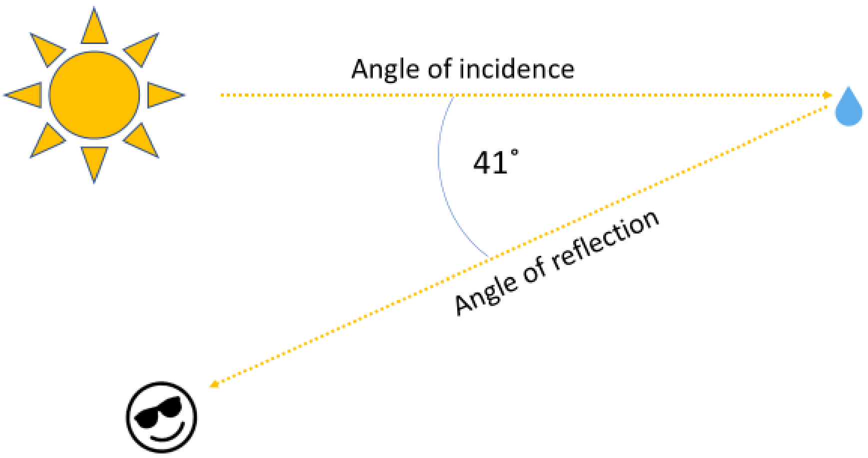
Note the eyepiece must be firmly against the eye, as otherwise the distances will be wrong (even wearing a pair of sunnies moves the device slightly away from your eye, so that the hoop will appear to be slightly too small). This is why a 'viewing window' is needed (otherwise you need to move the tube away from your eye to be able to see the hoop). Similarly, you need to be lining the device up with the centre of your head's shadow (where your eye would be).

Extension – getting into Snell's Law

This is where students play with some simple math to be able to calculate the angles of refraction as light travels through different media, which is what light is doing as it travels through air into a water droplet and out again to create a rainbow.

A student example to work with.
If we assume that light is travelling through air into water then n1 is the refractive index of the air and n2 is the refractive index of the water. See Figure 5 below.

Air has a refractive index of 1.00029 and water a refractive index of 1.33. A vacuum is considered to have a refractive index of 1.00, but for simplicity you could round the refractive index for air back to 1.00 for this purpose. For any known angle of incidence, get students to calculate the angle of refraction in this air to water scenario, if the light travelling from air to water has an angle of incidence of 35 degrees. What is the angle of refraction (θ_2)?



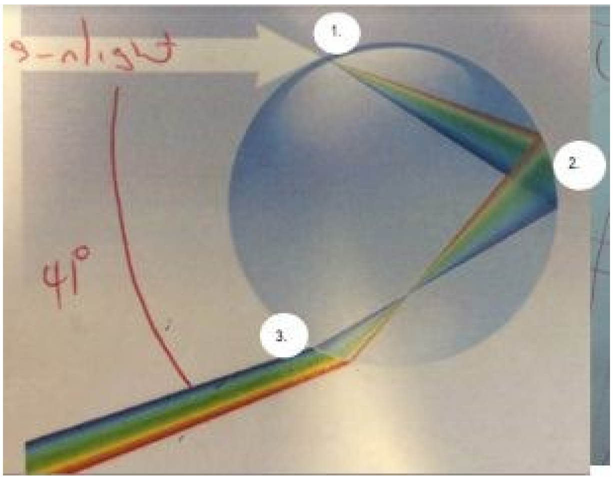


Figure 2. What happens to make a rainbow. Inside every spherical raindrop: sunlight enters the sphere and [1] refracts (changes direction), then [2] reflects off the 'back' of the raindrop, then [3] exits the front of that raindrop, and refracts a second time as it does so.

For any raindrop, the angle between the light entering the sphere and exiting again will always be 41°.

Figure 3. The finished Maunder and Hunt's Very Famous Rainbow Finder. Note the viewing window cut into the end of the tube.

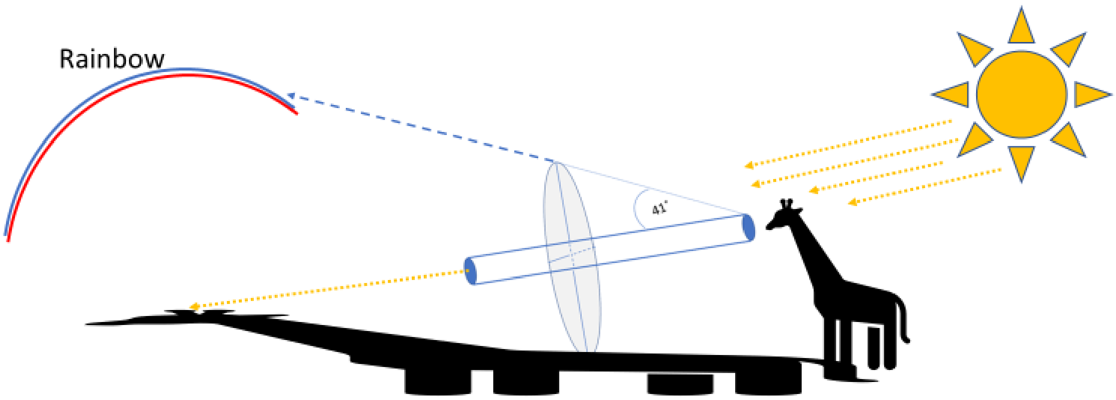


Figure 4. How to use your rainbow finder Step 1. Align the tool with its spine (the tube) parallel to the sun's rays with the longest end of the tube facing toward the sun. Look through the end of the tube furthest from the hoop and line the cross hairs (two crossed metal rods) with the shadow of your head. Look up through the viewing window to see the rainbow, which should be in a direct line with the hoop. Typically, you would not see the full rainbow unless you are up really high and the sun is really low in the sky. Note an easier way to ensure this is still aligned once you pull your head away is to look at the shadow of the tool itself. When aligned properly, the shadow of the tube will be a ring with cross hairs. See Figure 5 for step 2.

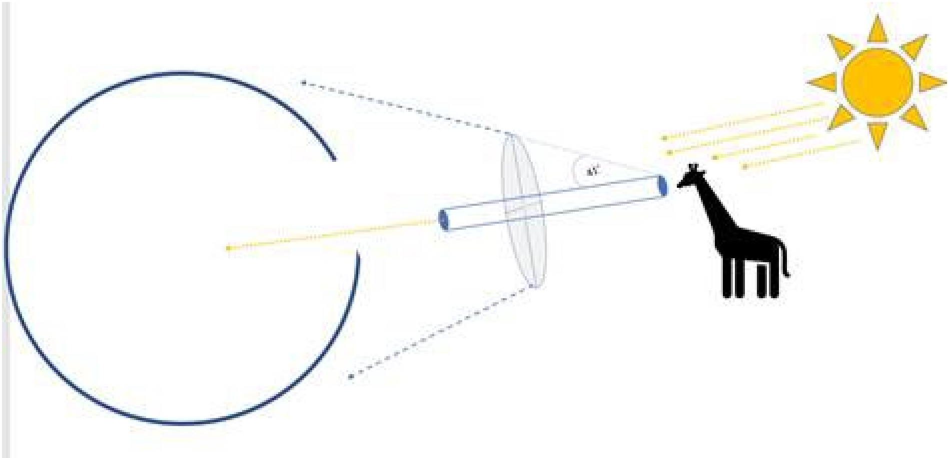


Figure 5. How to use your rainbow finder Step 2. If you look into the tool, the hoop should align with the rainbow - either where a natural rainbow already occurs, or where a rainbow will form if your mate squirts a mist of water in the air. Note, if it is a natural rainbow as depicted here, a chunk of the lower part of the rainbow will be below the line of sight (below the horizon) and you will only see the top half (an arc).

An online version of *How to find a rainbow* can be found [here]

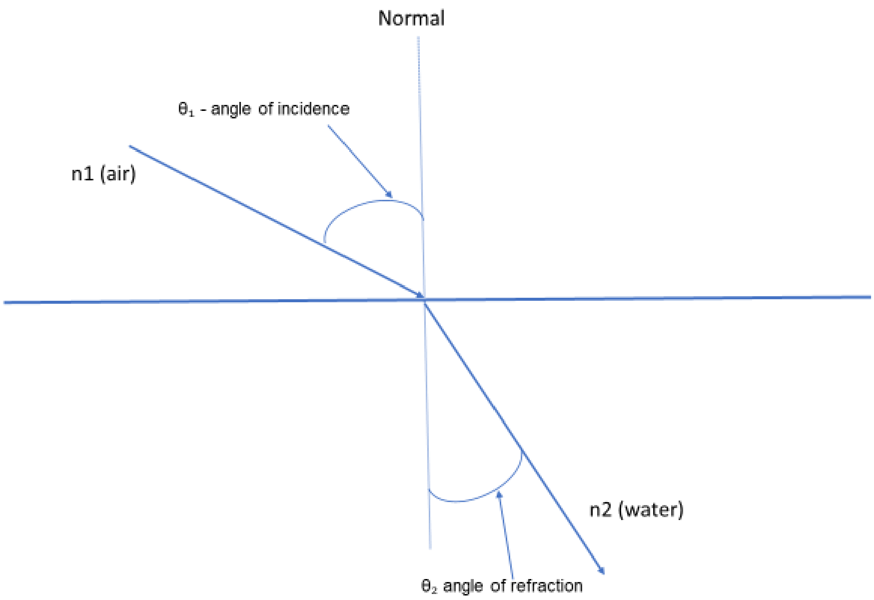


Figure 6. Snell's Law: $_1\sin(\theta_1) = n_2\sin(\theta_2)$, where n_1 and n_2 are the angle of incidence and angle of refraction.