

Double Rainbow

What causes double rainbows? Why is the order of the colors reversed?

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Double Rainbow, Kleskun Springs Valley, Sexsmith AB

While on vacation recently our family saw a double rainbow. How do these occur? Why did the second faint rainbow (which was on top of the first) have the opposite color sequence?

Ah, rainbows – those will-o'-the-wisps of ethereal beauty, made possible only by a full lineup of optics phenomena. Let's run down the list:

1. Refraction. When a ray of sunlight strikes a raindrop, the ray refracts, or bends, at the point where it passes out of the air and into the water of the drop. The angle of the bend is determined by (a) the intrinsic light-transmitting properties of air and water (every transparent substance has its own individual index of refraction) and (b) the angle at which the ray strikes the surface of the spherical droplet – whether, e.g., it hits the drop squarely or strikes a glancing blow off to one side.

2. Dispersion. Meanwhile, the drop is acting as a prism, splitting the white light of the ray into its component colors by refracting the different wavelengths at different angles: red wavelengths bend a certain amount, orange wavelengths a slightly different amount, and so on.

3. Internal reflection. Most of the light striking the raindrop passes straight through it and out the far side, but some of it reflects off the rear interior surface of the drop and is sent in some new direction. The ratio of light transmitted to light reflected is, once again, a function of the angle at which the ray hits the surface.

4. Refraction and dispersion, part 2. When the reflected light exits the drop and re-enters the air, it's refracted and dispersed a second time.

Light rays emitted by the sun are effectively parallel when they reach the earth, and raindrops are effectively all the same shape. So when sunlight shines into a sky full of raindrops, it's encountering millions of tiny, very similar spherical prisms and interacting with each in pretty much the same way: each produces a basically identical pattern of refracted, dispersed, reflected, and re-refracted light in a spectrum of colors. The reflected red light is at its greatest intensity at an angle of 42 degrees from the direction of the sun's rays, while the violet light has maximum intensity at 40 degrees. When you face a rainy sky with the sun at your back you see a ring of red light, forming the outer edge of the rainbow, at 42 degrees from the direction of the sunlight, a violet ring at 40 degrees forming its inner edge, and all the other colors of the spectrum in between. The rainbow is entirely an optical illusion; it changes its apparent position in the sky as you change your vantage point, meaning that no two people are ever seeing a rainbow the same way (and explaining why that pot of gold is so elusive). Also, because the light forming the rainbow is reflected at angles of 40 to 42 degrees, for the most part rainbows are seen only during the hours around sunrise and sunset: if the sun is higher than 42 degrees in the sky the rainbow reflected by the raindrops will be below the horizon for an observer at ground level. You get better viewing at greater altitude, and it's possible to see complete circular rainbows from an airplane.

Now, about double rainbows: What's happening here is that the ray of sunlight bounces twice off the back interior surface of the raindrop before re-emerging into the air. The second reflection inverts the order of the colors – the secondary violet band forms at 54 degrees, the red band at 50.5 degrees – so the secondary rainbow appears above the primary one, with red on the inner edge and violet on the outer. Because the twice-reflected light has had two chances to be transmitted out the back of the raindrop rather than reflected back toward the observer, the secondary bow is much fainter than the primary and frequently cannot be seen at all; it's typical for a secondary rainbow to be visible only at certain points along the arc.

If the light is strong enough to remain visible after being reflected three times inside the raindrop, an even fainter tertiary rainbow can sometimes be seen (at least in part) above the secondary one, with the red back on the outside and the violet on the inside. And rumor has it that it's occasionally possible to see a quadruple rainbow.

Nitpickers will ask: What about diffraction? Doesn't it play a role here too? All I have to say is (a) yes, diffraction – a quantum phenomenon where light waves cancel each other out or amplify one another – sometimes figures in rainbow formation, if the raindrops are small enough, in which case (b) all bets are off – you might get smaller rainbows inside the main bow, you might get rainbows with the red in the

middle – but (c) no way am I going to work out the math for this. If you're desperate to know this kind of stuff, well, that's why they invented physics grad programs.

References:

Eugene Hecht and Alfred Zajac, Optics, Addison-Wesley Publishing Company, 1974.

Frances W. Sears, Mark W. Zemansky, and Hugh D. Young, College Physics, Fourth Edition, Addison-Wesley Publishing Company, 1974.

— Karen

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