Optical Bench

Overview: Mirrors and filters and lenses, oh my! In this lesson, we'll learn a lot more about each of these items and how you can use them together to make an optical bench. An optical table gives you a solid surface to work on and nails down your parts so they don't move. Scientists use optical benches when they design microscopes, telescopes, and other optical equipment. We're going to make a quick and easy optical lab bench to work with your lenses. Well, technically our setup is called an optical rail, and the neat thing about it is that it comes with a handy measuring device so you can see where the focal points are for your lenses.

What to Learn: Lenses work to bend light in a certain direction, called refraction. Concave lenses work to make objects smaller and convex lenses make them larger. Light interacts with matter by transmission (including refraction), absorption, or scattering (including reflection).

Materials

- lenses (glass or plastic - magnifying lenses work also)
- two razor blades (new)
- index cards (about four)
- razor
- old piece of wood
- single hair from your head
- tape
- small binder clips
- aluminum foil
- clothespins (2-4)
- laser pointer
- popsicle sticks (tongue-depressor size)
- hot glue gun
- scissors and a sharp razor
- meter sticks (2)
- large candle (with adult supervision)
- bright light source (ideas for this are on the video)

Experiment

1. Use masking tape to fasten together the two meter sticks so that they're on top of each other. Be sure that you'll still be able to insert popsicle sticks between the two meter sticks in order to mount your lenses and filters.
2. Run a bead of glue along the tape you just added and attach a popsicle stick on each end of the now-attached meter sticks. These popsicle sticks will be your base, so be sure the numbers are at the top edge and easy to read.

3. To make the screen, grab a popsicle stick and a white index card. Place some glue along half of one long edge of the stick and attach it to the middle of the card. You can insert this new screen into the rail (between the two meter sticks) at one end.
4. Using a sharp knife, carefully cut out a small rectangle out of an index card. Remove the rectangle from the card.
5. Carefully place the two new razor blades side by side on the index card, facing each other atop the hole you just cut. They should be parallel and as close as you can get them without the razors actually touching. Secure them in place with tape.
6. Use a small bead of hot glue to attach another popsicle stick to the back of this index card which you've just taped the razors to. Insert the end of the stick into the optical bench. Tape around the meter sticks if it doesn't stand up straight.
7. To make an anti-slit, cut another rectangle in an index card with your razor blade.
8. Take a tiny piece of hair and tape it below the rectangular hole you just made. Stretch it across the middle of the hole and tape down the hair on the other side.
9. Flip over the card and glue a popsicle stick on the other side. Stand this up between the meter sticks in your optical rail (it doesn't really matter what order you put them in yet).
10. Place some hot glue on the side of another popsicle stick and attach this to a clothespin. Be sure the pin can still open and close. Press the stick down on the pin firmly until the glue dries.
11. To help with friction inside the clothespin, place a bead of hot glue inside on each jaw of the clothespin and hold it open until it dries. You can prop a popsicle stick inside and set aside while drying. This makes a higher friction surface to hold the lenses in place more securely. Alternately, you can wrap a rubber band around each jaw of the clothespin.
12. Insert a lens into the dry (or rubber banded) clothespin and insert the popsicle stick into the optical bench.
13. When making more clothespins for additional lenses, you can help prop them upright on the optical bench with small binder clips.
14. Now you've made your bench. Make sure all your items are about at the same height so that the light will hit everything evenly.
15. Turn out the lights and use a candle (with adult supervision) as your light source. Put it at one end of the optical bench. At the other end will be your screen. These items should be as close to the ends of the bench as possible so that your measurements are accurate.
16. Use the magnifying glass (a convex lens) in the middle, moving it back and forth until the image is focused on the screen.
17. Note how far away the magnifying glass is from the focused image. This is your focal point. Record the focal length on your data sheet.
18. Next, use two magnifying glasses. Move one at a time between the candle (or other light source) and your screen. Note where each focuses and record this data. Chances are they will not have the same focal point.
19. Then, put them close together and see where the focal point is when the magnifying glasses are held together like this. Note if your image size changes when both magnifying glasses are used. Also note if the image is more blurry or crisper.
20. Put your lenses in the optical bench and find the focal length for each individual one. Record this data on your table. You may want to record this on the edge of your lenses, or you can number them and put the number on the edge so that you can readily identity each lens.
21. *f* number is a ratio of focal length over diameter. Measure each individual lens diameter. Take the focal length data you recorded in the previous step and find the *f* number by dividing focal length by the diameter.
22. Next, mount your laser on the optical beam. Mount a slit opposite the beam.

23. Shine the beam through the slit toward a wall that's 6-10 feet away. You should see an interference pattern on the wall.
24. Complete the table:

Optical Bench Data Table

Lens Type	**Diameter** (inches or cm)	**Focal Length** *(inches or cm)*	***f* number** f = focal length ÷ diameter

Reading

Concave lenses are shaped like a "cave" and curve inward like a spoon. Light that shines through a concave lens bends to a point (converging beam). Ever notice how when you peep through the hole in a door (especially in a hotel), you can see the entire person standing on the doorstep? There's a concave lens in there making the person appear smaller.

You'll also find these types of lenses in "shoplifting mirrors." Store owners post these mirrors around help them see a larger area than a flat mirror shows, although the images tend to be a lot smaller.

If you have a pair of near-sighted glasses, chances are that the lenses are concave. Near-sighted folks need help seeing things that are far away, and the concave lenses increase the focal point to the right spot on their retina.

Concave lenses work to make things look smaller, so they're not as widely used as convex lenses. You'll find concave lenses inside camera lenses and binoculars to help clear weird optical problems that happen around the edges of a convex lens (called aberration).

Convex lenses bulge outward, bending the light out in a spray (diverging beam). A hand-held magnifying glass is a single concave lens with a handle. These lenses have been used as 'burning glasses' for hundreds of years – by placing a small piece of paper at its focal point and using the sun as a light source, you can focus the light energy so intensely that you reach the flash point of the paper (the paper auto-ignites around 450°F).

When you stack a large convex lens above a solar panel, the magnification effect makes it so you can get away with using a smaller photovoltaic cell to get the same amount of energy from the sun. You'll find convex lenses in telescopes, microscopes, binoculars, eyeglasses, and more.

Mirrors: What if you coat one side of the lens with a reflecting silver coating? You get a mirror!

In the video, you'll see me stick wooden skewers into a piece of foam to simulate how the light rays reflect off the surface of the mirror. Note that when the mirror (foam) is straight, the light rays are straight (which is what you see when you look in the bathroom mirror). The light bounces off the straight mirror and zips right back at you, remaining parallel. Now arch the foam. Notice how the light rays (skewers) come to a point (focal point). After the focal point, the rays invert, so the top skewer is now at the bottom and the bottom is now at the top. This is your flipped (inverted) image. This is what you'd see when you look into a concave mirror, like the inside of a metal spoon. You can see your face, but it's upside-down.

Slits A slit allows light from only one source to enter. If you have light from other sources, your light beam is more scattered and your images and lines become blurry. Thin slits can be easily made by placing the edges of two razor blades very close together and securing into place. We're going to **use an anti-slit using a piece of hair, but you can** substitute a thin needle.

Filters: There are hundreds to thousands of different types of filters that are used in photography, astronomy, and sunglasses. A filter can change the amount and type of light allowed through it. For example, if you put on red-tinted glasses, suddenly everything takes on a reddish hue. The red filter blocks the rest of the incoming wavelengths (colors) and only allows the red colors to get to your eyeball.

There are color filters for every wavelength, even IR (infra-red) and UV (ultra-violet). UV filters reduce the haziness in our atmosphere, and are used on most high-end camera lenses, while IR filters are heat-absorbing filters used with hot light sources (like near incandescent bulbs or in overhead projectors).

A neutral density (ND) filter is a grayish-colored filter that reduces the intensity of all colors equally. Photographers use these filters to get motion blur effects with slow shutter speeds, like a softened waterfall.

Exercises

1. Using only the shape, how can you tell the difference between a convex and a concave lens?
2. Which type of lens makes objects viewed through it appear smaller?
3. Which type of lens makes the objects viewed through it appear larger?
4. How do you get the *f* number?

Answers to Exercises: Optical Bench

1. How can you tell the difference between a convex and a concave lens? (Concave lenses are shaped like a “cave” and curve inward. Convex lenses curve outward.)
2. Which type of lens makes objects viewed through it appear smaller? (concave)
3. Which type of lens makes the objects viewed through it appear larger? (convex)
4. How do you get the f number? (It’s the ratio of focal length over diameter.)