Lesson Plan:
Particle or Wave
Adapted for QuanTime NM

LEARNING OBJECTIVES

At the end of the 40-minute period, the students should be able to:

1. Explain particle-wave duality.
2. Describe one way that light acts as a wave and one way that light acts as a particle.

BACKGROUND INFO FOR TEACHERS (teacher notes)

Focus: Particle-Wave Duality

For this activity, the teacher will build on fundamental principles of light through a demonstration of how classical particles (sand) behave, and how waves (lasers) behave. Light exhibits wave-particle duality, which means it has properties of both waves and particles.

Light as a Wave

Light is an electromagnetic wave and therefore has wave-like properties. It spreads out or **diffracts** after passing through an opening. It bends or **refracts** when moving into a different medium (like lenses in our eyes or glasses or contact lenses or even water). It **reflects** when it hits a barrier or mirror. It adds together or cancels out with other waves through a process called **interference**. All of these properties are observed with other types of waves (like water waves or sound waves), so light has wave-like properties.

Light as a Particle

Light acts as a particle, which we call “photons”, when it interacts with matter such as atoms or molecules. Atoms have electrons orbiting the nucleus at distinct energy levels. We call the energy levels “quantized” because they are discreet steps in energy – like steps on a staircase instead of a ramp of continuous levels. When a particle of light or photon of just the right energy hits the electron, the electron will absorb the photon and energy and jump up to the next energy level.

Notes

It’s a bit difficult to model the particle-like nature of light in a classroom, so we will rely on a classical model (sand) and then simulations/videos for the waves and quantum models (photons). We’ll wrap up with tie in to superposition and measurement.

Superposition is when a particle exists in a combination of two states. In this lesson, we’ll see a video describing how photons or electrons will pass through both a left slit and a right slit at the same time.

Measurement is when we observe the state of a quantum object. When a particle is in a superposition, measurement will “collapse” that superposition such that it is only in one state or the other. In this lesson, we’ll see a video describing that when scientists measure which slit the quantum particle goes through, we no longer see the interference pattern, indicating that the particle suddenly only goes through the right or left slight instead of both (as in before the measurement).

Watch a video: https://www.youtube.com/watch?v=0EzjZyY_GWU

CONNECTIONS TO SCIENCE STANDARDS

1-PS4-3	Plan and conduct investigations to determine the effect of placing objects made with different materials in the path of a beam of light

MS-PS4-2	Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials
HS-PS4-3	Waves and their Applications in Technologies for Information Transfer: 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.v

PROCEDURE

Preparation

- Understand Teacher's Notes.

Materials

- Teacher's Notes/Lesson
- A cup with a slit cut on the bottom. The slit should be wide enough to allow fine sand to go through it.
- A second cup with two slits that are about 1-1.5 cm apart.
- Fine sand
- Paper plate or paper towel or sheet of paper
- Low watt lasers
- A laptop or computer with access to the internet

Safety Note: Do not shine the laser at bodies. Do not shine the laser at eye-level. Do not shine the laser on any reflective surface. If the laser enters the eye, severe damage could occur. Have students all stand on one side of the room and shine lasers toward the empty side, or direct them to aim the lasers only at the floor (if not reflective) or ceiling (if not reflective).

Time: 40 min
Middle School – High School

DIFFRACTION

Step 1: (~6-8 min) Ask the students "*What do you think will happen if we put sand in a cup with a slit on the bottom and then gently raise the cup so the sand can fall through the slit? Draw your prediction.*"

Give them a few minutes to discuss and draw.

Pass out a cup with a single slit to each student group. With the cup on the table, pour about 2 Tbsp of sand into the cup.

Instruct the students to "*Gently lift the cup about 3 cm (3 finger widths) above the surface and observe what happens. Did your prediction match your observation? Why or why not?*"

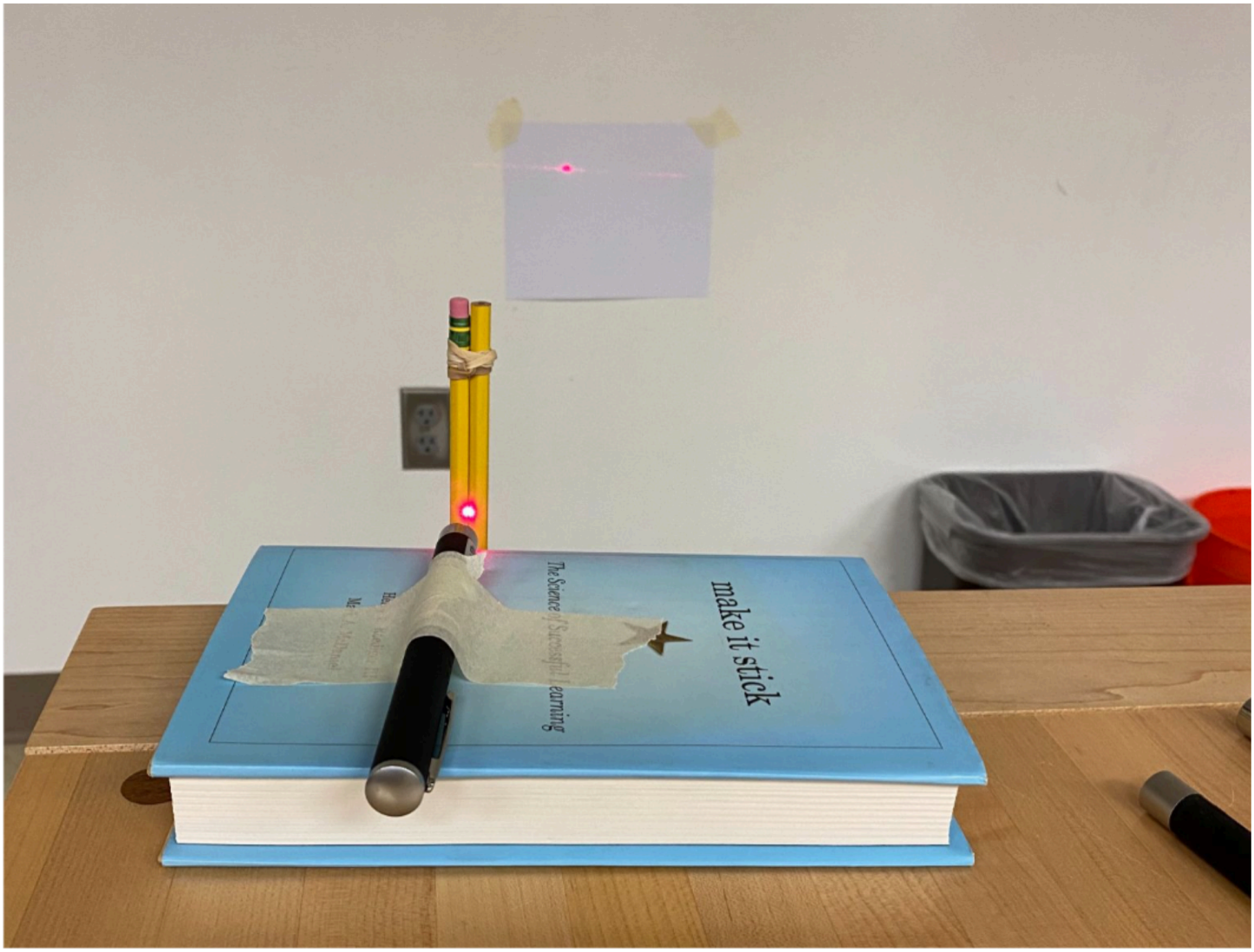
Explain to the students that “Grains of sand are localized particles.” Here are some questions for discussion:
“*What are other examples of particle behavior as it passes through slits?”*

- Rolling balls through a gap in the wall.

Step 2: (~6-8 min) Ask the students *“Would you expect waves to behave the same or differently? Draw your prediction.”*

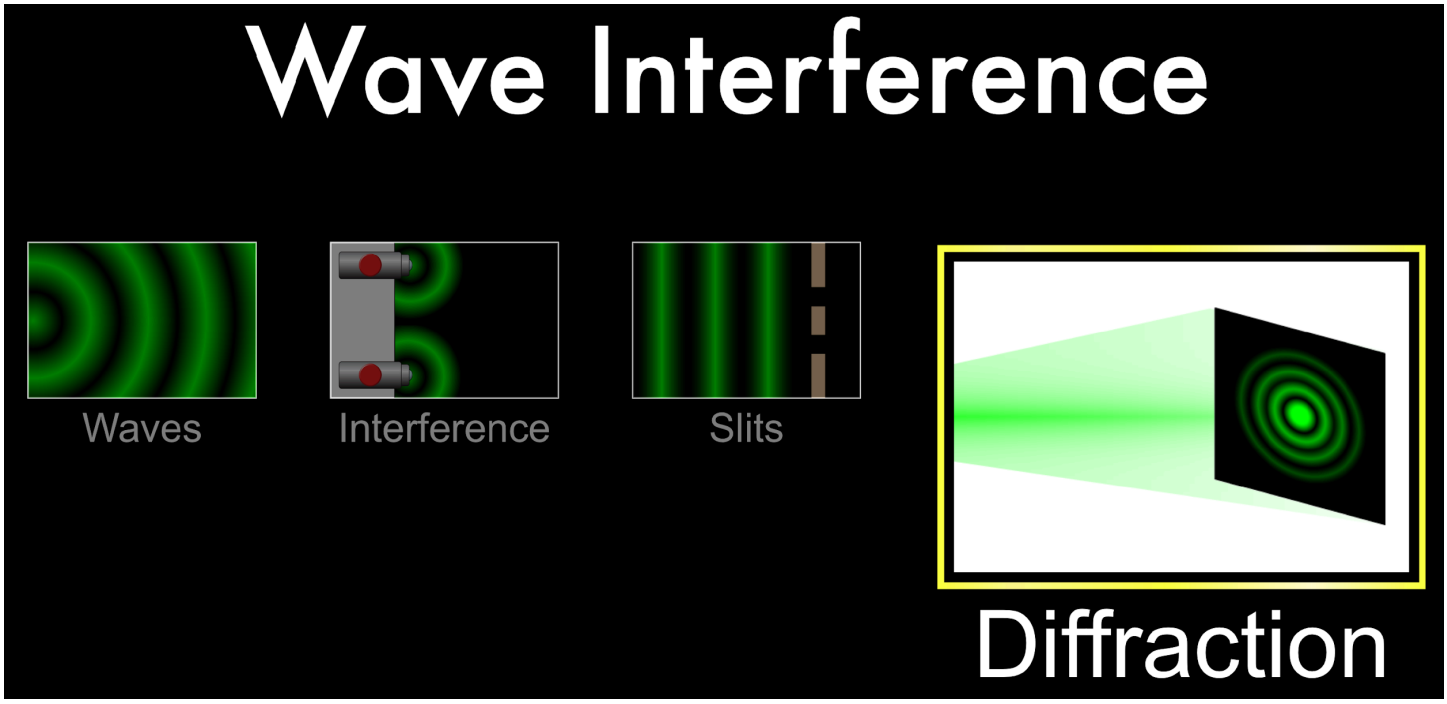
Give them a few minutes to discuss and draw.

Instruct students to take two pencils and hold them so they are touching. If needed, they can use rubber bands to hold them together. **REVIEW LASER SAFETY RULES** before passing out lasers to student groups. Ask the students to “*Test your prediction by shining the laser through the gap between the pencils. Observe what happens. Did your prediction match your observation?”*
A setup like this may be useful:

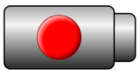


Explain to students that "*The laser light is acting like a wave. When waves pass through a small opening, they diffract or spread out. We see many bright spots on the wall as the crests of the waves hit the wall. This can be hard to visualize, so let's use a simulation tool."*

Step 3: (~4 min) Navigate to https://phet.colorado.edu/sims/html/wave-interference/latest/wave-interference_all.html and click on "Diffraction":



Students can choose between different diffraction patterns on the left. They can activate the laser by pressing the round red button on the laser at the top:



Give students a few minutes to explore laser light as it diffracts through different openings.

Which opening best matches the pattern that we saw from the laser through the pencils? Students should note that the single square opening looks closest to our pattern, but we only saw the horizontal pattern of light (not the vertical one shown in the image below). This is because our opening did not have the hard cut off on the top and bottom like a square does.

Step 4: (optional) (~2-4 min) If you have time, ask students to add a second set of pencils perpendicular to the first set – does the pattern look like the one on the simulator now?

INTERFERENCE

Step 5: (~4-6 min) Ask the students "*What do you think will happen if we put sand in a cup with TWO slits on the bottom and then gently raise the cup so the sand can fall through the slits? Draw your prediction.*"

Give them a few minutes to discuss and draw.

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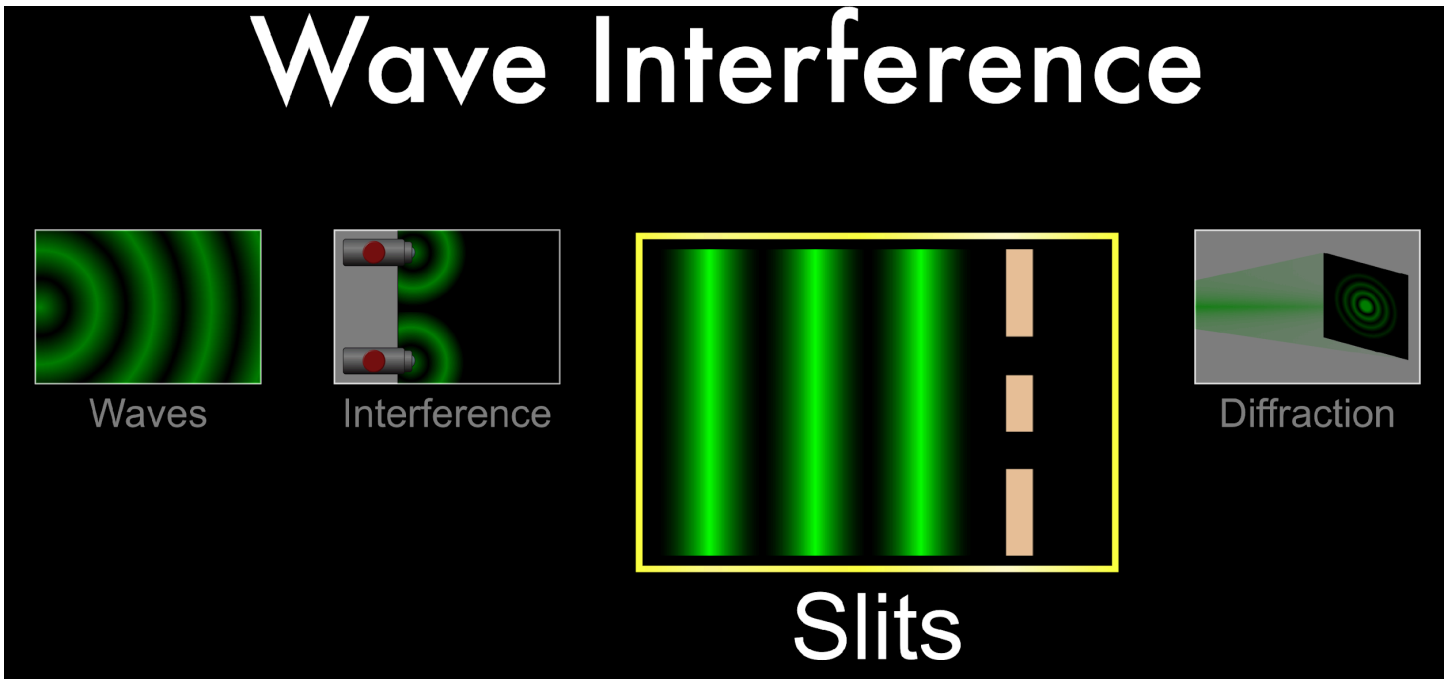
Pass out a cup with two slits to each student group. With the cup on the table, pour about 2 Tbsp of sand into the cup.

Instruct the students to "*Gently lift the cup about 3 cm (3 finger widths) above the surface and observe what happens. Did your prediction match your observation? Why or why not?*"

Step 6: (~6-8 min) Ask the students *"Would you expect waves to behave the same or differently? Draw your prediction and explain it."*

Give the students a few minutes to discuss amongst themselves, draw a predicted pattern, and reason through their explanation.

Navigate to https://phet.colorado.edu/sims/html/wave-interference/latest/wave-interference_all.html and click on "Slits":



Students should select "Two Slits" from the drop down on the left. Encourage the students to explore what happens when waves pass through a slit. They can select water waves, sound waves, or light waves in this tool:

Pressing the green button on the left will start the waves. They can check the "Screen" box to see the pattern at the end.

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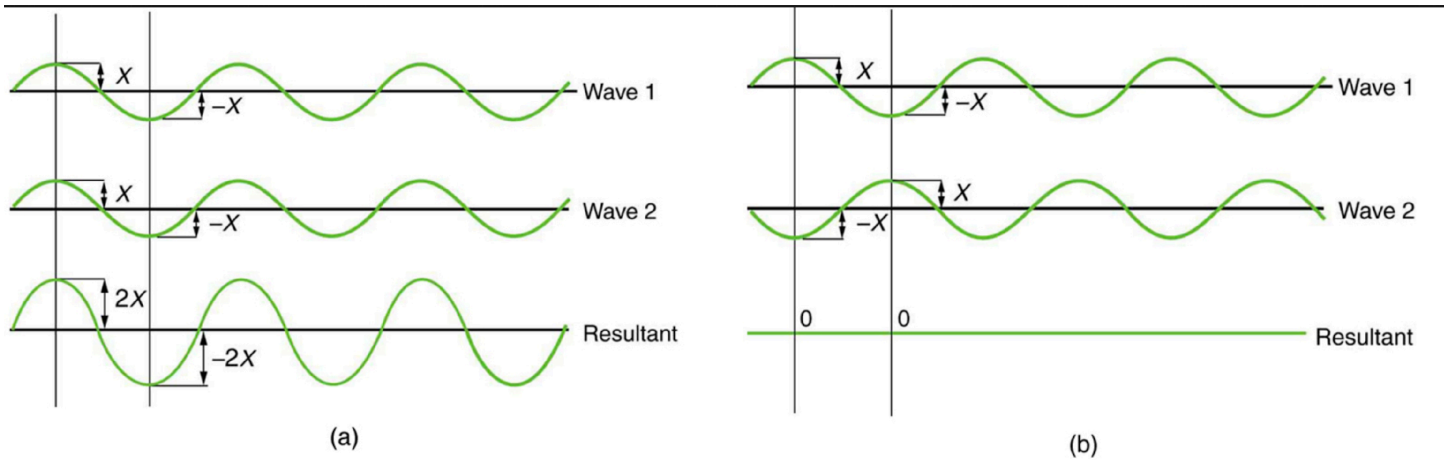
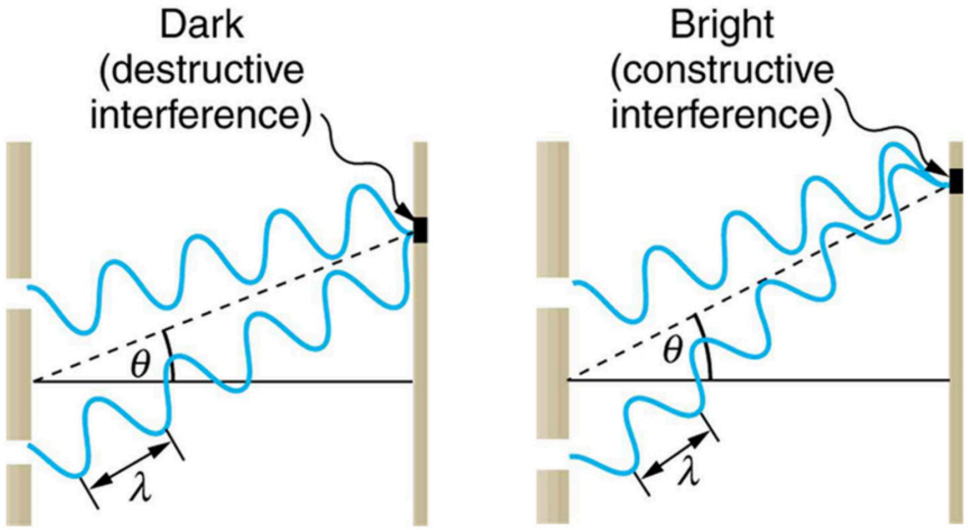
Explain to students that "*The pattern at the end is even more complicated than with a single slit. Not only is the wave diffracting through each slit, but it's also interfering as the waves through each slit overlap with the wave through the other slit. Interference just means "adding up"."* Here you can show examples of constructive and destructive interference:



Reference: https://courses.lumenlearning.com/suny-physics/chapter/27-3-youngs-double-slit-experiment/

The same thing happens when our light through the slits is interfering:



Reference: https://courses.lumenlearning.com/suny-physics/chapter/27-3-youngs-double-slit-experiment/

Step 7: (~6 min). Ask the students "If we had a light source like a laser that only emitted one photon of light at a time, what do you think we would see? Would the pattern look more like the sand or the laser?"

Give the students a few minutes to discuss amongst themselves and come to a prediction.

Tell students “Scientists were curious about this too, so they tested these predictions. The first experiment to do this used electrons instead of photons, but photons will act the same way. Let’s watch!”

Show the video: https://www.youtube.com/watch?v=0EzjZyY_GWU

Tie to superposition: In the double slit experiment when using single particles instead of waves, the particles create an interference pattern just like the waves. This means they would have had to go through both slits at the same time. In quantum science, we call this idea superposition. The particle was in a superposition of going through the left slit and the right slit.

Tie to measurement: When scientists explored further and actually measured which slit the single particles went through, there was no more interference pattern. It looked like the results from our sand (classical particles instead of quantum particles) going through two slits. This is because measuring something that is in a superposition will collapse the state into just one or the other: left or right slit.

ELABORATE/EXTEND

To add a laboratory element, these same concepts and tools can be used in this “Interference & Measurement: Measuring the Width of Your Hair” activity developed by the University of Waterloo’s Institute for Quantum Computing: https://q12education.org/project/interference-measurement https://q12education.org/project/interference-measurement

Additional Resources:

- The math behind double slit interference: https://courses.lumenlearning.com/suny-physics/chapter/27-3-youngs-double-slit-experiment/
- Similar Quantum for All lesson “Particle or Wave?”: https://q12education.org/wp-content/uploads/2024/04/Hands-on_Particle-or-Wave-HS-QuantumforAll.pdf
- Similar APS Physics Quest lesson “Particle Wave Duality”: https://www.aps.org/learning-resources/particle-wave-duality
- Similar Wonders of Quantum Physics lesson “Wave Particle Duality”: https://q12education.org/project/wave-particle-duality

Acknowledgements:

This material is based upon similar lesson plans created by Quantum for All lesson entitled “Particle or Wave, the APS Physics Quest lesson entitled “Particle Wave Duality”, and the Wonders of Quantum Physics lesson entitled “Wave Particle Duality”.

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