LIGHT 1

Learn about refraction, reflection, beam scattering, optical density, transmission, and absorption! Students investigate the electromagnetic spectrum by using lenses, mirrors and more as they build several projects including an eye-balloon, pinhole camera, optical kaleidoscope as well as experiments in splitting shadows into a rainbow, going on a black light treasure hunt, getting colors from black and white, investigating chemiluminescence by mixing cold light, and making a beaker totally disappear.

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This curriculum is aligned with the National Standards and STEM for Science.

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Introduction

Greetings and welcome to the study of light. This unit was created by a mechanical engineer, university instructor, airplane pilot, astronomer, robot-builder and real rocket scientist… me! I have the happy opportunity to teach you everything I know about electricity over the next set of lessons. I promise to give you my best stuff so you can take it and run with it… or fly!

To get the most out of these labs, there are really only a couple of things to keep in mind. Since we are all here to have fun and learn something new, this shouldn't be too hard.

One of the best things you can do as the student is to cultivate your curiosity about things. *Why did that move? How did that spin? What's really going on here?*

This unit on light is chock full of demonstrations and experiments for two big reasons. First, they're fun. But more importantly, the reason we do experiments in science is to hone your observational skills. Science experiments really speak for themselves much better than I can ever put into words or show you on a video. And I'm going to hit you with a lot of these science demonstrations and experiments to help you develop your observing techniques.

Scientists not only learn to observe what's going on in the experiment, but they also learn how to observe what their experiment is telling them, which is found by looking at your data. It's not enough to invent some new kind of experiment if you don't know how it will perform when the conditions change a bit, like on Mars. We're going to learn how to predict what we think will happen, design experiments that will test this idea, and look over the results we got to figure out where to go from there. Science is a process, it's a way of thinking, and we're going to get plenty of practice at it.

Good luck with this unit on the magic of light!

For the Parent/Teacher:
Educational Goals for Light 1

Scientist are still trying to make heads or tails of this thing called light, and near as they can tell, it sometimes interacts like a particle (like a marble) and other times like a wave (like on the ocean), and you really can't separate the two because they actually complement each other.

Energy can take one of two forms: matter and light (called electromagnetic radiation). Light is energy in the form of either a particle or a wave that can travel through space and some kinds of matter, like glass. We're going to investigate the wild world of the photon that has baffled scientists for over a century. Low electromagnetic radiation (called radio waves) can have wavelengths longer than a football field, while high-energy gamma rays can destroy living tissue.

Here are the scientific concepts:

- Light has a source and travels in a direction.
- Sunlight can be blocked to create shadows.
- Light is reflected from mirrors and other surfaces.
- The color of light striking an object affects how our eyes see it.
- We see objects when light traveling from an object enters our eye.
- Light can travel through a vacuum, like space.
- Light can change speeds, but the maximum speed is through a vacuum (186,000 miles per second).
- The three primary colors of light are red, blue, and green. Red and green light mixed together make yellow light.
- Prisms un-mix light into its colors or wavelengths.
- Light changes speeds when it passes through a different material.
- Lenses work to bend light in a certain direction, called refraction.
- Concave lenses work to make objects smaller and convex lenses make them larger.

By the end of the labs in this unit, students will be able to:

- Design and build a simple refractor telescope using lenses.
- Know how to demonstrate how compound microscopes work.
- Understand how to determine how to measure the speed of light.
- Differentiate observation from inference (interpretation) and know scientists' explanations come partly from what they observe and partly from how they interpret their observations.
- Formulate and justify predictions based on cause-and-effect relationships.
- Conduct multiple trials to test a prediction and draw conclusions about the relationships between predictions and results.
- Construct and interpret graphs from measurements.
- Follow a set of written instructions for a scientific investigation.

Master Materials List for All Labs

This is a brief list of the materials that you will need to do *all* of the activities, experiments and projects in this unit. The set of materials listed below is just for one lab group. If you have a class of 10 lab groups, you'll need to get 10 sets of the materials listed below. Most materials are reusable.

- 12" fishing line
- 12" string
- 12" thread
- 12" yarn
- 8 index cards
- sliced cheese (individually wrapped)
- baby oil
- ball
- biconvex plastic lens
- book of matches
- box
- calculator
- CD or DVD
- chocolate bar (extra-large bars work best)
- chocolate chips
- clear tape
- crayons OR markers
- dark evening inside your house
- dark room
- diffraction grating
- disposable cups (6)
- dollar bill
- feather
- fingernail polish (red, yellow, green, blue)
- fire extinguisher
- flashlight
- glass jar (2)
- gloves
- glue stick
- goggles
- handheld magnifying lenses (2)
- index cards
- laser (optional)
- meter stick (2)
- microwave (only one for entire class)
- milk or flour
- mini marshmallows
- nail
- paper
- paper plates
- paperclip
- pencil
- penny
- razor or scissors
- red, green, and blue true-color light sticks
- round balloon, white, 9 inches
- rubbing alcohol
- scrap piece of cardboard
- strainer, such as a coffee filter
- tack
- tape
- tracing paper
- UV black fluorescent light
- votive candle
- water

Lab Safety

Goggles: These should be worn when working with chemicals, heat, fire, or projectiles. These protect your eyes from chemical splatter, explosions, and tiny fast-moving objects aimed at the eyes. If you wear glasses, you can find goggles that fit over them. Don't substitute eyeglasses for goggles, because of the lack of side protection. Eyeglasses don't provide this important side eye protection.

Clean up Messes: Your lab area should be neat, organized, and spotless before you start, during your experiment, and when you leave. Scientists waste more time hunting for lost papers, pieces of an experiment, and trying to reposition sensitive equipment… all of which could have easily been avoided had they been taught organizational skills from the start.

Dispose of Poisons: If a poisonous substance was used, created, or produced during your experiment, you must follow the proper handling procedures for disposal. You'll find details for this in the experiments as needed.

Special Notes on Batteries: Do not use alkaline batteries with your experiments. Find the super-cheap kind of batteries (usually labeled "Heavy Duty" or "Super Heavy Duty") because these types of batteries have a carbon-zinc core, which does not contain the acid that alkaline batteries have. This means when you wire up circuits incorrectly (which you should expect to do because you are learning), the circuits will not overheat or leak. If you use alkaline batteries (like Energizer and Duracell) and your students short a circuit, their wires and components will get super-hot and leak acid, which is very dangerous.

No Eating or Drinking in the Lab: All foods and drinks are banned from your classroom during science experimentation. When you eat or drink, you run the very real risk of ingesting part of your experiment. For electricity and magnetism labs, always wash your hands after the lab is over to rinse off the lead from the electrical components.

No Horse Play: When you goof around, accidents happen, which means chemicals spill, circuits short, and all kinds of hazards can occur that you weren't expecting. Never throw anything to another person and be careful where you put your hands – it could be in the middle of a sensitive experiment, especially with magnetism and electricity. You don't want to run the risk of getting shocked or electrified when it's not part of your experiment.

Fire: If you think there's a fire in the room (even if you're not sure), let your teacher know right away. If they are not around (they always should be), smother the fire with a fire blanket or use a fire extinguisher and send someone to find an adult. Stop, drop, and roll!

Questions: If you're not sure about something stop and ask, no matter what it's about. If you don't know how to properly handle a chemical, do part of an experiment, ask! If you're not comfortable doing part of the experiment, then don't do it.

Lesson #1: Rainbow Shadows

Overview: Imagine you're a painter. What three colors do you need to make up any color in the universe? (You should be thinking: red, yellow, and blue… and yes, you are right if you're thinking that the real primary colors are cyan, magenta, and yellow, but some folks still prefer to think of the primary colors as red-yellow-blue… either way, it's really not important to this experiment which primary set you choose.)

Here's a trick question – can you make the color "yellow" with only red, green, and blue as your color palette? If you're a scientist, it's not a problem. But if you're an artist, you're in trouble already. The key is mixing light, not paint.

What to Learn: The three primary colors of light are red, blue, and green. Red and green light mixed together make yellow light. Sunlight can be blocked to make shadows.

Materials

- flashlights (3)
- fingernail polish (red, green, and blue)
- clear tape (NOT translucent)
- a white wall (or another large white surface)

Experiment

1. Make your room as *dark* as possible for this experiment to work.
2. Cover each flashlight lens completely with the clear tape. Be sure to get the edges and around the rim.
3. Paint one flashlight's tape layer red, one blue, and one green. Make sure there are no unpainted spots.
4. Allow the nail polish to dry.
5. Turn off all the lights.
6. Shine the flashlights together onto a white wall. What color is the wall? Record it on your chart
7. Now turn off the red flashlight. What color do you see now? Record your observation.
8. Place your hand, a pencil, or another object in front of the flashlight. Wave it around a bit. What color shadows do you see on the wall?
9. Experiment with the different color combinations while filling out the chart with your observations.

Rainbow Shadows Data Table

Lens #1 Color	Lens #2 Color	Shadow Color

Reading

The universe is made of matter and energy. Matter is anything that has mass, and all ordinary matter exists in four states, which we cover in our *Chemistry* unit. Electromagnetic radiation (EM) is energy in the form of waves or particles that are emitted from a source and travel through space and even through certain kinds of matter.

Visible light is a form of energy that we can see with our eyes, and the organelles (called cones and rods) collect light from images that we see and transmit these to the brain. Visible light makes up a tiny part of the electromagnetic spectrum. This energy can be measured and specified by its intensity (how bright), frequency (wavelength), polarization (the direction of the electric field), and phase (time shift).

White light makes up all the colors of the rainbow: red, orange, yellow, green, blue, and purple. Prisms can un-mix light into the individual colors by bending the light by different amounts. The red, green, and blue are the primary colors of light that mix together to form every other color we see.

When light strikes a surface, it can travel through the surface completely, partially, or be entirely reflected back, depending on the surface it strikes. Light can also enter a material and get completely trapped inside by internal reflections. In some cases, light can be absorbed, and when this happens, the absorbing material can heat up, change color, change state, or re-transmit the light at a completely different wavelength.

Light can be filtered and dissected into a special signature that allows scientists to identify the patterns and be able to tell which element generated the light in the first place. These patterns, or light signatures, are used extensively by astronomers and chemists to determine the properties of the light and the chemical reactions required to generate the light.

Most light isn't detectable by the human eye, which makes studying light more like investigating a crime scene. You'll quickly be puzzling the pieces together to explain why pencils break in a glass of water, how to focus light energy to fry eggs, and how lenses bend light to distort and magnify images in telescopes.

Mixing the three primary colors of light gives white light. If you took three light bulbs (red, green, and blue) and shined them on the ceiling, you'd see white. And if you could magically un-mix the white colors, you'd get the rainbow (which is exactly what prisms do).

If you're thinking yellow should be a primary color – it *is* a primary color, but only in the artist's world. Yellow paint is a primary color for painters, but yellow light is actually made from red and green light. (Easy way to remember this: think of Christmas colors – red and green merge to make the yellow star on top of the tree.)

Troubleshooting: This experiment has a few things to be aware of. If you're not getting the colored shadows, check to be sure that the flashlight is bright enough to illuminate a wall in the dark. Be sure to shut the doors, shades, windows, and drapes. In the dark, when you shine your red flashlight on the wall, the wall should glow red. Beware of using off-color nail polish – make sure it's really red, not hot pink. Alternately, you could use brightly-colored cellophane.

If you still need help making this experiment work, you can visit your local hardware store and find three flood lamp holders (the cheap clamp-style ones made from aluminum work well – you'll need three) and screw in colored "party lights" (make one red, one green, and one blue), which are colored incandescent bulbs. These will provide a lot more light! You can also add a fourth yellow light to further illustrate how yellow light isn't a primary color. Try using only red, yellow, and blue… you'll quickly find that you can't obtain all the colors as you could with the original red-green-blue lights.

Exercises

1. What are the three primary colors of light?
2. What color do you get when mixing the primary colors of light?
3. How do you mix the primary colors of light to get yellow?
4. Use crayons or colored pencils to draw what you saw when all three lights were shining on the wall and you waved your hand in front of the light.

Lesson #2: Kaleidoscopes

Overview: In the simplest sense, a kaleidoscope is a tube lined with mirrors. Whether you leave the end open or tape on a bag of beads is up to you, but the main idea is to provide enough of an optical illusion to wow your friends. Kaleidoscopes are an example of using light reflectors, which don't give off any light, but still bounce light back to your eyes.

The first kaleidoscopes were constructed in 1816 by a scientist while studying polarization (you'll learn more about polarization in a future lesson). Kaleidoscopes were quickly picked up as an amusement gadget by the public and have stayed with us ever since. Today you will be making your very own kaleidoscope.

What to Learn: Kaleidoscopes are an example of using light reflectors, which don't give off any light, but still bounce light back to your eyes. Light is reflected from mirrors and other surfaces.

Materials

Mirror Kaleidoscope

- 4-5 mirrors, all the same size
- tape
- scissors

Mylar Kaleidoscope

- Mylar
- index card or piece of cardboard
- hot glue gun
- scissors

Experiment

Mirror Kaleidoscope

1. Lay out a strip of tape, sticky side up.
2. Center one mirror on the tape with its reflective side pointing up.
3. Attach the second and third mirrors close to the first at 90-degree angles. One will be on the left; the other will be on the right.
4. Rip the excess tape off of one end and then carefully tape together the three identical mirrors, forming a triangular shape. Make sure that the reflective surface is on the inside.
5. Tape all the rough edges very well and peek through the opening as you walk around.
6. Look at the images the mirrors make on the inside while pointing it at various objects.

Mylar Kaleidoscope

1. Fold the index card into three equal pieces in order to make it a triangular tube.
2. Make sure your Mylar is the same size as each fold of the tube. Trim as needed.
3. Glue the Mylar down to the cardboard.
4. Fold your tube again, just making sure that the edges are as crisp as possible.
5. Tape lengthwise along the top edge of your triangular tube.
6. If you are making both kaleidoscopes, compare the reflections you see in this longer tube with those you saw in the mirror kaleidoscope.

Kaleidoscope Data Table

Number of Mirrors Used	Type of Mirror (Mylar or Glass, Flat or Curved, Shape and Size)	How were the Mirrors Arranged? (Triangle, Square…)	Effect on Image (What did it look like?)

Reading

A candle is a light source (or source of light waves). So are a campfire, a light bulb, and the sun. An apple, however, reflects light. It doesn't give off any light on its own, but you can see it because light bounces off the apple into your eye. If you shut off the light, you can't see the apple. In this same way, the sun is a light source, and the moon is a light reflector.

Light can be reflected off the surface of different materials. The incident angle of the light (the angle the light hits the material) is always the same as the reflected angle of light. We're going to build a kaleidoscope that uses mirrors to reflect light.

Kaleidoscopes use light from a source, such as the lights in your room or the sun in the sky, and reflect the light back to our eyes. The reflections bouncing all around on the mirrors or Mylar make interesting shapes for our eyes to see.

There are many variations for this experiment. You can do both the mirror and Mylar kaleidoscopes, or simply choose one that works best with the materials you're able to find.

For the Mirror Kaleidoscope, you'll find that if you use only two mirrors, you'll get a solid background. Add a third mirror and tilt together into a triangle (as shown in the video) and you'll get the entire field filled with the pattern. You can place transparent objects at the end (like marbles floating in water or mineral oil) or just leave it open and point at the night stars.

By changing the size and shape of the mirrors, you can change the dimensional effect you see. Just be sure to look at the mirror surface, not the opening. You can also make mirrors wider at the bottom and narrower at the top (this is easier to do with the Mylar-cardboard mirrors). Use four or five mirrors instead of three in different combinations to get different effects. You can also change the length of the mirrors or use curved mirrors instead of flat by lining the inside of an oatmeal box with Mylar.

Exercises

1. What is a light source?

2. What is a light reflector?

3. Sketch an image of something interesting that you were able to see as the light reflected from the multiple surfaces of the kaleidoscope to your eyes:

Lesson #3: Liquid Prism

Overview: A prism un-mixes light back into its original colors of red, green, and blue. In this experiment, water is our prism. You can make prisms out of glass, plastic, water, oil, or anything else you can think of that allows light to zip through.

What to Learn: Today you're going to play with splitting apart white light into its primary colors. The color of light striking an object affects how our eyes see it.

Materials

- mirror
- shallow baking dish
- sunlight
- index card

You'll also have one of the following:

- plain water
- baby oil or mineral oil
- water with one tablespoon of salt mixed in
- distilled white vinegar
- isopropyl rubbing alcohol
- clear liquid soap (do not mix with water)

Experiment

1. Set a tray of liquid in sunlight. If you're using water, then fill your tray with water. If you're using salt, mix a tablespoon of salt into the water and then set it in sunlight. If you're using anything else, fill it with your liquid and set it outside.
2. Lean a mirror against the inside edge of the tray and adjust it so that a rainbow appears.
3. Use the index card (or another white surface) so that you can clearly see the reflection from your prism.
4. You can also use a light bulb as an alternate light source by shining it through a slit in a flat cardboard surface. However, you'll find that sunlight is much more effective and will make a brighter, more complete rainbow.
5. Troubleshooting: This is one of the easiest experiments to do, and the most beautiful. The trouble is, you don't know where the water shadow will show up, so make sure you point the mirror to the sky and play with the angle of the mirror until you find the wavering rainbow. If you still have trouble, use a large sheet of white paper instead of the tiny index card.

Liquid Prism Data Table

Type of Liquid for the Prism	What did you observe?

Reading

What is a prism? Think of a beam of light. It zooms fast on a straight path, until it hits something, like a water drop. As the light goes through the water drop, it changes speed. This is called *refraction*, which we will discuss more in a future lesson. The speed change depends on the angle at which the light hits the water, and what the drop is made of. If it was a drop of mineral oil, the light would slow down a bit more because the fluid has more optical density. So when white light passes through a prism, like that water drop, it changes speed, which we can see with our eyes because it also turns colors.

Prisms un-mix light into its different wavelengths. When light hits the prism, most of it passes through, although a small bit of light does get reflected off the surface, but when it passes through it changes speed. Since the sunlight is made up of many different wavelengths (colors), each color gets bent by different amounts, and you see a rainbow out the other side. As long as the light travels at the same speed (like through the air), it's white. But as soon as the light hits the water and bends at different angles, the wavelengths separate and spread out, making the rainbow you see.

Troubleshooting: This is one of the easiest experiments to do, and the most beautiful. The trouble is, you don't know where the water shadow will show up, so make sure you point the mirror to the sky and play with the angle of the mirror until you find the wavering rainbow. Because the shadow is constantly moving, you can snap a few pictures when you've got it so you can look over the finer details later. If this project still eludes you, take a large sheet and use it instead of the tiny index card.

Exercises

1. What serves as the prism in this experiment?
2. What property can help make something a good prism material?
3. What are some other items that could be used as prisms?

Lesson #4: Lunar Phases

Overview: The Moon appears to change in the sky. One moment it's a big white circle, and next week it's shaped like a sideways bike helmet. There's even a day where it disappears altogether. So what gives?

What to Learn: The sun illuminates half of the Moon all the time. Imagine shining a flashlight on a beach ball. The half that faces the light is lit up. There's no light on the far side, right? For the Moon, *which* half is lit up depends on the rotation of the Moon. And which part of the illuminated side we can see depends on where we are when looking at the Moon. Sound complicated? This lab will straighten everything out so it makes sense.

Materials

- ball
- flashlight

Experiment

1. Assign one person to be the sun and hand them the flashlight. Stay standing up about four feet away from the group. The sun doesn't move at all for this activity.
2. Assign one person to be the Moon and hand them the ball. Stay standing up, as you'll be circling the Earth.
3. The rest of the people are the Earth, and they sit right in the middle (so they don't get a flashlight in their eyes as the Moon orbits).
4. Start with a new Moon. Shine the flashlight above the heads of the Earth. Move the Moon (ball) into position so that the ball blocks all the light from the flashlight. Ask the Earth kids how much light they can see on their side of the Moon (should be none). Which phase of the Moon is this?

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5. Now the Moon moves around to the opposite side of the Earth so that the Earth kids can see the entire half of the ball lit up by the flashlight. Ask the Earth kids how much light they can see on their side of the Moon (should be half the ball). Which phase of the Moon is this?

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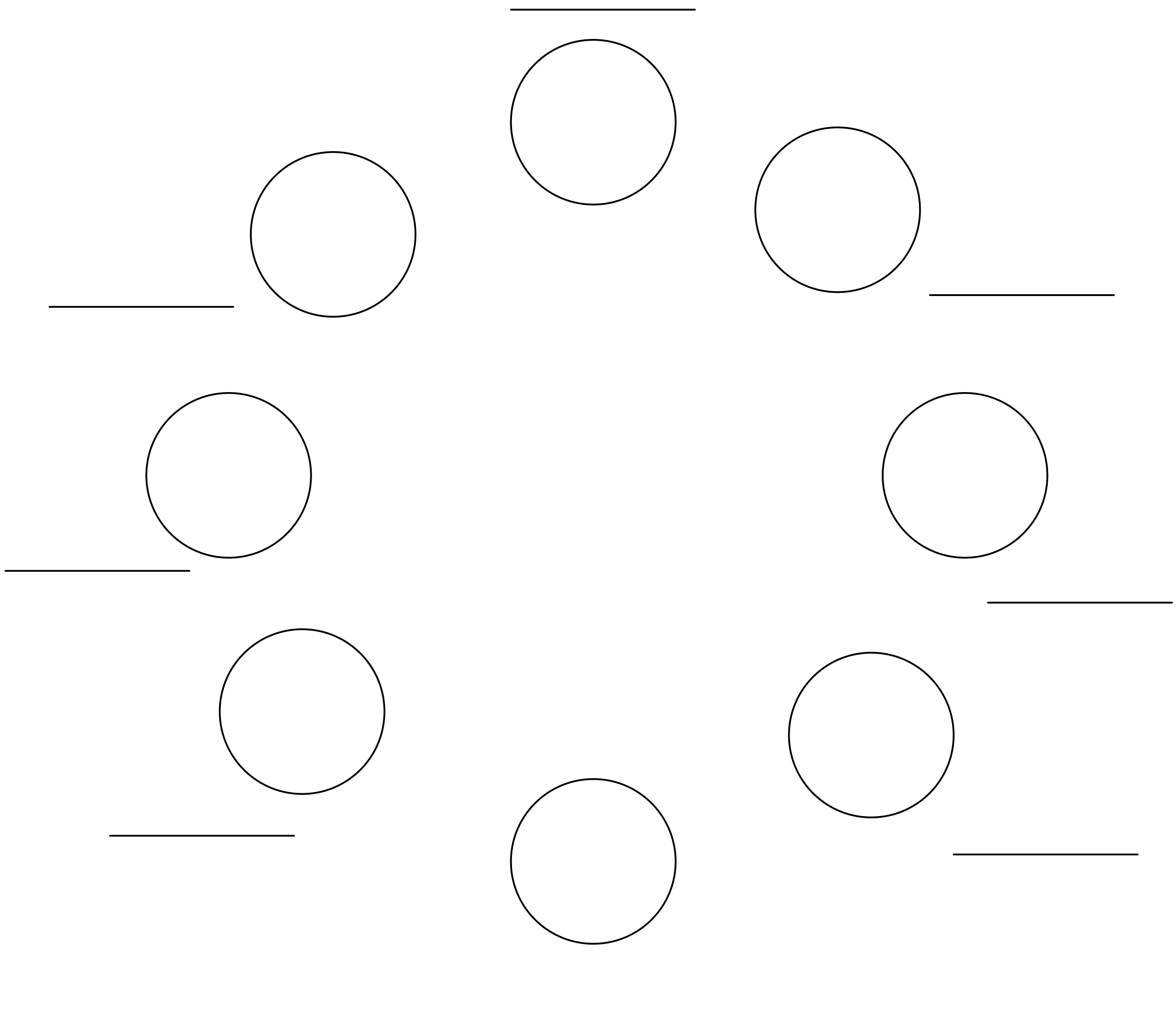
6. Now find the positions for first quarter. Where does the Moon need to stand so that the Earth kids can see the first quarter Moon?
7. Continue around in a complete circle and fill out the diagram. Color in the circles to indicate the dark half of the Moon. For example, the new Moon should be completely darkened.

Lunar Phases Data Observations



1. Now it's time to investigate why Venus and Mercury have phases. Put the sun in the center and assign a student to be Venus. Venus gets the ball.
2. Venus should be walking slowly around the sun. The sun is going to have to rotate to always face Venus, since the sun normally gives off light in every direction.
3. The Earth kids need to move further out from the sun than Venus, so they will be watching Venus orbit the sun from a distance of a couple of feet.

4. Earth kids: what do you notice about how the sun lights up Venus from your point of view? Is there a time when you get to see Venus completely illuminated, and other times when it's completely dark?
5. Draw a diagram of what's going on, labeling Venus's full phase, new phase, half phases, crescent, and gibbous phases. Label the sun, Earth, and all 8 phases of Venus like we did on the board for the Earth at the beginning of this lesson:

Reading

The sun illuminates half of the Moon all the time. Imagine shining a flashlight on a beach ball. The half that faces the light is lit up. There's no light on the far side, right? So for the Moon, *which* half is lit up depends on the rotation of the Moon. And which part of the illuminated side we can see depends on where we are when looking at the Moon. Sound complicated? This lab will straighten everything out so it makes sense.

One question you'll hear is: *Why don't we have eclipses every month when there's a new Moon?* Good question. The Moon's orbit around the Earth is not in the same plane as the Earth's orbit around the sun (called the ecliptic). It's actually off by about 5°. In fact, only twice per month does the Moon pass through the ecliptic.

The lunar cycle is approximately 28 days. To be exact, it takes on average 29.53 days (29 days, 12 hours, 44 minutes) between two full moons. The average calendar month is 1/12 of a year, which is 30.44 days. Since the Moon's phases repeat every 29.53 days, they don't quite match up. That's why on Moon phase calendars, you'll see a skipped day to account for the mismatch.

A second full Moon in the same month is called a *blue Moon*. It's also a *blue Moon* if it's the third full Moon out of four in a three-month season, which happens once every two or three years.

The Moon isn't the only object that has phases. Mercury and Venus undergo phases because they are closer to the sun than the Earth. If we lived on Mars, then the Earth would also have phases.

Exercises

1. Does the sun always light up half the Moon?
2. How many phases does the Moon have?
3. What is it called when the Moon appears to grow?
4. What is it called when you see more light than dark on the Moon?
5. How long does it take for a complete lunar cycle?

Lesson #5: Sky in a Jar

Overview: Have you ever wondered why the sky is blue? Or why the sunset is red? Or what color our sunset would be if we had a blue giant instead of a white star? This lab will answer those questions by showing how light is scattered by the atmosphere.

What to Learn: Particles in the atmosphere determine the color of the planet and the colors we see on its surface. The color of the star also affects the color of the sunset and of the planet. The color of light striking an object affects how our eyes see it.

Materials

- glass jar
- flashlight
- fingernail polish (red, yellow, green, blue)
- clear tape
- water
- dark room
- few drops of milk

Experiment

1. Make your room as *dark* as possible for this experiment to work.
2. Make sure your label is removed from the glass jar or you won't be able to see what's going on.
3. Fill the clear glass jar with water.
4. Add a teaspoon or two of milk (or cornstarch) and swirl.
5. Shine the flashlight down from the top and look from the side – the water should have a bluish hue. The small milk droplets scatter the light the same way our atmosphere's dust particles scatter sunlight.
6. Try shining the light up from the base – where do you need to look in order to see a faint red/pink tint? If not, it's because you are looking for hues that match our real atmosphere, and the jar just isn't that big, nor is your flashlight strong enough! Instead, look for a very *slight* color shift. If you do this experiment after being in the dark for about 10 minutes (letting your eyes adjust to the lack of light), it is easier to see the subtle color changes. Just be careful that you don't let the brilliant flashlight ruin your newly acquired night-vision, or you'll have to start the 10 minutes all over again.
7. If you are still having trouble seeing the color changes, shine your light through the jar and onto an index card on the other side. You should see slight color changes on the white card.
8. Cover the flashlight lens with clear tape.
9. Paint on the tape (not the lens) the fingernail polish you need to complete the table.
10. Repeat steps 7-9 and record your data.

Sky in a Jar Data Table

Flashlight Color	Location	Color(s)
White	*Side of jar*	
White	*Bottom of Jar*	
Red	*Side of jar*	
Red	*Bottom of Jar*	
Yellow	*Side of jar*	
Yellow	*Bottom of Jar*	
Green	*Side of jar*	
Green	*Bottom of Jar*	
Blue	*Side of jar*	
Blue	*Bottom of Jar*	

Reading

Why is the sunset red? The colors you see in the sky depend on how light bounces around. The red/orange colors of sunset and sunrise happen because of the low angle the sun makes with the atmosphere, skipping the light off dust and dirt (not to mention solid aerosols, soot, and smog). Sunsets are usually more spectacular than sunrises, as more "stuff" floats around at the end of the day (there are less particles present in the mornings). Sometimes just after sunset, a green flash can be seen ejecting from the setting sun.

The Earth appears blue to the astronauts in space because the shorter, faster wavelengths are reflected off the upper atmosphere. The sunsets appear red because the slower, longer wavelengths bounce off the clouds.

Sunsets on other planets are different because they are farther (or closer) to the sun, and also because they have a different atmosphere than planet Earth. The image shown here is a sunset on Mars.

Exercises

1. What colors does the sunset go through?

2. Does the color of the light source matter?

Lesson #6: Light Tricks

Overview: Today you get to see the science behind the illusion by learning how light striking an object affects how our eyes see it.

What to Learn: Light can be bent when it passes through materials. The amount that the light bends is called the *index of refraction.* How much light bends depends on the material it's passing through. This quality is measured for each individual material and is called the *optical density*. The more dense the substance, the slower the light travels through it, and the more the light bends.

Materials

- glass jar
- penny
- laser (optional)
- flashlight
- milk or flour

Light Tricks Data Table

When you do the pencil illusion trick, record your observations.

Water Level:	Water Level:	Water Level:

Experiment

1. Record your observations on the data sheet and in the exercises as you go.
2. Toss one coin into a water glass and fill with an inch of water. Hold the glass up and find where you need to look to see TWO coins.
3. Look through the top of the glass – how many coins are there now? What about when you look from the side?
4. Toss in a second coin – now how many are there?
5. Remove the coins and turn out the lights. Shine a flashlight beam through the glass onto a nearby wall. (Hint – if this doesn't work, try using a square clear container.) Stick a piece of paper on the wall where your light beam is and outline the beam with a pencil.
6. Shine the light at an angle up through the water so that it bounces off the surface of the water from underneath. Trace your new outline and compare… are they both the same shape?
7. Add a teaspoon of milk and stir gently. (No milk? Try sprinkling in a bit of white flour.) Now shine your flashlight through the container as you did in steps 4 and 5 and notice how the beam looks.
8. Use a round container instead of square… what's the difference?

Reading

Have you ever broken a pencil by sticking it into a glass of water? The pencil isn't really broken, but it sure looks like it! What's going on?

Light can be bent when it passes through materials. The amount that the light bends is called the *index of refraction.* How much light bends depends on the material it's passing through. This quality is measured for each individual material and is called the *optical density*. The more dense the substance, the slower the light travels through it, and the more the light bends. To be exact, when a beam of light hits a different substance (like moving from air to water), the wavelength changes because the speed of the light changes.

If you're thinking that the speed of light is always constant, you're right… in outer space, light travels at 186,000 miles per second. But the Earth is covered with an atmosphere, and as soon as the light passes into this thick cloud of nitrogen and oxygen gas, it slows down a bit. The speed of light changes whenever it passes from one material to another, like when it moves from water to ice, or to sunglasses, smoke, fog, or windows. How much the light speed slows down depends on what the material is made of. Mineral oil and window glass will slow light down more than water, but not as much as diamonds do.

Exercises

1. When one coin is in the water, you can actually see two: Are the coins both the same size? Which one is the original coin?

2. In step 2 of the experiment: How many coins are there when viewed from the top of the glass? What about when you look from the side?

3. What happened when you tossed in a second coin?

4. How did your outlines compare?

Lesson #7: Black Light Treasure Hunt

Overview: Ever notice how BRIGHT your white T-shirt looks in direct sun? That's because mom washed with fluorescent laundry soap (no kidding!). The soap manufacturers put in dyes that glow white under a UV light, which make your clothes appear whiter than they really are.

What to Learn: Light can be absorbed and retransmitted in a different color, depending on how the light strikes the object and the amount of energy the light initially has.

Materials

- UV black fluorescent light
- dark evening inside your house

Experiment

1. Turn off all the lights in your house and turn on your UV black light.
2. Find things that glow both inside and outside the house.
3. What fluoresces in your house? Here are some things to try: white paper (although paper made pre-1950 doesn't, which is how investigators tell the difference between originals and fakes), club soda or tonic water (it's the quinine that glows blue), body fluids (yes, blood, urine, and more are all fluorescent), Vitamins (Vitamin A, B, B-12 (crush and dissolve in vinegar first), thiamine, niacin, and riboflavin are strongly fluorescent), chlorophyll (grind spinach in a small amount of alcohol (like ethyl alcohol) and pour it through a coffee filter to get the extract (keep the solids in the filter, not the liquid)), antifreeze, laundry detergents, tooth whiteners, postage stamps, driver's license, jellyfish, and certain rocks (fluorite, calcite, gypsum, ruby, talc, opal, agate, quartz, amber) and the Hope Diamond (which is blue in regular light, but glows red).
4. Complete the data table.

Black Light Treasure Hunt Data Table

Item/Object	What color did it glow?

Reading

Light bulbs use *incandescence*, which means that the little wire (which is made from the element *tungsten)* gets so hot when you switch it on that it gives off heat and light. Unfortunately, these bulbs give off a lot of heat, which you'll notice if you bring your hand close to it after it's been on for a while. Incandescence happens when your electric stove glows cherry red-hot and you can visibly see the light energy. Our sun gives off energy through incandescence also – a lot of it.

On the other end of things, *cold light* refers to the light from a glow stick, called *luminescence*. A chemical reaction (chemiluminescence) starts between two liquids, and the energy is released in the form of light. On the atomic scale, the energy from the reaction bumps the electron to a higher shell, and when it relaxes back down it emits a photon of light.

Phosphorescenct light is the glow-in-the-dark kind of light you see after you charge up a glow toy with a bright light source. This delayed afterglow happens because when you charged the object with light, the light actually hits the atom's electron and whacks it into a higher energy state. When the electron relaxes back down its lower energy state, it emits a light particle of (usually) a different wavelength (color). That's why glow-in-the-dark toys are often a different color than the light they emit after charged up. Since light is a form of energy, then in order for things to glow in the dark, you have to add energy first.

Triboluminescence is the spark you see when you smack two quartz crystals together in the dark. Other minerals spark when struck together, but you don't have to be a rock hound to see this one in action – just take a Wint-O-Green Lifesaver in a dark closet with a mirror and you'll get your own spark show. If you chew the candy with your mouth open, you'll be able to see the sparks in your mouth with a mirror. The spark is basically light from friction.

Fluorescence is similar to phosphorescence, except that it requires a continual light source in order to glow. These types of paints are popular with dark amusement-park rides. If you look carefully, you'll see UV lights hidden all around to make the images glow as you speed through the ride. In nature, you'll find fluorescence in certain rocks, plants and animals. Fluorescent objects absorb the UV light and remit a completely different color. Like with phosphorescence, the light strikes the electron and bumps it up a level, and when the electron relaxed back down, emits a photon (light particle) of a different wavelength.

Fluorescent lights give out less heat, but more light. Since they don't lose as much energy to heat, they are more energy-efficient. I will usually hold up an incandescent bulb and a fluorescent bulb and ask the students how each makes light. A fluorescent tube is lined with white stuff called phosphor, which gives off light whenever it's struck by UV rays. The tube is filled with a gas that gives off UV rays when placed in an electrical field. When the bulb is turned on, electrons rip through the tube and go out the other side. As they go through, they smack into the gas vapor which releases light rays (UV in a fluorescent tube) that hit the phosphor on the inside of the tube, which then emits light. Fluorescent lights, or any tube of gas from the noble gases column on the periodic table, like neon, will also glow in an electrically charged field.

Phosphorescence is a type of fluorescence like you find in glow sticks and other glow-in-the-dark items.

Triboluminescence is a type of fluorescent light that comes from friction, like when striking two quartz crystals together. (You can hand out Wint-O-Green Lifesavers as part of their homework for the day and have them record their results in their lab.)

Exercises

1. Why are incandescent lights less energy-efficient than fluorescent lights?
2. What are the two types of fluorescent lights?
3. What kinds of things did you find that glow on your treasure hunt? Give at least five examples.

Lesson #8: Benham's Disk

Overview: Charles Benham (1895) created a toy top painted with a specific pattern. When you spin the black and white pattern, surprising arcs of color (called "pattern induced flicker colors") show up; and here's the odd part: Different people see different colors!

What to Learn: The color of light striking an object affects how our eyes see it. The cones and rods inside our eyes collect images that are transmitted to the brain.

Materials

- Benham's Disk sheet
- string (about 3 feet)
- 8 index cards
- glue stick

Experiment

1. Cut out the Benham's Disks.
2. Glue the disks to index cards for stability. Regular paper tends to flop around when you spin it quickly.
3. Label each disk with a number from 1 to 6 on the back side so you can record your observations in the data table later.
4. Spin the disks using the method you choose. Play with this a bit before you take data so you can get comfortable with how to do the experiment.
5. When you are ready, record your observations in the data table.

Reading

We can't really say why this effect with Benham's Disk happens, but there are a few interesting theories. The retina at the back of your eye has a bunch of light-sensitive cells called cones and rods. Your eyeball has two different ways of seeing light: cones and rods. Cones are used for color vision and for seeing bright light, and there are three types of cones (red, green, and blue). Rods are important for seeing in low light and they sense black, white, and gray shades. Together, they turn the light that enters your eye into an image.

Benham's Disk Data Table

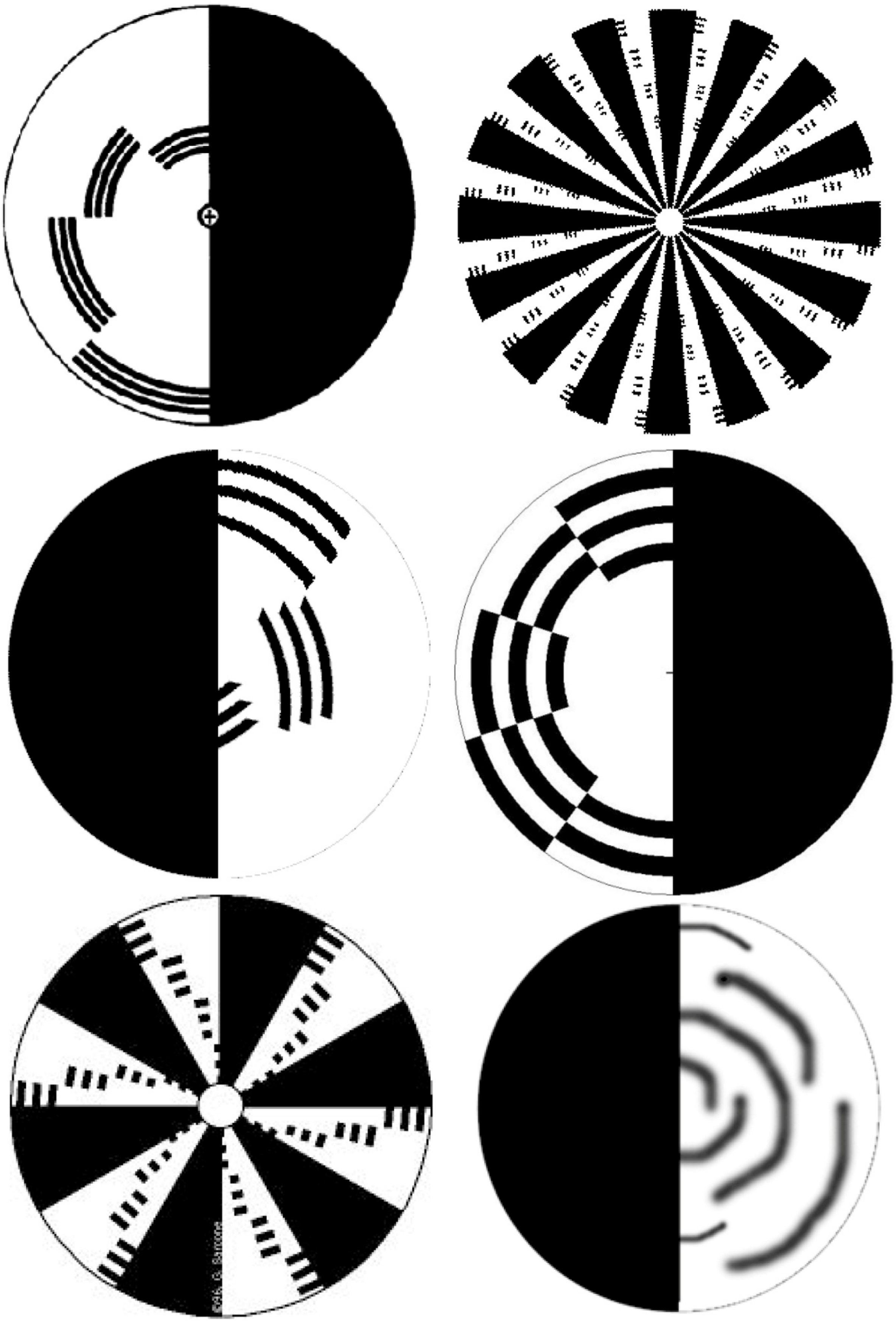
Disk #	What Colors Did You See?
1	
2	
3	
4	
5	
6	
Your Own Design #1	
Your Own Design #2	

Exercises

1. What colors were you able to see when the disks were spinning?

2. How did the different patterns look when they were spun?

3. How did speed and direction affect what you saw?



Benham's Disks

Lesson #9: Eye Balloon

Overview: In this lab, we are going to make an eyeball model using a balloon. This experiment should give you a better idea of how your eyes work. The way your brain actually sees things is still a mystery, but using the balloon we can get a good working model of how light gets to your brain.

What to Learn: We see objects when light traveling from an object enters our eye.

Materials

- biconvex plastic lens
- round balloon, white, 9 inches
- assistant
- votive candle
- black marker
- book of matches
- ruler

Experiment

1. Blow up the balloon until it is about the size of a grapefruit. If it's difficult to inflate, stretch the material a few times or ask an adult to help you.
2. You will need an extra set of hands for this portion. Ask your partner to hold the neck of the balloon closed to keep the air in while you insert the lens into the opening. The lens will need to be inserted perpendicular to the balloon's neck. It will prevent any air from escaping once it's in place. Like your eye, light will enter through the lens and travel toward the back of the balloon.
3. Hold the balloon so that the lens is pointing toward you. Take the lens between your thumb and index finger. Look into the lens into the balloon. You should have a clear view of the inside. Start to twist the balloon a little and notice that the neck gets smaller like your pupils do when exposed to light. Practice opening and closing the balloon's "pupil."
4. Have an adult help you put the candle on the table and light it. Turn out the lights.
5. Put the balloon about 20 to 30 centimeters away from the candle with the lens pointed toward it. The balloon should be between you and the candle. You should see a projection of the candle's flame on the back of the balloon's surface. Move the balloon back and forth in order to better focus the image on the back of the balloon and then proceed with data collection.
6. Describe the image you see on the back of the balloon. How is it different from the flame you see with your eyes? Draw a picture of how the flame looks.
7. The focal length is the distance from the flame to the image on the balloon. Measure this distance and record it.
8. What happens if you lightly push down on the top of the balloon? Does this affect the image? You are experimenting with the affect caused by near-sightedness.
9. To approximate a farsighted eye, gently push in the front and back of the balloon to make it taller. How does this change what you see?

Eye Balloon Data Table

Draw a picture of how the flame looks to you.	
Record the focal length from flame to the image.	
What happens to the image when you push down on the top of the balloon?	
What do you see when you push on the front and back of the balloon to make it taller?	

Reading

First, we'll discuss the parts of the balloon that relate to parts of your eye. The white portion of the balloon represents your sclera, which you may have already guessed is also the white part of your eye. It is actually a coating made of protein that covers the various muscles in your eye and holds everything together.

Of course, the lens you inserted represents the actual lens in your eye. The muscles surrounding the lens are called ciliary muscles and they are represented by the rubber neck of your balloon. The ciliary muscles help to control the amount of light entering your eyes. The retina is in the back of your eye, which is represented by the inside back of your balloon. The retina supports your rods and cones. They collect information about light and color and send it to your brain.

There are no light receptors in the area of your eye where the optic nerve attaches to your eyeball. This is your blind spot and if an image is in this spot, the light reflected off of it doesn't get perceived by your eye.

This is a fun experiment to play with using different ages of people. As folks get older, the shape of the eye changes and the blind spot can actually change. Ask a few fellow adults to help you demonstrate the lab and measure the distance for the blind spot based on how old the adults are. You can also test to see if different people with different vision have different blind spots. For example, is the blind spot the same for someone with 20/20 versus 20/40? Or with or without eyeglasses? Have fun with the different variations!

Exercises

1. How does your eye work like a camera?
2. How can you tell if a lens is double convex?
3. What is the difference between convex and concave?
4. Can you give an example of an everyday object that has both a convex and a concave side?
5. How can you change the balloon to make it like a near-sighted eye?
6. How can you change the balloon to make it like a far-sighted eye?

Lesson #10: Disappearing Frog

Overview: Your optic nerve can be thought of as a data cord that is plugged in to each eye and connects them to your brain. The area where the nerve connects to the back of your eye creates a blind spot. There are no receptors in this area at all and if something is in that area, you won't be able to see it. This experiment locates your blind spot.

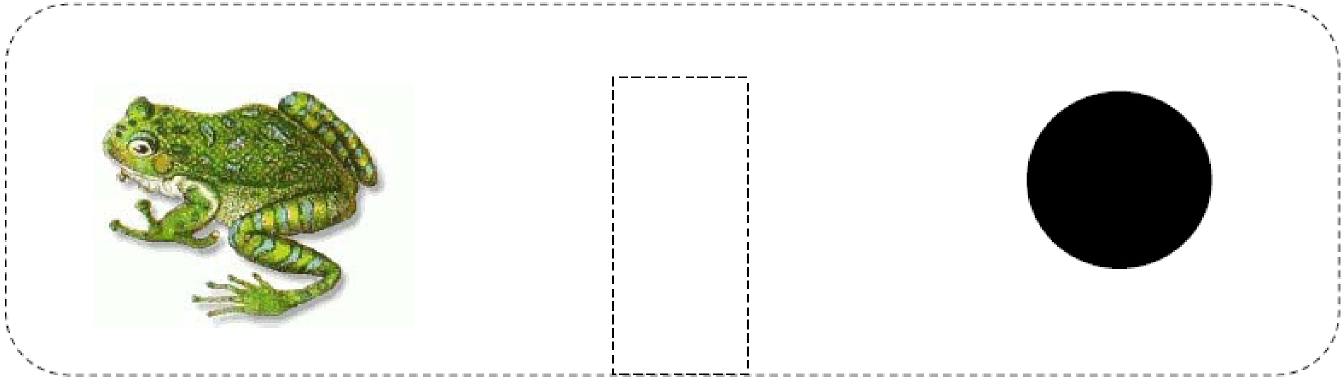
What to Learn: Cones and rods turn the light that enters the eye into images that are transmitted to the brain. Our eyes have a blind spot where the optic nerve connects to the back of the eye because there are no light receptors there.

Materials

- frog and dot printout
- meter stick
- scrap piece of cardboard

Experiment

1. Print out the frog and dot and remove the dotted portion. Attach it to the piece of cardboard, which should have a matching portion removed. You can place the paper and cardboard on the meter stick at the notched area.
2. Now to locate blind spots. First, close your left eye. Look at the frog with your right eye. Can you see the dot and the frog? You should be able to see both at this point, but concentrate on the frog. Now *slowly* move the stick toward you so that the frog is coming toward your eye. Pay attention and stop when the dot disappears from your peripheral vision. At this point, the light hitting the dot and reflecting back toward your eye is hitting the blind spot at the back of your right eyeball, so you can't see it. Record how far your eye is from the card for your right eye.
3. Continue to move the stick toward your face, and at some point you will notice that you are able to see the dot again. Keep moving the stick forward and back. What happens to the dot?
4. Repeat steps 2 and 3 with your left eye, keeping your right eye closed. This time, stare at the dot and watch for the frog to disappear. Move the paper on the stick back and forth *slowly* until you notice the frog disappears. You have found the blind spot for your left eye. Be sure to note the distance the paper is from your eye.



Disappearing Frog Data Table

Student Name	Right or Left Eye?	Distance from Eye to Frog

Exercises

1. What did you notice about the vision of the student and the blind spot that you measured?
2. Why do you think it's important to know where your blind spot is?

Lesson #11: Pinhole Camera

Overview: Today you get to learn how to make a simple camera using equally simple materials. It's surprising how sharp the images appear when you do this experiment!

What to Learn: Although this might seem obvious, we see objects when light traveling from an object enters our eye. We can detect light in other ways (as you'll find out in a later lesson), but the eyes detect only visible light.

Materials

- box
- tracing paper
- razor or scissors
- tape
- tack
- meter stick

Experiment

1. Use a cardboard box that is light-proof (no leaks of light anywhere).
2. Seal light leaks with tape if you have to. Cut off one side of the box (Note – there's no need to do this if you're using a shoebox.)
3. Tape a piece of tracing paper over the cutout side, keeping it taut and smooth.
4. Make a pinhole in the box side opposite of the tracing paper.
5. Point the pinhole at a sunny window and move toward or away from the window until you see its image in clear focus on the tracing paper.
6. If you have a magnifying glass, place it in front of the pinhole to help sharpen the image.
7. Complete the data table by measuring your camera with the meter stick.

Pinhole Camera Data Table

Measure:	Length (inches, feet, cm, or…?)
Box length (this is one dimension of the screen)	
Box width (this is the other screen dimension)	
Box height (this is the distance from the hole to the screen)	
Distance from hole to the window (or candle) when focused	

Draw a diagram of your experiment, labeling the different parts and distances measured from above:

Reading

Light travels in a straight line; it comes through the window and into the hole in your camera. The rays of light cross as they enter the tiny hole, creating an inverted image that you see projected on the screen.

The biggest problem with this camera is that the inlet hole is so tiny that it lets in such a small amount of light and makes a faint image. If you make the hole larger, you get a brighter image, but it's much less focused. The more light rays coming through, the more they spread out the image and create a fuzzier picture. You'll need to play with the size of the hole to get the best image. You can also light a single candle in the middle of the room (instead of using a bright window) for the kids to use their camera. Just be careful they don't get too close – the cameras are flammable!

You can let your students go crazy taking actual photos with this camera by sticking on a piece of undeveloped black and white film (use a moderately fast ASA rating if you can still find it), but I recommend using tracing paper and a set of eyeballs to view your images.

OPTIONAL: You can hold up a magnifying glass in front of the pinhole to sharpen the image.

Exercises

1. How do the images appear when they're projected onto the paper inside your camera?

2. Why do you think it's important to make the box as light-proof as possible?

3. Is there a part of your body that works similarly to the pinhole?

4. Sketch a picture of something you saw through your pinhole camera.

Lesson #12: Diffraction

Overview: When light passes through diffraction gratings, it splits (diffracts) the light into several beams traveling at different directions. If you've ever seen the "iridescence" of a soap bubble, an insect shell, or on a pearl, you've seen nature's diffraction gratings.

What to Learn: Ever play with a prism? When sunlight strikes the prism, it gets split into a rainbow of colors. Prisms un-mix the light into its different wavelengths (which you see as different colors). Diffraction gratings are tiny prisms stacked together. The direction that the beam gets split and diffracted depends on the spacing of the diffraction grating and also the wavelength of the incoming light.

Materials

- feather
- CD or DVD
- diffraction grating

Experiment

1. Take a feather and put it over an eye.
2. Stare at a light source through the feather, like an incandescent light.
3. You should see two or three lights and a rainbow X.
4. Aim the CD so the light hits the CD and makes rainbows.
5. Look at the light source through the diffraction grating.
6. Draw what you see for all three. Were they the same?
7. Take this on a "light treasure hunt" to find different light sources. Good choices are candles, incandescent bulbs, fluorescent bulbs, non signs, halogen lamps, streetlights, stoplights, and anything else you can think of that gives off light (except the sun).
8. Complete the table as you view the different light sources through your diffraction gratings.

Diffraction Data Table

Light Source	Diffractive Object *(Feather, CD, or Grating?)*	Draw What You See:

Reading

Ever play with a prism? When sunlight strikes the prism, it gets split into a rainbow of colors. Prisms un-mix the light into its different wavelengths (which you see as different colors). Diffraction gratings are tiny prisms stacked together. The direction that the beam gets split and diffracted depends on the spacing of the diffraction grating and also the wavelength of the incoming light.

The feather works because there are tiny "hairs" on the feather that are acting like tiny prisms.

Diffraction gratings were first discovered by James Gregory, right around the time Newton performed his famous prism experiments with bird feathers. The first diffraction gratings took a long time to construct, as they were individual hairs strung between screws.

A diffraction grating bends the light and splits it into different beams. You can see this very well when you use a monochromatic light source, like a laser, instead of a multi-wavelength light source.

Exercises

1. Which light source gave the most interesting results?
2. What happens when you aim a laser beam through the diffraction grating?
3. How is a CD different and the same as a diffraction grating?
4. Why does the feather work?

Lesson #13: Speed of Light

Overview: One of the biggest challenges with measuring the speed of light is that the photons move *fast,* too fast to watch with our eyeballs. So instead, we're going to watch the effects of microwave light and base our measurements on the effects the light has on different kinds of food.

What to Learn: Today you get to think and act like a real scientist by doing an experiment, taking measurements, using math to figure out an answer, and test different materials to see which gives you the best result.

Materials

- chocolate bar (extra-large bars work best)
- mini marshmallows
- chocolate chips
- American sliced cheese (the kind that comes individually wrapped)
- paper plates
- ruler
- calculator
- pencil and paper
- microwave (You'll only need one of these for the entire group.)

Experiment

1. First, you'll need to find the "hot spots" in your microwave. The video will demonstrate this for you, but here are the steps:
2. Remove the turntable from your microwave and place a naked bar of chocolate on a plate inside the microwave. (Make sure the chocolate bar is the BIG size – you'll need at least 7 inches of chocolate for this to work.)
3. Turn the microwave on and wait a few minutes until you see small parts of the chocolate bar start to bubble up, and then quickly open the door (it will start to smoke if you leave it in too long).
4. Look carefully at the chocolate bar without touching the surface… you are looking for TWO hotspots, not just one – they will look like small volcano eruptions on the surface of the bar.
5. If you don't have two, grab a fresh plate (you can reuse the chocolate bar) and try again, changing the location of the plate inside the microwave. You're looking for the place where the microwave light hits the chocolate bar in two spots so you can measure the distance between the spots.
6. Open up the door or look on the back of your microwave for the technical specifications. You're looking for a frequency in the 2,000-3,000 MHz range, usually about 2450 MHz. Write this number down on a sheet of paper – this tells you the microwave radiation frequency that the oven produces, and will be used for calculating the speed of light.
7. When you're ready to take a measurement, pop in the first food type on a plate (without the turntable!) into the best spot in the microwave, and turn it on. Remove when both hotspots form, and being careful not to touch the surface of the food, measure the center-to-center distance using your ruler in centimeters. TIP: If you're using mini-marshmallows or chocolate chips (or other smaller foods), you'll need to spread them out in an even layer on your plate so you don't miss a spot that could be your hotspot!
8. Note that when you measure the distance between the hotspots, you are only measuring the peak-to-peak distance of the wave… which means you're only measuring *half* of the wave. We'll multiply this **number by**

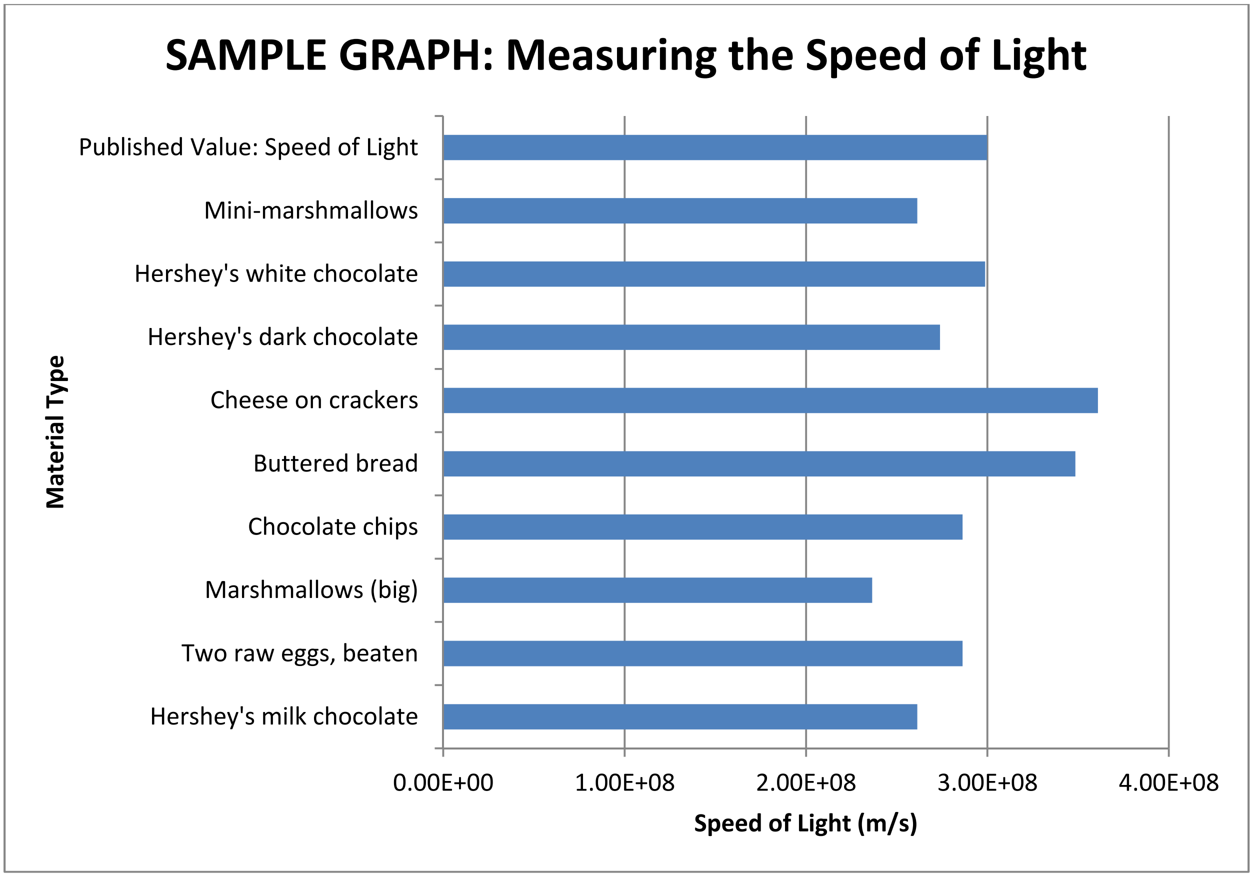
two to get the actual length of the wave (wavelength). If you're using centimeters, you'll also need to convert those to meters by dividing by 100.

9. So, if you measure 6.2 cm between your hotspots, and you want to calculate the speed of light and compare to the published value which is in meters per second, here's what you do:
   2,450 MHz is really 2,450,000,000 Hz or 2,450,000,000 cycles per 1 second
10. Find the length of the wave (in cm): 2 * 6.2 cm = (12.4 cm) /(100 cm/m) = 0.124 meters
11. Multiply the wavelength by the microwave oven frequency:
    0.124 m * 2,450,000,000 Hz = **303,800,000 m/s**
12. The published value for light speed is 299,792,458 m/s = 186,000 miles/second = 671,000,000 mph
13. Calculate % Difference by using this simple formula:
    % Diff = | Measured Value – Published Value | ÷ Published Value x 100

Speed of Light Data Table

Food Type	**Hotspot Distance** *(cm)*	**Calculated Speed of Light** *(m/s)*	**% Difference**

Graphing: Use the data from your table to make a graph of your results, putting the different types of food on the vertical axis and the measured (calculated) speed of light value on the horizontal axis. Refer to the sample while you create your own. In the graph sample, note that "3.00 E+08" means 3 with eight zeros after it, or 300,000,000 meters per second.



Reading

When you warm up leftovers, have you ever wondered why the microwave heats the food and not the plate? (Well, some plates, anyway). It has to do with the way microwave ovens work.

Microwave ovens use dielectric heating (or high frequency heating) to heat your food. Basically, the microwave oven shoots light beams that are tuned to excite the water molecule. Foods that contain water will step up a notch in energy levels as heat. (The microwave radiation can also excite other polarized molecules in addition to the water molecule, which is why some plates also get hot.)

One of the biggest challenges with measuring the speed of light is that the photons move *fast,* too fast to watch with our eyeballs. So instead, we're going to watch the effects of microwave light and base our measurements on the effects the light has on different kinds of food. Microwaves use light with a wavelength of 0.01 to 10 cm (that's the "microwave" part of the electromagnetic spectrum). When designing your experiment, you'll need to pay close attention to the finer details such as the frequency of your microwave oven (found inside the door), where you place your food inside the oven, and how long you leave it in for.

Lesson #14: Mixing Colors

Overview: There are two different sets of primary colors. The three primary colors of light are red, green, and blue. However, the three colors that artists use are red, *yellow,* and blue. What happens if you mix red, green, and blue paint?

What to Learn: The three primary colors of light are red, blue, and green. Red and green light mixed together make yellow light.

Materials

- scissors
- crayons OR markers
- sharpened wood pencil OR skewer
- index cards
- cup
- drill (optional)

Experiment

1. Stack the index cards
2. Use the cup to trace a circle on the top card.
3. Keep the cards stacked while you cut out the circles. They don't have to be perfect, but make sure all the sharp corners are cut off.
4. Using different color markers, make different colored slices (or pie pieces) on each circle. These are the colors that will blur together in your experiment.
5. Poke a hole through the center of the now-colorful circle with your pencil or skewer. Make sure the colored side is facing up toward you, not down toward the table.
6. To spin this like a top, make the "okay" symbol with your index finger and thumb. Put the skewer inside the circle your fingers make and spin it. Your hand will help to keep the top upright so that you are able to see how the colors blend together.
7. Optionally, an adult can help you use a drill, handheld mixer, or electric screwdriver to spin the circle much faster for a more noticeable effect.

Mixing Colors Data Table

Color and Percentage	Color and Percentage	Color and Percentage	Result
Example: blue 50%	*Example:* red 50%	*Example:* *(nothing here - some cells may be blank)*	*Example:* purple

Reading

Most kids understand how yellow paint and blue paint make green paint, but are totally stumped when red light and green light mix to make yellow light. The difference is that we're mixing *light*, not paint.

Lots of science textbooks still have this experiment listed under how to mix light: *"Stir together one of red water and one glass of green water (dyed with food coloring) to get a glass of yellow water."* Hmmm… the result I get is a yucky greenish-brown color. What happened? The reason you can't mix green and red water to get yellow is that you're essentially still mixing paint, not light. But don't take our word for it – test it out for yourself with this super-fast light experiment on mixing colors.

Exercises

1. What happens when blue and red are mixed on the spinner?
2. What happens when red and green are mixed on the spinner?
3. What colors would you mix to get orange?
4. What are the primary colors of light, and how do they differ from the primary colors we learn in art class?

Lesson #15: Mixing Cold Light

Overview: You can demonstrate how the primary colors of light mix together using glow sticks. The glow stick gives off its own light through a chemical reaction called chemiluminescence, which isn't the same as mixing paint together, since cups of paint are reflecting light, not generating it. It's like the difference between the sun (which gives off its own light) and the moon (which you see only when sunlight bounces off it to your eyeballs).

What to Learn This

Materials

- disposable test tubes
- red, green, and blue true-color light sticks (one of each)
- scissors (with adult help)
- gloves
- goggles
- strainer, such as a coffee filter or bit of cheesecloth

Experiment

1. Bend the light sticks to break the glass inside the container (you'll hear a little "crack"). Do this for all three light sticks. This will activate the sticks.
2. Slap your gloves on your hands and goggles on your eyes. No exceptions.
3. Stand over a sink and carefully cut one end off of the light sticks. Get an adult to help, as the plastic can be stiff to cut through.
4. Carefully pour a tiny amount of one of the colors into your test tube. If bits of glass come out also, use the cheesecloth as a strainer to catch the pieces of glass from inside the tube.
5. Now add a second color and swirl gently to mix. Record your observations in the data table.
6. Repeat steps 4 and 5 for your data table.
7. Note: You may not need all of the red, due to its level of color concentration. Only add about half of the red and swirl until the colors are completely mixed. Add more red if needed to adjust the color.
8. When you are done with this lab, discard the bits of glass in the trash and flush the liquid down the sink with plenty of water.

Mixing Cold Light Data Table

Color #1	Color #2	Color #3 (optional)	Resulting Color

Reading

When we talk about light, its three primary colors are actually red, green, and blue. As a painter, you already know that mixing these three colors together would get a muddy brown. But as a scientist, when you mix together three cups of cold light, you will get something different. You'd get white light.

The key is that we would be mixing light, not paint. Mixing the three primary colors of *light* gives white light. If you took three light bulbs (red, green, and blue) and shined them on the ceiling so they overlap, you'd see a white spot where the three converge. And if you could magically un-mix the white colors, you'd get the rainbow (which is exactly what prisms do).

If you're thinking yellow should be a primary color – it *is* a primary color, but only in the artist's world.
Yellow *paint* is a primary color for painters, but yellow *light* is actually made from red and green light. There's an easy way to remember this: think of Christmas colors – red and green merge to make the yellow star on top of the tree.

The cold light is giving off its own light through a chemical reaction called chemiluminescence, whereas the cups of paint are only reflecting nearby light. It's like the difference between the sun (which gives off its own light) and the moon (which you see only when sunlight bounces off it to your eyeballs).

Note: If you're wondering if the real primary colors for painters are cyan, magenta, and yellow, you're right… but some folks still prefer to think of the primary colors as red-yellow-blue… either way, it's really not important to this experiment which primary set you choose, since the experiment deals with light, not paint.

Exercises

1. What color do you get when you mix blue and green liquid lights?
2. What happens when you start to add the red light?
3. What is your final color result when mixing red, blue, and green lights?
4. How would your result differ if you instead mixed red, blue and green *paints*?

Lesson #16: Refractive Index

Overview: We're going to bend light to show the magic behind a popular optical illusion by using a cup of liquid as a lens.

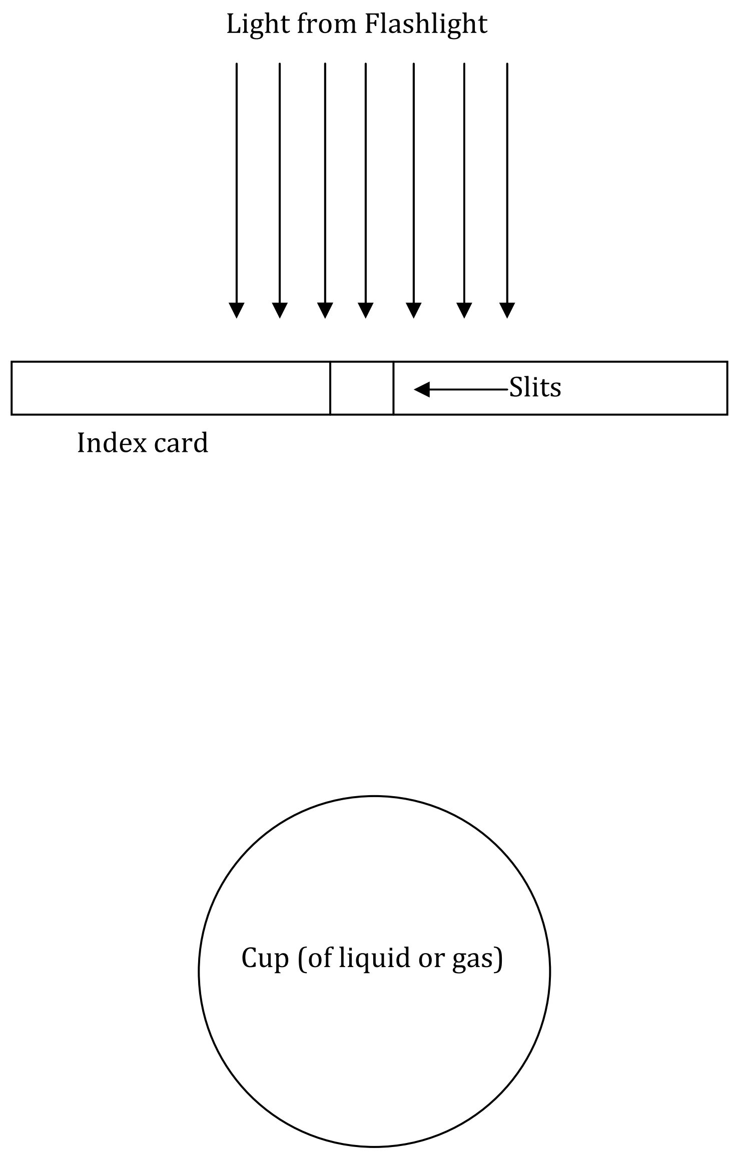
What to Learn: When a beam of light hits a different substance, it bends as it travels through the new substance. The speed at which the light travels and the wavelength (color) also changes. The amount of change depends on the index of refraction of the material.

Materials

- paper
- index card
- pencil
- scissors
- ruler
- disposable cups (4)
- flashlight
- rubbing alcohol
- water
- baby oil

Experiment

1. Turn off the lights and make the room very dark. If you don't have a dark enough room, you can do this experiment inside a shoebox.
2. Cut two small parallel slits in the index card about an inch apart, no thicker than a dime.
3. Place your sheet of paper on the table (see sample on next page).
4. Place an empty cup on top of the paper and trace around the cup so you have a small circle on the paper.
5. Hold the index card up about 4-6 inches from the cup.
6. Shine your flashlight through the index card, about 4 more inches away. You should see two beams of light hitting the cup.
7. Using your ruler, trace the beams of light from the flashlight along the paper before and after the cup and label the lines "air."
8. Repeat steps 7-9 by filling the cup with a different liquid each time and trace each line.


Light from Flashlight
Slits
Index card
Cup (of liquid or gas)

Reading

When a beam of light hits a different substance (like glass), the light bends and the speed of light changes, which means it slows down or speeds up as it travels through the new substance. The color of the light (called the wavelength) can also change, which is what prisms do to white light: Prisms bend the white light by different amounts to get a rainbow.

How much the light bends depends on the optical density of the substance. More dense materials bend the light more. Glass is optically denser than water, which is denser than air.

Optical Densities for Select Materials:

Vacuum (Space)	1.0000
Air	1.0003
Ice	1.3100
Water	1.3333
Pyrex	1.4740
Cooking oil	1.4740
Diamond	2.4170

Did you notice how Pyrex and cooking oil have the same optical density? This means if you place a Pyrex container inside a beaker of vegetable oil, it will disappear because the light will not bend, so you will not be able to detect one from the other. This trick also works for some mineral oils and Karo syrup.

(Note however that the optical densities of liquids vary with temperature and concentration, and manufacturers are not perfectly consistent when they whip up a batch of this stuff, so some adjustments are needed.)

Magnifying lenses, telescopes, and microscopes use this idea of bending light to distort images to make objects appear different sizes.

The light doesn't always appear to bend. For example, when light enters a new substance (like going from air to water) perpendicular to the surface (looking straight on), refraction does not occur. Where you are observing from will affect how the light appears to bend.

Exercises

1. Which substance bent the light the most?
2. What other kinds of materials do you think might work in the cup?
3. Can we see light waves?

Lesson #17: Fire and Optics

Because this activity involves fire, make sure you do this on a flame-proof surface and not your dining room table! Good choices are your driveway, cement parking lot, the concrete sidewalk, or a large piece of ceramic tile. Don't do this experiment in your hand, or you're in for a hot, nasty surprise.

Overview: Today you get to concentrate light, specifically the heat, from the sun into a very small area. Normally, the sunlight would have filled up the entire area of the lens, but you're shrinking this down to the size of the dot.

What to Learn: Magnifying lenses, telescopes, and microscopes use this idea to make objects appear different sizes by bending the light. When light passes through a different medium (from air to glass, water, a lens…) it changes speed and usually the angle at which it's traveling. A prism splits incoming light into a rainbow because the light bends as it moves through the prism. A pair of eyeglasses will bend the light to magnify the image.

Materials

- sunlight
- glass jar
- nail that fits in the jar
- 12" thread
- hair from your head
- 12" string
- 12" fishing line
- 12" yarn
- paperclip
- magnifying glass
- fire extinguisher
- adult help

Experiment Please do this on a fireproof surface! This experiment will damage tables, counters, carpets, and floors. Do this experiment on surface like concrete or blacktop.

1. Have your adult do these steps for you:
    a. Hold the magnifier above the leaf and bring it down toward the leaf until you see a bright spot form on its surface. Adjust it until you see the light as bright and as concentrated as possible. First you'll notice smoke, then a tiny flame as the leaf burns.
    b. You are concentrating the light, specifically the heat, from the sun into a very small area. Normally, the sunlight would have filled up the entire area of the lens, but you're shrinking this down to the size of the dot that's burning the leaf.
2. Screw the lid on the jar.
3. Tie one end of the thread to the paperclip.
4. Poke the other end of the thread inside the hole on the lid.
5. Unscrew the lid and tie a nail to the other end of the thread. You want the nail to be hanging above the bottom of the jar by an inch or two, so adjust the height as needed.

6. Bring your jar outside.
7. Question: *Without breaking the glass or removing the lid, how can you get the nail to drop to the bottom of the jar?*

Fire & Optics & Eyes Data Table

Material for Suspending Nail	**How Long Did It Take to Drop?** *(measure in seconds)*

Reading

Magnifying lenses, telescopes, and microscopes use this idea to make objects appear different sizes by bending light. When light passes through a different medium (from air to glass, water, a lens…) it changes speed and usually the angle at which it's traveling. A prism splits incoming light into a rainbow because the light bends as it moves through the prism. A pair of eyeglasses will bend the light to magnify the image.

This lab is in two parts. The demonstration you do with the kids is not the one they do for their activity. You're going to concentrate the power of the sun on a flammable surface.

Please do this on a fireproof surface! This experiment will damage tables, counters, carpets, and floors. Do this experiment on surface like concrete or blacktop.

Thermoelectric power plants use this principle to power entire cities by using this principle of concentrating the heat from the sun.

Never look through anything that has lenses in it at the sun, including binoculars or telescopes, otherwise what's happening to the leaf right now is going to happen to your eyeball.

Exercises

1. What happened to the leaf? Why?
2. How did you get the nail to drop?
3. Which material ignited the quickest?

Lesson #18: Simple Microscopes & Telescopes

Overview: Did you know you can create a compound microscope *and* a refractor telescope using the same materials? It's all in how you use them to bend the light. These two experiments cover the fundamental basics of how two double-convex lenses can be used to make objects appear larger when right up close or farther away.

What to Learn: Things like lenses and mirrors can bend and bounce light to make interesting things, like compound microscopes and reflector telescopes. Telescopes magnify the appearance of some distant objects in the sky, including the moon and the planets. The number of stars that can be seen through telescopes is dramatically greater than can be seen by the unaided eye.

Materials

- window
- dollar bill
- penny
- handheld magnifying lenses (2)
- ruler

Experiment

1. Place a penny on the table.
2. Hold one magnifier above the penny and look through it.
3. Bring the second magnifying lens above the first so now you're looking through both. Move the second lens closer and/or further from the penny until the penny comes into sharp focus. You've just made a compound microscope.
4. Who's inside the building on an older penny?
5. Try finding the spider/owl on the dollar bill. (Hint: it's in a corner next to the "1".)
6. Keeping the distance between the magnifiers about the same, slowly lift up the magnifiers until you're now looking through both to a window.
7. Adjust the distance until your image comes into sharp (and upside-down) focus. You've just made a refractor telescope, just like Galileo used 400 years ago.
8. Find eight different items to look at through your magnifiers. Make four of them up-close so you use the magnifiers as a microscope, and four of them far-away objects so you use the magnifiers like a telescope. Complete the table.

Simple Microscope & Telescope Data Table

For the last two columns, measure with your ruler carefully. Don't forget to label your units!

Magnification Used: ______________________________ (multiply the magnification of both lenses together)

Object Looked At	Did you use the Magnifiers as a Microscope or Telescope?	How Far Apart are the Lenses?	How Far is your Eye from the Eyepiece?

Reading

What I like best about this activity is how easily we can break down the basic ideas of something that seems much more complex and intimidating, like a telescope or microscope in a way that kids really understand.

Imagine tossing a rock into a still pond and watching the circles of ripples form and spread out into rings. Now look at the ripples in the water - notice how they spread out. What makes the ripples move outward is energy.

The ripples are like light. Notice the waves are not really moving the water from one side of the pond to the other, but rather moving energy across the surface of the water.

To put it another way, energy travels across the pond in a wave. Light works the same way – light travels as energy waves. Only light doesn't need water to travel through the way the water waves do - it can travel through a vacuum (like outer space).

Light can change speed the same way sound vibrations change speed. (Think of how your voice changes when you inhale helium and then try to talk.)

The fastest light can go is 186,000 miles per second – that's fast enough to circle the Earth seven times every second, but that's also inside a vacuum. You can get light going slower by aiming it through different gases. In our own atmosphere, light travels slower than it does in outer space.

Exercises

1. Can light change speeds?
2. Can you see ALL light with your eyes?
3. Give three examples of a light source.
4. What's the difference between a microscope and a telescope?
5. Why is the telescope image upside-down?

Light 1 Evaluation

Student Worksheet

Overview: Today you're going to take two different tests: the quiz and the lab practical. You're going to take the written quiz first, and the lab practical at the end of this lab. The lab practical isn't a paper test – it's is where you get to show your teacher that you know how to do something.

Lab Test & Homework

1. Your teacher will call you up so you can share how much you understand about the basics of light and how it works. Since science is so much more than just reading a book or circling the right answer, this is an important part of the test to find out what you really understand.
2. While you are waiting for your turn to show your teacher how much of this stuff you already know, you get to choose which homework assignment you want to complete. The assignment is due tomorrow, and half the credit is for creativity and the other half is for content, so really let your imagination fly as you work through it. Choose one:
    a. Write a short story or skit about light from the perspective of the photon or the wave. You'll read this aloud to your class.
    b. Make a poster that teaches the main concepts about light waves. When you're finished, you'll use it to teach to a class in the younger grades and demonstrate each of the principles that you've learned.
    c. Write and perform a poem or song about light. This will be performed to your class.

Light 1 Quiz

Name____

1. What are the three primary colors of light?

2. What color do you get when mixing the primary colors of light?

3. What is a light source? Please give an example.

4. What property can help make something a good prism material?

5. What is a light reflector? Please give an example.

6. Does the sun always light up half the Moon?

7. How many phases does the Moon have?

8. How does your eye work like a camera?

9. What is the difference between convex and concave?

10. Can you see ALL light with your eyes?

11. Give three examples of a light source.

12. What's the difference between a microscope and a telescope?

Light 1 Lab Practical

Student Worksheet

This is your chance to show how much you have picked up on important key concepts, and if there are any holes. You also will be working on a homework assignment as you do this test individually with a teacher.

Materials:

- Two magnifying lenses
- Glass of water
- Pencil

Lab Practical:

- Design and build an experiment that shows how to change the speed of light.

- Design a simple microscope to look at one of your hairs from your head.

Answers to Exercises and Quizzes

Lesson #1: Rainbow Shadows
1. What are the three primary colors of light? (red, blue, and green)
2. What color do you get when mixing the primary colors of light? (white)
3. How do you mix the primary colors of light to get yellow? (green and red light make yellow light)
4. Use crayons or colored pencils to draw what you saw when all three lights were shining on the wall and you waved your hand in front of the light.

Lesson #2: Kaleidoscopes
1. What is a light source? Please give an example. (a source of light waves – the sun, light bulbs, fire, etc. are all examples)
2. What is a light reflector? Please give an example. (A reflector does not emit light. Instead it bounces light off of it and reflects the light back to our eyes. Water, mirrors, the moon are all examples.)
3. Sketch an image of something interesting that you were able to see as the light reflected from the multiple surfaces of the kaleidoscope to your eyes.

Lesson #3: Liquid Prism
1. What serves as the prism in this experiment? (water or other clear liquid)
2. What property can help make something a good prism material? (transparency: a material that allows light to pass through it)
3. What are some other items that could be used as prisms? (glass, oil, clear plastic)

Lesson #4: Lunar Phases
1. Does the sun always light up half the Moon? (Yes. We don't always get to see it, which is because the Moon has phases.)
2. How many phases does the Moon have? (eight)
3. What is it called when the Moon appears to grow? (waxing)
4. What is it called when you see more light than dark on the Moon? (gibbous)
5. How long does it take for a complete lunar cycle? (about 29 ½ days)

Lesson #5: Sky in a Jar
1. What colors does the sunset go through? (The sunset goes through the colors of the rainbow as the sun sets lower in the sky, starting with yellow, then orange, and then red as it sets.)
2. Does the color of the light source matter? (Yes. White light gives the best results.)

Lesson #6: Light Tricks
1. When one coin is in the water, you can actually see two: Are the coins both the same size? Which one is the original coin? (the smaller coin is the reflection)
2. In step 2 of the experiment: How many coins are there when viewed from the top of the glass? What about when you look from the side? (one coin when looking from above, two when looking through the side)
3. What happened when you tossed in a second coin? (There were four.)
4. How did your outlines compare? (The first was a circle, the second was an oval.)

Lesson #7: Black Light Treasure Hunt

1. Why are incandescent lights less energy-efficient than fluorescent lights? (Incandescent light give off more heat and less light – they lose energy to heat and fluorescent lights do not.)
2. What are the two types of fluorescent light? (Phosphorescence and triboluminescience)
3. What kinds of things did you find that glow on your treasure hunt? Give at least five examples. (answers vary)

Lesson #8: Benham's Disk

1. What colors were you able to see when the disks were spinning? (answers vary)
2. How did the different patterns look when they were spun? (answers vary)
3. How did speed and direction affect what you saw? (answers vary)

Lesson #9: Eye Balloon

1. How does your eye work like a camera? (Both have lenses, both produce images with lots of components working together.)
2. How can you tell if a lens is double convex? (When you run your fingers across it, you feel two bumps on each side.)
3. What is the difference between convex and concave? (A concave surface curves inward, while a convex surface bulges out.)
4. Can you give an example of an everyday object that has both a convex and a concave side? (spoon)
5. How can you change the balloon to make it near-sighted? (lightly push down on the top)
6. How can you change the balloon to make it far-sighted? (gently push in front and back of the balloon to make it taller)

Lesson #10: Disappearing Frog

1. What did you notice about the vision of the student and the blind spot that you measured? (answers vary)
2. Why do you think it's important to know where your blind spot is? (so you can expect it and work around it if you need to)

Lesson #11: Pinhole Camera

1. How do the images appear when they're projected onto the paper inside your camera? (upside-down)
2. Why do you think it's important to make the box as light-proof as possible? (it allows only a small amount of light to pass through so that we can see the reflection better)
3. Is there a part of your body that works similarly to the pinhole? (our eyes)
4. Sketch a picture of something you saw through your pinhole camera.

Lesson #12: Diffraction

1. Which light source gave the most interesting results? (This varies with data.)
2. What happens when you aim a laser beam through the diffraction grating? (It splits into three beams of light, as shown in the second video.)
3. How is a CD different and the same as a diffraction grating? (A CD has a spiral of finely-spaced data tracks while the diffraction grating has a series of parallel lines. The CD splits the light the same way as the diffraction grating. The CD splits the beam into more than three beams.)
4. Why does the feather work? (There are tiny "hairs" on the feather that are acting like tiny prisms.)

Lesson #14: Mixing Colors

1. What do you see when blue and red are mixed on the spinner? (purple)
2. What do you see red and green are mixed on the spinner? (yellow)

3. What colors would you mix to get orange? (red and yellow)
4. What are the primary colors of light, and how do they differ from the primary colors we learn in art class? (Red, blue, and green are the primary colors of light – in art, the primary colors are red, yellow, and blue.)

Lesson #15: Mixing Cold Light

1. What color do you get when you mix blue and green liquid lights? (answers vary – green to blue)
2. What happens when you start to add the red light? (the color starts to pale)
3. What is you final color result when mixing red, blue, and green lights? (white)
4. How would your result differ if you instead mixed red, blue and green *paints*? (it would be a brown color)

Lesson #16: Refractive Index

1. Which substance bent the light the most? (oil)
2. What other kinds of materials do you think might work in the cup? (answers vary)
3. Can we see light waves? (yes)

Lesson #17: Fire and Optics

1. What happened to the leaf? Why? (You are concentrating the light, specifically the heat, from the sun into a very small area. Normally, the sunlight would have filled up the entire area of the lens, but you're shrinking this down to the size of the dot that's burning the leaf.)
2. How did you get the nail to drop? (By concentrating the energy from the sun using the magnifier.)
3. Which material ignited the quickest? (Refer to data table.)

Lesson #18: Simple Microscopes & Telescopes

1. Can light change speeds? (Yes, when it travels through different mediums.)
2. Can you see ALL light with your eyes? (No, only visible light, like a rainbow.)
3. Give three examples of a light source. (Answer will vary, but here are mine: sun, a candle, and a glow stick.)
4. What's the difference between a microscope and a telescope? (A microscope magnifies an image before the focal point; a telescope magnifies an image after the focal point. Both are used to make images appear closer and larger. A microscope is used when objects are near; a telescope is used for far away objects.)
5. Why is the telescope image upside-down? (Because you've focused the image beyond the focal point.)

Vocabulary for the Unit

The three primary **colors of light** are red, blue, and green. Red and green light mixed together make yellow light. Prisms unmix light into its colors (wavelengths).

Concave lenses work to make objects smaller (door peep hole), and are curved inward like a cave.

Convex lenses make them larger (magnifying lenses), and have a "bump" in the middle you can feel with your fingers.

The amount of **energy** a photon has determines whether it's a particle or a wave. Photons with the lowest amounts of energy and longest wavelengths (some are the size of football fields) are **radio waves**. The next step up are **microwaves,** which have more energy than radio waves. **IR** has slightly more energy, and **visible light** (the rainbow you can see with your eyes) has more energy and shorter wavelengths. Ultraviolet (UV) light has more energy than visible, and X-rays have even more energy than **UV**, and finally the deadly **gamma rays** have the most amount of energy.

Filters can be used to block certain wavelengths.

Intensity, or brightness, is the amount of photons (packets of light) you have in a certain amount of space. A flashlight has less intensity than a car headlight.

LASER stands for Light Amplification by Stimulated Emission of Radiation. Most lasers are monochromatic (one color). Lasers are concentrated beams of light, and are illuminated by small particles (like smoke and dust).

Lenses work to bend light in a certain direction (refraction). A lens is a curved piece of glass or plastic that changes the speed of the light. Lenses have the same effect on lasers as on light beams.

Light can be defined by four things: intensity (how bright), frequency (or wavelength), polarization (the direction of the electric field), and phase (time shift).

Objects can either be a **light source** (like the sun) or **reflect light** (like the moon).

Light can change speeds, but the maximum **light speed** is through a vacuum (186,000 miles per second). Light changes speeds when it passes through a different material (like water, glass, or fog).

Depending on the **optical density** of the material, light will bend by different amounts. Glass is optically denser than water. Water is more optically dense than air.

When two beams of light are out of phase with each other, it's like playing a *G* and *A* on the piano. This is called **phase shift**.

Blue and UV light eject electrons from metal plates, but red light does not (**photoelectric** effect).

Polarization has to do with the direction of the electric field. Your sunglasses are polarizing filters, meaning that they only let light of a certain direction in.

When a beam of light hits a window, it bends and changes speed (**refraction**). Technically, the wavelength (color) changes but the frequency stays the same. In order for this to happen, the speed of light must also change.

Razor-edge **slits** create interference patterns. Slits are skinny holes that allow light to pass through. Scientists use slits to filter out all other light sources except the one they want to use in their experiment.

When you change the **wavelength**, you change the color of the light. The wavelength (λ) equals the speed of light (c) divided by the frequency (ν), or $\boldsymbol{\lambda = c / \nu}$.