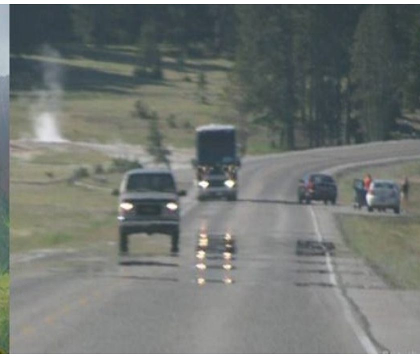
Module 12 - Lecture 36

In this last lecture, we will cover rainbows, mirages, and the green flash, which are not always covered in the classroom version of the course. Next time you see a rainbow or a mirage, you will be able to spot features that you might have overlooked otherwise. You will also know where to look for the green flash.

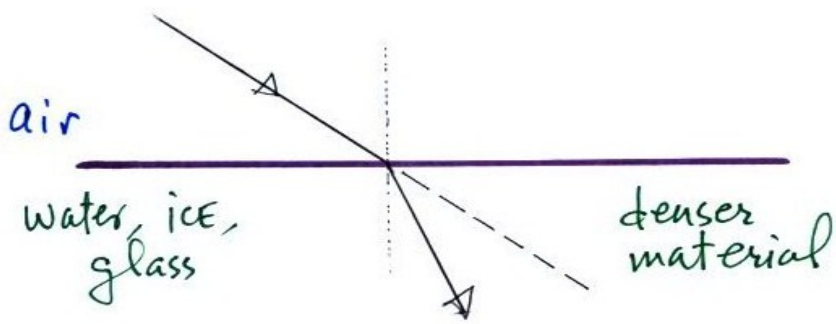
Rainbow



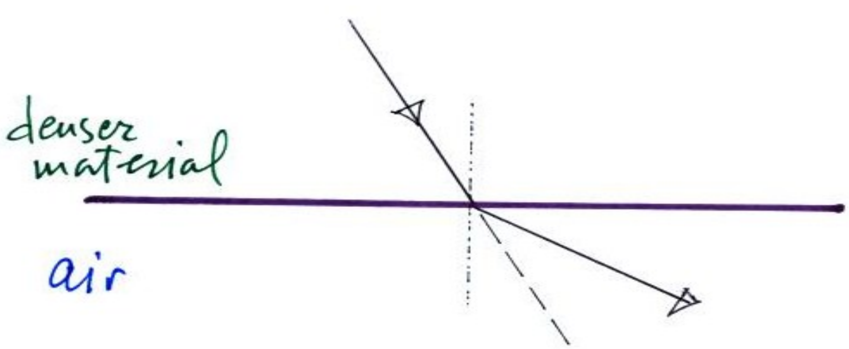
Inferior Mirage

Green Flash

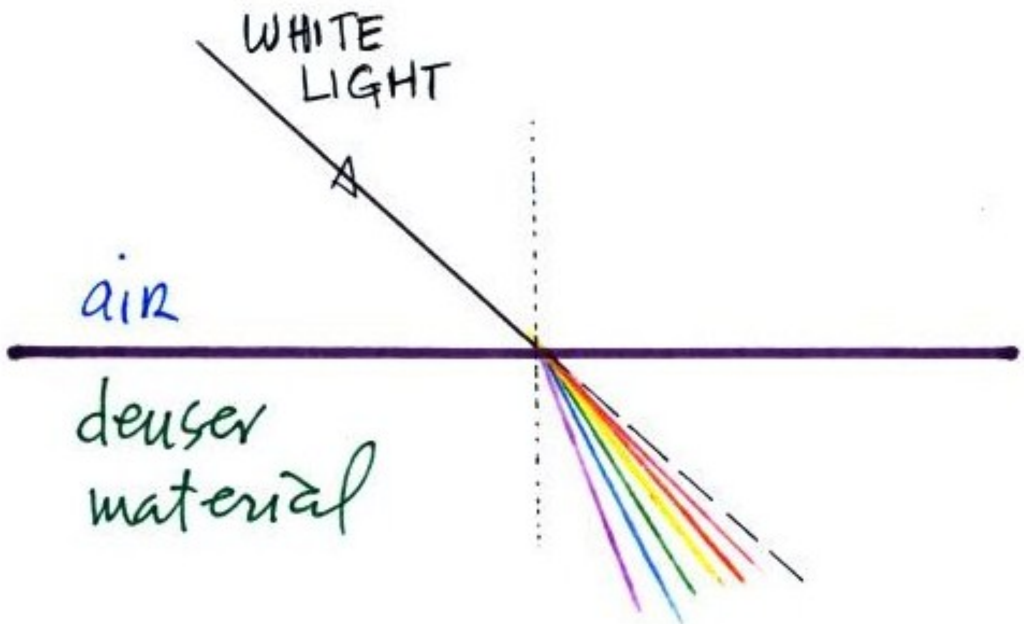
All three phenomena involve **refraction** which is the bending of light as it passes from one transparent material into another. A ray of light might travel from air into water, ice, or glass, for example. When the light passes into a denser material the light bends toward the normal. The normal is the dotted line perpendicular to the boundary between the two materials.



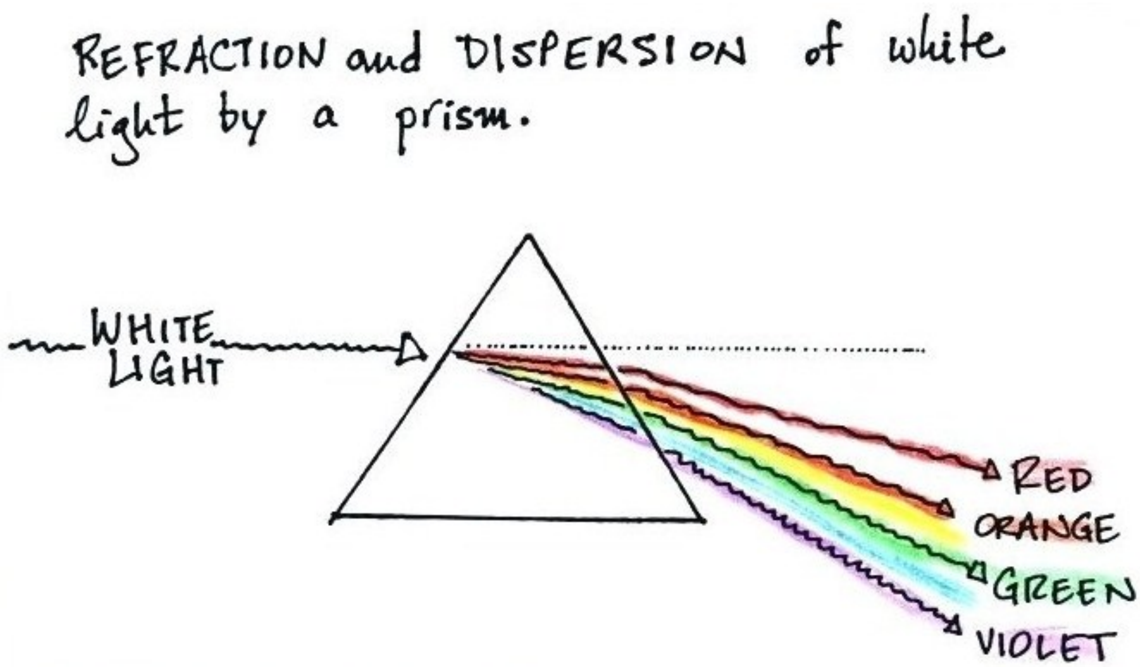
When the light travels from a dense material into a substance with lower density, it bends away from the normal.



The amount of bending depends on the wavelength or color of the light. The shorter wavelengths (**violet**, **blue**, **green**) are bent more than the longer wavelength colors (**yellow**, **orange**, and **red**). Thus white light can be split into its component colors as shown below. The separation of white light into colors by refraction is called **<u>dispersion</u>**.

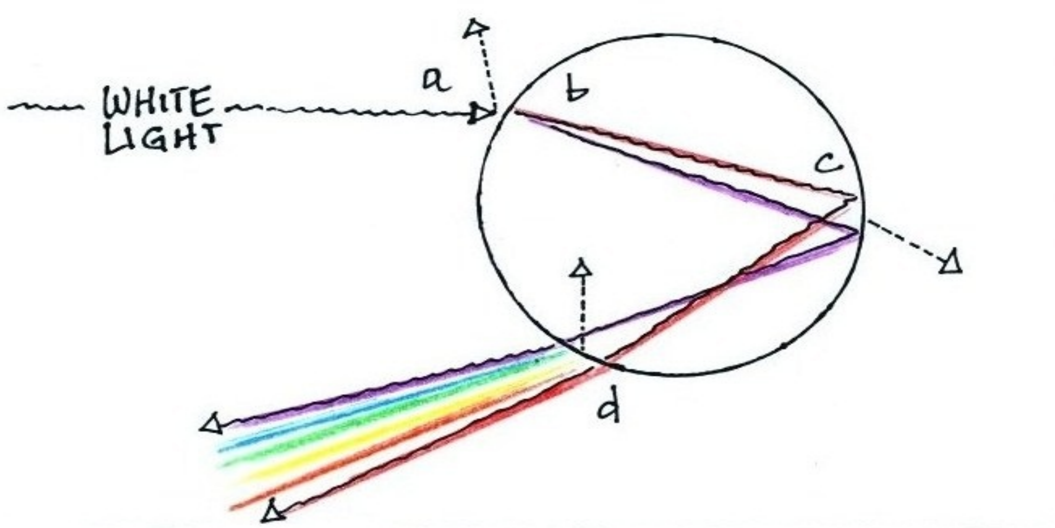


This is what happens when you shine light through a glass prism.

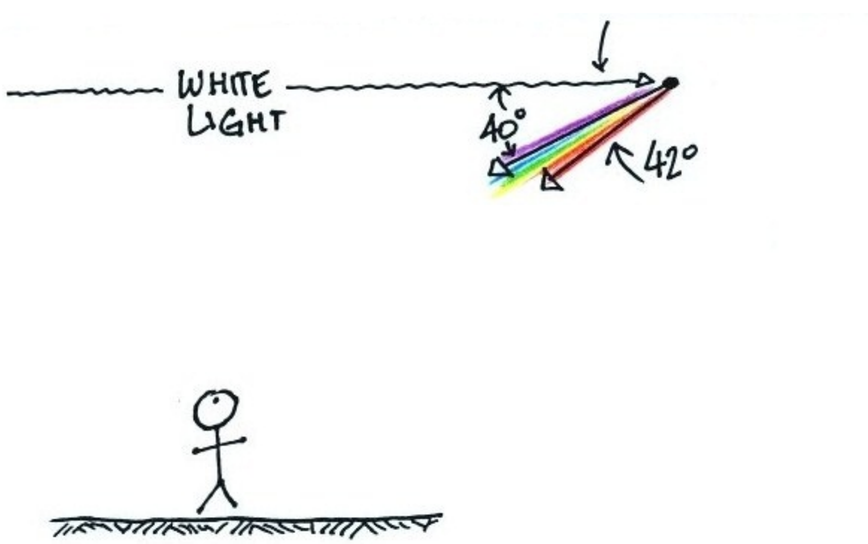


The figure below is a close-up view of a ray of white light striking a spherical raindrop. Some of the white light is reflected (a). The remainder (b) enters the raindrop. This light is bent (refracted) and split into colors (dispersed). Some of the colored rays of light reflect off the back inside surface of the raindrop (c). The colored rays of light emerge from the raindrop and head back, more or less, in the direction they came from (d). These are the rays you see in a rainbow.

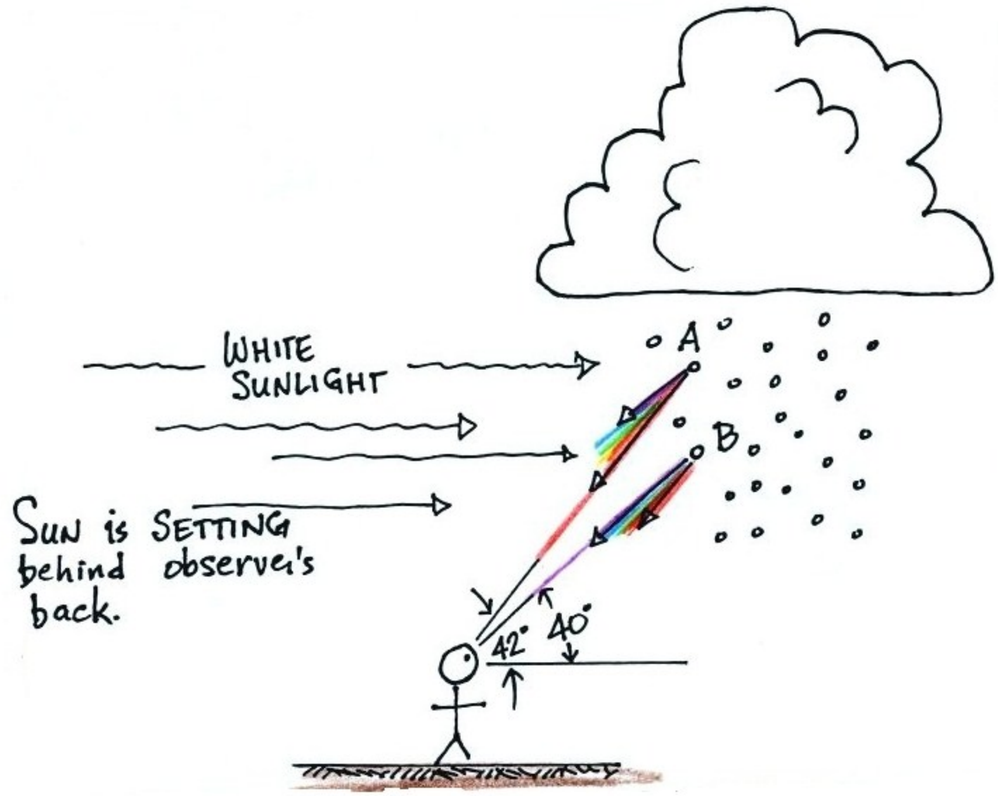
REFRACTION, DISPERSION, and REFLECTION of white light by a spherical raindrop.



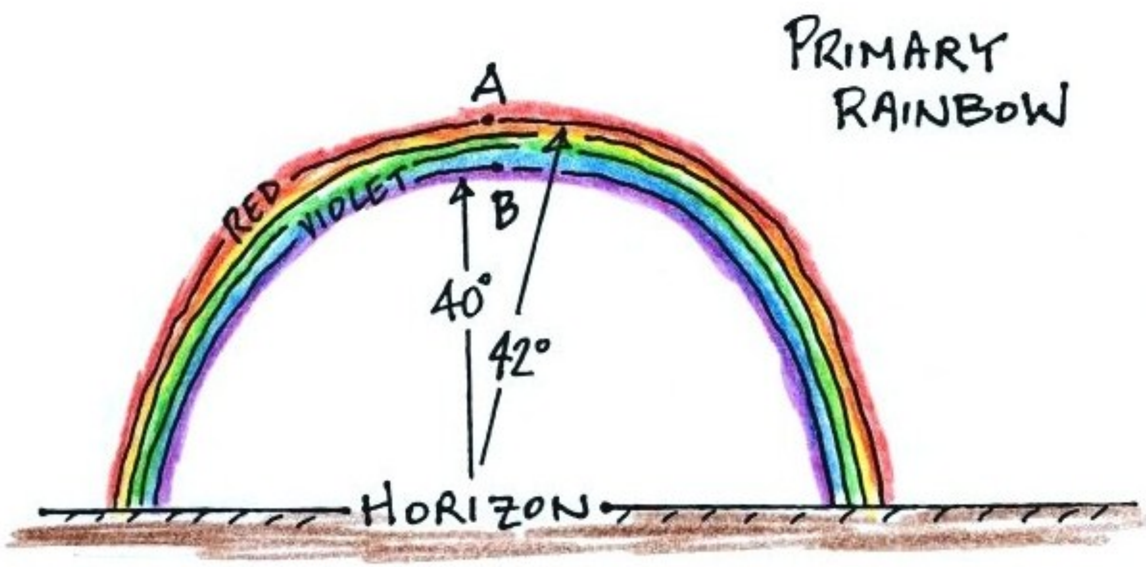
Someone down at the ground (standing with the sun at their back) would see colored light coming from the raindrop. Because each of the colors exits the drop at a slightly different angle (red at 42^o, violet at 40^o, the other colors at angles between 40^o and 42^o), a person only sees one color coming from each raindrop. He would see the ray that was headed straight toward his eyes. The other rays would either pass above the person's head or strike the ground near their feet.



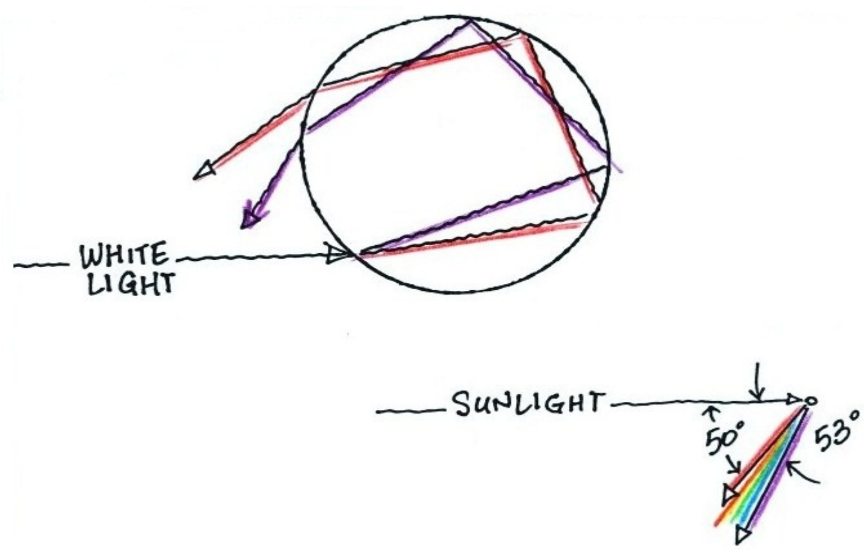
A person would see **red** light coming the drop A which is higher in the sky and **violet** light coming from drop B which is lower in the sky. He would see the other colors when they looked at the sky between A and B.



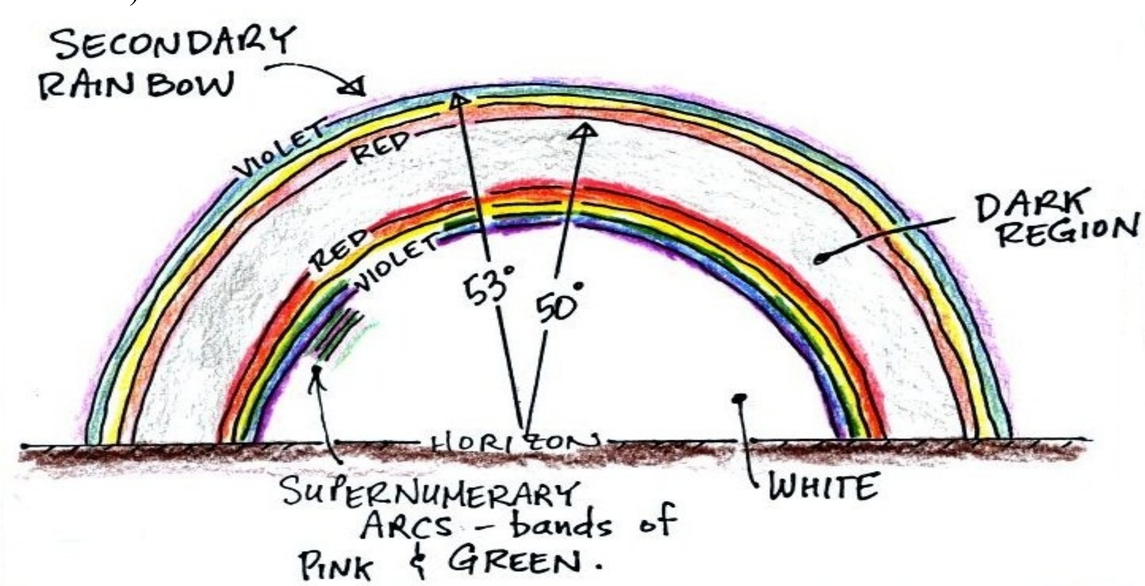
The next picture shows what a person on the ground would see. **Red** light comes from the top edge of the rainbow, **violet** from the lower edge. **Blue**, **green**, **yellow**, and **orange** are found in between.



Sometimes you will see a faint **secondary rainbow** above the **primary rainbow**. The following figure shows how the secondary rainbow forms. White light strikes the raindrop at a slightly different position. The white light is again bent and separated into colors but then is **reflected twice** inside the raindrop before emerging on the front side of the drop. An observer on the ground would need to look 53^o above the horizon to see the violet light and 50^o to see the red light.



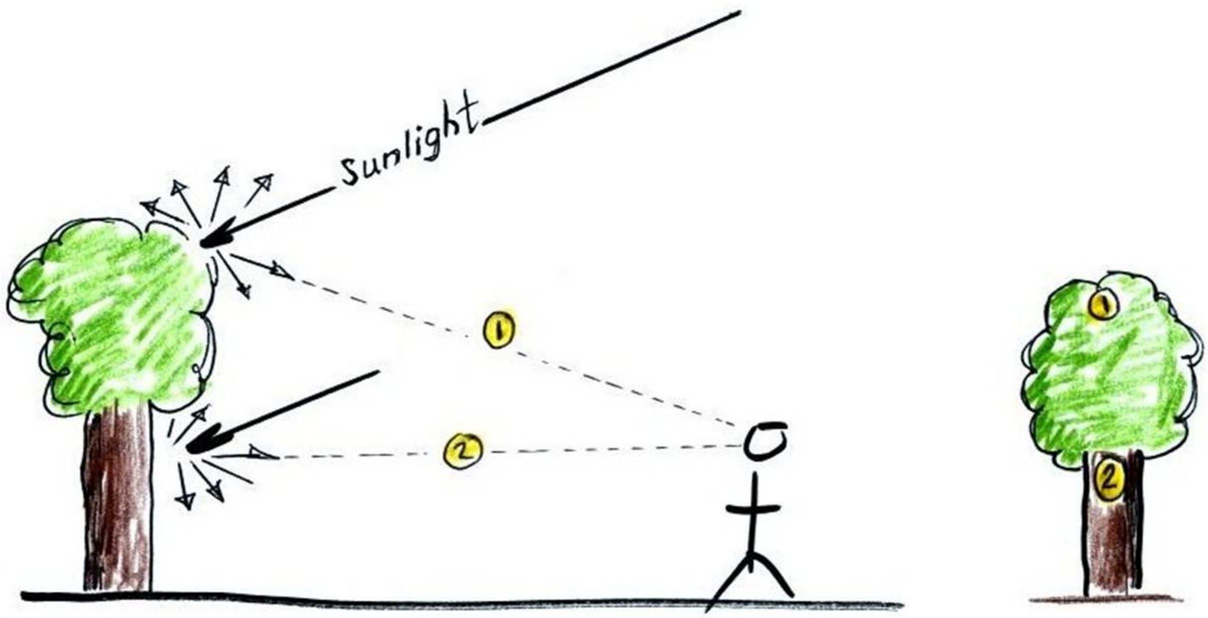
Here is a sketch showing both the primary and the secondary rainbow. The secondary rainbow is higher and dimmer than the primary rainbow. **The order of the colors in the secondary rainbow is also reversed**. Supernumerary arcs (faint bands of pink and green) are sometimes visible below the primary rainbow (we will not go into the cause of supernumerary arcs). Also the sky between the two rainbows appears darker than the rest of the sky (we will not explain that either).



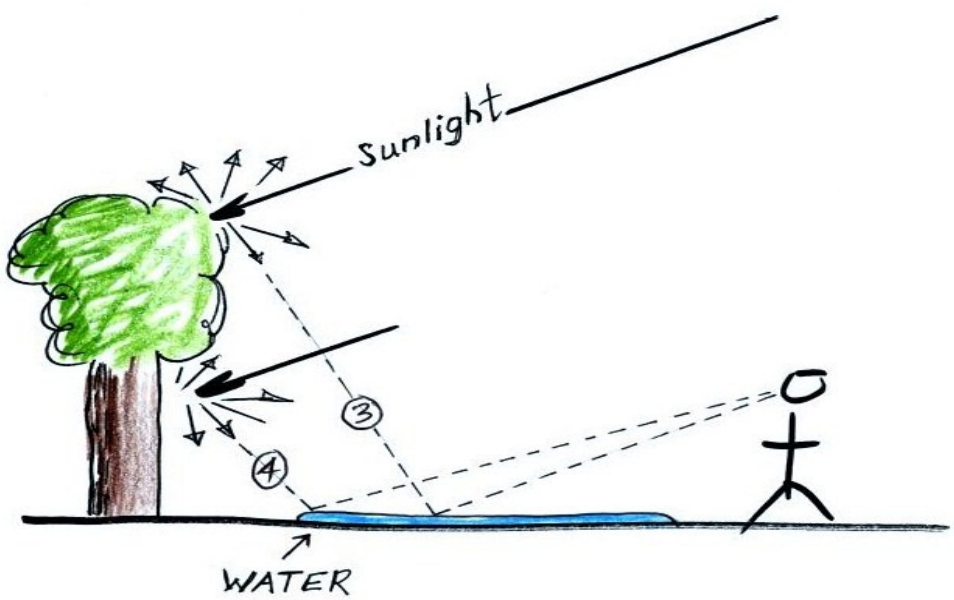
A primary rainbow has red on the outer edge of the bow, as you can see in the photograph below. Note also that the sky below the rainbow is brighter (whiter) than the sky above the rainbow. There is just a hint of a supernumerary arc (the faint bluish green band of light below the violet light on the bottom edge of the rainbow). This image is from www.webecoist.com.

The faint secondary rainbow is clearly visible in this picture (http://www.stonerforums.com/lounge/attachments/general-discussion/5086d1218129871-rainbows-dblrainbow.jpg). You can see the supernumerary arcs on the bottom edge of the primary rainbow. The bands of light in the arcs get smaller as you move further away from the rainbow.

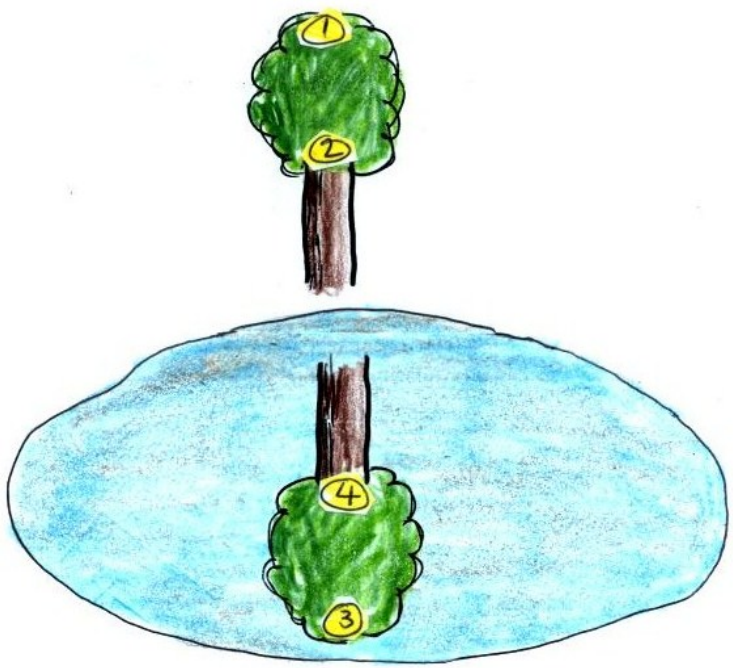
Next we will look at the formation of mirages. Here is a drawing of sunlight striking a tree. The light is **scattered** (sent off in all directions) by the tree. You will see green light coming from the top of the tree as you look back along light ray 1 and brown light coming from the tree's trunk when looking along ray 2. The figure on the right is what a person will see when they look at the tree.



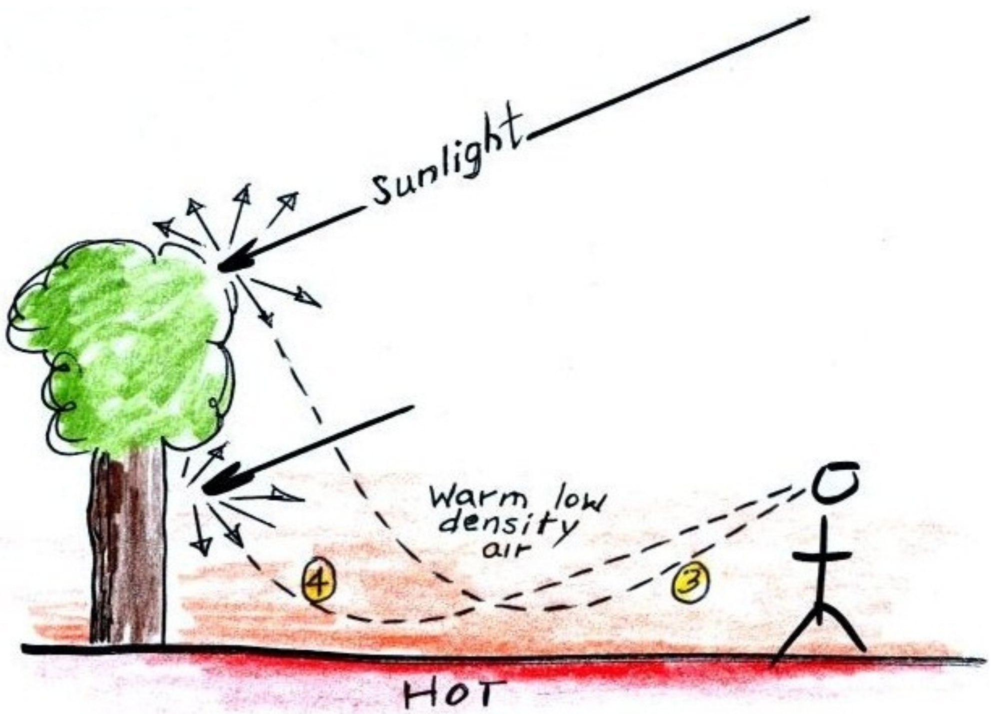
Now imagine there is water on the ground between you and the tree. You will still see rays 1 and 2 (not shown in the figure below). You will also see rays of light coming from the tree if you look down at the water because rays 3 and 4 are being reflected by the surface of the water.



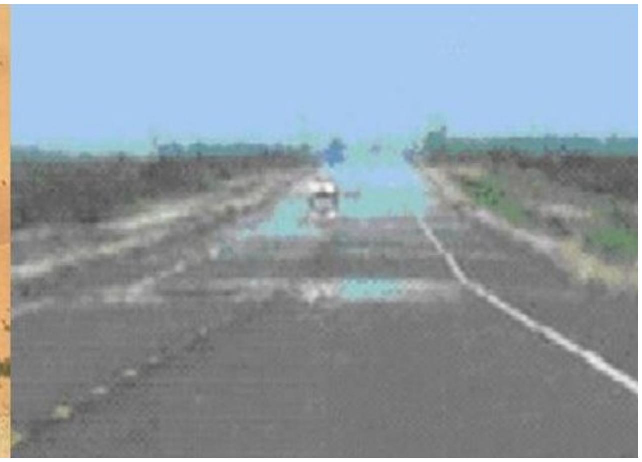
Now you see the tree when looking up and a reflection of the tree when looking down toward the ground. The blue light surrounding the tree is light from the sky that is reflected by the water.



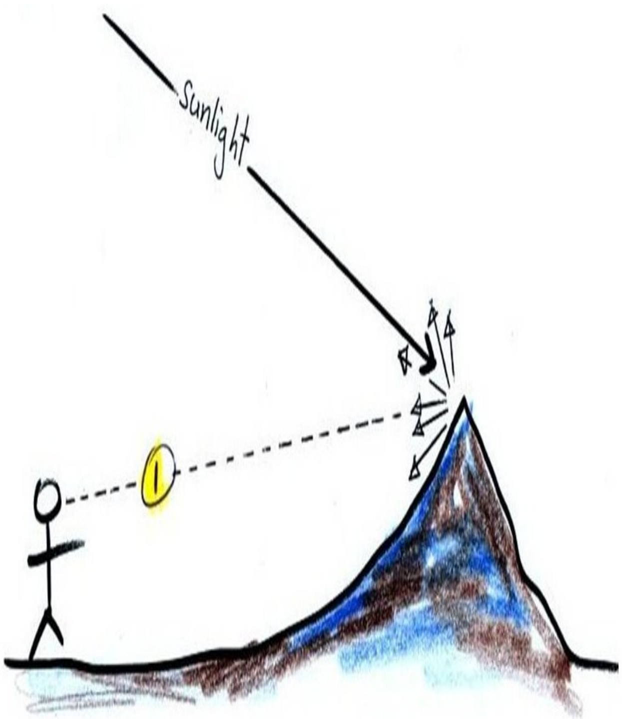
The same effect can be produced by refracted light (below). Light rays traveling into the warmer lower density air next to the ground are bent. This is an inferior mirage. The mirage image is inverted and below the normal image of the object.

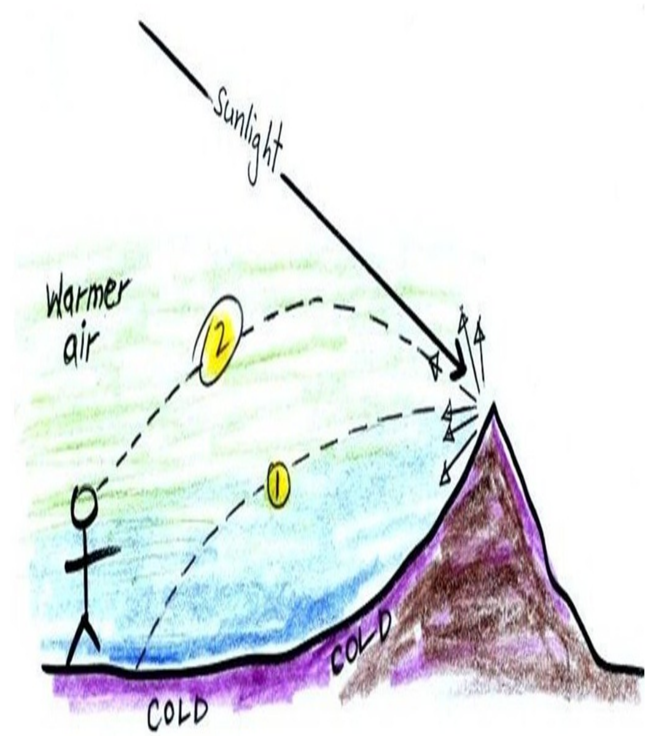


Your brain is not able to distinguish between these two kinds of refractions and assumes that refracted light and a mirage is the same thing. Here are examples of inferior mirages. In this desert setting, it is very unlikely that water is present in the picture on the left (http://www.world-mysteries.com/illusions/mirages.jpg). The blacktop (below right) becomes hotter than the ground on either side of the road. Light from the sky is being refracted and sent toward your eyes. An inferior mirage will make a hot road surface look like it is wet. The blue light from the sky is being refracted, not reflected.



Mirages can also form when the ground is cold (below). Normally you would see ray 1 when you look at a mountain top (left). When the ground and the air next to the ground are cold, light rays are bent. You no longer see ray 1 because it hits the ground at your feet and you need to look a little higher in the sky to see ray 2. As a result, the object appears bigger than its actual size.





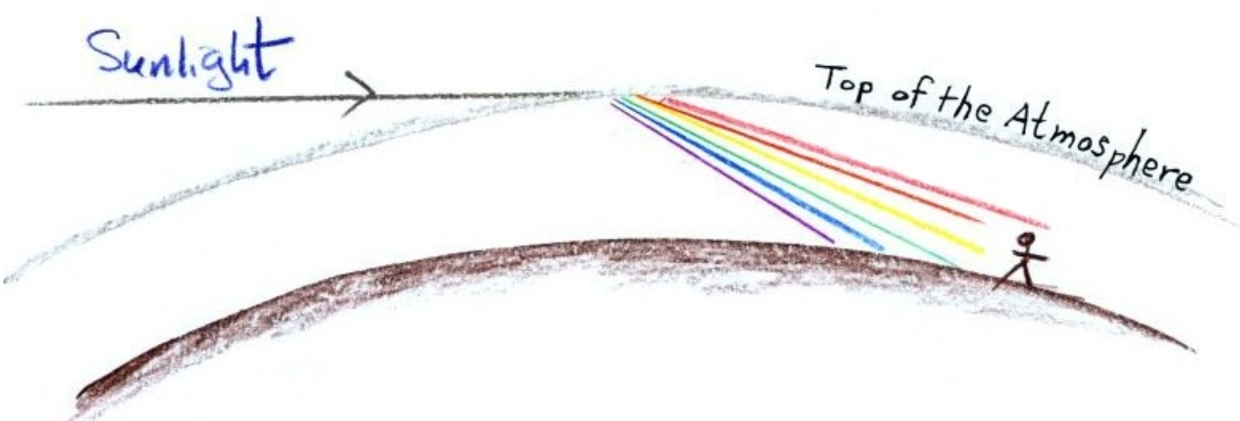
A **superior mirage** will make the mountain appear taller than it really is. A superior mirage is harder to spot because you only see one image and the mirage image is not upside down.

In this photograph, a distant cargo ship appears much taller than it really is http://en.wikipedia.org/wiki/File:Superior_mirage_of_a_boat_3.jpeg.

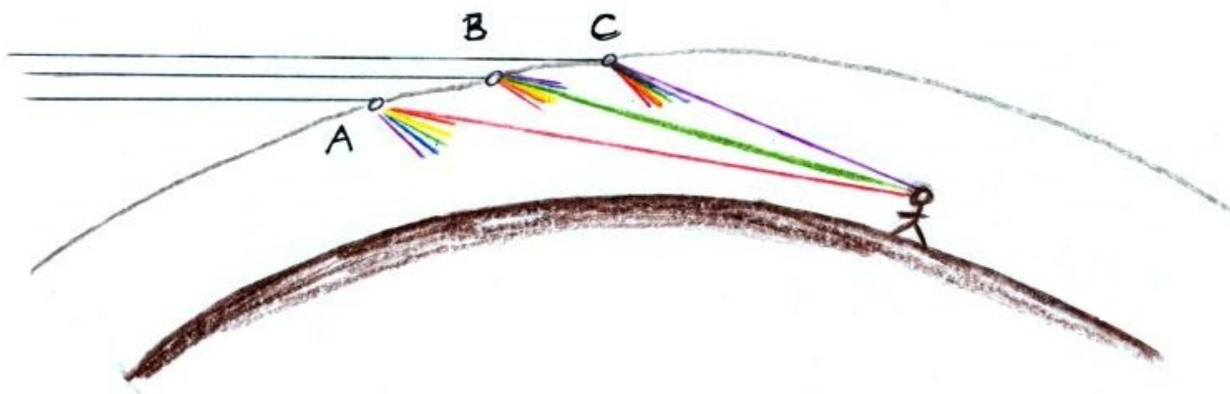
Below, the trees and buildings on a distant shoreline appear taller than they really are. They have effectively been stretched vertically http://www.astronomycafe.net/weird/lights/mirage9.jpg.

Now we will discuss the **green flash**, a flash or spot of green light that is sometimes visible just as the sun is setting. (The Green Flash is also the name of a brewing company located in San Diego.) Here is a photograph http://www.icstars.com/Mad/Astro/GreenFlashW.jpg .

Refraction is also involved with the formation of the green flash. As the sun sets, rays of white light strike the top of the atmosphere and are bent. The amount of bending is greatly exaggerated below.



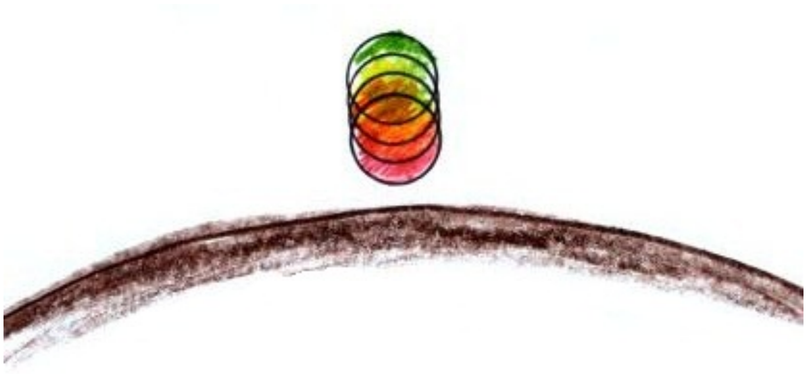
Now we have draw three different rays of sunlight striking the atmosphere at different locations. The person on the ground would see violet light when looking up at Point C, green light from Point B, and red light from Point A.



If the sun were a point of light in the sky, the sunlight could be refracted so that you see six separate spots of light, all of different colors above the horizon (below). A spot of violet light at Point C is a little higher on the horizon then the red light at Point A. As the sun sets, the points of light will disappear one by one below the horizon.

The sun is not a point of light, it is a bright disk. So refraction of sunlight means the sun's disk gets smeared out slightly into a set of overlapping disks of different colors. The colors that mix together in the middle produce white light (not the dark mix shown below).

And there is one more complication. As the different colors travel through the atmosphere, they have a longer path at sunset when the sun is low in the sky. The shorter wavelengths get scattered more than the longer wavelengths so that they do not reach the ground. So rather than a set of six disks with six colors, you can only see four disks as shown below.



If you watch closely at sunset, you may see the edge of the last disk of green light disappear below the horizon.

You will see just the green light. This is the green flash.

A photograph of the green flash is shown below
(http://farm1.static.flickr.com/140/369025833_4eea643719.jpg) .