LIGHT:

A Lab Manual for Teachers

Mike McKee
College of Optics and Photonics
University of Central Florida

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Mike McKee
CREOL, The College of Optics and Photonics
University of Central Florida
Orlando, Florida 32816

UCF CREOL, The College of Optics and Photonics

CREOL, the College of Optics and Photonics at the University of Central Florida, is one of the world's foremost institutions for research and education in optical and photonic science and engineering. CREOL started in 1987 as the Center for Research and Education in Optics and Lasers, and became a College in 2004, the first US graduate college in this area, offering interdisciplinary graduate programs leading to M.S. and Ph.D. degrees in Optics and Photonics. An undergraduate program offering a BS degree in Photonic Science and Engineering began in 2013 in partnership with the College of Engineering and Computer Science.

Online sales of this book benefits the Society of Optics Students at the University of Central Florida.

Society of Optics Students

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Introduction

This book was produced with the generous support of the Optics Society of America Foundation (OSAF) and the College of Optics and Photonics at the University of Central Florida in celebration of the International Year of Light.

Light based technologies are found across many fields. From medicine to the military and from industry to entertainment, in virtually every area of life there are important applications of light. Even in items such as a garage door remote control, light plays a role. Every computer chip is produced using light. Light is an enabling technology; it is a critical part of the development, production, or function of a vast array of products.

In the College of Optics and Photonics at the University of Central Florida, research is conducted in the area of photonics. Optics is generally thought of as the science of light and photonics is the technological application of light. Items such as your eyeglasses fall under the study of optics, while almost everything that is powered with an electrical source can be called a photonic device.

There are many careers in photonics. With an associate's degree, there is a high demand for individuals who can install and service photonic devices. A person with a Bachelor of Science in Photonic Science and Engineering is employed in a company or the government where he or she can design systems such as smartphones, displays, industrial manufacturing equipment, or even reconnaissance satellites. At universities, research scientists discover the scientific principles which lead to the development of new technologies.

The lessons in this manual are designed to be used in several grade levels. The text size indicates the general age level intended, with larger text designating that the lessons should be used with younger students. For the most part, many supplies are easy to obtain for nominal costs online or as part of a normal high school physics department's inventory.

Each lab contains a background information that includes information describing common misconceptions students may have. The section called "Teacher Guided Questions to Inquiry" lists questions that are designed to be used *in place of the lesson*. For example, in the lesson "How Fast Do Waves Travel" you may want to give the questions to the students, along with the supplies, and have them construct their own procedures, collect data, and conduct the analysis. The questions are designed to prompt their own investigation and are not just a list of questions that should be answered as a mini-quiz. For this reason, answers to the questions are not provided. The entirety of the lesson is what answers the question.

In many cases the Teacher Answer Sheet may have sample data as answers. Refrain from using this data as the "perfect answer" and it should be used as a guide to determine if the students used consistent scientific processes in the experiment.

Finally, it is highly encouraged that these labs be used PRIOR to teaching the content in the course. The lessons were designed with the premise that the students would not have prior knowledge in the content area and the lesson would be used as first exposure to the ideas and concepts. From this experience, you can then introduce the concepts via other instructional methods.

How Fast Do Waves Travel?

Description: Students will use a spring coil and rope to compare what affects the speed of a wave in different media.

Student Materials (per group):

- ☐ Toy spring coil
- ☐ Stopwatch
- ☐ Rope or Toilet Paper
- ☐ Tape Measure

Additional Teacher Materials:

- ☐ None

Background and Misconceptions:

Light is said to have behavior in which it sometimes acts like a wave and sometimes acts like a particle. This double way of describing light is called the dual nature of light.

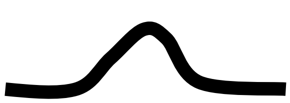
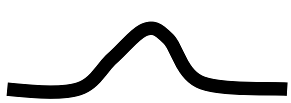
In the most basic description, light has behavior that is similar to any other wave such as a water wave. It can travel through different materials (each one called a **medium**) like water, or air, and the property of the medium can affect how fast it travels. In water, the speed of sound is 1493 meters per second, whereas in cold air it is only 331 meters per second.

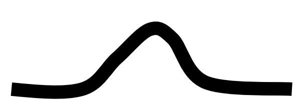
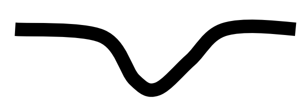
Using a slinky, it is easy to see how waves will travel and very easy to measure their speed. Many will think that the amplitude (the height of the wave) or the shaking speed (number of waves per second) will alter the speed of the wave. However, this does not happen. The speed of the wave only changes when it goes from one medium to another. A more dense material will transmit a wave faster than a less dense material. This is why a sound wave does not travel through the vacuum of space. There is simply nothing to shake around to transmit a sound wave.

Students will think that the wave carries or pushes the material in the medium. This misconception comes from what they observe on water, such as a surfer on the ocean. This wave is a crashing wave, and it generates surface and subsurface currents. On the open ocean, as a wave passes, a person only moves in a vertical circle in response to it, but does not get pushed by the wave.

One way to think of this idea is to have students do the wave in the classroom. By generating a wave – such as at a football stadium – they will get the idea that the wave energy travels, but all they do is move up and down in response to the wave.

When waves reflect off barriers, they can either reflect back in an opposite orientation or the same orientation. This has to do with the barrier. If the barrier is soft and flexible, the wave will cause the barrier to move, and the wave will be reflected with the same orientation. However, if the wave strikes a hard barrier, it will be inverted.

Bouncing off a flexible barrier	
Before	*After*
	

Bouncing off a solid barrier	
Before	*After*
	

To help collect better data, the rope and the spring coil can be held vertically, such as down a stairwell or with the students holding the slinky horizontally above the floor. This limits the friction of the spring coil and will produce the best results. Otherwise, place the spring coil on the floor and on surfaces such as linoleum or tile. Carpeting will make it difficult to collect good data.

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. Does the speed of a wave change in different types of media?
2. Use the two different materials (spring coil and rope) to find if there is a difference in speed between them.
3. What factors affect how fast a wave will travel through a spring coil and rope wave?
4. What can you do to increase the speed of a wave?

Additional Hints:

- In place of rope, use a 10 foot long piece of toilet paper that is double layered. Twist or braid it. The motion of the wave through a long piece of toilet paper is dramatically slower than through the spring coil.

How Fast Do Waves Travel?
TEACHER ANSWER SHEET

Procedures:

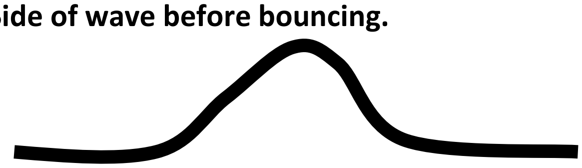
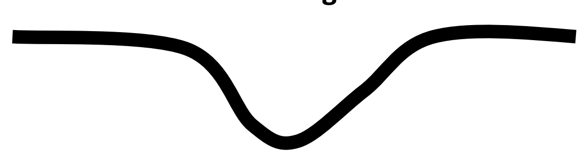
1. Predict: What variables do you believe will affect the speed of a wave?

Some possible student answers include:
- **Height of wave**
- **Type of material, or media**
- **How fast you move the spring coil back and forth**
- **Surface that the spring coil will lay on.**

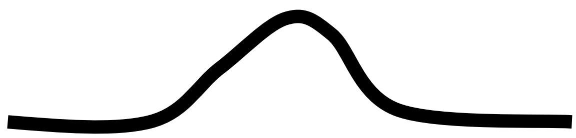
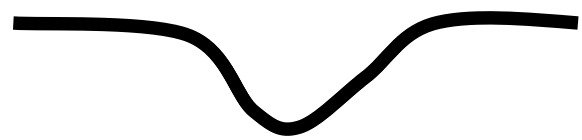
5.

Size of wave	Time 1 (s)	Time 2 (s)	Time 3 (s)	Ave. time (s)	Distance (m)	Speed (m/s)
Medium	1.30	1.38	1.27	1.32	4	3.0
Small	1.33	1.25	1.32	1.30	4	3.1
Large	1.32	1.29	1.30	1.30	4	3.1

(Speeds may vary depending on the way that the students stretch the spring coil and put tension on it.)

Side of wave before bouncing.	Side of wave after bouncing.
	

Size of wave	Time 1 (s)	Time 2 (s)	Time 3 (s)	Ave. time (s)	Distance (m)	Velocity (m/s)
Medium	**2.10**	**2.21**	**2.19**	**2.17**	**4**	**1.8**
Small	**2.05**	**1.98**	**2.23**	**2.09**	**4**	**1.9**
Large	**1.95**	**2.23**	**2.17**	**2.12**	**4**	**1.9**

Side of wave before bouncing.	Side of wave after bouncing.
	

<u>Questions:</u>

1. What happened to the position of the wave when it bounces off the lab partner's hand?

   It reverses direction. This happens whenever a wave bounces off a solid barrier like the partner's hand.

2. What effect, if any, does the height of a wave have on speed of the wave? Explain.

   It has no effect. The amplitude does not change how fast the wave travels through the spring coil or the rope.

3. Is there a difference in speed between the spring coil and the rope? Explain.

   Yes there is. The wave travels faster through the spring coil than through the rope. This difference is caused by the higher density of the spring coil. Waves will travel faster in a media that has a greater density.
4. As a wave goes past a point on the spring coil, does it move with the wave? Explain your answer. (Hint: Does the wave makes an object, such as a piece of tape, to continue to move with the wave down the spring coil, not if it just moves back and forth in response to a passing wave.)

   The wave does not carry parts of the medium with it. The wave only travels through the medium.

5. How did you measure the speed of waves through the spring coil and the rope?

   Determined the distance between each person's hand, and then determined the time it took for the wave to travel that distance. Then we calculated the speed by dividing the distance by the time.

How Fast Do Waves Travel?

Name ____ **Date** ____________________

Description: Is it possible that waves can travel at different speeds? Does a wave traveling through water move at a different speed than through air or rock? In this lab you are going to find out how the media affects the speed of the wave, and if the speed is affected by the amplitude of the wave.

Materials: 1 Spring coil 1 rope Stopwatch Tape measure

Procedures:

1. Predict: What variables do you believe will affect the speed of a wave?

2. Sit down on the floor and have your lab partner do the same. Stretch the spring coil out, but not so tightly that you will ruin it. DO NOT OVERSTRETCH THE SPRING COIL.

3. You are going to send a wave pulse down the spring coil. A wave pulse can be created by flicking your wrist to get one wave out of it.

4. Measure the distance between your hand and your partner's hand using the tape measure. Then, record the time it takes for the wave to travel from your hand to your lab partner's hand. Determine the speed of the wave. Speed of a wave is determined using the following formula:

$$\boxed{\text{Speed}\ (\text{m}/\text{s}) = \frac{\text{Distance (m)}}{\text{Time (s)}}}$$

5. Repeat these procedures changing the size, or AMPLITUDE of the wave. (Make large and small waves.) Determine the speed of each wave.

Size of wave	Time 1 (s)	Time 2 (s)	Time 3 (s)	Ave. time (s)	Distance (m)	Speed (m/s)
Medium						
Small						
Large						

6. Make a wave by flicking your wrist but ensure that there is enough energy to reach your partner's hand and bounce off returning to you. Watch carefully what happens to the side that it is on **before** and **after** it bounces off your lab partner's hand. Below make a drawing before and after it bounces off your partner's hand. You may have to do this several times to see the full effect and to determine what side the wave returns on.

Side of wave before bouncing.	Side of wave after bouncing.

7. Use the rope to repeat the above steps. Record in the table below the speed at which the wave travels down the rope to your lab partner's hand. Do this 3 times, find the average and record in the table.

Size of wave	Time 1 (s)	Time 2 (s)	Time 3 (s)	Ave. time (s)	Distance (m)	Velocity (m/s)
Medium						
Small						
Large						

8. Repeat the drawing for the side that the wave moves and returns on. Record in the space below. (This is the same as step 5 above.)

Side of wave before bouncing.	Side of wave after bouncing.

Questions:

1. What happened to the position of the wave when it bounces off the lab partner's hand?

2. What effect, if any, does the height of a wave have on speed of the wave? Explain.

3. Is there a difference in speed between the spring coil and the rope? Explain.

4. As a wave goes past a point on the spring coil, does it move with the wave? Explain your answer. (Hint: Does the wave makes an object, such as a piece of tape, to continue to move with the wave down the spring coil, not if it just moves back and forth in response to a passing wave.)

5. How did you measure the speed of waves through the spring coil and the rope?

Does Light Travel In A Straight Line?

Description: Students will examine the path of the light from a red laser beam as it enters a cup of water.

Student Materials (per group):
- ☐ Clear plastic cup
- ☐ Laser
- ☐ Water
- ☐ Milk
- ☐ Dropper

Additional Teacher Materials:
- ☐ None

Background and Misconceptions:

Light travels in straight lines until it either reflects, refracts or diffracts. In this experiment, the students will examine reflection and refraction to explore that light travels in a straight line unless it bounces off an object or bends as it travels through a different medium.

A medium is anything through which light travels, so this includes air, water, glass, and plastic. When light goes from one medium to another with different densities, it will bend. This is called **REFRACTION**. The only time it does not bend is when it is entering straight on, at a 0^o angle. At any other angle, the light bends inward, away from the surface of the water. At the point where a light ray enters water, we can draw an imaginary line called the Normal. When the light goes from a less dense (like air) to a more dense (like water) material, it will bend toward the normal. Reversing the path, when it goes from a more dense to less dense material, it will bend away from the normal. This happens in water, but also happens in glass or plastic. This is the reason why glass or plastic is used for lenses. The shape of the glass will cause the light to bend in a specific way and focus.

Light will also reflect off the surface of the water. By looking on the wall or ceiling the students will see the reflected beam of light. This is called regular **REFLECTION**. The light beams from the laser are going in all together and reflecting all together, remaining parallel to each other throughout their trip. Diffuse reflection occurs from almost every other surface – walls, cloth, paint, or tables. The light rays strike the surface and then reflect in many different directions. Using the laser with a piece of crumpled aluminum foil will show this effect. But all the individual light rays are still moving in a straight line.

DIFFRACTION is a phenomenon not explored here, but this causes light to spread out as it goes through narrow openings. Diffraction gratings glasses can be purchased that show a rainbow when looking at light.

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. How does light travel?
2. What happens when a beam of light goes into water?
3. How can you bend light?

Additional Hints:

- Make sure students use the lasers safely by not shining them in anyone’s eyes. (The hand held lasers are very safe, so even with an accidental exposure, there is no danger of blindness.)
- Purchase only the RED lasers. Do not purchase the GREEN lasers.
- Use the lasers that are available in many hardware stores or online. They are often called keychain lasers and should be available for around $5 each.
- Use a bit of milk in the water so the laser beam can easily be seen. Experiment with the drops needed. A drop or two in a cup of water is usually sufficient

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Does Light Travel in a Straight Line?
TEACHER ANSWER SHEET

Procedures:

<table>
<tr>
<td>5. Hold the laser above the water like in the picture.
6. Draw the laser beam you see inside the water.
</td>
<td>7. Hold the laser above the water at an angle, like in the picture.
8. Draw the laser beam you see inside the water.
</td>
</tr>
<tr>
<td>9. Hold the laser above the water at another angle, like in the picture.
10. Draw the laser beam you see inside the water.
</td>
<td>11. Holding the laser above the water in any point, see if you can find a place on the wall or the ceiling where you can see a reflection.
12. What happened to some of the light from the laser beam?

Some of it reflected, some of it went into the water. It bent as it entered the water.</td>
</tr>
</table>

Questions:

1. What direction does light travel? Is it curved or in a straight line?

   It is in a straight line.

2. What happens to the light when it goes into water?

   It bends and then goes straight in a new direction.

3. When does light seem to change direction?

   When it bounces off a surface or when it enters something like water.

Does Light Travel in a Straight Line?

Name ______________________________ Date ____________________

<u>Description:</u> Light from a laser beam can be used to see the direction that it travels. In this experiment, you are going to examine how light travels when it reflects from the surface of water and what happens when it goes into water.

<u>Materials:</u>	Clear plastic cup of water	Laser
	Milk	Dropper

<u>Procedures:</u>

1. Pour water into a clear plastic cup so it is ¾ full.
2. Put a drop of milk into the water so it is slightly cloudy.
3. Use the laser to experiment. In each case, draw a line to show the direction of the light from the laser to the water, and then draw how the laser beam looks once inside the water.
4. DO NOT SHINE THE LASER INTO OTHER STUDENT'S EYES

<table>
<tr>
<td>5. Hold the laser above the water like in the picture.
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<td>7. Hold the laser above the water at an angle, like in the picture.
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12. What happened to some of the light from the laser beam?
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</tr>
</table>

Questions:

1. What direction does light travel? Is it curved or in a straight line?

2. What happens to the light when it goes into water?

3. When does light seem to change direction?

What Energy Does A Light Bulb Emit?

Description: Students will measure the amount of heat that is emitted from a light bulb and examine how heat and light are often emitted together from light sources.

Student Materials (per group):
- ☐ Light bulb in lamp socket
- ☐ Thermometer
- ☐ Compact Fluorescent Lamp
- ☐ Black paper pocket

Additional Teacher Materials:
- ☐ None

Background and Misconceptions:

In most cases, light and heat are emitted together. There are various reasons why heat and light are released from an object. For example, the Sun emits light and heat as a result of a nuclear reaction in which hydrogen and helium atoms are slammed together with such tremendous forces that they release light, heat and other forms of energy.

However, an incandescent light bulb emits mostly heat. A small fraction of the energy in an incandescent light bulb is emitted as light. The light bulb has a tungsten filament inside that warms as electrons flow through it. As the energy increases, more energy is released as light. The reason that it does burst into flames (and the rest of the room around it) is that the filament is very small and the heat felt at only a couple of inches away dramatically drops off.

Some light sources emit little or no heat. One example is a glow stick. Chemicals inside the glow stick mix, producing a chemical reaction that releases light but not heat. Another example is a lightning bug.

Compact Fluorescent Lights (CFL's) much more efficiently convert electrical energy into useable light energy and with much less of the energy conversion wasted as heat. LED's also very efficiently convert electrical energy to light energy, but they again release a small amount of heat.

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. What forms of energy are emitted by a light bulb?
2. How can you measure the forms of energy emitted by a light bulb?
3. How are light bulbs and the sun similar?

Additional Hints:

- Use a 40-watt light bulb incandescent light bulb. Very bright LED light bulbs can be used (at least 600 lumen) for the experiment.
- Prepare a black paper pocket using a piece of construction paper that has been folded and taped to allow for a thermometer to slide in. The size should be approximately 3 inches by 5 inches.

Energy: What Energy Does A Light Bulb Emit?
TEACHER ANSWER SHEET

Procedures:

1. Plug in the light bulb. Describe what you see and feel.

It is bright and also feels warm.

2. Place a thermometer inside the black paper pocket.
3. Place the thermometer and paper pocket about 5 inches away from the light bulb.
4. Allow it to sit for about 3 minutes.
5. Record what you observe on the thermometer below.

It will go up at least 10 degrees Celsius.

Questions:

1. What does the light bulb give off?

   It gives off light and heat.

2. How is the light bulb similar to the Sun?

   They both give off light and heat energy.

3. In many cases, objects that give off light also give off heat. Can you think of one item that gives off light, but very little heat?

   A glow stick. (This is an advanced question so students may not be able to correctly answer.)

What Energy Does A Light Bulb Emit?

Name ______________________________ **Date** ____________________

Description: A light bulb and the Sun emit light. But that is not the only form of energy that is emitted. In this experiment you are going to determine another form of energy that is often emitted with light.

Materials:

- Light bulb in lamp socket
- Thermometer
- Compact Fluorescent Lamp
- Black paper pocket

Procedures:

1. Plug in the light bulb. Describe what you see and feel.

2. Place a thermometer inside the black paper pocket.
3. Place the thermometer and paper pocket about 5 inches away from the light bulb.
4. Allow it to sit for about 3 minutes.
5. Record what you observe on the thermometer below.

Questions:

1. What does the light bulb give off?

2. How is the light bulb similar to the Sun?

3. In many cases, objects that give off light also give off heat. Can you think of one item that gives off light, but no heat?

How Are Lenses Used to See Big and Small Things?

Description: Students will use a hand lens to create images similar to how a microscope and telescope create images.

Student Materials (per group):
- ☐ Hand Lens
- ☐ Print of different sizes
- ☐ Index cards or blank sheets of paper

Additional Teacher Materials:
- ☐ Telescope and microscope (optional)
- ☐ Light bulb (if no window)

Background and Misconceptions:

There are two tools used to make items visible that may be difficult to see with the naked eye. A microscope is a device that uses lenses to enlarge very small objects and it creates a type of image that is called a REAL IMAGE. This type of image is formed in an orientation that is upside down as compared to the object and it can be either smaller or larger. In a microscope, the images if formed so they is larger than the object.

Real images are the same type of images you see when a projector is used on a screen. The real image can be projected onto walls and other surfaces. (In contrast, there are virtual images. These types of images cannot be projected. They are only seen "inside" of a lens or mirror. When you see yourself in a flat mirror, this is a virtual image. You can see yourself, but that image can't be projected onto another surface.)

A telescope uses lenses or mirrors to collect light from large distant objects to form an image that is also a real image and upside down, but it's image is smaller as compared to the actual object. While it may be common to think that both a microscope and a telescope magnify, that is not correct. The telescope reduces the size of distant objects to make them easier to observe. Stars are very large objects. It would not be possible to enlarge the star to study it. If it were enlarged, it may be many times larger than our own star. The telescope gathers light and focuses it into a smaller image so that details emerge and allow it to be studied. In the nighttime sky, the stars appear small only because they are very far from Earth. Most stars that we see are tens to hundreds of light years from Earth. A light year is the distance that light travels in one year and is equal to 9,500,000,000,000 kilometers.

The hand lens is used to create images that are both larger and smaller than the actual object. This is caused by the distance of the hand lens to the object. When an object is placed closer to the hand lens than the focal point (the point where the light that goes through the lens combines to a single point) the image that is produced is larger, upright, and virtual.

When the object is placed farther than the focal point, the image that is formed is sometimes larger or smaller, but it is always upside down and real. If the object is farther than 2 times the focal length, it is always smaller.

An excellent applet that you can use to explore these effects can be found at:
http://www.physics.uoguelph.ca/applets/Intro_physics/kisalev/java/clens/index.html

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. Why do you use a microscope?
2. Why do you use a telescope?
3. What is the different between a microscope and a telescope?
4. How are the images formed from a microscope and a telescope different?

Additional Hints:

- If the classroom does not have a window, place a light bulb at one end of the room and have students image from the other side. Or also go outside in the hallway and observe out the door.
- If you have a microscope or telescope, set it up and have students compare the results of the experiment with the hand lens.
- Any double convex hand lens can be used, including magnifying glasses or a variety of inexpensive plastic hand lenses.
- Cut out the sheet with the print that has different sizes on it.
- In this experiment, you may want to withhold the procedures from the students initially and then have them try to create an image on the sheet of paper.

How Are Lenses Used to See Big and Small Things?
TEACHER ANSWER SHEET

Procedures:

1. Create an image of a big object (like a house) that is outside the classroom window:

Image may be different for every student; however, the image will be smaller and upside down as compared to the actually object. It will also be fainter than the light coming from the real object.

2. View an image of a very small object.

The image will be larger than the actual print. They will see this through the hand lens: This is LARGE, This is not too small, THIS IS VERY SMALL

Questions:

1. A microscope is used to see things that are too small to be seen with your eye. In which part of this experiment was the hand lens acting like a microscope?

   The part in which students were looking at the different-sized print.

2. A telescope is used to see large things that are far away, but may still be hard to see with your eye. In which part of this experiment was the hand lens acting like a microscope?

   The part in which students were looking at the objects out the window.

3. How is the image that shines on the paper (from outside) different from the image when looking through the hand lens?

   The image from outside is upside down and smaller. The image through the hand lens of the print was right-side up and larger.

4. Both a microscope and a telescope make it possible to see objects that are too hard for us to see with our eyes. How is a microscope different from a telescope?

   A microscope enlarges very small things. A telescope makes larger things that are far away smaller but easier to see so they are close up.

This is LARGE

This is not too small

This is very small
THIS IS VERY SMALL

This is LARGE

This is not too small

This is very small

THIS IS VERY SMALL

This is LARGE

This is not too small

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VERY SMALL

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How are Lenses Used to See Big and Small Things?

Name ______________________________ **Date** ____________________

Description: Lenses are pieces of plastic or glass that are curved so that light bends when it goes through the plastic or glass. Because light can bend as it goes through the glass or plastic, lenses can be used to magnify objects that are either very small or very far away.

In this experiment, you are going to explore how to use a lens to view things that are either very small or very far away.

Materials: Hand Lens; Sheet of paper; Paper with different-sized print.

Procedures:

1. Make an image of a big object (like a house) that is outside the classroom window:
   a. Aim the lens so it is pointed toward a window.
   b. Use the sheet of paper and move it back and forth until an image of the house or tree outside the classroom can be seen.
   c. What do you see on the paper? Draw the picture and write what you see.

2. View an image of a very small object.
   a. Use the lens to examine the sheet of paper with the different sized print.
   b. Write down what you see.
   c. Find other things that are very small that you can make larger.

Questions:

1. A microscope is used to see things that are too small to be seen with your eye. Which part of this experiment was the hand lens acting like a microscope?

2. A telescope is used to see large things that are far away, but may still be hard to see with your eye. Which part of this experiment was the hand lens acting like a microscope?

3. How is the image that shines on the paper (from outside) different from the image when looking through the hand lens?

4. Both a microscope and a telescope make it possible to see objects that are too hard for us to see with our eyes. How is a microscope different from a telescope?

What Light Is In A Laser?

Description: Students will use a pair of the diffraction glasses to observe the spectrum of laser light and understand that light is made up of other colors.

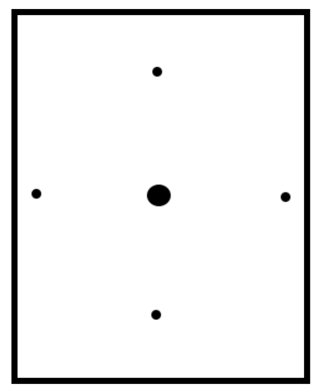
Student Materials (per group):
- ☐ Laser
- ☐ Diffraction Glasses

Additional Teacher Materials:
- ☐ Classroom lights

Background and Misconceptions:

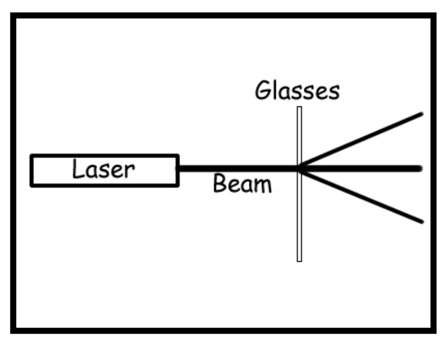
Diffraction glasses are glasses that have eyepieces made out of plastic in which narrowly spaced lines are etched. These lines are so close that when light shines through them, the light spreads out or diffracts. This is similar to what happens when light shines through a prism. They can be used to observe the light (spectrum) that makes up the colors we see. For example, when you look at a white light bulb through the diffraction glasses, the light spreads out and you will see all the colors of the rainbow: Red, orange, yellow, green, blue, and violet (leaving out indigo since it is almost indistinguishable from blue and violet). These colors combine in a white light bulb.

If you look through a pair of diffraction glasses at colored light bulbs, the spectrum is not full – in other words, you will not see all the colors. You will only see colors that make up the light. Parts of the spectrum will be missing. For example, when you look at a green light bulb, you will observe green through the diffraction glasses, possibly yellow or blue, but the red will be missing. This is because green light bulbs do not emit any red light. If the light bulb were a pure green bulb, even the yellow and blue would be missing, but because of the quality of the coating on the bulb, some yellow and blue leaks through the coating from the filament or gas inside.



A red laser is different. There is no filter that creates the red light from a red laser. It is created through a process that emits only red light. Therefore, when you look at the spot of light with the diffraction glasses, the ONLY color you will see is red light. In the diffraction glasses, this will look like a series of dots all around the central bright laser light. (The glasses make this pattern because many have lines that are etched in two directions – vertical and horizontal.)

CAUTION: When examining the laser light, DO NOT LOOK DIRECTLY INTO THE LASER BEAM. Shine the beam on a wall or the ceiling and then look at the point of light with the glasses. Also, the spectrum is easier to see when all the room lights are out. If you would like everyone to see the spectrum put one eye piece of the glasses over the opening where the laser light is emitted. This will cause the diffraction pattern to be projected onto the ceiling.



Many students will believe that lasers have a colored filter or light bulb inside that creates the red light. However, this red light is formed because of a gas or solid that is giving off red light. There are no filters that "color" the light red.

Try these other experiments/demonstrations with the laser and diffraction glasses:

1. Place colored filters in front of the laser to see how the colors will filter red light. Only blue and green filters will prevent the red light from passing. Other colors will allow it to travel through.
2. Use a laser on a mirror to show that the angle of incidence equals the angle of reflection. Use chalk dust, a water spray bottle or a fog machine to show the beam.
3. Shine the laser over the top of a hot plate or candle. The laser spot will move as the light goes through the less dense air just like star light shimmers in the atmosphere. The varying density of the air causes the light to refract or bend as it travels through the hot moving air above the hot plate or candle.
4. Shine a laser onto a glass or mirror and view the reflection. If you GENTLY push on the glass or mirror, the laser beam will move from the very small deflections of the glass.

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. What colors make up white light?
2. What colors are in red laser lights?
3. What do you observe when you look through a pair of diffraction glasses?
4. How can we use the diffraction glasses to examine the light that comes from a classroom light and the laser light?
5. What is the difference between the red laser light and the classroom lights? How can we use the diffraction glasses to examine the light?

Additional Hints:

- Many inexpensive diffraction glasses can be purchased online. Expect to pay less than $1 per pair, depending on quantity.
- Make sure students do not look directly into the laser beam.
- Let the students know that the lines that are etched into many glasses are both horizontal and vertical so they see colors in many different directions.

What Light Is In A Laser?
TEACHER ANSWER SHEET

Procedures:

1. Put on the diffraction glasses. What do you observe when you look at lights in the classroom?

All the colors of the rainbow. The colors of the fluorescent lights are slightly different than the colors seen on the overhead projector or from an incandescent light bulb. Red is missing from fluorescent lighting.

2. What colors are found in white light?

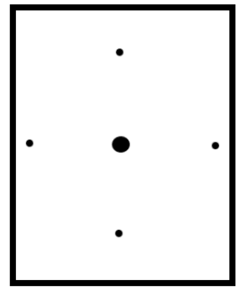
a. **Red**	d. **Green**
b. **Orange**	e. **Blue**
c. **Yellow**	f. **Violet**

3. Predict: When the teacher turns on the laser, look at the point of light on the wall. What colors do you think you will see when you look at the laser light?

Student answers, but may state that they see colors other than red.

4. Write the colors you see below: *(CAUTION: DO NOT LOOK DIRECTLY INTO THE LASER. Only look at the laser when it is shining on a wall, table, or ceiling. It is safe only to look at the reflection.)*

Will see only red light points and in the following layout:



Questions:

1. How is the laser light different than white light?

   The laser light has only the color red, whereas the white light is made up of all the colors of the rainbow.

2. If you looked at red light bulb what colors would you see through the diffraction glasses?

   You will see only red and possibly orange and yellow, depending on how "good" the red coating is on the light bulb. A cheap coating allows more colors to pass through from the filament.

3. Diffraction glasses split light into the colors that make it up. When you look at a green light bulb through the glasses, the red part is missing. What does this mean?

   The green bulb does not emit any red light so you don't see red light through the diffraction glasses.

What Light Is In A Laser?

Name ______________________________ **Date ____________________**

Description: Diffraction glasses can be used to peel light apart and see what colors make up the light. In this activity, you are going to find out what colors are in laser light.

Materials: Laser Diffraction Glasses Classroom lights

Procedures:

1. Put on the diffraction glasses. What do you observe when you look at lights in the classroom?

2. What colors are found in white light?
   a. ______________ d. _______________
   b. ______________ e. _______________
   c. ______________ f. _______________

3. Predict: When the teacher turns on the laser, look at the point of light on the wall. What colors do you think you will see when you look at the laser light?

4. Write the colors you see below: *(CAUTION: DO NOT LOOK DIRECTLY INTO THE LASER. Only look at the laser when it is shining on a wall, table, or ceiling. It is safe only to look at the reflection.)*

Questions:

1. How is the laser light different than white light?

2. If you looked at red light bulb what colors would you see through the diffraction glasses?

3. Diffraction glasses split light into the colors that make it up. When you look at a green light bulb through the glasses, the red part is missing. What does this mean?

What's In A Color?

Description: Students will use diffraction grating glasses to examine the spectra through various colored filters.

Student Materials (per group):

- ☐ Diffraction grating
- ☐ Red Bulb or LED
- ☐ Blue Bulb or LED
- ☐ Green Bulb or LED
- ☐ White Bulb
- ☐ Markers

Additional Teacher Materials:

- ☐ Light bulbs/overhead lights

Background and Misconceptions:

Light can be broken into component colors using a diffraction grating. Waves, light or any type of wave that goes through a narrow slit spreads out. The process that results from the wave spreading out as it goes through a narrow opening is called diffraction. When we use diffraction, it is possible to see which frequencies, or colors of light, make up the light that you see with your naked eye. Different colors of light have different spectra. (The spectrum is the light that makes up the colors we see.) For example, when you view a red light, the diffraction grating spreads out the light and you see that red, yellow and orange may be present in the spectrum, but not colors such as blue. If the light is from a red laser, you will see only red because lasers are comprised of exactly one frequency of light, whereas a red light bulb is not a single pure frequency. When a spectrum is present with all the colors, we call this a continuous spectrum.

Continuous Spectrum from White Light

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

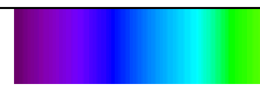
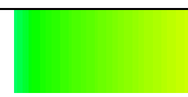
1. What happens when light passes through a prism?
2. What would happen if you passed light through a prism that was only one color?
3. Why are colored light bulbs "colored?"
4. Use the diffraction gratings to determine what makes up each type of light, both for the white light and the colored light bulbs.
5. What colors are hidden inside of light and how can the diffraction gratings be used to investigate the types of colors?

Additional Hints:

- The best light bulbs to use for this experiment are compact fluorescent light bulbs. Many home improvement stores sell red, blue and green CFL Bulbs.
- LED lights can also be purchased online or at an electronics store. Don't use colored incandescent bulbs because their color light output is not as pure.
- Diffraction grating glasses can be purchased online for less than $1 each by searching for "diffraction grating glasses."
- When using the diffraction grating and the colored filters, do not touch the plastic. Handle only by the cardboard frame.

What's In A Color?
TEACHER ANSWER SHEET

The spectra shown are approximate. Students may see parts of the spectra that are further to the left or right of what is depicted.

Color of Bulb or LED	Colors contained in the light.	Drawing of the colors and label of colors.
White Bulb	**All colors, red, orange yellow, green, blue, indigo violet**	
Red Bulb or LED	**Mostly red**	
Blue Bulb or LED	**Mostly blue with some green**	
Green Bulb or LED	**Mostly green, with some blue and red**	

Questions:

1. How does the spectrum change with the different colored bulbs?

   There are different parts of the spectra that are visible, but the light that is visible always matches the color of the filter. So if I am using red, I see the red part of the spectrum.

2. Compare the spectrum from the white bulb to the spectrum of the red, green and blue bulb. When you mix red, green, and blue light, why do you get white light?

   The white light is made up of all the colors of the rainbow. Red Blue and Green contain only parts of the rainbow, but when they are combined, all the colors are also combined and they make white light.

3. What do you think the diffraction grating glasses do?

   The diffraction gratings spread the light out so much that it is possible to see what makes up light.

What's In A Color?

Name ____ **Date** ____________________

Description: You will use diffraction grating glasses to examine different colored light bulbs and LED lights.

Materials: Red, Blue, Green Light Bulbs or Red, Blue Green LED's
White light bulb
Diffraction Grating Glasses
Markers

Procedures:

1. Look at the white light bulb through the diffraction grating. What do you see? Record your results in the table below. Make a drawing of the colors and label the colors in the table on the next page.
2. Look though the diffraction grating once again, but this time look at the different colored light bulbs. Write down what you see and make a drawing of what you see.

Color of Bulb or LED	Colors contained in the light.	Drawing of the colors and label of colors.
White Bulb		
Red Bulb or LED		
Blue Bulb or LED		
Green Bulb or LED		

Questions:

1. How does the spectrum change with the different colored bulbs?
2. Compare the spectrum from the white bulb to the spectrum of the red, green and blue bulb. When you mix red, green, and blue light, why do you get white light?
3. What do you think the diffraction grating glasses do?

How Do Colors Reflect?

Description: Students will examine the primary colors of light and pigments while exploring color subtraction processes.

Student Materials (per group):
- ☐ Colored Filters

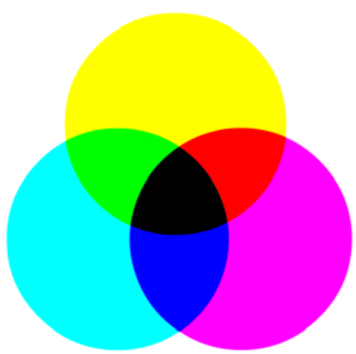
Additional Teacher Materials:
- ☐ PowerPoint Presentation or Handouts

Background and Misconceptions:

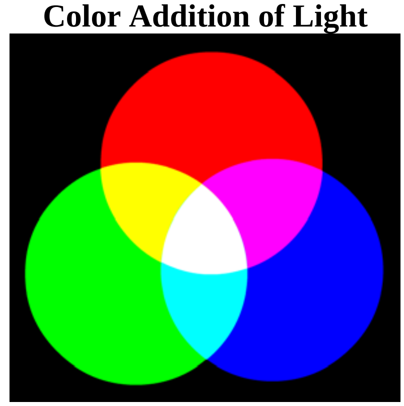
White light is made up of an equal proportion of Red, Blue, and Green colors. These are known as the primary colors of light. When red, blue, and green are mixed in varying proportions every other color of light can be formed and it is possible to form millions of different colors.

Likewise, pigments are made of compounds that subtract light, or absorb, and then reflect certain colors. When white light shines on something that appears black, the material absorbs all the colors so no light is reflected. When something appears red, the pigments absorb all colors except for red light. This is said to be a subtractive process. As a result, the primary colors of pigments are different from the primary colors of light; cyan, magenta, and yellow.

Color Subtraction of Pigments



Color Addition of Light



Most colors are a combination of two or three primary colors. Green light that is reflected from a surface is composed of yellow and cyan pigments. Therefore, the cyan and yellow pigments absorb red and blue light, with only green light remaining to reflect. On the other and, a cyan pigment will only absorb red light, leaving green and blue light to mix on their way to your eye so you see cyan light.

Colored Dot	*Absorbs this light*	*Remaining Light*
Cyan	Red	Green and Blue
Magenta	Green	Red and Blue
Yellow	Blue	Green and Red
Purple	Green	Red and Blue
Orange	Blue	Red and Green

After the experiment is completed, have students examine the results of the table. They will notice that certain filters do not transmit specific colors. For example, blue is never seen through the yellow filter. This causes some colors to appear differently through the filters.

In many art classes, students have learned that the primary colors are red, blue, and yellow. This is incorrect because it combines two colors from the primary colors of light and one color from pigments. One only needs to examine a color printer to find that it contains four cartridges: cyan, magenta, yellow, and black (to deepen the colors). They do not contain blue or red, because they are secondary pigment colors.

In this experiment, students will use the colored filters to examine the various colored dots on the PowerPoint presentation. The students should not look at the dots prior to examining them through the filters. Our brains have the ability to compensate for changes in perceived color and "see" what is not there. If you were to look at a red dot through a green filter, it should appear black. If you look at the red dot first, then view it immediately through a green filter, an optical illusion is formed whereby the brain takes the green color into account and adjusts so that you still see some red. In the answer key, most of the dots that appear black could also appear to be a gray color. Take this into account when grading.

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. How do colors you see change when viewed through filters?
2. How does the light in a room change how we see different pigments?
3. What causes the way we see colors to change?

Additional Hints:

- Make sure students do not look at the dots prior to looking at them through the colored filters.
- If you print out the slides, do so on a high quality printer and using high quality paper.
- Prepare your own presentation, replicating the colored circles found later in this lesson. Each slide should have a gray background for best results.
- Ensure that the lighting in the room is not tinted.

How Do Colors Reflect?
TEACHER ANSWER SHEET

Colored Circle↴	Red	Blue	Green	Yellow	Blue-Green (Cyan)	Magenta	Orange	Purple
1 Green	Black	Black	Green	Green	Green	Black	Green	Black
2 Blue	Black	Blue	Black	Black	Blue	Blue	Blue	Blue
3 Red	Red	Black	Black	Red	Black	Red	Red	Red
4 Yellow	Red	Black	Green	Yellow	Green	Red	Orange	Red
5 Purple	Red	Blue	Black	Red	Blue	Purple	Red	Purple
6 Orange	Red	Black	Green	Orange	Green	Red	Orange	Red
7 Magenta	Red	Blue	Black	Red	Blue	Magenta	Red	Purple
8 Cyan	Black	Blue	Green	Green	Cyan	Blue	Green	Blue

Questions:

1. Explain why a color such as red appears red.

   If white light shines on the object, only red light is reflected to a person's eye. All the other colors are absorbed by the pigments that make the object appear red.

2. Why do some colors appear black through the filters? Explain what is happening.

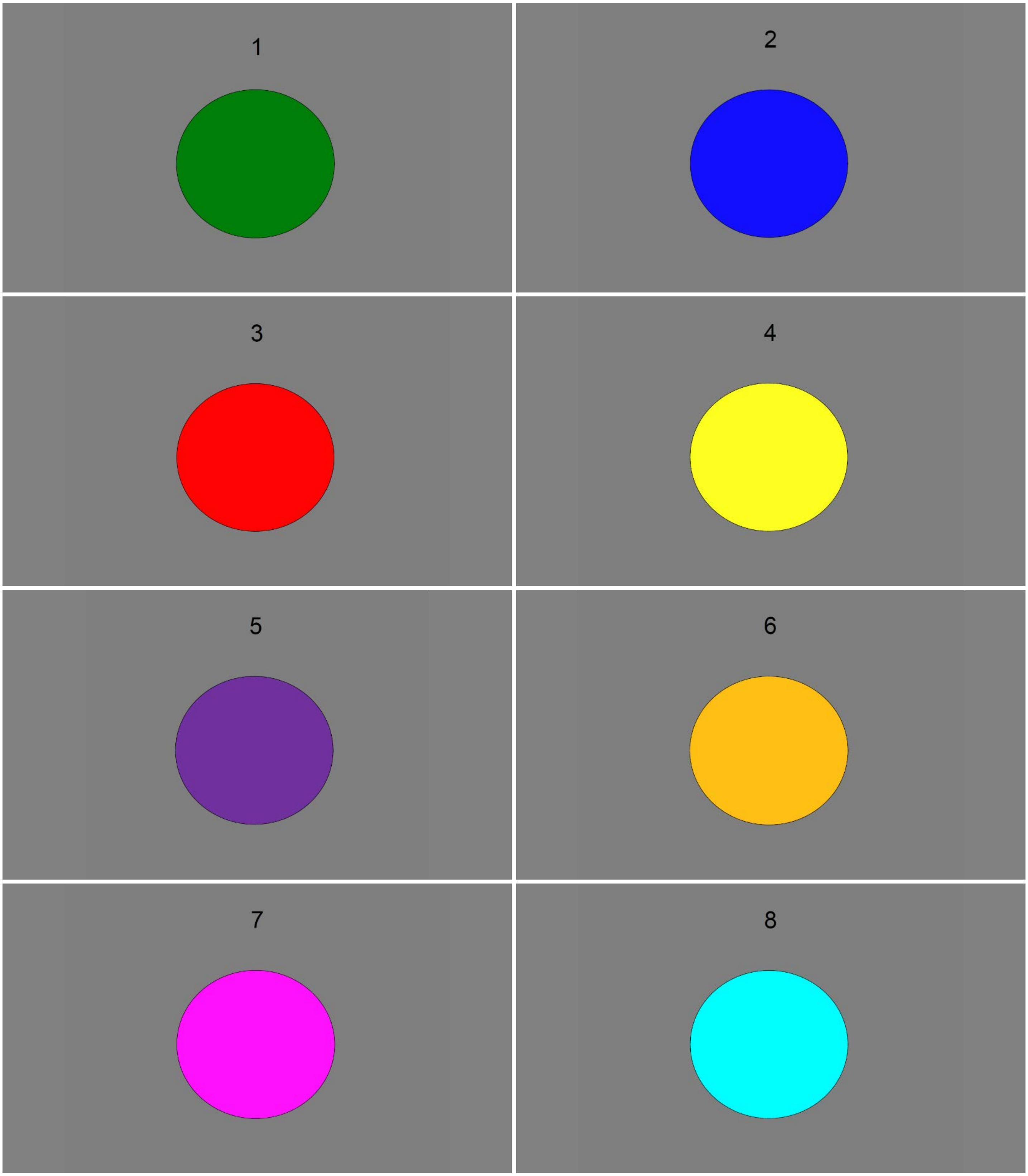
   The filters absorb certain colors and if the colored black dot is reflecting/transmitting colors that are absorbed by the filter, the dot will appear to be black. So if a red dot is viewed through a green or blue filter, those filters will absorb all other colors. Since red contains no red or green light, it will appear to be black through those filters.

3. By examining the chart from this experiment, what color of light does the following absorb?
   a. Cyan b. Magenta c. Yellow

   Cyan absorbs red **Magenta absorbs Green** **Yellow absorbs blue**

4. Based on your answer to number 3, explain why Cyan and Yellow are combined to produce a green pigment.

   Cyan absorbs red light while yellow absorbs blue light. The only remaining color not absorbed is green light.



Prepare a PowerPoint with the following colors on dark gray background: Green, Blue, Red, Yellow, Purple, Orange, Magenta, Cyan.

How Do Colors Reflect?

Name ____ **Date ____________________**

Background: The color you observe from the surface of an object, such as an apple, is very much controlled by the color of the light that shines on it. In this lab, we are going to observe the effect of color subtraction by using colored filters and colored circles.

Materials: Colored filters PowerPoint Presentation called "Color Subtraction"

Procedures:

1. Open up the PowerPoint Presentation found on the computer.

2. Using each of the colored filters shown below, observe each of the colored circles. Keeping one eye closed, hold the filter in front of your open eye, and observe the dots. There are a total of 8 colored dots. Do not view the colored circles before observing it through the filter. Record the apparent color on the sheet below. Each person in your group will record his or her own observations.

Colored Circle	Red	Blue	Green	Yellow	Blue-Green (Cyan)	Magenta	Orange	Purple
1								
2								
3								
4								
5								
6								
7								
8								

Questions:

1. Explain why a color such as red appears red.

2. Why do some colors appear black through the filters? Explain what is happening.

3. What color of light does the following absorb?
   a. Cyan b. Magenta c. Yellow

4. Based on your answer to number 3, explain why Cyan and Yellow are combined to produce a green pigment.

How Can Light Be a Fingerprint?

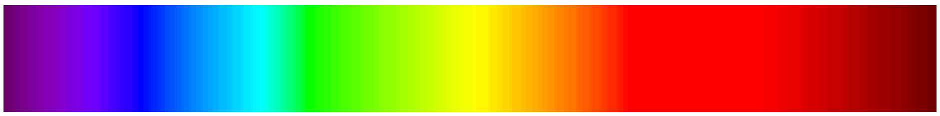
Description: Students will examine the spectra of gases to determine their composition.

Student Materials (per group):
- ☐ Diffraction Gratings

Additional Teacher Materials:
- ☐ He, Ne, H_2, O_2, Kr Spectral Tubes
- ☐ Spectral Tube Power Supply

Background and Misconceptions:

When light is viewed through a diffraction grating, the light spreads out into its composite colors. Incandescent light bulbs emit a continuous spectrum, a viewer will see a spectrum similar to the one below.



Continuous Spectrum

Light can be used to identify particular gases, similar to using DNA or fingerprints. Gases that are composed of one element or molecule will emit a spectrum that is not continuous. The light is emitted by first sending energy through a gas that excites the electrons causing specific wavelengths of light to be given off. Through a diffraction grating, the emission spectrum will appear as a series of discrete lines at specific points along the electromagnetic spectrum. For example, the emission spectrum for helium appears below.

Helium Spectrum

Astronomers use this process to examine a star's spectra and determine the composition of the star. Keep in mind that a star is composed of many elements. Each element's spectra overlap with each other, making the work of the astronomer a bit more difficult in unraveling the star's composition. It also takes some training to become expert at matching the spectra seen through the diffraction gratings with those that are standard. Often, the diffraction gratings do not represent all the lines clearly.

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. How can you identify the gases based on the spectrum you see with the diffraction gratings?
2. How can the spectrum be used to identify the composition of stars?
3. What will happen if the spectrum contains several gases?

Additional Hints:

- Use diffraction grating glasses that can be purchased in bulk for less than $1 at many online stores.
- When using the power supply and spectral tubes, use great caution. The power supply uses very high voltage to energize the spectral tubes and students should not touch them.
- This lab can be turned into a fun quick activity in which the students try to determine which element is contained in the tube.
- The student worksheets that contain the emission spectra must be printed in color. They can be laminated to be used repeatedly.

How Can Light Be A Fingerprint?
TEACHER ANSWER SHEET

<u>Questions:</u>

1. How easy is it to identify each gas? How important is it to be trained in identifying the gas?

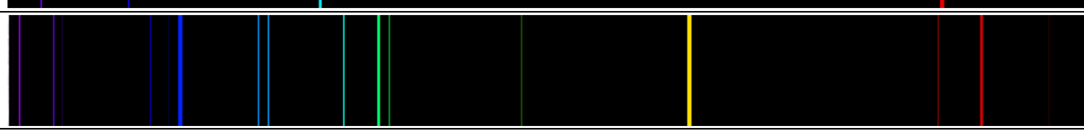
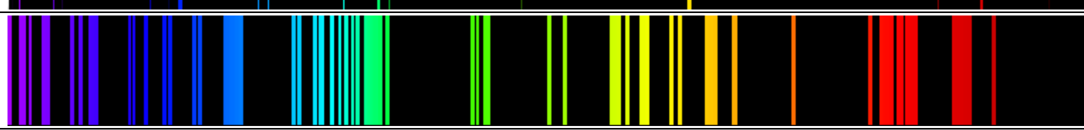
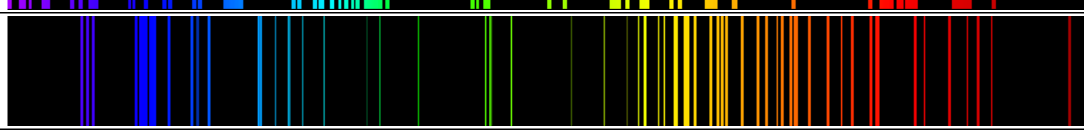
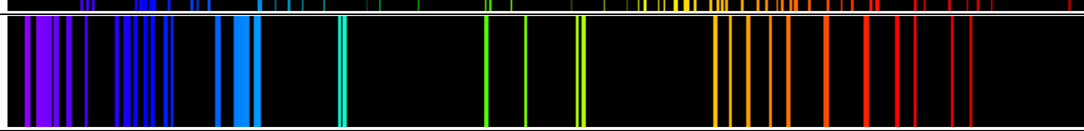
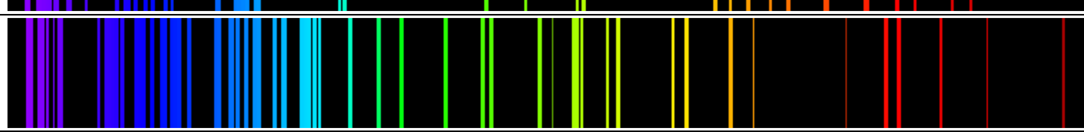
   It can be quite difficult since the diffraction grating may not show all the lines clearly. It is very important to be trained, just as police are trained to examine and match fingerprints.

2. Stars are made up of many elements. How do you think the spectrum might appear if there are three elements in a star?

   The spectra from the three elements would overlap producing a much more complicated spectra. The spectra would have to be disassembled to determine which elements are contained in the star.

3. Why is using a spectrum to identify gases important?

   It allows scientists and astronomers to identify elements, atoms, and molecules using light without necessarily having a sample in their labs. For example, it is impossible to go get a sample of star, but the spectra allows astronomers to discover the composition of a star.

Tube Number	Spectrum
Hydrogen	
Helium	
Nitrogen	
Neon	
Oxygen	
Krypton	

How Can Light Be a Fingerprint?

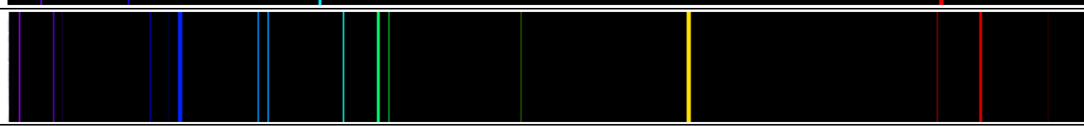
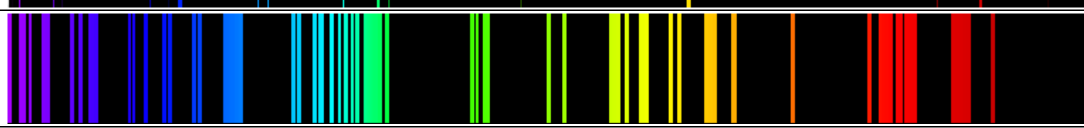
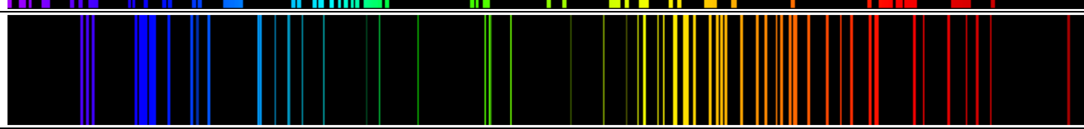
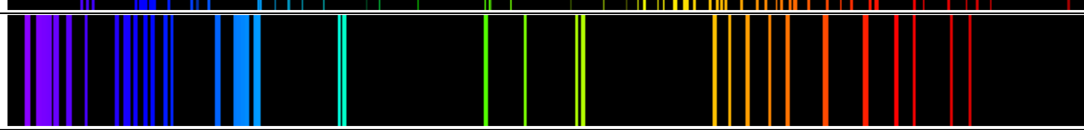
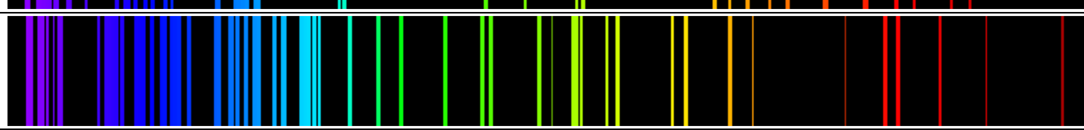
Name ____ **Date** ____________________

<u>Description:</u> Light can be made up of many different colors, but when examining different gases, it is possible to spread the light out and view its spectrum. The spectrum of a gas is similar to a person's fingerprint because it uniquely identifies it. In this experiment you are going to try to determine the type of gas you are viewing.

<u>Materials:</u> Spectral Tubes Diffraction Grating Power Supply

<u>Procedures:</u>

1. Use the diffraction grating to view each gases' spectrum.
2. Using the chart below, try to identify the gas.

Tube Number	Spectrum
	
	
	
	
	
	

<u>Questions:</u>

1. How easy is it to identify each gas? How important is it to be trained in identifying the gas?

2. Stars are made up of many elements. How do you think the spectrum might appear if there are three elements in a star?

3. Why is using a spectrum to identify gases important?

How Do You Make Colors?

Description: Students will use the primary colors of light to form other colors and describe how the primary colors of light form secondary and tertiary colors.

Student Materials (per group):
- ☐ Red LED
- ☐ Blue LED
- ☐ Green LED
- ☐ White paper or card
- ☐ Crayons or Markers (optional)

Additional Teacher Materials:
- ☐ All lights off in room

Background and Misconceptions:

When asked "What are the primary colors?" most will often respond with "red, blue, and yellow." This major misconception is often introduced at an early age in art classrooms. Yet, the question should more appropriately be asked as "What are the primary colors of light?" because there are two sets of primary colors: Light and pigments.

Primary colors exist because our eyes can only perceive three basic colors: Red, Blue, and Green. These three primary colors combine in different ways to produce all the other colors that can be seen. (Other animals perceive colors in different ways, so depending on their biology, may have different sets of primary colors.)

In the picture on the left, you see a picture of three colored circles that are overlapping. The circles are projections of colored light. When red and blue combine equally, they create the color MAGENTA. When red and green light combine equally, they create the color YELLOW. And when green and blue light combine equally, they create the color CYAN. Cyan, magenta, and yellow are called the SECONDARY COLORS of light. (These secondary colors of light represent the primary colors of pigments.)

The primary colors of light combine by adding together. This is called an ADDITIVE PROCESS because one starts with no light, and then combines the available light to produce all the other colors. When the light is mixed in unequal amounts, other colors can be formed. For example, to make the color orange, more red light is shone on the paper than yellow. This can be done by either moving the red light closer to the wall or paper, or by increasing the intensity of the light. (In contrast, pigments are formed in a SUBTRACTIVE PROCESS.)

When all three primary colors are combined equally, white light is produced.

The relationship between the primary colors of light and the primary colors of pigments now become obvious. When red, blue, and green lights are mixed and paired, they produce the primary colors of pigments. Likewise, when cyan, magenta, and yellow pigments are mixed and paired, they produce as their secondary colors of light, red, blue, and green pigments. For proof of this, one only needs to look inside of a color printer to observe the colors of the cartridges. One will see only magenta, cyan, yellow and black. The black cartridge is added for increased depth in the images and text produced. When all three colored pigments are combined in equal proportions, black is produced.

Whereas white is the TOTAL (all light added together) of the three primary colors of light, black is the absence (all light that is reflected is subtracted away) of light. The pigments absorb the light that is shining on the pigment and only reflect those colors you see.

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. What can you do with the three LED lights to make yellow light?
2. How can you make other colors of light than just red, blue, and green light?
3. What do you need to do to make orange, purple using only the three colors of light?

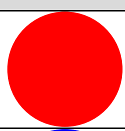
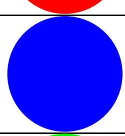
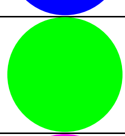
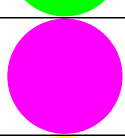
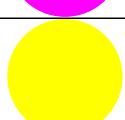
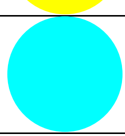
Additional Hints

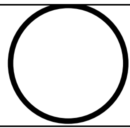
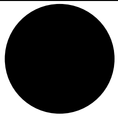
- Ensure the room is as dark as possible.
- It may occur that the best color matches between the circle and the LED's are at a point in which the lights are not equally distant from the card. This could occur because the batteries are not equally charged.
- Our perception of the mixed colors could cause some students to see the colors differently. You may need to practice with them to see the various colors.
- This section has two activities, one basic for lower grades, and one more advanced for upper grades.

How Do You Make Colors?
TEACHER ANSWER SHEET

<u>Procedures:</u>

1. Using the LED lights, try to make the following colors.
2. Record what you need to do to make the colors match the colored circles below.

Color of Circle	What did you do? How did you combine the LED's to make this color?
	**Only use the red LED.**
	**Only use the blue LED.**
	**Only use the green LED.**
	**Use the blue and red LED together and they are held at the same distance from the card.**
	**Use the green and the red LED together and they are held at the same distance from the card.**
	**Use the green and the blue LED together and they are held at the same distance from the card.**

	**All lights are used and they are all at the same distance from the card.**
	**No lights are used.**

<u>Questions:</u>

1. Is it possible to make the color red using more than one LED? Why is red called a PRIMARY color?

   No – the color red is a primary color because no other colors can be combined to form it.

2. Is it possible to make the color yellow using only one LED? Why is yellow called a SECONDARY color?

   Yes. You need to use red and green to make yellow light. Yellow uses 2 colors, so that makes it secondary.

3. If you wanted to make the color orange, what would you need to do?

   You will use red and green light, but the red light will be closer to the card so that there is more red mixed in to form the orange color.

4. What is the major difference between the lights used to form the white circle versus the black circle?

   White light is a combination of all the colors of light in equal proportions (all at the same distance from the card.) Black is the absence of all light.

How Do You Make Colors?

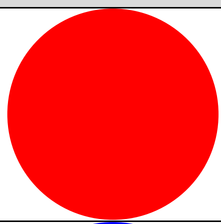
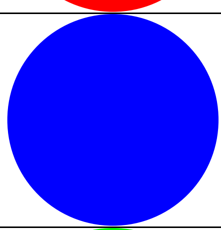
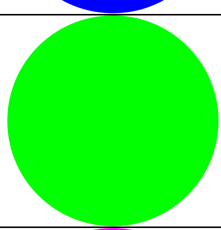
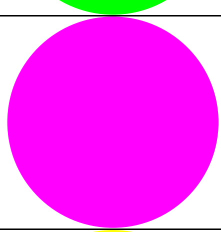
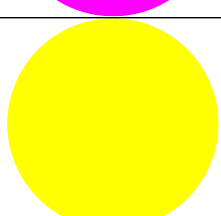
Name ____________________________ **Date** ___________________

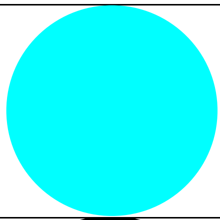
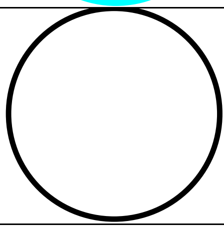
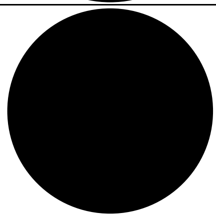
Description: All colors we see are the combinations of three basic colors that are called PRIMARY colors. In this experiment you are going determine how colors combine to form all other colors.

Materials: Red, Blue, Green LED White Paper or Card

Procedures:

1. Using the LED lights, try to make the following colors.
2. Record what you need to do to match the colored circles below.

Color of Circle	What did you do? How did you combine the LED's to make this color?
	
	
	
	
	

Questions:

1. Is it possible to make the color red using more than one LED? Why is red called a PRIMARY color?

2. Is it possible to make the color yellow using only one LED? Why is yellow called a SECONDARY color?

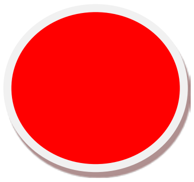
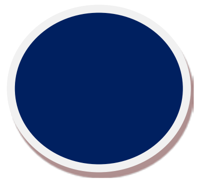
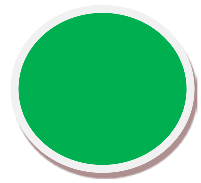
3. If you wanted to make the color orange, what would you need to do?

4. What is the major difference between the lights used to form the white circle versus the black circle?

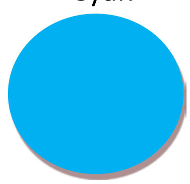
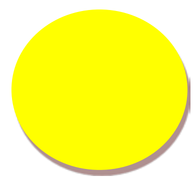
How Do You Make Colors?
TEACHER ANSWER SHEET

Procedures:

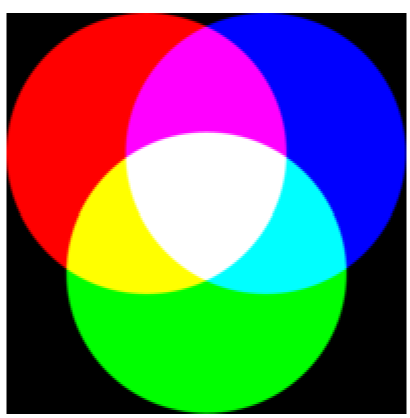
1. Shine the different colored flashlights onto the white sheet of paper and observe the color seen. In the table below, make a drawing of what you observe.

Red Light	Blue Light	Green Light
		

2. Mix the colors in various combinations. For example, use the red and blue light together. You may have to hold one light farther or closer to the paper than the other. Try to make sure the intensity of the light shining on the paper is about the same for each light bulb. In the table below, make a drawing of what you observe.

Red and Blue Light	Blue and Green Light	Red and Green Light
Magenta 	Cyan 	Yellow 

3. Mix all three lights together. What do you observe? Make a drawing below.

Red, Blue, and Green Light


Questions:

1. Some think that yellow is a primary color of light. Based on the results of your experiment, is yellow a primary color of light? Explain.

   No, because a primary color can not be created from the combination of two or more other colors. Since yellow is created when green and red are combined it is not a primary color. It is called a secondary color.

2. What are the other colors that were formed when you mixed red and blue together? What about you when you mixed blue and green together?

   When red and blue are mixed, the color magenta is formed. When blue and green are mixed, cyan is formed.

3. What do you need to do with the lights to make even more colors than the ones you saw in this experiment?

   By mixing the colors in different combinations or proportions, other colors can be created. For example, by mixing more red light into a combination of red and green, the color orange can be created. By changing the percentage of each that is shining on a white sheet of paper, it is possible to all other colors.

How Do You Make Colors?

Name ______________________________________ **Date** ____________________

Description: Only three colors of light are needed to be able to create all the other colors of the rainbow. These three colors are called the Primary Colors of Light. Our eyes are only able to see these three colors in various combinations that our brain interprets into the many different colors we observe.

In this laboratory activity, we are going to examine the formation of other colors from three primary colors.

Materials: 1 Red LED, 1 Blue LED, 1 Green LED, Crayons or markers, White Sheet of Paper

Procedures:

1. Shine the different colored flashlights onto the white sheet of paper and observe the color seen. In the table below, make a drawing of what you observe.

Red Light	Blue Light	Green Light

2. Mix the colors in various combinations. For example, use the red and blue light together. You may have to hold one light farther or closer to the paper than the other. Try to make sure the intensity of the light shining on the paper is about the same for each light bulb. In the table below, make a drawing of what you observe.

Red and Blue Light	Blue and Green Light	Red and Green Light

3. Mix all three lights together. What do you observe? Make a drawing below.

Red, Blue, and Green Light

Questions:

1. Some think that yellow is a primary color of light. Based on the results of your experiment, is yellow a primary color of light? Explain.

2. What are the other colors that were formed when you mixed red and blue together? What about you when you mixed blue and green together?

3. What do you need to do with the lights to make even more colors than the ones you saw in this experiment?

How Does Gravity and Light Change Plants?

Description: Plants adapt to their environment. Changes in positions and light can cause such adaptations. We will explore these in this experiment.

Student Materials (per group):

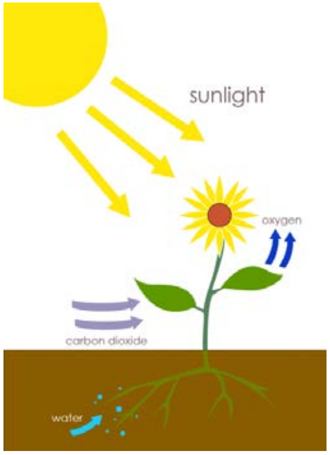
- ☐ Cardboard box
- ☐ Two Plants
- ☐ Tray

Additional Teacher Materials:

- ☐ Cabinet

Background and Misconceptions:

Plants need to have water, air, nutrients, and sunlight so they can create food to survive and grow. A process called photosynthesis uses sunlight to chemically convert water and carbon dioxide from the air into sugar. The plant also needs nutrients from the soil to help it perform biological processes. The waste product of a plant is oxygen.



Credit: At09kg from Wikipedia

Since sunlight is such an important factor in providing energy to covert carbon dioxide and water into sugar, the plant will often grow in the direction of the dominant light source. The roots will also grow in the direction of sources of water and nutrients.

However, roots are affected heavily by gravity. Roots will grow wherever gravity pulls them. The stems of the plants can withstand this to a certain extent but if the conditions change, it might cause the stems to grow differently to counteract the force of gravity.

Plants are made up of 95% water. If you were to remove the water, most of the solid parts of the plant (leaves, bark, limbs, truck, roots) are made from carbon and oxygen. These elements come from the carbon dioxide in the air and not from the nutrients in the soil. Sunlight does the important work of turning the elements found in the gases of the air into the solids of the tree.

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. What will happen if you turn a plant upside down?
2. How does light affect the growth of a plant?
3. How can you change the direction that a plant will grow?
4. Why do some plants grow with straight limbs and others are curved?

Additional Hints:

- Use plants with flexible stems, such as lima beans or pea plants.
- This experiment will take several weeks to perform.
- Make sure to assemble the cardboard boxes beforehand.
- Make sure that the light hits a small portion of the plant.
- It is recommended that after the experiment is carried out to unearth the plant and see how the roots have grown in the "sideways" experiment. This should show the effect of gravity not just on the leaves and stems but the roots as well.
- Instead of hanging the tray, you can place the tray on top of a cabinet with the plants hanging over its side.

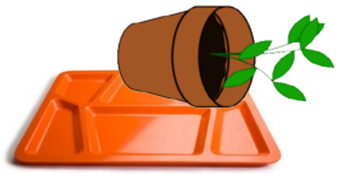
How Does Gravity and Light Change Plants?
TEACHER ANSWER SHEET

Procedures:

1. Observe the two plants and draw what they look like. Make sure to draw any unique characteristics the plant may have.

Plant 1	Plant 2
The plant will look healthy and growing upright.	**The plant will look healthy and growing upright.**

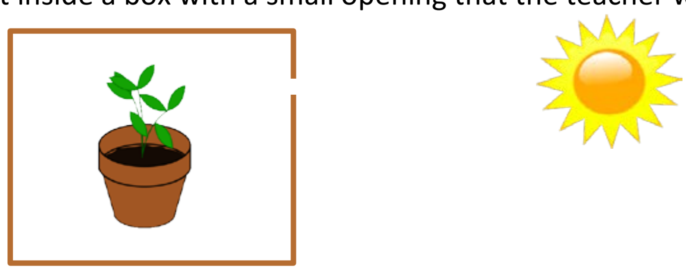
2. Plant 1: Hang a tray but place the plant pot on its side. Make sure the plant is hanging over the side so that the pot is the only thing touching the tray.



3. Record what happens to the plant over a 2-week period by writing or drawing.

Week	Observation
1-10	**After a while, the stems will start growing down below the tray and towards the ground. The roots, if you take them out, will start growing down towards the ground. Gravity is pulling it down.**

4. Plant 2: Place the plant inside a box with a small opening that the teacher will provide for you.



5. Place the opening of the box next to a sunny window. Observe and record what you see over the next two weeks.

Week	Observation
1-10	**After a while, the plant will grow toward the opening in the box where there is light.**

Questions:

1. What changes do you see in both plants?

   The plants are both growing differently due to the changes. The plants will grow toward the ground and toward the light.

2. Why do you think the plants grow in the direction that they do?

   Plants will find a way to get what they need to live.

How does gravity and light change plants?

Name ______________________________ **Date** ____________________

Description: Plants adapt to their environment. Two factors that can affect the way a plant grows are the direction that a plant might be placed and the direction of the sunlight. We will explore these in this experiment.

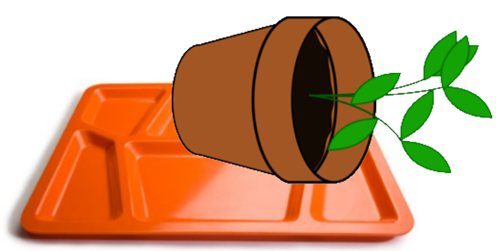
Materials: Cardboard box Two plants Tray to hang

Procedures:

1. Observe the two plants and draw what they look like. Make sure to draw any unique characteristics the plant may have.

Plant 1	Plant 2

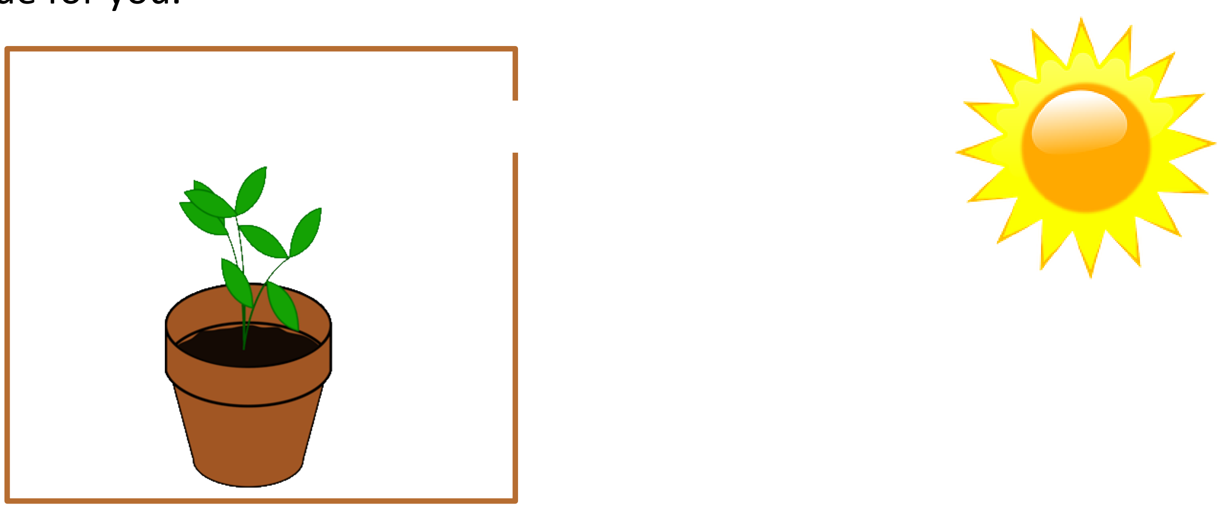
2. Plant 1: Hang a tray but place the plant pot on its side. Make sure the plant is hanging over the side so that the pot is the only thing touching the tray.



3. Record what happens to the plant over a 2-week period by writing or drawing.

Week	Observation
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

4. Plant 2: Place the plant inside a box with a small opening that the teacher will provide for you.



5. Place the opening of the box next to a sunny window. Observe and record what you see over the next two weeks.

Week	Observation
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Questions:

1. What changes do you see in both plants?

2. Why do you think the plants grow in the direction that they do?

How Can Chocolate Bars Be Used to Measure the Speed of Light?

Description: Students will place a chocolate bar in a microwave to determine the speed of light.

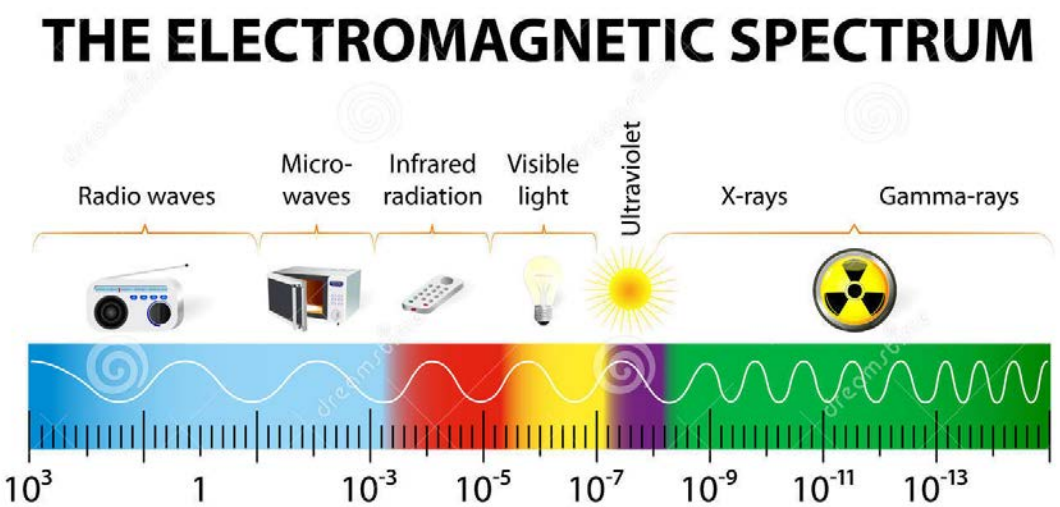
Student Materials (per group):
- ☐ Plain chocolate bar
- ☐ Ruler
- ☐ Calculator
- ☐ Paper towels
- ☐ Paper plate

Additional Teacher Materials:
- ☐ Microwave

Background and Misconceptions:

The speed of light is known as the ultimate speed limit. Nothing can travel faster than the speed of light. Light has properties of both a particle and a wave. Its particle form is known as a photon. Normally, when we think of waves, we think that the wave is traveling through something, but light can travel through materials like air, water, and transparent glass or it can travel through the vacuum of space. It does not require a medium.

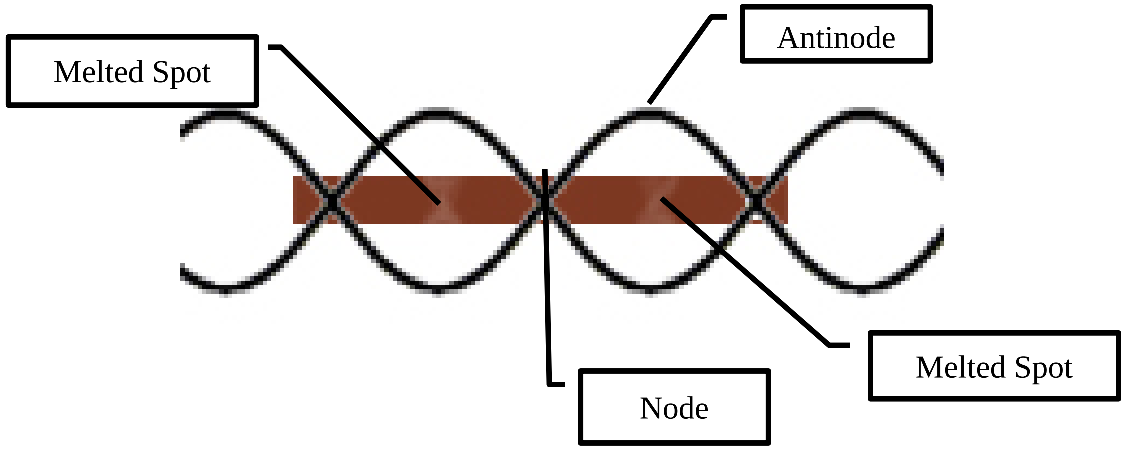
Until the late 19th century people used to think that light traveled at an infinite speed. Today we know this isn't true and that light actually has a finite speed. Even though the speed of light is 3.0×10^8 m/s, there are several ways to measure its speed and one way is to use chocolate bars and a microwave. The microwave is a form energy found on the electromagnetic spectrum and is similar to light. It only differs in its wavelength, frequency, and energy. Therefore, we can use microwaves to measure the speed of light.



Credit: Wikipedia

To accurately perform this experiment, remove the rotating plate from the microwave oven. It might be possible to turn it upside down. Then, place a paper plate on the glass plate. Put the chocolate bar on the paper plate. When the chocolate bar is stationary (not rotating) two melted spots will occur at the point where the antinodes of the microwave standing waves cause uneven heating and melting.

The microwave produces standing waves. Standing waves occur when a reflected and transmitted wave interact with each other producing a pattern similar to the image below. The point where the waves cross is called the NODE and the energy of the waves cancel each other out. An ANTINODE occurs at the point where there is the largest vertical gap between the wave peaks. It is in this location where maximum heating of the chocolate bar occurs.



The distance between the two melted spots is ½ the wavelength of the microwave. The distance between the center of the two melted spots should be about 6 cm. (0.06 m) Using the frequency from the microwave oven (which is 2450 MHz or 2,450,000,000 Hertz) the speed of light can be calculated. (Obtain the frequency from the tag on the oven or the user's manual.)

Using the formula below, you can find the speed of light using the frequency from the microwave and the distance between the melted dots. Make sure that you use meters for the units for distance and hertz (1/s) for the units for frequency:

$$c = \lambda f$$

c = Speed of Light (m/s)
λ = wavelength (m)
f = frequency (Hz or 1/s)

Remember that the distance between the two melted spots is ½ the wavelength, therefore we have to double the distance and use 12 cm (0.12m) as the wavelength.

$$c = .12\ m\ x\ 2{,}450{,}000{,}000\ Hz = \ 2.94x10^{8} m/s$$

This value is very close, considering that the speed of light is 3.0 x 10^8 m/s

Teacher Guided Questions to Inquiry: ***Use these questions to get the students started on their own inquiry!***

1. How can we use a chocolate bar to find the speed of light?
2. What are microwaves?
3. If melted spots on a chocolate bar are ½ the wavelength of microwaves, how can we use this to find the speed of light?

Additional Hints:

- Explain to students that microwaves and light are a part of the electromagnetic spectrum and both travel at the speed of light.
- Test with a chocolate bar to make sure it is long enough. If not, put another one end to end.
- Measure from the center of each spot to get the most accurate measurement.
- Ensure that the rotating plate is not used in this experiment.
- Do not over heat the chocolate bar.

How Can Chocolate Bars Be Used to Measure the Speed of Light?
TEACHER ANSWER SHEET

Data below are sample data. Ensure the student data is consistent.

	Frequency of Microwave Oven (Hz):	2,450,000,000 Hz	
	Group 1	Group 2	Group 3
Distance between melted spots (m)	.06 m	.055 m	.062 m
Wavelength (m) (Distance x 2)	.12 m	.11 m	.122 m
Speed of Light (m/s)	294,000,000 m/s	269,500,000 m/s	298,900,000 m/s
Difference from the actual speed of light (m/s)			

Questions:

1. The speed of light is the same for both microwaves and light waves. Microwaves have a lower frequency as compared to light waves. What does this mean about the wavelength of light waves as compared to microwaves?

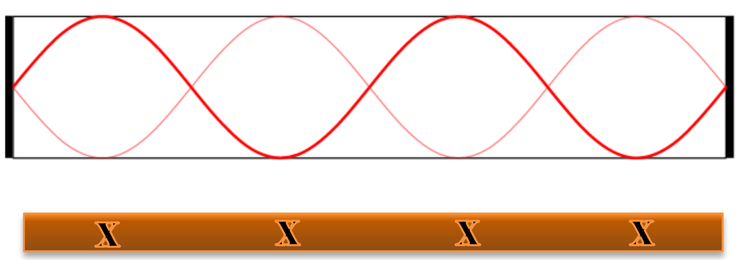
   The wavelength will be shorter for light waves as compared to microwaves.

2. What do you think would have happened to the chocolate if it were put on the rotating plate rather than a stationary one?

   The location where the waves are striking the chocolate will continually change and there will be no single spot where the chocolate melts. It will melt more evenly.

3. The spots were created by a standing wave. A picture of the standing wave is below. What which points will you find the melted chocolate if you were to place the bar across the length of the wave.

   The locations of the X's indicate where the chocolate will melt. These are the locations of the antinodes.



How Can Chocolate Bars Be Used to Measure the Speed of Light?

Name ______________________________ **Date ____________________**

Description: Microwaves are part of the electromagnetic spectrum and are similar to light waves because they both travel at a constant speed; the speed of light. Both light waves and microwaves can be measured by wavelength and frequency. In this experiment, you are going to use a microwave to melt spots on a chocolate bar and use these spots to find the speed of light.

Materials:

Microwave	Chocolate bar	Rulers
Calculators	Paper plate or towel	Paper towels

Procedures:

1. Remove the glass rotating plate from the microwave, turn it upside down and put it back into the microwave.
2. Place a paper plate on the glass rotating plate.
3. Place a chocolate bar on the paper plate. You might need a second one placed end to end, but the teacher will instruct you on this if needed.
4. Turn on the microwave until you see spots on the chocolate bar just starting to melt.
5. Carefully remove chocolate bar and paper plate.
6. Record the frequency of the microwave and record in the table below.
7. Measure the distance between the centers of the melted spots on the chocolate bar. Record this in the table below.
8. Record at least 2 other group's measurements in the table below.
9. Multiply the distance between the dots by 2 to determine the wavelength.
10. Use the formula to calculate the speed of light and record in the table.

$$c = \lambda f$$

c = Speed of Light (m/s)
λ = wavelength (m)
f = frequency (Hz or 1/s)

11. The speed of light is 300,000,000 m/s. Find the difference between this value and your values for the speed of light.

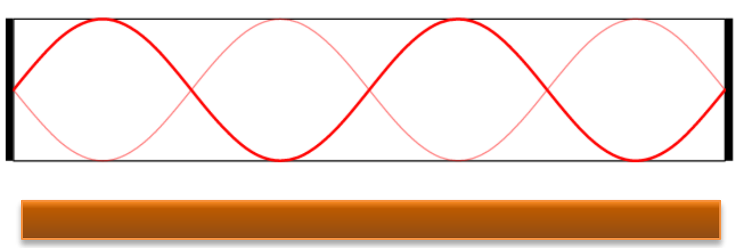
Frequency of Microwave Oven (Hz):			
	Group 1	Group 2	Group 3
Distance between melted spots (m)			
Wavelength (m) (Distance x 2)			
Speed of Light (m/s)			
Difference from the actual speed of light (m/s)			

Questions:

1. The speed of light is the same for both microwaves and light waves. Microwaves have a lower frequency as compared to light waves. What does this mean about the wavelength of light waves as compared to microwaves?

2. What do you think would have happened to the chocolate if it were put on the rotating plate rather than a stationary one?

3. The spots were created by a standing wave. A picture of the standing wave is below. What which points will you find the melted chocolate if you were to place the bar across the length of the wave.



How is Light Absorbed and Transmitted?

Description: Students will examine the absorption and transmission of light by color filters with the help of a light source and a diffraction grating.

Student Materials (per group):
- ☐ Light source
- ☐ Set of color filters
- ☐ Lens
- ☐ Diffraction grating/CD/DVD disk
- ☐ White screen/piece of paper

Additional Teacher Materials:
- ☐ Other light sources (if available)

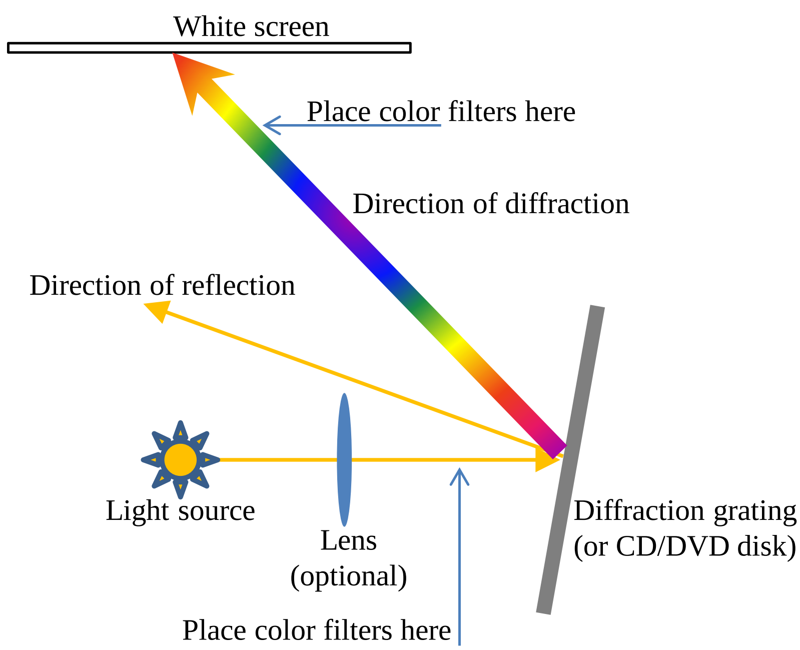
Background and Misconceptions:

White light can be represented by as little as just three colors of an equal proportion – the Red, Blue, and Green colors. More often, natural white light contains all the rainbow colors (from blue to red). Many objects appear to have their colors because they absorb some colors, and then reflect or transmit other colors. Color filters are especially made to usually absorb most of the colors and transmit one specific color.

A diffraction grating is a special device which can take a white light and separate it into consisting colors, spreading them out into different directions. It also acts as a bad mirror, reflecting some portion of the incident light.

Students will be able to examine how color filters affect light coming from a light source and then diffracted by a grating. They will see that the white light from the incandescent lamp (tungsten) consists of a rainbow of colors. The other light sources (such as LEDs) contain only 1-3 relatively narrow colors.

First, let the students build a small experimental setup similar to shown on a schematic below. Then allow them experiment with the color filters to see the effect on the spectrum appearing on the screen. The student should fill the table and answer some questions once they are comfortable with their observations.



Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. If several types of the light source are available (such as tungsten bulb, LED flash light, fluorescent lamp, etc.), ask what students can tell about the nature of the light source and the differences between them by conducting this experiments on each of the light sources. Do all of these light sources have all the colors included in their output?
2. If there are mercury/krypton/argon (calibration) lamps available, ask what is especial in these lamps compared to others. Can students see intense lines in the color spectra of these? Which of the light sources is closer by its nature to our Sun and why?

Additional Hints:

- If the light source is not bright enough, dimming the room light might be necessary for the lab.
- Lens might be needed to collimate/focus light source on to the grating.
- Diffraction grating also acts as a regular mirror. Make sure students are looking not at the reflected light but at dispersed colors – they should be in a different direction compared to the reflection.

How is Light Absorbed and Transmitted?
TEACHER ANSWER SHEET

Filter	Before the Grating	After the Grating
No Filter	**Before the grating see the white-yellowish light coming from the source. On the screen see a rainbow of dispersed colors from blue to red.**	**On the screen see a rainbow of dispersed colors from blue to red.**
Red	**Before the grating see only the red color after the filter. On the screen see only the red color.**	**Moving filter through the rainbow of dispersed colors students can block (meaning that the filter will absorb it) each of the colors except for the red.**
Blue	**Before the grating see only the blue color after the filter. On the screen see only the blue color.**	**Moving filter through the rainbow of dispersed colors students can block (meaning that the filter will absorb it) each of the colors except for the blue.**
Green	**Before the grating see only the green color after the filter. On the screen see only the green color.**	**Moving filter through the rainbow of dispersed colors students can block (meaning that the filter will absorb it) each of the colors except for the green.**
Yellow	**Before the grating see only the yellow color after the filter. On the screen see only the yellow color.**	**Moving filter through the rainbow of dispersed colors students can block (meaning that the filter will absorb it) each of the colors except for the yellow.**
Blue-Green (Cyan)	**Before the grating see only the cyan color after the filter. On the screen see only the cyan color.**	**Moving filter through the rainbow of dispersed colors students can block (meaning that the filter will absorb it) each of the colors except for the cyan.**
Magenta	**Before the grating see only the magenta color after the filter. On the screen see only the magenta color.**	**Moving filter through the rainbow of dispersed colors students can block (meaning**

		that the filter will absorb it) each of the colors except for the magenta.
Orange	**Before the grating see only the orange color after the filter. On the screen see only the orange color.**	**Moving filter through the rainbow of dispersed colors students can block (meaning that the filter will absorb it) each of the colors except for the orange.**
Purple	**Before the grating see only the purple color after the filter. On the screen see only the purple color.**	**Moving filter through the rainbow of dispersed colors students can block (meaning that the filter will absorb it) each of the colors except for the purple.**

Questions:

1. Based on your observations, what are the main differences between the filter being placed before and after the grating?

   Answer may vary, but the student should note that if the filter is placed before the grating then only one color goes through it and then grating does almost nothing to it. If the filter is placed after the grating, then if it is inserted in the part of the spectrum different from the color of the filter, this part will be blocked on the screen. The color of the filter is transmitted through it.

2. What do you think color filters do to the light coming from the light source?

   Answer may vary, but the student should note that the filter blocks (absorbs) all the colors of the light except of the color of the filter, which is transmitted through the filter. This changes white light into the colored light.

3. What do you think color filters do to the color rainbow after the diffraction grating?

   Answer may vary, but the student should note that all the rainbow colors different from the color of the filter are blocked (absorbed) by the filter, while the color of the filter is transmitted. Depending on where the filter is placed, this can make part of the rainbow or the entire rainbow disappears, leaving only the color of the filter being transmitted.

4. If you combine your ideas from answers (2) and (3), what can you say about the nature of the light from the source?

   Answer may vary (especially depending on the light source), but the student should note that the color of the light source is a mixture (superposition) of colors seen after the diffraction grating.

5. Based on your observations can you explain why the color filters have their names (red, green, blue, etc.) and why they appear to have color?

   Answer may vary, but the student should note that the color filters block (absorb) all the colors except of the color corresponding to their name. This color is transmitted through the filter. This makes filters to be "colored".

How is Light Absorbed and Transmitted?

Name ____ **Date** ____________________

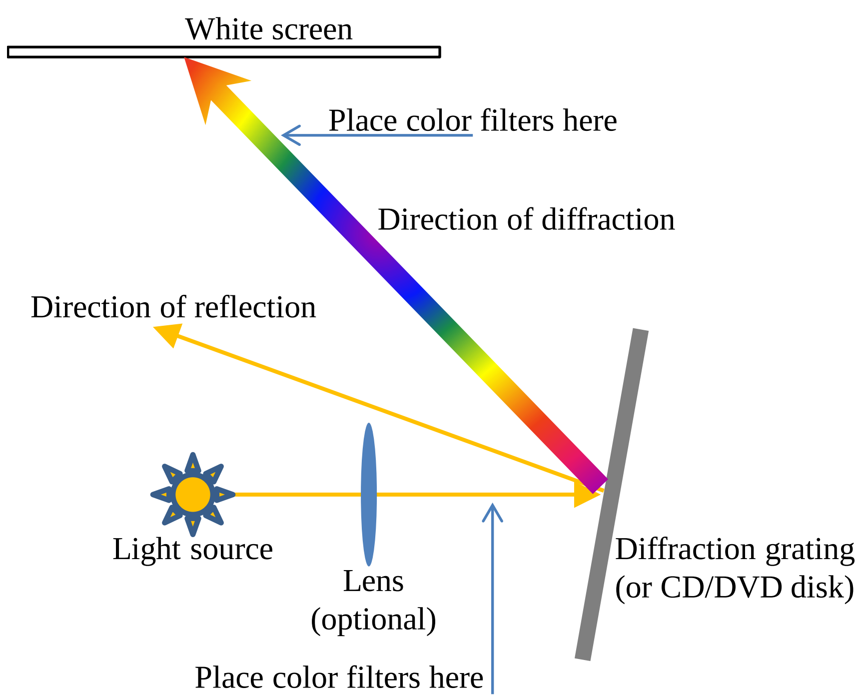
Description: The light from a bulb, flashlight, Sun, or other non-specialized source can be seen as a combination of different colors, called the spectrum. Almost every object absorbs some colors and transmits or reflects other colors. In this lab you are going to observe how this happens, and also understand colors and names of some representative objects – set of color filters made to transmit specific colors.

Materials:

Light source	Color filters	Lens
Diffraction grating	White sheet of paper	

Procedures:

1. Setup the light source to shine into the diffraction grating (orient it initially at almost 0 degrees relative to the angle of light incidence). If the source is not bright, then use a lens to focus more light onto the grating. Using the white screen find the position where the light is dispersed by the grating into a rainbow of colors. Have enough distance between the screen and the grating to clearly see different colors. You might need to adjust position of the screen and the angle of the grating to achieve best results.



2. Using set of color filters, place each of the filters first in between of the light source and the grating and then in between of the grating and the white screen. Observe colors seen on the white screen and their change compared to when no filter is in place. Record your observations in the table below. Make sure you record colors you see on the screen and the changes.

Filter	Before the grating	After the grating
No Filter		
Red		
Blue		
Green		
Yellow		
Blue-Green (Cyan)		
Magenta		
Orange		
Purple		

Questions:

1. Based on your observations, what are the main differences between the filter being placed before and after the grating?

2. What do you think color filters do to the light coming from the light source?

3. What do you think color filters do to the color rainbow after the diffraction grating?

4. If you combine your ideas from answers (2) and (3), what can you say about the nature of the light from the source?

5. Based on your observations can you explain why the color filters have their names (red, green, blue, etc.) and why they appear to have color?

How do Polarizers Change the Light We See?

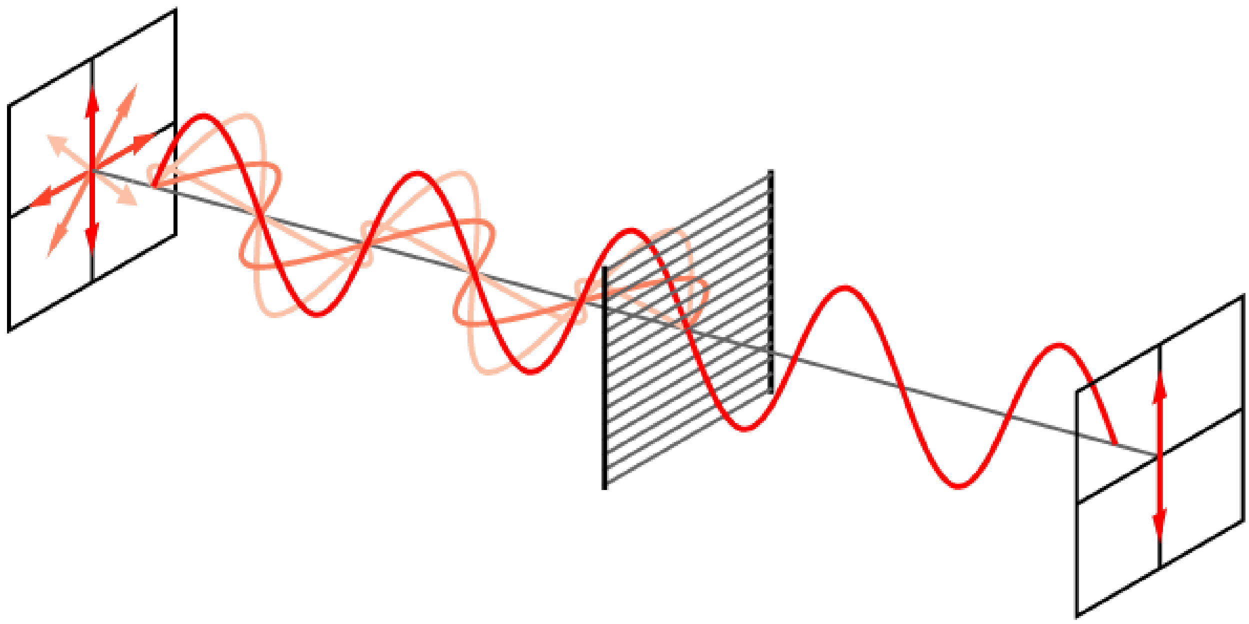
Description: Students will examine polarization of light sources of a regular lamp, laser, Sun, and thin-film polarizers.

Student Materials (per group):
- ☐ Light source
- ☐ 2 thin-film polarizers
- ☐ Laser
- ☐ White screen (piece of paper)

Additional Teacher Materials:
- ☐ None

Background and Misconceptions:

Normally, light travels in a straight line and the waves that make up the light are oriented in many directions around the direction of travel. This type of light is said to be UNPOLARIZED light. This is similar to making a rope wave and then moving the wave around in a circle in many different directions. However, if the rope wave were to encounter a picket fence, only certain orientations of waves, there are parallel to the openings of the picket fence, are able to continue through. Waves that are all oriented in a single directions are said to be POLARIZED.

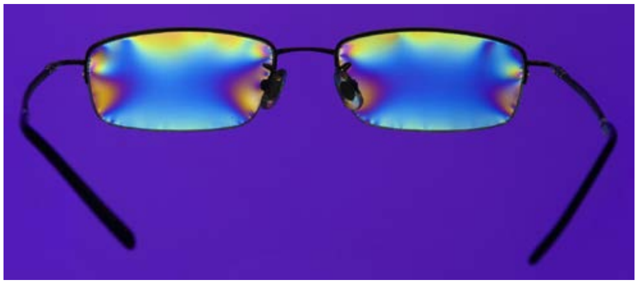


Credit: Bob Mellish

Polarization can either occur naturally, as it occurs in minerals or in the atmosphere, or in manufactured materials such as polarizing filters. Calcite is a mineral that causes light to be polarized in two directions. When a polarizing filter is placed on the image and rotated, only one image appears as the polarizer is rotated, indicating that the light has been split into two polarized images.

A linear polarizer is a sheet of plastic that is made in such a way as to allow light that is oriented in a specific direction to pass. If a second polarizing sheet is placed perpendicular to the first, similar to placing a picket fence that is perpendicular to another one, no light will pass through. It is possible to get polarizing sunglasses and try this effect. Looking at a light and then turning one with respect to other will result in a complete blocking of the light.

Polarizers can also be used to examine stresses in clear plastics. In the image below, the glasses are sandwiched between two polarizing films. As the light goes through one polarizer, it is oriented in only one direction. Then, it passes through the plastic glass lenses. The lenses are imperfect and they alter the light on their way to the second polarizing filter. This causes an interference pattern that can be used to determine the amount of stress in the lenses. Where there are a greater number of colors there is a greater level of stress. Engineers can create models of buildings made of plastic and the stresses can be analyzed.



Once students are comfortable with the concept of polarization and understand how polarizers work, let them examine other polarized and unpolarized light sources around them. For example, LCD computer screens, some cell phone screens, and other types of LCD displays are polarized. Sunlight, fluorescent bulbs, and incandescent bulbs are unpolarized.

Teacher Guided Questions to Inquiry: ***Use these questions to get the students started on their own inquiry!***

1. What happens to light through one or two polarizing films?
2. How can you reduce the amount of light you see using polarizing sunglasses?
3. How can you use a polarizer to determine if sunlight and reflections are polarized?

Additional Hints:

- Polarizing films are found in some types of sunglasses and are used in some glasses used in 3-D movies. To test, use two pairs of sunglasses, and place one lens over the other and rotate. If they turn light and dark, the lenses are polarizing films.
- Best value for polarizing film is to purchase a larger sheet and cut into 2 inch square pieces for the students. Many science supply companies have the polarizing films.
- Helium Neon Lasers emit red light. The common keychain lasers can be used. Do not use green lasers since they tend to be more powerful than red lasers and can easily damage the eye.

How do Polarizers Change the Light We See?
TEACHER ANSWER SHEET

Procedures:

1. Take one of the thin-film polarizers and look through it at a light source. Do you see any difference between looking through the polarizer and without it?

   The light should look a little darker, but there should be no other differences.

2. Slowly rotate polarizer in your hand by at least 90 degrees (keeping perpendicular to your direction of sight), and observe if there is any difference. Write down what you note.

   Student should note that when they look through the polarizer the light source is darker, however nothing changes when they rotate polarizer.

3. Keep holding one polarizer in front of the light source. Take the second polarizer that is oriented in the same direction and look at the light source through both of them. What difference can be noticed?

   There is very little difference as compared to looking through one polarizer.

4. Rotate one polarizer relative to another (with one polarizer turned perpendicular to the other). Note what happens to the light and write down your observations.

   Once the second polarizer is used, the intensity of the light source seen through the polarizers can be significantly modified compared to a single polarizer. The maximum intensity is almost the same as with just one polarizer. Once the polarizers are turned 90 degrees relative to each other from this maximum transmission, the light source should be almost invisible, that no light goes through the pair of polarizers.

5. Now take the laser and a white screen. Make sure the laser beam is pointed at the screen. Never look directly into the laser beam. Place one of the polarizers between the screen and the laser into the beam. Observe laser beam on the screen. Is anything different compared to what you saw from the regular light source? Rotate polarizer, observe and note how light intensity changes on the screen.

   Depending on the original orientation of the polarizer and particular polarization of the laser beam, students might see no difference or significant difference between the laser with and without polarizer. Rotating polarizer should reveal significant change in the light intensity. The effect is the same as when they look at the regular light source using two polarizers.

6. Place second polarizer next to the first one, rotate them relative to each other and note how light intensity changes.

   Once two polarizers are used with the laser, the first can transmit just a part of the laser light or all the light intensity, depending on it orientation. The second polarizer acts the same way as in case of the regular light source. The biggest difference is that now the light intensity in between of two polarizers can be changed based on the orientation of the first polarizer.

Questions:

1. Your polarizer transmits only linearly polarized light. When you use it to look at the regular light source (and rotate it), what can you say about polarization of the light coming from it?

   The regular light source is unpolarized since there appears to be no change in the way that the light source appears as it is rotated while viewing the light bulb.

2. If you compare your observations for the regular light source and the laser, what can you say about polarization of the laser light? How did you get to this answer?

   The laser light is polarized. This is because the effect of an individual polarizer being rotated with the laser is the same as when the second polarizer is used with a regular light source.

3. Many sunglasses use polarizers for their lenses. Reflections from the sun are polarized. How can this be helpful?

   The glasses will reduce the intensity of the sunlight in a general way, but since the reflections are polarized, the sunglasses can dramatically reduce glare and unwanted reflections which are often very distracting.

How do Polarizers Change the Light We See?

Name ______________________________ **Date** ____________________

Description: In this lab we are going to observe polarization of the light, see how it can be modified, and find what we can learn about polarization of the common light sources we encounter every day.

Materials: Regular light source (lamp, flashlamp)
2 linear thin-film polarizers
Helium Neon Laser
White screen

Procedures:

1. Take one of the thin-film polarizers and look through it at a light source. Do you see any difference between looking through the polarizer and without it?

2. Slowly rotate polarizer in your hand by at least 90 degrees (keeping perpendicular to your direction of sight), and observe if there is any difference. Write down what you note.

3. Keep holding one polarizer in front of the light source. Take the second polarizer that is oriented in the same direction and look at the light source through both of them. What difference can be noticed?

4. Rotate one polarizer relative to another (with one polarizer turned perpendicular to the other). Note what happens to the light and write down your observations.

5. Now take the laser and a white screen. Make sure the laser beam is pointed at the screen. Never look directly into the laser beam. Place one of the polarizers between the screen and the laser into the beam. Observe laser beam on the screen. Is anything different compared to what you saw from the regular light source? Rotate polarizer, observe and note how light intensity changes on the screen.

6. Place second polarizer next to the first one, rotate them relative to each other and note how light intensity changes.

Questions:

1. Your polarizer transmits only linearly polarized light. When you use it to look at the regular light source (and rotate it), what can you say about polarization of the light coming from it?

2. If you compare your observations for the regular light source and the laser, what can you say about polarization of the laser light? How did you get to this answer?

3. Many sunglasses use polarizers for their lenses. Reflections from the sun are polarized. How can this be helpful?

What is the Wavelength of Light?

Description: Students will collect data using a diffraction grating to determine the wavelength of various colors of light.

Student Materials (per group):

- ☐ Diffraction grating
- ☐ Light bulb and base
- ☐ 2 meter sticks

Additional Teacher Materials:

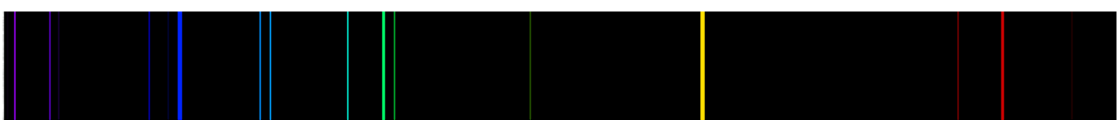
- ☐ Spectral Emission Tube
- ☐ Power supply for emission tube

Background and Misconceptions:

When light passes through a diffraction grating, the light is broken into its component colors. If one knows the spacing of the lines in the diffraction grating, it is possible to find the wavelength of light for a specific color. While the colors run together to form a continuous spectrum, scientists have established a range of wavelengths that correspond to the colors our eyes perceive. In the table below are the values for the wavelengths and frequencies for the visible light spectrum.

Color	Wavelength	Frequency
Red	6.25×10^{-7} to 7.40×10^{-7} m	4.05×10^{14} to 4.80×10^{14} Hz
Orange	5.90×10^{-7} to 6.25×10^{-7} m	4.80×10^{14} to 5.10×10^{14} Hz
Yellow	5.65×10^{-7} to 5.90×10^{-7} m	5.10×10^{14} to 5.30×10^{14} Hz
Green	5.00×10^{-7} to 5.65×10^{-7} m	5.30×10^{14} to 6.00×10^{14} Hz
Cyan	4.85×10^{-7} to 5.00×10^{-7} m	6.00×10^{14} to 6.20×10^{14} Hz
Blue	4.40×10^{-7} to 4.85×10^{-7} m	6.20×10^{14} to 6.80×10^{14} Hz
Violet	3.80×10^{-7} to 4.40×10^{-7} m	6.00×10^{14} to 7.90×10^{14} Hz

The white light bulb will emit a continuous spectra, while the use of a spectral tube will emit a discontinuous spectra. For example, the helium spectra shown below, has specific color lines at specific distances from the source. Using this spectra to measure the wavelength of blue light will yield results which are much more precise to obtain.



Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

- How can we measure the wavelength of light?
- Which type of light will yield more accurate results: The light from a light bulb or the light from a spectral tube?

Additional Hints:

- The value of the diffraction grating line spacing is listed in the lab. Check your diffraction gratings to ensure they match the value in the lab. If they do not, give the students the value for your diffraction gratings.
- If you do not have access to a spectral tube and power supply, use a red and green laser or a set of red, blue and green LED's.

What is the Wavelength of Light?
TEACHER ANSWER SHEET

Color of line that you are measuring	Distance from bulb to color. (m)	Distance from grating to bulb (m)	Tan θ x/L	Angle θ (Degrees)	Sin θ	Wavelength of light $\lambda = d \sin\theta$ (m)
Red	.36	1	.36	20	0.34	6.50×10^{-7}
Blue	.24	1	.24	13	.23	4.40×10^{-7}
Green	.27	1	.27	15	.26	5.00×10^{-7}
Yellow	.33	1	.33	18	.31	5.90×10^{-7}

<u>Questions:</u>

1. Compare your answers with the following accepted answers:

Red	0.000000650 - 0.000000700	Or	6.25×10^{-7} - 7.40×10^{-7} m
Green	0.000000500 - 0.000000550	or	5.00×10^{-7} - 5.65×10^{-7} m
Blue	0.000000440 - 0.000000480	or	4.40×10^{-7} - 4.85×10^{-7} m

Calculate the percentage of your results for each color of light.

$$\text{Percentage Difference} = \frac{|\text{Your value - Accepted value}|}{\text{Accepted Value}} x100\%$$

Student answers should indicate no more than a 10% error reflecting a good experimental practice. If you chose, you can have the students conduct the experiment again.

2. Did you get a similar result for the wavelength of light with the spectral emission tube as you did with the light bulb? Why or why not?

Student answers should indicate that they did get similar answers but they will likely not be exactly the same. However, the values should fall within the range allowed in question 1 above.

3. The speed of light in a vacuum is 3.0×10^8 m/s. Use the equation $c = \lambda f$ and your calculated values for the wavelengths of light in the table above to calculate the frequencies of the light waves.

   The frequencies should be in the following ranges:
   Red: 4.05×10^{14} - 4.80×10^{14} Hz
   Green: 5.30×10^{14} - 6.00×10^{14} Hz
   Blue: 6.20×10^{14} - 6.80×10^{14} Hz
   Yellow: 5.10×10^{14} - 5.30×10^{14} Hz

4. As you increase the frequency of light you increase the amount of energy that the light has. Based on this, which color has more energy? Which has the least energy?

   Red has the least energy and blue has the most energy.

What is the Wavelength of Light?

Name ____ **Date** ____________________

<u>Description:</u> Light is said to have a dual nature because it has wavelike and particle like behavior. It can has a wavelength, just like a water wave has a wavelength. The length of a wave for a water wave is quite long compared to the length of a light wave. In the length of a meter, there are nearly 1 BILLION waves.

In this experiment, we are going to calculate the length of a single wave of light traveling at over 186, 000 miles per second.

<u>Materials:</u> Diffraction grating Light bulb 2 meter sticks Spectral Emission Tube

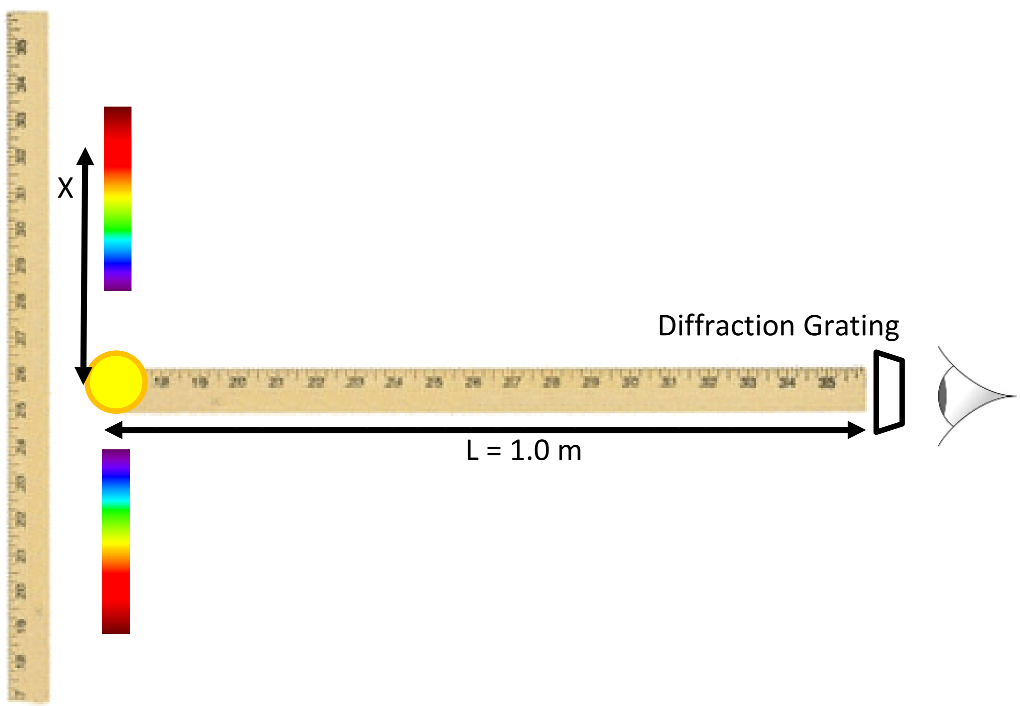
<u>Procedures:</u>

1. Put one meter stick in front of the light bulb. Make sure the light is at the 0.00 meter mark.

2. Use the diffraction grating to look at the light bulb. You will see a rainbow off to either side of the light bulb. If it is not to the left or right of the bulb turn it so that the colors are left or right, not up and down.

3. Place the diffraction grating 1.00 meter away from the light along the second meter stick which is perpendicular to the first meter stick. This is the **distance from the bulb to the grating (L)**

4. Measure the distance from the light bulb to the color red along the meter stick. Record this in the table under **Distance of bulb to colors (x)**



5. Repeat the above procedure, measuring the distance from the bulb to the color blue as you see it projected in space.

6. Do the same thing again for the color green. (Repeat steps 2 and 3)

7. Do the same thing again, but chose either RED, BLUE or GREEN when you view the spectral emission tube. (Make sure you only chose red, blue or green, no other color!) Record the data in the table.

8. The diffraction grating is made of etched lines. You have to determine the spacing between each etched line. There are 527, 560 lines per meter. The **distance between each line is 0.0000019 meters.**

9. Use the following formulas to solve for the wavelength of light:

$$\frac{x}{L} = \text{Tan}\,\vartheta$$

x = Distance from bulb to color
L = Distance from grating to bulb.

$$\lambda = d \sin \vartheta$$

λ = wavelength of light
d = space between etched lines of grating.

Color of line that you are measuring	Distance from bulb to color. (m)	Distance from grating to bulb (m)	Tan θ x/L	Angle θ (Degrees)	Sin θ	Wavelength of light λ = d sin θ (m)

Questions:

1. Compare your answers with the following accepted answers:

Red	0.000000650 - 0.000000700 m	Or	6.50×10^{-7} - 7.00×10^{-7} m
Green	0.000000500 - 0.000000550 m	or	5.00×10^{-7} - 5.50×10^{-7} m
Blue	0.000000440 - 0.000000480 m	or	4.40×10^{-7} - 4.80×10^{-7} m

Calculate the percentage of your results for each color of light.

$$\text{Percentage Difference} = \frac{|\text{Your value - Accepted value}|}{\text{Accepted Value}} x100\%$$

2. Did you get a similar result for the wavelength of light with the spectral emission tube as you did with the light bulb? Why or why not?

3. The speed of light in a vacuum is 3.0×10^8 m/s. Use the equation $c = \lambda f$ and your calculated values for the wavelengths of light in the table above to calculate the frequencies of the light waves.

4. As you increase the frequency of light you increase the amount of energy that the light has. Based on this, which color has more energy? Which has the least energy?

What Energy is Hiding?

Description: Students will rotate through various stations and make predictions about the forms of energy that are present in the object at the station. Then, students will be given the results and will compare with their predictions.

Student Materials (per group):
- ☐ Flashlight
- ☐ 2 Thermometers, non-mercury
- ☐ Battery operated toy car
- ☐ Battery operated radio
- ☐ Electric pencil sharpener
- ☐ 1.5 volt C or AA battery
- ☐ Pencils
- ☐ Radiometer
- ☐ Christmas light bulb
- ☐ Light bulb and lamp (low wattage)

Additional Teacher Materials:
- ☐ Wire cutters
- ☐ 6 Index cards for stations
- ☐ String of Christmas lights

Background and Misconceptions:

Energy is the ability to do work. You cannot see or touch energy, but you can observe the effects of energy. There are several forms of energy, below some of them are:

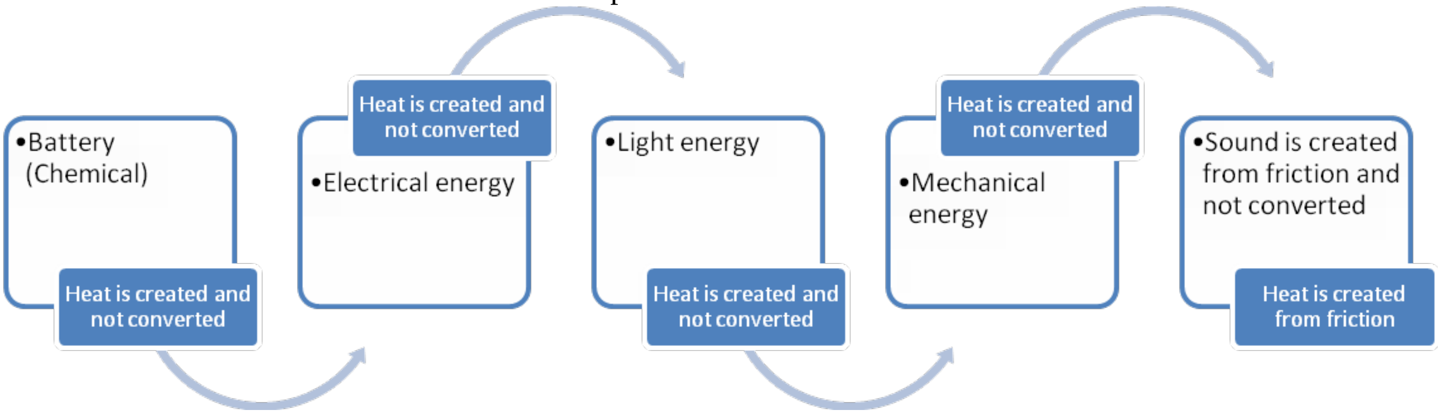
- **Chemical –** energy stored and released as a result of chemical reaction.
- **Mechanical –** energy stored and released as a result of an object moving, such as a car or a simple machine.
- **Electrical -** energy stored and released as a result of moving electrons.
- **Light (radiant) –** energy stored and released as a form of electromagnetic radiation.
- **Sound** (is often described as a form of mechanical energy) – energy stored and released as sound.
- **Nuclear** (the only form not explored in this lab) – energy stored and released by the particles inside the nucleus of an atom.

Energy is a difficult concept to describe to students because it is not visible. Energy is stored in various objects such as batteries. When it is allowed to do work, we see the effects. When a battery is hooked up to wires and a light bulb, the stored chemical energy is converted into electrical energy. The electrical energy pushes electrons in the wires (called electricity). Electricity is turned into light and heat in the light bulb. In every case, as energy is converted from one form to another, it never converts perfectly. Some of the energy is lost in the form of heat and/or sound.

Students often do not believe that sound is a form of energy. In fact, some scientists classify sound as a type of mechanical energy. Sound results from something vibrating. A speaker moves back and forth quickly to produce sound. The moving speaker moves air particles back and forth that in turn move our ear drums, which we then interpret as sound. Since the particles of air are small, a special classification is given to sound, but in the end, it is still the result of a object moving. Sound can cause objects to move, and in front of very loud and large speakers, one can often feel puffs of air as the speakers move large volumes of air. When they are very loud, they can also break glass or ruin eardrums! On the first launch of the Space Shuttle Columbian in 1981, the noise from the ignition of the solid rocket boosters reflected off the launch pad and damaged metal within the spacecraft. Since then, water has been poured on the pad at ignition to reduce the noise level.

Heat often is a very unusable form of energy. Although heat energy is used to make turbines move in electrical power plants, most often it can't be captured for useful purposes.

An excellent example of the transfer of several forms of energy is using a battery to power a flashlight that shines on a radiometer is below. Follow the steps:



In the last step, a small amount of sound is created as the fans of the radiometer rub against the pin. Often heat and sound are produced together when objects move. You may want to demonstrate this for the students and then show this diagram.

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. What are different forms of energy?
2. What causes heat energy?
3. How do you know that there is energy at work?
4. What is the difference between stored energy and energy in motion?
5. Can you find evidence of energy in various objects around the classroom?
6. What are sources of stored energy?

Additional Hints:

- Set up the lab in 6 stations:
  - Station 1: Flashlight with thermometer.
  - Station 2: Battery operated toy car, with batteries. Setup with space for the car to move freely.
  - Station 3: Electric Pencil Sharpener. Provide extra pencils.
  - Station 4: Radiometer and light bulb in lamp. Use a low wattage incandescent light bulb in a lamp. If the sun is used, point out that the source of light for the sun is a separate source of energy. It is not chemical. It is nuclear energy.
  - Station 5: Christmas light bulb with battery. Cut a light bulb out of a string of lights and strip the ends so they can be connected to the battery easily. Use only 1.5 volt batteries.
  - Station 6: Battery operated radio.
- If you can't find a radiometer, check a local science center or online at science supply companies.
- Have students use a thermometer or have them touch various parts of the objects to see if they heat up while they are in motion or after they have moved for a while.
- A string of old Christmas lights is a good source for light bulbs. Cut the wires between each bulb then strip the wires at each end, leaving about ½ in of bare wire. Connect to each end of a 1.5 volt AA, or C battery to make it glow.

What Energy is Hiding?
TEACHER ANSWER SHEET

Procedures:

These forms of evidence were present.

Energy Form	Station 1 Flashlight	Station 2 Car	Station 3 Sharpener	Station 4 Radiometer	Station 5 Light bulb	Station 6 Radio
Electrical	X	X	X		X	X
Mechanical		X	X	X		
Sound		X	X			X
Heat	X	X	X	X	X	X
Chemical	X	X			X	X
Light	X			X	X	

Questions:

1. Which forms of energy are most difficult to identify?

   It is likely the chemical and heat energy, because they are present inside hidden devices or objects.

2. Which forms are the easiest to identify?

   Mechanical, light, sound because they are easiest to observe with the 5 senses.

3. What form of energy do all the objects have in common?

   Heat – This is because as the energy is converted from one form to another, there is energy loss due to heat.

4. What is energy?

   Energy is the ability to do work or make something happen.

5. Batteries are a source of chemical energy. There are chemicals inside the battery that then produce other forms of energy. What are other forms of energy that the battery can produce?

   All other forms – light, heat, sounds, mechanical and electrical.

6. Sound and mechanical energy are very similar. Some say that sound energy is mechanical energy. What would be a reason for saying they are the same?

   Sound energy is just the vibration or movement of particles back and forth. Mechanical energy is the energy of something moving as well, so in both cases, there are objects moving.

What Energy Is Hiding?

Name ______________________________ **Date** ____________________

Description: There are many forms of energy: Electrical, Mechanical, Light, Heat, Sound, Chemical, and Nuclear. Energy can either be stored or it can make things move. You can't touch energy, but you can see the effect energy has on objects. In this experiment, you are going to identify forms of energy found in some classroom objects.

Materials:

Flashlight	Thermometer
Toy car	Radiometer
Battery powered radio	Light bulb and lamp
Electric pencil sharpener	Christmas light bulb
Battery	Pencil

Procedures:

1. There are six stations set up around the room. Go to each station and observe.
    - Station 1: Flashlight with thermometer.
    - Station 2: Battery operated toy car.
    - Station 3: Electric pencil sharpener.
    - Station 4: Radiometer and light bulb in lamp.
    - Station 5: Christmas light bulb with battery.
    - Station 6: Battery operated radio.

2. At each station, use the Energy Checklist below to check off which forms of energy are present at each station under the PREDICTION SECTION.

3. After you do this, your teacher will give you the answers and identify the correct forms of energy. Do not change your predictions when you teacher gives you the corrections.

Energy checklist

Place a check mark where there is evidence of one of the forms of energy.

Energy Form	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Electrical						
Mechanical						
Sound						
Heat						
Chemical						
Light						

These forms of evidence were present. Your teacher will give you the answers for the table below.

Energy Form	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Electrical						
Mechanical						
Sound						
Heat						
Chemical						
Light						

Questions:

1. Which forms of energy are most difficult to identify?

2. Which forms are the easiest to identify?

3. What form of energy do all the objects have in common?

4. What is energy?

5. Batteries are a source of chemical energy. There are chemicals inside the battery that then produce other forms of energy. What are other forms of energy that the battery can produce?

6. Sound and mechanical energy are very similar. Some say that sound energy is mechanical energy. What would be a reason for saying they are the same?

What is Good and Bad About the Sun?

Description: Students will examine the Sun using a pinhole camera and then identify things that are good and bad about the Sun.

Student Materials (per group):
- ☐ Pinhole camera made of paper
- ☐ 2 White sheets of paper

Additional Teacher Materials:
- ☐ 100 watt light bulb
- ☐ Pin

Background and Misconceptions:

The Sun is the source of all life on Earth. It is also the source that drives the weather, provides for plant growth, creates the seasons, and even helped to create the petroleum we use in our cars or airplanes. There are many other benefits. However, there are also consequences of Sun exposure: Heat waves, bad weather such as hurricanes and thunderstorms, and even damage to our health in the form of cancer and sunburns.

It is important for students to understand that there are benefits and consequences to everything. When all is tallied, the Sun is far more beneficial than detrimental. Simply put, life would not be possible nor would we have evolved had it not been for the Sun. Without the Sun, no life would exist.

On a sheet of paper, create a T-Chart with the following format:

Good about the Sun?	Bad about the Sun?

Students will record ideas or paste pictures of items that represent good and bad things about the sun.

Teacher Guided Questions to Inquiry: ***Use these questions to get the students started on their own inquiry!***

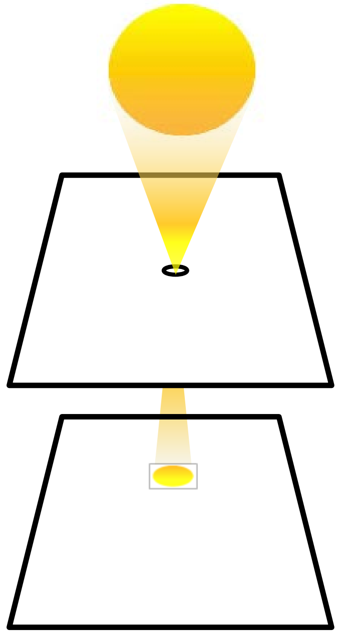
1. What are good things about the Sun?
2. What are bad things about the Sun?
3. Even if there are bad things about the Sun, does that outweigh the benefits?
4. If there are bad things about the Sun, should we get rid of it (if we could, but we can't!)?

Additional Hints:

- Make sure students do not look at the Sun if you use the pinhole camera.
- If you are using the light bulb, make sure students don't touch it.

To make the pinhole camera:

- Obtain a full sheet of paper
- Use a stick pin to punch a small hole that is circular. Make sure there are no ragged edges.
- Hold the paper with the hole above a white sheet of paper and directed toward the Sun.
- The circle that you see on the white paper is a projection of the Sun.
- Tell students to NOT look at the Sun.
- They should only look DOWN at the pieces of paper.
- If it is a rainy day, use the light bulb to simulate the Sun.



What is Good and Bad About the Sun?
TEACHER ANSWER SHEET

Procedures:

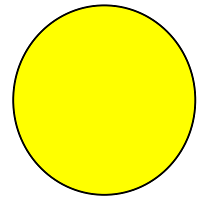
1. Go outside and look at the picture of the Sun with a pinhole camera. (DO NOT LOOK AT THE SUN!)

2. What do you see? Draw a picture.

3. Find pictures and cut them out and place on at T-Chart that shows things that are good with the sun and things that are bad with the sun.

4. Make your T-Chart and label the top of a sheet of paper with the following headings:

Draw picture



Good about the Sun?	Bad about the Sun?
Gives life	Can give sunburns
Warms	Can cause hurricanes, bad weather
Makes plants grow	Too much causes health problems
Makes the weather occur	Can make you hot
Creates the seasons	
Gives energy	
Helps tell time	

What is Good and Bad About the Sun?

Name ______________________________ **Date** ____________________

<u>Description:</u> The Sun is the source of all life on Earth. You will learn about what is good and bad about the Sun.

<u>Materials:</u> Pinhole Camera

<u>Procedures:</u>

1. Go outside and look at the picture of the Sun with a pinhole camera. (DO NOT LOOK AT THE SUN!)

2. What do you see? Draw a picture.

3. Find pictures and cut them out and place on at T-Chart that shows things that are good with the sun and things that are bad with the sun.

Draw picture

4. Make your T-Chart and label the top of a sheet of paper with the following headings:

Good about the Sun?	Bad about the Sun?

What are the Properties of Convex Lenses?

Description: Students will examine and categorize the types of images produced by convex lenses.

Student Materials (per group):

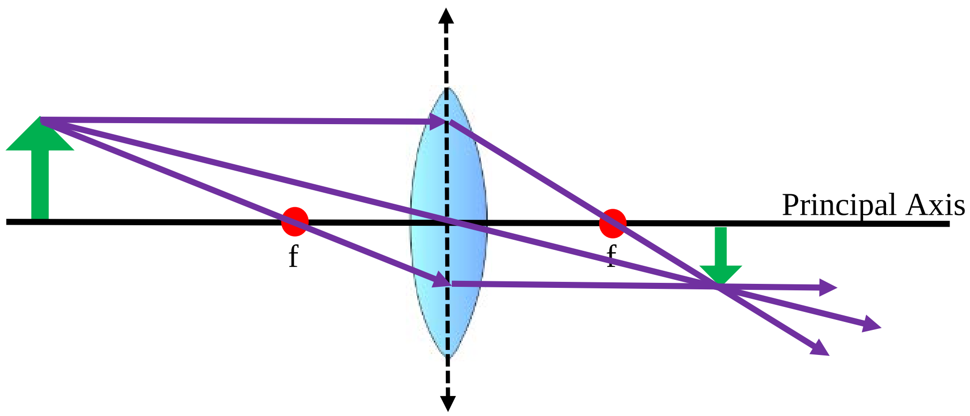
- ☐ Convex lens
- ☐ Meter stick
- ☐ Card
- ☐ Lens Holder
- ☐ Light Bulb and Base

Additional Teacher Materials:

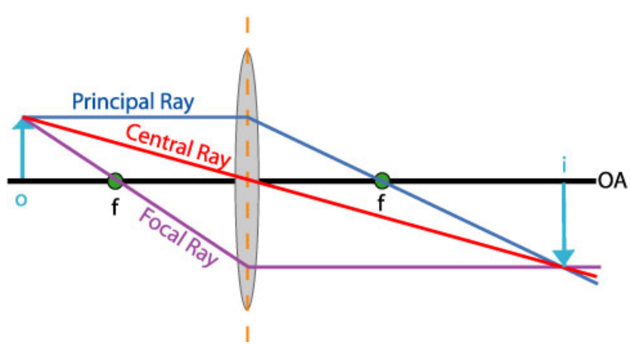
- ☐ None

Background and Misconceptions:

Double convex lenses are simple lenses that are thicker at the center than at the edges. They can focus light and causes the image to be either larger or smaller than the object. In the image below, the object is the larger arrow on the left side. The three lines originating from the top of the arrow are principal rays used to find the location, orientation, and type of image that is formed. The point where the three principal rays cross tells us the location of the image. The procedure for finding the image location using principal rays can be found in the activity "How Do I Use Ray Diagrams to Predict How an Image will Look."



The ***f*** shows the location of the focal point. The focal point is the point where lens focuses the light rays to a single point. While they focus at a single point, the light rays do not stop at the focal point. They continue past this point and begin to diverge. At double the distance of the focal point, there is a point called the Center of Curvature and this is referred to as 2F in this lab.

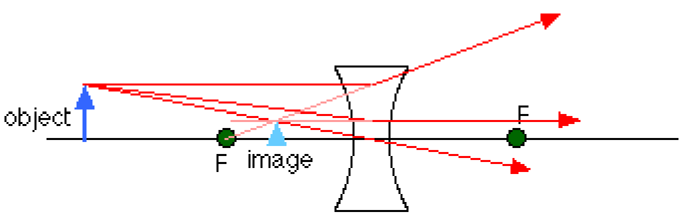


Credit: Clipartpanda.com

Type of Image	Real Image	Virtual Image
Orientation	Inverted	Erect
Size	Larger, Same Size or Smaller	Larger
Image is located:	On the opposite side of the lens as compared to the object	On same side of lens as the object
Object is located:	Beyond focal point	Inside of the focal point

The table above summarizes the types of images that are formed through a lens. Real images can be projected onto screens, cards, or even your hand. A virtual image exists "inside" of the lens. This type of image is apparent when you look through a magnifying glass. When a magnifying glass is held close to an object, the object can appear quite large and it is one that appears inside of the lens, on the same side of the lens as the object.

Whereas convex lens can produce either real or virtual images, concave lenses only form virtual images. Their light always diverges; light does not pass through a focal point. However they still have a virtual focal point through which light that is diverging has its rays lined up with this point. In the diagram below, you will notice that after the light passes through the lens, the light rays diverge in several directions, but if you follow those light rays backwards, they will pass through the focal point located on the left side of the lens, on the same side as the object.



Credits: Boston University

In the second part of the experiment, a laser is shone through a concave lens and the width of the laser dot that is cast can be used to create a graph and calculate the focal point. By plotting the diameter of the laser dot vs. distance from image to the dot, it is possible to approximate the focal length. Students should plot the graph, find the equation for the line (y=mx+b) and then solve for X. X is the focal length for the lens.

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. What are the properties of a convex lens?
2. What types of images can be formed by a convex lens?
3. What do you need to do to form an image that is larger or smaller than the object?
4. What happens when light goes through a concave lens?
5. Is it possible to form an image in a concave lens?

Additional Hints:

- Phet has a great website with a geometric optics applet at http://phet.colorado.edu.

What are the Properties of Convex Lenses?
TEACHER ANSWER SHEET

Focal Length - F (cm)	**30**
2F	**60**
Height of light bulb, h_o (cm)	**15**

	Beyond 2F (cm)	At 2F (cm)	Between 2F and F (cm)	At F (cm)	Between F and lens (cm)
Distance of object to lens. (cm)	**80**	**60**	**40**	**30**	**20**
Distance of image to lens (cm)	**40**	**60**	**80**	**Infinity**	**50**
Height of image (cm)	**10**	**15**	**30**	**Infinity**	**40**
Type of image (real, none or virtual)	**Real**	**Real**	**Real**	**No image**	**Virtual**
Orientation (inverted or erect.)	**Inverted**	**Inverted**	**Inverted**	**No image**	**Erect**

Questions:

1. Use the data from Table 2 to summarize the characteristics of images formed by convex lenses in each of the following situations: State in terms of LARGER or SMALLER, REAL or VIRTUAL, INVERTED or ERECT.

   A. The object is located beyond 2F.

   The image is smaller, real, and inverted as compared to the object.

   B. The object is located at 2F

   The image is the same size, real, and inverted as compared to the object.

   C. The object is located between 2F and F.

   The image is larger, real, and inverted as compared to the object.

   D. The object is located at F

   The image is undefined.

   E. The object is located between F and the lens.

   The image is larger, virtual, and erect as compared to the object.

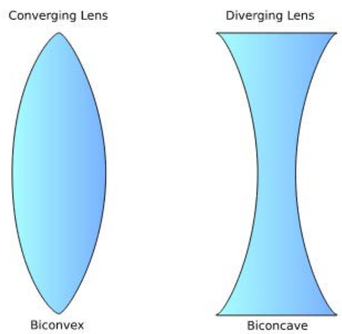
2. For **each** of the real images you observed, calculate the **focal length** of the lens using the lens equation shown below. Do your values agree?

   As an example, for the first lens measurement beyond zero we obtain:
   1/40 + 1/80 = 3/80 f = 27
   This is very close to the actual focal length.

What are the Properties of Convex Lenses?

Name ____ **Date** ____________________

<u>Description:</u> Lenses are made out of a plastic or glass that cause light to bend to produce images.



There are two different types of lenses: **Convex** and **Concave**. A convex lens is one that is thicker in the center than at the edges. These types of lenses are used in telescopes and microscopes. They can make objects appear larger or smaller. A concave lens is thinner in the center than at the edge. These lenses make objects appear smaller.

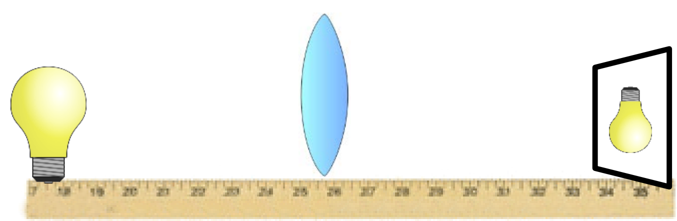
Both produce one of two different types of images. One type of image formed in both is called a **VIRTUAL IMAGE**. This image can be seen but not projected. A **REAL IMAGE** can be seen and projected. The real image is like one projected from a slide or movie projector. The lenses that project the image can be "touched" or projected onto your hand. The virtual image, similar to virtual reality, only exists inside the lens. You have to look in the lens to see it; it is not possible to project a virtual image onto a surface.

In this lab, you are going to explore the properties of convex and concave lenses, and determine the types of images they produce.

<u>Materials:</u> Convex lens Meter stick Card Lens Holder. Light Bulb

<u>Procedures:</u>

1. *Locate the focal point. The focal point is the point where all the rays of light meet*. Point the meter stick toward the window or some distant object. Put the card at one end of the meter stick. Along the meter stick move the convex lens back and forth until you see a clear image of the trees far in the distance on the card. Record the distance from the lens to the image on the card as **FOCUS**. Also, multiply the focus by **2** to find **2F**.



2. Place the lens in the middle of the meter stick.
   Put a light bulb at one end of the meter stick so that it's position is **beyond 2F** - (*For example, if your focus was 20 cm, the starting distance should be larger than 40 cm*). Place the card at the other end. **Move the card back and forth until you see a clear image of the light bulb on the card**. Measure the distance between the light bulb and the lens. Enter into table. Measure the distance between the card and the lens. Enter into the table.

3. Record the orientation (right side-up or upside-down). Also determine if the image is real or virtual. (See background for information.)

4. Measure the size of the object (the light bulb) and the size of the image on the card. Record these values in the table.

Focal Length - F (cm)	
2F	
Height of light bulb, h_o (cm)	

5. Repeat the above experiment. Place the card **AT 2F**. Measure the object distance, image distance, and height of the image as described above.

6. Repeat experiment again but place the light bulb between 2F and F, then AT F, then finally between F and the lens.

	Beyond 2F (cm)	At 2F (cm)	Between 2F and F (cm)	At F (cm)	Between F and lens (cm)
Distance of object to lens. (cm)					
Distance of image to lens (cm)					
Height of image (cm)					
Type of image (real, none or virtual)					
Orientation (inverted or erect.)					

Questions:

1. Use the data from Table 2 to summarize the characteristics of images formed by convex lenses in each of the following situations: State in terms of LARGER or SMALLER, REAL or VIRTUAL, INVERTED or ERECT.

A. The object is located beyond 2F.

B. The object is located at 2F

C. The object is located between 2F and F.

D. The object is located at F

E. The object is located between F and the lens.

2. For **each** of the real images you observed, calculate the **focal length** of the lens using the lens equation shown below. Do your values agree?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

f = focal length.

d_o = distance from object to lens.

d_i = distance from image to lens.

How Do You Find the Focal Length of a Concave Lens?
TEACHER ANSWER SHEET

A. What is the focal length of the lens?

This should match with good approximation the focal length of the lens.

B. Why is it negative?

It is negative because the focal point is behind the lens, in a location that is opposite what it would be if it were a convex lens.

C. How does it compare to the focal length obtained from the package?

If the measurements were completed correctly, it should be close in value. The value should be within 10% of the accepted value.

How Do You Find the Focal Length of a Concave Lens?

Name ______________________________________ **Date** ____________________

Description: Concave lenses produce images that are divergent and are virtual. While the light does not focus in a concave lens, it is possible to find the virtual focal point by graphing data collected from the lens. In this experiment, you are going to determine the focal length of a concave lens.

Materials: Convex Lens, White paper or card, Meter stick, Ruler, Laser, Lens holder

Procedures:

1. Place a concave lens in a lens holder and place it on the meter stick. Place a screen on one side of the lens. Take the lens and screen to a laser.

2. Shine a laser beam through the concave lens so that circle is formed on the screen. Measure the distance from the screen to the lens and the diameter of the circle of the light projected onto the screen. Record these data in the table. Move the lens and repeat the measurements for five additional sets of data.

3. **Find the Focal Length of the Concave Lens**. Using a graphing program, plot a graph of the image diameter vs. distance from the lens. The rays expanding from the lens will cross through the focal point. Use y=mx+b to calculate the focal length. The point where the line crosses the **X-Axis** is considered to be the focal point. If you do this correctly, you will find that the focal length is negative.

    - Horizontal Axis is Distance from the lens, measured in centimeters.
    - Vertical Axis is Diameter of image on screen, measured in centimeters.
    - Plot the graph
    - After the graph is plotted, right click the graph and select "Format Trendline"
    - Under Trendline options, select Linear
    - Select Display Equation on chart. This will be in the format of y=mx+b.
    - Choose Automatic Curve Fit
    - Calculate X from your equation. X intercept is equal to the focal length.

Distance from lens (cm)	Diameter of screen image (cm)

A. What is the focal length of the lens?

B. Why is it negative?

C. How does it compare to the focal length obtained from the package?

How Does Light Travel from a Source?

Description: Students will use foam core boards as shadow casters to determine the inverse squared law of light.

Student Materials (per group):

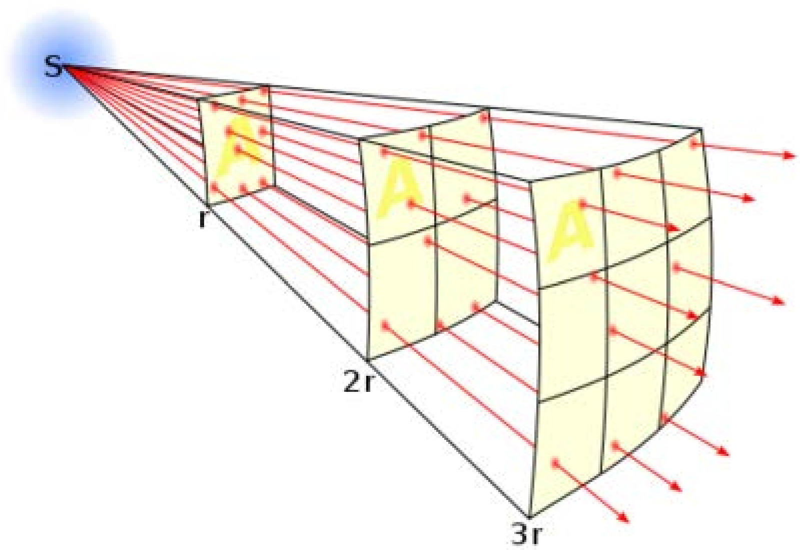
- ☐ Ring Stand
- ☐ Foam-core Boards
- ☐ Light bulb
- ☐ Meter stick

Additional Teacher Materials:

- ☐ Sharpie Marker
- ☐ Scissors or box cutter

Background and Misconceptions:

When a light bulb is turned on, the light travels in all directions. Imagine that if you drop a rock into water. The water waves spread out as circles in all directions, continuing to increase in size. This happens in two dimensions. Similar to water waves, the light waves spread out as a sphere, continuing to increase in size, in three dimensions. As a result, as the size of the light sphere increases the intensity of the light decreases. This can be demonstrated by drawing a square on a balloon. When the balloon is inflated, the size of the square increases and this means that the intensity or density of whatever was inside that square must decrease.



Credit: Wikipedia

The intensity of the light at various distances can easily be determined using a rule called the Inverse Squared Law. If you know the distance of a light source from a surface, say at 100 centimeters, and then if you double this distance, the intensity of the light at 200 cm is ¼ that of 100 cm. If you happen to know the intensity, the factor is multiplied by the intensity at the various distances to find the new intensity. If the intensity at 100 cm is 400 lumens/steradian (a unit of intensity), then the intensity at 200 cm is ¼ of 400 lm/sr or 100 lm/sr.

This rule applies to all forces that act at a distance. Gravitational pull decreases following the inverse squared law. The force of attraction between two charged particles decreases following the inverse squared law. The intensity of sound also decreases following the inverse squared law.

It should be noted that intensity of light is a physical characteristic of the wave and indicates the amount of power for a given area. This is different from brightness. Brightness relates to how we perceive light and can change for person to person and even for different colors. Our eyes do not respond in a linear fashion to light intensity. For example, a lamp that is dimmed to 10% of its maximum measured light output is perceived as being dimmed to only 32%. Likewise, a lamp dimmed to 1% is perceived to be at 10%.

Teacher Guided Questions to Inquiry: ***Use these questions to get the students started on their own inquiry!***

1. How does the intensity of light change with distance?
2. How can you determine the rule used to find out light intensity changes with distance?

Additional Hints:

- While this lab uses shadows for measuring the inverse squared law, caution students that this applies to light intensity and not shadows.
- Prepare 18"x24" foam core boards by drawing a grid of 16 squares on one side and a grid of 9 squares on the other side. Cut a set of smaller "shadow-caster" boards out of foam core so that it is the same size as one of the 16 squares that is drawn on the larger board.
- Use light bulbs that cast distinct shadows. Some light bulbs such as compact fluorescent bulbs cast fuzzy shadows and will produce errors of measurement.

How Does Light Travel from a Source
TEACHER ANSWER SHEET

	Distance from light bulb to shadow-caster. (cm)	Number of squares covered by the shadow-caster.	Ratio of shadow-caster to the number of squares covered.	Intensity of light at distance **r**.
Original distance	**25**	**16 squares**	**16/16 = 1/1 = 1 full board**	**25/25 = 1**
2X the distance	**50**	**4 squares**	**4/16 = 1/4**	**50/25 = 2 I = ¼**
3X the distance	**75**	**1 square on the 9 square side**	**1/9**	**75/25 = 3 I = 1/9**
4X the distance	**100**	**1 square on the 16 square side**	**1/16**	**100/25 = 4 I = 1/16**

Questions:

1. As you move the shadow-caster farther away from the bulb, what happens, and by what amount does the size of the shadow change? In other words, if you double the distance between the bulb and the shadow-caster, but what amount does the shadow change?

   As you move farther away from the light source, the size of the shadow decreases and does so by following a rule called the inverse squared law.

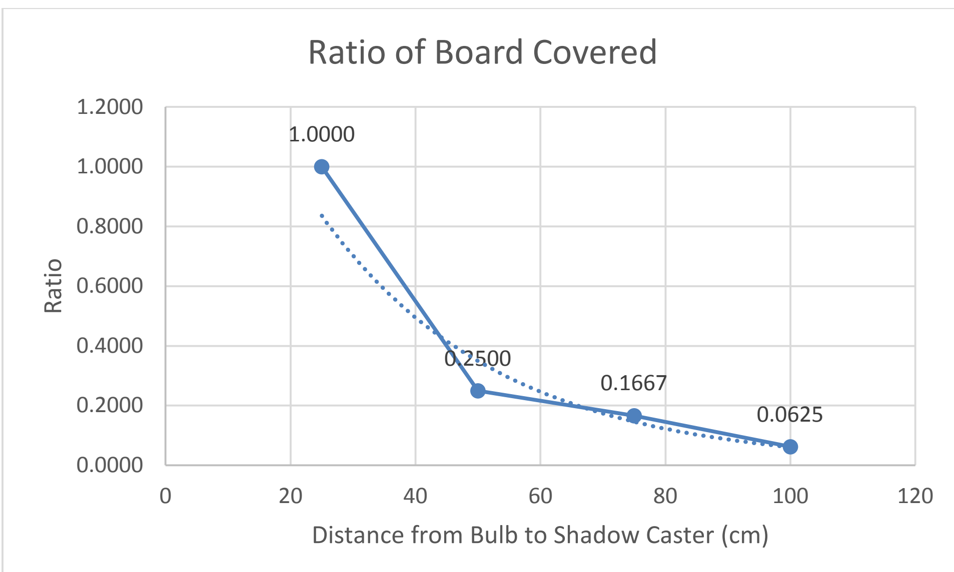
2. Why does the intensity of light change with distance?

   Because it is spreading out as a sphere and the light is going in all directions. As the distance from the light bulb increases, the sphere of light moving away from it is also increasing, but the intensity of the light is decreasing.

3. Light leaves a source, such as a light bulb, traveling in all directions. Therefore at any instant, we can describe a sphere of light coming from the bulb. What is the relationship between this sphere of light and the inverse squared law you have examined in this lab.

   As the distance from the light bulb increases, the intensity of the light decreases by one over the distance from the light bulb, squared. So as this sphere of light increases, the intensity of light decreases. This is similar to a balloon. As the balloon gets bigger, the surface increases spreading out the intensity of light that might represent the surface of the balloon.

4. Using a graphing program, create a graph from your data. Plot the distance from the light bulb to the shadow caster against the ratio of the board covered. Explain the meaning of the graph produced.



   As the distance increases, the intensity of the light decreases as $1/r^2$.

How Does Light Travel from a Source

Name ____ **Date** ____________________

Description: Light travels away from a light source as a sphere. Let's say you shine a light on a card at a distance of one meter. For example, the amount of light striking a card is 400 lumens. (A lumen is a measure of light intensity.) If we move the card to a distance of 2 meters the amount of light striking the card will only be 100 lumens. If we move the card to 4 meters (so it is now 4 times farther way than it was when it was at 1 meter) the amount of light striking the card is only 25 lumens. The light does not decrease in a linear way. The light follows what we call the INVERSE SQUARED LAW OF LIGHT. We use the following formula to explain this:

$$I = \frac{1}{r^2}$$

I = intensity of light.

r = distance from light source.

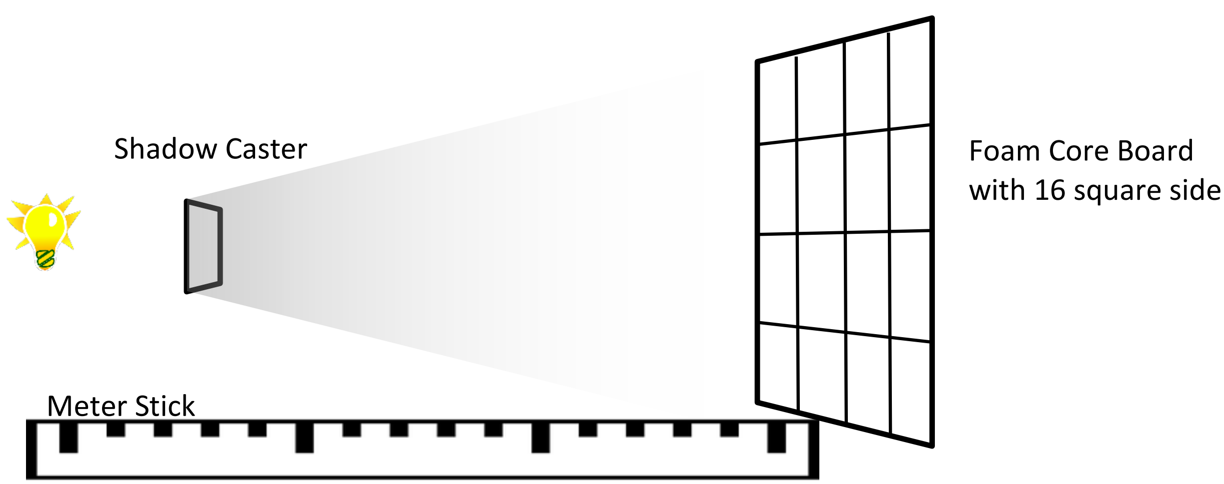
According to this law, if you DOUBLE THE DISTANCE, R, you have 1/4 the light. If you move the card 4 TIMES farther away, you have 1/16th of the light.

During this lab, you will be investigating the relationship between light intensity and distance for a light bulb.

Materials: Ring Stand Foam-core Boards Light bulb Meter stick

Procedures:

1. Place the large foam-core board against the ring stand. The ring stand will support it. Make sure the side with 16 squares is facing the bulb. Try to place the board so that it is completely vertical. Place the meter stick on the table so that the 100 cm mark is against the foam-core board. At the other end of the meter stick, line up the CENTER of the light bulb with the zero mark on the meter stick.



2. Hold the smaller foam-core board (shadow-caster) in front of the bulb so that the shadow cast on the larger board completely covers the board, but does not overlap past the board. Move the card back and forth until you get a perfect fit of the shadow size on the larger board. Measure the distance from the light bulb to the shadow-caster. Also, notice the number of squares covered on the larger board. Record both numbers on the table below.

3. Report the ratio of the board that is covered. This is equal to *(the number of squares covered) / (the number of squares on the board)*. If the board is covered fully, it should be reported as 1/1 and if it is 25% covered, it should be reported at ¼. **Report this ratio as a fraction!**

4. Double the distance from the light bulb to the shadow-caster. For example, if your first distance is 10 cm, move the shadow-caster to 20 cm. Record this new distance and determine the number of squares covered. Also determine the ratio.

5. Repeat the steps again, but move the shadow-caster to a position that is THREE times as far away from the light bulb as compared to the ORIGINAL position. For this, you will need to turn the board to the opposite side to record your measurements. This is the side with 9 squares.

6. Repeat the steps again, but move the shadow-caster to a position that is FOUR times as far away from the light bulb as compared to the ORIGINAL position. For this, you will need to turn the board to the original side to record your measurements. This is the side with 16 squares.

7. In the final column of the table below, use the inverse squared law to determine the amount of light (or in this case shadow) that is on the board from each of the distances. Use the formulas below:

$$r = \frac{\text{Distance from light bulb to caster}}{\text{Original Distance}} \longrightarrow \mathrm{I} = \frac{1}{r^2}$$

	Distance from light bulb to shadow-caster. (cm)	Number of squares covered by the shadow-caster.	Ratio of shadow-caster to the number of squares covered.	Intensity of light at distance **r**.
Original distance				
2X the distance				
3X the distance				
4X the distance				

Questions:

1. As you move the shadow-caster farther away from the bulb, what happens, and by what amount does the size of the shadow change? In other words, if you double the distance between the bulb and the shadow-caster, but what amount does the shadow change?

2. Why does the intensity of light change with distance?

3. Light leaves a source, such as a light bulb, traveling in all directions. Therefore at any instant, we can describe a sphere of light coming from the bulb. What is the relationship between this sphere of light and the inverse squared law you have examined in this lab.

4. Using a graphing program, create a graph from your data. Plot the distance from the light bulb to the shadow caster against the ratio of the board covered. Explain the meaning of the graph produced.

How Do We Know Photosynthesis is Occurring?

Description: Students will collect evidence of photosynthesis in a water plant by counting the number of bubbles released into the water.

Student Materials (per group):

- ☐ 3 Sprigs of Elodea (waterweed)
- ☐ 3-250 ml Beakers or similar sized jars
- ☐ Distilled Water
- ☐ Pinch of Baking Soda
- ☐ 1 Light bulb (100 watts)

Additional Teacher Materials:

- ☐ Sharp knife

Background and Misconceptions:

Photosynthesis is the synthesis of chemical compounds with the aid of light and carbon from carbon dioxide in the atmosphere. Light plays in important role in the process of photosynthesis. Without light, the chemical reactions do not occur and they cannot produce the necessary sugars the plant needs to survive. As a byproduct, oxygen is produced. Nearly all of the mass of a plant comes from water stored in the leaves and stems and carbon extracted from the carbon dioxide in the atmosphere.

Students often think that photosynthesis is a substance rather than a process. They think that the plants get the energy and food it needs to grow directly from the water and nutrients they take up through their roots. They believe this food accumulates over time and then the plants live off of it. Photosynthesis is a highly complex process where plants convert light energy into chemical energy. Even scientists are still trying to unravel the mysteries of photosynthesis. The chlorophyll in plants trap light energy from the sun and produces sugars. This process takes place in the chloroplasts of a plant cell. In addition to light, plants need other raw materials to complete the photosynthesis process. This includes water (particularly the hydrogen molecules) which the plants take up through its roots and carbon dioxide from the air. The light energy that is captured combines with the carbon dioxide and hydrogen to make sugars. Glucose, one of the sugars, becomes stored energy. Most of the oxygen becomes a waste product and is released into the air. Plant leaves have thousands of microscopic openings called stomata. The stomata are where carbon dioxide is taken in and the oxygen is released.

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. How do we know photosynthesis is occurring a plant?
2. What types of evidence can we observe to know that photosynthesis is taking place?

Additional Hints:

- The easiest place to find Elodea is at a pet superstore in the aquarium section. It may also be called anacharis.
- To prep the Elodea for the students, the teacher will need to cut the step on an angle and remove several of the leaves near the bottom of the stem.
- The light fixture should can either be a freestanding bulb or a gooseneck lamp that clamps to a table.
- Once student have completed their first set of observations have them design additional experiments to test their ideas about what variables can affect the rate of photosynthesis.
- The photosynthesis process is still a very complex process for young students to comprehend. Spend on focusing on the importance of photosynthesis and stray from attempting to have them memorize the formulas. Stress the importance of light in this process.

How Do We Know Photosynthesis is Occurring?
TEACHER ANSWER SHEET

Procedures:

1. Place one Elodea stem in each jar, with the stem facing upwards, make sure the whole stem is submerged.

2. Place a small pinch of baking soda into the water (this increases carbon dioxide in the water).

3. Pour distilled water into the jar so the stem is complete submerged. Adjust the stem if needed.

4. Place one jar 5 cm away from the light fixture, another beaker 10 cm away from the first, and then place the third 15 cm away from the first.

5. Prediction

   Student answers may vary, but they should have a logical explanation. The one that is closest to the light will undergo the greatest photosynthesis.

6. Turn the light on and make sure the light is only shining directly on the first jar.

7. Wait about 2 minutes.

8. Make a qualitative observation about what is happening in each jar. Draw what you observe in the boxes below.

Jar 1	Jar 2	Jar 3
Students should observe that the plant nearest the light fixture will produce far more bubbles than any of the other jars. Students could try to count and record the number of bubbles over a period of 3 minutes. **The baking soda adds more carbon dioxide to the environment for the elodea leaf to take in. The gas bubbles coming from the Elodea leaves are oxygen bubbles, a result of the final step in the photosynthesis process.**		

Questions:

1. How does the rate of photosynthesis change with the distance from light source?

   The rate slows down as you increase the distance from the light bulb.

2. What other variables could you change that could affect the rate of photosynthesis?

   Amount of baking soda in the water, the type of water, the color of the light, the amount of light.

3. How important is light to photosynthesis?

   It is the most important – without the light, photosynthesis will not occur.

How Do We Know Photosynthesis is Occurring?

Name ______________________________ **Date** ____________________

Description: By observing 3 Elodea stems in water you be looking for evidence that photosynthesis is happening.

Materials:

3 Beakers or jars	3 Springs of Elodea
1 Pinch of Baking Soda	1 Light fixture
Distilled Water	

Procedures:

1. Place one Elodea stem in each jar, with the stem facing upwards, make sure the whole stem is submerged.

2. Place a small pinch of baking soda into the water (this increases carbon dioxide in the water).

3. Pour distilled water into the jar so the stem is complete submerged. Adjust the stem if needed.

4. Place one jar 5 cm away from the light fixture, another beaker 10 cm away from the first, and then place the third 15 cm away from the first.

5. Write a prediction as to which plant will undergo the greatest amount of photosynthesis.

6. Turn the light on and make sure the light is only shining directly on the first jar.

7. Wait about 2 minutes.

8. Make a qualitative observation about what is happening in each jar. Draw what you observe in the boxes below.

Jar 1	Jar 2	Jar 3

Questions:

1. How does the rate of photosynthesis change with the distance from light source?

2. What other variables could you change that could affect the rate of photosynthesis?

3. How important is light to photosynthesis?

What is the Electromagnetic Spectrum?

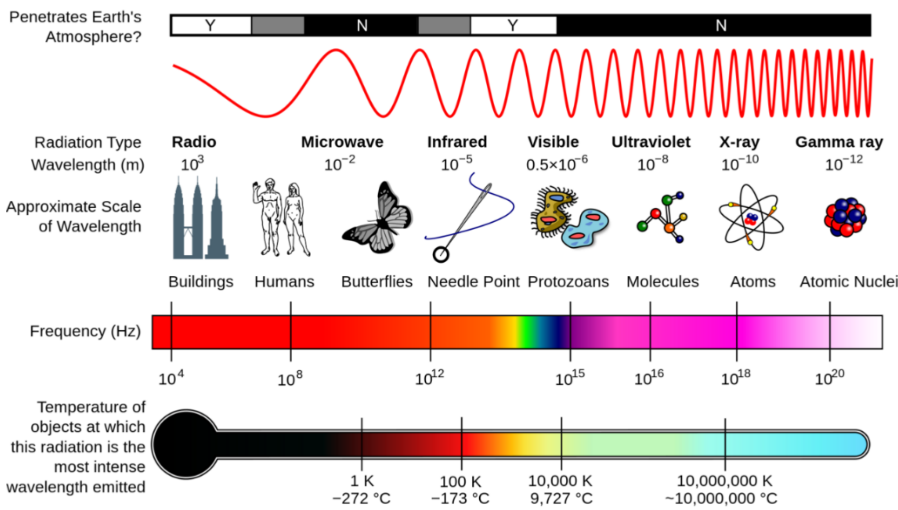
Description: Students will explore the diagram of the electromagnetic spectrum to become familiar with the various types of radiation represented.

Student Materials (per group):
- ☐ Color copy of the EM Spectrum

Additional Teacher Materials:
- ☐ None

Background and Misconceptions:

The electromagnetic (EM) spectrum is a range of wavelengths that have the ability to travel through the vacuum of space. EM radiation has properties of both a particle and a wave. In its particle form, it is known as a photon. Each of the forms of EM radiation found on the diagram is recognizable by their related technologies, but all travel at the speed of light, $3.0x10^8$ m/s. As the wavelength decrease, the frequency must increase for the speed to be a constant.



Credit: Wikipedia/NASA

Radio waves have the longest wavelength and can be meters or kilometers long. Gamma rays have the shortest wavelength. As the frequency increases, so does the energy level. Therefore red light has less energy than blue light and radio waves have less energy than gamma rays.

Solar cells and photodetectors are devices that use sunlight to produce electricity. This phenomenon is called the Photoelectric Effect. When a blue light is shone on a solar cell, it causes electricity to flow. However, when red light is shone on the same solar cell, no matter how bright or intense the red light is, no electricity will flow. This discovery was made by Albert Einstein, for which he won the Nobel Prize in Physics. Early hypotheses held that light was a wave so it was predicted that brighter light shining on a solar cell will cause electricity to flow. Yet, observations did not support the prediction. No matter how bright the light was, electricity never flowed if the frequency of the light was too low. The only explanation for the observed effect was the light was not just a wave, but that it also had particle-like behavior.

Astronomers are able to use photon energy level to draw conclusions about stars. Blue stars, with higher energy photons are also hotter than red stars, with lower energy photons. The observation of stellar spectra is an important tool in determining the composition of stars.

When a picture is taken of an object, the object, such as a pack of cards, is much larger than the wavelength of light that is shining on it. However, if you continue to look at smaller objects, there is a point where it is impossible to use light to image the object. For example, light cannot be used to image atoms and molecules. It is generally understood that objects cannot be imaged if they are less than ½ the wavelength of the radiation that is shining on them. We cannot use radio waves to image objects such as houses, people, or cars. The wavelength of the radio waves is far too large to image these, but radio can be used to measure structures such as stars and galaxies.

The EM spectrum is comprised of radiation with a dual nature. It has properties of a particle and a wave, can travel through the vacuum of space, is massless, and travels at the ultimate speed limit. Nothing goes faster than the speed of light.

Teacher Guided Questions to Inquiry: ***Use these questions to get the students started on their own inquiry!***

1. What is the EM Spectrum
2. How does light compare from radio or X-rays?

Additional Hints:

- Print out the EM Spectrum on color paper. You might want to laminate to keep for many classes.

What is the Electromagnetic Spectrum?
TEACHER ANSWER SHEET

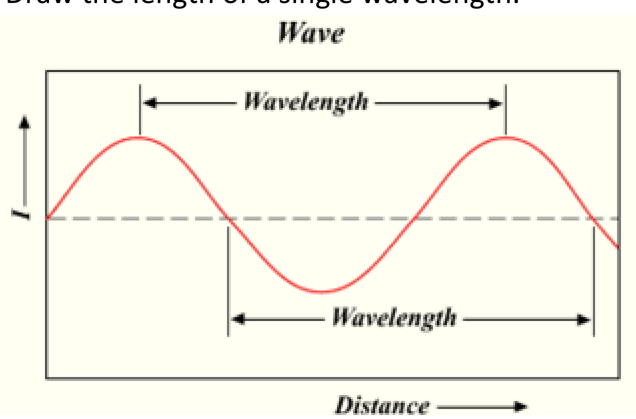
A. What happens to the wavelength as the EM spectrum changes from radio to gamma rays?

The wavelength decreases.

B. Does the picture of the wavelength accurately reflect real wavelength of the radiation? Explain.

No it does not. The wavelength of radio is about the length of a skyscraper so a single wave would not fit on the sheet of paper. The wavelength is shown to give a sense of relative size with relationship to each other.

C. Draw the length of a single wavelength.



Credit: Wikipedia

D. The speed of light is $3.0x10^8$ m/s. What is the speed of radio radiation if the frequency is $5x10^8$ Hz and the wavelength is 0.6m?

It is the same.

E. What is the speed of ultraviolet radiation if the frequency is $1.2x10^{15}$ Hz and the wavelength is $2.50x10^{-7}$m?

It is the same.

F. What happens to the wavelength of the radiation as the frequency increases? Why?

It decreases. Since the wavelength is decreasing, the frequency has to increase. This occurs because the speed of light (or radiation) is a constant.

G. The EM spectrum shows the types of radiation that can travel through the vacuum of space. The radiation is said to have properties of both a particle and a wave. The particle is called a "photon." Sometimes the radiation acts like a particle, such as when its amount of energy is described. Sometimes it acts like a wave, such as when radiation reflects, refracts or diffracts.

Energy is directly related to its frequency. Which of the following have the highest energy? Explain.

Microwave | Visible | X -rays

The X-rays because they have the highest frequency and therefore the highest energy.

H. What is the relationship between the energy of radiation and the temperature?

They have a direct relationship. As the energy increases, the temperature of the radiation increases.

I. Stars are classified by color. Red stars are cooler while blue stars are hotter. How is this consistent with the EM spectrum?

Blue stars will emit radiation that is at a higher frequency and therefore at a higher energy level and temperature. Red stars will emit radiation that is at a lower frequency and therefore at a lower energy level and temperature.

J. Our eyes can see radiation that is in the visible part of the EM Spectrum. What would need to happen to our eyes to be able to "see" in the microwave part of the spectrum.

They would have to evolve so they would be larger and be able to detect the radiation. Since the wavelength is longer, the receiving part of our new "eyes" would need to be longer or wider.

K. Some antennas are long while others are shorter. How do you think the size of a microwave antenna compares with that of a short wave radio antenna?

The microwave antenna will be much shorter because the wavelength is much smaller than radio waves.

L. Radiation from the EM Spectrum can be used to make images of objects. Radio images can be used to image objects such as stars or entire galaxies. However, the size of the object limits the type of radiation that can be used to image an object. It is generally understood that if the object is half the wavelength or smaller as compared to a specific wavelength of radiation, the radiation can't be used to image it. If a the point the protozoans are 5×10^{-7} m in length, which types of radiation can be used to image them?

Light, UV, X-rays and gamma rays.

M. Can atoms be imaged using visible light? Why or why not?

They can not because they are less than ½ the wavelength of visible light.

N. What can be said about the amount of radiation that we can see with the human eye?

It makes up a very small amount of the overall EM spectrum.

O. Given your answer to the previous question, how important is it to have tools such as radio telescopes, X-ray machines, and infrared detectors? Explain your answer.

It is very important because most of the radiation that is emitted by sources is given off in parts of the spectrum that is invisible to the human eye. Without these other tools we lose a great deal of information about the structure and function of objects and the universe.

What is the Electromagnetic Spectrum?

Name ____ **Date** ____________________

Description: The electromagnetic spectrum is the range of frequencies

Materials: Color Copy of the EM Spectrum

Procedures:

1. Use the copy of the electromagnetic (EM) spectrum chart to research and answer the following questions.

A. What happens to the wavelength as the EM spectrum changes from radio to gamma rays?

B. Does the picture of the wavelength accurately reflect real wavelength of the radiation? Explain.

C. Draw the length of a single wavelength.

D. The speed of light is 3.0×10^8 m/s. What is the speed of radio radiation if the frequency is 5×10^8 Hz and the wavelength is 0.6m?

E. What is the speed of ultraviolet radiation if the frequency is 1.2×10^{15} Hz and the wavelength is 2.50×10^{-7}m?

F. What happens to the wavelength of the radiation as the frequency increases? Why?

G. The EM spectrum shows the types of radiation that can travel through the vacuum of space. The radiation is said to have properties of both a particle and a wave. The particle is called a "photon." Sometimes the radiation acts like a particle, such as when its amount of energy is described. Sometimes it acts like a wave, such as when radiation reflects, refracts or diffracts.

   Energy is directly related to its frequency. Which of the following have the highest energy? Explain.

   Microwave | Visible | X -rays

H. What is the relationship between the energy of radiation and the temperature?

I. Stars are classified by color. Red stars are cooler while blue stars are hotter. How is this consistent with the EM spectrum?

J. Our eyes can see radiation that is in the visible part of the EM Spectrum. What would need to happen to our eyes to be able to "see" in the microwave part of the spectrum.

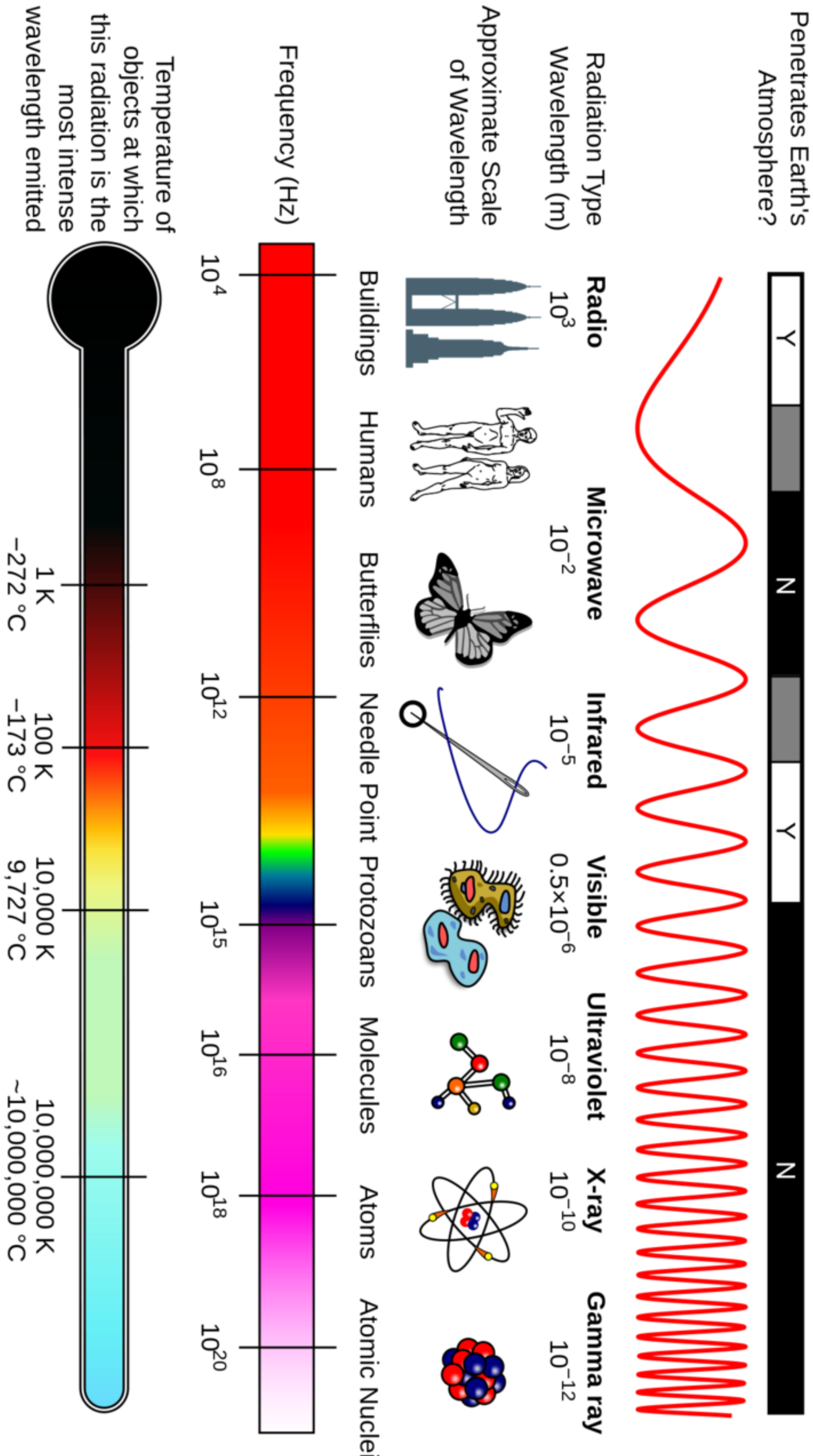
K. Some antennas are long while others are shorter. How do you think the size of a microwave antenna compares with that of a short wave radio antenna?

L. Radiation from the EM Spectrum can be used to make images of objects. Radio images can be used to image objects such as stars or entire galaxies. However, the size of the object limits the type of radiation that can be used to image an object. It is generally understood that if the object is half the wavelength or smaller as compared to a specific wavelength of radiation, the radiation can't be used to image it. If a the point the protozoans are 5×10^{-7} m in length, which types of radiation can be used to image them?

M. Can atoms be imaged using visible light? Why or why not?

N. What can be said about the amount of radiation that we can see with the human eye?

O. Given your answer to the previous question, how important is it to have tools such as radio telescopes, X-ray machines, and infrared detectors? Explain your answer.



Credit: Wikipedia/NASA

How Does Light Reflect Off Mirrors?

Description: Students will observe how light reflects off mirrors and crumpled aluminum foil.

Student Materials (per group):
- ☐ Plane Mirror
- ☐ Laser
- ☐ White Sheet of Paper
- ☐ Milk
- ☐ Dropper

Additional Teacher Materials:
- ☐ None

Background and Misconceptions:

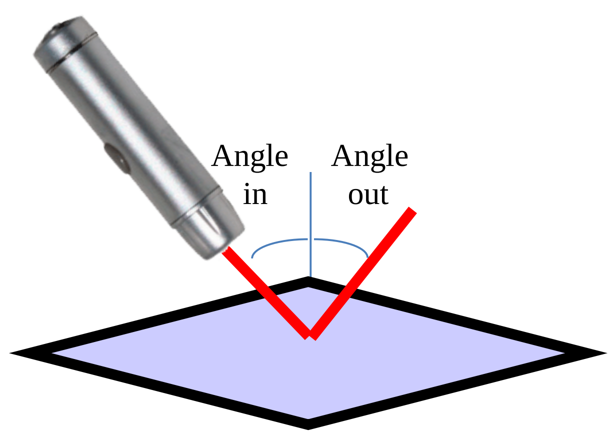
Light travels in straight lines unless it encounters a surface or some other material such as glass, water, or air. Then, it can do one of several things; it can reflect, refract, or diffract.

When light reflects it occurs either as regular or diffuse reflection. Regular reflection occurs when light rays bounce off a very smooth and even surface that is highly reflective, such as a mirror. The light rays remain organized before and after reflection and they scatter very little when the encounter the mirror. This is why we are able to see our image in a mirror.

All other objects, walls, floors, furniture, clothing, even our skin, undergo diffuse reflection. The light strikes these surfaces and is scattered in many different directions. Some of the light is also absorbed and reflecting specific wavelengths, by the surface giving it its color.

Whenever reflection occurs, it follows the law of reflection. The angle that the light strikes the surface is the same angle that the light leaves the surface, but it changes direction. Scientists define this angle with reference to a line that is perpendicular to the surface at the point where the light ray strikes. This is called the Normal Line.

This law applies to all surfaces, not just smooth surfaces like mirrors. Most surfaces are not smooth which causes the perpendicular line at one point to be oriented in a different direction as compared to another point. This causes the light to reflect in many different directions. The aluminum foil used in this experiment shows that light can bounce off irregular surfaces, demonstrating scattering.



As a demonstration you can show how light will also reflect off the surface of the water. By looking on the wall or ceiling the students will see the reflected beam of light. When the water is disturbed the waves cause the light to shimmer in many different directions. A tennis ball can also be used to show how light rays reflect and how the different angles cause the ball to bounce in different directions.

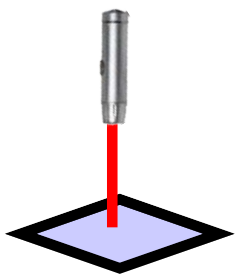
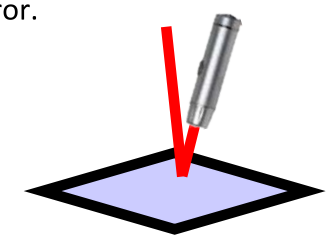
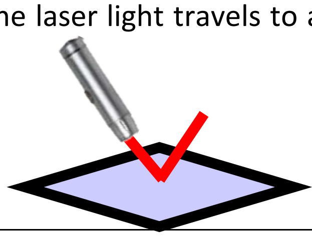
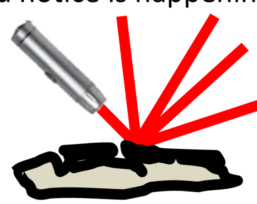
Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. How does light travel?
2. How can light bounce off of smooth mirrors?
3. How is light reflecting off a mirror different than off a piece of aluminum foil?

Additional Hints:

- Make sure students use the lasers safely by not shining them in their eyes. (The hand held lasers are very safe, so even with an accidental exposure, there is no danger of blindness.)
- Purchase only the RED lasers. Do not purchase the GREEN lasers.
- Use the lasers that are available in many hardware stores or online. They are often called keychain lasers and should be available for around $5 each.
- Smooth aluminum foil can be used in place of mirrors for the first part of this experiment.

How Does Light Reflect Off Mirrors?
TEACHER ANSWER SHEET

5. Hold the laser above the mirror like in the picture. 6. Draw the how the laser light travels to and from the mirror. 	7. Hold the laser above the mirror at an angle, like in the picture. 8. Draw the how the laser light travels to and from the mirror. 
9. Hold the laser above the mirror at another angle, like in the picture. 10. Draw the how the laser light travels to and from the mirror. 	11. Hold the laser above a crumpled piece of aluminum foil and move it around. 12. What do you notice is happening? 

Questions:

1. What direction does light travel? Is it curved or in a straight line?
   It is in a straight line.

2. What happens to the light when it goes into mirror?
   It reflects in a different direction, but the direction that is leaves is the same angle that it strikes the mirror.

3. How is a rough surface, like crumpled aluminum foil, different from a smooth mirror?
   The light scatters in many different directions as opposed to all the light reflecting in the same direction and staying aligned.

4. Does light reflect off of a non-shiny surface like a wall? How do you know it does or doesn't?
   It does reflect. The evidence that it reflects is because you can see the light from the laser.

How Does Light Reflect Off Mirrors?

Name ______________________________ **Date** ____________________

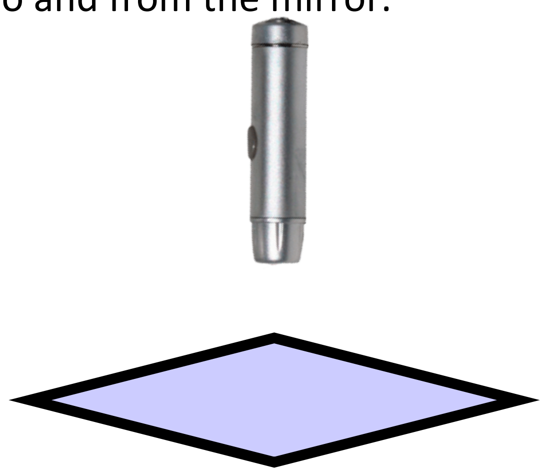
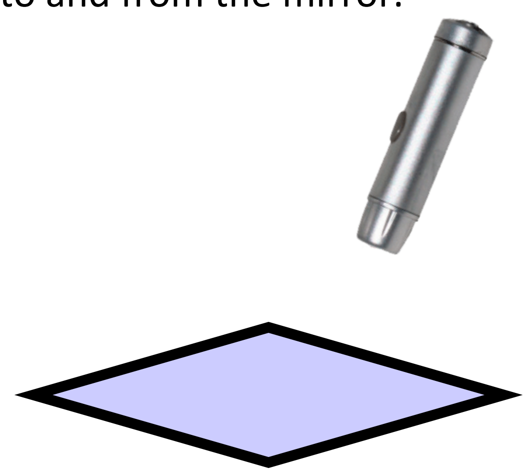
<u>Description:</u> Light from a laser beam can be used to see the direction that it travels. In this experiment, you are going to examine how light travels when it reflects from the surface of a mirror and aluminum foil.

<u>Materials:</u>	Plane Mirror	Laser
	Aluminum foil	

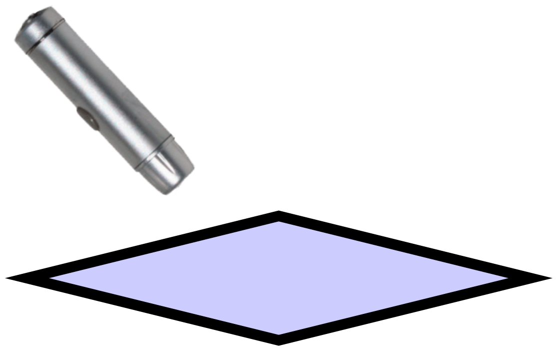
<u>Procedures:</u>

1. Place the mirror on a flat table.
2. Shine the laser onto the mirror as shown in the pictures.
3. Hold the sheet of paper over the mirror so you can see where the laser beam reflects.
4. In each of the pictures below, shine the laser onto the mirror and examine how it reflects. Draw how the laser travels to the mirror and away from the mirror.

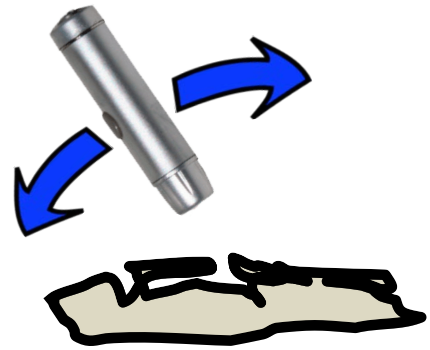
DO NOT SHINE THE LASER BEAM INTO OTHER STUDENT EYES

5. Hold the laser above the mirror like in the picture. 6. Draw the how the laser light travels to and from the mirror. 	7. Hold the laser above the mirror at an angle, like in the picture. 8. Draw the how the laser light travels to and from the mirror. 

9. Hold the laser above the mirror at another angle, like in the picture.
10. Draw the how the laser light travels to and from the mirror.



11. Hold the laser above a crumpled piece of aluminum foil and move it around.
12. What do you notice is happening?



Questions:

1. What direction does light travel? Is it curved or in a straight line?

2. What happens to the light when light reflects off a mirror?

3. How is a rough surface, like crumpled aluminum foil, different from a smooth mirror?

4. Does light reflect off of a non-shiny surface like a wall? How do you know it does or doesn’t?

How Can We See More Stars in the Sky?

Description: Using a hand lens that will simulate a telescope, students will determine that the number of stars that can be seen in a picture is much greater using the lens than with the naked eye.

Student Materials (per group):

- ☐ Hand lens, plastic
- ☐ Star Picture

Additional Teacher Materials:

- ☐ Meter stick or tape measure (optional)

Background and Misconceptions:

A telescope's main function is not to magnify, but to gather enough light so that distant and faint stars can be seen. The largest telescopes use very wide mirrors in an effort to collect as much light as possible. In addition, long exposures are conducted to further increase the light that is gathered. The best telescopes use mirrors as their main light collecting surface. Lenses are prone to chromatic aberration which causes some light from the edges of the lens to focus improperly. The result is that images can be fuzzy.

The Hubble Space Telescope is one telescope that has a large mirror, but it is not the largest. It has a 90" mirror but it has the advantage of being far above Earth's atmosphere. The atmosphere bends the light as it travels through to the ground. This phenomenon causes the twinkling of stars. (And, a common misconception is that only stars twinkle. In fact, planets and even satellites twinkle. There is nothing special about the light that comes from the stars as the light interacts with the distortions in the atmosphere.)

The largest telescope is the Gran Telescopio Canarias (GTC) in the Canary Islands at a massive 10.4 meters. This is as long as a modern commercial passenger bus.

In the picture in this lab, it is common for astronomers to use the inverse image of the star field. It is often easier to count the stars when the background is white and the stars are black. The image that is used in the lab is the same picture that is in the procedures. In addition you will notice one star with 2 lines. This was used to point out a specific star for research purposes. You may also notice that some stars are somewhat fuzzy. These are actually distant constellations that have hundreds of millions of stars contained within. For the purposes of this lab, they will be counted as a star point.

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. How many stars can be seen at night?
2. How do telescopes help increase the number of stars that can be seen?
3. How is the hand lens like a telescope?
4. How can you increase the number of stars that you can see at night?

Additional Hints:

- The picture may be a bit grainy when printed. Make sure students identify only stars and not the graininess of the picture. Above is an example of the graininess you may see. There is one star present.

How Can we See More Stars in the Sky?
TEACHER ANSWER SHEET

Procedures:

1. The star picture your teacher will provide is a negative of this picture. The white stars will appear as black spots, and the black background will appear white.

1. Hold the star picture about 6 feet away. Count how many stars you see in the box.	7-10 stars will be visible.
2. Hold the star picture about 1 foot away. Count how many stars you see in the box.	20-25 stars will be visible.
3. Use the hand lens to count the number of stars in the box.	About 40 stars

Questions:

1. What does a hand lens do?

   It magnifies objects.

2. How does the hand lens help in counting the stars?

   It makes the fainter and smaller stars easier to see.

3. How is a hand lens similar to a telescope?

   They both help magnify, and they allow small faint things to be seen.

How Can We See More Stars In The Sky?

Name ______________________________ **Date** ____________________

Description: There are many tools that an astronomer uses to learn about the stars in the sky. One tool, the TELESCOPE, can help astronomers see more stars that are farther away. In this experiment, you are going to learn how telescopes can help see more stars in the sky.

Materials: Hand Lens
Star Picture

Procedures:

1. The star picture your teacher will provide is a negative of this picture. The white stars will appear as black spots, and the black background will appear white.

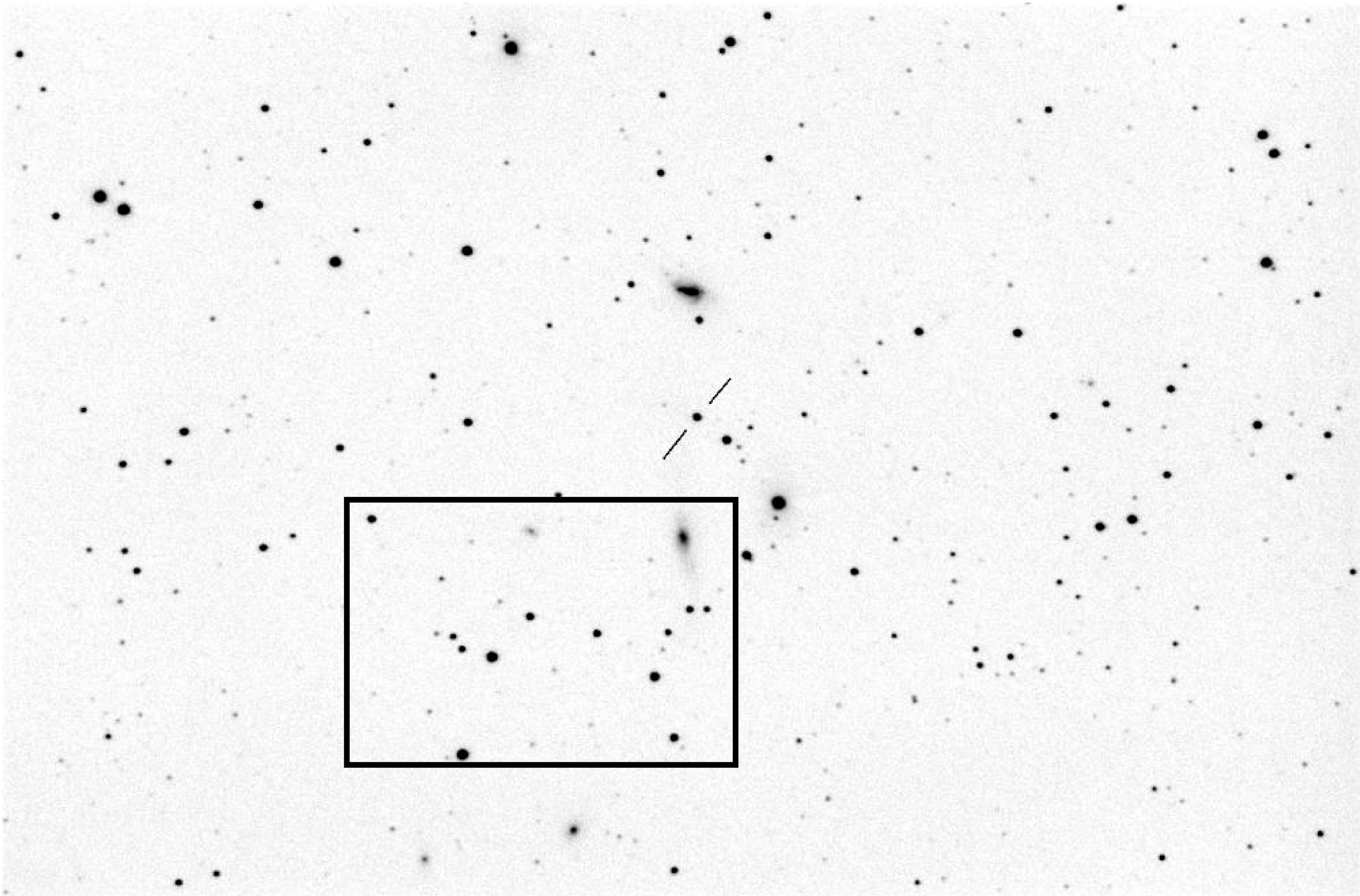
2. Hold the star picture about 6 feet away. Count how many stars you see in the box.	
3. Hold the star picture about 1 foot away. Count how many stars you see in the box.	
4. Use the hand lens to count the number of stars in the box.	

Questions:

1. What does a hand lens do?

2. How does the hand lens help in counting the stars?

3. How is a hand lens similar to a telescope?



What are the Properties of Concave Mirrors?

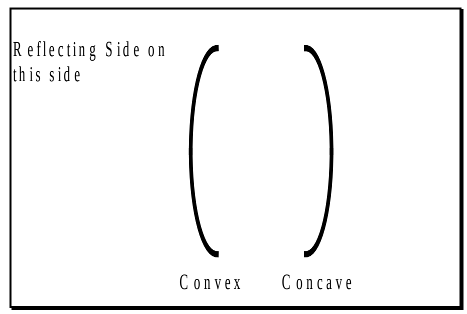
Description: Students will observe the types of images that are formed from convex and concave mirrors and will describe them in terms of size, orientation, and type.

Student Materials (per group):
- ☐ Convex mirror
- ☐ Concave Mirror
- ☐ Cardboard Screen
- ☐ Light Source
- ☐ Plane Mirror
- ☐ Holders
- ☐ Metric Ruler
- ☐ 2 meter sticks

Additional Teacher Materials:
- ☐ None

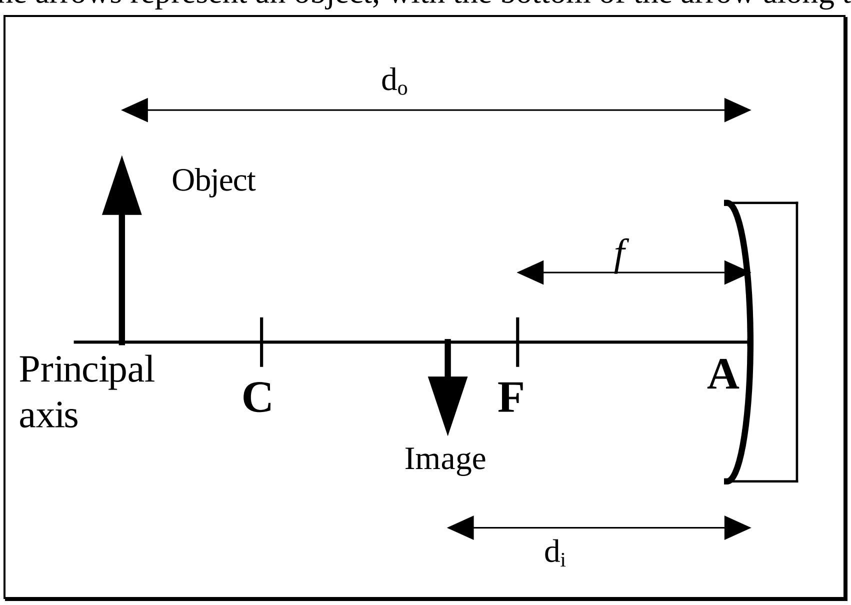
Background and Misconceptions:

Spherical mirrors are portions of a sphere, one side of which is silvered and serves as a reflecting surface. If the inner side is the reflecting surface, the mirror is a **concave mirror**. If the outer side is the reflecting surface, the mirror is a **convex mirror**.



There is an imaginary line, called the Principal Axis that can be drawn perpendicular to the surface of the center of the mirror at Point A. Along this line, we find the following: F which is the focus and C, which is the center of curvature. The center of curvature is also equal to twice the focal length, or 2f. The distance from the surface of the mirror to the Focus is called the Focal Length (f).

The arrows represent an object, with the bottom of the arrow along the principal axis. The principal axis also represents a single ray of light. It travels along this line both as it goes toward the mirror and when it reflects from it.



$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

f = focal length.
d_o = distance from object to lens.
d_i = distance from image to lens.

The mirror equation above, which is the same as the lens equation, represents the position of the object from the mirror as $\boldsymbol{d_o}$ and the position of the image as $\boldsymbol{d_i}$.

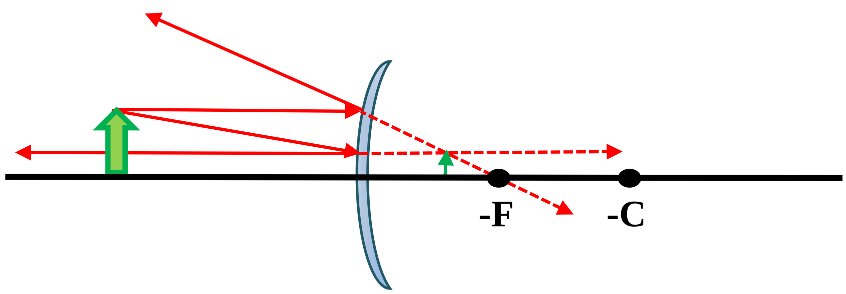
Concave mirrors create images that are similar to those produced by convex lenses.

Type of Image	Real Image	Virtual Image
Orientation	Inverted	Erect
Size	Larger, Same Size or Smaller	Larger
Image is located:	On the same side of the mirror as compared to the object	On opposite side of the mirror as the object
Object is located:	Beyond focal point	Inside of the focal point

The table above summarizes the types of images that are formed with a mirror. Real images can be projected onto items such as white screens, cards, or even your hand. A virtual image exists "inside" of the mirror. A plane mirror is a great example of this. You see the image in the mirror but it can't be projected.

When you look at yourself in a concave mirror in which the image appears to be larger and erect, this is a consequence of placing your face inside the focal length. Cosmetics mirrors have a focal length that is perhaps 20-30 inches so that you can get inside the focal length and produce an image that is much larger than the object (your face.)

Whereas concave mirrors can produce either real or virtual images, convex mirrors only form virtual images. Their light always diverges and the light does not pass through a focal point. However they still have a virtual focal point through which light that is diverging in which the rays line up with this point. In the diagram below, you will notice that after the light passes reflects off the mirror, the light rays diverge in several directions, but if you follow those light rays backwards, they will pass through the focal point that is located on the right side of the mirror, on the opposite side as compared to the position of the object.



The image that is formed appears as an image inside the mirror. It is upright and smaller. Mirrors that are often found on the passenger side of cars will use concave mirrors to allow you to see other cars.

Teacher Guided Questions to Inquiry: ***Use these questions to get the students started on their own inquiry!***

1. What types of images are formed in a convex mirror?
2. What types of images are formed in a concave mirror?
3. How can you produce am image that is larger than an object using a convex mirror?
4. Is it possible to project an image using a concave mirror?

Additional Hints:

Some science supply companies have metal mirrors. These are suggested for use with students. Both sides are silvered so they can be used for both convex and concave mirrors.

What are the Properties of Concave Mirrors?
TEACHER ANSWER SHEET

Focal Length - F (cm)	10 cm
C	20 cm
Height of light bulb, h_o (cm)	10 cm

	Beyond C (cm)	At C (cm)	Between C and F (cm)	At F (cm)	Between F and mirror (cm)
Distance of object to mirror (cm)	**30**	**20**	**15**	**10**	**5**
Distance of image to mirror (cm)	**15**	**20**	**30**	**Infinity**	**-10**
Height of image (cm)	**5**	**10**	**20**	**No Image**	**20**
Type of image (real, none or virtual)	**Real**	**Real**	**Real**	**No Image**	**Virtual**
Orientation (inverted or erect.)	**Inverted**	**Inverted**	**Inverted**	**None**	**Erect**

Questions:

1. Summarize the characteristics of images formed by concave mirror in each of the following situations:

B. The object is located beyond C	**Image is smaller, real, inverted.**
C. The object is located at C	**Image is the same size as the object, real, and inverted.**
D. The object is located between C and F.	**Image is larger, real, and inverted.**
E. The object is located at F	**No image can be formed.**
F. The object is located between F and the mirror.	**Image is larger, virtual, and erect.**

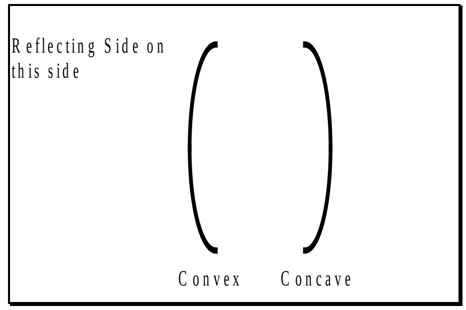
2. For each of the real images you observed, calculate the focal length of the mirror using the mirror equation shown below. Do your values agree? Also, determine the percentage difference using the formula below.

Your Value is the value you get in the table below under Focal Length. The Accepted Value is obtained from the mirror package or your teacher.

Student data should be consistent with their results, but should have percentage differences of less than 10%.

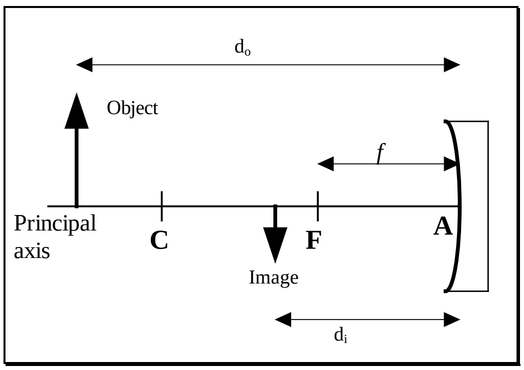
What are the Properties of Concave Mirrors?

Name ____ **Date** ____________________



Background: Spherical mirrors are portions of a sphere, one side of which is silvered and serves as a reflecting surface. If the inner side is the reflecting surface, the mirror is a **concave mirror**. If the outer side is the reflecting surface, the mirror is a **convex mirror**.

There is an imaginary line, called the Principal Axis that can be drawn perpendicular to the surface of the center of the mirror at Point A. Along this line, we find the following: F which is the focus and C, which is the center of curvature. The center of curvature is also equal to twice the focal length, or 2f. The distance from the surface of the mirror to the Focus is called the Focal Length (f).



The arrows represent an object, with the bottom of the arrow along the principal axis. The principal axis also represents a single ray of light. It travels along this line both as it goes toward the mirror and when it reflects from it.

The mirror equation above, which is the same as the lens equation, represents the position of the object from the mirror as $\boldsymbol{d_o}$ and the position of the image as $\boldsymbol{d_i}$.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

f = focal length.
d_o = distance from object to lens.
d_i = distance from image to lens.

In this experiment, you will explore the properties of convex, concave and plane mirrors.

Materials:

Convex mirror	Concave Mirror	Cardboard Screen	Light Source
Plane Mirror	Holders	Metric Ruler	2 meter sticks

Procedures:

1. Locate the focal point. The focal point is the point where all the rays of light meet. Put the card at one end of the meter stick. Make sure you point the meter stick out the window. Along the meter stick move the concave mirror back and forth until you see a clear image on the card. (You are aiming for something which is far away, like the trees in the distance.) Record the distance from the lens to the image on the card as **Focus**.

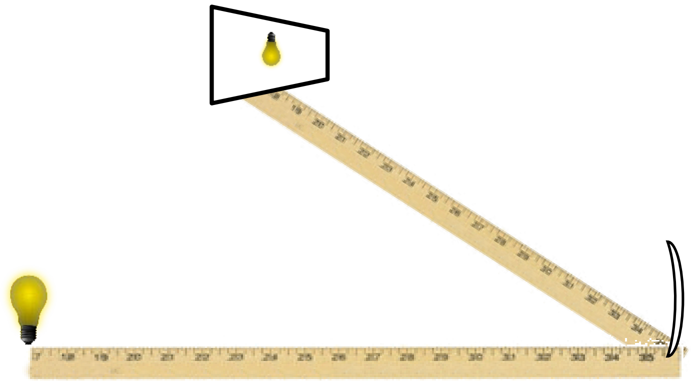
Focal Length - F (cm)	
C	
Height of light bulb, h_o (cm)	

2. The center of curvature, C, is two times the focal length. Record this in the table above. Arrange the two meter sticks, mirror, light source, and screen, as shown in the figure on the next page. Use a piece of masking tape to hold the meter sticks in place.

3. Place the light bulb at a distance greater than **C** from the mirror. Measure the **height** of the light bulb and record this value in the table as $\mathbf{h_o}$. Move the screen back and forth along the meter stick until you obtain

a sharp image of the light source. Determine the **distance of the image** from the mirror, **d_i**, by measuring from the mirror to the screen. Record this measurement and the measurements of **object distance**, **d_o**, and **image height**, **h_i** , in the table.

4. Record the **orientation** (right side-up or upside-down). Also determine if the image is **real** or **virtual**. (See background for information.)



5. Repeat the above experiment. Place the light bulb at **C**. Measure the object distance, image distance, and height of the image as described above.

6. Repeat experiment again but place the light bulb between **C** and **F**, then **AT F,** then finally between **F** and the mirror.

	Beyond C (cm)	At C (cm)	Between C and F (cm)	At F (cm)	Between F and mirror (cm)
Distance of object to mirror (cm)					
Distance of image to mirror (cm)					
Height of image (cm)					
Type of image (real, none or virtual)					
Orientation (inverted or erect.)					

Questions:

1. Summarize the characteristics of images formed by concave mirror in each of the following situations:

A. The object is located beyond C	
B. The object is located at C	
C. The object is located between C and F.	
D. The object is located at F	
E. The object is located between F and the mirror.	

3. For each of the real images you observed, calculate the focal length of the mirror using the mirror equation shown below. Do your values agree? Also, determine the percentage difference using the formula below.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

f = focal length.
d_o = distance from object to mirror
d_i = distance from image to mirror

$$\text{Percentage Difference} = \frac{\text{Accepted Focal Length} - \text{Your Focal Length}}{\text{Accepted Focal Length}} \; x\, 100\%$$

	Focal Length	Percentage Difference
A. The object is located beyond C		
B. The object is located at C		
C. The object is located between C and F.		
D. The object is located at F		
E. The object is located between F and the mirror.		

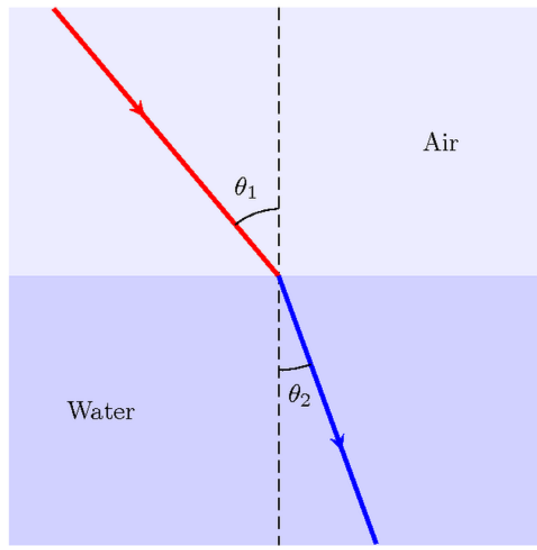
How Do You Measure the Index of Refraction in Water?

Description: Students will use glass and water to measure the indices of refraction.

Student Materials (per group):
- ☐ Semicircular Dish
- ☐ Water
- ☐ Glass plate
- ☐ Graph Paper
- ☐ Ruler
- ☐ Cardboard
- ☐ Pin

Additional Teacher Materials:
- ☐ None

Background and Misconceptions:



When light goes from one medium to another, it can bend or refract. Refraction is evidence that light can behave with wave-like properties. Pictured below, the wave represented by the red line will bend when the ray goes from air to water. Since water is more dense than the air, the ray will bend toward the dashed line, called the Normal. The normal is a line that is perpendicular at the point where the ray is striking the surface.

If you were to follow the ray in the opposite direction, going from the water into the air, the ray will bend away from the normal. Light will bend away from the normal when light goes from a more dense material into a less dense material.

If we measure the angle between the normal and the direction of the rays, we can use a formula for the index of refraction to find a value that represents the amount of bending. The value for the index of refraction is a is a dimensionless unit. Larger values indicate greater amounts of bending. The table shows some values of common substances.

$$\text{Index of Refraction} = \frac{\text{Sin}\,\vartheta_i}{\text{Sin}\,\vartheta_r}$$

ϑ_i = Angle of incidence.

ϑ_r = Angle of refraction.

Material	Index of Refraction (n)
Air	1.00
Water	1.33
Diamond	2.42
Human Lens	1.4
Crown Glass	1.5-1.75

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. How does light behave when it travels through glass?
2. Why do your legs look shorter when you are sitting on the edge of the pool dangling them in the water?
3. How can you use water or glass to bend light?
4. How can you measure the index of refraction of light?

Additional Hints:

- The curved dishes can be purchased at some science supply companies. Alternatively it is possible to purchase round clear dishes, cut them in half, and then glue a piece of Plexiglas on the open half to create a semicircular dish.
- This lab has been broken into two parts and will likely take at least 2 days to complete both parts. This lab requires careful measurement to obtain good results.

How Do You Measure the Index of Refraction in Water?
TEACHER ANSWER SHEET

Material	Angle of incidence (θ_I)	Sin θ_I	Angle of refraction (θ_I)	Sin θ_r	Index of refraction
Water	42	.67	30	.50	1.34

How Do You Measure the Index of Refraction in Glass?
TEACHER ANSWER SHEET

Material	Angle of incidence (θ_I)	Sin θ_I	Angle of refraction (θ_I)	Sin θ_r	Index of refraction
Glass	40	.64	25	.42	1.52 (glass type will affect this number)

Questions:

1. What happened to the light as it entered the water and glass? (Describe how it behaved with respect to the normal line.)

   The light bends toward the normal as it enters the water or glass and bends away as it leaves the glass.

2. Determine the percentage of error for your answer for the index of refraction for water to that accepted value which is 1.33. Explain what might have contributed to your error if you were off.

$$\text{Percentage Error} = \frac{|(\text{Your Value - Accepted Value})|}{\text{Accepted Value}} x100\%$$

   Students' answers should be less than 10% error.

3. You hold a flash light and shine it on the flat side of the curved dish. What happens to the light after it passes through the dish. (Does it spread out, come to a point, etc.?)

   It will spread out.

4. Why is it important that we know how much light bends as it goes through different materials? What are some applications of refraction in everyday life?

   One important application is for making lenses for people. By knowing the index of refraction for various substances the design of eyeglasses can be changed or lightened. Glass and plastics bend light differently and new materials can be created to cause light to bend more or less while making the eyeglasses lighter.

How Do You Measure the Index of Refraction in Water?

Name ____ **Date** ____________________

Description: You may often sit on the edge of a pool and dangle your feet in the water. When you look at your feet and legs in the water, they look distorted. This effect is caused by REFRACTION. Refraction of a wave occurs when a light ray enters a material of different density. As it passes from one medium to the other, the light ray bends, or refracts. While it is interesting to see your legs shorter and fatter than they actually are, this effect is also important for making corrective glasses, contact lenses, and telescopes.

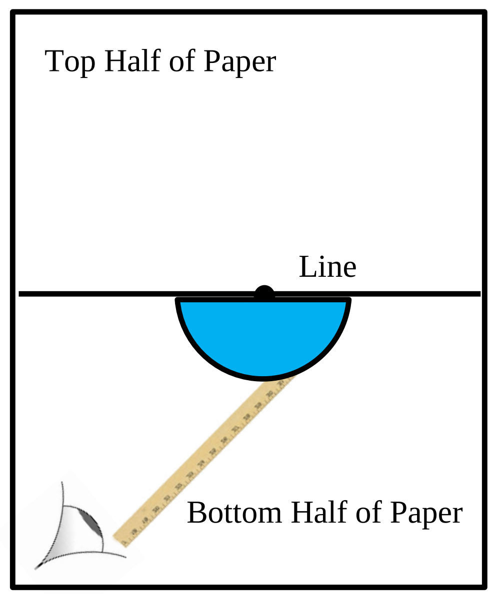
Knowing how much light bends is important and scientists have assigned numbers to the amount that light bends when it enters different media. These numbers start at 1.00 and increase. A number of 1.00 indicates air or a vacuum. Some materials are many times more dense than air and will bend the light more. Diamond, for example, bends light dramatically. These numbers are called the INDEX OF REFRACTION.

In this lab, you are going to determine the index of refraction for water and glass.

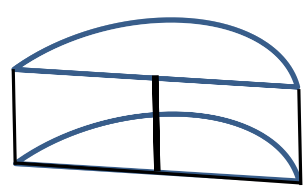
Materials: Semicircular Dish. Water Glass plate Graph Paper Ruler Cardboard Pin

Procedures, Lab 1:

1. Draw a line on the graph paper dividing the paper in half.

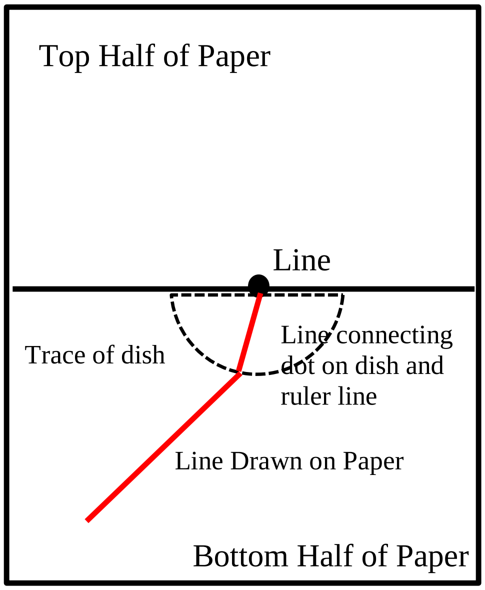


2. Make sure there is a line drawn on the curved edge of the dish. This line will be your object.
3. Place the edge of the dish along the straight line so that the dish is on the bottom half of the paper and trace the outline of the dish on the paper.
4. Mark the position of the object (the line) on your paper.
5. Lay a ruler on the bottom half of the paper. Adjust the position until the edge of the ruler seems to point at the object when you look through the water.
6. Draw a line along the ruler edge to the edge of the dish.
7. Repeat steps above but line up the ruler at a different position.
8. *THIS PICTURE SHOWS WHAT YOUR PAPER SHOULD LOOK LIKE AFTER YOU ARE FINISHED DRAWING THE LINES AND TRACING THE DISH.*



View from the Side

9. Remove the dish and connect the lines on the sheet with the object position.



10. At the point where the line is drawn on the flat surface, draw a line perpendicular to the surface. This is called the **normal**.

11. Measure the angle of the light to the normal in both the water (which is angle $\boldsymbol{\theta_r}$ in the table) and air (which is angle $\boldsymbol{\theta_I}$ in the table**)**.

12. Calculate the index of refraction for water using the formula below.

$$\text{Index of Refraction} = \frac{\text{Sin}\,\vartheta_i}{\text{Sin}\,\vartheta_r}$$

$\vartheta_i = \text{Angle of incidence.}$

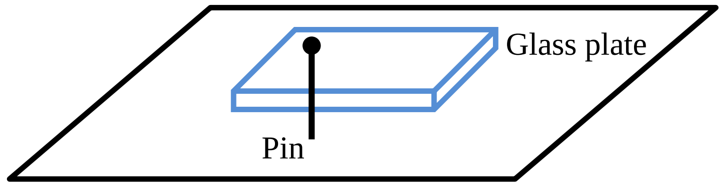
$\vartheta_{\text{r}} = \text{Angle of refraction.}$

The index of refraction tells us how much light will bend when it goes from one medium to another. The index of refraction for air is 1.00.

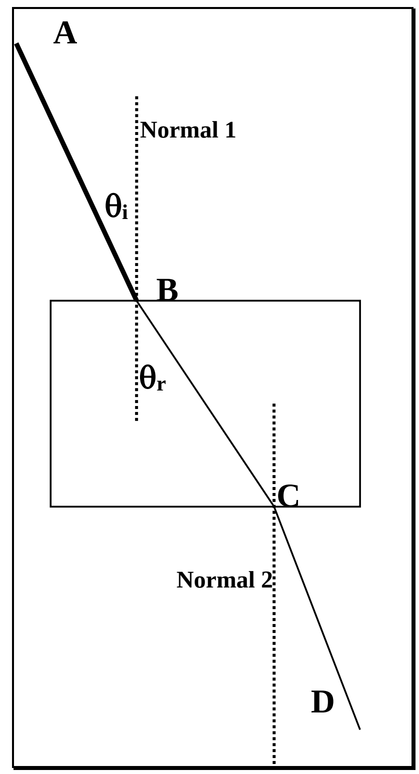
Material	Angle of incidence (θ_I)	Sin θ_I	Angle of refraction (θ_I)	Sin θ_r	Index of refraction
Water					

How Do You Measure the Index of Refraction in Glass?

1. Repeat the above steps but this time use a glass plate. You will use the pin as a way of looking through the glass for a reference. See the diagram.



2. Place the glass plate in the center of the paper. Trace an outline of the glass.



3. Remove the glass plate. Mark a point called **B**

4. From Point **B**, draw a line that is perpendicular to the glass plate and call this Normal 1.

5. Draw a line that is at a 30° angle from the normal and label the end of that line as **A**. The angle formed at is 30° is θ_I, the angle of incidence.

6. Replace the glass plate over the outline on the paper. With your eyes on a level with the table and end of the glass plate, look through the plate until you see the line **AB**. Use your ruler to line up the line AB so that it seems to continue the line through the glass. Draw this line and label it as **CD**.

7. Remove the glass plate and draw a line between the two lines that were drawn.

8. At point C, on the edge of where the paper draw another normal line, Normal 2.

9. Measure the angle formed between BC and Normal 1. This is the angle of refraction, θ_r. Record the value of this angle in the table below. Using the formulas, solve for the index of refraction.

$$\text{Index of Refraction} = \frac{\text{Sin}\,\vartheta_i}{\text{Sin}\,\vartheta_r}$$

ϑ_i = Angle of incidence.

ϑ_r = Angle of refraction.

The index of refraction tells us how much light will bend when it goes from one medium to another. The index of refraction for air is 1.00.

Material	Angle of incidence (θ_I)	Sin θ_I	Angle of refraction (θ_I)	Sin θ_r	Index of refraction
Glass					

Questions:

1. What happened to the light as it entered the water and glass? (Describe how it behaved with respect to the normal line.)

2. Determine the percentage of error for your answer for the index of refraction for water to that accepted value which is 1.33. Explain what might have contributed to your error if you were off.

$$\text{Percentage Error} = \frac{|(\text{Your Value - Accepted Value})|}{\text{Accepted Value}} \text{x}100\%$$

3. You hold a flash light and shine it on the flat side of the curved dish. What happens to the light after it passes through the dish. (Does it spread out, come to a point, etc.?)

4. Why is it important that we know how much light bends as it goes through different materials? What are some applications of refraction in everyday life?

What is the Diameter of the Sun?

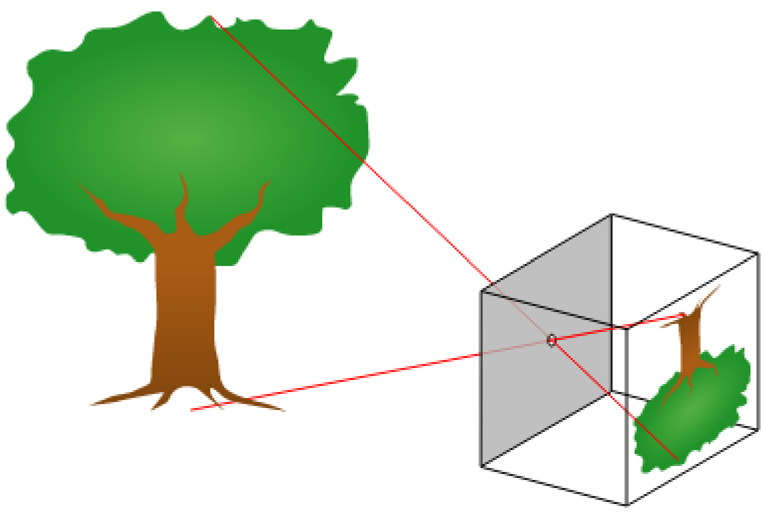
Description: Students will use a pinhole camera to determine the diameter of the sun.

Student Materials (per group):
- ☐ Aluminum foil
- ☐ Meter Stick
- ☐ Ruler
- ☐ Pin or small nail
- ☐ Paper

Additional Teacher Materials:
- ☐ None

Background and Misconceptions:

Pinhole cameras are constructed by making a small hole (about the size of small nail) in a piece of paper or cardboard. By doing so, the small hole intercepts only a very limited set of light rays, causing the pinhole to act as lens, focusing the light inside of a box or on a sheet of paper. Since the pinhole allows limited light to pass, the image is very dim. It is useful for indirect viewing of the sun. The image that is formed is smaller, inverted, and real.



Pinhole cameras are also known as Camera Obscura and are among the earliest types of cameras. The pinhole effect was first noted in China in the 5th century BC.

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. How can we safely examine the sun?
2. How can we measure the diameter of the sun?
3. How does a pinhole camera produce an image of the sun?

Additional Hints:

- The camera will work well outside but it is best if the sheet of paper is shaded so the image can be measured more accurately.

What is the Diameter of the Sun?
TEACHER ANSWER SHEET

Trial	Diameter of the sun's image (m)	Distance between the foil and paper (m)	Diameter of the sun	Percentage Difference
1	**.003**	**.32 m**	**1,400,000**	**.7%**

Questions:

1. The actual distance between the earth and sun varies from a minimum of 147,097,000 km to a maximum of 152,086,000 km. Recalculate the diameter of the sun using your distance between cards measurement and the minimum distance between the earth and sun in the formula.

Minimum value	Maximum value

   Student values will vary, but ensure they have calculated it correctly. It is highly likely that their value will be within the accepted values for the distances to the sun.

2. Does the accepted actual diameter of the sun fall between your calculations of the minimum value and maximum value? How do the calculations affect your estimation of the accuracy of your measurement as opposed to the percent difference you calculated above?

   Students may give yes or no answers, but they should back it with support from the data. It is likely that their value will fall between the accepted values so in this case the error may be 0. If so, check the internet to find the distance to the sun on the day of the experiment.

What is the Diameter of the Sun?

Name ____ **Date** ____________________

Description: Eratosthenes was the first to determine, in relative terms, the distance to the sun and the moon. But because of many assumptions he made, he inaccurately determined that the distance to the sun was 20 times greater than the distance to the moon. In reality, the sun is 400 times farther from the earth than the moon. At an average distance of 150,000,000 kilometers (93,000,000) the suns light requires a little over 8 minutes to reach earth. But how do astronomers determine how wide the sun is? Obviously, it is not possible to fly to the moon and measure it using a meter stick. But, we can use a meter stick without leaving earth to measure the diameter of the sun.

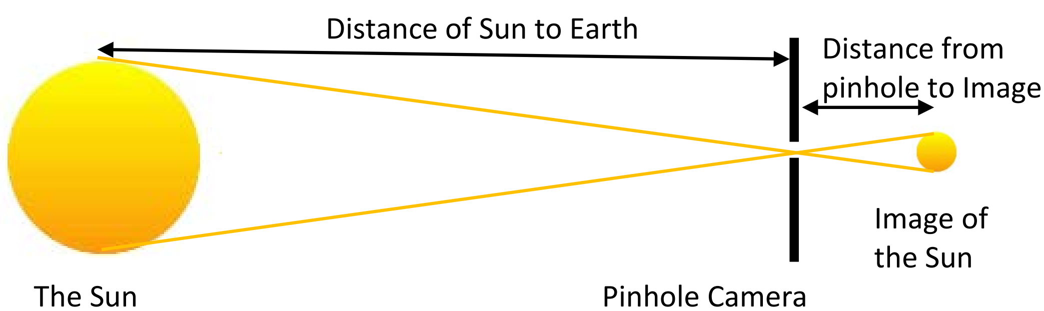
In this experiment, you are going to determine the diameter of the sun.

Materials: Aluminum foil Meter Stick Ruler Pin Paper

Procedure:

1. Using the pin, poke a small hole in the aluminum foil to create a pinhole camera. Make sure the diameter of the hole is as small and round as you can possible make it.

2. Hold the aluminum foil perpendicular to the light rays from the sun. Hold the foil so that a nice circular image of the sun is cast below it. See image.



3. Hold the paper underneath the foil, and try to hold it in the shadow of the foil. Create a nice circular image of the sun on the paper. While you hold it steady, carefully measure the diameter of the image of the sun. Record this value on the table below.

4. Without moving either card, also measure and record the distance between the foil and the paper. Record this in the table below.

5. Repeat the measurements for at least 4 different distances between the foil and paper.

6. Calculate the diameter of the sun by using the following formula:

$$\frac{\text{Diameter of sun (km)}}{\text{Distance to sun (km)}} = \frac{\text{Diameter of sun's image (m)}}{\text{Distance between foil and paper (m)}}$$

The distance from the Earth to the Sun is 150,000,000 km.

7. Determine the percentage difference between the calculated value and the actual value of 1,390,000 km.

$$\text{Percentage Difference} = \frac{|\text{Your value for diameter - Actual value}|}{\text{Actual value}} x100\%$$

Trial	Diameter of the sun's image (m)	Distance between the foil and paper (m)	Diameter of the sun	Percentage Difference
1				
2				
3				
4				

<u>Questions</u>:

1. The actual distance between the earth and sun varies from a minimum of 147,097,000 km to a maximum of 152,086,000 km. Recalculate the diameter of the sun using your distance between cards measurement and the minimum distance between the earth and sun in the formula.

Minimum value	Maximum value

2. Does the accepted actual diameter of the sun fall between your calculations of the minimum value and maximum value? How do the calculations affect your estimation of the accuracy of your measurement as opposed to the percent difference you calculated above?

How Do I Use Ray Diagrams to Predict How an Image Will Look?

Description: Students will create ray diagrams to predict the type of image formed.

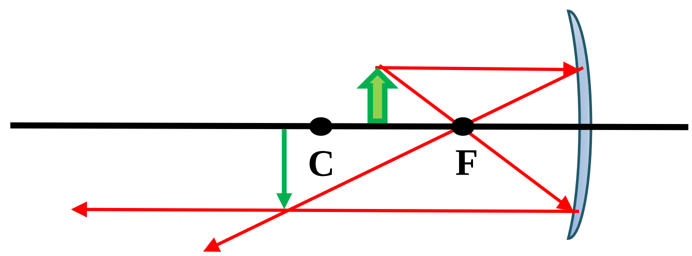
Student Materials (per group):
- ☐ Ray Diagrams Worksheet
- ☐ Ruler

Additional Teacher Materials:
- ☐ None

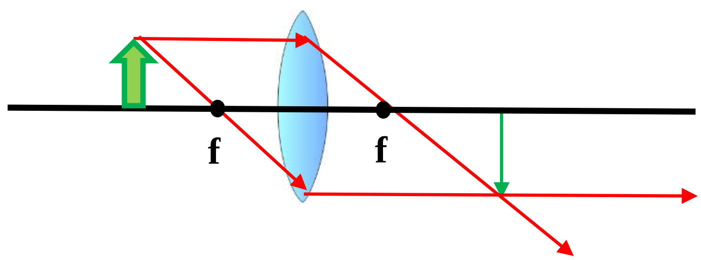
Background and Misconceptions:

Ray diagrams are used to find the positions of images with respect to objects for lenses and mirrors. There are some general rules to follow. In each case, draw 2 sets of lines that start with the top of the image. The bottom of the image must sit on the principal axis for this process to work correctly.

Mirrors:
1. Draw a line parallel to the principal axis
2. Reflect off the mirror.
3. Draw line through the focus.
4. Draw a second line through the focus.
5. Reflect off the mirror.
6. Draw line parallel to the principal axis.
7. Where the lines cross, draw the image.

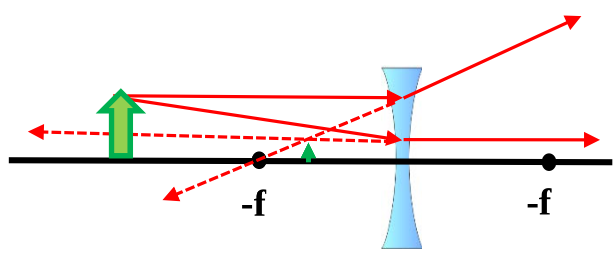


Lenses:
1. Draw a line parallel to the principal axis
2. At the lens, turn to line up with the focus.
3. Draw a line through the focus.
4. Draw a second line through the focus
5. Go through the lens
6. Draw line parallel to the principal axis.
7. Where the lines cross, draw the image.



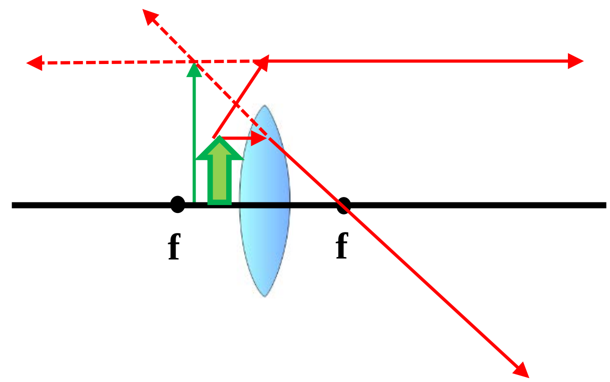
There are variations of this when using diverging lenses and mirrors or when the object is inside the focal point. See these types below.

Diverging Lens:
1. Draw a line parallel to the principal axis.
2. At the lens, the ray will go through the lens.
3. Direct the ray that goes through the lens along the same line as the focus that is on the same side as the object.
4. Draw the line going away from the left hand focus.
5. Draw a second line that is aimed for the focus on the right side.
6. At the lens stop and turn.
7. Direct the ray so it parallel to the principal axix.
8. On each divergent rays, draw dotted lines backwards until they each cross.
9. Where the lines cross, draw the image.



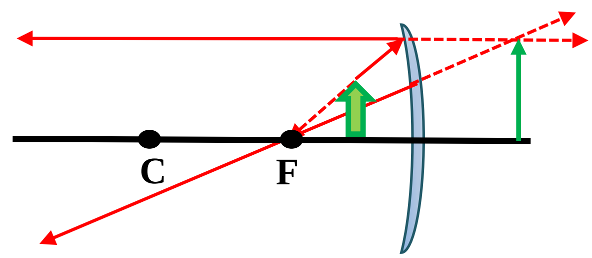
Converging Lens, inside focus:

1. Draw a line parallel to the principal axis.
2. At the lens, stop and turn.
3. Draw a line through the focus.
4. Draw a second line toward the lens that is lined up with the focus on the left side, but going away from it.
5. At the lens, stop and turn.
6. Draw a line parallel to the principal axis.
7. On each divergent rays, draw dotted lines backwards until they each cross.
8. Where the lines cross, draw the image.



Converging Mirror, inside focus

1. Draw a line parallel to the principal axis.
2. Reflect off the mirror.
3. Draw a line through the focus.
4. Draw a second line toward the mirror that is lined up with the focus, but going away from it.
5. Reflect off the mirror.
6. Draw a line parallel to the principal axis.
7. On each divergent rays, draw dotted lines backwards until they each cross.
8. Where the lines cross, draw the image.



Teacher Guided Questions to Inquiry: ***Use these questions to get the students started on their own inquiry!***

1. How can ray diagrams be used to predict the size, orientation, and type of image that is formed.

Additional Hints:

- No additional hints

How Do I Use Ray Diagrams to Predict How an Image Will Look?

Name ____ **Date** ____________________

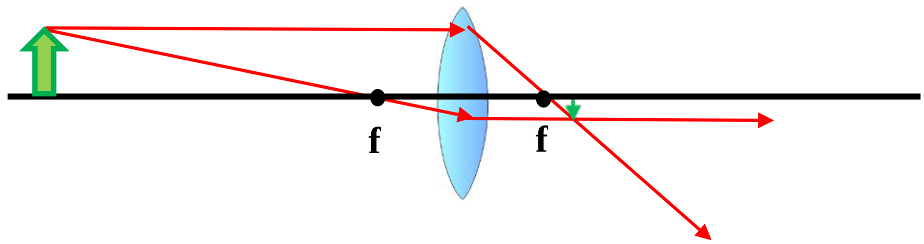
Directions: Draw the ray diagrams for the lenses and mirrors and provide information about the image.

Type: **Real**

Orientation: **Inverted**

Size: **Smaller**

Position, relative to f and 2f **:** **Between f and 2f**

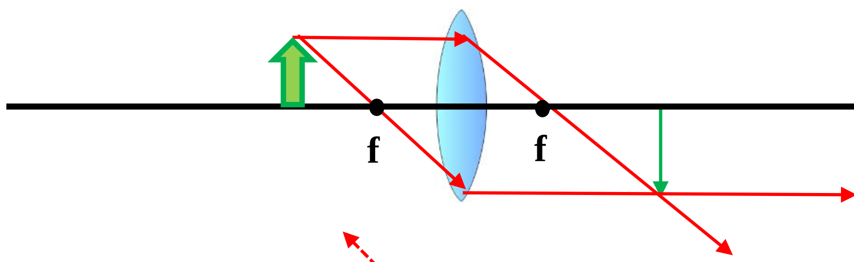


Type: **Real**

Orientation: **Inverted**

Size: **Larger**

Position, relative to f and 2f : **Beyond 2f**

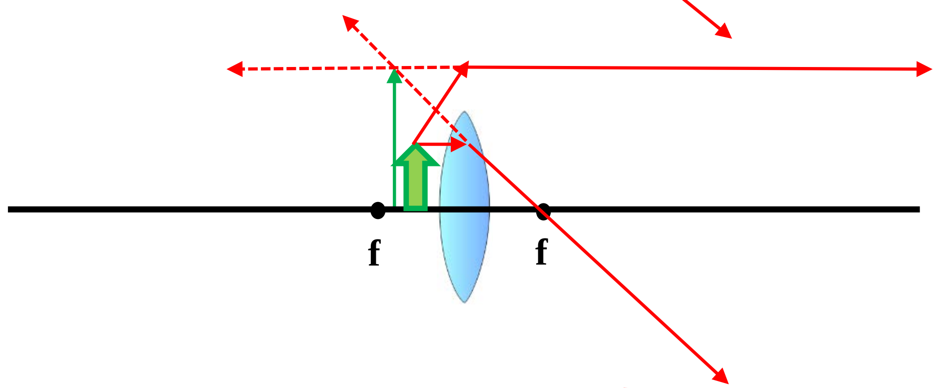


Type: **Virtual**

Orientation: **Erect**

Size: **Larger**

Position, relative to f and 2f : **Between f and lens.**

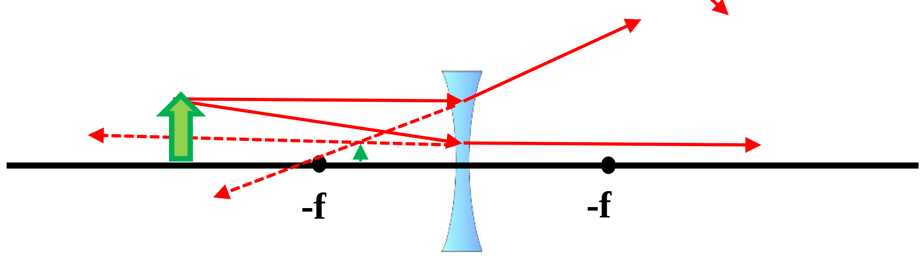


Type: **Virtual**

Orientation: **Erect**

Size: **Smaller**

Position, relative to f and 2f : **Between f and 2f**

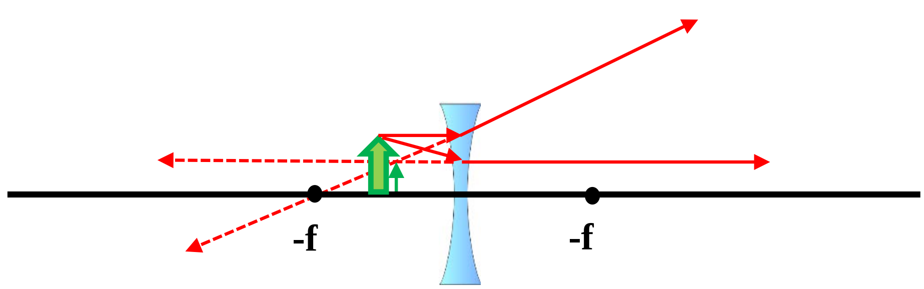


Type: **Virtual**

Orientation: **Erect**

Size: **Smaller**

Position, relative to f and 2f : **Between f and 2f**

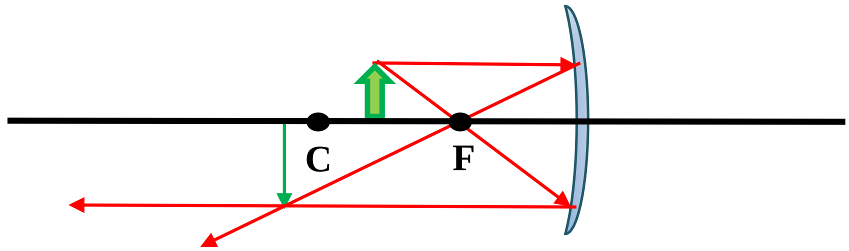


Type: **Real**

Orientation: **Inverted**

Size: **Larger**

Position, relative to f and C : **Beyond C**

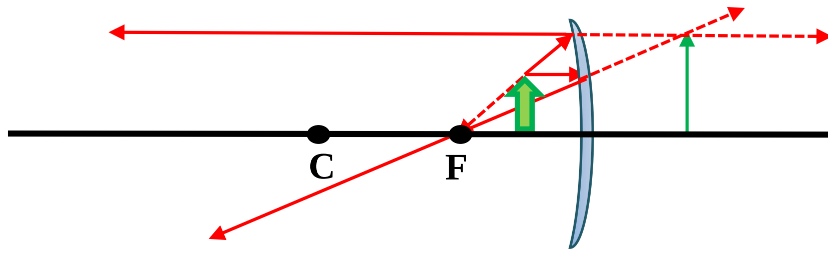


Type: **Virtual**

Orientation: **Erect**

Size: **Larger**

Position, relative to f and C : **Between –f and mirror (-f is “inside” the mirror)**

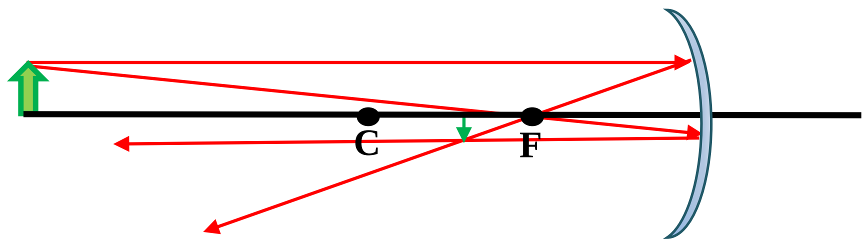


Type: **Real**

Orientation: **Inverted**

Size: **Smaller**

Position, relative to f and C : **Between f and C**

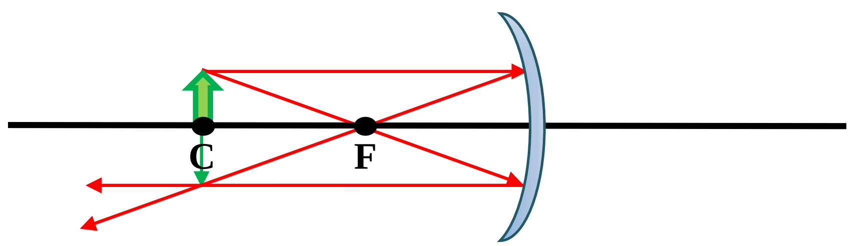


Type: **Real**

Orientation: **Inverted**

Size: **Same size**

Position, relative to f and C : **At C**

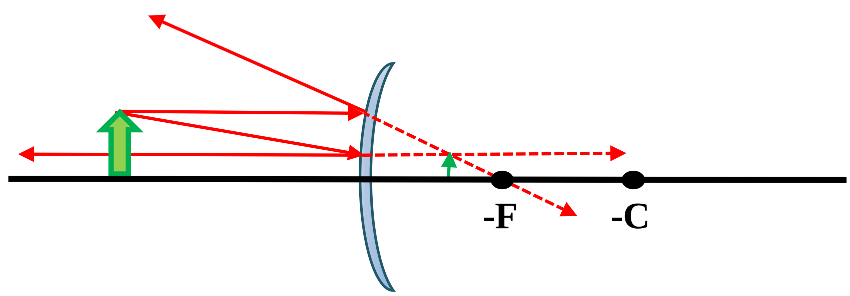


Type: **Virtual**

Orientation: **Erect**

Size: **Smaller**

Position, relative to f and C : **Between –f and mirror.**



How Do I Use Ray Diagrams to Predict How an Image Will Look?

Name ______________________________ Date ______________

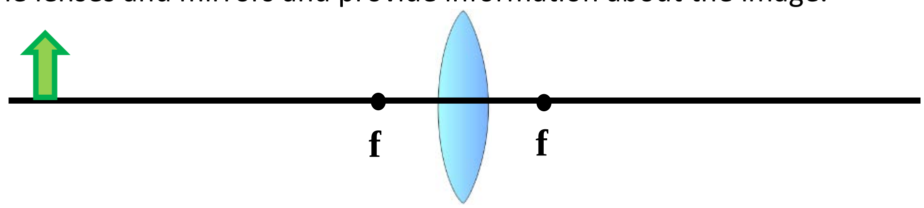
Directions: Draw the ray diagrams for the lenses and mirrors and provide information about the image.

Type:

Orientation:

Size:

Position, relative to f and 2f :

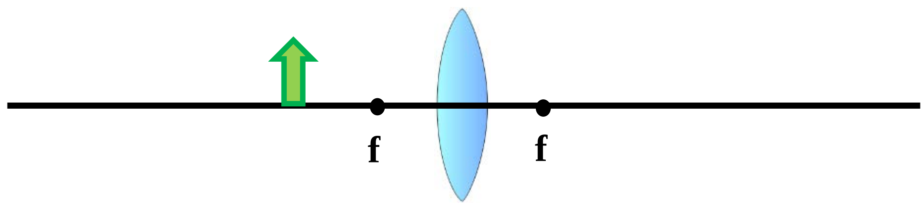


Type:

Orientation:

Size:

Position, relative to f and 2f :

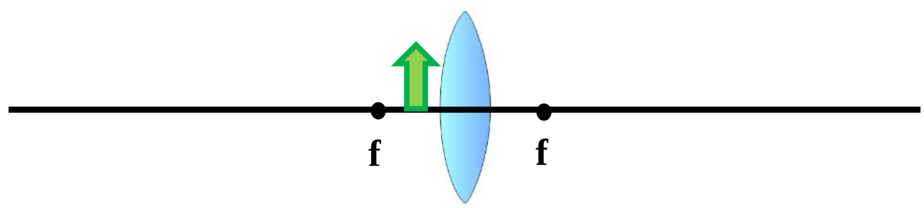


Type:

Orientation:

Size:

Position, relative to f and 2f :

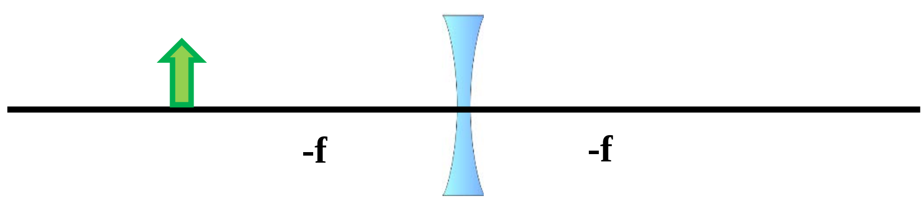


Type:

Orientation:

Size:

Position, relative to f and 2f :

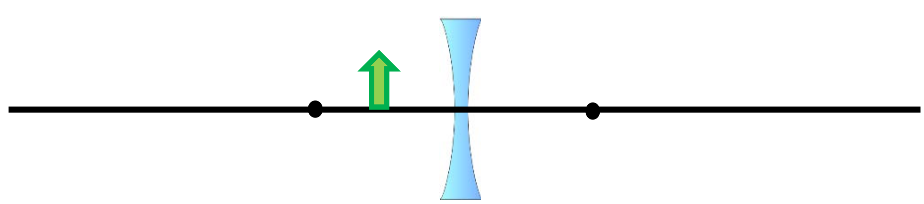


Type:

Orientation:

Size:

Position, relative to f and 2f :

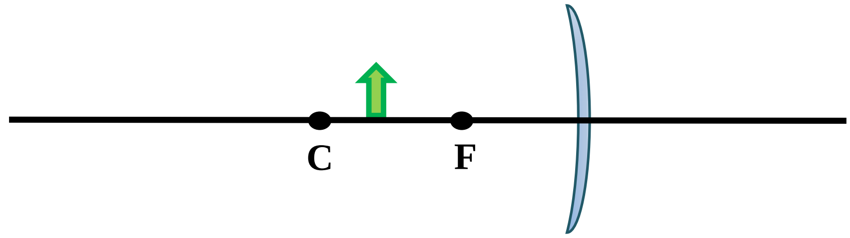


Type:

Orientation:

Size:

Position, relative to f and C :

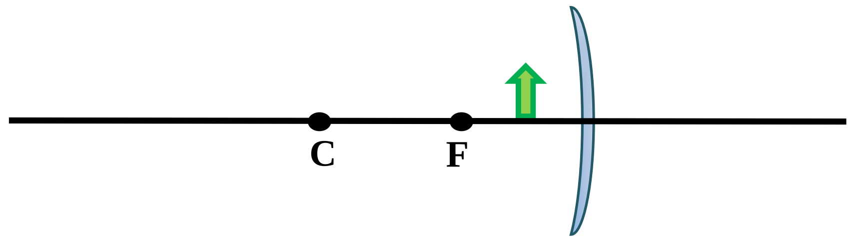


Type:

Orientation:

Size:

Position, relative to f and C :

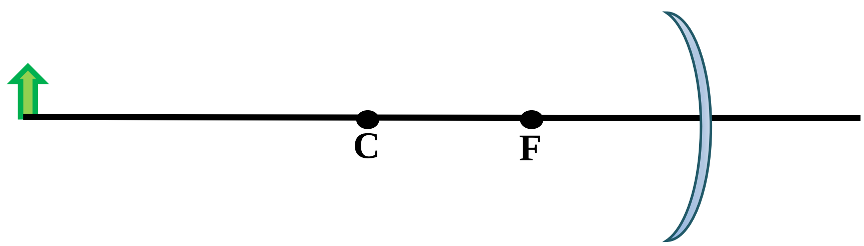


Type:

Orientation:

Size:

Position, relative to f and C :

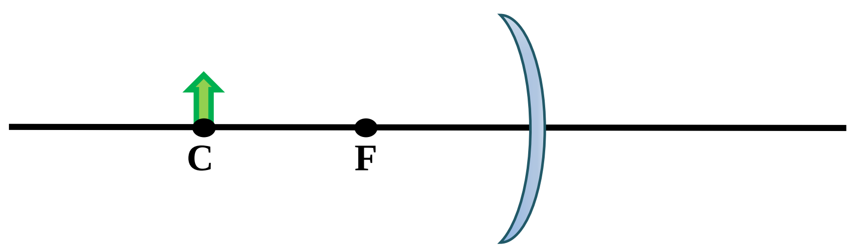


Type:

Orientation:

Size:

Position, relative to f and C :

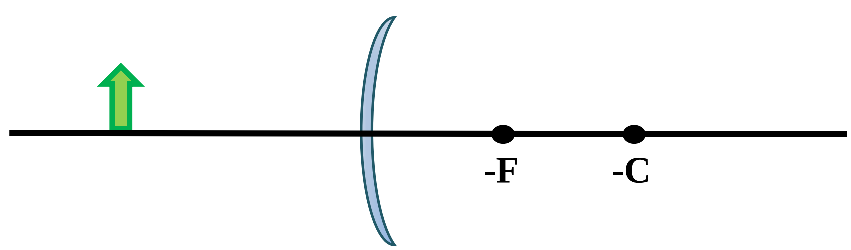


Type:

Orientation:

Size:

Position, relative to f and C :



How Do Bubbles Show Colors?

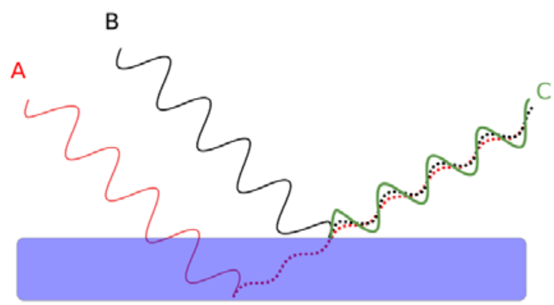
Description: Students will give the colors they see in bubbles.

Student Materials (per group):
- ☐ Bubble solution
- ☐ Wand

Additional Teacher Materials:
- ☐ None

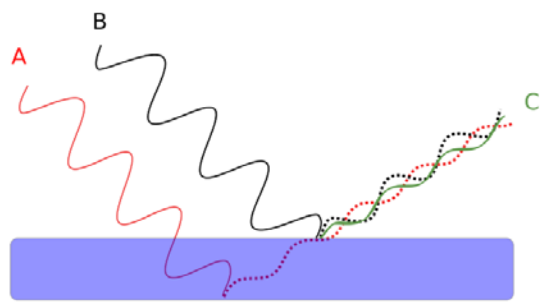
Background and Misconceptions:

A soap bubble is called a thin film. While it may be thin, it is still think enough for light to reflect off 2 surfaces as light travels through the film. One is the front surface of the film, where the light goes from air to bubble. The other is the inside surface where the light goes from bubble back to air. This effect can be seen in windows at night where there are double images.



When white light strikes the soap film, some light is reflected immediately (Ray B) from the front surface and some light will travel through the bubble and then reflect off the back surface (Ray A). When the back surface light reflects it can join up with the light from the front surface and interfere with each other.

If the interference is constructive, meaning that the peaks and troughs of the waves are in sync with each other, they can combine to produce different colors. And the colors produced depend on the thickness of the film. At greater thicknesses, you see more red, blue, and green streaks of color. But as the bubble starts to dry out at its thickness decreases, red disappears first, then the yellow fades, followed by green and blue. If it is thin enough, the bubble will be clear and no colors can be seen. Colors seen in the bubble are dependent on the thickness of the bubble.



Images Credit: Jhbdel/Wikipedia

There are locations where you will see no colors. This is caused by destructive interference. Two reflected waves are out of sync with each other, with the trough of one wave lining up with the crest of second wave. The two waves cancel each other out so no colors are seen.

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. What do you think causes colors in bubbles?
2. What colors do you see in bubbles?
3. Do the bubbles you see change over time?

Additional Hints:

- As an extension, the bubbles can be viewed under different colors of light or through colored filters.
- Use high quality soap bubble or add glycerin to extend the length of time the bubbles exist.

How Do Bubbles Show Colors?
TEACHER ANSWER SHEET

Procedures:

1. Using the bubble solution, make bubbles and observe. In the table below, make your observations under the following conditions.

What colors do you see when you blow bubbles?
Many different colors: red, blue, green, yellow.
When you initially blow a bubble, what color do you mostly see?
Lots of blue and green, with some yellow and red.
Wait a while and watch. How do the colors change? What colors do you see?
The red disappears and then the yellow disappears.
Watch the colors until just before the bubble breaks. What are the colors now?
It can be clear with no color or just the blue is left. This depends on the when the bubble will break.
How do you think the colors are being produced?
Take student answers. If this experiment is conducted as an inquiry lab, they will not likely guess the correct answer that is shown in the background information.

How Do Bubbles Show Colors?

Name ______________________________ **Date** ____________________

<u>Description:</u> Bubbles are thin films that cause white light to interfere with itself. When this happens, different colors are produced. In this experiment you are going to examine the different colors you see in bubbles and when you see the colors.

<u>Materials:</u> Bubble Solution Paper Towels

<u>Procedures:</u>

1. Using the bubble solution, make bubbles and observe. In the table below, make your observations under the following conditions.

What colors do you see when you blow bubbles?
When you initially blow a bubble, what color do you mostly see?
Wait a while and watch. How do the colors change? What colors do you see?

Watch the colors until just before the bubble breaks. What are the colors now?
How do you think the colors are being produced?

Is Light a Wave or a Particle?

Description: Students will conduct experiments to examine the dual nature of light.

Student Materials (per group):
- ☐ White Construction Paper
- ☐ Black Construction Paper
- ☐ Bendable Gooseneck Desk Lamp
- ☐ Triangular Prism

Additional Teacher Materials:
- ☐ Light Sensitive Paper

Background and Misconceptions:

A wave is a vibration that moves through solid objects: water, air, and the ground. We see them every time we drop a pebble in a pond. Waves ripple outward. When we speak sound waves vibrate the air in front of us and travel outwards to another person. Waves have several properties. Waves can reflect, transmit, and deflect.

When you speak loudly in an empty room you can hear an echo as the wave from your voice bounces off the wall and continues to reflect off of other walls multiple times creating the echo effect. The same wave can be heard through the wall but it sounds very faint. A portion of the wave is reflected producing the echo we hear, but a portion of the wave is transmitted through the wall and can be heard by another person standing on the other side of the wall.

A wave can also deflect from its path of travel. Normally waves travel in straight lines but when it encounters an obstacle it can bend around the obstacle.

Light can behave as a wave in some cases. It bends when it travels from air into glass. How much it bends depends on the color of the light. Each color has a frequency associated with it. Red is the lowest frequency and blue is the highest frequency, with higher frequencies more energetic.

Particles exhibit behavior much like a bouncing ball. They collide and rebound like billiard balls. But light is a very special particle. It doesn't have a rest mass. In other words, when a particle is motionless, its weight can be measured. However, light doesn't come to a stop so it does not have rest mass. Instead light has a special ability. It can be absorbed. When light encounters other particles it gets absorbed and at the same time light particles can be ejected from other particles. This is called the photoelectric effect.

A light particle is called a photon. Photons always move at the speed of light until absorbed by an object. The speed of light is very fast. It is the fast thing in the universe.

When an object absorbs a photon it gains energy from the particle. That energy can cause different effects in the material. If an electron absorbs a photon with the right amount of energy it can be ejected from an atom.

Teacher Guided Questions to Inquiry: *Use these questions to get the students started on their own inquiry!*

1. Why is the sky blue?
2. Why does a rainbow appear mostly after it rains?
3. Why does standing in direct Sunlight feel warmer than standing in the shade?
4. Why is the ground warmer in the Sunlight than in the shade?

Additional Hints:

- Light sensitive paper can be purchased online or in many craft stores. Make sure that the container remains sealed at all times to prevent exposure from light.

Is Light a Wave or a Particle?
TEACHER ANSWER SHEET

Questions: Part I

1. As the initial beam of light passes through the prism, does it make a straight line or does it bend?
   The light beam will bend and the colors will separate.
2. How many colors do you see on the target? What are the colors?
   There will be each color of the rainbow separated in order from red to violet. (red, yellow, green, blue, violet)
3. How many colors do you see from the lamp? How many colors are in the beam from the lamp?
   Only white light comes from the lamp. But white light has all the colors in it blended together to create white light. Every time we see white light it is the mixing of all colors.
4. Are the number of colors on the target the same number of colors coming from the lamp?
   Yes, the white light beam is simply being split into all its various colors. If the colors were recombined using a lens then it would make a white light beam again.
5. Explain why you think the number of colors is different or explain why you think the number of colors is the same.
   The students may think the number of colors is different since only white light is visible going into the prism and many colors are seen leaving the prism. If they say the white light is only one color this is okay. Let them know the white light is all the colors blending to make white light.
6. Is this behavior of the light a wave-like property or a particle like property?
   This behavior exhibits the wave-like properties of light because it bends as it passes through a medium that is denser than air.

Questions: Part II

1. When the paper was exposed to the light what happened to the paper?
   The paper absorbs the light and reacts to the light. The paper will leave a bleach pattern wherever it is exposed to the light.
2. Do you think the paper changed because it absorbed the light?
   The paper changes because it reacts by absorbing the photon. Absorbing the light / photons allows it to chemically react and lighten.
3. If the paper absorbed the light would this be the particle behavior of light or the wave behavior of light?
   The absorption of light is related to radiation properties of light interacting with matter. For the light to be absorbed it has to be viewed by its properties as a photon. The electrons in the material absorb the photons and react.
4. What effect did Einstein win the Nobel Prize in Physics for in 1905?
   Einstein won the Nobel Prize in Physics in 1905 for the Photoelectric Effect which proved the particle-like properties of light as it interacted with electrons.

Is Light a Wave or a Particle?

Name ____ **Date** ____________________

Description:

While we all know what light is but the nature of light is a different thing. Scientists know that light has both wavelike and particle-like characteristics. When light travels through narrow openings, it diffracts, or spreads out. This is a wavelike behavior. At other times, it acts like a particle. Light shining on a solar cell, converting radiant energy into electrical energy, is evidence that light is a particle. The particle form of light is called a PHOTON. In this experiment, you are going to conduct experiments that demonstrate the wavelike and particle-like behavior of light.

Materials:

- White Construction Paper
- Black Construction Paper
- Light Sensitive Paper
- Bendable Gooseneck Desk Lamp
- Triangular Prism

Procedures:

1. Testing the wave properties of light:
   a. Fold a piece of white construction paper in half.
   b. Cut a thin slit along the folded edge from the center down to one edge. This piece will be the light filter to narrow the lamp beam.
   c. Using another piece of white construction paper in half, fold one edge in one inch deep and fold the opposite edge out one inch deep. This piece of paper will stand upright to function as the target for the light beam.
   d. Refer to the diagram for help with the setup:
      i. The desk lamp will be brought as low to the desk as possible but allowing a little bit of light to come out on one side.
      ii. The filter, the paper with the slit cut in it, will be opened enough to stand on its edge and set in front of the lamp as close it as possible without touching the bulb.
      iii. The prism is the next piece of equipment and will be placed about six to twelve inches from the filter.
      iv. The target, the paper with the folded edges, will stand on its edge in six to twelve inches from the other side of the filter and the lamp.

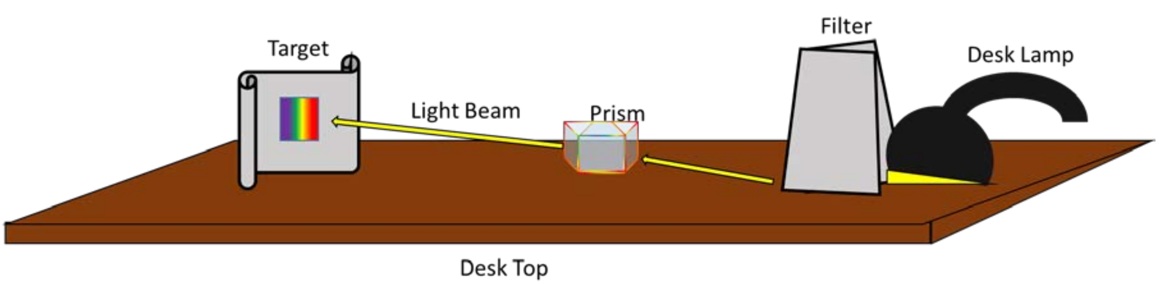


Figure 0.1 Diagram of the set up for part 1 of the experiment.

   e. Turn out the classroom lights to minimize the light pollution.
   f. Adjust the prism so that the face of the prism pointing toward the light source is perpendicular to the light beam.
   g. Now adjust the target so that the light beam passing through the prism is perpendicular to the beam.
   h. Observe the results and as the questions for part 1.

2. Testing the particle properties of light:
    a. Using the black construction paper cut out a design you like such as a snow flake, a star, a tree, your name, or something creative.
    b. Read the directions on the light sensitive paper.
    c. Turn out the classroom lights then open your light sensitive paper.
    d. Place your design on the light sensitive paper on your desk.
    e. Now, once everyone is ready, turn on the lights.
    f. Wait a few minutes.
    g. Turn off the lights.
    h. Finish processing the light sensitive paper according to the instructions.

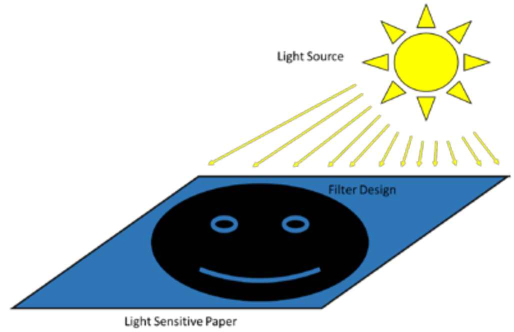


Figure 2 The light sensitive paper with personally designed filter being exposed to the light source.

Questions: Part I

1. As the initial beam of light passes through the prism, does it make a straight line or does it bend?

2. How many colors do you see on the target? What are the colors?

3. How many colors do you see from the lamp? How many colors are in the beam from the lamp?

4. Is the number of colors on the target the same number of colors coming from the lamp?

5. Explain why you think the number of colors is different or explain why you think the number of colors is the same.

6. Is this a behavior of the light a wave-like property or a particle like property?

Questions: Part II

1. When the paper was exposed to the light what happened to the paper?

2. Do you think the paper changed because it absorbed the light?

3. If the paper absorbed the light would this be the particle behavior of light or the wave behavior of light?

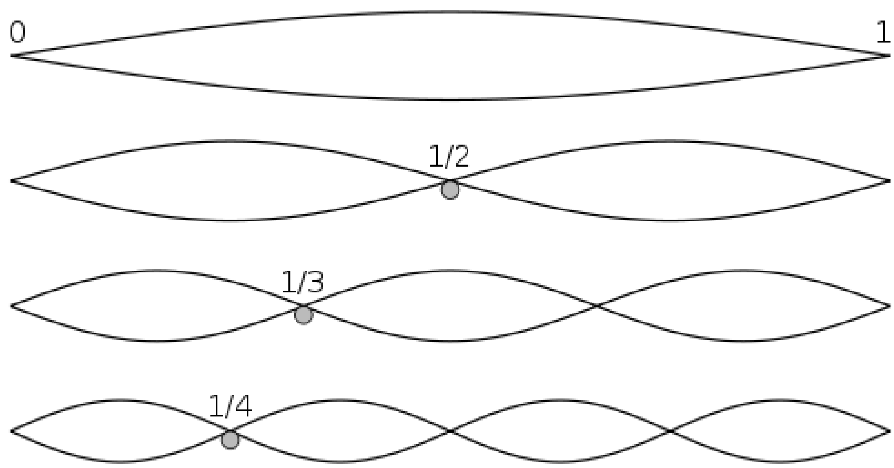
4. What effect did Einstein win the Nobel Prize in Physics for in 1905?

Demo: Standing Waves

Materials: Slinky 2 Volunteers

Procedures:

1. Stretch the slinky between 2 volunteers.
2. Designate 1 student as the "shaker" and the other student as the "holder".
3. Have the shaker move the slinky up and down until each of the wave patterns appear below.



Description:

Timed correctly, the shaker produces an outgoing wave that is in time with the wave reflected back from the holder. This causes an interference between the outgoing and reflected waves. When this occurs repeatedly in sync, there are points in which the wave does not move. This point is called the NODE. At the point where there is maximum displacement, there is an ANTINODE. The node is the point where the outbound and reflected waves undergo destructive interference. At the antinode, the waves undergo constructive interference. On the first wave above, which is ½ wavelength, there are two nodes (each at the hands of the volunteers) and one antinode.

As the number of nodes increase, the frequency of the wave increases and the wavelength decreases. The speed of the wave remains the same because the speed is dependent on the type of material and not on speed or height of the wave.

Questions:

1. How do you think this type of wave is produced?
2. What do you notice about how quickly the shaker is moving the slinky to produce different standing waves?
3. What do you think will happen if both volunteers try to make waves?
4. What is happening at the point where there is a node?
5. What is happening at the point where there is an antinode?

Notes:

It is best to use slinkies that are 2 times as long as the normal store purchased slinkies. Two metal slinkies can easily be connected to each other. It is also recommended that metal slinkies be used.

Demo: Photoelectric Effect and Fluorescence

Materials: Glow in the Dark Card or Stars, Red LED, Blue LED, Green LED

Procedures:

1. In a dark room, hold up a Glow in the Dark or Stars. These are made out of material that will glow green when exposed to light.
2. Shine a red LED onto the card. What is noticed?
3. Shine a green LED onto the card. What is noticed?
4. Shine a blue LED onto the card. What is noticed?
5. In each case, hold the red LED closer and further from the card. Notice any changes.

Description:

Light has a dual nature; it has both wave-like and particle-like properties. Light that shines through a diffraction grating, producing a spectrum is one example of wave-like behavior. It was the discovery by Heinrich Hertz in 1887 that was explained by Albert Einstein that light also had particle-like properties.

When light shines on a phosphorescent card, it will only glow when the light is above a given frequency (the material determines this frequency.) For example, when a red light shines on the card, it doesn't fluoresce. But when a blue or green light shines on the card, it begins to fluoresce. The wave-like properties could not explain this effect. It was only the discovery that light is made of particles with discrete amounts of energy that could explain it. Red light, no matter how bright, doesn't cause fluorescence. If light had ONLY wave-like behavior, the card should start to fluoresce in brighter light, *but it never does*. The red light does not have enough energy to cause fluorescence.

Both Hertz and Einstein discovered the Photoelectric Effect. When light shines on phosphorescent materials, specific frequencies (and therefore energies) of light can cause electrons around an atom to gain energy. This elevates the electron to a higher energy state. However, the electron cannot remain in this elevated energy state, so it quickly returns to its ground state. When this happens, it releases energy in the form of a photon. The light is shifted to a lower wavelength (toward the red end of the spectrum.) The electrons require specific amounts of energy to be lifted to higher energy states. In the case of the card used in this demonstration, red light does not have enough energy to eject the electron.

In the demonstration, the intensity of the light can be altered by bringing the red LED closer to the card.

Questions:

1. If light were a wave, what would you expect to happen as brighter light shines on the card?
2. After seeing the effect of the red, blue, and green lights on the card, what can you say about the nature of light? Does it make sense that it is a particle or a wave?
3. Given your observations, which color of light in the visible spectrum is the most energetic?

Notes:

Purchase glow in the dark cards or stars online at science supply companies. Check the quality of the cards or stars prior to conducting this experiment.

Demo: Water Fiber Optics

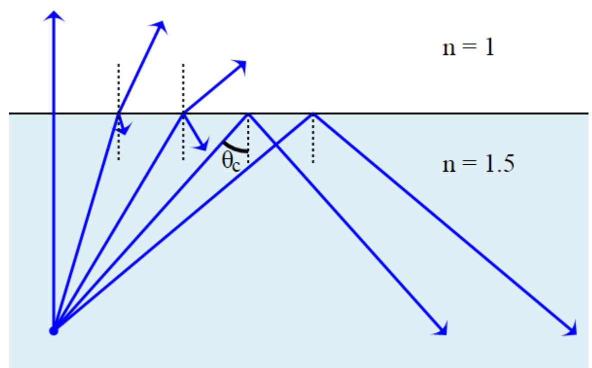
Materials:	2 Liter Bottle	Water	20 Penny Nail	Heat Source
	Laser or Flashlight	Plastic Box	Tongs	Stand

Procedures:

1. Prepare the 2-liter bottle by punching a smooth hole in one side, half way down from the top. Use a heat source such as a Bunsen burner or hair dryer to heat the nail. Use tongs to hold the nail while heating.
2. When it is sufficiently hot, use the nail to melt a smooth hole in the bottle.
3. Set the bottle on a stand so it is elevated for the students to see.
4. Fill the bottle with water and cap. This will prevent the water from flowing out of the hole.
5. On the side opposite the hole, aim a laser or LED light through the bottle to the hole.
6. Open the cap slightly, so water will flow out smoothly and into the Plastic Box.
7. Put your finger in the water stream to show that the light is flowing through the water.

Description:

When light travels from a more dense medium, such as water, to a less dense medium it bends away from an imaginary line that is drawn perpendicular to the surface at the point where the light ray intersects. This line is called the Normal (represented by the dotted line.) As the angle of a light ray increases, the refracted ray also increases, until it reaches a point where all the light is reflected back into the water. This is called Total Internal Reflection and effectively, the light ray is reflecting off the air and back into the water. Total Internal Reflection allows fiber optics to function. The cables are made of very thin fibers of glass through which laser light shines, carrying information. The light stays in the glass fiber, even when the fiber is bent.



Credit: Lasse Havelund

When light shines through the bottle into water, the light follows the path of the water. The light bounces off the air, back into the water, demonstrating total internal reflection. When you put your finger in the stream, you see your finger illuminated. You might notice this effect in water fountains, where the light follows the stream until the water breaks up into droplets.

Questions:

1. What do you notice happening to the light in the stream of water?
2. Does a laser light or regular flashlight change how the light behaves in the stream?
3. What do you think is causing the light to act this way?
4. What can be some uses for this phenomenon?

Notes:

When you punch the hole with the hot nail, use caution. Make sure the hole is smooth and round so the water flows as a smooth stream.

Demo: Laser Eye Checks

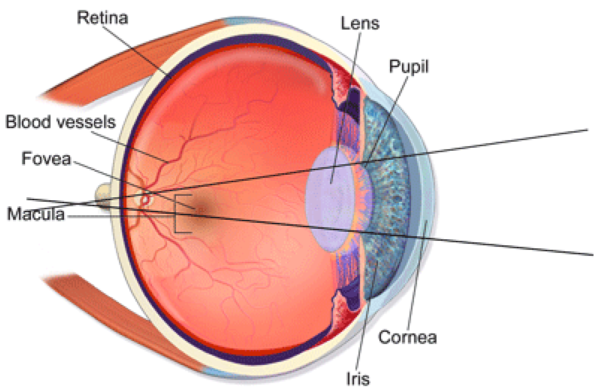
Materials: Laser Lens 2 Ring Stands 2 Clamps

Procedures:

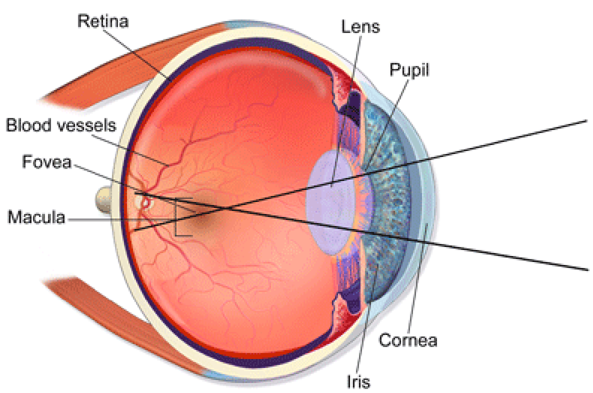
1. Place the lens and laser into the clamps on ring stands. Align the laser to point to through the lens.
2. Shine the laser spot on a distant wall so a speckled or spotted pattern appears.
3. Look at the speckled pattern on the wall (DO NOT LOOK DIRECTLY INTO THE LASER BEAM.)
4. Watch the pattern and then turn your head back and forth. Watch the direction that the spots move.
5. If the spots move in the same direction you are turning your head, you are either farsighted or normal. If they move in the direction opposite you turn your head, you are nearsighted.

Description:

When the laser light shines through the lens, it appears as a grainy specular pattern. This is a very complex interference pattern caused by the lens in our own eyes as the light is focused on our retina.



Farsighted Eye



Nearsighted Eye

In normal eyes, the light that passes through the lens focuses onto the retina. When you turn your head back and forth, the speckles travel in the direction of your head. (In perfect eyes, a person may not even see these speckles.)

In farsighted eyes, the light focuses behind the retina. As a result of this, when you move your head to the left, the speckles also move to the left.

In a nearsighted eye, the light focuses in front of the retina. This causes the speckles to shift to the right when you move your head to the left and is a result of parallax. Parallax can be demonstrated by holding your index finger up. Close your left eye and look at your finger and its position with respect to the background. Now switch eyes, opening your right and closing your left. Notice that the position of your finger appears to move with respect to the background. When you switch from left to right eye, your finger moves from the right to the left.

Questions:

1. What do you notice happens to the speckled pattern when you turn your head?
2. What is your vision and does this test match it?

Notes:

Make sure students look only at the reflection of the laser light that shines on the wall and never directly into the beam. If the pattern is not sufficiently larger, use a diverging lens or converging lens with a shorter focal length.

Demo: Polarization and Stresses

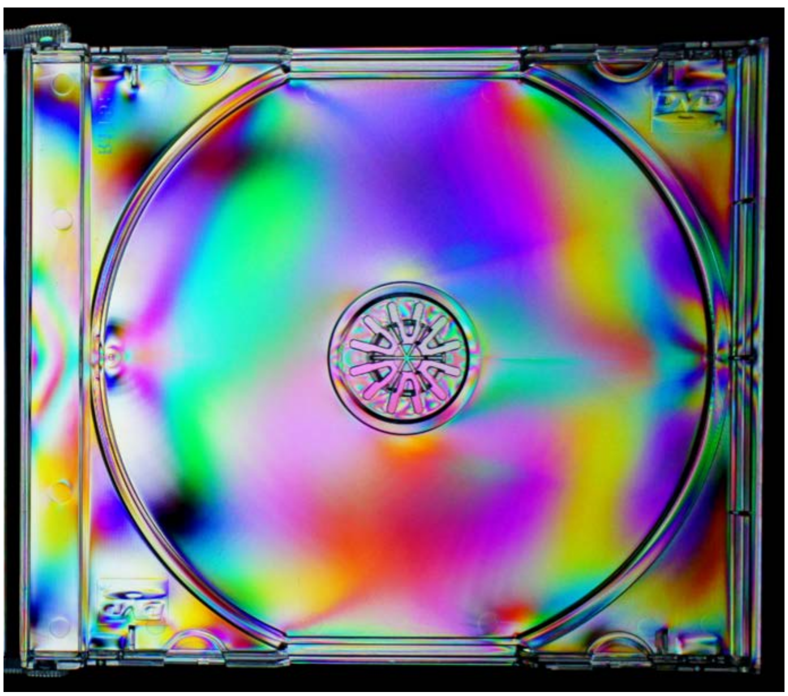
Materials: 2 Polarizing Filters Clear Plastic Items

Procedures:

1. Show a single filter in front of a light. Have students observe the brightness of the light through it.
2. Place another filter on top of the first, so their polarizations are parallel to each other. Show to students.
3. While holding one over the other, rotate on filter slowly by 90° and have students observe.
4. Now place a clear plastic object between them and observe as you rotate one filter. Have students observe.

Description:

As described in the activity “How do Polarizers Change the Light We See?” light that goes through a polarizer is oriented in specific direction, rather than in multiple directions. The filters can be used to see stresses in transparent materials. As the light travels through the polarizing filter and then through the plastic, the light starts to separate and becomes out of step with itself. Think of a marching band; the members are normally in sync with each other. But imagine if the left side of the band encounters a stretch of mud. That part of the band will fall behind the right side of the band, which is proceed on at normal speed. When the left side gets out of the mud, it is out of sync with the right side. The resulting new combination of the two sides will result in a new band structure. In the same way, light goes out of sync and when it emerges through the second filter, we see this in the various colors.



Credit: Wikipedia

The density of colors indicates stresses are present. Where there is a high degree of changing colors in a short space, there is high stress and this is a location where it is more likely to break. Squeezing or bending the plastic will alter the colors that are seen.

Questions:

1. What do you notice happens when two filters are overlapped and are turned with respect to each other?
2. What happens when the plastic object is placed between the two filters?
3. What does the density of colors tell you about the object?
4. Where can this process be useful?

Notes:

Filters can be obtained from science supply companies and in many commercial sunglasses. Plastic objects include overlapping pieces of tape on Plexiglas, a piece of plastic wrap (try stretching it under the filters while observing), plastic rulers, or protractors. Avoid plastic that is colored.

Demo: Plasma Ball Lighting

Materials: Plasma Ball Compact Fluorescent Light Bulb 2 Quarters

Procedures:

1. Turn on and have the students observe the pattern and the distribution of the filaments of glowing gas within the plasma ball.
2. Have a student touch the plasma ball and observe how the distribution of the gases changes.
3. Bring a compact fluorescent bulb near the plasma ball and have the students observe.
4. Place one quarter on top of plasma ball so it sits in contact with the glass.
5. Hold a second one above, and slowly bring the edge of the quarter close to the flat surface of the first that is sitting on the glass. You may even have to touch and then separate slowly. Sparks will appear between the two quarters.

Description:

The plasma ball is filled with gases, most often neon, but can include argon, xenon, and krypton. The small inner sphere is a Tesla Coil. It emits high frequency (by electricity standards, but not by standards of the electromagnetic spectrum), high voltage alternating current producing radio frequencies. When this energy passes into the gas, it excites the gas and causes it to glow. When you touch your hand to the plasma ball, you create a path of least resistance for the flow of the radio energy. You are acting as an antenna causing the energy to be directed to your finger. This causes a single larger filament to appear.

When a fluorescent light bulb is brought nearby, the radio frequency excites the gases inside, causing it to glow. While the globe seals in the gases, it can't seal in the radio energy. It is able to pass through the glass with ease.

When one quarter is brought near another quarter placed on the top of the plasma ball, a small spark is seen. This spark is similar to lighting in that it has sufficient energy to ionize the air, causing it to glow. Very high temperatures are needed to cause air to glow. Yet, due to the limited number of air molecules found within the spark, the heat output is still very low. Temperature is a measure of the average vibration of individual molecules, while heat is a measure of energy within a given mass of material. Also unlike lightning, which results from a buildup and quick release of energy, all in one direction, the spark is sustained because the current flows back and forth repeatedly.

Questions:

1. What evidence can you provide that energy is passing through the glass?
2. What causes the gases to glow inside the plasma ball?
3. How is the spark in the coin gap different from a static electricity spark or lightning?

Notes:

Use caution when demonstrating the spark between the coins to limit the duration to a few seconds at a time.

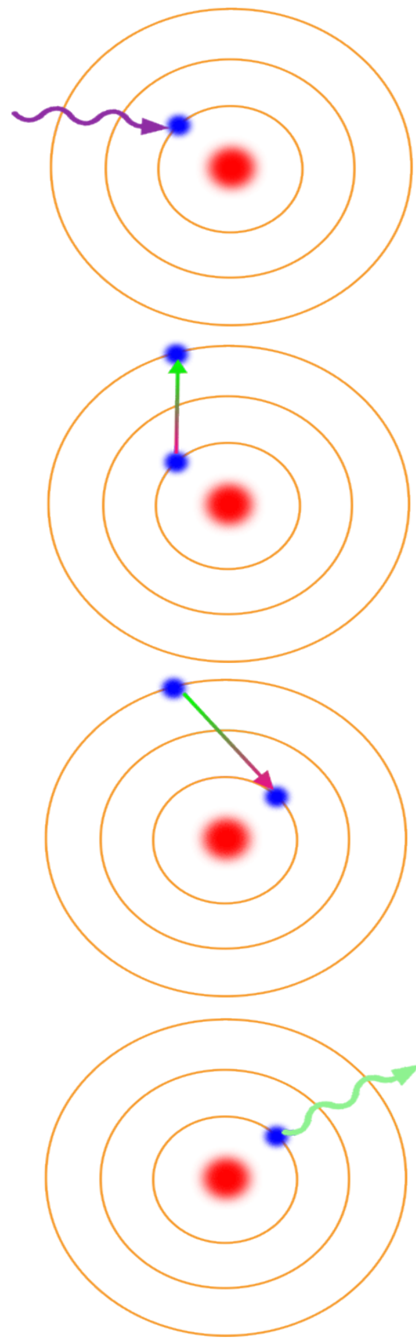
Demo: Ultraviolet Lighting

Materials:

	UV Light	Mr. Clean Cleaning Solution	Tonic Water with Quinine
	Calcite	Other fluorescent materials	

Procedures:

1. Examine each of the materials under the UV light.
2. Have students observe.



Description:

When ultraviolet light shines on certain types of materials they can be seen to glow in the dark or fluoresce. Fluorescence is a process by which light stimulates electrons, causing them to gain energy, jump into a different energy level, falling back to a lower energy level, and releasing a photon.

When ultraviolet light shines on Mr. Clean, the chemical absorbs the light. If the wavelength, and thereby the energy of the light is just right, the electron will jump to a higher energy level. It is not possible for the electron to jump to half way marks. It either has the energy to jump up one or two levels or it does not. When this occurs, the electron finds itself in an excited state. It cannot remain in this state. It must immediately return to its ground state.

Sometimes on its way to the ground state it jumps to a lower state. In either case, when it drops back down, it releases energy in the form of a photon. Depending on amount of energy released, the photon may be in the visible part of the spectrum. In the case of Mr. Clean, green light is given off. In all cases, the light given off is a lower wavelength than the light shining on it.

Questions:

1. What do you notice about the light that shines on the objects versus the light that is given off? Where do they appear on the EM Spectrum?
2. Is it accurate to stay that the UV light is being reflected by the minerals and solutions? Explain why.
3. After viewing this demonstration, describe the process of light emission using ultraviolet light.
4. How can this process be useful?

Notes:

There are some powders that glow in the dark and can be used as an activity to show the spread of disease. There are many minerals that will fluoresce. Earth space science teachers may already have these available.

Demo: Compare the Beams

Materials: Red Laser, White LED Flashlight, Diffraction Gratings, 1 Ring Stand, 2 clamps

Procedures:

1. Clamp the flashlight and the red laser to a ring stand.
2. Shine the flashlight and the red laser onto a far wall. Make sure students cannot accidentally look into the laser beam.
3. Have students compare the two beams in terms of the following:
    a. Beam Width
    b. Beam Color
    c. Spectrum (use the diffraction gratings, viewing each light source individually)

Description:

Laser light differs from normal light in several ways. The table below summarizes some important characteristics. The laser was conceptualized in 1957 by Charles Hard Townes and Arthur Leonard Schawlow and later the name was coined by a graduate student, Gordon Gould. In 1960, Theodore H. Maiman created the first operational laser. Laser stands for Light Amplification by Stimulated Emission of Radiation.

Lasers contain something, such as a gas, that is made to "lase." An electric current is used to energize the gas that results in the release of photons. These photons strike other excited atoms, causing them to emit additional photons of the same wavelength. The gas is in a chamber with mirrored ends. The photons bounce back and forth, striking more excited atoms and giving even off more photons. One of the mirrors is partially silvered so a bit of the light passes through, producing a beam of light. An excellent video of this process can be seen at https://www.youtube.com/watch?v=R_QOWbkc7UI . As a result of this process the light is coherent, meaning that all the waves are "marching" in sync with each other.

	Laser Light	**Normal Light**
Color	Monochromatic	Multiple colors
Waves	All waves in step and coherent	Out of phase with each other
Orientation	Waves are in parallel with each other	Waves are not parallel to each other
Energy	Far more energy per unit area.	Less energy per unit area.
Beam Spread	Maintains a tighter beam	Spreads out a great deal more.
Spectrum	See only 1 dot and 1 color	See all the colors of the rainbow

Questions:

1. View the laser and flashlight. How do they compare? How are they similar and different?
2. View the spectrum of each light. How do they compare? How are the similar and different?
3. How do you think the luminance of each spot compares to each other. Compare the dot of the laser to a similar sized area of the flashlight. Which is brighter, dot to dot?

Notes:

Ensure students do not look directly into the laser beam.

Demo: Colors in the Shadows

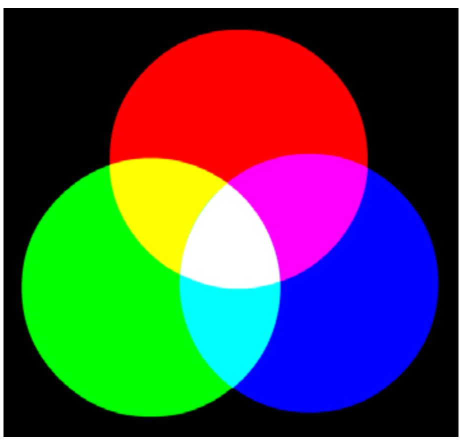
Materials: 3 Light Bulb Sockets with Bases — Red, Blue, Green Compact Fluorescent Bulbs — Large Index Card

Procedures:

1. Line up the light bulbs so they are equally distant from a white screen or wall.
2. Turn on all three bulbs. Have students notice the color of the blended light on the screen.
3. Hold the card in front of the light bulbs and have students observe the colors that appear in the shadows.
4. Turn off each light bulb, leaving the other two on, and progress through the following combinations to observe the colors: Red + Blue, Red + Green, Blue + Green.

Description:

The primary colors of light are red, blue, and green. Light combines using an additive process. We start with no light, then by combining red, blue, and green it is possible to produce white light and all the colors we see.



When added in equal proportions, Red and Green form Yellow light, Red and Blue form Magenta light, and Green and Blue form Cyan light. By varying the proportions, millions of colors are produced. When all three lights are turned on and a card is held up blocking some light, Yellow, Cyan, and Magenta can be seen in the shadows of the three light bulbs. The card is blocking one light (and if held close enough, it will block 2 or all 3.) For example, yellow is seen in the shadow of the blue bulb because the red and green light are mixing.

This demonstration can be used to correct the misconception that the primary colors of light are red, blue, and yellow. Students likely will know that primary colors can't be produced using a combination of other colors, so point out that yellow is produced by combining red and green. They should understand that yellow can't be a primary color of light (but it is a primary color of pigments.)

Questions:

1. How does this demonstration prove that yellow is not a primary color of light?
2. How can you change this demonstration to produce pink or orange light?
3. How can only three colors produce all the colors we see?

Notes:

It is best to use the compact fluorescent or LED bulbs. The colored incandescent bulbs, although much cheaper, produce colors that are not as pure so the results will not be as dramatic.

Demo: Pirate Eyepatches

Materials: Eyepatches Objects such as Balls, Books, or Pencils

Procedures:

1. Put on the eyepatch at the beginning of class. Make sure it is comfortable, adjusting it may accidentally expose the covered eye to light while it is trying to adjust. (If you need to adjust it, just make sure to close that eye tightly until the patch is back on.)
2. After about 30 minutes of wearing the eyepatch, the teacher will dim all the lights in the room and cover any windows, making the room as dark as possible.
3. Before removing to eyepatch, the teacher will hold up different items, and you will attempt to identify them. Then, the teacher will ask you to locate several items located around the room, without leaving your seat.
4. Now swap the eye that the eyepatch is currently on, and repeat step 3 with both the old and some new items.
5. Lastly, remove the eyepatch completely and repeat step 3.

Questions:

1. Was it easier to identify the items once the eye that was covered by the eyepatch was uncovered?
2. Did you notice anything else different about your vision after you started using the previously covered eye?
3. Did completely removing the eyepatch make the identification tasks any easier? Was there anything strange in your vision once the eyepatch was completely removed?

Students may or may not say that it helped, but they should claim that the help was minimal at most. Most students should also say something along of the lines of there being an odd sensation after the eyepatch is removed, as though it was still there, even though it's not. Some may describe the feeling as if there was something directly in front of their face even when nothing is there. This is simply due to the fact that the other eye has not adjusted to the dark, so its vision is reduced dramatically compared to the eye that was covered. The brain compensates for this by creating the illusion that something must be covering up or sitting right in front of that eye, even though nothing is there.

Notes:

The human eye is made up of both rods and cones. We have many more rods than cones in our eyes (about 120 million rods as compared to only about 6 million cones), and they are nearly 1000x more sensitive than cones as well. However, rods are not sensitive to color like cones are. Instead, they are responsible for other things, like *dark-adapted* vision. This means that the rods in our eyes are what help us adjust to seeing in the dark, but rods are slow to adapt, which is why it takes a while for that adjustment in our vision to happen. This is also why color is not so easy to discern even after the eyes are adjusted to dim lighting, because the cones have shut down at this point.

One surprising group of people that are believed to have taken advantage of this is pirates! It is actually a misconception that pirates wore eyepatches due to having some kind of eye injury, instead they wore them to keep one eye adjusted to the dark at all times so they could see clearly in even the darkest of ships interior rooms at a moment's notice by simply swapping the eye that the eyepatch is on. This was especially useful when raiding a ship, when the pirates wouldn't have time to wait around for their eyes to adjust to darkness before plundering the loot buried in the dark, lower levels of the ship.