CSEO SCIENTIST IN THE CLASSROOM PARTNERSHIP

Properties of Waves

Last Updated: July 2022

GOAL: To investigate properties waves by studying reflection, diffraction, and refraction of light.
TN STATE STANDARDS: 8.PS4.1 Develop and use models to represent the basic properties of waves including frequency, amplitude, wavelength, and speed.
8.PS4.2 Compare and contrast mechanical waves and electromagnetic waves based on refraction, reflection, transmission, absorption, and their behavior through a vacuum and/or various media.

This lesson was adapted from Vanderbilt Student Volunteers for Science. Additional information about the lesson may be found at https://studentorg.vanderbilt.edu/vsvs/.

Lesson Outline:

I. Introduction
Students discuss the properties of waves.

II. Demonstration of wave patterns using a String Wave Machine

III. Wave Behavior

A. Reflection
Students use a laser pen, a mirror, and a finger to trace the path of the reflected laser beam.
Students observe that the angle of reflection is the same as the angle of incidence.

1. Demonstration: Total Internal Reflection in a Light Pipe
SCP fellow shines a red laser through a light pipe to demonstrate total internal reflection.

B. Refraction
Refraction will be demonstrated using a jar of water and a straw.

C. Diffraction

a. Diffraction Gratings - Students hold up what looks like a blank slide and look at room lights or outside light through a window and see separation of white light into several rainbows. The slide actually contains about 1500 lines per centimeter. Each space between two grooves acts as a slit through which light can pass. When illuminated with white light, the diffraction grating has the same effect as a prism.

b. CD - Students hold the CD in a way that produces "rainbow" patterns. CD's have many parallel grooves so the CD acts like a diffraction grating.

D. Optional: The Appearing Coin
Students will learn a "magic" trick using the concept of refraction.

Materials:

1 String-it wave machine
16 bags for Reflection experiment containing:
  1 mirror mounted on a block of wood
  1 red laser pointer
1 plastic bag containing 32 CDs and 32 diffraction gratings
1 acrylic light pipe
8 4-oz jars containing water and a straw
8 styrofoam cups with a penny taped in the center
8 bottles of water
32 Observation sheets
16 Instruction sheets (in page protectors)

I. Introduction

Write the following vocabulary words on the board: **wave**, **reflection, diffraction, refraction, laser**

Ask students to tell what they know about waves.

These points may come up in the discussion or you may choose to add them to the discussion. Remember to keep this discussion short.

- "A wave is a disturbance that transfers energy from one place to another without transferring matter". (From Glencoe textbook.)
- There are 2 types of waves – transverse and compressional.
- All waves have properties that can be measured – amplitude, wavelength and frequency.
- All waves exhibit the same behavior – reflection, refraction, diffraction and interference.

II. Properties of Waves

Materials:
String wave machine

Turn machine on and adjust it so that it has 2 standing waves (see training presentation).

Draw the waves on the board.
Point out the crest, trough, amplitude and wavelength.

III. Wave Behavior

A. Reflection

Tell students they are going to investigate how waves behave, by studying light waves.

> **Safety Note:** Tell the students that they will be using lasers to study some properties of light waves, and that there are several rules that **must** be followed**:**
> Be **very careful** with the laser pointer.
> **Never** aim it at anyone.
> When turning it on, always have it **pointed away from your eyes and from other persons**. Eye damage can occur with direct eye exposure to some laser beams.

The term "laser" is an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. Lasers emit a single wavelength of light; the wavelength of the red laser pointer light is 670 nanometers.

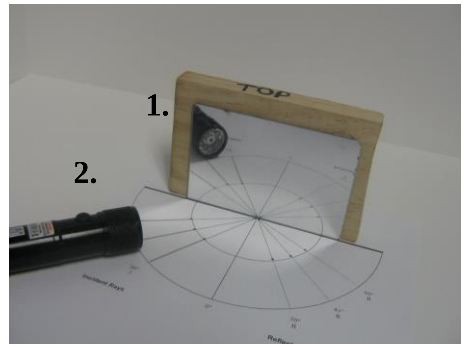
Divide the class into pairs.

Materials – each pair needs:
2 Observation sheets
1 Instruction sheet
1 Mirror mounted on a wooden block
1 laser pointer

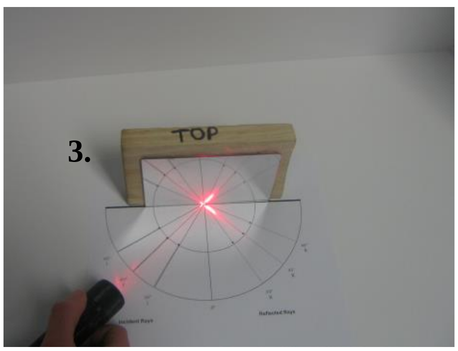
Ask students what happens to light when it strikes a surface?

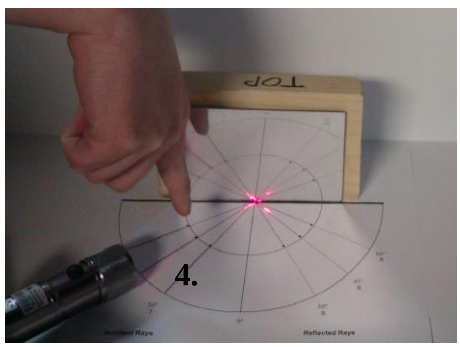
- When light strikes an object, it is either **transmitted** (allowed to pass through), or **reflected** (bounced back to your eyes so that you can see the object).
- When light hits a smooth surface, such as a mirror, regular reflection occurs. Ask students what we call the image that we see in the mirror. *A reflection.*
- Tell students that they are going to experiment with reflecting light in a mirror.

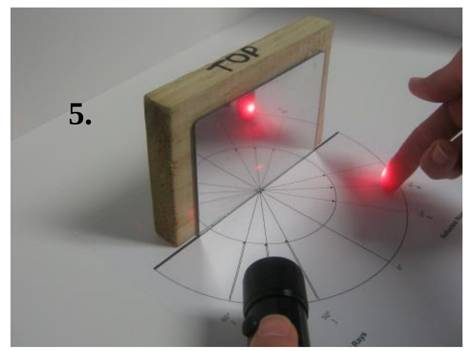
Tell the students to:



1. Place the block of wood with the mirror on the marked line on the observation sheet.
2. Designate one student to hold the laser pointer. Remind the students to NEVER look directly into a laser beam.
3. Shine the laser along the **solid 45° line** and toward the **"X"**
4. Angle the laser so its reflected beam lands on the paper within the semi-circle. "Trace" the incident laser beam with a finger along the 45° line in towards the mirror. Adjust the position of the laser if necessary.
5. Now tell the students to trace the **reflected** beam with a finger and to note which line the finger moves along. (It should be close to the dotted 45° line.)







6. Tell the students that the light from the laser to the mirror is called the incident ray and the light from the mirror is the reflected ray.
7. Explain that when light goes in at an angle on one side (left or right) it comes out at the same angle on the other side. (It is helpful to some students if you draw this on the board or relate it to

> **Note:** The concept the students should learn is that light can bounce or reflect. Light goes in at one angle and comes out on the opposite side at an equal angle.

a billiard table.)

8. Allow the students to try other angles (moving the ruler and laser) to see what happens. Remind students to aim for the "X" in the center.
9. After a brief time of experimentation with other angles, ask the students what they can conclude about the reflection of light.
    - Light can be reflected by using a mirror.
    - When you shine a light straight into a mirror, it comes straight back.
    - When you shine a light into a mirror at an angle, it will come out at an equal angle on the opposite side of the mirror.
    - Incoming light is reflected at the same angle as the outgoing light.
10. Ask students how other waves show reflective behavior?

    Sound waves can echo.

Water waves bounce back from a barrier.

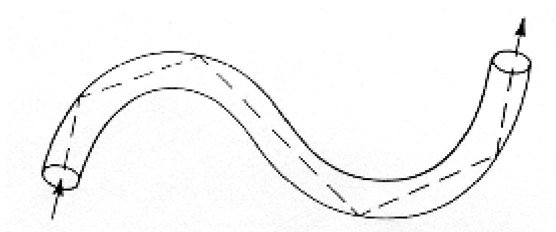
Total Internal Reflection Demonstration

A. Light Pipe: Demonstration

Materials:
1 acrylic light pipe
1 laser pointer

Show the students the acrylic light pipe.
Hold the light pipe like a lollipop with the center pointing toward the class (but not directly at any person's eyes).
Turn off the classroom lights, and ask students what they think they will see when the red laser is shone through the long end of the pipe.
Show students that the red light can be seen at the horizontal end, and that no light escapes to the ceiling. If the room is dark enough, the red light can be seen traveling around the tube.

Explanation: When the angle of incidence is high enough (above a critical angle characteristic of the substance; 42° for glass), the incident light is totally reflected inside the medium.



Explanation: Because of total internal reflection, light can be "piped" from one location to another in glass, plastic rods, or other fiber optic material. On entering the "light pipe" at an angle greater than the critical angle of pipe material, the light undergoes repeated internal reflections and follows the contour of the pipe.

B. Refraction

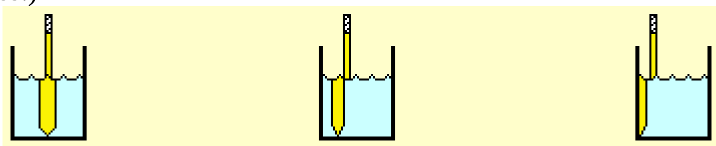
Water Refracts Light

1. Give each group a jar containing water and a straw lying at an angle in the jar.
2. Tell the students to rotate the jar while looking at the straw. Ask them what they observe. *The straw will appear to be bent at the point where it emerges from the water.*
3. Tell the students to unscrew the lid and to hold the straw vertically in the center of the jar, so that half is in/out of the water. Look at the straw "straight on" at the center point, and then slowly move it to the side of the glass (do not move your head with the straw). Ask them what they observe.
4. Tell students to hold their observation sheet behind the jar and shine the laser through the water in the jar. Note where the red beam is on the paper.
5. Tell students to move the laser up so that the beam now shines through the air in the jar. Note where the beam moves to on the observation sheet.

Explanation:

- The bending of light or **refraction** occurs when light waves pass from one medium (or substance) to another.

- The speed of a wave depends on the substance that it is traveling through. Since light is a wave, its speed changes when it changes medium. In this example, the speed of light is slower in water than in air.
- As the wave slows down, it also changes its direction. So the light wave "bends" as it enters the water.
- **Refraction only occurs when light waves pass into a different medium, at an angle**.
- The straw did not appear to be "broken" when viewed in the center of the jar. (When you look at it "straight-on".)
- The straw becomes more "broken" as it moves across the jar. (When you look at it from different angles.)



Reference: http://www.physicsclassroom.com/mmedia/optics/bp.html

> **Important.** Collect **all** laser pointers and count them to make sure you have them all. **Do not continue with the lesson until you have placed the laser pointers in the box**. Also, make sure the laser pointers are not left on in the cases. If one is on in the case, open it and rotate the pointer so the button is to one side, not straight up.

C.   Diffraction

Materials:
32 CDs
32 diffraction gratings

Ask students if they know what diffraction is?
- All waves can be bent when they move around a barrier or through an opening, this is called **diffraction**.
- For light to be diffracted, it must pass through a slit that is very narrow.

a.   Looking Through a Diffraction Grating

A SCP fellow/teacher should show students how to hold the diffraction grating.
- Hold the slide by the cardboard only.
- Do not touch the clear film in the cardboard holder.
- Hold the diffraction grating close to (but not touching) the eye and look at any lights or windows in the room.
- Several rainbows should appear.

Hand out a diffraction grating and CD to each student.

CAUTION: Do not look directly at the sun with a diffraction grating.

Explanation:
- Diffraction grating slides consist of many equally spaced parallel grooves -- typically about 1500 lines per centimeter.
- Each space between two grooves acts as a slit through which light can pass.
- The light bends around the edges of the grooves.
- When illuminated with white light, the diffraction grating has the same effect as a prism in that it separates white light into a spectrum of colors.
- However, the order of the colors is opposite from that seen in a spectrum made by a prism.

b. CD

Tell the students to pick up the CD and notice the "rainbow" pattern from the room lights.

- CDs have many parallel grooves so the CD acts as a diffraction grating.
- The different colors in white light are bent different amounts, so a full spectrum of color can be seen when light is shone onto a CD.
- All wavelengths are diffracted at different rates, so diffracted visible light is split into a rainbow of colors.

Sound waves diffract around buildings – you can hear sounds that are made around "corners".
Light waves cannot diffract around buildings – you cannot see around corners if a building is in the way.

D. Optional: The Appearing Coin

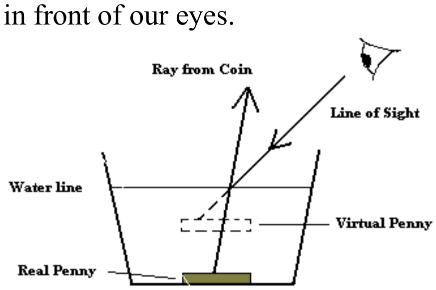
Materials:
8 styrofoam cups with a penny taped in the center
8 bottles water

Tell students that the next activity involves the property of refraction and may be used as a magic trick to try on their family.

Have students in each group do the following:

1. Place the styrofoam cup with the penny on the desk.
2. Select one student in each group to pour the water.
3. Have the students in the group stand so they can easily see the coin.
4. Now have the students back up slowly and stop when the coin has just disappeared from sight. (Tell the students that they may not stop at the same point as other students because they are different heights and have different lines of vision. They should stop just as soon as the coin disappears from sight and should not go back too far.)
5. Tell the designated student to slowly pour water in the cup. The other students should raise their hands as soon as they can see the coin again.
6. Continue to pour the water into the cup until all the students raise their hands. (If they cannot see the coin, they went back too far.)

Explanation: **Refraction** causes this effect. When water is added, the light is bent so that the coin becomes visible. This experiment shows that light is bent as it travels at an angle through one medium (water) into another (air). As light rays from the coin cross the water/air boundary, they speed up and bend. Our brains are programmed to assume that light rays travel straight from an object to our eyes. Therefore we see the coin straight in front of our eyes.



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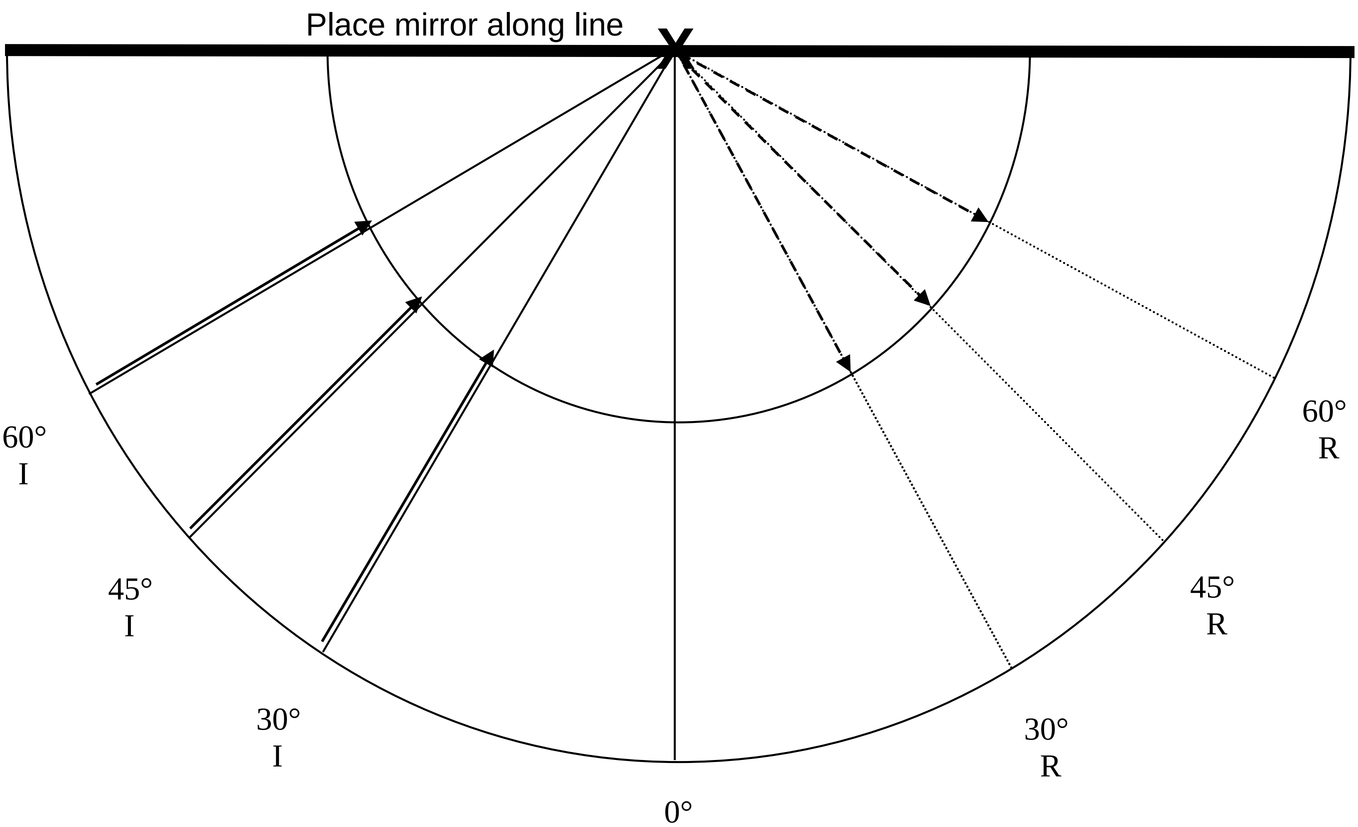
OBSERVATION SHEET



Incident Rays

Reflected Rays

Properties of Waves Instruction sheet

NEVER aim the laser pointer at anyone.

1. Introduction

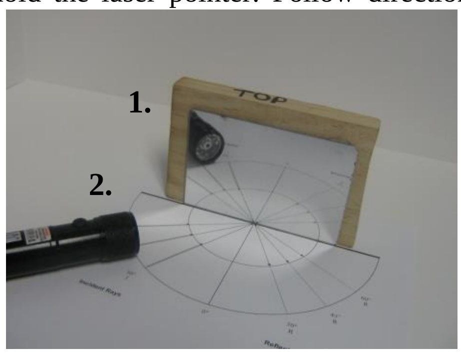
2. Look at String Machine Standing Waves.

Identify amplitude, wavelength, crest, trough.

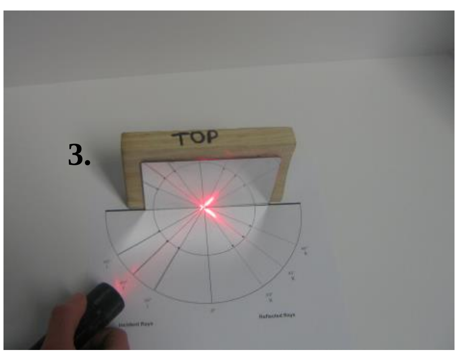
3. Wave Behavior

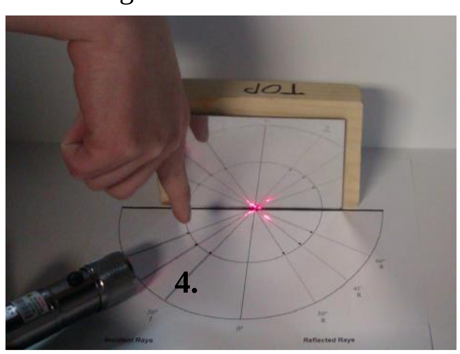
A. Reflection

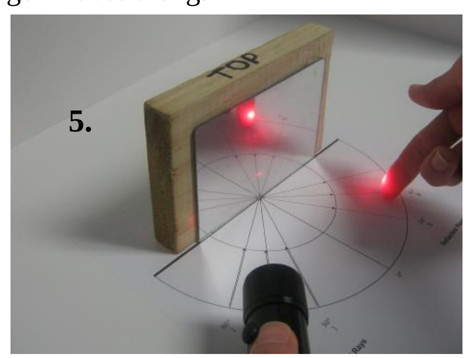
1. Place the block of wood with the mirror on the bolded marked line on the observation sheet.
2. Designate one student to hold the laser pointer. Follow directions #3-5 using the pictures for reference.



3. Shine the laser along the **solid 45° line** and toward the **"X"**. The light from the laser to the mirror is called the incident ray and the light from the mirror on the dotted line is the reflected ray.
4. Angle the laser so its reflected beam lands on the paper within the semi-circle. "Trace" the **incident** laser beam with a finger along the 45° line in towards the mirror. Adjust the position of the laser if necessary.
5. Now trace the **reflected** beam with a finger and note which line the finger moves along.







6. A teacher will now explain the relationship between the incident angle and reflected angle. Listen. Then go on to #7.
7. Now try other angles (moving the ruler and laser) to see what happens. REMEMBER, always aim for the "X" in the center. Record what happens.

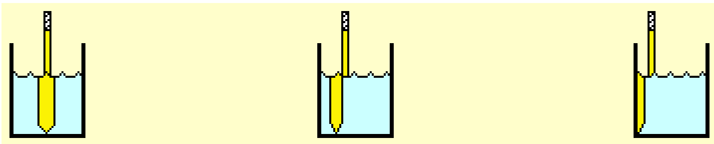
Total Internal Reflection and Fiber Optics

A. Demonstration - Light Pipe

B. Refraction

A. Water Refracts Light

1. Rotate the jar while looking at the straw. What appears to happen to the straw?
2. Unscrew the lid and hold the straw vertically in the center of the jar, so that half is in/out of the water.
3. Look at the straw "straight on" at the center point, and then slowly move it to the side of the glass (do not move your head with the straw). What do you observe?
4. Hold your observation sheet behind the jar and shine the laser through the water in the jar. Note where the red beam is on the paper.
5. Move the laser up so that the beam now shines through the air in the jar. Note where the beam moves to on the observation sheet.



C. Diffraction

A. Diffraction Gratings

1. Hold the slide by the cardboard only.
2. Do not touch the clear film in the cardboard holder
3. Hold the diffraction grating close to (but not touching) your eye and look at any lights or windows in the room.
4. A rainbow should appear.

B. CD

- Pick up the CD and notice the rainbow pattern from the lights.

D. The Appearing Coin (Optional, if time permits)

1. Place the styrofoam cup with the penny on the desk.
2. Stand so you can easily see the coin.
3. Select one person in your group to pour the water (but do not pour water until step 5).
4. Back up slowly and stop when the coin has just disappeared from sight. (Taller students will have to back up further. Water pourer does not move.)
5. Slowly pour water in the cup. The other group members should raise their hands as soon as they see the coin again.
6. Continue to pour the water into the cup until all group members raise their hands.