

Rearview Mirror Rainbow: An Optics Investigation

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When driving on a sunny day, one can sometimes observe a small solar spectrum in the rearview mirror of a vehicle. The formation of this “rainbow” results from the prism-like structure of the rearview mirror.^{1,2} Our investigation of this phenomenon reveals that the resulting spectrum is formed in a manner similar to the way a rainbow is formed by a water droplet. We suggest a



Fig. 1. The red arrow in the figure indicates the approximate direction that the solar rays initially strike the rearview mirror. The time of day was around 3:00 p.m. The image was taken from the passenger side of the car.



Fig. 2. A close-up of the observed solar disk (or spectrum) from Fig. 1. Notice the roughly circular nature of the colors in the spectrum.

demonstration that you can perform so that your students can observe this phenomenon. All that is required is a sunny day, a ring stand, a clamp holder, and rearview mirror.

Figure 1 illustrates the solar spectrum observed in the rearview mirror. This spectrum occurs when the Sun’s rays strike the mirror entering from top left or right of the front windshield. Depending on the time of year, it is visible starting in early to late morning. Either the driver or the passenger can observe the spectrum, but this depends on the time of year

and the direction of travel. (To be safe, we recommend you only look for the phenomenon when you are a passenger!)

One of the defining characteristics of this spectrum is that it is roughly circular in shape, as seen in the closeup in Fig. 2. This is not unexpected since a slitless spectroscopy retains the shape of an extended source.³ (One can easily verify this property of slitless spectroscopy by observing a frosted light bulb of roughly circular shape through a diffraction grating.)

In Fig. 3, we illustrate the origin of this solar spectrum. The rearview mirror in most vehicles is a wedge-shaped piece of glass with a silvered back surface. The Sun’s rays enter the top of the front window and strike the rearview mirror. Upon entering the front of the mirror, the primary ray is split into its component colors. Recall that the index of refraction of light in a material is the ratio of the speed of light in a vacuum to the speed of light in the material. Since the speed of light in material depends on wavelength, the index of refraction is wavelength dependent. Blue light is known to have a larger index of refraction than red light. According to Snell’s law, its angle of refraction will be smaller than that of red light:

$$n_{\text{air}} \sin \theta_i = n_{\text{blue}} \sin \theta_{\text{blue}} = n_{\text{red}} \sin \theta_{\text{red}}$$

As shown in Fig. 3, the blue ray bends closer to the normal than the red ray. Subsequently, each ray reflects off the back mirror surface according to the law of reflection. Finally, each ray emerges from the front surface of the mirror and experiences one more refraction. The observer’s eyes will extrapolate the reflected rays backward: the resulting image is one in which a “red” disk occurs above the “blue” disk. Careful

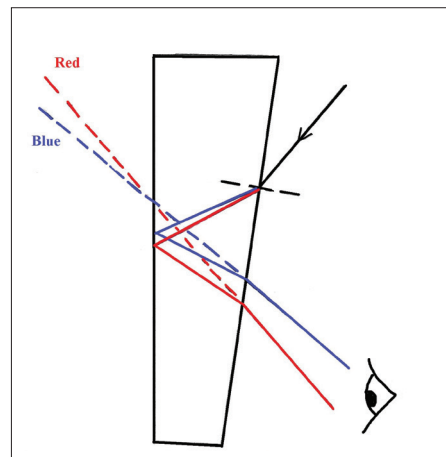


Fig. 3. In this diagram, the rearview mirror is in the daylight viewing position. A ray from the Sun refracts upon entering the front glass surface; due to differences in refractive indices, the component colors are dispersed. The refracted rays reflect off the silvered portion of the rearview mirror. These reflected rays refract once more upon exiting the mirror. These rays diverge but the observer sees a virtual image behind the front surface of the mirror. We only follow a single ray from the Sun in order to avoid clutter in the sketch. In reality, the first reflected image is much too bright for use to discern the rainbow clearly, and we discovered that the solar spectrum in the rearview mirror actually comes from rays that reflect internally, as in rays 2-4 of Fig. 4.

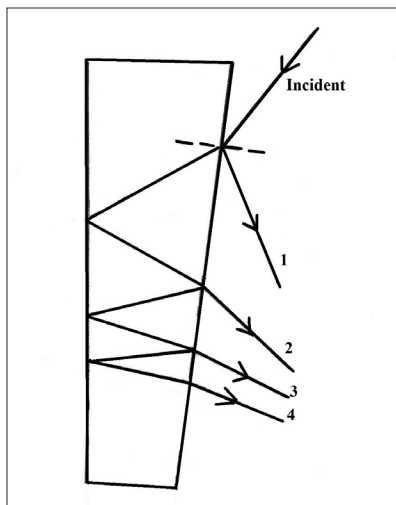


Fig. 4. In reality, multiple reflections occur in the rearview mirror. Ray 1 reflects externally and does not undergo dispersion. Rays 2–4 are all internally reflected rays and all experience dispersion exhibiting a rainbow like structure. There is a fourth reflection off the back surface, but we have not included this in the diagram.

experimentation that the situation with the rearview mirror is actually more complex.

We first attempted to reproduce this phenomenon in the lab with a single-LED flashlight (e.g., a Mini Maglite LED flashlight) and a manual-dimming, rearview mirror purchased for \$15 from an automotive parts store. Figure 5 shows our laboratory setup and results. To observe a spectrum, the room must be dark. As elaborated by Jones and Edge in a previous *TPT* paper, an incident ray undergoes multiple reflections (one external and several internal), as shown in Fig. 4.¹ Each subsequently reflected ray emerges from the front surface with

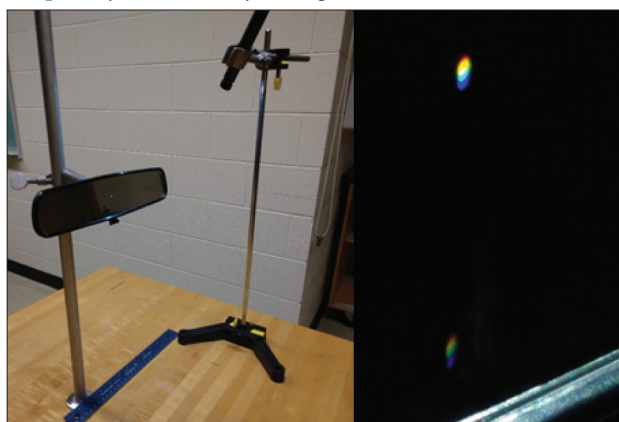


Fig. 5. A laboratory setup (left) using a rearview mirror and a single-LED Mini Maglite flashlight. A standard 12-inch ruler (blue) is on the table for scaling purposes. The third and fourth reflections in the mirror are observed in a completely darkened room (right), after zooming in using a cell phone camera. The spectrum is small and difficult to see without using a camera that can zoom in.

observation reveals the presence of other colors (orange, yellow, a faint hint of green, and some cyan).

The optics of sunlight interacting with a raindrop to form a rainbow is similar to this situation.⁵ A ray of sunlight strikes the front surface of the raindrop and the transmitted ray experiences dispersion, creating multiple colored rays. The beams then travel through the raindrop and reflect off the back surface of the raindrop. These reflected rays again traverse the water drop, exiting at the front of the drop.

However, we found by



Fig. 6. A simple setup for outside observations of the Sun (right) using a ring stand with a one-meter length rod, a clamp holder, and a rearview mirror. An observer (center) locating the solar spectrum in the mirror. The spectrum observed near the bottom of the mirror after the third reflection from the back of the silvered mirror surface (right).



Fig. 7. An image showing the first (top red circle) and second (bottom blue circle) reflections from the back of the mirror.

substantially lower intensity than previous rays.

In the lab, we found that the spectrum from the third internal reflection is the most easily observed. However, the spectrum is quite small and only clearly shows the circular nature of the colors when one takes a photograph and zooms in.

Our next idea was to take the experiment outside (Fig. 6). This requires only a ring stand, a clamp holder, the rearview mirror, and, of course, a sunny day. The Sun must be about 30° or so to perform this demonstration.

Note that you must first orient the mirror so that the Sun and observer are on opposite sides of the mirror and the Sun must be slightly behind the observer. For example, if you are on the left side of the mirror, the Sun needs to be on the right side of the mirror and slightly behind your shoulder. The first reflected image is much too bright to distinguish much color. Maintain a position so that you can see the image but also lower the mirror: as you lower the mirror you will observe that the second image is still too bright. If you drop down to the third reflected image of the Sun, as in Fig. 7, you begin to see something similar to the photograph in Fig. 2. Dropping the mirror

one more time, you can observe the best spectrum yet, Fig. 6 in the rightmost image. This outdoor experiment has two advantages: it produces a spectrum that is large enough to see easily with the unaided eye and demonstrates what we observe when in a vehicle.

This phenomenon relates to a number of concepts discussed in a second-semester college physics course: reflection, refraction, dispersion, prisms, and rainbows. You can make this as simple as showing the students the phenomenon and discussing the basic concepts above. Alternatively, you can have them dig deeper into the optics. Start by having them read the *TPT* papers by Jones and Edge¹ and by Layton.² They can observe the phenomena of dispersion and multiple reflections. They can discuss the conservation of energy with the diminishing intensity with multiple reflections of the same source. Finally, you can ask a couple of challenge questions: is the image real or virtual and would a flat glass mirror produce a spectrum?

We do not readily see this phenomenon at night with the headlights of cars approaching from behind. Why? A rearview mirror with a manual dimming “function” has a small lever at the bottom back that allows one to tilt the mirror into one of two positions. In the daylight position, the back (silvered) surface is oriented parallel to the vertical. This daylight position uses the back surface for reflection. In the nighttime position, the front surface is oriented parallel to the vertical. At night when the mirror is used as intended, the light rays simply reflect off the front glass surface of the device.² When the mirror is left in the daylight position, the incoming rays strike the front surface very close to normal incidence but still travel to the back silvered surface. The resulting dispersion

produces individual color images that would closely overlap, and color addition of the unresolved images would make the observed image appear as a single headlight of normal color. (A close inspection of headlights at night will reveal a faint hint of red on the top and blue on the bottom of the image of an oncoming headlight.) In fact, overlapping colors occur in our daytime image. If you look at the solar image in Fig. 1, it is difficult to discern any green but cyan is present: this is due to overlapping images of green and blue. From the intensity and level of overlap, this appears to be a spectrum observed after the third reflection. Finally, it is important to note that this phenomenon cannot be observed in a rearview mirror with an electronic auto-dimming function as such mirrors are constructed with a flat piece of glass.⁶

References

1. Edwin R. Jones and R. D. Edge, “Optics of the rear-view mirror: A laboratory experiment,” *Phys. Teach.* 24, 221 (April 1986).
2. William Layton, “Rearview mirror dimming function,” *Phys. Teach.* 49, 578 (Dec. 2011).
3. “Spectroscopy of planetary nebulae,” <http://www.astrosurf.com/buil/us/spe6/planet.htm>, accessed Feb. 25, 2019.
4. “Auto-dimming mirrors,” <https://cecas.clemson.edu/cvel/auto/systems/auto-dimming-mirror.html>, accessed Feb. 25, 2019.
5. “Rainbows: An arc of concentric colored bands,” [http://www2010.atmos.uiuc.edu/\(Gh\)/guides/mtr/opt/wtr/rnbw/frm.rxml](http://www2010.atmos.uiuc.edu/(Gh)/guides/mtr/opt/wtr/rnbw/frm.rxml), accessed June 14, 2019.
6. “Auto-dimming mirrors,” <https://cecas.clemson.edu/cvel/auto/systems/auto-dimming-mirror.html>, accessed Feb. 25, 2019.

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