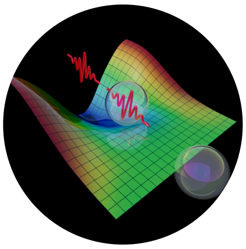

Quantum Mechanics Lesson 4: Wave Properties of Particles

Wave Properties of Particles

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Grade Level	12th Grade	**Duration**	3 days
Subject	Science		
Course	Physics		

Essential Question

Is light a wave or a particle? Is a particle a wave?

Summary

In this lesson, students observe standing waves in strings, rods, pipes, and hoops through videos and teacher demonstrations. Students investigate the ‘particle in a box’ problem using a PhET simulation, which presents the electron as a wave with discrete wavelengths. Students investigate wave functions as orbitals in atoms. Students investigate and explain the spectral emission of hydrogen atoms.

Snapshot

Engage

Students complete the I Think/We Think instructional strategy about standing waves and observe a demonstration of a real standing wave on a string.

Explore

The students observe the teacher demonstrations about standing waves in strings, rods, pipes and hoops through videos.

Explain

Students investigate the ‘particle in a box’ problem using a PhET simulation, which presents the electron as a wave with discrete wavelengths.

Extend

Students investigate wave functions as orbitals in atoms through videos and readings. Students investigate and explain the spectral emission of hydrogen atoms using spectroscopes and lamps.

Evaluate

Students use the 3-2-1 instructional strategy to show what they have learned about wave properties in particles.

Standards

Next Generation Science Standards (Grade 3)

3-PS2-3: Ask questions to determine cause and effect relationships of electric or magnetic interactions between two objects not in contact with each other.

Next Generation Science Standards (Grade 3)

HS-PS4-1: Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
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.

Oklahoma Academic Standards (Physical Science)

PS.PS3.3 : Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*

Attachments

- Hydrogen Emission Lines Handout-Student Handout - Spanish.docx
- Hydrogen Emission Lines Handout-Student Handout - Spanish.pdf
- Hydrogen Emission Lines Handout-Student Handout.docx
- Hydrogen Emission Lines Handout-Student Handout.pdf
- Lesson Slides-Wave Properties of Particles.pptx
- Particle in a Box Student Handout - Spanish.docx
- Particle in a Box Student Handout - Spanish.pdf
- Particle in a Box Student Handout.docx
- Particle in a Box Student Handout.pdf
- Teacher's Guide_ Hydrogen Emission Lines Handout.docx
- Teacher's Guide_ Hydrogen Emission Lines Handout.pdf
- Teacher's Guide_ Particle in a Box.docx
- Teacher's Guide_ Particle in a Box.pdf
- Teacher's Guide_ Wave Functions in Atoms.docx
- Teacher's Guide_ Wave Functions in Atoms.pdf
- Wave Functions in Atoms Student Handout - Spanish.docx
- Wave Functions in Atoms Student Handout - Spanish.pdf
- Wave Functions in Atoms Student Handout.docx
- Wave Functions in Atoms Student Handout.pdf

Materials

- Lesson Slides (attached)
- Particle in a Box Student Handout (attached, one per student)
- Wave Functions in Atoms Student Handout (attached, one per student)
- Hydrogen Emission Lines Student Handout (attached, one per student)
- Teacher’s Guide: Particle in a Box handout (attached, optional)
- Teacher’s Guide: Wave Functions in Atoms handout (attached, optional)
- Teacher’s Guide: Hydrogen Emission Lines handout (attached, optional)
- Singing rods demonstration kit
    - **Materials Included in Kit:**
    - Aluminum rod, ½" diameter, 24" long
    - Aluminum rod, ½" diameter, 18" long
    - Aluminum tube, ½" o.d., 24" long
    - Metal rod, ?" diameter, 24" long

    - Rosin bag, 2 oz
- Sound tubes
    - **Materials Included in Kit:**
    - Steel tube, 2" diameter, 17" long
    - Wire disks, 2¼" diameter, 20 mesh, 3
- Whirly tube
- Standing wave generator- https://www.flinnsci.com/standing-wave-generator/ap6161/
- Adjustable strobe light
- Science Notebooks
- Computer or access to computer lab (1 per 2 students)
- Spectroscopes or spectral slides
- Hydrogen and helium lamps
- Lamp power supply

30 minutes

Engage

Use the attached **Lesson slides** to present the lesson.

Display **slides 3-4** to introduce the essential questions and learning objective to the class.

Display **slide 5**. Show the video called **What is a Standing Wave?** Answer a prompt about the video. Encourage students to jot down some notes and key points in their Science Notebooks while watching the video.

Embedded video

https://youtube.com/watch?v=aTaT1orpHg8

Display **slide 8**. Explain to the class that they are to participate in another "I Think/We Think." Ask them to create a new T-Chart on a clean sheet of paper in their Science Notebook. Have them label the left side "I Think" and the right side "We Think."

On the left side under "I Think," have the students independently write their response to the prompt: "How are standing waves dependent on frequency and why do only certain frequencies produce standing waves?" Give students two minutes to write their answers. After two minutes, ask students to find a partner. Ask them to share with one another what they have written on their paper and come up with a new response.

Ask the students to write down the new response on the right side under "We Think." Give the students two-three minutes to discuss and write down their new description. Ask for volunteers to share what they have written.

25 minutes

Explore

Teacher's Note: Demonstration Alternatives

If you are unable to perform the Singing Rods demonstration, unhide **slide 12** and show the video Singing Rods and Tubes. You can also show Dramatically Demonstrate Nodes, Anti-nodes and Standing Waves.

Embedded video

https://youtube.com/watch?v=3zrtu6c71Xk

Possible Student Answer

The instructor can hold the rod where the standing wave or mode has a node since there is no displacement at the node. If he touches the rod anywhere else, the rod will not be able to vibrate up and down.

After a quick discussion about the question, start the video again and let it play until complete.

Display **slide 10**. You will perform a 'Singing Rods' demonstration. You will need at least one aluminum rod and some rosin. During the demonstration, hold the rods at two different node positions and then at any position away from the node. Ask the students why the rod stops 'singing' when you hold it away from the node.

Suggest they think about the first video where they could see the wave in the rod.

Display **slide 11** and ask students the following questions:

- Which wave picture(s) go with the demonstration based on where the rod was held?
- What should the fourth wavelength be?

Call on a few students to answer the questions.

If you are unable to perform the Singing Rods demonstration, unhide **slide 12** and show the video "Singing Rods and Tubes."

Display **slide 13** and perform the Whirly tube demonstration. You will need one whirly tube. Hold the tube just above the wide end and whirl it slowly and then speed up until you hear the first tone. Spin the rod faster to create a second tone. Spin the rod even faster to create a third and then fourth tone.

Ask the students the following questions:

- Why can only four tones be heard? Why does the tone instantly jump up instead of continuously increasing?
- Where are the missing tones that the tube can't produce?

Call on a few students to answer the question. If needed, guide the students to the answer that only certain standing waves can fit in the tube.

Display **slide 14.** Inform students that this image shows how some waves fit perfectly inside the tube. Any wavelengths that are in-between the lengths shown will not fit in the tube. Have students get out their Science Notebooks and draw the picture for the fourth mode.

Next, perform the sound tubes demonstration. You will need one sound tube. Explain to the class that this is another example of standing waves in tubes.

Perform a demonstration of standing waves with a “Stringin’ It” machine or other wave generator and a strobe light. Demonstrate at least three different wavelengths during the demonstration. Ask the students the following question: How many nodes and antinodes are in each of the standing waves generated?

If you do not have the materials to perform the Sound Wave or a Stringin’ It machine, demonstration, unhide **slides 15 and 16** and demonstrate these waves. Display **slide 17** and have students draw a picture of each standing wave. Instruct them to label all of the *nodes* and *antinodes*.

End Day 1.

30 minutes

Explain

Start here for Day 2. Remind students of the essential questions and the learning objective.

Inform the students that they will investigate something known as quantum states. Use **slide 18** to define wave functions. Have students record this definition in their Science Notebooks.

Display **slide 19.** Present the Schrodinger Equation to students. This equation predicts the wave function and the behavior of the quantum state. It is like Newton's Second Law for Classical Motion. This equation factors time, mass, position, kinetic and potential energies.

Display **slide 20.** Show the video [What is the Schrodinger Equation, Exactly?](https://youtube.com/watch?v=QeUMFo8sODk)

Embedded video
https://youtube.com/watch?v=QeUMFo8sODk

Display **slide 21**. Present some unusual ideas about wave functions.

Display **slide 22.** Use the slide to explain the meaning or particle in a box.

Display **slide 23.** Use the slide to define probability densities and have students record this definition in their Science Notebooks.

Teacher's Note: Particle in a Box Handout

You can make a copy for each student and have them record answers on handout or make a class set and have students record answers in their Science Notebooks.

Display **slide 24**. Introduce the Particle in a Box simulation. Pass out the attached **Particle in a Box** handout to each student. Place the students in pairs and have them share a computer to complete the handout. Have students navigate to the PhET simulation Quantum Bound State.

Slides 25 - 28. These slides may be used in teacher discussion or presented if students can't access the simulation.

Slide 25. Emphasize that the bottom graph is the wave function for the first mode of the standing wave.

Slide 26. Emphasize that the bottom graph is the wave function for the second mode of the standing wave.

Slide 27. Emphasize that the bottom graph is the wave function for the third mode of the standing wave.

Slide 28. Emphasize that this graph shows the probability densities for the first three standing waves. This graph comes from the square of the first three wave functions. The anti-nodes represent the most probable location of the electron in the box. The nodes represent positions where the electrons cannot exist.

Extend

Teacher's Note: Safety

Remind students not to stare directly at the lamp for extended periods of time. The spectrum can be seen when looking to either side of the lamp.

Teacher's Note: Activity Prep

You may want to cover windows to block out as much light as possible.

Display **slide 29**. Assign students a new partner and pass out the attached **Wave Functions** handout to each pair of students.

Have students read through Figure 2 of the handout. Then pause the activity.

Display **slide 30.** Show the Standing Wave in Vibrating Hoop video. Emphasize that circular standing waves exist and electrons in atoms can be thought of as standing waves.

Embedded video
https://youtube.com/watch?v=df3oJPi9_mg

Display **slide 34**. Discuss questions with the class. Have students record responses in their Science Notebooks.

Display **slide 35.** Pass out the attached **Hydrogen Emission Lines** handout to each pair of students. Pair up students and allow students time to read through the handout and answer the questions in their Science Notebook or on notebook paper. Collect the papers or Science notebooks to review when students are finished.

Evaluate

Display **slide 36** and introduce the students to the 3-2-1 instructional strategy. Inform the students that they will use this strategy to assess what they have learned throughout this lesson. Students will answer the following in their Science Notebook or on a sheet of notebook paper.

3 -Statements showing what you learned about electrons having properties of waves.

2- Questions you have about electrons having properties of waves.

1- Thing you found most interesting about electrons having properties of waves.

Resources

Arbor Scientific. (2009 February 23). Dramatically demonstrate nodes, Anti-Nodes & standing waves! | Singing rods | Video. YouTube. Arbor Scientific. https://www.youtube.com/watch?v=EYhwKve0MZU

K20 Center. (n.d.). 3-2-1. Strategies. https://learn.k20center.ou.edu/strategy/117

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Koon Physics. (2020 December 24). Hydrogen discharge lamp. Video. YouTube. https://www.youtube.com/watch?v=JiKb9jcD0Xs

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The Physics Classroom. (2023 January 5). What is a standing wave? Video. YouTube. https://www.youtube.com/watch?v=aTaT1orpHg8

3D Modeling & STEM. (2019 November 19). Amazing 3D standing wave motion. Video. YouTube. https://www.youtube.com/watch?v=vraQIQSW-Rc

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