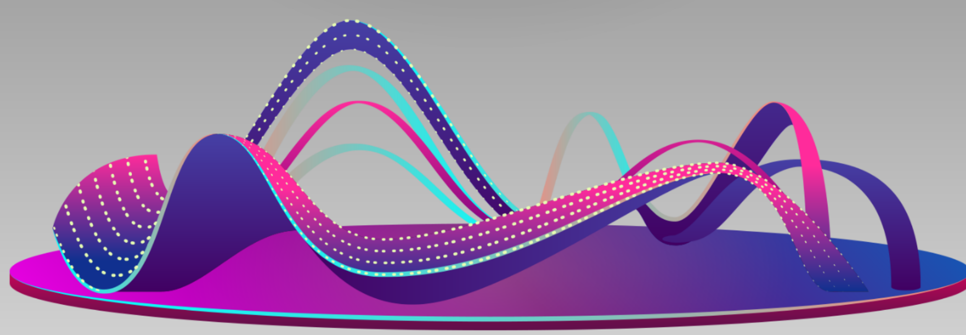
Explorations In OPTICS

OPTICS MAGIC INSIDE!



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EDITORS

ACKNOWLEDGEMENTS

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We also thank SPIE, the International Society for Optics and Photonics, notably former Manager of Education Services Kathleen Robinson (who gave Dumpster Optics its name) for supporting our workshops at the SPIE Optics and Photonics conference and to both SPIE and Optica (formerly OSA) for supporting our workshops at ETOP (Education and Training in Optics and Photonics). Thanks also to the Optica Foundation for a grant that allowed us to hone these experiments and demonstrations by practicing workshops for over a decade with hundreds of young students each year. Optica also provided funding to record the Optics Exploration videos with students of Eastern Connecticut State University's Theater and Communication Programs. Finally, we are grateful to Dr. Perla Marlene Viera González of Universidad Autónoma de Nuevo León, Mexico for translating much of this work into Spanish.

Some drawings in this book are from *Introduction to Optics and Photonics, 2nd edition,* by Judy Donnelly and Nicholas Massa, available from Photonics Media in Pittsfield, MA (www.store.photonics.com).

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*The PHOTON Projects (FOTEP, DUE #9553762 ; PHOTON, DUE #0053284, PHOTON2 DUE #0302528; PHOTON PBL, DUE #0603143) and the PBL Projects (STEM PBL, DUE #0903051; Advanced Manufacturing PBL, DUE #1204941; Advanced Photonics Manufacturing PBL, DUE #1801115) were funded by the National Science Foundation's Advanced Technological Education program (NSF-ATE). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. For more information on these projects visit our website at www.pblprojects.org

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▶ indicates a video of this experiment is on the PBL Projects YouTube channel

INTRODUCTION

Who this book is for

This is a book of quick and easy inquiry-based demonstrations and experiments for anyone who wants to provide STEM outreach and/or education with a focus on optics and photonics – teachers, parents, students, engineers and scientists. Familiarity with optical science is not required but will enhance the activities. We have used these experiments in both large and small venues with students from kindergarten through high school and senior groups. With the addition of calculations they were part of a distance-learning community college "home lab" course offered to working technicians and teachers. Because the materials are simple and readily available, they can be the perfect answer to a classroom request for a science demonstration, an outreach fair or even a child's science fair project.

Where the activities come from

From 1995 - 2006, the PHOTON Projects of the New England Board of Higher Education were funded by the National Science Foundation's Advanced Technology Education program to develop curricula and materials for teaching optics and photonics to secondary and post-secondary students. The Projects also provided professional development to teachers and faculty who along with industry mentors developed a community of educators that began in New England and now spans the globe.

The original Explorations in Optics (2005) were adapted from some of the favorite demonstrations that PHOTON Projects' participants shared during professional development workshops. Some of the experiments have the designation **OPTICS MAGIC!** This subset of the demonstrations can be used for icebreakers to start a lesson or to provide a complete lesson on their own. Optics Magic formed the basis of most of our outreach as we continued to add to and refine our experiments and demonstrations through workshops for students and adults at optics education conferences around the world.

By 2015 we realized that dazzling optical magic demonstrations were perfect for getting students' attention, but not as effective at teaching science. In alignment with the newly published Next Generation Science Standards (NGSS), we developed the longer, more involved Dumpster Optics lessons[1], based on these demonstrations and others but with the requirement that materials had to be commonly found at home or easy to obtain at very low cost. Dumpster Optics was designed to be taught in an upper elementary school classroom as part of a science curriculum. The lessons include PowerPoint slides (English and Spanish), student worksheets and detailed technical notes for parents and teachers. If you are looking for more background on optical science than is provided here, Dumpster Optics is a good place to start. The nine lessons are available for free on the PBL Projects website www.pblprojects.org/dumpster-optics/

During the Covid19 pandemic lockdown of 2020, Optica hosted a series of eight interactive webinars based on the Dumpster Optics lessons that used many of the experiments in this book. Webinar recordings can be found on the PBL Projects web site at www.pblprojects.org/resources-from-pbl-osa-webinars. PBL Projects also hosts a YouTube channel with, among other educational offerings, videos of most of the Explorations recorded by students of Eastern Connecticut State University's Theater and Communication Programs. The direct link is www.youtube.com/PBLProjects

A few general hints

These demonstrations and activities use inexpensive and easily found materials. They have all been student and teacher tested, but it's always a good idea to try them out first before performing any experiment with students. In particular, before doing any optics activities *be sure to find out in advance what kind of room lighting you will have*. Usually just turning room lights off will work, but sometimes you might need to improvise if an activity works best in darkness. We have found that a deep carton painted black on the inside can double for a dark room in some cases.

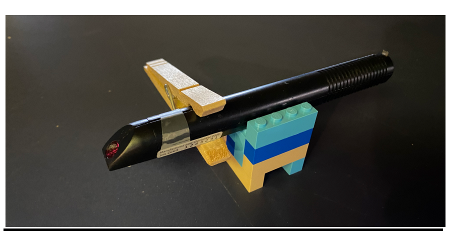
The explanations in the "Science Facts" sections are aimed at 10-12 year-olds, that is, 4^{th}-6^{th} graders in the U.S. Of course, you can adjust them to the sophistication of your audience, but if you can explain physics to a ten-year-old you can explain it to anyone.

In the Resources chapter at the end of this book we provide information on materials used in the experiments, including sources for the more "scientific" materials if you prefer to use them. Certain activities require inexpensive but not necessarily household items (like chemistry lab watch glasses). These are indicated in the instructions and sources for finding them are in the Resources chapter.

Several experiments use laser pointers, which we usually buy at a dollar store. These can be held in the "on" position with a spring-type clothespin over the power button, and mounted at the required height on building blocks such as Lego®. It is important to talk about laser safety, even with low power laser pointers especially when working with younger students. In the U.S., lasers sold as pointers must be low power and require a label detailing the power and wavelength. We usually use red laser pointers with less than 5 mW power. Basic rules for laser pointers include:

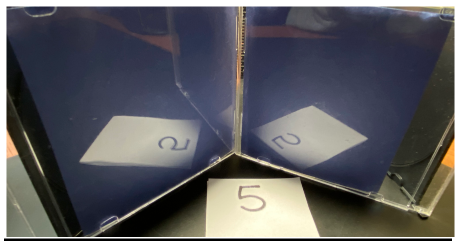
- Keep the laser still on the table so the beam is at table height
- Don't point the laser at another person (or animal)
- Don't look into the end of the laser at the beam
- If you are using mirrors, be careful to keep reflections confined to your table. Use books or other objects to keep the beam from shining past the space where you are using it

The Laser Institute of America has an older but still useful resource on using laser pointers.[2]



Laser pointer mounted on plastic building blocks. The power button is held on with a clothespin.

Mirrors can be difficult to find and use. Glass mirrors can break. Also, some experiments require mirrors be mounted vertically, which can be difficult if the mirrors aren't rectangular. Small plastic mirrors from a science supply shop can be expensive. We were lucky for a time to be able to purchase large acrylic mirror sheets and cut these into the size we needed with a laser engraver. We have included a few suppliers of sheet mirror in the Resources chapter for anyone who may have access to a laser engraver. For a totally free source of acceptable (although not great) mirrors we use CD jewel cases. Remove the liner notes and replace with plain dark paper.



Two plastic CD jewel cases, standing vertically next to each other. The liner notes have been removed and replaced with dark paper.

1. THE COLORS OF LIGHT

Exploring Light Spectra

CAUTION! Do not look into the laser cavity or at any reflections of the laser from shiny surfaces. Do not look into the sun!

Question: Can you tell what wavelengths (colors) are produced by a light source by just looking at the light? What kind of instrument do you need to separate the colors to see them?

Materials

- Cardboard tube – a paper towel tube (cut to 15 cm) or toilet tissue tube. For a large group we sometimes buy "craft tubes" that are a bit sturdier from online sellers like Amazon.
- Plastic transmission diffraction grating. You can buy them (see the Resources chapter) or make one by peeling the label from a discarded recordable CD. Scratch the metallic label with scissors or the end of a paperclip then place tape on the scratch and pull. You can use sturdy scissors to cut the CD into a piece that fits the end of the tube. If you buy a diffraction grating, be sure it's a "linear" grating.
- Aluminum foil and rubber band
- "CAUTION: DO NOT LOOK AT THE SUN OR INTO A LASER" sticker. You can print this on a mailing label or just write it on the tube to remind yourself to be careful.

Science facts

Recognizing colors is one of the first things you learned to do as a child. Isaac Newton used a prism to separate sunlight (or "white" light) into the colors of the rainbow: Red, Orange, Yellow, Green, Blue, Violet. The colors of visible light are a part of the electromagnetic spectrum, which also includes radio waves, microwaves, infrared, ultraviolet, x-rays and gamma rays.

Each color in the visible spectrum has a different wavelength (the distance from one wave crest to the next). Red light has the longest waves and violet light has the shortest waves.

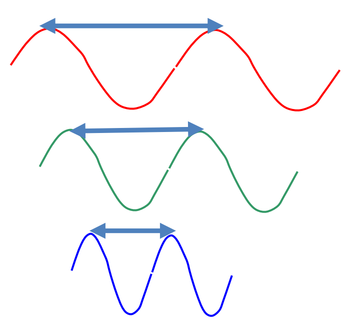


Figure 1.1 - Wavelengths of red (longest), green, and violet (shortest) light

Often the color that you see contains several of the fundamental colors of light. For example, a television screen or computer monitor displays many different colors, but if you look with a magnifier at the screen you will see only very tiny red, green and blue pixels (spots). The combination of varying amounts of the three colors produces all the colors you see on the screen.

In this experiment you will examine the colors radiated by several different sources of light. When the colors are displayed in order of wavelength we call it the *spectrum* of the light source. A rainbow is the spectrum of sunlight.

You could use a prism for this experiment, but prisms are a little difficult to work with and they are often expensive. Like a prism, the very closely spaced tiny grooves of a *diffraction grating* can break light into a spectrum. These can be very expensive or just a few cents each depending on the quality. But you can find a grating for free – a discarded recordable CD. Did you ever notice that light reflected from a CD shows rainbow colors? The narrow grooves of a CD are a type of diffraction grating.

To get the clearest spectra, you will construct a s*pectroscope*, a device for looking at spectra. (A device that actually lets you measure the spectrum is called a *spectrometer.*) The tube of the spectroscope keeps out room light, and the pinhole or slit on the end lets you look a narrow "slice" of the source so colors don't overlap.

<u>Procedure</u>

1. Cover one end of a cardboard tube with aluminum foil. Hold the foil in place with a rubber band. Make sure the foil is stretched smoothly across the end of the tube.
2. Poke a small hole (about 2-3 mm) in the center of the foil with the point of a pencil or, if you can do it neatly, cut a thin slit with a sharp knife.
3. Place the diffraction grating or CD piece on the other end of the tube. Usually we don't glue the grating so it can be used without the tube for other experiments. It's fine to glue the CD when it's in the right position. If you made a slit rather than a hole, the spectrum should be spread out from side to side as in Figure 1.3. That is, if the slit is vertical when you look into the grating the spectrum should be horizontal. If you have trouble finding the spectrum look on the inside walls of the tube, not at the position of the slit.

<u>Observing light sources</u>

4. Look through the diffraction grating with the pinhole or slit pointed toward a source of light. You will see a bright spot in the center that will have the same color as the source itself. On either side, you will see one or more "spectra"- a full rainbow for a source like a light bulb and individual lines for sources like streetlights or energy saving fluorescent bulbs. You may have to look quite a bit to the side of the central spot to see the spectra. Focus on one of these spectra, which will include some or all of the colors of the visible spectrum. For an example of what you will see, look at Figure 1.3.
5. Find at least five different light sources. Hint: anything that glows should work, for example, light bulbs and LEDs, a cell phone screen, candle flame, street lights, etc. A colored light, such as a green night light or a color holiday bulb, would be a good choice.

6. If you have a laser pointer, you can include it as one of your sources. However, DO NOT look directly into the laser with your spectroscope. Shine the laser on a piece of white paper and look at the light reflected from the paper. You can view the spectrum of sunlight the same way, by looking at sunlight reflected from white paper.

Figure 1.2 - The cardboard tube spectroscope. Look through the grating or CD piece on the back end of the tube toward the foil. This drawing shows a slit on the front end but you can also just poke a small hole into the center of the foil.

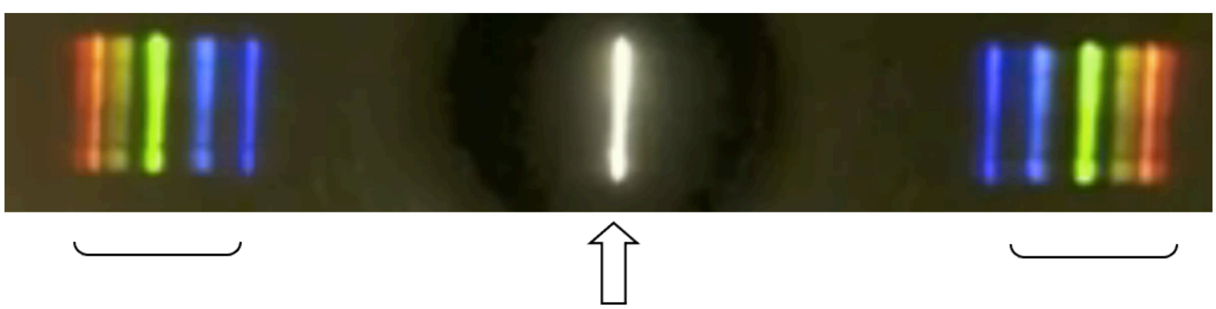


Figure 1.3 – A photo of the spectrum of a compact fluorescent bulb seen by looking into a cardboard tube spectroscope. The arrow points to the slit that faces the light source. There are two spectra, one on each side of the center. If you don't see them at first, look to the sides of the tube rather than at the slit. Sometimes you might see more than one complete spectrum on each side, it depends on the grating you use. How is this spectrum different from a rainbow?

Recording Your Observations

Fill in the data table with one line for each light source. List the type of light that you were observing (LED, laptop screen, incandescent bulb, candle, etc.) and a description of the spectrum you see through the spectroscope. You can draw the spectrum with crayons or colored pencils if you prefer.

OBSERVATIONS

Type of light source	Colors you saw in the spectrum and what color is brightest

Conclusions

- Do the spectra of the colored sources contain only the color you see with your eye? That is, if you look at a red light bulb, will it always show only red light or might other colors be present?
- Do some light spectra have more colors than others?
- Why do you think the spectra of different light sources are different?
- Can you tell what colors are in a light source by looking at it with your unaided eye?

Application

Spectroscopy has many uses in astronomy, earth science, food inspection, crop health[3], manufacturing, sensing and more. For example, Mars rocks can be studied by an instrument called "laser induced breakdown spectroscopy" (LIBS). A Mars rover equipped with LIBS fires a laser at a rock, making a small puff of glowing vapor that is imaged by the spectrometer. The pattern of wavelengths produces tells scientists what the rock is made of. You can find more interesting applications of looking at spectra from both Earth and space on the NASA web site[4].

What Color is a Tomato?

OPTICS MAGIC!

Question: Can your eyes be fooled by the color of a light source? Can you make your friends think a tomato is a plum?

Materials

- A small tomato that you can mostly hide in your hand. You can also use small colored candies.
- At least two different color lights like finger LED lights or Christmas tree lights. You could also use a flashlight, covering the end with blue, green or red plastic film or a tightly stretched balloon. A balloon dims the light so you'll need a dark room.

Science Facts

The color you see when you look at an object depends on the wavelengths reflected by the object, the wavelengths present in the light illuminating the object, and the color sensitivity of your eyes. A red tomato reflects a range of wavelengths, primarily red but also extending into the orange.[5] However, when it's illuminated by a blue LED, only blue light is reflected. Red light isn't reflected because a blue LED light doesn't contain red wavelengths. If there is some stray light in the room coming from the windows or if you use a filter over a flashlight, then there might be some red wavelengths that are also reflected by the tomato. The tomato will then look like a purple plum, a combination of both red and blue.

Procedure

1. In a very dark room, hold the tomato in your hand so that only a small portion of the surface is visible. (You don't want the shape of the tomato to be visible, just a bit of the skin.) If you are unable to darken the room, place the tomato (or a few pieces of colorful candy) in a deep box so that it is well shaded from ambient light. It helps to paint the inside of the box flat black to minimize reflections of room light.
2. Shine the colored light on the object and observe the color of the illuminated surface. For example, red candies in green light may look black. Try different colors, if you have them, and different objects as well.

Observations

For each object and each illumination type, answer the following questions. Be sure to say what the object was and what type of illumination you used.

1. What color is the object under "white" light (sunlight or room lights)?
2. What color light did you use?
3. What color did the object appear under this color of light?
4. Why did the object appear to be the color you saw?

Record your observations

Object you observed	Color of light used	Color the object appeared	Why did the object appear to be the color you saw?

Application

Lighting plays an important role in marketing. Figure 1.4 is a photo showing the effect of different types of lighting on a retail store display. The items are identical on both left and right sides of the photo. Why do they look different? Check out the lighting in a local supermarket – are the same lights used for meat and produce?

Figure 1.4. Photo taken at the Southern California Edison Lighting Center, 2004. The items in the displays are the same colors on both sides of the wall, only the lighting is different.

2. EXPLORING PINHOLE IMAGES

OPTICS MAGIC!

Question: Can you make an image (picture) with just a pinhole?

Materials

- Large carton or box
- Aluminum foil
- Sharp pencil (or a thick needle, like an embroidery needle)
- Tape
- Translucent paper, like waxed paper or tracing paper
- Electrical tape to cover any light leaks, if needed

Science Facts

How does a pinhole camera work? As you can see in Figure 2.1, sunlight reflected from the top of the tree passes through the small pinhole in the front of the box and strikes the back of the box at the bottom. Light from the bottom of the tree also passes through the pinhole and strikes the back of the box at the top. The light from top and bottom does not overlap because the pinhole is so small. Thus, an image of the tree is formed on the back of the box. The image is upside down and its size can be found by geometry (similar triangles).

If the hole is too large, the overlapping rays will form a blurry image or no image at all. If it's too small, the image will be very dim because so little light enters the box. To use the box as a camera, it must have no light leaks that would allow more light than the pinhole. The film is placed on the inside, at the image location. Exposure times can be very long – several seconds outside on a sunny day to up to several hours indoors. The Resources chapter has links to instructions to make and use a simple pinhole camera[6].

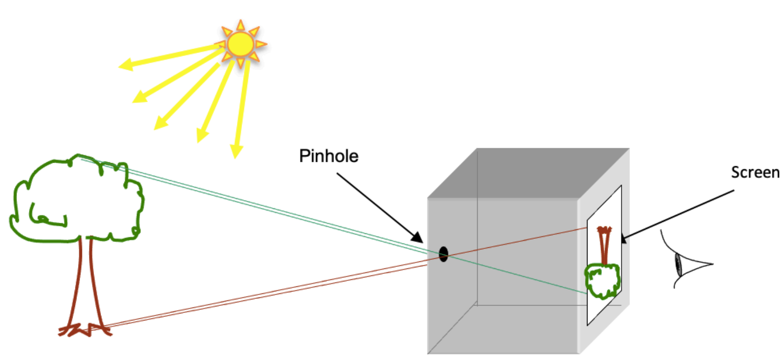


Figure 2.1 - The pinhole camera viewer uses a tiny pinhole to make an image. Geometry shows how light from different parts of the object (tree) are kept separate on the back of the box to form an image.

Procedure

1. Cut a hole approximately 5 cm square in the center of one end of the box. Check to make sure the edges and corners of the box will not let in any stray light. You can cover any small holes or cracks with black electrical tape if necessary.
2. Cut a larger hole, around 10-15 cm, in the box opposite the pinhole. The actual size will depend on the size of the box.
3. To make the pinhole, stack a few 6-7 cm squares of aluminum foil. Pierce the stack with the tip of a sharp pencil or thick needle. The inner foil pieces should have neat pinholes, with clean edges. The pinhole should be 2-3 millimeters across. Tape one of these foil pieces over the hole in the box, centering the pinhole over the cutout. (Figure 2.2)
4. Cut a piece of waxed or tracing paper to cover the large hole. This will be the viewing screen.

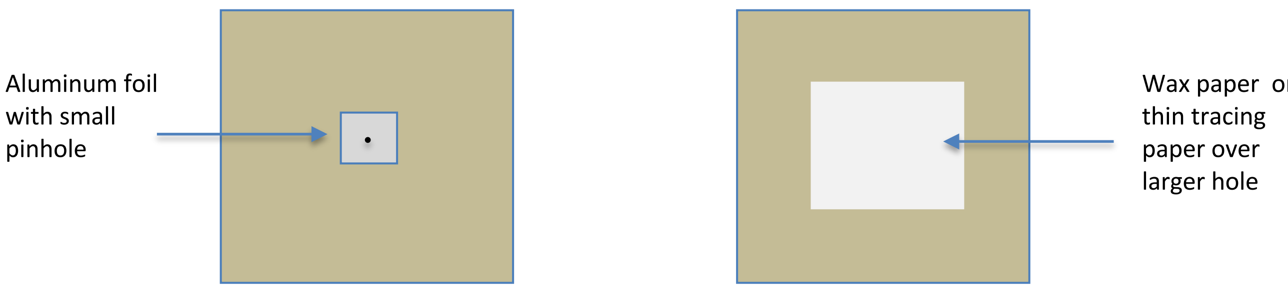


Figure 2.2 – (Left) Front of box, (Right) Back of box

Aim the pinhole toward a light source and look at the screen at the back of the box. A lamp in a darkened room makes a good object. Or stand in a darkened room and point the pinhole toward a sunny window

Alternate method of viewing the image: This requires a fairly large box (you have to put your head almost inside!) but it gives a sharper image. Instead of a wax paper screen, use the inside of the box to see the image. To do this, do not cut a hole in the back of the box. Leave the bottom of the box open and hold the carton over your head. Look for the image on the inside of the box facing the pinhole. This works best with a bright light bulb as the object.

Observations

What did you use for an object? Describe the image you saw- was it upright or upside down? Sharp or blurry? Describe any other features of the image that you noticed.

Applications

Many photographers enjoy creating pinhole images because of their unusual qualities. Cameras with laser drilled pinholes can be bought online, or cardboard cartons and oatmeal containers can be used to make simple "recycled junk cameras" that can be used with film paper for quickly developed black and white photos. Figure 2.3 shows photos taken with an oatmeal box camera. Because the box is a cylinder, the film is curved and produces oddly distorted photos.[5]

Figure 2.3. (Left) An oatmeal box pinhole camera. The pinhole is in the piece of aluminum taped to the box. (Middle) The film paper was taped inside the box, following the curve. The image on film paper is a negative. (Right) The image was scanned and digitally processed to form a positive image.

A very common (but often unrecognized) pinhole image can be seen under the canopies of leafy trees. The round blotches on the ground are pinhole images of the sun. Can you find any images of the sun under trees in your neighborhood? During an eclipse of the sun these round spots turn to crescents. (Figure 2.4)

Figure 2.4. (Left) Pinhole images of the sun under dense vines. The small holes between the leaves create overlapping pinhole images of the sun. (Right) Pinhole images of the sun under a leafy tree during a partial eclipse of the sun.

3. BENDING LIGHT – REFLECTION

The Disappearing Beaker

OPTICS MAGIC!

Note: This is a traditional but messy experiment that is also amazing and fun. A less messy variation with water gel beads is also described in the procedure.

<u>Questions:</u> What does transparent mean? Can you see a transparent object? Can you make a glass disappear?

<u>Materials</u>

- Two Pyrex® (borosilicate glass) beakers or custard cups, a small one that fits completely inside the larger one. Other types of glass may or may not work – experiment to find out! The inner glass is the one that's important- a small Pyrex® cup inside a different glass container would work.
- Inexpensive vegetable oil (really- don't use that expensive olive oil here)

<u>Science Facts</u>

In order for you to see something, light must go from the object into your eyes. A glowing object like a light bulb emits light that you can see directly, but other objects must reflect light from the sun or other light source for you to see them.

Whenever light travels from one material into another (for example, from air into glass or glass into water) part of the light is reflected and part of the light is transmitted into the second material. The amount of light reflected depends on the speed of light in the two materials. Scientists speak of the *index of refraction* of the material, which is a way to express how fast light travels in the material compared to its speed in a vacuum. For example, glass has an index of refraction of around 1.5, which means that light travels 1.5 times faster in a vacuum than in glass.

When light goes from air to glass it slows down in the glass, and about 4% of the light is reflected at the surface. That's enough for you to be able to see the glass, even though we say it's "transparent". This is illustrated in Figure 3.1. But cooking oil and borosilicate (Pyrex®) glass have about the same index of refraction, that is, light travels at the same speed in both. So, no light is reflected if the glass is surrounded by oil and therefore you can't see it!

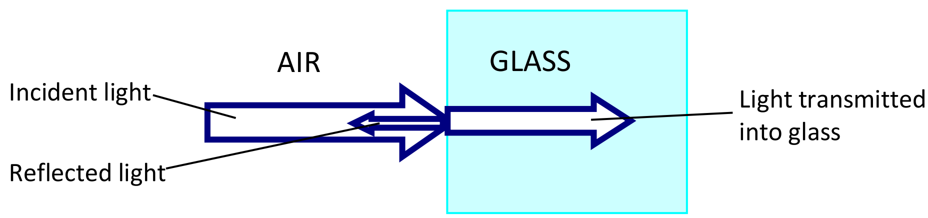


Figure 3.1 - Light is reflected from glass because it has a different index of refraction than air. There will be a reflection at the second glass surface too, but this is not shown in the drawing.

Procedure and Observations

1. Place the smaller beaker in the larger beaker.
    - Can you see the smaller beaker?
    - Why can you see the smaller beaker? (Think about the speed of light in air and in glass.)
2. With the smaller beaker still inside the larger beaker, carefully pour the oil into the smaller beaker only until it is full (see Figure 3.2).
    - Can you see the smaller beaker?
    - Why can you see the smaller beaker?

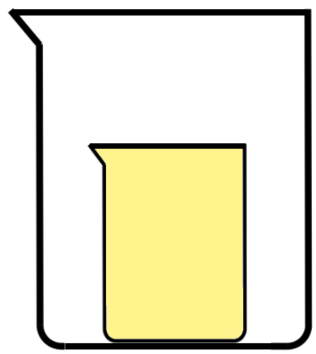


Figure 3.2 – Smaller beaker with oil inside larger beaker

3. Now continue pouring the oil into the smaller beaker so that it overflows into the larger beaker. Continue pouring until the smaller beaker is completely submerged in oil.
    - Can you see the smaller beaker?
    - Why can't you see the smaller beaker anymore? What does this mean about the index of refraction (speed of light) of the oil compared to the glass?

This demonstration may also be done with water (and less mess) using gel beads from a craft store. Look in the flower arranging aisle for colorless gel beads to use in water. When saturated with water, the beads can't be seen. It does take a while for them to fully expand, however, so put them in water several hours or the night before you want to use them. The beads are invisible because light doesn't change speed going from water into the beads (which are nearly all water themselves) so there is no reflection. If you put your hand in the glass of beads you can feel them though!

If you want to dry the beads to reuse, you need to expand them in distilled water or they will turn brown as they dry.

Application

To minimize the amount of light reflected and maximize the amount transmitted the index of refraction (speed of light) in the incident and transmitting materials should be as close as possible. Sometimes, "index matching fluids" are used, for example, when two optical fibers are joined in a temporary splice to minimize reflection back into the signal source.

An application you may have seen is the gel applied before a medical ultrasound examination. Many people think the purpose is to make the ultrasound transducer slide more easily over the skin. In fact, it is index-matching gel to maximize sound energy transmission from the transducer into the body. Without the gel, much of the ultrasound would be reflected back by the thin layer of air between the transducer and the skin. To get a good echo return signal from inside the body, it's important that most of the sound be transmitted, not reflected at the skin's surface.

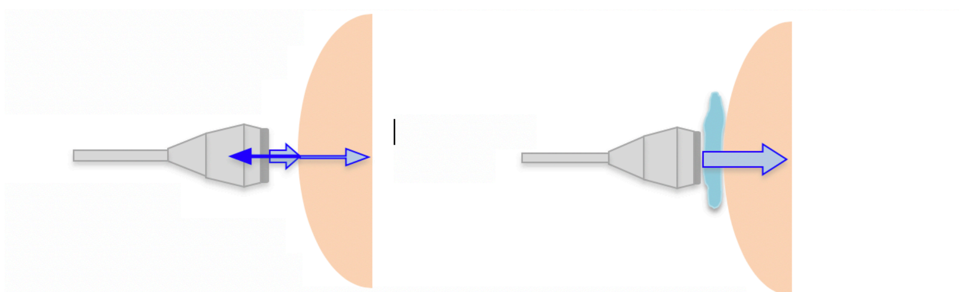


Figure 3.3 – Left: Sound waves traveling from left to right are partially reflected at each surface where the speed of sound changes going from a thin layer of air into skin. Right: Index (of refraction) matching gel between the ultrasound transducer and skin minimizes back reflection and maximizes the amount of energy entering the body.

Laser Target Shoot

CAUTION! Do not look into the laser cavity or at any reflections of the laser from shiny surfaces. Do not look into the sun!

<u>Question:</u> How does reflection work? Can you use the law of reflection to hit a target with a laser beam?

Materials

The Hands-on-Optics program[6] has a version of this experiment but they use a kit that had expensive plastic mirrors and custom mirror holders. Here's how you can do it with CD jewel cases.

- 1 laser pointer, put on blocks or books as needed to get the beam to mirror height
- 2 mirrors. You can use CD jewel cases for mirrors. Remove the label and replace with dark construction paper. They even stand upright by themselves. If you use mirrors you need to find a way to make them stand vertically, for example, mounting them on wood blocks.
- Protractors (printable ones from the internet are fine)
- String, Masking tape, Meter stick as needed
- Target (see below)

Science Facts

When light strikes a shiny surface it leaves the surface at the same angle it entered. We call this the Law of Reflection:

"The angle of reflection equals the angle of incidence."

The light that strikes the surface is "incident" and the light that leaves is "reflected" (See Figure 3.4). In this Exploration you will use this law to help you place mirrors so that a laser beam hits a target.

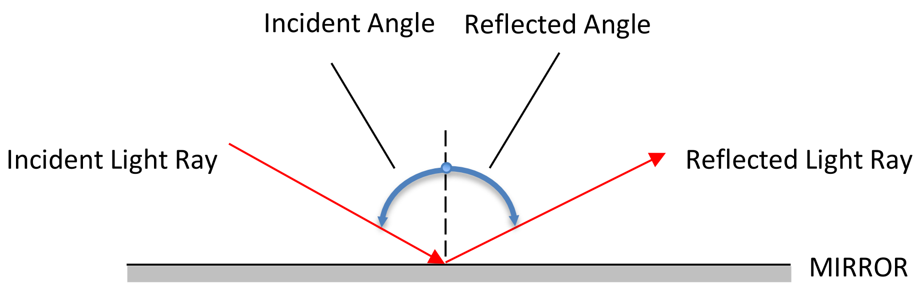


Figure 3.4 - The law of reflection. Notice how the angles are measured – from a line drawn perpendicular to the mirror (the dashed line), not from the mirrored surface itself. The light rays (arrows) show how a laser beam would be reflected from the mirror.

Rules

1. The laser and target will be set up for you by the instructor or assistant. *You may not move either the laser or target. You may only move the mirrors*
2. **The laser must be kept turned off until you have set up the mirrors.** When you're ready, the instructor or assistant at your table will turn on the laser. *You may not move any mirrors while the laser is on.* (Figure 3.5)
3. If you don't get 20 points on your first try, the instructor or assistant will turn the laser off and you may move the mirror(s) and try again. You can keep trying until time is up for that round.
4. If the laser falls on a line between regions of the target, you will be awarded the average of the points on either side.
5. The mirrors must be at least 25 cm from the laser and from each other.

<u>The Challenge (times can be adjusted as needed)</u>

Round 1: You have 10 minutes to hit the target using ONE mirror.

Round 2: You have 15 minutes to hit the target using TWO mirrors.

⇨In each round, the highest score will be recorded.

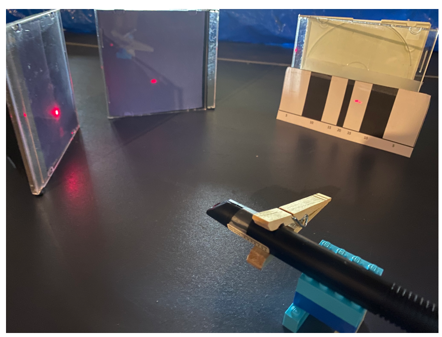
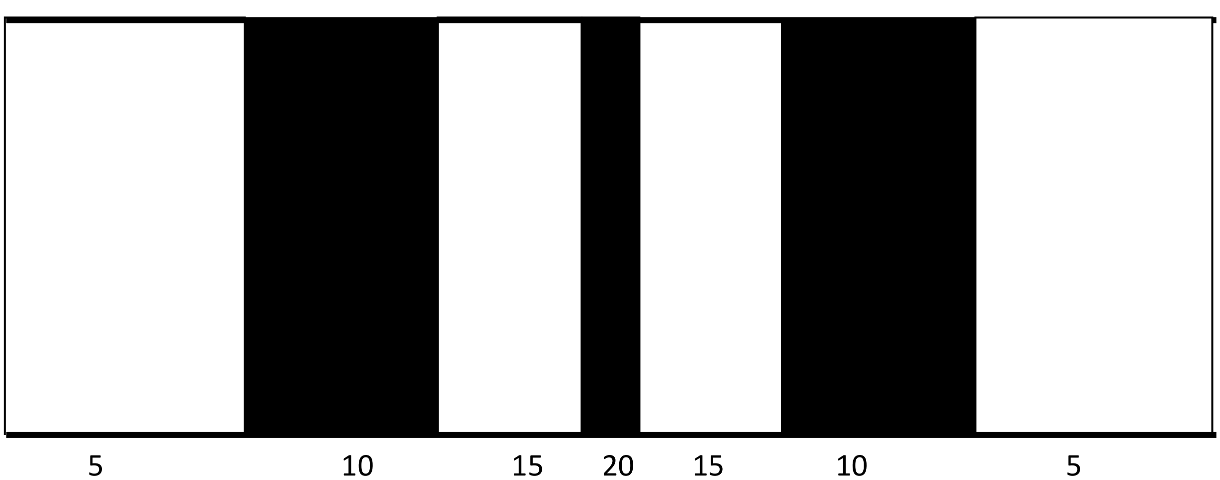


Figure 3.5 – Laser target shoot with two mirrors. Note that the laser is held "on" by a clothespin, this was only to take a photo. In the actual challenge the target is off until the mirrors are set up, then turned on by hand.

Sample Target- Cut out the target and mount it on a block so it is vertical



The Amazing Bedazzled Kaleidoscope

OPTICS MAGIC!

This is a wonderful activity and is actually less expensive than making kaleidoscopes with kits for a whole classroom. Plastic mirrors are usually quite expensive, and glass mirrors are fragile so this is a good compromise.

<u>Question</u>: How many times can you multiply yourself?

<u>Materials</u>

- Three large rectangular mirrors (We use the kind you mount on the back of a door or a wall, available inexpensively at big box stores.)
- Duct tape, lots of it
- Optional: Decorations for the backs of the mirrors

<u>Science Facts - reflection from more than one mirror</u>

Kaleidoscopes work by reflection, and the law of reflection is not difficult to understand. But the explanation for the formation of multiple images is not as simple. Multiple reflections can be easily illustrated, though, with two small, flat square or rectangular mirrors. Glass mirrors can be hard to find and they might be too fragile for some students. CD jewel cases can be used as mirrors that work nearly as well. Remove the liner notes (if any) and replace with dark construction paper. It's easy to stand the cases vertically without having to resort to blocks or other supports.

Place the two mirrors so edges touch and they stand vertically making an angle of around 150^{o}. It helps to have a “hinge” of tape to hold the mirrors together. Place a small object such as a paper clip on the table between and in front of the mirrors. As expected, an image forms in each of the mirrors, so you see two images. As the angle between the mirrors is made smaller more images appear due to multiple reflections in the two mirrors.

An interesting exercise is to count the number of images that appear as the angle between the mirrors is made smaller. Use a printed number “5” for the object and observe the orientation of the multiple reflections- do they all face the same way? How many images can you make as the angle between mirrors gets smaller? (Figure 3.6)

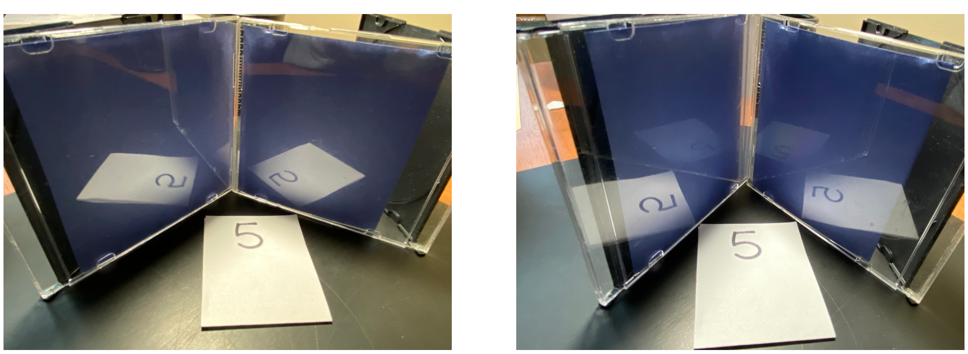


Figure 3.6 Multiple images in two mirrors. CD jewel cases don’t make the best mirrors so the second set of images (right) are more difficult to see.

Kaleidoscope Construction Procedure and Observations

1. Carefully tape the three mirrors together at their edges. Tape around the edges of the two openings as well. The mirror part should be facing inward.
2. Optional: Decorate the outside (backs) of the mirrors with jewels, stick-on sparkles, etc. This really grabs attention.
3. To use: Have students stand on each end and look into the kaleidoscope opening.

- How many faces do you see?
- Do you see complete faces or parts of faces?

4. Try looking at other objects such as a large number “5” (look at the orientation of reflections), or bright colored pictures.

Application

You see an application of multiple images often – when you are in a fitting room where you try on clothes. But kaleidoscopes are interesting in their own right. Since its invention by Sir David Brewster in 1816, the kaleidoscope has been enthusiastically embraced by both curious children and serious artists. The Brewster Kaleidoscope Society was founded in 1986 “to share and promote the beauty, creativity, and joy of these mirrored tubes of magic.” The society’s web site has links to kaleidoscope artists in the U.S., U.K. and Japan as well as diagrams showing how the number and orientation of images change as the angle between the mirrors change.[7]

Figure 3.7 – Using the Giant Bedazzled Kaleidoscope with a class 5th graders. Left: looking at and photographing multiple images of faces. Right: Here, colorful stickers on a clear plastic sheet were the object.

4. BENDING LIGHT – REFRACTION

Gelatin Optics

CAUTION! Do not look into the laser or at any reflections of the laser from shiny surfaces.

Questions: How does refraction work? Can you focus light with gelatin?

Materials

- Slabs (around 1.5 cm thick) of very stiff gelatin. You can use plain gelatin or flavored sugar-free. It's best not to use the kind with sugar because it makes a sticky mess. See preparation instructions in the procedure
- Something to cut with – knives work, but 2 cm wide strips cut from a plastic folder can be bent to shape and are smooth and less dangerous. Large round cookie cutters are also good for making "lenses".
- Laser pointer (the dollar store red ones are fine)

Science Facts

In a vacuum, light travels at 300,000,000 meters per second or 186,000 miles per second. When light enters a transparent material like glass (or gelatin), it slows down and its wavelength (the distance between wave crests) shortens. Because of this, a beam of light traveling from one substance to another can change direction.

To understand why a wave changes direction when it changes speed, think about a marching band in neat even rows, marching along a paved surface bordered by deep mud. The marchers can walk faster on the pavement than in the mud, where their feet sink in the ooze. When the marchers at the end of each row reach the mud, they will take shorter steps and slow down. The result is that the rows will bend. (See Figure 4.1.) In the drawing, the white circles represent the heads of the marchers.[8]

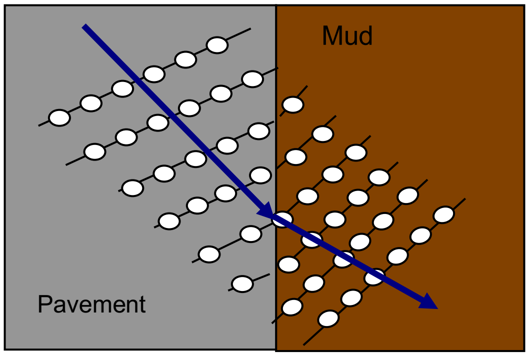


Figure 4.1 - The rows bend when the marchers go from pavement (fast steps) to mud (slower steps).

Waves behave in a similar fashion. In Figure 4.1, the rows of marchers are like the crests of waves. You can see how waves will bend when they go from a medium where they travel fast to a medium where they move more slowly, for example, if waves go from air into water or glass.

The bending of waves as they go from one material to another is called *refraction*. Refraction of light explains many things you see around you every day, such as the apparent bending of a spoon when it is partially submerged in water and how lenses work, including those in eyeglasses. When scientists talk about refraction, they speak of *incident* light, the light that strikes the surface, and *refracted* light, the light enters the second *medium* (or material). The angles or incidence and refraction are measured from a line drawn at 90^o to the surface. This is similar to the law of reflection where there were incident and reflected rays, both measured from a line drawn to the surface. (Figure 4.2).

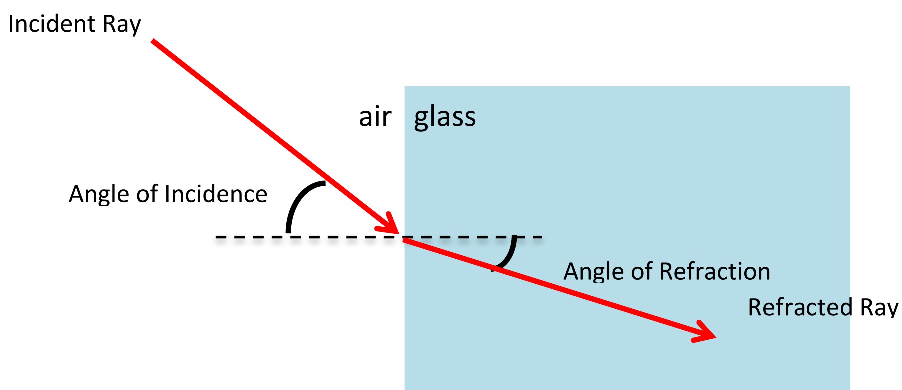


Figure 4.2 - Incident and refracted rays and angles of incidence and refraction. Note the way the light bends when it goes from air on the left to glass on the right. Compare to the bending of the rows of marchers in Figure 4.1. What will happen with the light gets to the second surface on the right? Which way will the light bend?

Procedure and observations

1. **To make the gelatin:** Make the gelatin in a pan that will allow the gelatin block to be around 1.5 cm thick. If it's too thin it will be hard to handle. Use half the usual amount of water recommended on the package. On flavored gelatin packages, follow the recipe for "blocks" or Jigglers® (on the Jello® package). Remember to lightly oil the pan to make it easier to remove the gelatin. If it is stiff enough it doesn't need refrigeration except on really hot days.
2. To make a large quantity of gelatin for experimenting, try asking the local butcher for small plastic meat trays. It's easier to handle in small trays rather than in a large pan.
3. Remove the hardened gelatin carefully and cut into shapes for experimenting. Use a cookie cutter or thin flexible piece of plastic to cut "convex" and "concave" lens shapes. A knife is not recommended unless it has a smooth (not serrated) blade and you can make a smooth, even cut.

Activity 1 - Which way does light bend?

4. On a piece of paper, draw two long lines that cross at a 90^o angle. Draw a few more lines for different angles of incidence. Cut a gelatin rectangle about 3 cm x 4 cm. The size is not important, but the edges must be very straight and smooth. Place the gelatin block so the center of one edge is where the two long lines intersect. (See Figure 4.3)

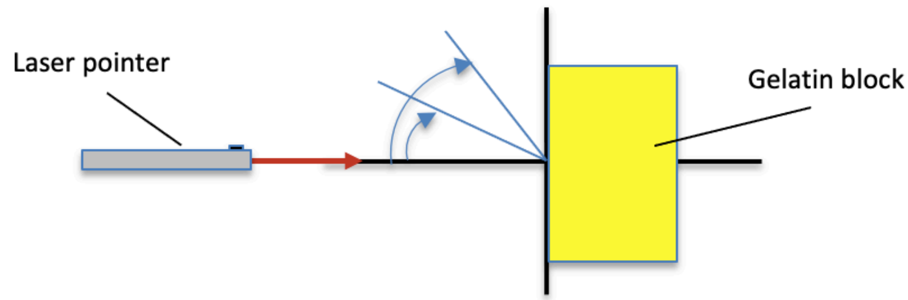


Figure 4.3 - Gelatin block and paper with lines drawn on the paper below, as seen from above

5. Place the laser so that it strikes the gelatin block straight on (at 0^o incident angle, as shown in Figure 4.3).

   Does the beam of light bend when it goes from the air straight into the gelatin? When it goes from the gelatin back into the air on the other side?

6. Shine the laser beam along each of the other lines you have drawn. Each time, notice which way the beam bends where it enters the block of gelatin.

7. **Observation :** Which way does the beam bend as it enters the gelatin block? As the angle of incidence increases, does the beam bend more, less, or the same amount?

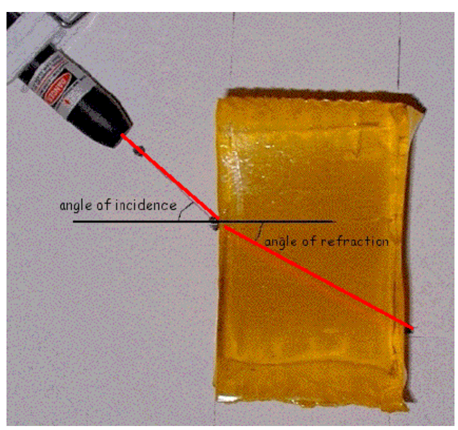


Figure 4.4 - Photograph of the gelatin block and laser. The laser beam is highlighted so that it is easier to see. In fact, light from a laser pointer isn't normally visible at in air- do you know why?

Activity 2– Make a Lens!

8. To cut gelatin "lenses" into the "cookie" shapes shown in Figure 4.5 you will need to use the circle cookie cutter and a flat block of gelatin. Notice that the curved surfaces are actually parts of circles. Practice until you can make shapes with smooth sides that look like the ones in Figure 4.5.

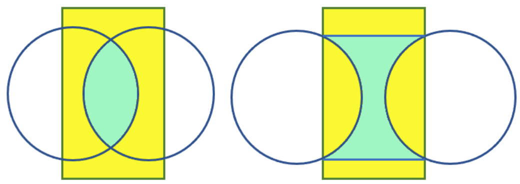


Figure 4.5 - Lens shapes cut of a gelatin block using a circle cookie cutter. The circles show the position of the cookie cutter. The green shaded shapes are the gelatin "lenses" that you will use for this experiment.

9. Place one of the "lenses" on a piece of paper. Shine the laser through one edge of the lens and observe how the light behaves as it passes through the lens (Figure 4.6). Shine the laser pointer along one of the arrows as shown in Figure 4.6 and trace the path of the beam on the other side with a pencil. It may be a bit spread out and messy, depending on how smooth the gelatin surface is.
10. Move to another (parallel) position and repeat. Draw at least 5 rays and see what happens on the other side of the lens. A lab device called a "ray box" makes this super easy, but they are more expensive than a dollar store laser pointer. (See the supplier list in the Resources chapter.)
11. Repeat with the other shaped lens.

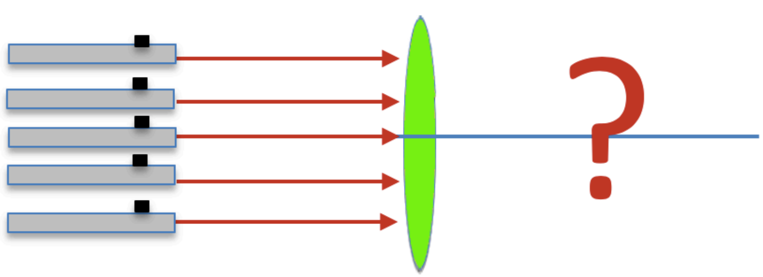


Figure 4.6 - Make sure the rays enter the lens so they are parallel to the line through the center of the lens.

What does the lens on the left in Figure 4.5 (called a converging lens) do to the light?

What does the lens on the right in Figure 4.5 (called a diverging lens) do to the light?

<u>**Conclusion**</u>

How does refraction of light explain how a lens works?

Gelatin Optical Fiber

CAUTION! Do not look into the laser or at any reflections of the laser from shiny surfaces.

<u>Questions:</u> How does optical fiber work? Can you make an "optical fiber" out of gelatin?

Materials

- Slabs (around 1.5 cm thick) of very stiff gelatin. See the Gelatin Optics exploration for details and instructions
- Something to cut the gelatin- you need to make a long, straight, smooth cut. A strip cut from a plastic folder would work
- Laser pointer (the dollar store red ones are fine)
- Advanced topic: Sugar, if you want to try GRIN (graded index) gelatin (see below)

Science Facts

If you tried the gelatin refraction exploration you saw how light bends as it goes from air to gelatin and then back into air. When light goes from where it travels faster to where it travels slower, it bends toward the perpendicular line to the surface (the normal line). If light goes from where it travels slower to where it travels faster, it bends away from this line. Light travels faster through air than it does through gelatin.

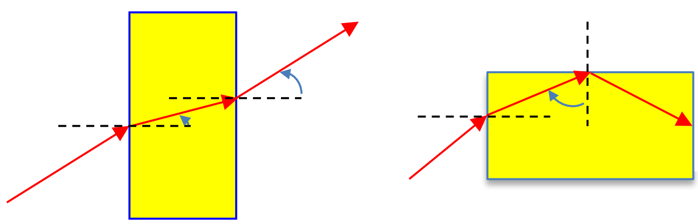


Figure 4.7 – (Left) Refraction of a light ray as it goes from air to gelatin (shown in yellow) and back into air. Light bends toward the normal line when it enters from air into gelatin, it bends away from the normal line with it exits the gelatin into air. (Right) Inside the gelatin, light strikes the air-gelatin surface at a large enough angle to be reflected back into the gelatin rather travel into the air.

But under certain circumstances, light in the gelatin is "trapped" and can't exit into the air. This is called *total internal reflection* and it happens when light in the gelatin meets the air surface at a large enough angle (called the *critical angle*). When this happens, all the light is reflected back into the gelatin instead of transmitted into the air. You may have seen this effect looking into the corner of a fish tank – the water acts like a mirror and it looks like there are duplicate fish.

Optical fiber works by trapping light by total internal reflection. Ultra-pure glass allows light to travel for many tens of kilometers before it requires amplification. It's difficult to believe, but hair-thin optical fiber can transmit much more data than copper wire, which is why it rapidly replaced copper as a transmission medium for communications. Optical fiber has many other uses as well, such as sensors and image transmission (endoscopes).

Procedure and Observations

1. Cut the longest thin strip you can out of your slab of gelatin. It should be at least 1 cm wide so that you can handle it without breaking.
2. Shine the laser at an angle into one end.

- What does the light do inside the gelatin?
- If you change the angle (move the laser) what do you notice?
- Do you see any light exiting the far end?

3. Try bending the “fiber” into a gentle curve.

- Does the light follow the “fiber” around the bend?

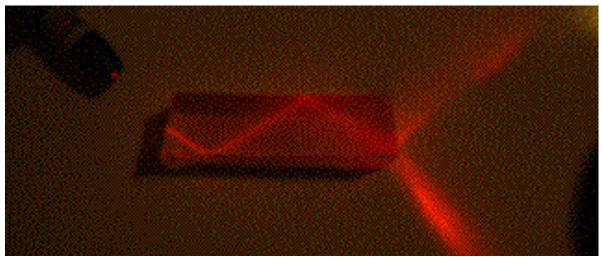


Figure 4.7 – A gelatin “optical fiber” showing total internal reflection. The laser is in the upper left corner.

Advanced topic: GRaded INdex gelatin (hat tip to Groot Gregory who demonstrated this at an Optica Educators’ Day)

Graded index materials have an index of refraction that changes gradually throughout the material rather than abruptly as with the gelatin-air boundary. The index of refraction of gelatin can be increased by adding sugar.

Procedure

1. To make GRIN gelatin, mix boiling water and gelatin powder as usual for gelatin optics. Then, add as much sugar as you can dissolve in the mixture while it is still hot. You can make a slab or mold it in a cylinder (Figure 4.8). Remember to coat the inside of any container you use with oil for easier removal.
2. After the gelatin has set, remove it from the container and cover it with cold water for a few hours. Sugar will diffuse out from the surface in contact with the water, resulting a gradually changing sugar concentration and a gradually changing index of refraction, higher in the center and lower towards the edges.

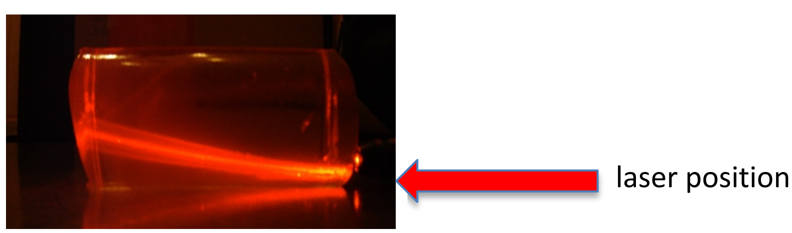


Figure 4.8 – GRIN gelatin. This piece was made in a large (4.5 cm diameter) plastic prescription medicine container. The laser beam enters horizontally from the lower right curves inside the gelatin.

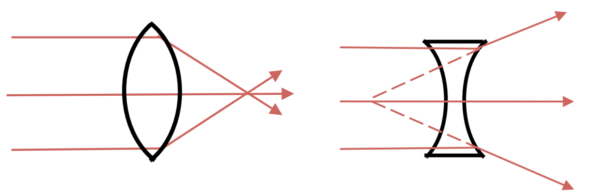
Exploring Lenses - The Magic Lens

OPTICS MAGIC!

CAUTION! Do not look into the laser or at any reflections of the laser from shiny surfaces.

Question: Can a double convex lens make light diverge?

Physics books often include ray diagrams like the one below showing how a beam of light behaves as it passes through a lens. It might lead you to believe that a lens thicker in the middle will always bring light to a focus. Is this always true?



Materials

- Two watch glasses (these are used in a chemistry laboratory); suppliers are listed in the resources chapter
- Tube of silicone caulk, like bathroom or aquarium caulk
- Fish tank large enough to hold the lens submerged in water
- Laser pointer
- Clamps to hold the lens in place in the tank (optional)

Science Facts

A lens works by refraction, the bending of light as it goes from one material into another where it changes speed. The law of refraction (known as Snell's law) tells us the direction that light bends when it goes from one material to another. The angles that a ray of light makes as it enters and exits the are measured from what is called a "normal line," that is, a line that makes a 90^{o} angle to the surface. If light travels more slowly after it crosses the surface, it bends toward the normal line. If it travels faster on the other side, it bends away from the normal line. This behavior explains how the lens is able to focus light to a point.

Figure 4.9 shows a beam of light from a laser entering a plate of glass. The laser light bends toward the normal line when it enters the glass and away from the normal line when it leaves the glass.

When used in air, a lens made of glass that is thicker in the center than at the edges will cause light rays to bend so that after passing through the lens they meet at a point on the other side. Light travels more slowly in glass than in air. We call this type of lens a converging lens. Figure 4.10 shows how the light bends as it enters the glass from the air and then leaves the glass to return to the air. The point where the light rays meet is called the focal point of the lens.

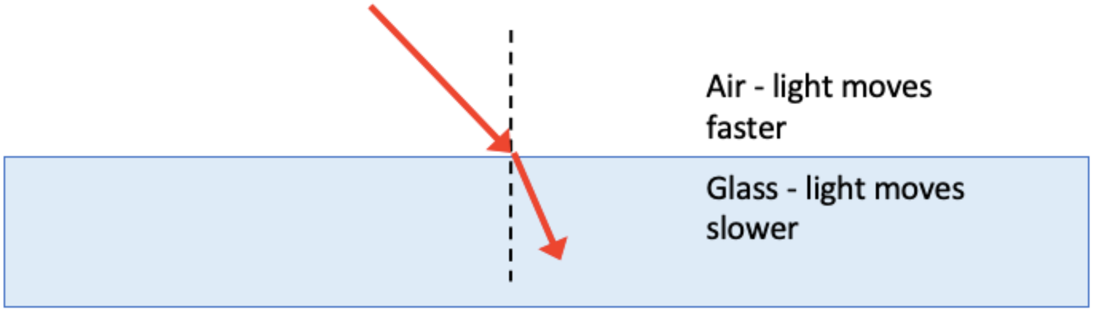


Figure 4.9 - Light bends toward the normal (dashed) line when it enters a material where it travels more slowly (air to glass in this case). Which way will it bend when it enters a material where it travels faster (glass to air)?

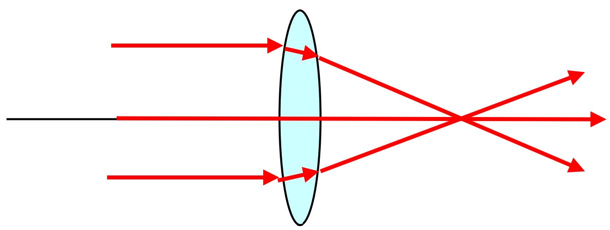


Figure 4.10 - A converging lens brings light rays to a focus on the other side

Procedure

1. First you need to make the "air lens". Clean the two watch glasses, then carefully squeeze a thick bead of caulk all the way around the edge of one of them. Be sure there are no gaps, or your lens will leak! Gently push the second watch glass onto the first so that their edges are sealed together as shown in Figure 4.11. Let the caulk dry completely.

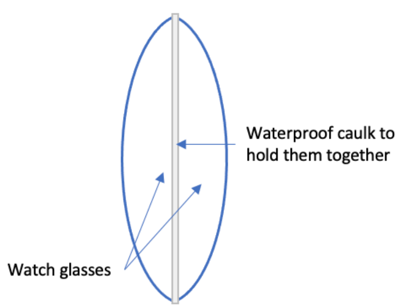


Figure 4.11 - Construction of the "air lens". Be sure to seal the edges completely so water can't get inside!

2. When the caulk is completely dry, fill the fish tank and add just a drop or two of milk to the water. This helps you see the laser better.
3. What do you think will happen when light goes through the air lens when it is under water? (You'll need to hold the lens in place- it will float!) Using a laser pointer, shine it into the lens at several places at several keeping the beam straight and parallel to the table. (Figure 4.12) If you have a glass or plastic lens repeat the experiment with that lens in the tank of water. (A large magnifier with a handle works well.)

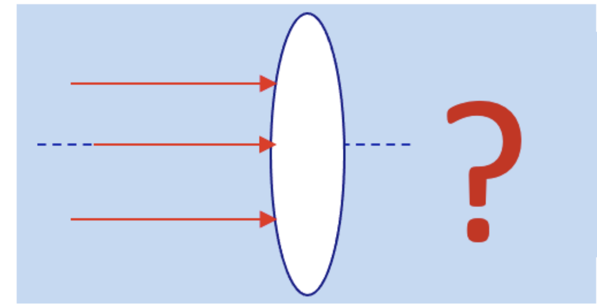


Figure 4.12 – What happens when you shine laser beams through a lens made of "air" under water?

Observations

Does the submerged air lens cause light to converge to a point or does it make the light spread out (diverge)?
How would light behave with a solid glass lens under water?

Conclusion

Is it true that a lens thicker in the middle than at the edges *always* focuses light to a point?
What else besides the shape of a lens determines how it light bends when passing through it?

Sound travels faster in plastic than it does in water. What shape should a plastic lens have in order to focus an underwater beam of ultrasound?

The Misbehaving Lens: Application

How do swim goggles improve your vision under water? Your eyes focus light onto your retina, where sensors (rods and cones) detect the image and send the information on to your brain. (Figure 4.13) But most of the focusing is actually done by the cornea, rather than the lens, because lens power depends in large part on the difference in index of refraction (speed of light) of the lens compared to the surrounding medium. The eye's lens is surrounded by fluids whose index of refraction is not that much different from the lens, but the cornea is normally surrounded by air. (The lens does help you focus on nearby objects by changing its shape.)

When you open your eyes underwater, your vision is blurry because the difference in index of refraction between water and your eye is not enough to focus light on the retina- you become severely hyperopic (farsighted). (Figure 4.14) Swim goggles restore the air film in front of your eye and allow the cornea to do its job (Figure 4.15).

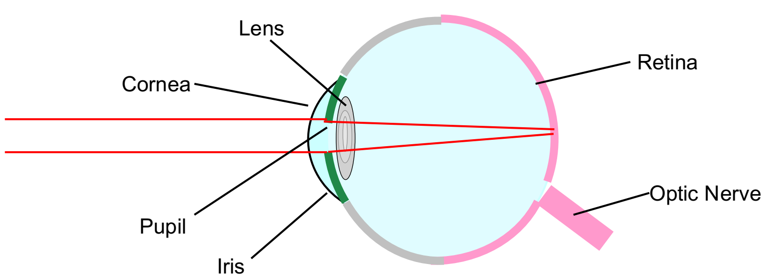


Figure 4.13 – Normal eye in air. Most of the focusing power is due to the difference in index of refraction between the curved cornea and the surrounding air.

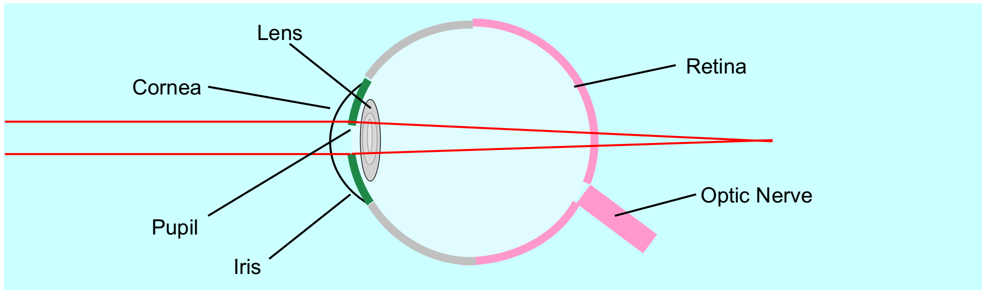


Figure 4.13 – Under water, the index of refraction change between the medium and the cornea is reduced and light from a distant object focuses behind the retina. It's similar to being farsighted- everything looks blurry.

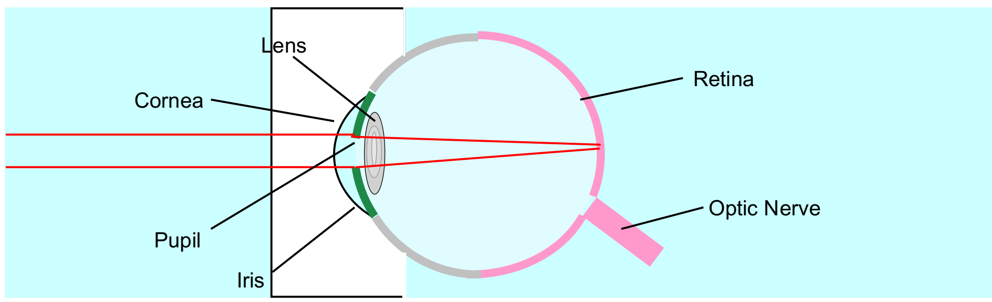


Figure 4.14 – Swim goggles (white rectangle) restore the air film at the cornea, allowing the eye to focus.

5. BENDING LIGHT – DIFFRACTION

How Thick is Your Hair?

CAUTION! Do not look into the laser or at any reflections of the laser from shiny surfaces.

Question: **How can you use a laser to measure the thickness of your hair?**

Materials

- Laser Pointer
- Tape measure or ruler
- A clothes pin to hold the laser power button down
- Something to mount the laser on, if needed
- Paper and tape

Science Facts

Imagine a tree standing in the sunlight. Behind it on the grass is a shadow where the leaves, branches and trunk block the sunlight from continuing onto the ground. Shadows caused by large objects like trees and people look very much like the object, although the shadow may be distorted depending on where the light is. However, when light passes through a very small opening, patterns of dark and light form that may look nothing like the object. This is called *diffraction*.

Diffraction is easiest to see with laser light, but you can see diffraction with ordinary light by holding two pencils close together side-by-side and looking at a light source through the tiny crack between them. A computer screen or blue sky works well as a light source, and you need to put your eye a few centimeters from the pencils. With practice, you will see dark and light bands that we call "fringes". (Figure 5.1) The bands are caused by the diffraction of light as it passes through the tiny opening. Diffraction is one of the most fascinating aspects of light!

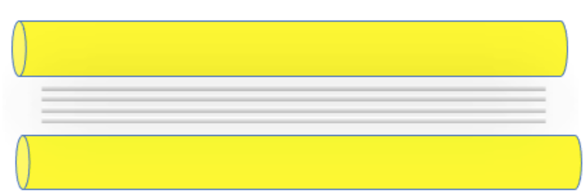


Figure 5.1 - Representation of the fringes between two pencils. This shows only a small part of the pencil and the crack between them is actually only a millimeter or so across. The fringes are parallel to the crack.

Scientists have developed equations that predict what the diffraction pattern will look like when light passes through or around small obstacles. In this Exploration you will shine laser light around a hair and observe a pattern of dark and bright spots. We'll measure these and calculate the width (diameter) of the hair.

To do the calculation we need a way to tell which fringe we're talking about. They all look about the same so we number them, starting at the center of the pattern. The first dark fringe nearest the center of the pattern is m=1, the next is m=2 and so on. Figure 5.2 shows how the dark fringes are numbered. You will actually see many more fringes than in Figure 2, and they probably won't be sharp lines as shown in the drawing. The center of the pattern will be a little blurry, as shown in the photo on the left of Figure 5.2.

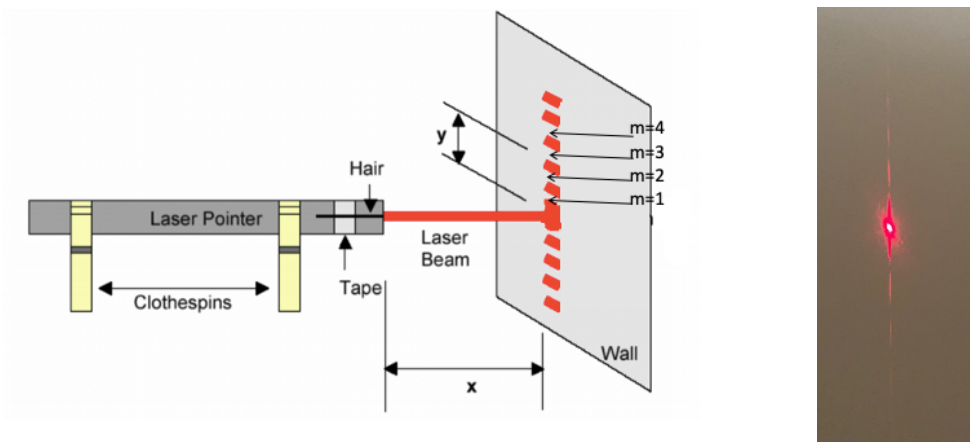


Figure 5.2 – (Left) Diffraction pattern caused by a hair. (right) "x" is the distance from the hair taped to the laser to the wall or screen. "y" in this diagram is the distance from the (bright) center of the pattern to the third, or m=3, dark fringe. The distance to the screen is much greater than shown. (Right) Photograph of the hair diffraction pattern. This was taken from about 2 meters from the end of the laser.

The formula to calculate the diameter of the hair is:

$$d = \frac{m\lambda x}{y}$$

In this formula:

d = diameter of the hair

m = the order, or number from the center, of the dark fringe you measured (1,2,3, etc.)

λ = the wavelength of the light (This is written on the laser warning label.)

x = the distance from the hair to the wall or screen

y = the distance from the bright center of the pattern to the dark fringe you are measuring

You can see that you need to know which fringe you are looking at (*m*) as well as the distance to the fringe.

Procedure and observations

1. Tape a piece of hair across the output aperture of a laser pointer. Be sure the laser is off when you do this!

2. Point the laser pointer at a wall approximately 2-3 meters away, far enough so the fringes are separate enough to measure. Tape a piece of paper to the wall to serve as a screen that you can write on. (Please don't write on the wall!)
3. Turn on the laser pointer and observe the pattern formed on the wall.

   What does this pattern look like? Does it look like the shadow of a hair? Are there many fringes or just a few? Are they clear or blurry?
4. With a pencil, mark the center of the pattern. Call this ***y*** =0. Mark the positions of several dark fringes on either side and number them – m = 1 for the closest to the center, then m=2, on so on.
5. Measure the distance from the laser pointer to the wall and record the value of ***x***. Now you can take the paper down.
6. Measure the distance between the center of the pattern (***y*** = 0) and one of the dark fringes you marked. Also record ***m***, the order of the fringe whose distance you measured. Record the values of ***y*** and ***m***.
7. Record the wavelength of the laser. It should be listed on the side of the laser pointer (it's typically 650 nm). Be sure the laser is off when you look for the label!
8. Using the equation to calculate the diameter of the hair. It should be approximately 70-100 μm (one micrometer = 1/1,000,000 of a meter).

Conclusions

Compare your results with your classmates. Is there a difference between blonde and brown hair? Some students have measured the size of their pets' hair! What might be a practical use of this experiment?

Data for the Thickness of a Hair Experiment

Type of hair you used (color, coarse or fine, etc): ___________________________

x = ____________________

m = ____________________

y = ____________________

λ = ____________________

Calculated hair thickness (diameter): ______________________________

Exploring Resolution

__Question:__ **How close together can words be on a sign so you can still read it from a distance? How close can stars be to be seen as separate objects? Does it depend on wavelength (color)?**

Materials

- Patterns of red dots and blue dots, 1 mm across, spaced 1 mm apart. Draw them on a piece of paper or print Figure 5.4 on white paper using a color printer.
- Meter stick

Science Facts

When light passes through a small opening, it spreads out, or diffracts. The diffraction pattern that results from light passing through a small round hole is a central bright spot (called the Airy disk) surrounded by dimmer rings of light around the disk in bull's eye fashion. (Figure 5.3) The size of the center disk depends on the wavelength (color) of the light, the size of the hole and on how far the hole is from the viewing screen. It might surprise you to learn that light passing through a small hole spreads more than light passing through a larger hole! Red light also spreads out more than blue light.

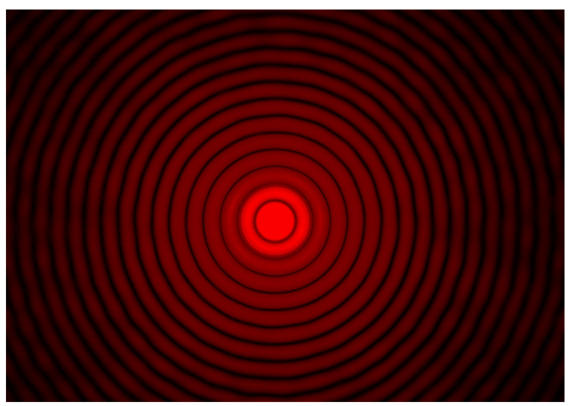


Figure 5.3 – Photo of the diffraction pattern that forms when red laser light passes through a 0.09 mm pinhole. (from Wikimedia Commons, user Bautsch, Public Domain)

When light from two small points of light (like stars) pass through the same hole (like the pupil of your eye), the light from each source will produce its own diffraction disk. *Rayleigh's Criterion* states that you will be able to tell that there are two small dots rather than one dot when the center of one diffraction disk falls on the edge of the other. (Figure 5.4) If the disks are closer than that or farther away, the two spots will blur together. Of course, this assumes that the system making the image of the dots (your eye) is otherwise perfect, which isn't usually the case. Rayleigh's criterion also applies to the lenses of instruments such as microscopes and telescopes. Even though they can have large apertures, tiny points of light at a large distance can still appear as one blur.

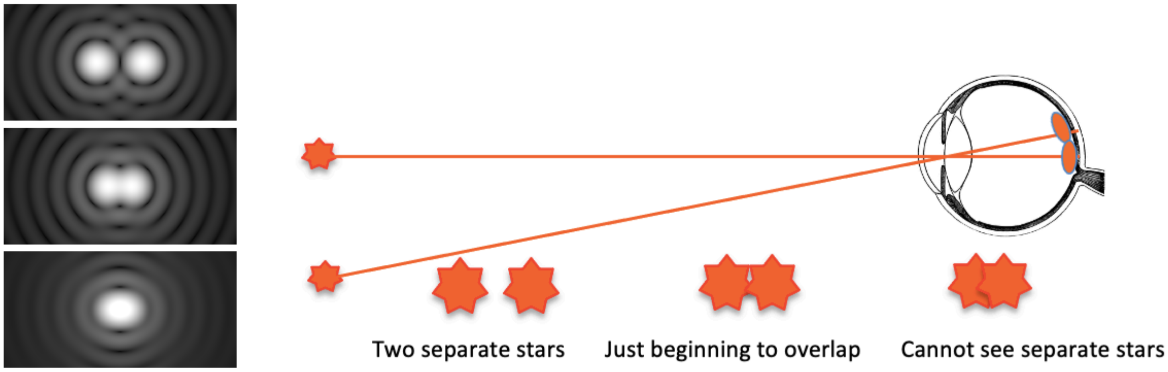


Figure 5.4 – (Left) Rayleigh's criterion. (From Wikimedia Commons, user Spencer Bliven, public domain) (Right) When the diffraction disks are overlapping the two stars appear as one blob. In reality the distance to the stars is, of course, much farther.

Procedure and Observations

1. Copy or print the pattern shown in Figure 5.5. Tape the pattern on a wall.
2. Stand far enough away from the patterns in a well-lighted room so that they appear to be solid lines, that is, you can't see separate dots. Walk slowly toward the patterns. Carefully observe the patterns. At some point can you see separate dots instead of solid lines? Which dots can you see first, red or blue?
3. Record the distance where you can see the separate blue dots and the distance where you can see the separate red dots.

Questions/Conclusions

Does the distance at which the spots can be resolved depend on color? If so, how?

Application

Diffraction and Rayleigh's criterion limits how small letters can be on highway signs and how close together lights on an airport tower can be. It also explains the style of painting called *Pointillism*, or stippling. In these paintings, millions of tiny dots merge together when viewed from a distance. In fact, two neighboring dots of different color can appear to form a third color when viewed from far away. How can this be? If you live near an art museum, see if they have any Pointillistic paintings on display and note at what distance the different color dots begin to merge. What other very common devices depend on colored dots appearing to merge together?

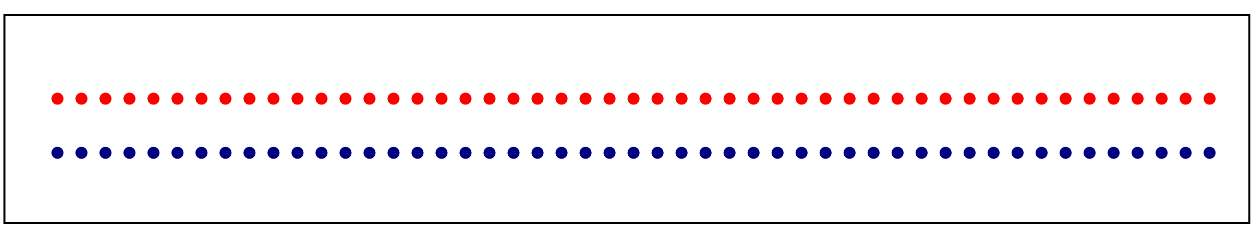


Figure 5.5 - Red and Blue dot pattern

6. EXPLORING POLARIZATION

Exploring Polarized Light

<u>Questions:</u> What is polarized light? How is polarized light produced? What is polarized light used for?

Materials

- You will need a polarizing filter to detect polarized light. Polarized sunglasses will do if you have them. Or you can buy inexpensive polarizing filters from the sources in the Resource chapter. Photographers often have polarizing filters but they can be expensive. For some experiments you can use the polarized light from an LCD screen like a tablet or laptop screen.
- Bowl of water (or a lake if you're near one!). You can also use a polished floor.
- Transparent plastic objects: ruler, protractor, comb, etc.

Science Facts

Imagine you and a friend are holding the ends of a rope. You shake your end up and down and waves travel down the rope to your friend. You could also shake the end of the rope side to side or in any other another direction and the waves you make will change their vibration direction to match. (Figure 6.1)

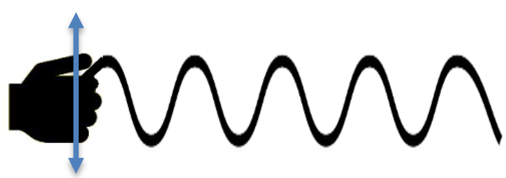


FIgure 6.1 – Shaking the end of a rope to make waves.

Like the waves you made on a rope, the vibrations of light waves are perpendicular to the direction that the light is traveling. *Natural* or *randomly polarized* light has waves that vibrate in all directions, and the direction of vibration changes randomly in time. In Figure 6.2, the arrows in the diagram on the left represents natural, unpolarized light. The wave is traveling in the direction of the blue arrow, and some of the vibration directions are shown in red.

The diagram on the right represents *polarized* light, with only up and down vibrations. When light is polarized, the vibrations are in one direction only. You may wonder if polarized light is unusual. In fact it's around you all the time! Polarized light may be produced by passing it through a polarizing filter (sometimes called a polarizer), scattering it from molecules (like air molecules), reflecting it from a nonconductive surface, and or passing light through certain crystals. In this Exploration you will make and observe polarized light.

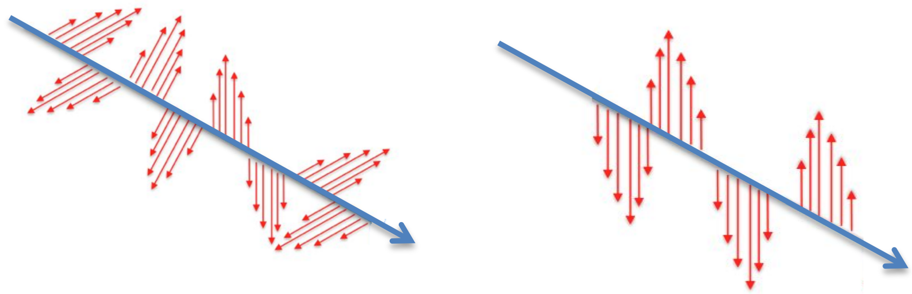


Figure 1 - Natural (left) and vertically polarized (right) light. The blue arrows show the direction that light is traveling. The red arrows represent the direction of vibration of light waves- on the left, waves vibrate randomly in many directions, on the right, all waves are vibrating in the same direction, in this case vertically.

Procedure and observations

Activity 1 – Reflecting polarized light

1. Look at the still surface of a bowl of water. (You can also look at a polished floor.) Rotate the polarizer (or sunglass lens) while looking through it

<u>Observations:</u>

- What do you see? Does the reflection from the surface of the water change?
- When you can see the brightest reflection, the polarizer is allowing light wave vibrations to pass. The waves reflected from the water are vibrating mostly horizontally so they can pass through the filter when it is held with the *transmission axis* horizontal. Like the slats in a picket fence, the polarizer is aligned to let this vibration through.

2. Mark the polarizer with a piece of tape so you know which direction is the transmission axis. If you are using sunglasses be careful not to damage the lens.
3. Repeat with the other polarizer.

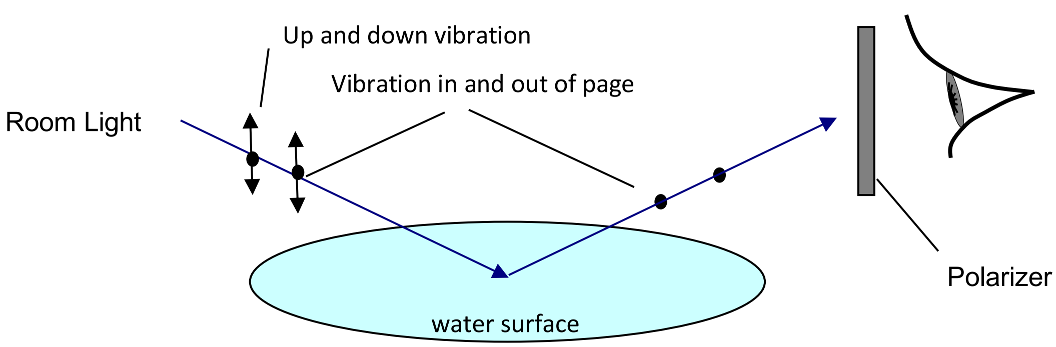


Figure 6.2 - Reflecting polarized light. Randomly polarized light (coming from the left) is reflected so that it is polarized (on the right). The double tailed arrows represent vibration in the plane of the page. The dots mean vibration in and out of the page (they represent the tail of an arrow). Reflected light from a surface such as water, ice, or even a polished floor mainly has wave vibrations in one direction. (The viewing angle determines how polarized the reflected light is. We'll ignore this.)

Activity 2 – Polarizer pair

1. Now that you have labeled the transmission axis of each polarizer, look through one of them at a source of light (a lamp is fine). The light you see passing through the polarizer is linearly polarized, that is, the waves all vibrate in the same direction! You can change the direction of polarization by rotating the plastic but your eye can't see the difference because humans can't sense polarization.
2. Hold the polarizer so that it is producing vertically polarized light. (The transmission axis is vertical.) Place the second polarizer in front of the first with its transmission axis also vertical. Without moving the first polarizer, rotate the second through 360 degrees (Figure 3).

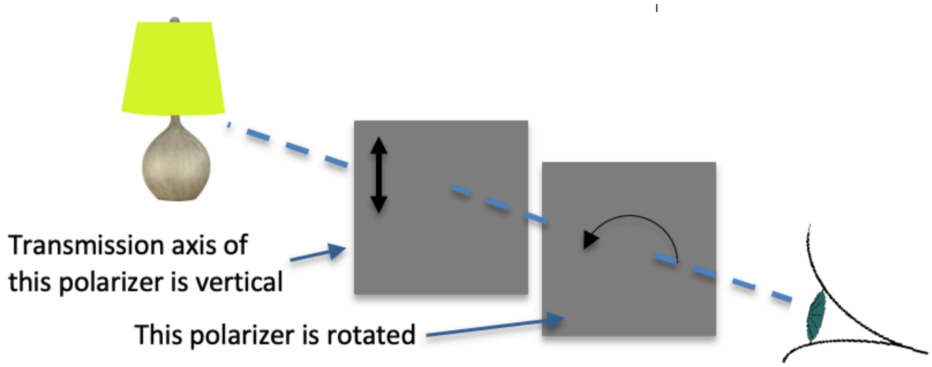


Figure 6.3 – Looking through two polarizers. The front polarizer is rotated. If you don't have two polarizers, you can use a single polarizer (like sunglasses) and the light from an LCD screen on a laptop or tablet.

Observations:

- How does the lamp appear when you look through one polarizer, compared to looking directly at it without a polarizer?
- What happens when you rotate the front polarizer?
- How many times does the light dim during the 360-degree rotation?

Conclusions:

How does the polarization of light explain your observations?

How do polarized sunglasses work to cut down glare? Does it matter in what direction the lenses are mounted in the frames?

If you see some really inexpensive glasses in a dollar store marked "polarized" how can you find out if they really are polarizing or just dark tint?

Activity 3 – Polarization by scattering

When light is scattered from very small particles like molecules, the scattered light is polarized. This is called *Rayleigh scattering*. One molecular scatterer that is easy to find is air! On a sunny day, look at the blue sky through one of the polarizers or a pair of polarized sunglasses. Look at a patch of sky AWAY from the sun, and rotate the polarizer in front of your eye as you look through it. Look at other parts of the sky as well. **DON'T LOOK AT THE SUN!**

Observation:

- What do you see when you rotate the polarizer?

Conclusion:

What does this observation tell you about the light scattered by the atmosphere? Bees and other insects use the polarization of the sky to navigate (their eyes are adapted to sense polarization). They have to stay home if the sky is cloudy!

Activity 4 – Stress patterns in plastic (changing the direction of polarization)

Once again, look through the two polarizers toward a lamp. Arrange them so the transmission axes are crossed and no light gets through. Place a piece of plastic film (food wrap is fine) between the "crossed" polarizers, and stretch the plastic film. Look through both polarizers and the film. (Figure 6.4)

You can also hold the plastic film in front of an LCD screen (like a laptop or TV) and just use one polarizer. The light from an LCD screen is polarized.

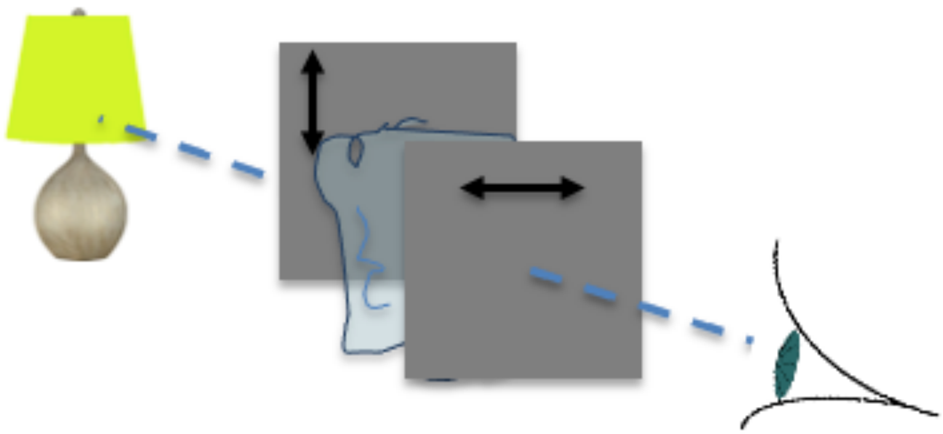


Figure 6.4 - Looking through a "sandwich" of two polarizers with plastic in between

Observations:

- What do you see when you look through the crossed polarizers with nothing between them?
- What happens when the film is between the polarizers?
- Does what you see change if you stretch the film?
- What if you rotate one of the polarizers?

Conclusion: What does the plastic film do to the polarized light passing through the first polarizer? Why do the colors appear?

Place other plastic transparent objects between the polarizers- a clear plastic ruler (twist it and see what happens), a comb, a protractor, or a pair of eyeglasses (look at the lenses).

Applications

Polarized light can be used to study stresses in a structure. If a model of a structure such as a bridge is built of transparent plastic, it can be weighted to simulate actual operating conditions. Viewing the model in polarized light helps to visualize where the structure will stressed.

Figure 6.5 - Eyeglasses viewed between to crossed polarizers. The lenses are squeezed by the frames.

Photographers also use polarizing filters. The two photos below were taken one after the other on a sunny day. For which one did the photographer place a polarizing filter over the camera lens? How can you tell? Why would a fisherman want to wear polarized sunglasses?

Figure 6.6 – A duck on a pond with and without a polarizing filter on the camera. Photos courtesy Albert Yee, Philadelphia, PA)

The Magic Box - Fun with Polarization

OPTICS MAGIC!

<u>Question</u>: Can you use light to make a magic box with a "wall that isn't there"? Where does the wall come from? Why can you push your finger through it with no resistance?

<u>Materials:</u>

- A small rectangular cardboard box such as a shoe box or tissue box
- Four small (about 4 cm) square linear polarizing filters
- Tape

<u>Science facts</u>

Before you do this experiment you should understand how polarized light works. You need to know the transmission axis of each of the four polarizers that you will use. Activity 1 of Exploring Polarization (page 40-41) tells you how to do this.

<u>Procedure</u>

1. Look through each polarizer in turn at the reflection from a shiny floor or water surface. Rotate the polarizer until the reflection is bright, the transmission axis will be horizontal. (See Exploring Polarized Light beginning on page 40.) Mark the polarizers along the edge parallel to the transmission axis.
2. To build the magic box, you need to cut rectangles from both the front and the back sides of the cardboard box. Each rectangular opening should be just large enough to be completely covered the two polarizer squares when they are placed side by side. (Figure 6.7) Carefully align these openings so you can look right through the box.

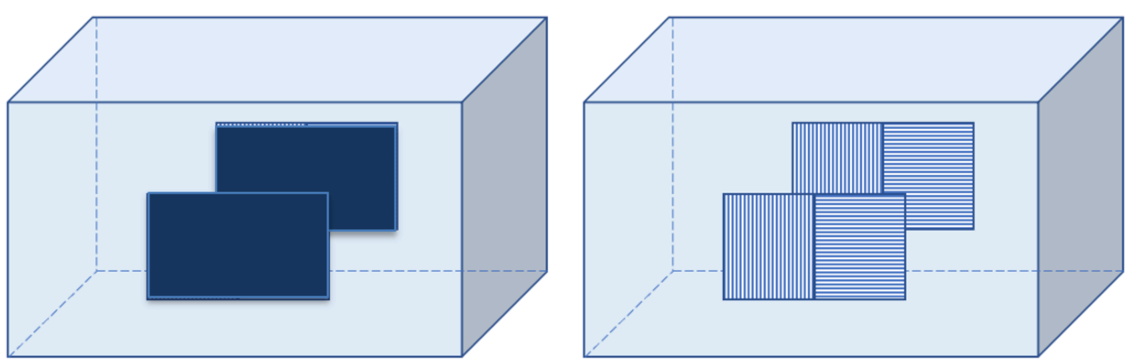


Figure 6.7 - Construction of the magic box. (Left) Rectangular holes cut in opposite sides of the box. (Right) Orientation of the four polarizers. Note that the transmission axes of matching pairs (left, right) are in the same direction. The polarizers completely cover the holes cut in the box.

3. Tape two of the polarizing filter squares to the front opening. One filter should have its transmission axis in the vertical direction and the other in the horizontal direction. Look through the box and describe what you see.

Observation:

- Can you tell just by looking through them which polarizer is vertical and which is horizontal? Why or why not?

4. Tape the other two polarizing filter squares over the back opening. The orientation of the transmission axes is correct if, when viewed from the front, the vertical polarizers (front and back) are both on the same side. (Figure 6.7)

Observation:

- What do you see when you look through the box, when you look through both pairs of polarizers?
- Does it matter if you look straight through (so the centers of the front and back of the box are lined up) or at an angle?

5. If one end of the box is open you can put your hand right "through" the wall, explaining to your audience that you have power over solid matter!

Conclusion:

Where does the "wall" come from? Why do you need to use polarizers?

Polarized Light Art

OPTICS MAGIC!

Question: Can you use polarized light to make a colorful picture out of colorless plastic?

Materials:

- Polarizing filter or sunglasses) and an LCD monitor from a laptop or tablet. You can also use two polarizing filters if you have them
- Pieces of cellophane tape (clear packing tape works well) or you can use the cellophane wrapping material from produce such as lettuce or broccoli. If you use cellophane you'll need a glue stick to attach it to the plastic square.
- Optional: A small square of clear plastic about the same size as the polarizers

Science Facts:

Before you use polarized light to create art, you should do the *Exploring Polarized Light* experiment on page 40. Here you learn that "natural" or randomly polarized light consists of light waves that vibrate in all directions. When light is polarized, the vibrations are in one direction only. In this exploration, you will create polarized light by using a polarizing filter or using the light from an LCD screen which is polarized inside the screen there is a piece of polarizing material.

In *Exploring Polarized Light* you also learn that if you place two pieces of polarizing filter so the transmission axes are parallel, nearly all the light passes. If the transmission axes are at right angles, no light passes. But if you put certain types of material in between the crossed polarizers, some light may get through and colors may appear from clear colorless material.

In this Exploration we will use tape or cellophane to change the direction of polarization of light. (Some clear plastics also work- experiment!) You will make a "sandwich" with cellophane between an LCD screen and polarizer. Polarized light exits the LCD screen, and then the direction of polarization is changed when it passes through the cellophane. The amount the polarization direction changes depends on the wavelength (color) of the light as well as the thickness and direction of the cellophane. If you then rotate the top polarizer, you will see different wavelengths at different angles of rotation. (Figure 6.8)

Procedure

1. Cut the pieces of cellophane or tape into various shapes. Experiment by varying the thickness of the shapes from one to several layers thick.
2. Stick the tape onto the plastic square. If you use plain cellophane you can attach it with a glue stick. The clear plastic is to protect the LCD screen from the sticky glue or tape. NOTE: Not everything sold as "cellophane" is really cellophane (which is made from cellulose). Some plastic films sold as cellulose don't work very well in this experiment. Try a variety of materials and see what works best!

3. When your piece of "art" is complete, place it against the LCD screen. Look at the piece you assembled through a polarizing filter or sunglasses. Rotate the filter- what do you see?

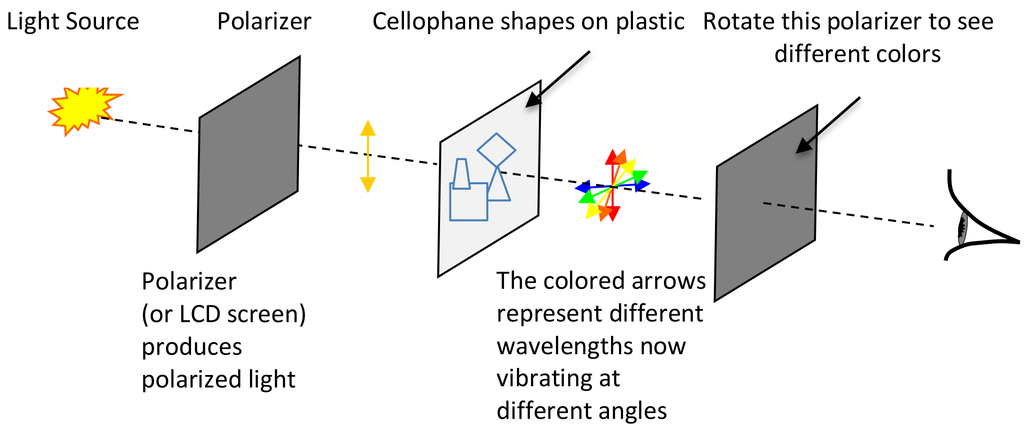


Figure 6.8 - Colors are produced because the cellophane rotates the direction of polarization. How much it is rotated depends on both the wavelength of the light and the thickness of the cellophane

Conclusions

Did the thickness and direction of the cellophane make a difference in the color you saw? What other materials would this work with besides cellophane?

Application

Austine Woods Comorow was a well-known artist who used this technique, which she called *Polage®*, to create beautiful works of art that change as you look at them through a moving polarizer. Some of her pieces cover complete walls in museums and other public spaces. You can see her art on her website austine.com.

For more on polarization in nature, visit the web site polarization.com.

7. EXPLORING SCATTERING

<u>Question:</u> Why is the sky blue?

Materials

- 1 fish tank (A small container will not work as well.)
- 1 flashlight, the kind you can focus to a narrow beam is best but not essential
- Several drops of milk or cream

Science Facts:

Why is the sky blue? Sunlight, as you know, contains into all the colors of the rainbow. When sunlight passes through the atmosphere, the shorter (bluer) wavelengths are scattered in all directions by tiny molecules of gas (mainly nitrogen and oxygen). Longer (redder) wavelengths travel in straighter lines with much less scattering. This is called *Rayleigh scattering.* "Sky blue" is not a single blue wavelength because the light from the sky includes a small amount of other scattered colors as well.

On a clear day the sky directly above your head is deep blue because of the atmospheric scattering of blue light. But you may have noticed that toward the horizon, the blue color of the sky becomes paler, or less *saturated*. This is because light travels through a much deeper layer of atmosphere to get to your eyes when you are looking toward the horizon. (Figure 7.1) Over this longer distance the reds and greens have more time to scatter. The addition of the rest of the colors of the spectrum to the scattered blue light creates a whiter or paler shade of blue.

In this exploration, you will observe Rayleigh scattering in a fish tank filled with water to which a few drops of cream or milk have been added.

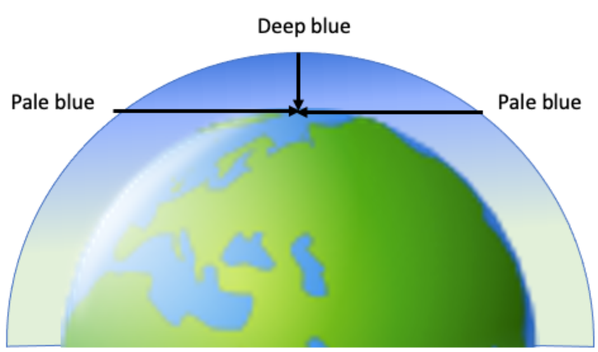


Figure 7.1 - Light travels through a deeper layer of atmosphere when you look toward the horizon than when you look straight up overhead. Note: Earth's atmosphere is much thinner than shown in this drawing, and it doesn't have a sharp edge.

Procedure

1. Fill the fish tank with at least 5 cm of water and add one or two drops of milk. Mix the water and milk in the tank so that it looks just barely cloudy. Too much milk will ruin this experiment, so you need to add it one drop at a time and observe the results before adding more. Note: You may be able to do this experiment in a tank with fish in it, especially if the water isn't crystal clear. Don't add milk and try to avoid the fish with the flashlight.
2. Shine the flashlight into one end of the tank as shown in Figure 7.2.

Observations:

- Observe the color of the flashlight beam in the tank from the side of the tank. Do you see a color tint? What color? The effect will be very slight. It helps to dim the room lights to see the faint color.
- Look at the beam through the water from the end of the tank. What color is the light? Look briefly at the color of the flashlight bulb (not too long or you'll see spots for a while). Compare the color of the light looking through the length of the tank to the color of the light when you look at it directly, not through the water. Explain the difference

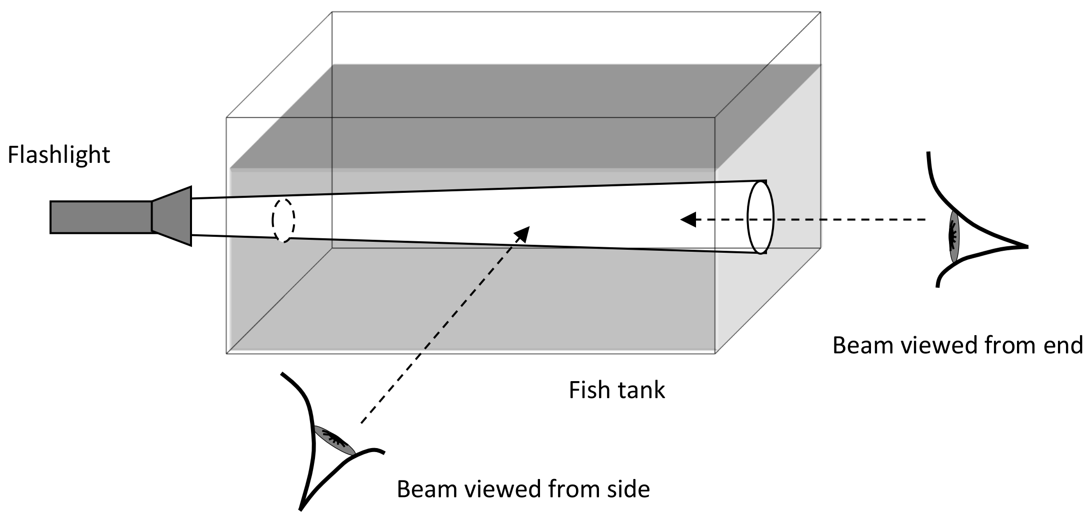


Figure 7.2 - Observing the light from a flashlight from the side and the end of the tank of water

Conclusion

Which end of the light spectrum, blue or red, is scattered out of the beam in all directions in the tank? Which end of the spectrum, blue or red, goes with little scattering from one end of the tank to the other? In your own words, use the results of this experiment to explain why the sky is blue. Why do you think the sun appears red at sunset? (Hint: Look at Figure 1.

Research

If the shortest wavelengths are scattered the most, why isn't the sky violet? (Hint: think about the spectrum of sunlight and how your eyes perceive color. What colors are your eyes most sensitive to? Least sensitive?)

Optional Exploration

Try this if you have already done the *Exploring Polarized Light*. Look through a polarizer at the beam from the side of the tank. Rotate the polarizing material in front of your eye (Figure 7.3). What do you see? Look into the end of the tank, toward the light, and repeat. Where is the light polarized?

Is the blue sky polarized? Take your polarizer outside and look through it at the sky. DO NOT LOOK AT THE SUN! Some insects have special structures in their eyes that can detect polarization. How might being able to see polarized light help them navigate?

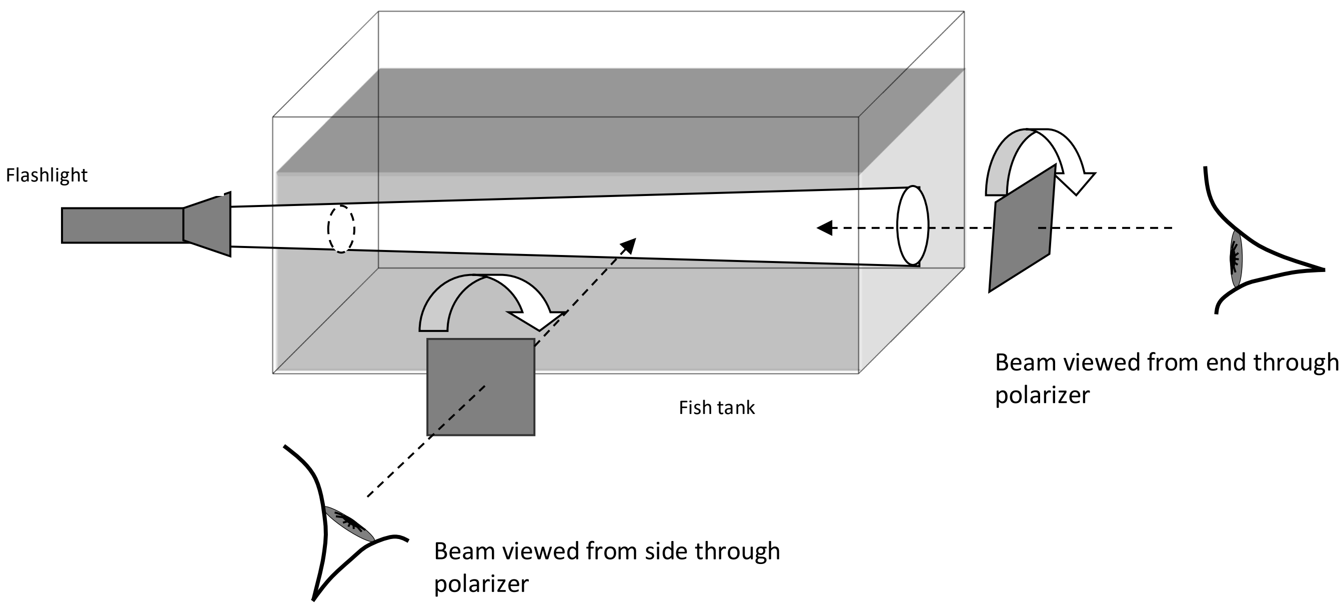


Figure 7.3 - Observing the flashlight beam through a polarizer.

8. EXPLORING LASER BEAMS

CAUTION! Do not look into the laser cavity or at any reflections of the laser from shiny surfaces.

Question: Does laser light spread out as the beam travels through space? In what other ways is a laser beam different from a flashlight?

Materials:

- Laser pointer (a red pointer from a dollar store is fine)
- Flashlight
- Diffraction grating or a discarded recordable CD
- Piece of waxed paper
- Meter stick and ruler

Science Facts:

Did you know the word LASER is an acronym? It stands for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. A laser is a special type of light source that has unique properties that make it very important for today's technologies. Unlike a flashlight, a laser typically produces only one wavelength. We say that lasers are *monochromatic* (one color). Laser light is extremely bright; it can be brighter than the sun! Laser light also spreads out very little when shined across a distance. (See Figure 8.1.) Laser light is also *coherent* which means the waves in the beam stay "in step" with each other. This leads to interesting optical effects, as you will see.

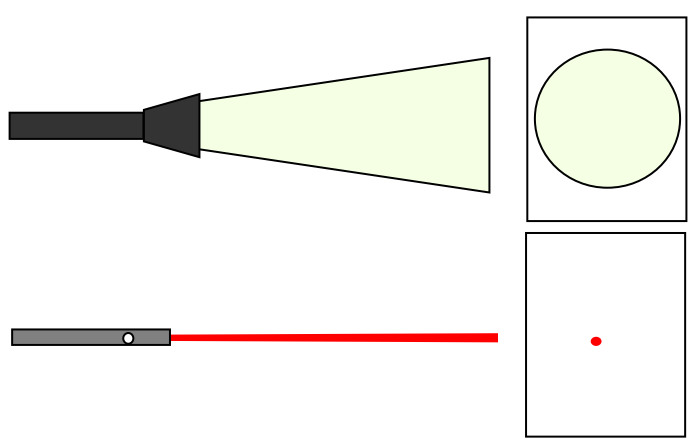


Figure 8.1 – Flash Light vs. Laser Pointer. Flashlights produce "white" light, while lasers pointers produce colored light. (Other types of lasers produce types of light you can't see like UV or IR.) The spots of light produced by each type of light may be seen by shining it on a piece of paper taped to a wall.

The special properties of laser beams allow them to:

- Travel very far distances (to the moon and back!)
- Be focused down to very small spots (to less than 1/10 the size of a human hair) for cutting, welding, and drilling steel, ceramics and other really hard materials
- Make very precise measurements (like measuring the size of an atom)
- Cut tissue in laser surgery without blood

You know that when you turn on the light bulb in a lamp in your home, the light spreads to illuminate the entire room. A flashlight beam, on the other hand, spreads less and illuminates a only circular area. We call this spreading of a light *divergence*. Do you think a laser beam spreads out? After all, laser pointers are used to make small spots on a screen across the room.

In this exploration, you will find out if a laser beam diverges and learn some other ways a laser is different from a flashlight.

Procedure:

1. Tape a piece of white paper on the wall.
2. First, you will look at laser divergence, or spreading. Working with a partner, hold the flashlight about one half meter from the wall and shine it onto the piece of paper. Mark the "edges" (diameter) of the beam. You will have to make your best guess about where the beam edges are. Repeat with the laser.
3. Move back as far as you can from the wall and shine the flashlight onto the piece of paper again. Again, mark the edges of the beam. Repeat with the laser. BE CAREFUL not to shine the laser in anyone's eye! Keep the beam well below eye level.

<u>Observation 1</u>:

- Which beam spreads more, the flashlight or the laser? Did the laser spread at all? What would happen if you tried to shine the laser to hit a target 100 meters away? What do you think happened when scientists shined a laser at the moon?

4. Next, you will look at the color of laser light. If you have a diffraction grating, shine the flashlight beam through it and onto the piece of paper on the wall. Notice any colors that you see on the paper. Repeat with the laser pointer.

   If you don't have a diffraction grating, reflect the flashlight beam from the CD onto the wall. What colors do you see? Repeat with the laser the laser and carefully reflect the beam from the CD or DVD onto the paper on the wall. Do not let the laser shine in anyone's eyes!

<u>Observation 2</u>

- What colors make up the flashlight beam? What about the laser beam?

5. Finally, you will observe one of the effects of laser coherence. Put the waxed paper over the end of the flashlight and shine it on a piece of white paper or a plain wall. Repeat with the laser.

Observation 3

- What did the flashlight spot look like? Did the laser light spot different (aside from being red)? Do you notice any shimmering spots? (This is called laser *speckle.*)

Optional Math Exploration- Use math to predict the size of a laser beam at a distance from you.

You will need to carefully measure the diameter of the beam at two different distances from the lasers. You also need to measure the distance between the wall and the laser each time.

1. Hold the laser about one half meter from the wall so the beam is on the piece of paper. With your tape measure, measure the actual distance from the wall and record this distance as $\mathbf{X_1}$. See Figure 8.2.
2. Measure the diameter of the beam. One way to do this is to mark what seem to be the edges of the beam on the paper with a pencil, then turn off the laser and measure the distance between the marks. Record this value as $\mathbf{D_1}$.
3. Move back as far as you can from the wall and shine the laser onto the piece of paper again. BE CAREFUL not to shine the laser in anyone's eye! Keep the beam well below eye level.
4. With your tape measure, measure the diameter of the beam again. Record this value as $\mathbf{D_2}$.
5. With your tape measure, measure the distance from the wall. Record this value as $\mathbf{X_2}$.

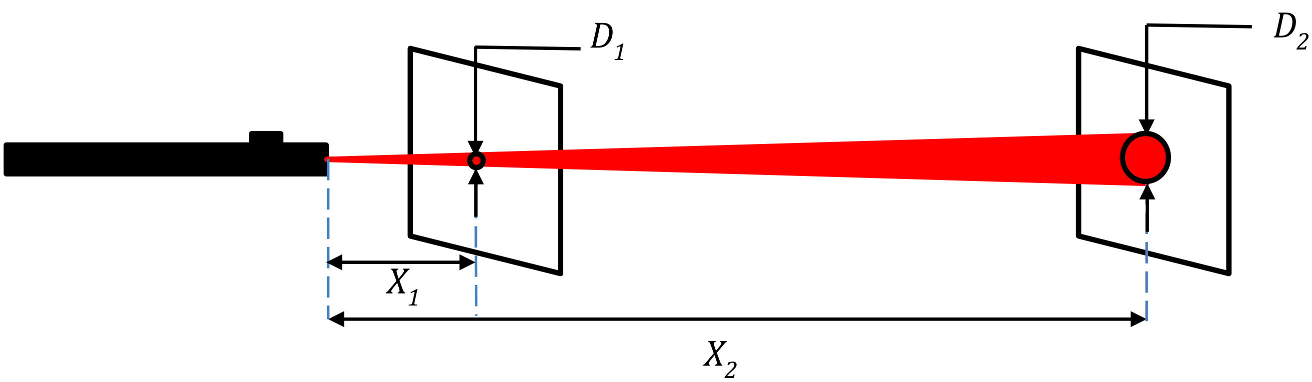


Figure 8.2 - Measurements to determine spreading of laser beam

DATA from Math Exploration

X_1 = ____________ D_1 = _______________

X_2 = ____________ D_2 = _______________

You can use the formula on the next page to calculate how large the beam diameter will be will be at a distance X_3. In the formula, D_3 is the diameter of the beam at the distance X_3. Can you calculate what the beam diameter would be:

1. 100 meters away
2. 1609 meters away (1 mile)
3. 385,000,000 meters away (the average distance to the moon)

$$\text{Beam Diameter at distance } X_3 = \frac{D_2 - D_1}{X_2 - X_1} . X_3$$

Conclusions

How is a laser beam different from a flashlight? Name as many differences as you can.

Why can't you shine a flashlight on the moon and have the reflection be received back on Earth?

9. LIGHT YOU CAN'T SEE

CAUTION! Do not stare at the UV light or shine it in someone's face.

Exploring Fluorescence and Phosphorescence

Questions: What are fluorescence and phosphorescence? How are they similar? How are they different?

Materials

- UV flashlight or UV LED (See the Resources chapter for where to find these)
- A red laser pointer
- Other sources of light such as colored LED finger lights (See the Resources chapter for sources)
- A square of glow-in-the-dark material (or glow-in-the-dark stars or other toys)
- Fluorescent minerals or other fluorescent materials. Many laundry detergents have whiteners that fluoresce. The ink that you are stamped with upon entry to some venues is also fluorescent (see the Resources chapter for sources of this ink).

Science Facts

The electrons in atoms are generally in their lowest energy state. Sometimes, though, they can be *excited* into a higher energy level by heat, a high voltage, absorbing light or another means. Visible light can be produced when the excited electrons return to a lower energy level. The energy of the light *photon* is equal to the difference of the two energy levels, that is, to the amount of energy the electron loses when it goes to a lower level.

The excited electrons in a material may all give off their energy quickly – this called *fluorescence*. For example, in a fluorescent light bulb high energy ultraviolet light produced inside the bulb causes the atoms in the bulb's coating to produce visible light. Sometimes the electrons release energy slowly, over a longer period of time. This process is known as *phosphorescence*, and it is what causes glow-in-the-dark materials to emit light for a long time.

The ultraviolet light waves used in this exploration have higher frequency and higher energy than visible light. The longer the wavelength of light, the lower its frequency. So red light photons have less energy than blue, which have less energy than ultraviolet.

Part 1: Phosphorescence

Procedure

1. In a darkened room (it does not need to be completely dark), place the item with glow-in-the-dark material on a table. What do you think will happen if you shine each of the light

sources – the laser, the UV light, a colored LED – on the material? Write down your predictions before you try it.

2. Test your predictions by shining each of the lights onto the material. Record

- Which color lights make the material glow. Why do only some colors make the material glow?
- How long does the material glow after the light is removed?
- Were there any surprises?

Part 2: Fluorescence

Procedure

1. Observe the fluorescent material under normal room lights. If you have whitening detergent, dab a bit on the back of your hand.
2. Now turn off the room lights so that the room is dark. Shine the UV light on the materials and observe and record any differences in appearances when the light is on compared to when it is off. Does the glow last after the light is removed?
3. Try the other colored lights- do you notice anything? Why does this only work with UV? (How is UV "different" from visible light?)

Conclusion

Both fluorescence and phosphorescence result from atoms releasing energy in the form of light. What is the difference between them? Why do you think detergent might be fluorescent?

Exploring UV Light and Sunscreen Lotion

CAUTION! Do not stare at the UV light or shine it in someone's face.

Question: How well does sunscreen protect against UV light?

Materials:

- UV light (or you can use the sun- but do not look at the sun!)
- UV beads (See the Resources chapter for sources for UV color change beads)
- Different types of sunscreen lotion, small pieces of glass or plastic wrap, and a brown plastic medicine container

Science Facts

UV beads contain a pigment that responds to ultraviolet light by changing color. UV light has high energy and can cause skin damage such as sunburn, wrinkles and skin cancer. Sunscreen lotions protect against UV by absorbing the light so it does not reach the skin.

Procedure

1. Expose the UV beads to the ultraviolet light or to the sun. What do you observe?
2. Return the beads to a dark place (or bring them in the house) until they turn white again. (Note that if UV beads are left in sunlight they will eventually bleach and no longer change color.) Or, use a second group of beads. Place the beads under the glass or plastic and expose them to ultraviolet light or to the sun- do they still change color?
3. Spread the sunscreen on the glass or plastic wrap. (You can also put it directly on the beads but it's messy!) Place the sunscreen-covered glass or plastic it over the beads and expose to the UV light again. Be sure the beads are white before you begin this experiment. What do you observe? Is all of the UV light blocked? If you have different types of sunscreen lotion compare the effects of different types.
4. Place a few of the white beads in the medicine container and expose to UV light. Do the beads change color? Why do you want to protect medications from UV light?
5. Many new fabrics have an SPF number. Do they protect any better than a cotton tee shirt? Try using different fabrics and place a UV bead underneath and then expose to UV light. What was the result?

Conclusion:

How does sunscreen protect your skin from ultraviolet light? Are all sunscreen lotions equally effective? Why is it important to protect your skin from exposure to ultraviolet light?

10. RESOURCES

Where to Find Supplies

Of course, the go-to place is often *Amazon.com* but if you want to look locally try a dollar store. Etsy (*etsy.com*) and EBay (*ebay.com*) can be good sources of materials too.

1. Inexpensive **laser pointers** are available from a number of sources, but be sure you are purchasing a *legal* pointer (<5 mW in the USA). One good source is your local pet store- they sell red laser pointers as "cat teasers". Dollar stores like Dollar Tree often have laser pointers that are equipped with flashlights as well.
2. Color **LED finger lights**. Party stores and big box stores like Walmart have these on their websites. If you want to buy in quantity, check *Amazon.com* sellers. LED finger lights are the most convenient source of different color lights.
3. **Ultraviolet (UV) flashlights**. Inexpensive versions are sold to hunters as "urine finders"! Check *Amazon.com* for prices or visit your local sporting goods store.
4. **Watch glasses** can be found in chemistry labs. You certainly don't want to buy expensive ones, nor do you need them in quantity. If you can't find a chemist to give you a couple, try *Amazon.com* sellers.
5. **Ray boxes** are really cool for optics experiments but they can be expensive. You don't really need one for these Explorations, you can just use a couple of laser pointers (and a friend to help hold them). If you really want a ray box, Arbor Scientific has a set including a lasers ray box and acrylic shapes that eliminate the need for gelatin for around $100.

   Acrylic sheet mirror (if you have the means for cutting it) can be found at building supply stores, local plastics dealers and online at suppliers like Johnson Plastics Plus (*jpplus.com*).
6. You can buy **polarizers** at Educational Innovations, teachersource.com, if you don't want to use polarized sunglasses (which can be expensive). Rainbow Symphony online store (*rainbowsymphony.com*) sells polarizers mounted in slides and cardboard polarizing glasses for 3D movies (cut these in half to get two polarizers) however they just sell in quantity. If you'd like a LOT of polarizing material, the *polarization.com* shop sells it by the foot. Their laminated polarizer is rigid and easy to handle.
7. You can make your own **diffraction grating** from a scrap recordable CD. Scratch the metallic coating side, place tape over the scratch and pull to remove the coating. With sturdy scissors you can cut it into smaller shapes if desired. If you really want to buy a grating, Educational Innovations, *teachersource.com* and Rainbow Symphony Store *rainbowsymphony.com* sell single axis (sometimes called linear) gratings mounted in slides and in sheets. (Single axis works best for experimenting.)
8. **UV color change beads** are available at a number of vendors. We usually buy at Educational Innovations, *teachersource.com*.
9. **Fluorescent materials** Search for blacklight invisible ink (try *blacklightworld.com*) or use whitening detergent- it’s cheaper!

REFERENCES

1. Dumpster Optics lessons are online at pblprojects.org/dumpster-optics. There is no cost to download and use these lessons.

2. An older but still useful guide to laser pointer safety. www.lia.org/resources/laser-safety-information/laser-pointer-safety

3. Spectral bands used in measuring crop health eos.com/make-an-analysis/agriculture-band

4. ChemCam on Mars mars.nasa.gov/msl/spacecraft/instruments/chemcam

5. Spectral reflectance (including from a tomato) hyperphysics.phy-astr.gsu.edu/hbase/vision/spd.html

6. Details on making an oatmeal box camera users.rcn.com/stewoody/makecam.htm

7. The Hands-On-Optics instructions are available at spie.org/education/education-outreach-resources

8. The Brewster Kaleidoscope Society brewstersociety.com

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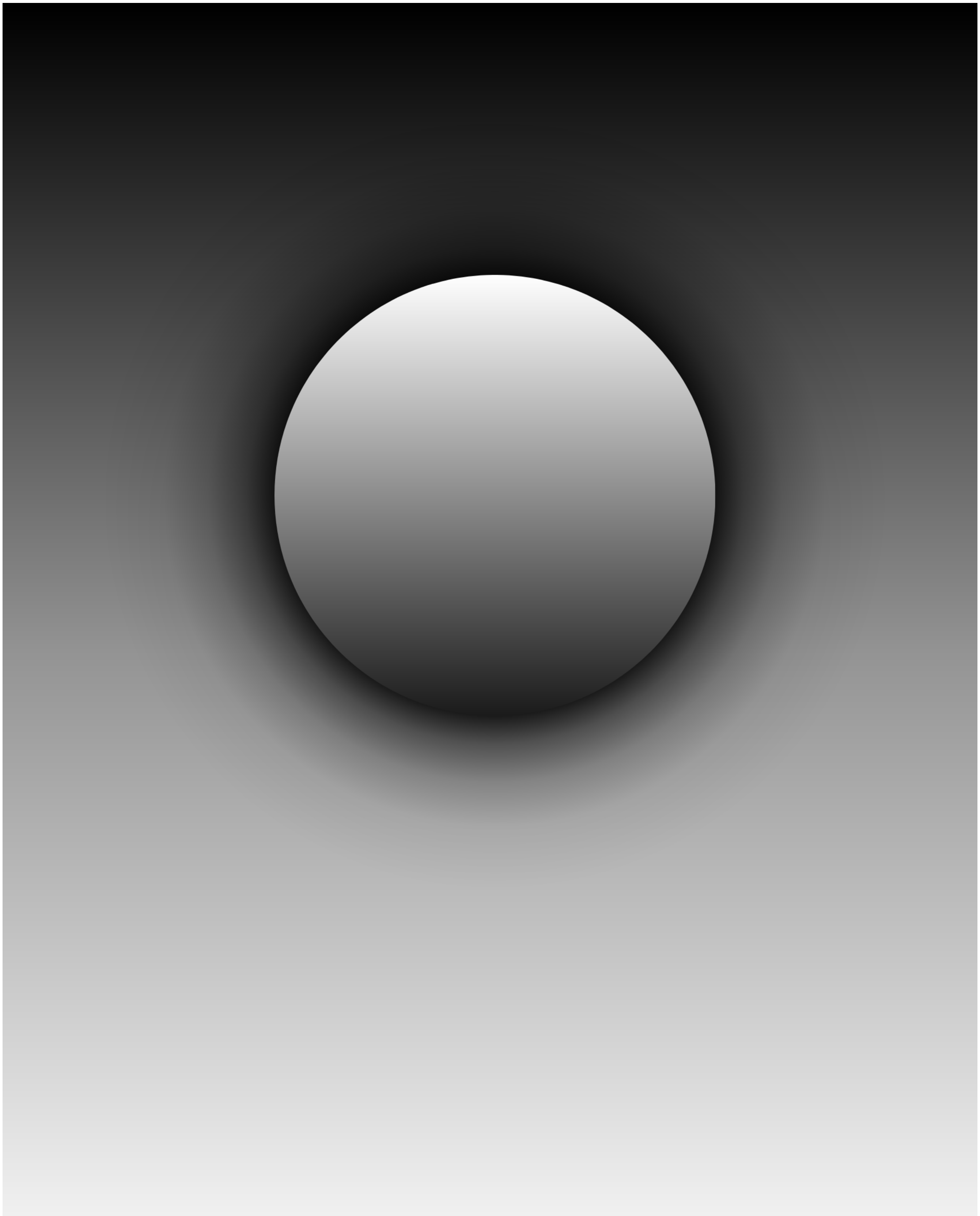
NOTES



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