Diffraction and Interference

In this instructional segment, students will investigate interference and diffraction of light and sound waves. Students will evaluate the interference of 2 waves interacting. Students will develop and use models to perform calculations related to interference and diffraction. Finally, students will plan and carry out investigations to analyze the diffraction of light waves. This is part 3 of 3 instructional segments for waves.

Student Science Performance	
Grade or course: Physics	**Title:**
Topic: Waves	Diffraction and Interference

Performance Expectation for GSE:

SP4. Obtain, evaluate, and communicate information about the properties and applications of waves.

a. Develop and use mathematical models to explain mechanical and electromagnetic waves as a propagating disturbance that transfers energy.
(*Clarification statement:* Mathematically describe how the velocity, frequency, and wavelength of a propagating wave are related.)

b. Develop and use models to describe and calculate characteristics related to the interference and diffraction of waves (single and double slits).

g. Plan and carry out investigations to describe changes in diffraction patterns associated with geometry and wavelength for mechanical and electromagnetic waves.

Performance Expectations for Instruction:

1. Students will develop and use models to perform calculations related to interference and diffraction.
2. Students will analyze interference in the context of superposition, constructive, and destructive interference.
3. Students will use a diffraction grating and a laser pointer to calculate the distance between slits and the percent error associated with these calculations.

Additional notes on student supports

Materials:

Engage and Explore

- Laser
- Diffraction Grating
- White Paper
- Inquiry Handout

Explain:

- Computer
- Projector
- Power Point
- Chart Paper

Elaborate

- Computer with Internet Access
- Handout

Students will continuously obtain, evaluate, and communicate information. This is not a linear process. Students will communicate through writing and discussions to allow for formative assessment. This benefits the teacher, student, and whole group to guide instruction to clarify misconceptions or extend content.	
Engaging Learners	**Phenomenon: A diffraction grating will cause a laser pointer's dot to split into several dots.**
	Obtaining Students will point a laser at the wall. Students will document observations. Students will then shoot the laser pointer through the diffraction grating and document observations.
	Evaluating Students will compare the observations that they made with and without the diffraction grating and develop a pictorial model.
	Communicating Students will state a claim about why the laser beam was separated into multiple dots when using the diffraction grating. (*Teacher Notes*: *Do not tell them it is a diffraction grating, just give them the materials and allow them to perform the investigation, this should not take a great deal of time)*
Exploring	*Obtaining* Give students the formula: $m \cdot \lambda = \mathbf{x_m \cdot d/L}$ (*Teacher Notes: Make sure that you define that the variables as x, d, and L are all measured in meters; x is the distance between the dots, d is the distance between the slits, and L is the distance from the diffraction grating to the wall)* Students will define diffraction and adjust variables in the formula by moving closer and farther away from the wall with the laser and diffraction grating. Students will receive this following lab handout: Diffraction Inquiry Lab Handout
	Communicating Students will write up their procedure (i.e. plan an investigation) to calculate the distance between the slits. *Teacher Notes: Students will need to discover in the obtaining portion of the lesson that they can measure all the values except the distance between the slits.* Once you approve their procedure, students will complete the investigation.

	Evaluating After students have data from their investigation, they should use the value that they found for ***d*** to get an actual value for ***x***. They will use the ***actual x*** and ***calculated x*** to find the percent error. Sample Lab Procedure
	Formative Assessment of Student Learning
Explaining Finalizing Model	*Obtaining* Students will use their experience from diffraction lab as well as written and online sources (such as online simulations) to describe diffraction and interference.
	Evaluating Students will construct a graphic organizer to analyze diffraction and interference using print and digital sources and data from the investigation. (*Teacher Notes: You may want to give them some more practice with calculations involving diffraction*)
	Communicating Students will share their graphic organizers and as a class compile information to refine their conceptions.
Elaborating Applying Model to Solve a Problems	**Phenomenon: Silence is produced when two speakers are pointed at each other.**
	Obtaining Students will analyze information related to constructive and destructive interference as well as the principle of superposition. *Teacher Notes: Make sure that students understand that the amplitude of waves in phase are added and this is called constructive interference. The amplitudes of waves out of phase are subtracted and this is called destructive interference.* Students will use the simulation: PhET simulation: Wave Interference and play with different settings to begin to further study interactions between waves. (Attribution: PhET Interactive Simulations, University of Colorado Boulder; https://phet.colorado.edu) *Teacher Notes: the Interference and Diffraction Activity sheet has additional demonstration or investigation options.*
	Evaluating Students will use the simulation to complete the investigation: 2-D Interference Simulation Handout.

	Communicating Students will share their findings from the investigation with their peers. Students will work in groups of 2 to 3 to develop a model that is evidence for the Law of Superposition.
Evaluation	***Assessment of Student Learning***
	Students will develop and share a model that represents diffraction and a model that represents interference. Students will then compare and contrast these wave behaviors in the context of sound and light waves. The product should also include sample calculations for each of the models.
SEP, CCC, DCI	**Science Essentials**
Science and Engineering Practices	● Developing and using models ● Planning and carrying out investigations ● Using mathematics and computational thinking
Crosscutting Concepts	● Patterns ● Cause and Effect
Disciplinary Core Ideas	From *A Framework for K-12 Science Education:* ● PS4A: Wave Properties ● PS4B: Electromagnetic Radiation

Additional Supports for struggling learners:

The following supports are suggestions for this lesson and are not the only options to support students in the classroom. These supports target students that struggle with science material, this lesson or a previous lesson. These are generalized supports and do not take the place of IEP accommodations as required by each student's Individualized Education Program.

General supports for the following categories:

Reading:	Writing:	Math:
1. Provide reading support by reading aloud or doing partner reads 2. Have the teacher model what they are thinking when reading the text 3. Annotate the text with students so that they may refer to it as they work through the lab	1. The teacher can provide a sentence starter for the students. 2. The teacher can give students an audience to write to (i.e. Write a letter to your sibling explaining this topic). 3. The teacher can provide constructive feedback during the writing process to help students understand the expectations.	1. Provide calculators as needed. 2. Provide graph paper as needed.

Supports for this specific lesson if needed:

Performance expectations for instruction:

1. The teacher should provide information to students in various formats to reach as many students as possible.
2. The students should be given adequate time to complete each part of the lesson.
3. The students should be allowed to express their knowledge in various formats.
4. The teacher should be sure to provide multiple ways for the students to communicate their knowledge of the material.

Engage:

1. The teacher should have clear and consistent guidelines for using the laser in the lab. These guidelines should ensure the safety of everyone in the class.
2. The teacher should consider providing students with an organizer to record observations.
3. The teacher should be prepared to repeat directions as needed.
4. The teacher should consider providing students with a template to make their claim and provide their initial reasoning.

Exploring:

1. The teacher should be sure to provide students with equations that they need to complete their assignment.
2. The teacher may need to explicitly teach how to use the formulas. It may be beneficial for the teacher to work a problem then have students work a few together prior to asking students to practice individually.
3. The teacher should provide practice using formulas to solve problems.

4. The teacher should use intentional and flexible grouping to group students. Best practice is to use data to drive student groupings.
5. The teacher should provide students with the handout to plan and carry out their investigation.
6. The teacher may need to use guiding questions to assist students in the planning process.
7. The teacher may need to use guiding questions to assist students in using their data to calculate X.

Explaining:

1. The teacher should consider providing students with sources that they can use in their research.
2. The teacher should consider providing students with a graphic organizer to use in analyzing diffraction and interference.
3. The teacher should consider providing students with practice in doing calculations.
4. The teacher should have multiple ways that students can share their work. These formats could include using technology, gallery walks or presentations.

Elaborating:

1. The teacher should consider a formative assessment to determine which students need re-teaching, reviewing or enriching.
2. The teacher should provide students with an organizer to record data about the PhET simulation.
3. The teacher should consider doing an additional demo or activity with students to provide more practice with waves.
4. The teacher should use flexible and intentional grouping to group students. Best practice is to use data to drive student grouping.
5. The teacher should have multiple ways that students can share their work. These formats could include using technology, gallery walks or presentations.
6. The teacher should be sure to provide multiple ways for the students to communicate their knowledge of the material. These formats could include drawing, diagramming, writing or verbally explaining.
7. Students may need additional time to complete their assignment.

Evaluating:

1. The teacher should consider giving students multiple formats to communicate their knowledge. This could be drawing, writing or designing a presentation.
2. Students may need additional time to complete their assignments.

Pre-Lab Wave Properties of Light

Formulas of Concern:

$m \cdot \lambda = x_m \cdot d / L$ Relative Deviation = Mean – d

$v = f \cdot \lambda$ Absolute Deviation = Mean of the Relative Deviation

$d \cdot \sin\theta = m \cdot \lambda$

Procedure for each section of the Lab:

1.

2.

3.

4.

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Wave Properties of Light

Formulas of Concern:

m·λ = xm·d/ L v = f·λ

d·sin = m·

Procedure for Each section of the Lab:

1. Find the **d** for the diffraction grating. The λ for the red laser is 652 nm.

2. The value for **d** and **λ** will remain constant for all other trials. Do 5 trials changing **L** and measure the value for **x** (actual x). You will need to construct a table.

3. Using the value for **L**, calculate the value for **x (calculated value).**

4. Find the percent error for each of the 5 trials and write a paragraph summary regarding diffraction.

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2D Interference Simulation Handout

Learning Goals:

- Interpret a 2D top view picture of a wave.
- Identify areas of constructive and destructive interference in 2D.
- Predict the behavior of water, sound, or light when you have two sources.
  - What will happen in constructive areas?
  - What will happen in destructive areas?

1. Open the "Wave Interference" simulation from the PhET website (in Sound & Waves). (Attribution: PhET Interactive Simulations, University of Colorado Boulder; https://phet.colorado.edu)

2. On the water simulation, what does the crest (peak) of the wave look like in the top view? What does the trough look like?

3. When you add two drips, what changes about the waves' patterns?

4. What does the wave look like in the area that the two waves constructively interfere? Describe both the top view and what the side view would look like.
   a. TOP:

   b. SIDE:

5. What does the wave look like in the area that the two waves destructively interfere? Describe both the top view and what the side view would look like.
   a. TOP:

   b. SIDE:

6. Switch to the sound simulation.

a. What do you think will happen when you put two speakers next to each other?

b. Why do you think this will happen?

c. Try it (putting two speakers together) and tell me what happened.

7. Now switch to the light simulation.
   a. What do you think will happen when you put two light sources next to each other?

   b. Why do you think this will happen?

   c. Try it (putting two light sources together) and tell what happened.

   d. What happens when you use one light source and two slits?

8. What is similar about all three of these simulations (i.e. water, sound & light)?

9. How do you know that these things are waves and not particles? Think about what would happen in the two slit experiment if they were particles.

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Interference and Diffraction Activities:

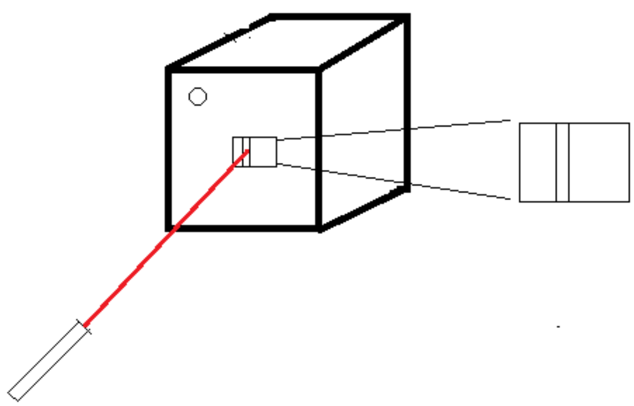
Depending on equipment and class size, these options can be used for interference and diffraction investigations in place of or alongside the simulations.

Students use simple materials to investigate interference and diffraction. They are asked to make predictions about light in a box before completing the experiment or demo.

Have students respond to the following scenario:

Can light waves interact with other light waves? Explain your thinking.

Consider the following diagram:



There is a closed box and the only way for light to get into the box is through two very thin slits as shown. The box is closed, and no other light can get in. A laser pointer is pointed at the narrow slits and the laser light enters the box.

Describe what you would see at the back of the box if you looked in (the wall opposite of the narrow slits).

Draw what this would look like at the back of the box.

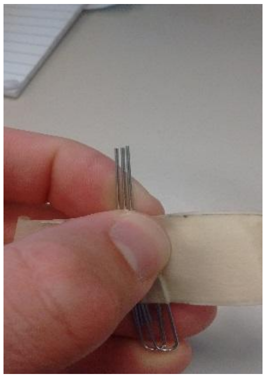
Explain why you predicted this:

Students do not calculate anything with the diffraction equation, but they do change variables in the set-up to see how the diffraction pattern is altered. Calculations will be completed as a class with the hair thickness.

There are several ways to create a double slit experiment with simple materials. Teachers can create example setups and allow students to use during an investigation.

1. Slits (as narrow and parallel as possible) can be cut into paper or aluminum foil with a sharp blade. Darken the surrounding area with a permanent black marker. A laser pointer will show a typical interference pattern.

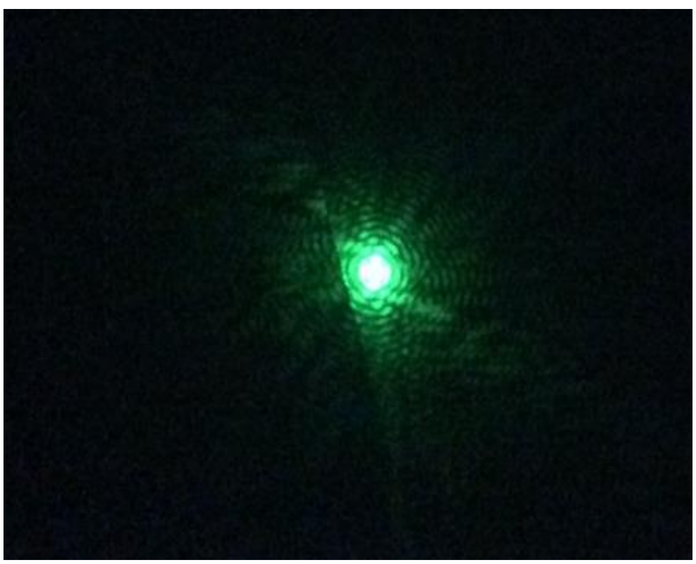
2. Paper clips can be used instead of cutting slits into paper or foil (mechanical pencil lead will work too). Take 3 small paper clips and bend a straight section in each. Tape them together so that they close together. When the laser will produce a diffraction pattern with these. To project and trace the pattern, the students may have to be a couple meters away from a wall. Before they trace the pattern, be sure that they are getting a pattern that clearly shows bright and dark spots.



Pin-hole interference:

This can be done as a class demo or at stations (the room must be dark to see the pattern best). In a piece of aluminum foil, make a very small hole with a pin; tape this foil so it stationary 1-2 meters from whiteboard. Aim laser through hole and project onto whiteboard. This takes a little practice and adjustment to produce a clear pattern; depending on the size of the hole, you might get rings or lines. If you can make the laser and the foil on a stand, it is easier to adjust. Place the foil on a rolling chair to easily adjust distance.

Example:



The image is sort of blurry, but you can see the rings around the center.

Students are asked to make predictions before seeing the result.

<u>Discussion</u>: the math is beyond the scope of this course, but students might be surprised to find that have experience this type of diffraction before. “Rings” around the moon are caused by diffraction of tiny ice or water droplets in the atmosphere. Car headlights and streetlights make the same type of rings on a foggy day.

Thickness of a human hair with diffraction

Class Demo:

Students are surprised to see that a human hair can work as a diffraction grating. With this set-up, the class can calculate how thick a hair is. The hair acts as a single-slit diffraction source. This demo allows students to see how the light waves interfere with the diffraction patter before introducing real gratings.

Equation:

$$y = m\lambda Dd$$

Materials:

Laser pointer (with known wavelength)

Meterstick

1 piece of hair (longer works better)

Volunteers

Dry erase board

1. Have a student hold the hair tight vertically (around 2 meters away from the board). A second student will aim laser at strand of hair to hit the dry erase board.
2. Measure the distance between the hair and the board (D),
3. When a diffraction patter appears, a student can trace the points of the central maximum (or dot) and the first corresponding dark and light spots). And measure the distance between the central maximum and the first dark spot (y). The order (m) is 1 for this set-up. Since this is single-slit interference, the bright spots occur at half-wavelengths and the dark spots occur at full wavelengths.
4. Have students calculate (d, the distance between slits, or in this case, the hair thickness) and compare to a researched value for the thickness.

Extension:

A laser pointer can be reflected from the back of a CD and the central and first order maximums are measured. From this, students can calculate the distance between the grooves in a CD; students can compare to that of a DVD (much less space between grooves= more storage). This could be more open-ended.

Interference with sound waves:

Using an app:

Demonstrate sound wave interference with an app; there are several function generator apps that are free and work well. Two waves can be played with the app at the same time. The phase shift of one wave can be changed to 180 degrees to completely cancel out the waves. You can also show partial destructing interference as the phase shift is approaching 180 degrees. Actual function generators work as well. The waves must be from same source in order to be coherent.

The app can be on a phone or tablet (there are computer programs as well) and with headphones or speakers, students can hear how the phase shift causes the waves to cancel. Allow students time to make predictions.

Interference with separate speakers

The app can be used with separate Bluetooth or connected speakers also. Students can hear how the volume of the note is decreased as the phase shift approaches 180 degrees.

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