QUEST
Day 1 Summer 2026

PROPERTIES OF WAVES

Introduction: Properties of waves are fundamental to our understanding of how energy and information move through different media. These concepts are key to many technologies used in our society. Telecommunications use fiber optics and radio wave to transmit data. Ultrasounds, Magnetic Resonance Imaging (MRI), and X-ray technologies are based on wave behaviors to assist medical professionals diagnose and treat patients. Instruments and audio equipment rely on frequency and amplitude for pitch and volume. Waves are used by seismologists to study earthquakes and understand the Earth's interior. Electromagnetic waves help scientists study distant stars and galaxies. Wave properties also help scientists test, understand and develop technologies in the world of quantum mechanics.

Prior Knowledge:
Students should understand that waves can transmit energy.

NGSS:
HS-PS4-1 Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.
HS-PS4-3 Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.
HS-PS4-4 Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
HS-PS4-5
Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

ENGAGE

Waves in nature: Tsunami
There are many videos online including these below:

Tsunami: Race Against Time | Nat Geo
https://youtu.be/fH2MtMByP10?si=JsK8cqNp2l7Nm8vl See 10:17 and 19:18

The 2004 Indian Ocean Tsunami As It Happened (beginning has waves)
https://youtu.be/rZ_ae1N6t5Y?si=YlZW6SqjLkf3eUVh

General Background Knowledge/Relevance
Exploring examples of wave mechanics helps students build a conceptual and practical understanding of how waves behave. It assists with students understanding how these behaviors are applied to real-world technologies. Wave concepts like interference, diffraction, refraction, and standing waves can be demonstrated to allow students to visualize these concepts. This visualization will help students better understand the quantum connection and its relationship to technologies that shape our world.

KJ Matsler, 2026 Developed for classroom use by Quantumforall.org under CC BY-NC-SA
Permission granted for classroom use only.

PROPERTIES OF WAVES
Station 1 Snaky

Objective: Students will be able to identify key parts of a wave and visualize wave interactions and properties.

Materials/Supplies:
Snaky and/or Slinky™
Rope (approximately 2 meters).

Part A: Slinky™ Snaky: Interactions at boundaries of different Media
The Snaky is a long helical ~1 inch diameter spring that can be used to demonstrate waves and other phenomena. A Slinky™ is a toy, a helical spring of a larger diameter that stretches more than the Snaky. Although both can be used in this explore, the snaky is less likely to get tangled and is therefore usually preferred.

A mechanical wave is a disturbance that moves through a physical medium without a net movement of matter. There are two ways matter can move to produce a wave: 1) the particles move parallel to the direction of the energy disturbance in longitudinal waves, or 2) the particles move perpendicular to the direction of the energy disturbance in transverse waves.

Waves react when entering a new medium. This will be explored using a Snaky and a Slinky™ connected or a Snaky and rope. A transverse pulse is a single disturbance produced by moving the Slinky™ or Snaky quickly to one side by "flicking" one's wrist. A longitudinal pulse is created by holding a Slinky on the floor and quickly pushing it forward (parallel to movement) and then pulling it back.

Safety Information: The Snaky and Slinky™ should be handled carefully. All activities should be performed on the floor or a long lab table. If one or both ends are released while stretched, the springs can snap back quickly, possibly causing injury and damaging the equipment. Never let go of the springs unless they are slack as there is the possibility of serious damage to the eyes.


Slinky

Attach a spring (Snaky) and a Slinky™ together using wire or twist ties, zip ties, or strong string wrapped around the connection.


Snaky Slinky


Snaky

Put the Snaky and Slinky on the floor and stretch it out for a reasonable distance as per your instructor.
NOTE: The distance is typically about 4 meters, just enough so the Snaky is slightly stretched. The Slinky will obviously stretch easier but be sure students do not stretch it too far nor just let it go. The latter will result in a mess of coiled springs that will not be salvageable. Typically assign someone to hold on to both and be very specific in telling them the consequences if they do not release them gently at the end.

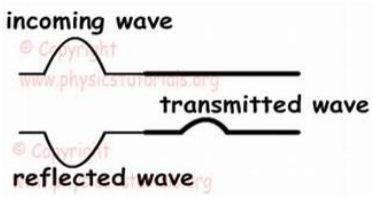
Determine which medium is "more dense".
Predict what will happen as a pulse travels the length of the connected pair.
Test the prediction and sketch what is observed: 1) before the pulse reaches the boundary and

KJ Matsler, 2026 Developed for classroom use by Quantumforall.org under CC BY-NC-SA
Permission granted for classroom use only.

2) after the pulse reaches the boundary.
What happens to the phases of the reflected and transmitted pulses at that point?

Repeat, paying particular attention to the phase of the pulse as it reaches the boundary between the Snaky and the Slinky™ (specifically whether the pulse is on the right or the left of side of the Snaky or the Slinky™). What happens to the phases of the reflected and transmitted pulses at that point? Does the Slinky move the same direction (L or R) as the Snaky was moving? Does the part of the wave that is reflected back onto the Snaky move in the same way the incoming wave was moving? Make sure this is accurately portrayed in your drawing. Compare with peer's drawings.
Ans: Part of the wave is transmitted, and part is reflected. The transmitted and reflected pulses are smaller. The reflected portion will not have a phase change.

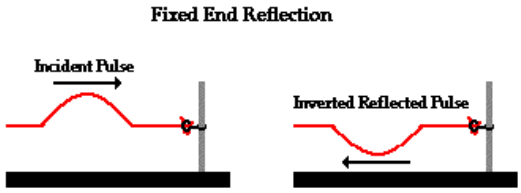
Is the result the same when the pulse is sent from the Slinky™ to the Snaky? Make a new drawing if it is not. Include information about the original and transmitted pulses.
Ans: A portion of the wave will still be transmitted, and a portion will be reflected. The reflected portion will have a phase change. When a pulse goes from the Slinky™ to the Snaky the reflected pulse will be out of phase because the pulse is going from a less dense medium to a denser medium.



Summarize your observations about the phases of the original and transmitted pulses in 1-2 sentences.

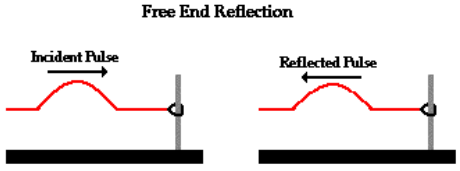
Part B: Snaky: Reflections from fixed or free end boundaries
This section will explain why the reflected pulse differed depending on where the pulse originated.
Using only a Snaky attach approximately 2 m of string or rope to one end.
Send a pulse from one end while holding the opposite end of the spring tightly to simulate a <u>rigid barrier.</u>

1. How do the phases of the original and reflected pulses compare when a wave is reflected from a rigid (or fixed) barrier?
   Ans: The reflected pulse will be out of phase from the original pulse.



Send a pulse from one end of the rope while holding the opposite end of the spring loosely by the string to simulate a non-rigid barrier.

1. How do the phases of the original and reflected pulses compare when a wave is reflected from a non-rigid barrier? [1]
   Ans: The reflected pulse will be in phase with the original pulse.



2. Which type of barrier was represented by the pulse going from the Snaky to the Slinky™?
   Ans: more to less dense

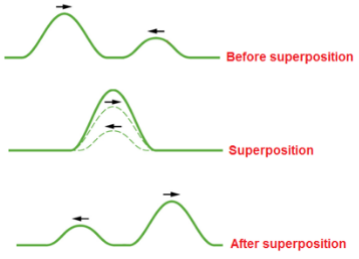
Part C: Snaky: Superposition and Interference

[1] Image source: physicsclassroom.com

KJ Matsler, 2026 Developed for classroom use by Quantumforall.org under CC BY-NC-SA
Permission granted for classroom use only.

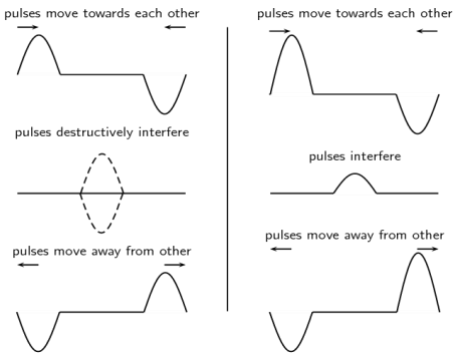
The principle of superposition states that when two or more disturbances (pulses) occupy the same space at the same time the resulting disturbance or pulse is the algebraic sum of the amplitudes (heights) of each pulse. Following the interaction the pulses pass through each other, each continuing in its original direction of travel, and the original amplitudes remain unchanged. Constructive interference occurs when two or more pulses meet each other to create a larger pulse. Such as crests meeting or troughs meeting. Destructive interference takes place when two or more pulses meet and result in a smaller amplitude disturbance. For example, a crest meeting a trough may result in an amplitude of zero or anything less than the largest amplitude.

Using pulses that are both pulled to the side (transverse pulse). Experiment with pulses of the same and different sizes and with pulses in phase (same side) and not in phase (opposite side).



3. What happens when the pulses meet? Do the pulses appear to pass through each other or do the pulses "bounce back" from the collision with another pulse?
   Ans: The pulses pass through one another

4. How does the maximum displacement (amplitude or height) where the pulses meet compare with the displacement of each pulse prior to the interaction?
   Ans: *If the pulses are on the same side the displacement is larger than either pulse alone. (Constructive interference) If the pulses are on opposite sides the displacement is smaller than either pulse alone. (Destructive Interference)*

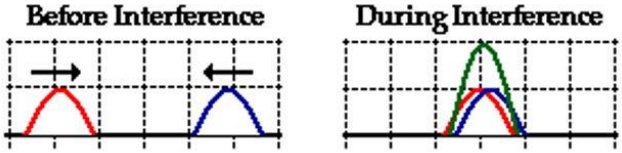


5. Sketch your observations including sketches of before pulses meet, when the pulses meet and after the pulses meet.

Interference is the phenomenon that occurs when two waves meet while traveling through the same medium. The interference of waves causes the medium to take on a shape that results from the net effect of the two individual waves upon the particles of the medium. When two upward displaced pulses having the same shape meet up with one another while traveling in opposite directions along a medium, the medium will take on the shape of an upward displaced pulse with twice the amplitude of the two interfering pulses. This type of interference is known as **constructive interference**. If an upward displaced pulse and a downward displaced pulse having the same shape meet up with one another while traveling in opposite directions along a medium, the two pulses will cancel each other's effect upon the displacement of the medium and the medium will assume the equilibrium position. This type of interference is known as **destructive interference**.

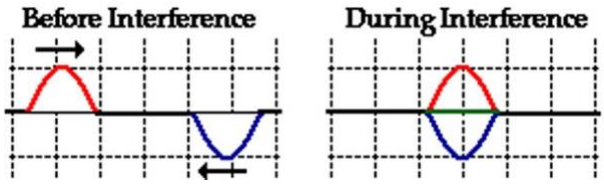
For the following diagrams Red=Wave 1, Blue=Wave 2, Green=Result of the combination

Constructive Interference:



KJ Matsler, 2026 Developed for classroom use by Quantumforall.org under CC BY-NC-SA
Permission granted for classroom use only.

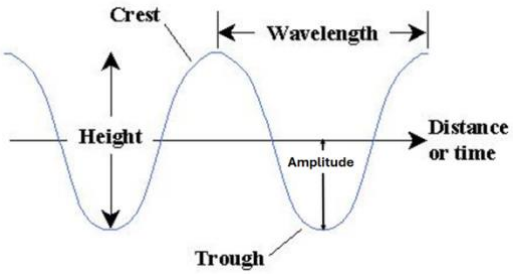
Destructive Interference:



Wave Terminology

Crest – The highest point or peak of a transverse wave above the rest position (equilibrium).

Trough – The lowest point of a transverse wave below the rest position (equilibrium)



Wavelength – The distance between two consecutive points in phase on a wave. Common measurement is between crest of to crest or trough to trough.

Wave Height – The vertical distance between the crest of a wave and the trough of a wave.

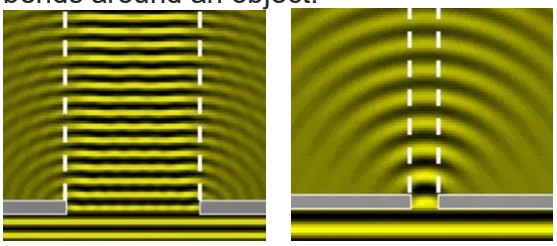
Amplitude – The maximum displacement of a point on a wave from its rest position. One half of the wave height.

Frequency – How many wavelengths pass a fixed point each second.

Reflection – Occurs when a wave strikes an object and bounces off of it.

Refraction – The bending of a wave caused by a change in its speed as it moves from one medium to another.

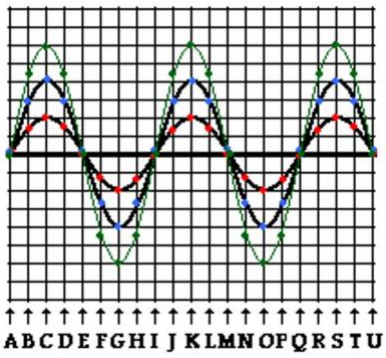
Diffraction - The property of waves where an object causes a wave to change direction as it bends around an object.



Wave Interference – The combined effect of individual waves meeting at the same place and at the same time.

Constructive Interference – When two or more waves overlap and their displacements add together, creating a wave with greater amplitude.

Destructive Interference – When two or more waves overlap and their displacements cancel each other out, resulting in a wave with reduced or zero amplitude.

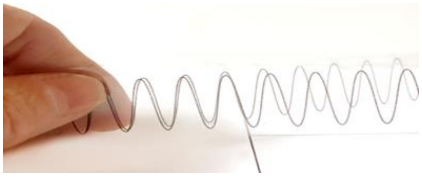


Principle of Superposition – When two or more waves cross at a point, the displacement at that point is equal to the sum of the displacements of the individual waves. Video link for standing wave:
https://youtu.be/zBMaDdLjCKA?si=d4Hb7q2LeyvrDEHq

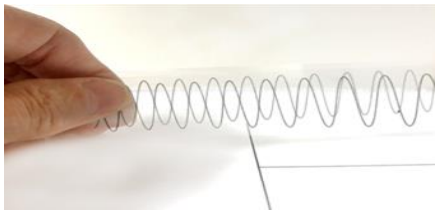
KJ Matsler, 2026 Developed for classroom use by Quantumforall.org under CC BY-NC-SA
Permission granted for classroom use only.

EXPLORE
Station 2
Modeling Superposition

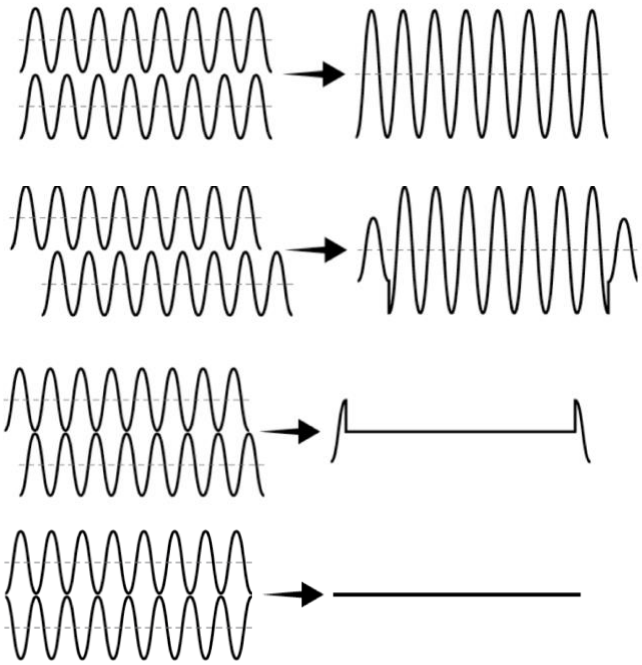
***NOTE: This activity is a modification from The Perimeter Institute's Resource: Investigating the Nature of the Electron — https://perimeterinstitute.ca/outreach**. For more activities on gravitational waves go to Perimeter Institute Resources: Wave Model Applications or Gravitational Waves*



1. Use the transparencies provided and place one on top of the other so they "match" and look like one wave. Observe at several intervals and sketch how the resulting wave would appear.
2. Slowly slide ONE of the transparencies to the right. Observe at several intervals and sketch what the resulting wave would appear. Describe how this interference relates to superposition and how the amplitude would be affected.



ANS: The top part (arch) of the wave is called a crest, and the opposite (going down) is called a trough. When two waves overlap it is called superposition. When two arches match up (same direction) it is called constructive interference, and the amplitude is the sum of the two individual amplitudes. When they do not match up, it is called destructive interference, resulting in less amplitude than the larger original amplitude. Below are some examples students could model with the wave transparencies. The resultant wave is shown on the right side of the arrow.
Identify the type of superposition (constructive, destructive).

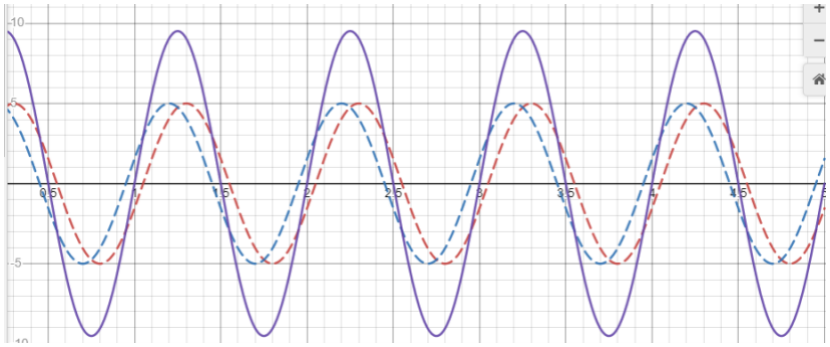


KJ Matsler, 2026 Developed for classroom use by Quantumforall.org under CC BY-NC-SA
Permission granted for classroom use only.

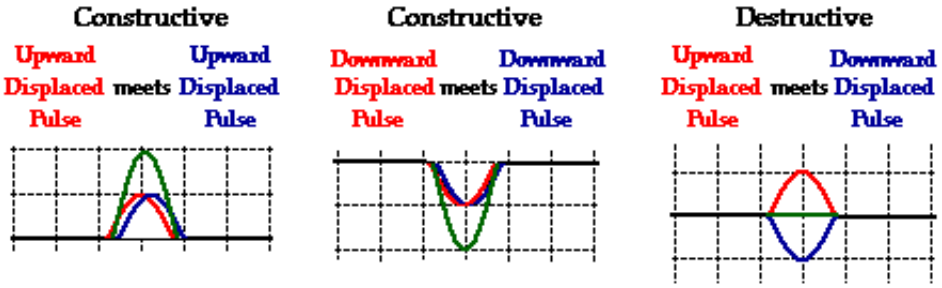
EXPLORE
Station 3 Desmos Simulation

Open the Desmos Standing Waves Simulation https://www.desmos.com/calculator/nk2gqsfk9k and screen or phone capture different interference patterns. The Red Wave is #1, the Blue Wave is #2 and the purple wave is the superposition of the two waves. Vary the frequency (i.e. change the wavelength), run the simulation, pause the simulation and sketch the resulting waveform due to the superposition of the red and blue waves. Repeat at least 3 times.

Teacher notes: When the red and blue wave crests overlap the waves are in phase and the greatest inerference takes place. In the image below the red and blue waves are out of phase.



1. Discuss with your group where there was constructive and destructive interference in the activity.
2. The diagrams below show two waves (i.e. similar to in a Snaky) where one is blue and the other is red. The waves are interfering in such a way as to produce a resultant shape in a medium; the resultant is shown in green. In two cases (on the left and in the middle), constructive interference occurs and in the third case (on the far right, destructive interference occurs.



KJ Matsler, 2026 Developed for classroom use by Quantumforall.org under CC BY-NC-SA
Permission granted for classroom use only.

EXPLORE
Diffraction

For more detailed background, go to IQC Educator's Guide: Measuring the Width of Your Hair

Objectives:
Students will explore the behavior of wave diffraction.
Students will understand interference is a wave property that occurs when two waves meet and interference applies to multiple systems, including those on the quantum-mechanical scale. Understanding interference is key to quantum technologies including quantum computing and quantum sensing.

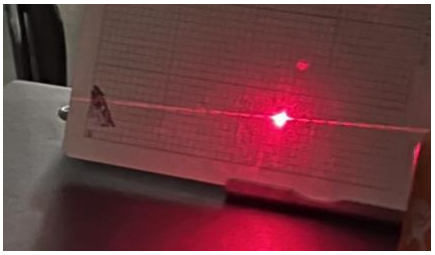
Materials/Supplies:
Laser pointer (red laser)
A strand of hair
Measuring tape/ruler/meter stick
Whiteboard or wall with paper
Tape, Index card, medium binder clip (as a stand), scissors
Calculator
Laser Safety sheet to be at each station/group



Instructions:
Divide students into smaller groups so half the room (half the groups) will have red lasers and half will have green.

Student instructions are provided in the Appendix.

1. Mount the hair so it stands vertically.
2. Create a long, clear path from the mount to the wall.
3. Measure the distance "d" from the hair to the wall.
4. Shine the laser onto the wall or white board through the hair. Be sure to keep the laser steady.[2]
5. Observe the pattern made by the laser hitting the hair. Trace the pattern in the space provided on the worksheet.
6. Measure the separations "s" between the dark spots.
7. Calculate the width "w" of your hair using the following formula:



$$w = \frac{2d\lambda}{s}$$

w = hair width
d = distance from the hair to the wall
s = separation of dark spots
λ = wavelength of the laser

Have students compare the separations between the dark spots for different colored lasers. They may do a gallery walk to observe experiments of different groups to compare different type, colors of hair, and textures. If there is time, they can put multiple hairs on one index card to compare patterns.

[2] This can be done by setting the laser on a book or another support which could also be an engineering design project.

KJ Matsler, 2026 Developed for classroom use by Quantumforall.org under CC BY-NC-SA
Permission granted for classroom use only.

The relationship between the width of the hair and the size of the pattern is not what one might expect. A smaller hair results in a larger interference pattern, the opposite of what we would expect from other behaviors of light like shadows. A full derivation of the formula is possible with some trigonometry (see Appendix), but there are easier, hands-on ways to convince students that this is the case.

Gauge (AWG)	Width (mm)
24	0.511
28	0.321
30	0.255
34	0.160

Introducing the activity by showing students objects with a known width and demonstrating that thinner objects produce wider diffraction patterns. Jewelry wire is particularly useful for this, as it comes in a variety of sizes that are easy to distinguish by eye and produce clear interference patterns, with 28-34 gauge being particularly effective and easily accessible at craft stores or online retailers. Most human hairs are between one hundred and one thousandth of a centimeter wide. Students may be interested in comparing different types and colors of hair, including artificial hair.

Alternative options include using a laser printer to print either lines or slit on overhead transparencies. Most laser printers have a resolution of 600 dots-per-inch (dpi), translating to 0.04 mm, making it possible to print objects comparable to the width of a hair. The patterns, while quite visible, will not be as clean as the hair or wire since the printer leaves gaps between the dots that produce other interference patterns. A third option would be to use a 3D printer, where the height resolution (layer height) can be as small as 0.1 mm.[3]

Lasers need to be low wattage for safety.
Red laser wavelength = 650 nanometers= 6.5×10^{-5} cm
Green laser wavelength = 532 nanometers = $5.32\ 10^{-5}$ m

A darker room is ideal for seeing the interference pattern of the laser on the wall. Students will be able to see the constructive and destructive interference patterns (bright and dark spots). To see the interference pattern clearly and gather accurate measurements, the mount for the hair should be at least 2 meters away from the wall.

Make sure to review laser safety with students before performing this activity.
Groups of 2-3 students are recommended for this activity. Turning the lasers may give a clearer diffraction pattern, especially if using inexpensive lasers.

Students should share findings and observations from the Explore activity and the teacher will introduce concepts and vocabulary on parts of a wave and terminology as appropriate. Teachers should emphasize that different wavelengths produce different gaps in the diffraction patterns (red and green lasers) and therefore diffraction can be used to separate colors. Students can also use diffraction glasses to see that diffraction separates the colors of white light by viewing ceiling lights. Refraction will also spread out the spectrum, which is explored in the next section.

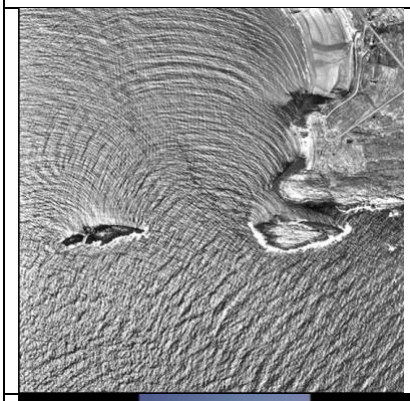
[3] For more detailed background, go to IQC Educator's Guide: Measuring the Width of Your Hair

KJ Matsler, 2026 Developed for classroom use by Quantumforall.org under CC BY-NC-SA
Permission granted for classroom use only.

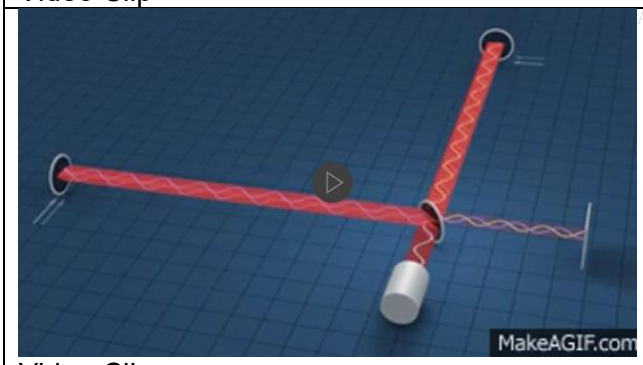
EXPLAIN and REVIEW
Overview

View the Veritasium video: The Original Double Slit Experiment (start around 4:00)
https://youtu.be/luv6hY6zsd0?si=1TTXR4sOLxFQC-2W

Photos and videos can be utilized to help students identify different properties and components of waves such as the one shown. One suggestion would be to assign a wave property to each group and have students find their own examples or even find an example with multiple properties. The following images and video clips may be used for group evaluation or individual evaluation. Have students identify the terminology/vocabulary related to wave properties.

Evaluate Image/Video	***Possible Responses***
	Diffraction Wave Interference Superposition Wavelength Frequency Crest Trough
 Video Clip	Wave Heights Amplitude Standing Waves Crest Trough
 Image	Wave Interference Constructive and Destructive Interference Superposition Amplitude Wave Height Wavelengths Crest Trough

KJ Matsler, 2026 Developed for classroom use by Quantumforall.org under CC BY-NC-SA
Permission granted for classroom use only.

 Video Clip	Standing Waves Amplitude Wave Height Crest Trough
 Video Clip	Reflection Wave Interference Constructive and Destructive Interference Superposition Crest Trough Wavelength Frequency
 Video Clip	Wave Interference Constructive and Destructive Interference Superposition Crest Trough

KJ Matsler, 2026 Developed for classroom use by Quantumforall.org under CC BY-NC-SA
Permission granted for classroom use only.