Where the Sun's Rays Meet

Did you ever hear the one about the optical engineer whose sons decided to go into ranching? They had a new cattle ranch, and needed advice on what to name the ranch. Their father suggested they name it Focus, because that's where the sons raise meat. Which brings us to the subject of this article . . . lenses. This is a short series of experiments you can do at home with youngsters to help them understand why lenses and mirrors are used to bend light.

I asked my daughter Jamie what lenses do, and she said they help you see better. She wasn't sure what else they do or are used for. She said that mirrors, however, are used to annoy friends by flashing lights in their eyes [translation: "I'm not sure what you're asking"]. When I asked what "focus" meant, she said she really didn't know, except that you could focus cameras.

To understand how lenses and mirrors are used, it's helpful to first have some understanding of how they behave. We started with the concept of focus. Jamie and I took a magnifying lens into the backyard, and tried the classic experiment of burning holes in black paper. It took a little while for her to understand that you have to hold the lens facing the sun, and a certain distance from the paper, but she really liked this experiment. To show her how this happens, we held a piece of cardboard along the axis of the lens, *i.e.*, parallel to the light and bisecting the lens, so she could see the light coming together and spreading out again, as in Figure 1. I told her that the lens bent the light, so that the sun's rays all met at one point, called the focus. She also noted the spectral aberrations and asked me about that.

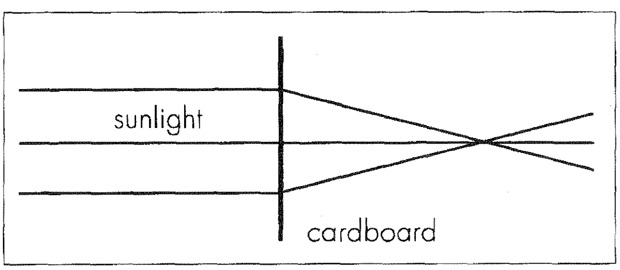

Figure 1. Focusing the sunlight—conceptual diagram for the child.

I next asked her if she thought the region surrounding the focus would be brighter, darker, or the same as the rest of the paper, if you held the paper perpendicular to the light (in the hole-burning position). She thought it would be the same. But when you focus the light on the paper, the region surrounding the focus is fairly dark, because the light has been collected at the center. Looking at Figure 1, Jamie was able to predict that when you move the lens higher or lower, the bright point of light at the center spreads into a bright disk surrounded by a darker region.

Pointing out that the lens was collecting the light from its whole area, and pointing it toward the focus, I explained that how much light is collected should depend on the size of the lens. We had a race between a small magnifying lens and a large magnifying lens to verify that the larger one caused the first sign of smoke. There happened to be a glass of slightly milky water left out (from an earlier experiment I had tried that didn't work very well), and Jamie placed the lens over the water. Since the sun was nearly overhead, she was able to see the beams travel in the water, and pointed out to me that you can see the slanted beams, and the focus, in the water also.

Now, to create an image of a scene, we went into a slightly darkened room. Standing with our backs to an open window, we used the magnifying lens to focus an image of the backyard on a white sheet of paper. I drew a figure something like Figure 2 to show Jamie that the light coming from each region of the scene is focused on a different place on the paper, creating an image.

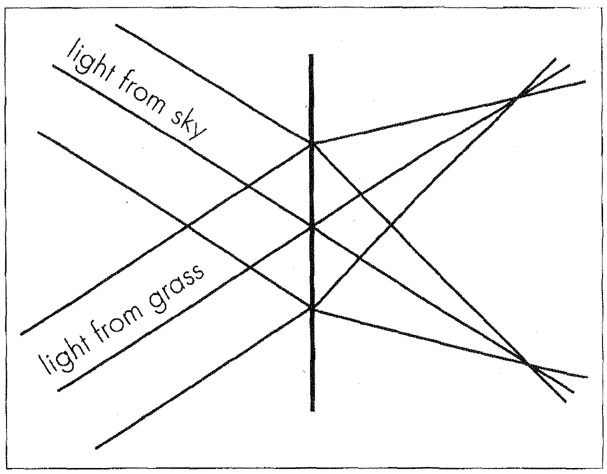

Figure 2. Creating an image of the backyard.

Our next experiment was to see what happens with objects closer to the lens. Using the convex lenses from the OSA Optics Kit, we tried an experiment based in part on the kit, and further inspired by the February 1993 "Light Touch" article by Betsey Davis, "Math Isn't Just Numbers Anymore." With a candle as a source, we used a clothespin to hold up the lens, and imaged on an index card held up by another clothespin. We measured the image distance as a function of object distance. Jamie has only had linear equations (8th grade math), so I didn't go into the lens equation, but she understood that the distance to the image increases as the object distance decreases from large distances to close

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to the focal length. The curve asymptotically approaches the lines represented by $y = f$, and $x = f$, where f is the focal length.

When Jamie started the plot, she expected a linear relationship, and was surprised when the plot started to curve. She measured extra points to characterize the asymptotic behavior, and was puzzled by the curve. I explained that on one axis, we're saying that as the object gets farther away, the image approaches the focus; on the other, we're saying that as the object gets close to the focal distance, the image gets far away. She understood this and thought it was great.

As we did the above experiment with the candle, we noted that not only the placement of the image changed, but so did the size of the image. Thus, lenses can be used for magnification. We also tried simply removing the lens. When we did, there was no image on the index card. This showed that one function of a lens is to create an image. I told Jamie this is one way to create an image on the film of a camera.

Our final experiment with this lens setup was a demonstration of the effect of a pair of glasses. We discussed what would happen if the lens in someone's eye was defective, so the image did not fall where the retina is. We moved the index card slightly to create an out-of-focus image, simulating this situation. In this case, you would want some way to move the image to where your retina is. Moving the card back so the image was in focus, we put in a pair of weak glasses in front of the lens, and moved the card until the image was once more in focus. This showed that the glasses had indeed slightly moved the position of the image, and could be used to correct this type of vision problem.

Lenses and mirrors can be used for a variety of reasons. We talked about some of these and discussed some specific examples. Glass and mirrors can be used to change the direction of the light, as in car mirrors. They can change the location or size of an image, as in magnifying lenses and car mirrors that say "objects are closer than they appear." Lenses and mirrors can be used to form an image where one is needed to collect energy and to redistribute light.

As an example of how lenses or mirrors can be used to redistribute the light, I used a flashlight reflector. We had noted earlier that, just as collimated light meets at the focus, a candle placed at the focus of a lens will create nearly collimated light. In a flashlight, we want light from a small point, the lightbulb, to go out in a nearly straight line. Jamie asked if this was done with a lens. I told her it was done with the reflector.

To show how this happens, we took off a reflector from a large flashlight and placed a small piece of paper through the hole where the bulb is normally mounted, extending it out into the area where the bulb filament normally goes. Aiming the reflector at the sun, we immediately saw the paper start to smoke. Jamie realized that the reflector also had a focal point. When we point the reflector at the sun to set the paper on fire, we bring collimated light to a focus; when we use a small bulb in a flashlight, we place a source on the focal point to create nearly collimated light.

These experiments took about half an hour. My kids liked the experiments pretty well, but they both thought the Focus pun was terrible.

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Once these approximate functions are programmed into the user's spreadsheet or program database, the uses are evident. One possibility includes integrating to estimate the effect of various weightings of longitudinal chromatic aberration on the MTF, for example. Specification of allowable focal shift or tolerances upon system collimation can also be obtained outside the simple "quarter-wave" region.

The purpose in presenting this information is to indicate how a look at the literature can frequently yield some "oldies but goodies" that can be used very profitably to supplement present day analysis methods. Surprisingly, I have not come across current references to this paper or to this simple approximation in the literature, and it does not seem to be widely known.

How-To

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layers of management and the elimination of barriers between divisions (engineering–manufacturing) when teams were used in place of management hierarchies. I have seen production cycles (on laser communication equipment and satellites, not tire pumps) reduced from 18 months to 8. I have seen technical problems that confounded management for years resolved in a matter of weeks, once the people closest to the problem were involved in the fix. Most importantly, I have seen workers invest themselves in business objectives and commit to organizational success.

By the way, your employees ought to know this stuff regardless of whether you are pushing teams. Employees notice if you are making a continuous investment in them. If you are letting them become obsolete, it's just like letting your plant and equipment run down—you won't be able to compete long term.

The return can more than pay for the investment if management and team members are committed. Remember the key words: investment and commitment. Good Luck.