Berkeley Engineers and Mentors

Let There Be Light!

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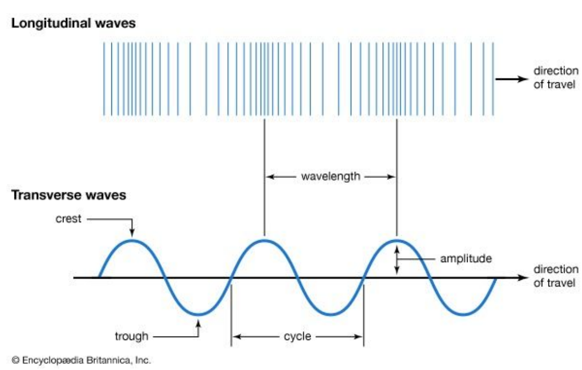
Adapted from: Lights! Camera! Hologram!

Field of Interest: Physics

Brief Overview (1-3 sentences)	**Agenda**
The mentees will be introduced to the idea of light as a wave and learn about the properties of light, such as reflection and refraction. After visualizing the colors of light, they'll learn about the interactions of light and surrounding objects and ways we can apply the properties of light to create awesome effects.	● Introduction ● Module 0: Light as a Wave ● Module 1: Refraction ● Module 2: Reflection ● Module 3: Absorption ● Module 4: Making Holograms ● Conclusion
Teaching Goals/Key Terms ● Light is a **wave** - specifically a type of electromagnetic wave ● **Reflection**: light bouncing off object/changing direction ● **Refraction**: change in direction of a wave due to a change in medium ● **Absorption** of light: when light hits an object, all wavelengths of light are absorbed except for the color we see	

Background for Mentors: Module 0

Module 0
• Light is a wave
• Properties of waves
   • Transverse waves
   • Longitudinal waves
   • Wavelength
• Electromagnetic Spectrum
	Light is an electromagnetic **wave**, which is a wave that is created as a result of vibrations between an electric field and magnetic field, and carries energy. Electromagnetic waves are different from mechanical waves (ex. sound) as they do not require a medium to propagate. There are two types of waves: **transverse** and **longitudinal**. Particles of a **transverse wave** move perpendicular to the direction of the wave. On the other hand, particles of a **longitudinal wave** move parallel to the direction of the wave. Waves can be measured in multiple ways, such as amplitude, frequency, and **wavelength.** In a transverse wave, the amplitude is the distance from the equilibrium point to the crest of the wave and determines the intensity(brightness) of light. The frequency of a wave is the number of waves that pass through a certain point in a given time and shows how fast a wave moves. The **wavelength** of a wave is the distance over which the wave's shape repeats and is inversely proportional to frequency. The wavelength and frequency also determine the color of visible light in a light wave: waves with a high frequency and short wavelength appear blue/violet while waves with a low frequency and high wavelength will appear red/orange.
	
	
	
	Figure 1: Longitudinal & Transverse Waves
	
	The **electromagnetic spectrum** displays the range of frequencies of electromagnetic waves and their corresponding wavelength and energy. The 7 types of electromagnetic waves are radio, microwaves, infrared, visible light, ultraviolet, X-Ray, and gamma rays where radio waves have the least energy and gamma rays have the highest energy.

Background for Mentors: Module 1

<table>
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Module 1

- Refraction
- Wavelength
- Visible light

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Light has several fundamental properties, including speed, frequency, and wavelength, but this module will focus more on refraction and wavelength.

Refraction is the change in direction of a wave as it changes media (such as from air to plastic and back to air). It's responsible for rainbows. The index of refraction is different for different media and also varies with wavelength, so the angles of refraction also vary with wavelength.

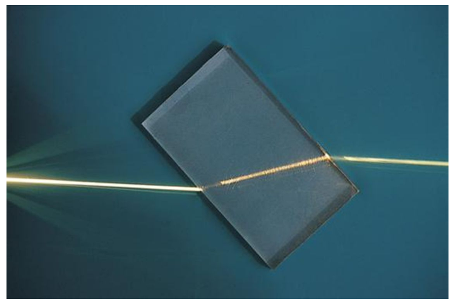

Figure 3: Refraction with Plastic

The degree of refraction is determined by the change in wave speed and the initial direction of the wave relative to the direction of change in the speed. The refraction of light follows Snell's Law:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

Wavelength is defined as the distance between subsequent crests in a wave, such as a light wave. Wavelength is inversely proportional to **frequency**, and frequency is directly proportional to **energy.** Thus a wave with a higher wavelength has lower frequency and subsequently a lower energy than a wave with a lower wavelength. Given this information, visible light of which color has the highest energy? What about the lowest energy?*

Visible light comprises only a small portion of the electromagnetic spectrum and is what we see as the different colors. The specific wavelength of light determines its frequency and energy.

White light is a fairly uniform mixture of all wavelengths. **Dispersion** is the spreading of white light into its full spectrum of wavelengths.

*Violet light (400-450 nm) has the highest energy in the visible light spectrum, and red light (635-700 nm) has the lowest energy in the visible light spectrum.

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Background for Mentors: Module 2

Module 2

- Reflection
  - Specular
  - Diffuse
- Wavelength

Reflection occurs when light changes direction at the interface between different media.
Reflection can be classified as specular or diffuse. **Specular** reflection is mirror-like, and light rays are reflected off a smooth surface at specific angles. An example of specular reflection is the reflection from the surface of a mirror, as seen below.

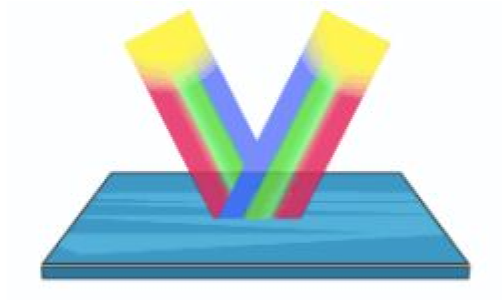


Figure 4: Specular Reflection

Diffuse reflection is produced by rough surfaces, from which light rays reflect off at different angles. An example of diffuse reflection is the reflection of light off a rough metal surface. Most instances in reflection in real-life scenarios exhibit diffuse reflection, as surfaces are generally not perfectly smooth.

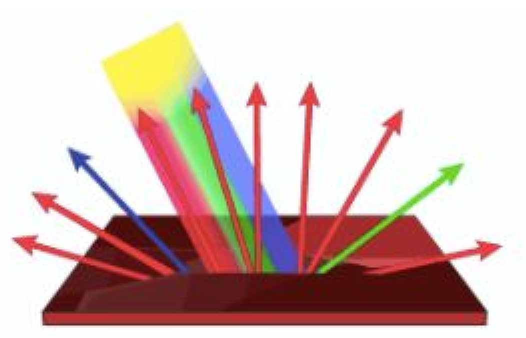
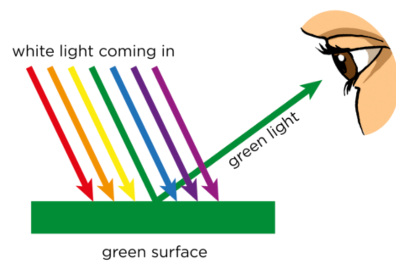


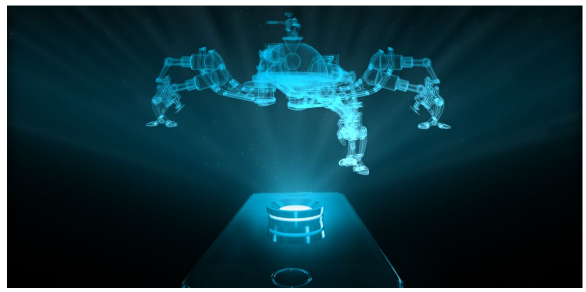
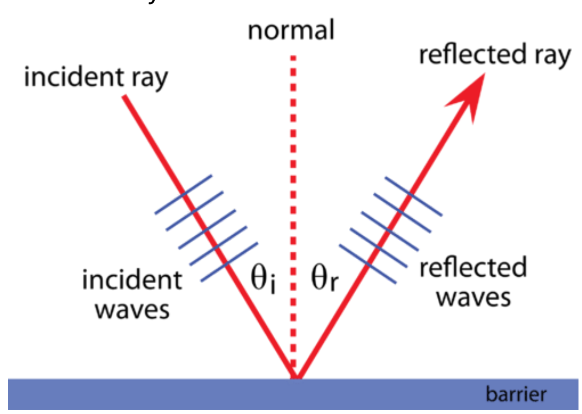
Figure 5: Diffuse Reflection

We've seen that **wavelength** is the distance between waves. In this module, we'll continue to visualize the different colors of light, emphasizing the relationship between the wavelength of light and the color we perceive. The colors we see are in the **visible light spectrum**, a subset of the larger electromagnetic spectrum.

Background for Mentors: Module 3

Module 3 • Absorption • Pigment	**Absorption** of light depends on the electromagnetic frequency of the transmitted light and the natural frequency of the electrons of the atom. Natural frequency is frequency at which electrons in an atom vibrate. When light with the same frequency as the natural frequency interacts with the atom, the electrons are vibrated which converts the vibrational energy into thermal energy. The light that is used to vibrate the electrons isn't seen again because it is converted to thermal energy. Such absorption of light allows us to identify the colors of objects. When light hits an object, the object **absorbs** certain frequencies and **reflects** the rest. **Pigments** are chemicals capable of absorbing more than one frequency of light. For example, chlorophyll, a pigment found in plants, **absorbs** blue and red frequencies of light and **reflects** green. This is why leaves appear to be green.  **Figure 7:** Absorption and Reflection of a Green Object Absorbance of light is widely used in science in order to characterize different materials. One method of characterization is UV spectroscopy, which allows scientists to identify what frequencies of light are absorbed by a certain molecule or material.

Background for Mentors: Module 4

Module 4 • Reflection • 2D vs. 3D	A **hologram** is a 3D image of light formed by the interference of light beams from a **coherent light source**, which can produce radiation with the waves vibrating in phase. An example of a coherent light source is a laser. We can also make a hologram in the module with the video played on a smartphone.  **Figure 7:** Hologram Projector **Reflection** is the change in the direction of waves as they bounce off a barrier. The incident ray approaches the barrier, and the light ray is termed the reflected ray.  **Figure 8:** Graphic of Reflection Reflection is responsible for the formation of the 3D image comprising the hologram as light bounces off the sides of the plastic. 2D and 3D refer to two-dimensional and three-dimensional. A 2D object exists in one plane (ex. x and y) while a 3D object exists in two planes (ex. x, y, and z). Thus a shape that has a length and a width is 2D. A prism that has a height, length, and width is 3D. The hologram video playing on the phone is 2D, but the image projected appears to be 3D due to the reflection of light rays from the plastic sides. Four variations of the same image in the YouTube video are projected onto the four faces of the pyramid, and each side projects the image to the center. This creates the illusion of a 3D figure in the middle of the pyramid.

Introduction

Light is an important topic to understand as it is all around us and is responsible for many fascinating phenomena as well as the most seemingly mundane aspects of life. From the way we perceive color to the utilization of lasers in laser eye surgery, light has a wide spectrum of applications. The colors we can see with human eyes comprise the visible light spectrum, a very small portion of the entire electromagnetic spectrum.

<table>
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<td>
Concepts to Introduce

Light can be thought of as both a wave and a particle and displays properties of both

As a wave, light can be transmitted, reflected, refracted, diffracted, absorbed, polarized, or scattered
As a stream of particles, light is responsible for the photoelectric effect and can cause the emission of electrons after hitting metal

The wavelength of light determines its characteristics (ex. energy, frequency, color as applicable)
The properties of light are responsible for numerous phenomena

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Current or Past Events

The photons of light do not interact, but attraction has been observed between photons, which defies the accepted laws of physics
https://news.mit.edu/2018/physicists-create-new-form-light-0215
The speed of light in a vacuum was first measured in 1676 by the Danish astronomer Ole Roemer by timing the eclipses of Jupiter's moon Io
$c = 3.0 \times 10^8$ m/s
https://www.amnh.org/learn-teach/curriculum-collections/cosmic-horizons-book/ole-roemer-speed-of-light

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Questions to Pique Interest

What do we need to 'see' things?

Without light, we won't be able to see things.

What is the fastest thing in the universe?

Light! Light can go around the Earth 7.5 times in 1 second.

Where does light come from?

Natural sources of light include the sun, stars, fire, electricity
Some animals and plants can make their own light (bioluminescence: seen in fireflies, mushrooms, etc.)
Artificial light is created by humans

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Inspiring Scientists, Careers, Applications

Light is necessary for us to see things! We "see" things as the light reflected off of various objects are detected by our eyes.
The refraction of light through water drops creates rainbows in the sky.
Scientists use different properties of light for multiple tasks!

Absorption: Used to characterize materials (spectroscopy)
Refraction: Used in microscopes, telescopes, and different types of lenses

Medical Applications

Lasers are used in laser eye surgery to correct vision.

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Module 0: Light as a Wave

This module is a DEMO that will introduce the students to what light is as well as different types and properties of waves using a slinky.

Teaching Goals	Materials
1. Light is a **wave.** a. **Transversal:** particles of the medium move in a direction perpendicular to the direction of the wave b. **Longitudinal:** particles of the medium move in a direction parallel to the direction of the wave 2. **Wavelength** is the distance between two waves. Longer wavelength means less energy. 3. **Electromagnetic Spectrum** displays the range of frequencies of electromagnetic waves and their corresponding wavelength and energy.	• Slinky

Procedure

1. Two people will grab the ends of the slinky and put it on the floor. One person holds down the slinky as the other person moves the slinky.
2. Shake the slinky from side to side. This is a **transversal wave**.
3. Push the slinky towards the other person. This is a **longitudinal wave**.
4. Shake the slinky from side to side again. Point out that the distance between two waves is the **wavelength**.
5. Shake the slinky slowly then faster. When the slinky shakes slowly, the wavelength increases (distance between two waves is greater). When the slinky shakes faster, the wavelength decreases (distance between two waves is smaller).

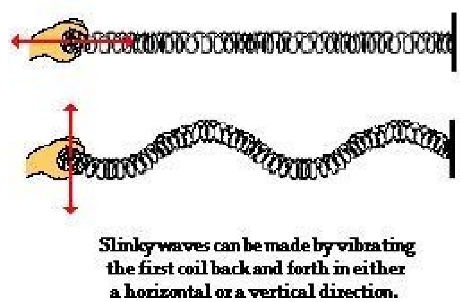

Figure 1. *Slinky Wave*

Module 1: Refraction of Light

This is a quick demo for the students to visualize the colors of light and learn about the relationship between color and wavelength. They'll be seeing how white light can be separated into light that displays the colors of the rainbow.

Teaching Goals	Materials

1. **Refraction**: change in direction of a wave due to a change in medium
2. **Wavelength**: distance between waves
    a. Light with a shorter **wavelength** bends more, and thus light of different colors is refracted to differing amounts
3. **Visible light**: portion of electromagnetic spectrum that accounts for the colors we can see, red to violet colors
    a. Contains range of approximately 380-740 nm
	• White paper
	• Glass prism
	• Flashlight (optional)

Procedure

1. Place white paper on a flat surface where it is exposed to sunlight, if possible.
2. Place the prism on or hold it above the paper.
3. Rotate the prism until the light rays **refract** and form a rainbow on the paper (Figure 2).
4. If conditions are not sunny, then shine the flashlight beam at the prism so that the same effect is achieved.
5. The rainbow formed displays the array of colors in the **visible light** spectrum, from red to violet. The white light is composed of all the colors, and after passing through the prism, the colors separate into distinct bands. The colors bend by differing amounts depending on wavelength and thus form all the colors.
6. A sequence of colors from red to violet is formed, since the index of refraction increases as wavelength decreases.

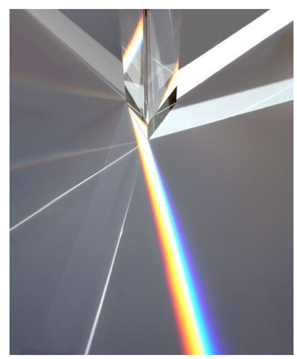

Figure 2: *Rainbow from Glass Prism*

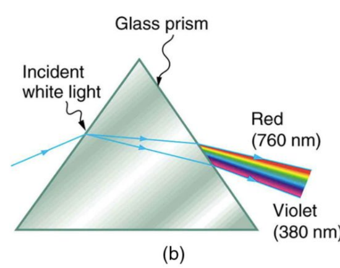

Figure 3: *Light Passing Through Prism*

Classroom Notes

Be careful when handling the glass prism! It can be quite fragile.

Module 2: Reflection of Light

Students will explore the colors of light by creating their own devices to scatter light beams. Light reflects off the reflective surface of CDs and appears as rainbow beams of light! The shape of the snowflake — and thus the shape and position of the holes in the paper through which light can pass — affects the appearance of the light rays but not the colors.

Teaching Goals	**Materials**

1. **Reflection**: light bouncing of object/changing direction
    a. **Specular reflection:** mirror-like, reflection off smooth surfaces
    b. **Diffuse reflection:** light rays reflect off at random angles
2. **Wavelength**: distance between waves
	• White paper
	• Scissors
	• CD
	• Tape
	• Flashlight (optional)

Procedure

1. Firstly use the scissors and white paper to cut out a snowflake shape.
    a. Start by folding the paper into a right-angled triangle and cutting off the excess to form a square (1).
    b. Fold the paper in half diagonally twice to form a small triangle (2 and 3).
    c. Fold the paper triangle in thirds as shown (4 and 5), and then cut across the bottom in a straight line (6).
    d. Use scissors to make cuts on the folded edges and the cut edge on the bottom, making sure not to cut completely across the folded edges.
2. After the snowflake is made, use tape to attach it by the sides to the reflective side of a CD.
3. By moving the device in the presence of light (either sunlight or from a flashlight), the beams of light will be reflected in all the colors of the rainbow through all the cuts in the paper.

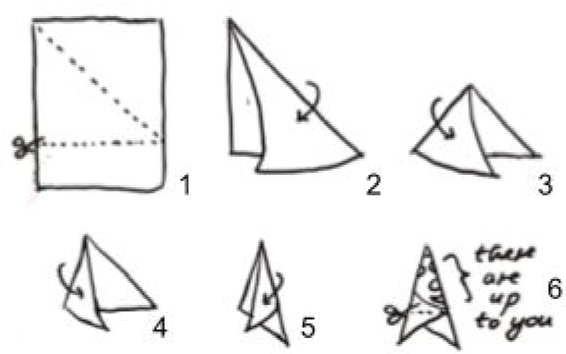

Figure 4: *Paper Snowflake Diagrams*

Figure 5: *Snowflake on CD*

Classroom Notes

Cutting the paper snowflakes may prove challenging for younger students, and mentors can assist them with the process as they deem necessary.

Module 3: Absorption of Light

Students will learn about the absorption of light and how we see objects of different colors by placing objects under different colored light. Students are free to use ANY objects as long as they have one red, one green, and one blue object.

Teaching Goals	Materials
1. **Absorption of light**: When light hits an object, all other wavelengths of light are absorbed except for the color we see 2. **Pigment**: chemicals capable of absorbing more than one frequency of light.	• Colored Cellophane (red, green blue) ○ Alternative: clear plastic bag and Sharpies (red, green, blue) • 1 flashlight / smartphone • 1 rubber band • 3 objects to look at (one of each color) • Printed Observations Worksheet (Optional)

Procedure

1. If you are using colored cellophane, proceed to step (2). If you are using Sharpies and a plastic bag, cut a 7 in by 7 in piece. Draw 4 squares on the piece of plastic and fill them in with a Sharpie. (Fig. 6) Fold in half twice. (Fig. 7) Repeat for the other colors.
2. Secure the red filter onto the flashlight with a rubber band. You can use the flashlight on your smartphone as well. Make sure that the flashlight is fully covered. Record the color of the light on the observations worksheet. Repeat with other filters.
    a. The color of the light should be the same as the color of the filter (cellophane) because other wavelengths of light are **absorbed** except for the wavelength of the light that corresponds to the color of the light.
3. Remove the filter and shine the flashlight on an object. Record the color of the object. (Fig. 8)

Figure 6. Draw 4 squares on the plastic and fill with a Sharpie.

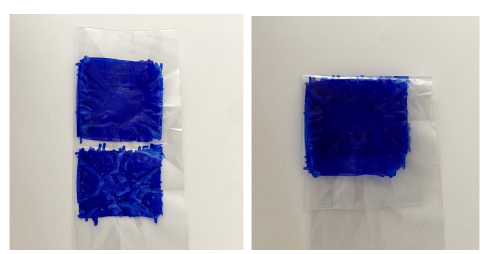

Figure 7. Fold the plastic in half twice.

4. Apply different filters (similar to step 1) and shine the flashlight on the object. Record the color of the object. (Fig. 9)
    a. If the color of the object and the light are the same, the object will be normal (same color).
    b. If the color of the object and the light are different, the object will appear black. This is because the object **absorbs** the wavelength of light that passed through the filter, so nothing is **reflected** from the object.
5. Try applying two filters to the flashlight. Record the color of the light.
    a. A new color (not red, green, or blue) should form.
6. Repeat step 5 for the rest of the filters.
7. Try applying all three filters to the flashlight. Record the color of the light.
    a. No light should pass through the filters. This is because the filters **absorbed** all wavelengths of light so nothing is **reflected** from the filters.

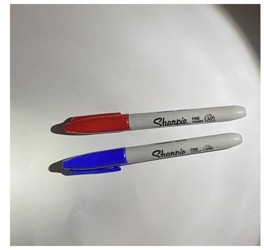

Figure 8. Objects under white light.

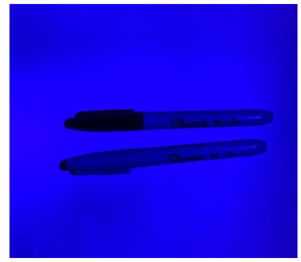

Figure 9. Objects under blue light.
Top: Red Sharpie; Bottom: Blue Sharpie.

Classroom Notes

Other sources of light may interfere with this demo and not produce the results wanted. If this is a problem, try the demo in a darker environment (ex. In a closet, turn the lights off, etc).

Module 4: Making Holograms

The students will be constructing plastic hologram machines to bring 2D videos into 3D life! This can occur through the refraction of light rays.

<table>
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<td>
Teaching Goals
1. Refraction: change in direction of a wave due to a change in medium
2. 3D vs. 2D
    a. 2D video translated to 3D hologram
<hr>
MD Goals
written by MD, not applicable for every module
List and explain how to reinforce MD goals during the module.
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<td>
Materials
• Plastic
• Marker
• Scissors
• Tape
• Smartphone to play video
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Procedure

1. Introduce the module by asking the mentees to define the difference between 2D and 3D.
2. Carefully mark the shape of trapezoids of 1 cm x 3.5 cm x 5 cm on plastic, and use scissors to cut out 4 trapezoids.
3. Tape the plastic together into the shape of an inverted pyramid on the four sides.
4. The next step is to open a 3D hologram video from YouTube on a smartphone.
    a. A variety of these videos can be found at the playlist: https://www.youtube.com/playlist?list=PLKw3xGWQxLgy49D2qJlaHQYDNrg1lVbET& or alternatively by looking up "3D hologram video" on YouTube.
5. Place the "hologram machine" on top of the smartphone in the middle of the video display so that the pyramid opens up on top.
6. Explain how the machine works and how the image appears inside of the machine.

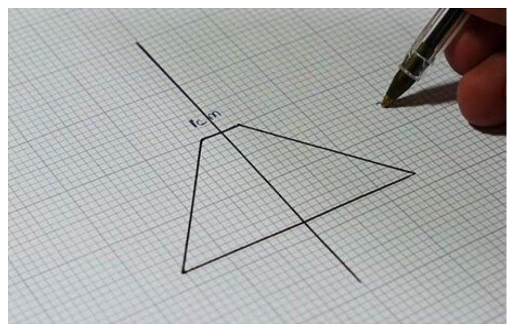

Figure 10: *Diagram of Trapezoid*

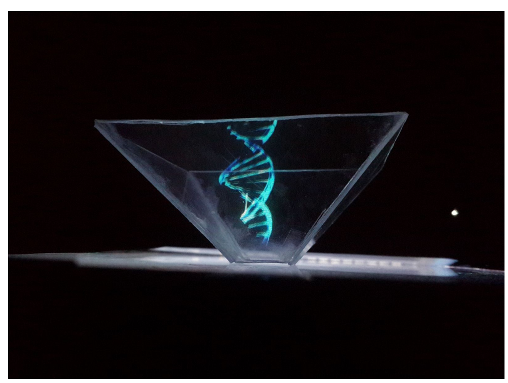

Figure 11: *Hologram Machine on Phone*

Classroom Notes

The sole purpose of the smartphones in this module is to play the hologram videos, and not anything else. Hopefully they can keep their attention on the holograms and do not become distracted. When cutting out the plastic trapezoids, younger students may need assistance, as the edges can be sharp.

Conclusion

In this lesson, the students have had the opportunity to learn about light and its unique properties. Through demos and experiments, they were able to visualize some of these properties. Ask to see if the students can distinguish the differences between reflection and refraction and what determines the color of light (its wavelength). The goal is that the students are able to come out of this experiment with a greater understanding of light and its applications in real-life scenarios.

References

- Specular and Diffuse Reflection, Michael W. Davidson, Molecular Expressions. https://micro.magnet.fsu.edu/primer/java/reflection/specular/index.html#:~:text=The%20reflection%20of%20light%20can,as%20illustrated%20in%20Figure%201).
- Ole Roemer and the Speed of Light, American Museum of Natural History. https://www.amnh.org/learn-teach/curriculum-collections/cosmic-horizons-book/ole-roemer-speed-of-light
- Physicists Create New Form of Light, Jennifer Chu, MIT News. https://news.mit.edu/2018/physicists-create-new-form-light-0215
- Lights! Camera! Hologram! Patrick Oare and Niger Faustino, BEAM. https://drive.google.com/file/d/1lgrObaObcttS72g2VR-UKltP0r3Cz6Vb/view
- Rainbow Science: Creating Light Patterns with a CD, Chelsey, Buggy and Buddy. https://buggyandbuddy.com/about/all-about-me/
- How to Make a Rainbow - Simple Science Experiments, Rookie Parenting Science. https://www.rookieparenting.com/make-your-own-rainbow-science-experiment/
- Light Absorption, Reflection, and Transmission, The Physics Classroom. https://www.physicsclassroom.com/class/light/Lesson-2/Light-Absorption,-Reflection,-and-Transmission
- Understanding Absorption of Light - Why do we see different colors?, Rebecca Emerich, Edmund Scientific. https://www.youtube.com/watch?v=VwNKPgo3oxA
- BEAM Graham Civic Auditorium, David Paner and Monica Oh, BEAM. https://drive.google.com/drive/u/1/folders/1P7m9wjnsSlZiFzi1Ac6ScErsOG4ilF1F

Summary Materials Table

Material	**Amount per Site**	**Expected $$**	**Vendor (or online link)**
Slinky	1 per site		Amazon
Glass Prism	1 per site		Amazon $10.99 for 1
Flash Light	4 per site		Inventory

White Paper	1 per student		Inventory
Scissors	4 per site		Inventory
CD	1 per student		Amazon $14.88 for 100
Tape	2 rolls per site		Inventory? Idk if we have much clear tape tho
Red Cellophane	4 per site		Amazon 100 ft x 16 in roll (can make 1200 pieces)
Green Cellophane	4 per site		Amazon 100 ft 16 in roll
Blue Cellophane	4 per site		Amazon
Rubber Band	4 per site		Inventory
Plastic Trapezoids	4 per group		Amazon $10.99 for 25 sheets