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16 May

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UCF | CREOL, The College of Optics and Photonics
UNIVERSITY OF CENTRAL FLORIDA

Introduction

These kits were made with the generosity of the IEEE Foundation, Jenoptik, and the College of Optics and Photonics at the University of Central Florida in celebration of the International Day of Light.

ETOP, Education and Training in Optics and Photonics, is a conference held every two years, that brings together leading optics and photonics educators from all around the world and from all levels and orientations to discuss, demonstrate and learn about new developments and approaches to teaching in these fields. Through presentations, panel discussions, workshops and exhibits, it is the intent of this conference to inform professors, students, teachers and professional trainers on how to teach optics and photonics for the future. We also inform and inspire students outside of the conference hall and inside the classrooms and have created these Photon Fun kits to share with you!

Our hope is that the experiments within will serve as a fun and informative experience for your students, as well as spark interest in further exploration into Optics and Photonics.

Inside the kit you will find several parts that can be used to perform Free-Space Optical Communication, which will give students the opportunity to see the practical relationship between photons and electrons, as well as see how we convert to and from electrical and optical signals to form the backbone of the internet.

During the instructions, you'll find a comprehensive walkthrough on setting up the demonstration complete with pictures to walk you through step by step. Also, following the experimentation will be a comprehensive explanation of the science behind the phenomena explored through the kit, as well as practical explanations for what we see. We hope that these will prove helpful in assisting the students with explaining their findings through the experiment.

As well as the primary demonstration, we'll also include some additional experiments which explore fun and different aspects of optics and photonics for your students to investigate.

For more information on a degree in Optics and Photonics and the UCF Bachelor of Science in Photonic Science and Engineering, go to www.creol.ucf.edu

How Can Light Carry Sound?

Description: Students will modulate an LED to send audio across free space towards a solar panel which and back into sound.

Student Materials (per group):

- ☐ Diffraction Gratings

Additional Teacher Materials: (In Kit)

- ☐ Solar Panel
- ☐ Red and blue LEDs
- ☐ 470 Ω Resistor
- ☐ Speaker
- ☐ 2- Male 3.5 Audio Connectors
- ☐ Several Wires
- ☐ Solderless Breadboard

Addition Items Not In Kit

- ☐ Small Screwdriver
- ☐ 9V Battery

Background and Misconceptions:

How can we use light to communicate over long distances? Well, to answer that question we have to look at and understand the nature of light, as well as how we can take full advantage of its properties. Light possesses a dual nature and is simultaneously a particle and a wave based on the context in which you view it. That idea stands at the core of this experiment and is essential in answering that question. Let's take the example of someone talking on the phone and go step-by-step, explaining how scientists and engineers have managed to use light to make this process possible.

It starts with sound, a mechanical wave, that gets processed by a speaker which converts these soundwaves into an electrical signal. There is then an LED, a Light-Emitting Diode, which produces an optical wave that we then stack with an electrical signal in a process called Modulation. The light now carries the sound information. This optical signal travels from the source to a receiver, in our case, a solar panel. At the solar panel, the light from the LED hits the panel which converts the signal back to being an electrical signal since the light's intensity is now varying due to its modulation. This signal then travels to a speaker which converts the electric signal into soundwaves which we can then hear. Through this process we take mechanical waves and convert them into electrical current, the flow of electron particles, and then convert those particles into waves of light. When the waves of light hit the solar panel the light, now treated as a particle called a photon, is absorbed and converted to an electrical signal. This electrical signal reproduces the original sound when played.

But at first glance, the only part of that featuring light was the LED and the Solar Panel, so how can we say that light, and it's dual nature, stand at the center of this process? It comes down to those two elements, and how photons and electrons are related.

An LED is a device made of a material called a semiconductor, capable of both absorbing and transmitting electrical signals. Materials which can only absorb are called insulators, while materials which only carry or transmit electricity are called conductors. When a current is passed through the LED, the material reacts with it. The energy provided by the electrons in the current allows the electrons in the material to jump to a higher energy state outside of the valence band. However, the upper energy bands are like a party, it's exciting and there's a lot going on, but the electron can't stay there forever, eventually it gets tired. When the electron gets tired, it falls back down to the lower state, and the drop in energy states produces a photon, a particle of light. In a diode, this light then escapes the semiconductor and gets focused in a direction to be used as a light source. Using these, we can convert directly from electrical signals, electrons, to optical signals, photons.

But this process also works in reverse, and it is how solar panels work. Solar panels are also made of semiconductor material, and when light hits the semiconductor material, the photon is absorbed to allow electrons to move to a higher state. This also creates a hole where the electron used to be, and another electron in the higher state will quickly fall down into it. This process, this movement of electrons from lower states to higher states and back again creates the motion of electrons we call current, and it flows out of the solar panel and into an electrical grid to create clean energy. However, if the signal we sent was modulated, meaning it was carrying information, we can absorb the photons, convert them to electrons, and then process the signal to reproduce the information carried as sound.

You can see then the role that light plays in this experiment. We see light as a particle when we're talking about electron flow, but we also treat it like a wave when we discuss modulation or the encoding of information. We see how an LED takes electrons to produce photons, and how a solar panel takes in photons to produce electrons, and how this entire process allows us to move information from one place in one form to another place in a different form.

But what if you were to learn that every time an electron dropped from an upper state to a lower state it produced a photon? If that was true, why isn't your battery glowing? Well, the answer is that it is. When the photon is produced, it's absorbed by the material again, and the process keeps going to sustain the flow of electrons. As this happens, the waste material of the absorption of light is heat. Light is synonymous with heat, and anything which produces light produces heat, and vice versa. This process is called Blackbody Radiation, and it occurs in the sun just as it occurs in electric devices and in the human body.

Discussion:

Before getting right into the experiment, we consider it helpful to try and ask ourselves what we expect to see as a result of the experiment. From the name alone, we'd expect that we'd achieve some sort of information transfer over free space using the setup, but how does it work? What factors are at play? These are the sorts of conversations that can let people form their own opinions based on what they know, and then prove or disprove them through empirical study using the experiment,

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

1. Why use light to transmit information over an electrical signal?
2. How do we transmit light over long distances?
3. If the internet is based on optical communications, can we see the information as it travels?
4. What separates the radar waves we use for communications from the red light you'll use in the experiment? Why use one over the other?

Additional Hints:

- Be careful with the wires that are attached to the solar panels. We did our best to find some more rugged wires, but they are still fragile. You might want to tape them to the panels at the connection points so they don't loosen and fall off.
- Setup the kit and try it out prior to demonstrating for the students.
- Try to move objects such as combs or other object with small gaps and listen to the effect. Try to shine it as a fluorescent bulb to see if you can hear a 60 hz hum.
- Lesson 4 is designed for advanced physical science students or physics students.

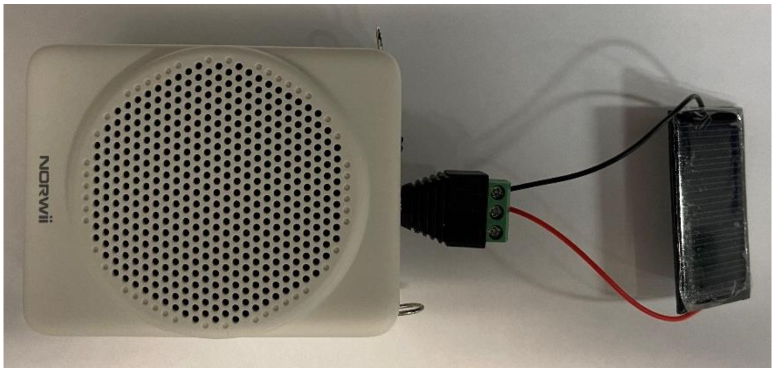
Below are some additional lessons found from the Light Manual for Teachers, these require additional materials not provided in the kit, but we recommend giving them a look as the materials are cheap and easy to get in bulk and would make for good supplementary lessons to further interest in Optics and Photonics. The PDF of the manual is available for free at the following website:

https://photonics.creol.ucf.edu/resources/

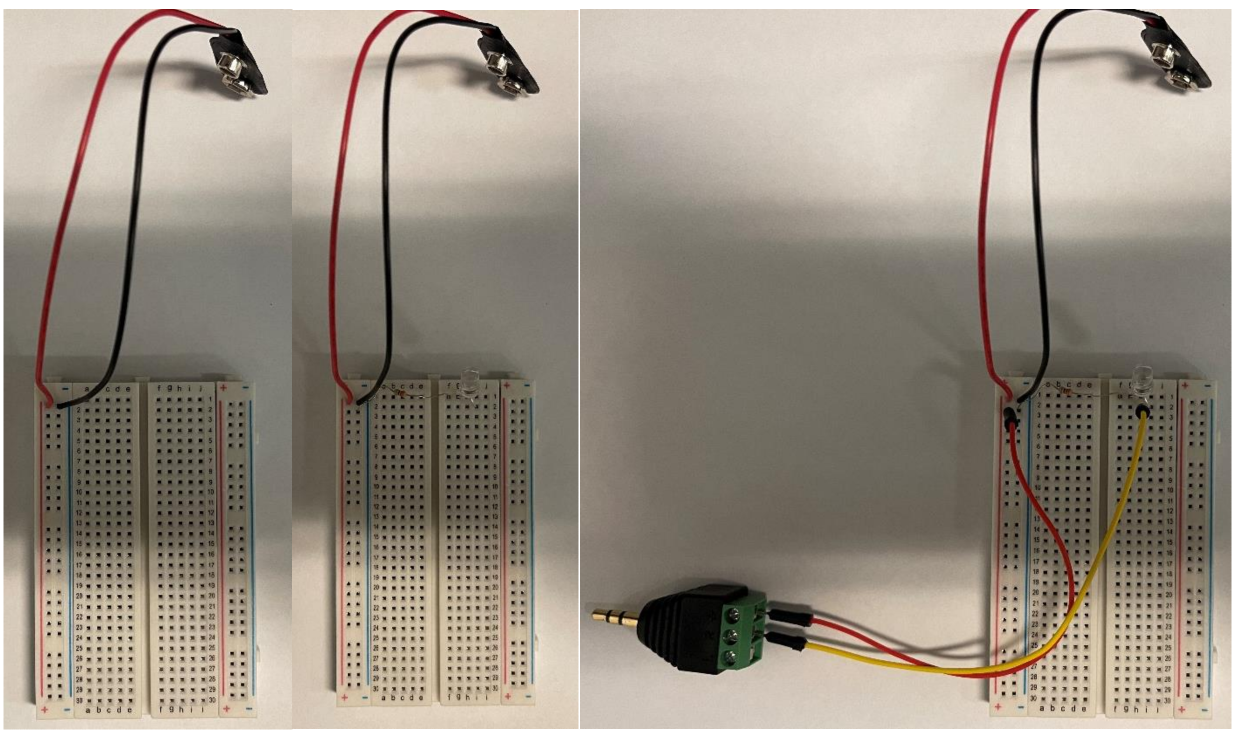
https://creol.ucf.edu/wp-content/uploads/sites/2/2019/05/Light-Curriculum-Manual-2016.pdf

Teacher Demonstration Experimental Set-Up:

1. Starting with the receiver circuit, take a male 3.5mm audio jack and use the screwdriver to loosen the ports on the adapter. Take the solar panel and plug the red wire into the left or right channel, and then plug the black wire into the ground channel of the adapter. Plug this into the Voice Amplifier's AUX port.



2. Insert the red wire of the 9V adapter into the top left corner of the breadboard, and the black wire directly next to it (Left Image). Then, connect the resistor to the node below the black wire and to F1 on the board. Connect the LED's short leg next to the resistor in G1 and the long leg into I2 (Middle Image). Then, connect a wire from F2 to the ground of the 3.5mm adapter, and another wire to the node below the red wire of the adapter (Right Image). This completes the transmitter.



How Can Light Carry Sound

TEACHER ANSWER KEY

Name ____ **Date** ____________________

	Spot of Maximum Audio Quality	Spot of Low Audio Quality	Spot of No Audio Transmitted
How far away was it?			
What did you see on the panel?			
How far to the side was it?			
What did you see on the panel?			

Generally, the best sound comes from being fairly close to the LED and having the brightest spot.

Moving the LED far and away causes the sound to drop off dramatically, since the intensity of the light varies as $1/r^2$. Doubling the distance between the light and the panel causes the light intensity to fall by ¼.

Moving it left and right has less of an effect until it moves farther out of the spot range.

1. Which affects the system more, transverse movement (forward and back) or lateral movement (side to side)?

   Forward and backward.

2. What is the beam shape on the solar panel? What correlation is there between the beam and the audio quality?

   Somewhat round, but answers may vary.

3. Try changing the Red LED for the Blue LED, what changes?

   Not much – you may notice some slight better performance from the blue LED.

Lesson 2:

	Brightness Level across LEDs	Spot of Maximum Audio Quality	Spot of Low Audio Quality	Spot of No Audio Transmitted
For Parallel, how far away was it?				
For Series, how far away was it?				

The total light output of LED's in parallel will be brighter than those in series. (2 LED's in series each use half of the 9V battery power, whereas LED's in parallel use 9 volts each). For both, the best sound audio is when the panel is close to the LED, but the parallel LEDs have a combined light output that is greater and will therefore be better

1. What were some differences between the Parallel LEDs versus the single LED? Any similarities?

   More lights in parallel produce more light and therefore more sound.

2. What were some differences between the Series LEDs versus the single LED? Any similarities?

   More lights in series reduce the amount of light from each LED and will have a degraded effect on sound output.

3. Which configuration did you think was the best and which one the worst? Explain why.

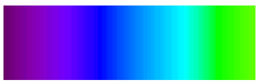
   Parallel since more light is produced that can be captured by the solar panel.

Lesson 3:

1. What do you see looking at the red light when wearing the diffraction glasses? Try changing out the red LED for the blue LED, and repeat. You can also draw a picture if you have colored markers or crayons.

   This is representative of a red LED – but could vary:

   This is representative of a blue LED – but could vary:



2. What do you see looking at a point source like a flashlight? You can also draw a picture if you have colored markers or crayons.

   This is representative of a blue LED – but could vary:

Lesson 4:

1. If the temperature of the sun is $5778°K$, then what is the peak wavelength of light emitted by the sun? What kind and color of radiation is that according to the electromagnetic spectrum? Is this surprising to you?

   502 nanometers or somewhat green light. Since our atmosphere scatters blue light, by the time the light arrives at the surface of earth, it has shifted in appearance to be a bit yellower.

2. If the average temperature of a human is $98.6°F$, what is that in Celsius? What is that in Kelvin? What is the peak wavelength of light emitted by the human body? Is it visible?

   37 6$°C$ or 310 K

   9.3 mm, which is in the infrared portion of the EM Spectrum.

How Can Light Carry Sound

Name ____ **Date** ____________________

<u>Materials:</u> Free Space Optical Communication Kit

<u>Procedures:</u>

Lesson 1: Connect the male audio jack to a computer or other device to play music from. Position the LED and the Solar Panel at a distance 10cm away.

- Move the solar panel further away and then closer to the LED. Note the distance where audio quality is the best, poor, and lost. Note the light hitting the solar panel and the shape of the light.
- Move the solar panel 10cm from the LED and then move the panel to the left and right (laterally). Note when the audio quality is the best, poor, and lost. Note the light hitting the solar panel and the shape of the light.
- Compare the results of the first two parts of the lesson, are the numbers the same? Why would one affect the system more than the other?
- Compare the shape of the light that you saw on the solar panel for each of the steps, what conclusion can you draw from your observations that explains the results you got?

	Spot of Maximum Audio Quality	Spot of Low Audio Quality	Spot of No Audio Transmitted
How far away was it?			
What did you see on the panel?			
How far to the side was it?			
What did you see on the panel?			

4. Which affects the system more, transverse movement (forward and back) or lateral movement (side to side)?

5. What is the beam shape on the solar panel? What correlation is there between the beam and the audio quality?

6. Try changing the Red LED for the Blue LED, what changes?

Lesson 2:

Connecting a second LED to the circuit, both in series and in parallel with the other LED. For series, connect the second LED directly below the other led (Short Leg to G2 and Long Leg to I3) and then move the wire to the 3.5mm jack to the long leg of the second LED (G3). For parallel, connect them side by side (Short Leg to H1 and Long Leg to J2) and do not move the wire to the 3.5mm jack.

- Connect the LED in Parallel. Note the brightness of the LEDs compared to when there was only one. Is there a noticeable change?
- Set the solar panel at 10cm and note the audio quality as you did in Lesson 1. How far away can you move the panel before audio is lost? Is this better or worse than with one LED? How is background noise (which can be heard as static)?
- Connect the LED in Series. Note the brightness of the LEDs compared to when there was only one. Is there a noticeable change?
- Again, set the solar panel to 10cm from the LED and note the audio quality as you did in Lesson 1. How far away can you move the panel before audio gets lost? Is this better or worse than with one LED? How is background noise?
- Compare the brightness and audio quality of the LED in parallel versus series? What is the difference between them? Is one better or worse than one another?

	Brightness Level across LEDs	Spot of Maximum Audio Quality	Spot of Low Audio Quality	Spot of No Audio Transmitted
For Parallel, how far away was it?				
For Series, how far away was it?				

4. What were some differences between the Parallel LEDs versus the single LED? Any similarities?

5. What were some differences between the Series LEDs versus the single LED? Any similarities?

6. Which configuration did you think was the best and which one the worst? Explain why.

Lesson 3:

Materials: Diffraction Glasses

Procedures:
Using the provided diffraction glasses, look at the LED while it is on, as well as the flashlight on your phone or any other point source. Remember to avoid looking at the sun directly while wearing any modifying optical equipment which may present a risk to your vision and health.

3. What do you see looking at the red light when wearing the diffraction glasses? Try changing out the red LED for the blue LED, and repeat. You can also draw a picture if you have colored markers or crayons.

4. What do you see looking at a point source like a flashlight? You can also draw a picture if you have colored markers or crayons.

Materials: None additional required

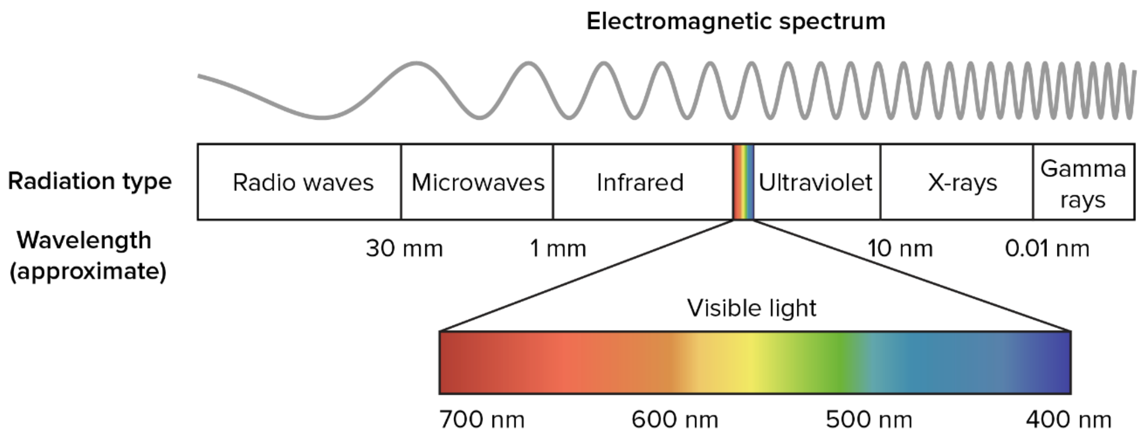
Procedures:

Lesson 4 (Advanced): In the background, we mentioned how anything which produces light produces heat, and vice versa. Use the equation below and the EM Spectrum to determine the relationship between wavelength and temperature.

Equation, called **Wien's Law:** $\lambda = 2898\mu m/T$

Lambda, λ, is in micrometers, and Temperature, T, is in Kelvin.

Conversions for Fahrenheit to Celsius to Kelvin: $(T[°\boldsymbol{F}] - 32) * \frac{5}{9} = T[°\boldsymbol{C}]$, $T[°\boldsymbol{C}] + 273.15 = T[°\boldsymbol{K}]$



Source: Khan Academy, https://www.khanacademy.org/science/biology/photosynthesis-in-plants/the-light-dependent-reactions-of-photosynthesis/a/light-and-photosynthetic-pigments

3. If the temperature of the sun is 5778°K, then what is the peak wavelength of light emitted by the sun? What kind and color of radiation is that according to the electromagnetic spectrum? Is this surprising to you?

4. If the average temperature of a human is 98.6°F, what is that in Celsius? What is that in Kelvin? What is the peak wavelength of light emitted by the human body? Is it visible?

Demo: Water Fiber Optics

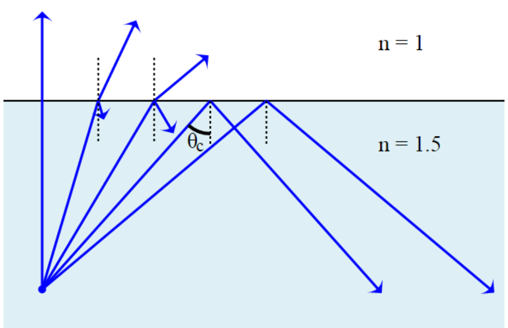
Materials:	2 Liter Bottle	Water	20 Penny Nail	Heat Source
	Laser or Flashlight	Plastic Box	Tongs	Stand

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:

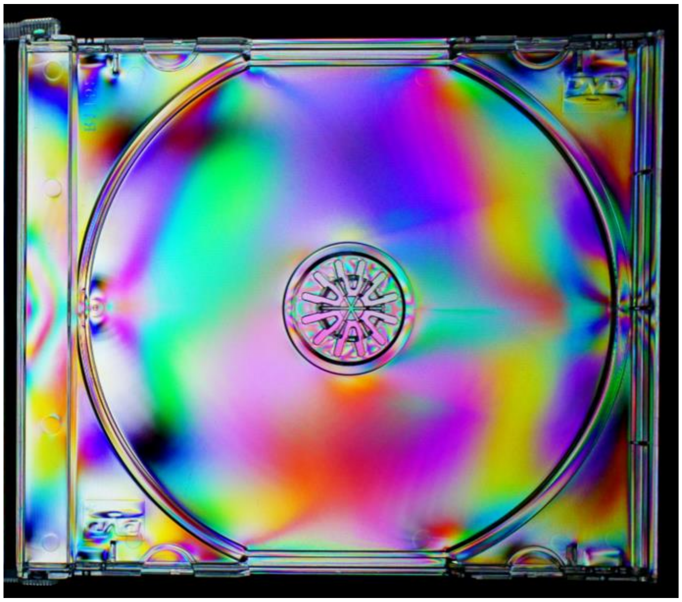
When you punch the hole with the hot nail, use caution. Make sure the hole is smooth and round so the water flows as a smooth stream.

Demo: 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.

How Can Light Be a Fingerprint?

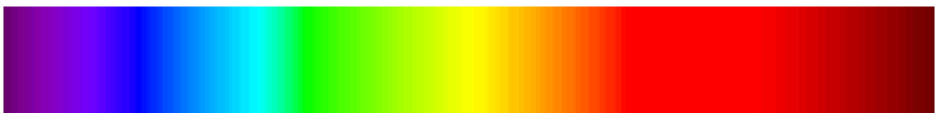
Description: Students will examine the spectra of gases to determine their composition.

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

Questions:

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

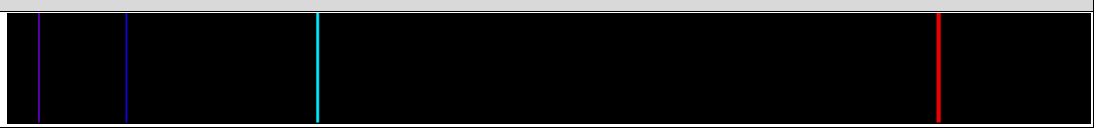
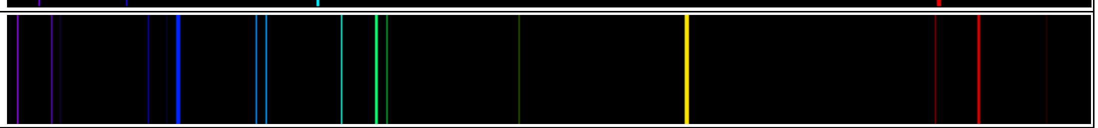
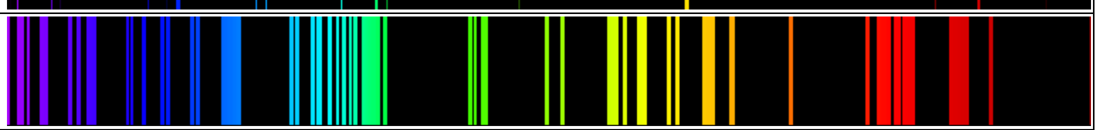
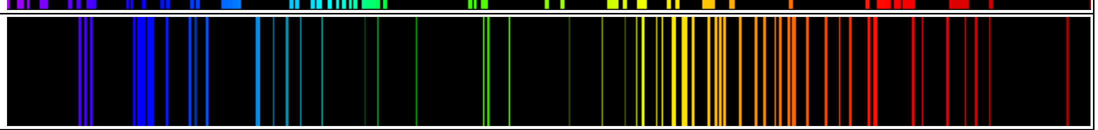
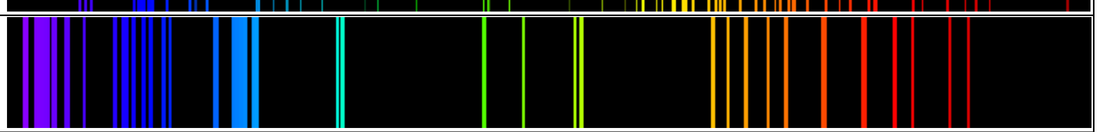
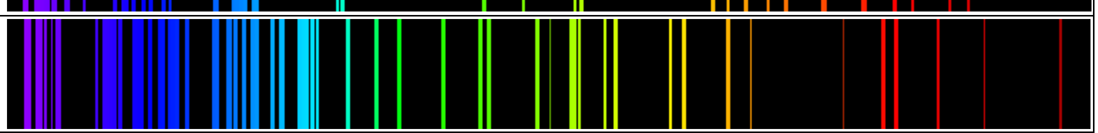
   It can be quite difficult since the diffraction grating may not show all the lines clearly. It is very important to be trained, just as police are trained to examine and match fingerprints.

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	

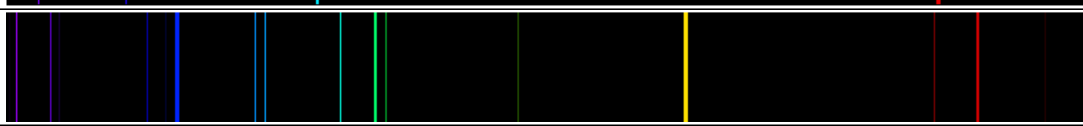
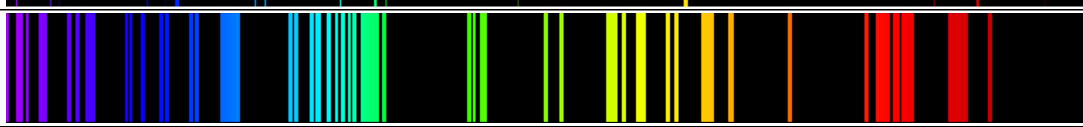
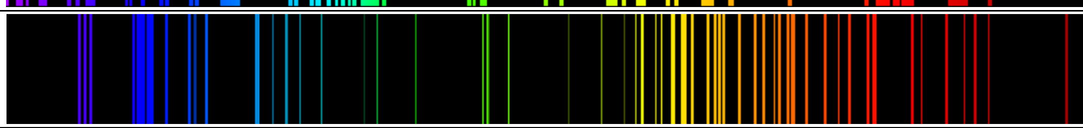
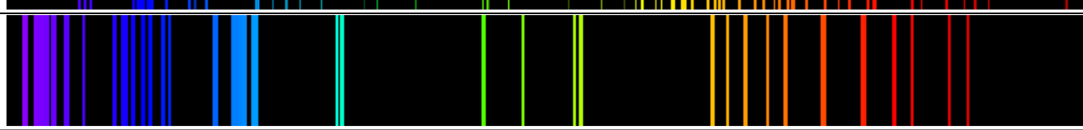
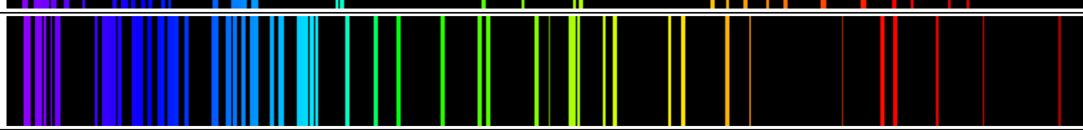
How Can Light Be a Fingerprint?

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?