
IMH TEP'S

LEGACY ACADEMY

**The Nature of Light: The Speed of Light in
Gelatin and Wave-Particle Duality**

Grade 9 Activity Plan

9.9 The Nature of Light: The Speed of Light in Gelatin and Wave-Particle Duality

Objectives:

1. To discover how the speed of light differs in different materials.
2. To investigate how the speed of a light beam changes when passing from one medium to another, using Snell's law.
3. To investigate the particle-like and wave-like behaviour of a light beam, thus discovering the quantum mechanical nature of light.

Keywords/concepts: quantum, light quanta, wave-particle duality, interference, photon, speed of light, Snell's law, incident light, interface, electromagnetic radiation, electrodynamics.

Curriculum outcomes:

Grade 8: 109-5, 112-8, 113-2, 209-2, 209-6, 210-11, 308-8, 308-10.

Take-home product: Wave-particle duality experiment apparatus (return items which belong to the school).

Written by: Dario Brooks, July, August 2016.

Segment	Details
African Proverb and Cultural Relevance (5 min.)	"If you close your eyes to facts, you will learn through accidents." Unknown
Pre-test (10 min.)	Ask the students about their understanding of light and its makeup. Brainstorm ideas of how light travels, and with what speed.
Background (15 min.)	Discuss the nature of light and what it is made of (photons). Talk about the connection of light to electromagnetism (electricity travels at the speed of light; light is an electromagnetic wave). Introduce the speed of light as the "speed limit of the universe". Give a brief history of the experiments leading to the discovery of the particle-like and wave-like behaviours of light.
Activity 1 (20 min.)	Shine a laser pointer through a container of gelatin on an angle and observe how light is bent after entering the gelatin. Use Snell's law to determine the speed of light through the gelatin.
Activity 2 (25 min.)	Shine a laser pointer through pinholes in an index card. Observe the interference pattern on the wall from the laser traveling through two pinholes side-by-side, recreating the famous double-slit experiment.
Post-test (15 min.)	"Light redirection"

Suggested interpretation of the proverb: Even though it is important to learn all of the facts and rules in a particular subject, sometimes it is also important to ignore some facts while experimenting. As in the famous double-slit experiment, simply opening your eyes and letting your imagination guide you can be enlightening and even lead to a discovery nobody ever thought possible.

BACKGROUND INFORMATION

Light is an amazing phenomenon. Throughout history, scientists and philosophers have been driven by curiosity to investigate the true nature of light and discover where it comes from, its interesting properties, and how it can be used. All of the greatest thinkers in history have searched for the answers to those questions: Galileo, Newton, Einstein, and many other famous scientists all spent a significant amount of their lives theorizing about the properties of light, and then experimenting to test their theories. There is still much we don't know about light despite how much we've uncovered about its properties, and some of the best minds alive today are still working tirelessly to discover more about it. The area of physics that deals with the study of light and its properties is called **Optics**. Historically, optics was believed to be a topic of physics independent of other areas. However, with the work of physicists in the mid to late 19th century, most notably a Scottish theoretical physicist named **James Clerk Maxwell**, light was discovered to actually be a wave caused by **electromagnetic fields**, and so optics became a branch of electromagnetism. Optics then became a branch of particle physics when the **photon** was discovered definitively as the particle of light in the early 20th century by Einstein, Arthur Compton, and others. Optics finally became known to be a branch of **quantum mechanics** (and electromagnetism) during a period of intense research on light and electromagnetic radiation during the mid- to late-20th century. This research was again largely led by Einstein and Paul Dirac, and continued by famous physicists such as Richard Feynman and Freeman Dyson during their work in **quantum electrodynamics** after Einstein's death. Today, **quantum optics** is the branch of physics which uses methods of both classical and quantum physics to study the properties of light and other forms electromagnetic **radiation**.

James Clerk Maxwell made the discovery that electric fields and magnetic fields were both force fields resulting from the same phenomenon, and the separate fields of electricity and magnetism were merged into **electromagnetism**. Particularly, Maxwell discovered that changing electric fields created magnetic fields, and changing magnetic fields created electric fields. So, a changing electric field creates a magnetic field, which creates an electric field, which creates a magnetic field, and so on. This pattern causes a form of radiation, **electromagnetic radiation**, which consists of **electromagnetic waves**. Maxwell later found that a portion of these waves travel at the **speed of light**, and so those waves became known to be what we perceive as visible light.

Einstein followed Maxwell's work extensively during his early career. This led him to discover that the speed that light travels through empty space (**vacuum**) was the "speed limit of the universe", meaning that no matter can ever travel at a speed equal to or greater than the speed of light; this fact was the foundation of his formulation of the **theory of special relativity**.

Later experiments by Einstein and other physicists in the area of optics sought to settle a long-standing debate in science concerned with whether light was a

wave, propagating through space like ripples in a pond, or a particle, traveling through space in straight lines at a constant speed like harmless, invisible bullets shot from a gun. It wasn't until the mid 20th century, after the formulation of the theory of **quantum physics**, that several experiments confirmed that light in fact behaves as both a particle AND a wave. These experiments are known as **double-slit experiments**.

Today, it is well known that light can be bent and slowed down when traveling through substances other than air or empty space. Double-slit experiments are also performed easily with everyday items you can find in your home or classroom. In this activity we will perform experiments with the bending of light and its decreasing speed through gelatin. We will also recreate our own version of the double-slit experiment and see the unusual properties of light it reveals to us.

Activity 1: The Speed of Laser Light Through Gelatin

Purpose: To observe the bending of a light beam as it moves from one medium to another, and determine the speed of light through the second medium.

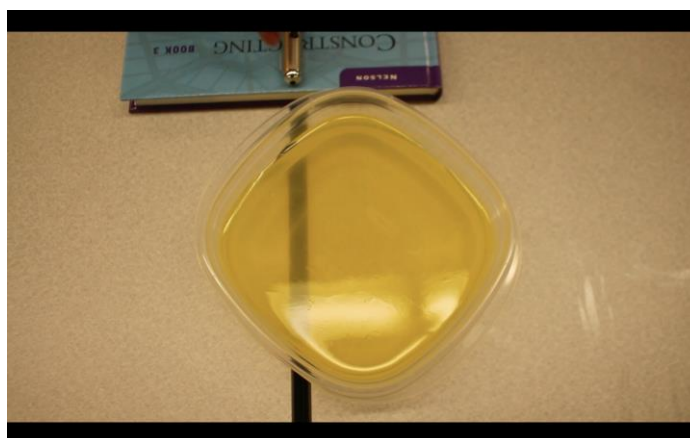
Item	Quantity (10 students)
Laser device (e.g. laser pointer)	5
Stable mounting device (e.g. a book)	5
Protractor	5
Clear or light coloured gelatin mix	5
Square plastic container	5
Calculator	5
Tape	5

TO BE DONE BY MENTOR (prior to activity): Prepare six containers of gelatin in square clear plastic (e.g. Tupperware) containers. The gelatin may take several hours to set, so it is impractical to prepare during the activity.

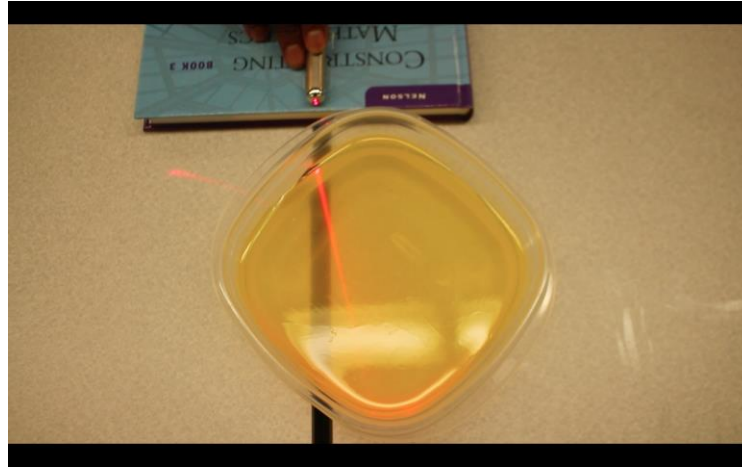
Procedure:

1. **Mentors:** Pair up students.
2. Tape the laser device to a stable mount, such as a textbook.
3. Align the laser beam along a straight line on the desk or floor below the stable mount.

Note: The purpose of this step is to obtain an accurate reading of the original path of the laser, since it is very difficult to see the laser beam passing through the air. Floor tiles or a straight edge ruler are particularly easy to use for this; an example setup is shown in the photo below.

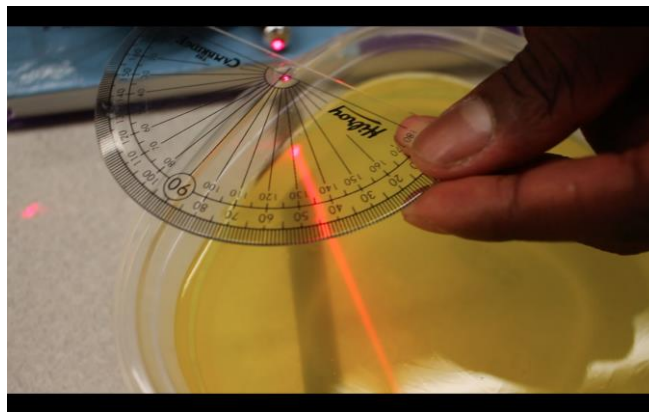


4. Place the container of gelatin in front of the laser device so that the laser beam strikes the side of the container at an angle, and then passes through the gelatin inside. The beam of light should be very visible passing through the gelatin, as in the photo below.



5. Use a protractor to measure the following angles, with respect to the **normal** to the side surface of the container:
 - The angle at which the laser strikes the side of the container (the **incident angle**).
 - The angle between the normal and the beam of light seen inside the gelatin (the **departing angle**).

See the picture below. To get an idea of what angles you are measuring, look at [Figure 1](#).



Note 1: The **normal** to a surface is a line that travels outward from the surface at a right angle. So, imagine a line going straight through the side of the container, passing through the point where the laser strikes the surface. This line stretches into the gelatin in one direction, and outward perpendicularly from the side of the container in the other direction. To measure the angles, place the protractor so that the normal is aligned along the zero line, and the wall of the container is aligned with the 90°

line. These angles can be difficult to measure, so just be as accurate as possible. Make multiple measurements of each angle and take their average.

Note 2: If you are using a laser device that operates with a button, one partner can hold down the button to create the beam while the other partner measures the angles.

6. Use **Snell's law** to calculate the speed of light in gelatin.

Note: Snell's law is given the mathematical form

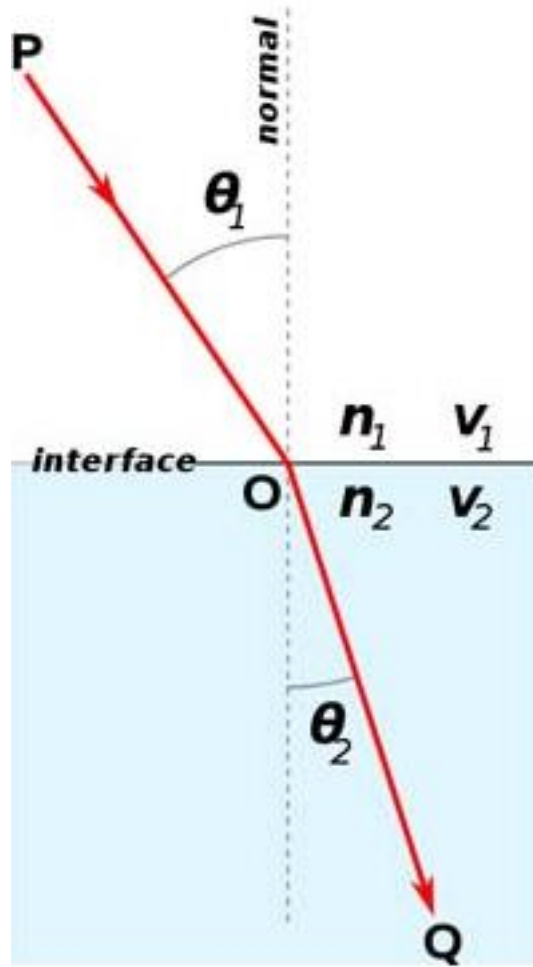
$$\frac{\sin(\theta_1)}{\sin(\theta_2)} = \frac{v_1}{v_2},$$

where:

- θ_1 is the incident angle.
- θ_2 is the departing angle.
- v_1 is the speed of light in the first medium. The first medium for us is air, so $v_1 = c = 300000000$ metres per second; that's approximately 1079000000 kilometres per hour!
- v_2 is the speed of light in the second medium, which is gelatin. This is the value you have to find using your calculator.

A visual representation of a possible interface setup is shown in [Figure 1](#).

Figure 1:



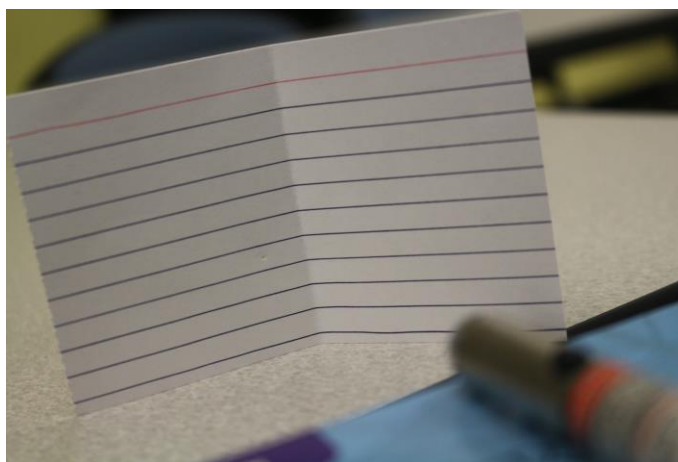
Activity 2: Wave-Particle Duality of Light

Purpose: To observe the wave-like properties of light and contrast them with what we know about the particle theory of light.

Item	Quantity (10 students)
Laser device (e.g. laser pointer)	5
Stable mounting device (e.g. a book)	5
Pin or needle	5
Tape	5
Index card	5

Procedure:

1. **Mentors:** Pair up students.
2. Tape the laser device to a stable mount, such as a textbook.
3. Fold then unfold the index card to form a slight bend so that it can stand up in front of the laser device on its own.

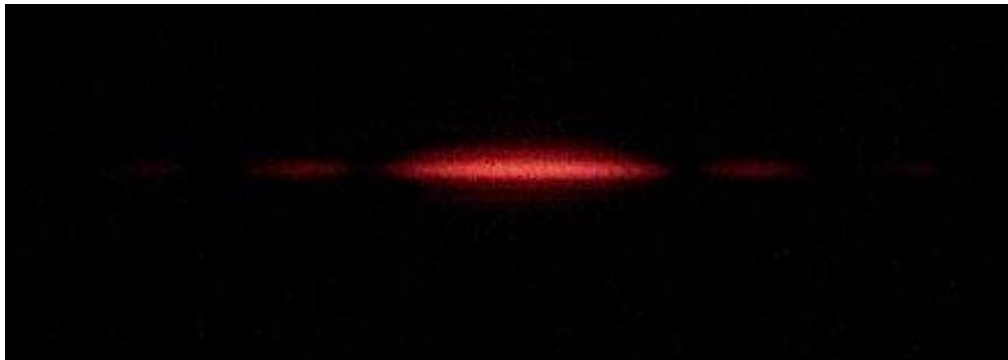


4. Poke a tiny hole in the index card using the pin and stand it up at least 10 feet away from the wall. Test where to poke the hole by standing the index card and shining the laser onto it.
5. **Mentors:** Have a short discussion with the students about what they should expect to see on the wall when the laser passes through the pinhole in the darkened room.
6. Turn off the lights and close the curtains to make the room as dark as possible.
7. Turn on the laser device and adjust the angle so that the laser passes through the pinhole in the index card and onto the wall. Have one

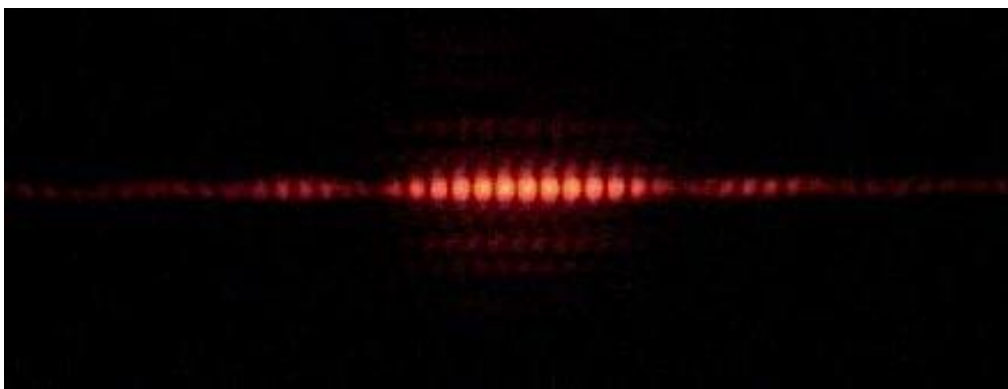
- partner hold down the button on the laser pointer, and the other partner look closely at the pattern on the wall, being careful not to put their face in the path of the laser. Take note of the pattern you see on the wall.
8. Poke a second pinhole into the index card as close as possible to the first hole without creating one larger hole. The holes should be close enough together that the laser can pass through both holes at once.
 9. Adjust the laser device so that the laser passes through both holes; again, one partner holding down the button while the other looks closely at the pattern on the wall. Take note of what you see projected on the wall.
 10. **Optional:** If possible, cover one of the pinholes with a piece of paper without moving the laser device or the index card. Observe and take note of how the light pattern on the wall changes.

Explanation: You should have observed:

- a) A solid “blob” of light on the wall when projecting the laser through one hole.



- b) A striped blob of light on the wall when projecting the laser through two holes.





c) (Optional
solid blob of

covered one of the two holes.

step): Again a long
light when you

What is happening is that the light particles, called photons, are passing through the holes in the index card and interfering with each other on the other side, just like water waves in a lake interfere with each other. All waves experience two things during interference: **constructive interference** happens when two waves which are in-phase with each other (happening at the same time) meet and add together, and **destructive interference** happens when two waves which are out-of-phase with each other meet and cancel each other out. Constructive interference is responsible for the bright bands of the light pattern on the wall, while destructive interference is responsible for the dark stripes in the light pattern on the wall.

Why does this happen? After all, two baseballs that travel through holes next to each other don't destroy each other nor combine to make a bigger baseball, so why does this happen with photons? This leads us to conclude that light behaves as both a particle *and* a wave: light is made of particles called photons which interfere with each other like waves! This activity is a recreation of the famous **Double-Slit Experiment** which was originally performed in the early 20th century, which first indicated the **wave-particle duality** of light.

References and additional resources:

Background information:

http://abyss.uoregon.edu/~js/21st_century_science/lectures/lec13.html

<http://www.upscale.utoronto.ca/GeneralInterest/Harrison/DoubleSlit/DoubleSlit.html>

http://www.sciencebuddies.org/science-fair-projects/project_ideas/Phys_p009.shtml#background

- "Introduction to Electrodynamics, 3rd Edition" by David J. Griffiths. Published by Pearson.
- "Quantum Theory for Mathematicians" by Brian C. Hall. Published by Springer.
- "A Modern Approach to Quantum Mechanics, 2nd Edition" By John S. Townsend. Published by University Science Books.

Activity 1:

http://www.sciencebuddies.org/science-fair-projects/project_ideas/Phys_p009.shtml#summary

Activity 2:

<http://www.education.com/science-fair/article/light-wave-thomas-young-double/>

<http://ffden->

2.phys.uaf.edu/webproj/212_spring_2014/Khan_Howe/TheDoubleSlitExperiment/KhanHowe/Single_slit_and_double_slit2.jpg

Post Test

Light Redirection

This activity should be done as one big group.

In this activity, you will use the containers of gelatin used in Activity 1 to try to redirect a bent laser beam back along its original path. Begin by shining the laser through the first container of gelatin and observing where the beam shines through the other side. Then, use a second container of gelatin to try and bend the new laser beam back towards its original path. Finally, use a third container of gelatin to try to bend the laser beam so that it lines up and travels along its original path.

Experiment with different numbers of gelatin containers to see how many different designs you can make with the beams of light. Also try to bend the light around various objects. Try to bend the laser around various objects so that the beam comes out on the other side in line with the original laser, but never having touched the object in its path. From what you know about light and how our vision works, can you think of interesting applications of bending light around objects?

Materials list

Materials	Store	Cost
Type S Laser Pointer	Canadian Tire	\$9.99
Brass and Steel Safety Pins, assorted sizes, 40-pack	Wal-Mart	\$2.67
Scotch Magic Tape, 6-pack	Wal-Mart	\$10.67
Staples Index Cards, 5"x8", 200-pack	Staples	\$7.01
Oxford Set of Mathematical Instruments (for protractor)	Wal-Mart	\$5.47
JELL-O Jelly Powder, Lime	Wal-Mart	\$.97
Ziploc brand Containers, Medium, Square, 3-pack	Wal-Mart	\$4.47
Sharp EL531XGBWH Scientific Calculator	Staples	\$12.94