PARTICLE OR WAVE?

LEARNING OBJECTIVE
Students will observe light properties demonstrating the dual nature of light in order to understand how light behaves as both a wave and a particle.

NGSS CONNECTIONS
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.

QIS KEY CONCEPTS
C2.2 Students will compare and contrast quantized energy levels to continuous energy ranges.
C2.3 Students will be able to describe the experimental evidence for quantization.
P2.2 A quantum state is a mathematical representation of a physical system, such as an atom, and provides the basis for processing quantum information. Students will describe that many properties of quantum systems are quantized, meaning that they are restricted to discrete values, and explain experimental evidence for quantization.

MATERIALS:
A cup with a slit cut on the bottom. The slit should barely be wide enough to allow fine sand to go through it. Use another cup and make 2 slits (similar to one slit in size) that are about 1-1.5 cm apart.
Fine sand
Paper plate, paper towels, or sheet of paper
Pencils, rubber bands
Low watt lasers (i.e. cat laser toy) of different colors

SAFETY: Do not shine the laser on any reflective surface. Do not shine the laser in a manner that the beam enters an eye as severe damage could occur. Use the surface provided or the ceiling to observe patterns discussed in this activity.

ENGAGE or PHENOMENON
Predict what will happen if you place sand in a cup with a single slit on the bottom and then gently raise the cup so the sand can fall through the slit(s). Draw your prediction.

Place about 2T of fine sand in a cup with a single slit or the 3D holder provided (that has slits) while it is resting on a paper plate.

Predict what will happen when you gently lift the cup/holder about 3 cm above the surface. Draw the predicted profile pattern the sand will leave on the surface. Justify your prediction.

Gently lift the cup/holder about 3 cm above the surface and observe.
Did your prediction match your observation? Explain.
Repeat using two slits that are about 1cm apart from each other.
Grains of sand are localized particles.
How do two grains of sand interact when they arrive at the same location at the same time?

Make a general statement about how classical localized particles behave when passing through a double-slit apparatus and describe the pattern they make after they have passed through the apparatus.

**EXPLORE**
Take two pencils and hold them so they are touching, use rubberbands if necessary. Based on observations from the sand phenomenon, predict what will be observed when light is passed between the two pencils representing the single slit.
Sketch your prediction and provide your reasoning.

Test your prediction by observing a LED. Light the LED using the coin battery provided and hold the LED/coin device in one hand while holding the pencils in the other hand. View the LED through the pencil slit by placing the pencils vertically and close to your eye. Place the LED horizontal (i.e. the bright end facing the pencils) about 0.35 m from the pencil.
Draw what you see and compare to your prediction.

*NOTE: IF a low wattage red laser is available, the teacher can set up a laser beam through the two pencils as shown in the picture. However, exercise caution and practice safety because the laser can reflect off the screen/wall into someone’s eyes.*

Based on prior observations using double slits and sand, predict what will be observed if the light passes through a double slit.

*Note: For a double slit, use commercial diffraction grating, which is hundreds of small slits.*

Observe the LED by looking through the diffraction grating.
Record your observations.
Does this model support the wave or particle nature of light? Justify your answer.

Use a small wattage laser and a diffraction grating to observe the behavior of light as it passes through the small slits.
Compare/contrast the patterns formed from light going through a single slit and a double slit.

Use your observations to classify light as a wave or a particle. Be prepared to defend your answer.

**EXPLAIN**
How do the activities in the Explore support light as a wave? As a particle?

Ans: Analogy for Light
Sand in cup = Particles of light
Sand falling through slits = Photons going through slits
Sand particles hit each other and change direction = Photons hit each other and change direction

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**Comparison/Summary**

**Particles**
- Localized
- One place at a time
- Can bounce off other particles
- Forms a 2 pile distribution

**Waves**
- Non-localized (delocalized)
- Spread out
- Can pass through other waves (interfere)
- Forms an interference pattern

**EXTEND**

Tennis balls are sent toward two slits. The distributions of the marks they make on a wall on the other side of the barrier when one slit is open are shown below. Based on the first two diagrams, which distribution would result if both sides were open at the same time? **ANS: B**

Photo credit: Perimeter Institute

![Tennis ball distributions](image1.png)

**Explanation**

Explain how water waves would spread out behind a double slit barrier as compared to light. **ANS: Both interfere.**

![Water waves](image2.png)

**Using data and evidence from your observations, provide a scientific description of light.**

**ANS: may vary but should include descriptions of how light has properties of particles (like grains of sand) and properties of waves (bending such as around diffraction gratings and interference).**

**Predict whether electrons are particles or waves and identify characteristics based on your prediction.**

How would electrons appear if they passed through double slits?

Research what scientists have found to happen experimentally.
How does data support a wave-behavior description of electrons?
How does data support a particle-behavior description of electrons?
Write a paragraph describing the results of the double-slit experiment if electrons were used. Use language your younger sibling could understand.

**TEACHER NOTES**

**BACKGROUND**
Note: A more detailed description and explanation for this activity as well as others can be downloaded from *The Perimeter Institute Resources, The Challenge of Quantum Reality.*
[https://perimeterinstitute.ca/outreach](https://perimeterinstitute.ca/outreach)

Classical particles move as localized particles and in the double-slit experiment they produce a known distribution.

Waves have characteristics common to water and light and interference is easy to see. The interference can be explained in terms of destructive or constructive interference. Perimeter Institute has an activity using transparencies and wave patterns to help students understand this type of interference.

There are countless applications students should be aware of regarding properties of light. A few include sensors, solar panels, spectroscopy, CAT scans, LCDs, and measuring small displacements that are undiscernible to the human eye.

**Sample results for shining a laser through the diffraction grating. Note: Green lasers are usually very strong, use with caution and do not allow students to play with them unsupervised.**

Below is a picture of laser passing through a commercially designed double slit. If available, use different colored lasers and compare the distribution of spots. **NOTE: one of the safest ways to do this is to shine the lasers on the ceiling.**
Video Resources:
Electrons https://www.youtube.com/watch?v=ZqS8Jjkk1Hl
Double Slit Interference Buildup https://www.youtube.com/watch?v=H11hJWlcUY0

How does data support a wave-behavior description of electrons?
TN: Presence of interference patterns suggest wave-like behavior

How does data support a particle-behavior description of electrons?
TN: Detection of individual, localized electrons illustrate particle-like behavior.

Write a paragraph describing the results of the double-slit experiment if electrons were used. Use language your younger sibling could understand.
TN: Electrons are emitted and detected as particles. This behavior occurs when electrons are measured with a detector. The interference pattern that builds up over time illustrates wave-like behavior. So, the electron double slit experiment provides evidence of both particle-like behavior and wave-like behavior. Electrons can behave like particles OR waves, depending on how we observe them. Different models can describe the same phenomena but ALL quantum objects (protons, neutrons, atoms, molecules) exhibit wave-particle duality.