Experiencing Light's Properties Within Your Own Eye

Michael Mauser, Wheat Ridge, CO

Seeing the reflection, refraction, dispersion, absorption, polarization, and scattering or diffraction of light within your own eye makes these properties of light truly personal. There are practical aspects of these within the eye phenomena, such as eye tracking for computer interfaces. They also offer some intriguing diversions, for example, being able to identify polarized light with the naked eye. Finally, some interesting features of the eye are revealed, like the presence of particles within the eye.

Reflection

Referring to Fig. 1, you can see that light must pass through the cornea, the aqueous humor, the lens, and the vitreous humor before it reaches the retina. Because of their differing indices of refraction, some light will be reflected at the interfaces at the front and back of the cornea and the front and back of the lens. The images these surfaces make are called Purkinje images I, II, III and IV, respectively, named after Johannes Purkinje. The dual Purkinje image eye tracker uses the relative positions of Purkinje images I and IV. Its principle of operation can be demonstrated by looking down on a biconvex lens held under an overhead light and observing the motion of the images formed by the front and back surfaces as you tilt the lens (see Fig. 2).

To see these corresponding reflections in your own eye, you need a mirror and a bright, concentrated source of light —I find a Maglite® with the bulb exposed works well. Position the mirror with the light behind and to its side (as shown in Fig. 3) so that light hitting your eye is visible in front of your pupil in the reflection in the mirror. This is Purkinje image I. Move the light around until you notice a smaller and dimmer[1] but still very clear image moving the opposite direction, going down when the brighter image goes up and vice versa. This is Purkinje image IV.

Purkinje image III can be seen while observing images I and IV. It will move the same way as image I, it will be located between images I and IV, and it will be larger and somewhat indistinct due to the nature of the surface of the front of the lens.

Finally, if the light is held to the extreme side while you look in the mirror, you will see Purkinje image II next to image I, giving you some idea of the thickness of the cornea. As you move the light around, you will see that this image is always on the side of image I away from the light, because the radius of curvature of the inside of the cornea is less than that of the outside.[2]

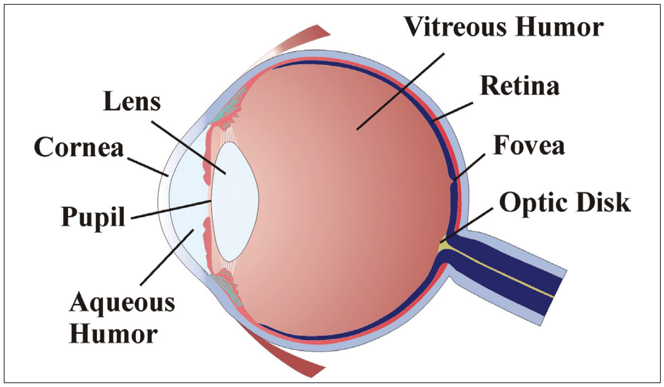

Fig. 1. Schematic of the eye.

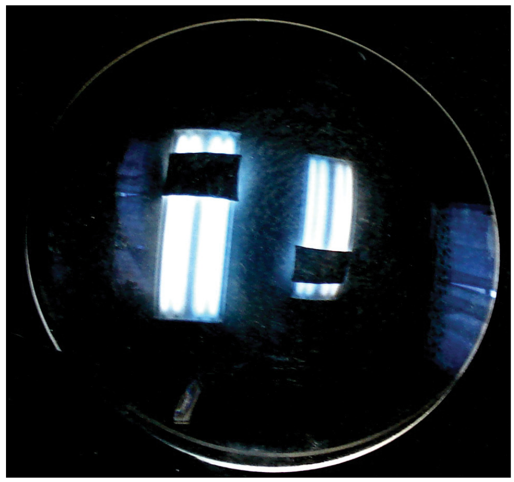

Fig. 2. Images of an overhead light fixture reflected from the front and back surfaces of a biconvex lens. Aluminum foil placed on the fixture near one end makes image reversal apparent.

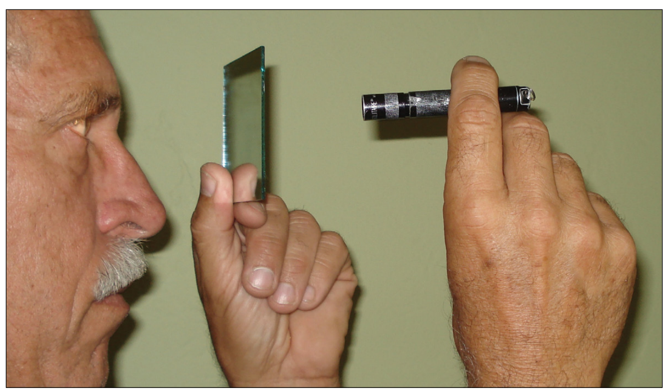

Fig. 3. Using a flashlight and mirror to see Purkinje images I and IV in the reflection of your pupil.

Refraction

Refraction is often imprecisely referred to as the "bending" of light as it passes between two materials with different optical properties. Light is refracted as it passes from the air to the cornea, from the cornea to the aqueous humor, from the aqueous humor to the lens, and from the lens to the vitreous humor. Most of the refraction occurs as light passes from the air to the cornea and the lens changes shape to do the final focusing of an image.

You can easily change the cornea's effective shape by adding fluid on the surface. Put a few drops of saline solution in your eye (or cry). If you now bend over so the excess fluid collects in front of your eye, you can notice how your focus changes by looking down at a page with writing on it. With a little practice, you can see the individual colored pixels of an LCD screen on a cell phone held closer to your eye than you could otherwise focus.

You can also flatten or wrinkle the cornea. You may have noticed that after pressure is applied to the closed eyelids (such as by lying face down on a pillow), your vision is a little blurred, or that after squinting for a while, horizontal lines appear to be doubled. With a little practice you can learn to deliberately elicit these effects.[3]

Dispersion

Dispersion refers to the separation of white light into colors, such as occurs in a prism, and it is due to materials having different refractive indices for different wavelengths. The dispersion of light in a convex lens can be observed by looking through it at black print on white paper. Adjust the position for extreme magnification and you will see the sharp edges degrade into colored fringes. Chromatic aberration also occurs in our eyes. Edge and Jones[4,5] describe some ways of seeing it, but I prefer the following method.

Use a drawing program to make a color version of Fig. 4 on a flat screen computer monitor using a saturated red, blue, and black.[6] Use a pin to make a hole about 1 mm diameter in an opaque card. Hold the hole close to your eye (10 to 20 mm) and look at the figure through the hole as you slowly adjust the card from side to side or up and down slightly without moving your eye. The hole restricts light to only portions of the lens in your eye. You should see the horizontal black line in the red move up a *very small amount* as you move the hole down and the vertical black line in the red move to the right as you move the hole to the left.[7] If you wear glasses you can demonstrate the chromatic aberration in the lenses by moving your head from side to side and up and down while looking at the lines.

Chromatic aberration in your eyes can make it harder to see details under light that has both short and long wavelengths. If you are target shooting, you might use blue blocker glasses so you don't see the short wavelength blue light. If you are looking at fine details, you might use a monochromatic light so you only see with light that has a limited range of wavelengths.

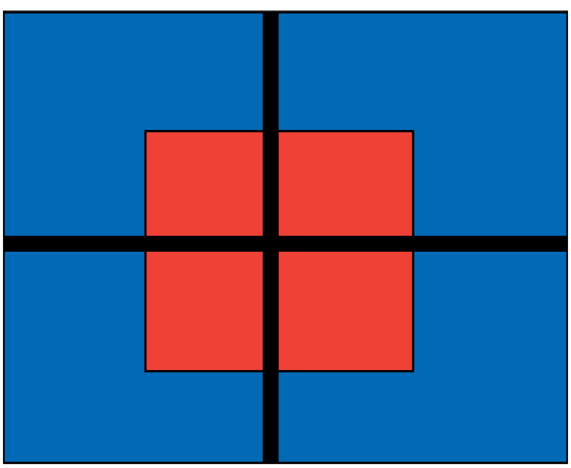

Fig. 4. Pattern for two-color Vernier demonstration for chromatic aberration.

Absorption

Blue light is partially absorbed by a yellow pigmented area in the tissue centered on the fovea, where our center of vision is on the retina. We are normally unaware of this because our vision compensates for the difference. The presence and shape of this area can be seen by looking at alternating blue and green fields of light at about one cycle per second with one eye while the other eye is closed. While you can move your eye between two fields of light, I find it is easier to keep the eye steady and cycle the color. The yellow pigment blocks blue light while passing green and red light, so you will momentarily see a darker shape in the blue field and a lighter spot in the green field. The spot is usually ring shaped, fuzzy, about the size of your thumb held at arm's length (or 2°), and it moves with your eye's movements.

To demonstrate this to visitors at the Arizona Science Center, I prepared flashlights by covering half the lens with a blue filter (LEE Filters #119) and the other half with two layers of a green filter (LEE Filters #139) and sandwiching these with a white diffusion film (a single layer of typing paper will also work). I have visitors hold the flashlight close to one eye and move the flashlight so that the blue and green fields are alternated while they stare straight ahead. Most report being able to see the spot, which is called Maxwell's spot after James Maxwell, who first accurately investigated the phenomenon. The shape can vary between the two eyes and with changes in diet. The absorption of blue light by the yellow pigment helps reduce the effect of chromatic aberration near the center of our vision and may protect the retina from ultraviolet light.[8,9]

Polarization

If you are wearing polarizing glasses you can notice that the light from a clear sky or from most LCD screens is polarized if you tilt your head. But you can also see when blue light is polarized with the unaided eye. Close one eye and with the other eye look at a white flat screen display that emits polarized light (as many cell phone screens do) while tilting your head from shoulder to shoulder or rotating the display back and forth. You should see a faint yellowish hourglass- or bowtie-shaped spot in the center of your vision, and you might also see a pair of blue spots on either side of the yellow spot. The spot is about the size of your thumbnail at arm's length, but it is faint and you have to keep moving your head or the display or it will disappear. You can hold a cell phone screen within 10 mm of your eye because you don't need to focus. This allows you to use just a small patch of white screen.

The spot is called Haidinger's brush after Wilhelm von Haidinger. It is due to the preferential absorption of blue polarized light by pigment molecules that are arranged in a circular pattern in the fovea.[10-11] Your vision quickly adjusts to this uneven absorption of light, causing the spot to quickly disappear unless either your eye or the orientation of the polarized light is rotating. You can also observe Haidinger's brush by rotating a piece of polarizing film in front of a bright background. I fitted a flashlight with a blue LED and some light-diffusing film topped by a polarizing film and mounted it in a holder with a handle so that it could be turned back and forth on its axis.

Scattering and diffraction

Scattering and diffraction occur when waves encounter obstacles, openings, and edges. Visible interference patterns result when light encounters obstacles of a size comparable to the wavelength of light. If you look at a bright point source of light in a dark room (such as the exposed bulb of a Maglite®) or a distant, bright, full spectrum light outside on a dark night, you will see shimmering colored rays of light surrounding the light. The rays are called the *ciliary corona* and result from particles in your eyes scattering light that then interferes, resulting in a separation of colors on your retina.[12] If the light is monochromatic you will see a haze of short lines instead of colored rays.

Another way to see light interference originating inside your eye is to look at the shadows of the floating blood cells in front of your retina. Use a needle to make a small hole (about 0.3 mm) in some aluminum foil and cover the hole with some "invisible mend"- type cellophane tape to diffuse light. Face a bright light and hold the hole close to your eye (about 20 mm) so that you see a disk of light. Within the disk you will see the shadows of things on and in your eye.[13,14] Most readily noticeable will be particles that are set in motion with your eye movements and which have diffraction patterns. The smallest of these will be single blood cells floating close to the surface of the retina. There is a bright spot in the center of these shadows due to light diffracting around the cell and constructively interfering.[15]

Concluding remarks

Some of these activities can be hard to do for the first time with only written instructions, so be sure to master them so you can more effectively help students. The difficulties people have are mostly due to not understanding what they are supposed to be seeing and only rarely due to vision problems.

References

1. The Fresnel equations quantify the reflection as a function of the refractive indices.
2. M. Tscherning, *Physiologic Optics*, 3rd ed. (Keystone Publishing Co., Philadelphia, 1920), pp. 50–56. (Available at: www.books.google.com.)
3. G. J. Bull, "Lid pressure on the cornea," in *Transactions of the Eighth International Ophthalmological Congress, Second Sitting* (University Press, Edinburgh, 1894), pp. 107–124. (Available at: www.books.google.com.)
4. Ronald Edge and E. R. Jones, "Why do red and blue lines move in opposite directions?" *Phys. Teach.* **22**, 462–464 (Oct. 1984).
5. R. D. Edge, "The optics of the eye lens," *Phys. Teach.* **27**, 392–393 (May 1989).
6. You may notice a slight displacement in the vertical black line due to the vertical alignment of the subpixels on a color LCD screen. I find I am able to use the chromatic aberration in my eye to just about cancel this out.
7. David A. Atchison and George Smith, *Optics of the Human Eye* (Elsevier Health Sciences, Philadelphia, 2000), p. 182.
8. Tos T. J. M. Berendschot and Dirk van Norren, "Macular pigment shows ringlike structures," *Invest. Ophth. Vis. Sci.* **47**, 709–714 (2006). (Available at: www.iovs.org.)
9. There are few to no receptors for blue light in the very centermost part of our vision and this also helps counter the effects of chromatic aberration.
10. Giles Skey Brindley, *Physiology of the Retina and Visual Pathway*, 2nd ed. (Edward Arnold Ltd., London, 1970), pp. 140–141.
11. Bill Reid, "Haidinger's brush," *Phys. Teach.* **28**, 598 (Dec. 1990).
12. Thomas J. T. P. van den Berg, Michiel P. J. Hagenouw, and Joris E. Coppens, "The ciliary corona: Physical model and simulation of the fine needles radiating from point light sources," *Invest. Ophth. Vis. Sci.* **46**, 2627–2632 (2005). (Available at: www.iovs.org.)
13. You can also see the shadow of the wrinkle in the cornea that results from squinting.
14. Jearl Walker, "'Floaters': Visual artifacts that result from blood cells in front of the retina," *Sci. Am.* **246** (4), 150–162 (April 1982).
15. Harvey E. White and Paul Levatin, "'Floaters' in the eye," *Sci. Am.* **206** (6), 119–127 bibliography 200 & 202 (June 1962).

Michael Mauser, *PhD retired engineer/teacher, Denver Museum of Nature and Science volunteer.*
10745 W 35th Ave., Wheat Ridge, CO 80033
michaelwmauser@gmail.com