What's in the kit

- Four (4) ***Lens Holders***
- Two (2) f_1 ***Lenses***: 50mm diameter, double convex lenses, focal length 150mm
- Two (2) f_2 ***Lenses***: 50mm diameter, double convex lenses, focal length 50mm

LASER CLASSROOM

Exploring Invisibility

Everything, and I mean EVERYTHING you see is light, and nothing else. You can see light that either

1. comes from a source (like a light bulb or a flame or the sun) OR
2. bounces off the objects around you.

Either way, all you ever see is light. Light enters your eye, your brain makes sense of it, and that, in the most simple terms is visibility.

Invisibility happens when an object that "should" bounce light into your eye does not. The object is present, but no light bounces from it into your eye, so it appears to "not be there". Now, you can simply cover an object and no light from it will get into your eye, but that is not really invisibility in the way that we like to think about it. What we'd really like, is to be able to see around and behind the invisible object, as though it were not there at all. That's a little more tricky.

One way to achieve invisibility is by bending light. Bending light is called refraction, and its actually something we see all the time. Check out that duck up there. Is it really split in half? No. It is not split in half. But it sure looks like it's split in half. What's going on?

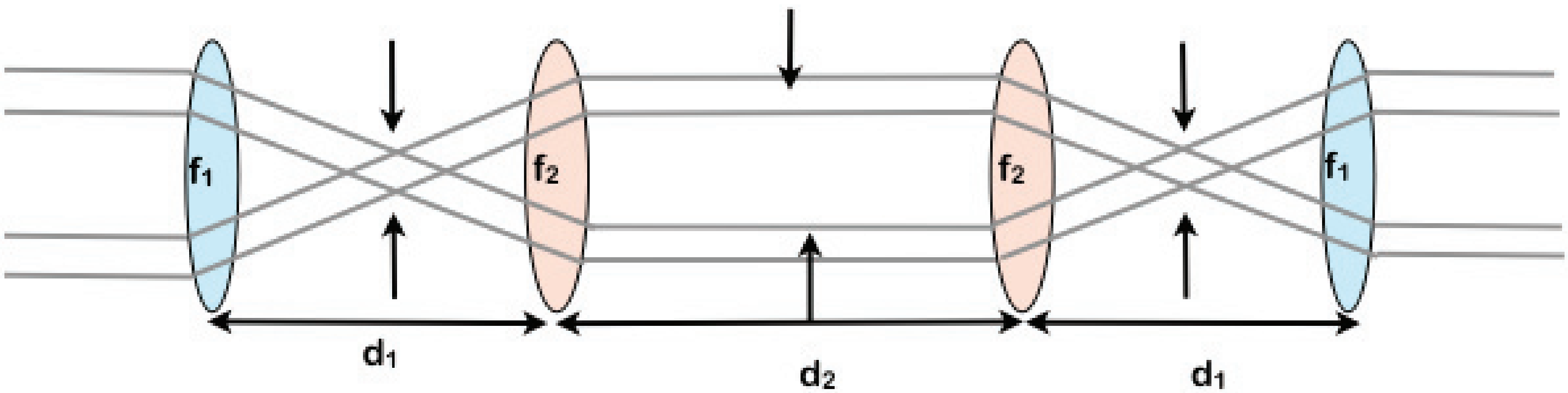
REFRACTION

When light travels from one medium (air) into another (water, glass, plastic, etc.) it changes speed. This change in speed causes the light to "bend". When light bends, it appears to come from somewhere other than where the object actually is. That's what's happening with the duck. Instead of bouncing off the duck directly into our eyes in a straight line the way light usually does, the light travels from outside the water, into the water where it bounces off the duck, through the water and then back out of the water and THEN into our eyes. All that traveling in and out of the water causes the light to bend in such a way that what we end up seeing is a duck whose bottom half has shifted and looks as though it's been cut in half!

THE ROCHESTER CLOAK

It turns out that by using a set of 4 lenses, scientists at the University of Rochester have figured out a pretty cool way to make light bend around objects so that all you can see is what's behind them! Let's go ahead and replicate it with your kit to make some things invisible.

Cloaked Regions



By setting up the four lenses as shown above, you can create cloaked regions. Each "set" is composed of two lenses (**f_1 and f_2**) at a distance from one another (**d_1**). Then each "set" is set at a distance from the other (**d_2**).

The distances between the lenses and the sets of lenses is a function of the focal lengths of the lenses you start with and is defined by some simple math:

1. Start with 2 sets of lenses with different focal lengths. For this kit, we chose focal lengths of 50mm and 150mm so that the entire set up would fit neatly on a single meter stick. But really - any two positive focal lengths will do.
2. Separate **f_1** from **f_2** by the sum of their focal lengths to arrive at **d_1**, the distance between the two lenses in each set . In our case

$$d_1 = 150mm + 50mm = 200mm$$

3. Separate the two sets according to the formula so that the two **f_2** lenses are d_2 apart.

$$d_2 = 2 f_2 (f_1 + f_2) / (f_1 — f_2)$$

$$d_2 = 2x50mm(150mm+50mm)/150mm-50mm$$

$$d_2 = 100mm(200mm)/100mm = 200mm$$

LASER CLASSROOM

Invisibility in the Classroom

WHAT'S IN THE KIT

- Four (4) ***Lens Holders***
- Two (2) f_1 ***Lenses***: 50mm diameter, double convex lenses, focal length 150mm
- Two (2) f_2 ***Lenses***: 50mm diameter, double convex

Straight forward set up

step by step instructions for creating a cloak with the included lenses

1. On a flat table or lab bench, stick the meter stick to the surface
2. Place one lens in each lens holder and mark or otherwise keep track of whether each lens is $\mathbf{f_1}$(focal length 150mm) or $\mathbf{f_2}$ (focal length 50mm)
3. Place the first $\mathbf{f_1}$ (150mm) lens at the 0 end of the meter stick.
4. Place the first $\mathbf{f_2}$ (50mm) lens at 200mm
5. Place the second $\mathbf{f_1}$ lens at 400mm
6. Place the second $\mathbf{f_2}$ lens at 600mm
7. Place a patterned back ground beyond 600mm
8. While looking straight down the axis of the four lenses, place an object (like a pencil) perpendicular to the line of sight and move it up and down and back and forth to discover areas of invisibility (places where the light is directed, or refracted, around the object so that you can see the back ground)

LASER CLASSROOM

Lab Challenge - Build your own cloak

1.Start with four lenses,: 2 lenses of known focal length f_1 and 2 more lenses of unknown focal length f_2

2.Group the lenses into 2 sets; each set having one lens of f_1 and one lens f_2

3.Calculate d_1 and d_2 using the following math

d_1 (the distance between lenses in a set) = $f_1 + f_2$

AND

d_2 (the distance between the sets of lenses) = $2 f_2 (f_1 + f_2) / (f_1 — f_2)$

4. Place one set of lenses (f_1 and f_2) along the meter stick a distance d_1 from one another

5. Place the second set of lenses at a distance d_2 from the first set of lenses. Place the lenses in the second set the same distance (d_1) from each other

6. While looking straight down the axis of the four lenses, place an object (like a pencil) perpendicular to the line of sight and move it up and down and back and forth to discover areas of invisibility (places where the light is directed, or refracted, around the object so that you can see the back ground).

Adapted from

Joseph S. Choi and John C. Howell, "Multidirectional Invisibility with Rays of Light- A “Rochester Cloak”", AAPT (American Association of Physics Teachers) Advanced Labs, Beyond the First Year II (BFY 2) Conference, College Park, MD (July, 2015).

Full presentation and additional downloadable classroom resources for the Rochester Cloak are available at

http://www.compadre.org/advlabs/bfyii/Detail.cfm?id=6081

AND

http://www.josephschoi.com/research.html#BFY2presentation

LASER CLASSROOM

LASER Classroom™ is the home of LASER Blox™ and of all the tools and resources you need to teach and learn about Light, Lasers and Optics.

LASER Classroom' mission is to create resources and partnerships that make teaching and learning about light, lasers and optics accessible, engaging and fun so that teachers and students are empowered and prepared to enter the 21st century workforce

LASER Classroom™ is a registered DBA of OnPoint Lasers, Ltd.

D&B: 825248925
EIN: 26-1640172
MN ID: 9187588
CCR#: 1B2H1
NAICS

- 334510 (Laser systems)
- 339930 (Science Kits)
- 453110 (School Supply Stores)

LASER Classroom
Corporate Office
1419 Main St. NE
Minneapolis, MN 55413

800-840-7829
orden@laserclassroom.com

LASER Classroom
Warehouse
507 Wilkie Drive
Winona, MN 55987

LASER CLASSROOM™