Rainbows

Dale Durran, ATMS 101, University of Washington

You see a rainbow when sunlight is refracted as it enters a rain drop, reflected once or twice as it travels along a path inside the drop, refracted a second time as it exits the drop, and finally travels to your eye. The angle between the incident ray of sunshine and the ray that exits the drop and subsequently reaches your eye is determined by the color of the light and the number of internal reflections inside the drop. The situation for red light is shown in Figure 1. The red ring on the primary

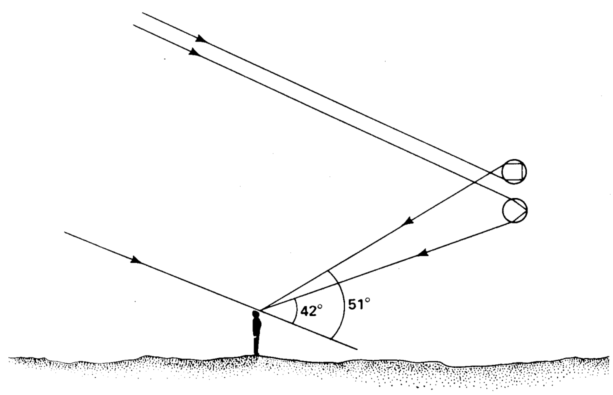

Figure 1: Ray paths for red light arriving at your eye from the primary and secondary rainbows. From Robert Greenler, *Rainbows, Halos and Glories,* Cambridge University Press, 1980.

rainbow, which is formed when the light reflects just once inside the raindrop, makes a 42° angle to the incoming solar beam. Since all the sunbeams are parallel to each other, the red light arriving at your eye from the rainbow also makes a 42° angle with an imaginary sunbeam passing directly through the back of your head. The collection of raindrops that produce the red light you see in a rainbow is, therefore, the collection of all the raindrops that lie at a 42° angle away from an imaginary beam of sunlight passing through the back of your head. These drops lie along the surface of a cone whose tip coincides with your eye and thus, the red light appears to form a circular arc. If there actually is sunlight on the back of your head, the shadow of your head will be at the center of the circle containing the arc of the rainbow.

Suppose you are on flat ground. How high (in degrees) can the top of the rainbow extend above the horizon? Can it extend directly over your head (i.e., 90°)? At what times of day will the top of the rainbow appear highest in the sky?

There are times of the day when the sun is too high in the sky for rainbows to be visible to an observer on flat ground. How high does the sun have to be in order to prevent you from seeing the primary rainbow?

The red ring on the secondary rainbow, which is formed when the light reflects twice inside the raindrop, makes a 51° angle to the incoming solar beam. The secondary rainbow is fainter than the primary bow because every time the beam of light is reflected inside the rain drop, some light is also transmitted through the surface of the drop and that light is lost.

Note that the rays of light shown in Figure 1 bend as they enter and exit the rain drop. Light changes direction when it slows down or speeds up as it passes from one medium (such as air) into another medium (such as water). (The speed of light is a constant in a vacuum, but not when it is traveling through different media.) If you see a pole jutting out of a clear pool of water at angle, the pole appears to bend where it enters the water. The apparent kink in the pole is produced as light rays traveling toward your eye from the underwater portion of the pole bend as they pass through the surface of the water.

Violet light is refracted through a greater angle than red light as light passes into and out of the rain drop. The net effect of this difference in refraction is shown in Figure 2; the violet light leaving the drop makes an angle of only 40° with the

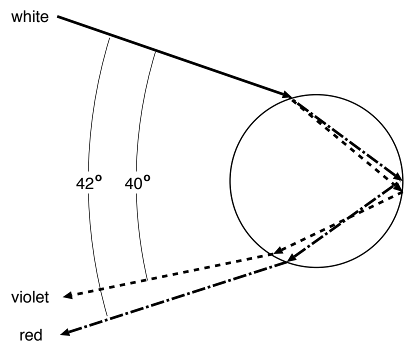

Figure 2: Ray paths through a water droplet that responsible for the primary rainbow. The red light (dot-dashed line) emerges at a 42° angle with respect to the solar beam (solid line). The blue light (dashed line) at a 40° angle.

incoming solar beam. Thus, the violet ring on the primary rainbow will be at only a 40° angle away from the imaginary beam of light passing through your head, and the violet ring will look smaller than the red ring on the rainbow. In other words, the violet ring lies inside the red ring on the primary rainbow. There is progressively less refraction of blue, green, yellow and orange light, and the rings associated with each of these colors are sandwiched between the violet and red rings of the rainbow. The difference in the angle through which red and violet light are refracted is also responsible for the fact that the violet ring lies on the *outside* of the secondary rainbow, with the red ring on the inside. Try sketching a figure, similar to Figure 2, illustrating why the blue and violet rings lie outside the red ring on the secondary bow.