Lesson Plan: Light Reflection & Refraction

Background

Reflection is the change of direction of light when it strikes an object. When you look at yourself in a mirror or see an image of yourself in a window or a pool of water, the image you see is caused by light that is **reflecting** from you. When light strikes objects, it bounces off, or **reflects** from the object and enters your eyes, allowing you to see the objects. Reflection is happening everywhere – mirrors, windows and pools of water have flat surfaces that reflect a clear image of objects. However, beyond images reflected from flat surfaces, reflection of light allows us to see *all* objects, from the chair you are sitting on and the pencil in your hand, to the desk with the paper you are writing on.

Much like reflection, **refraction** also describes a change in direction of light, but it differs from reflection. **Refraction** Is a noticeable "*bending*" of light when it travels from one substance to another. You can see the effects of refraction of light in a swimming pool, where you may have thought that the bottom of the pool was a lot closer to the surface of the water than it is. This effect is caused by refraction, or the change in the direction of light as it travels from air into water. The bending of light, or refraction, is caused by the *slowing down* of the speed of light as it goes from air into water!

Different substances cause different amounts of refraction. For example, salt water **refracts** light more strongly than fresh water. The ability of substances to bend light, or refract, is measured by their **index of refraction**. The index of refraction for a substance is calculated by taking the speed of light without the substance (i.e., in a vacuum) divided by the speed of light in the substance. The index of refraction can also be calculated by measuring the bending of light as it travels from one substance to another – we demonstrate how you can do this in Experiment 2.

Objectives & Grade Level

Demonstrate reflection of light using a metal spoon and show how curved surfaces differ in the images they reflect. Demonstrate refraction of light as it travels from air into water using a laser pointer and a container of water. Appropriate for beginning to advanced high school science classes; see **Notes** for advanced students.

Materials

- Shiny metal spoon
- Large glass or plexiglass container
  An aquarium or large bowl can be used; the container should be clear and at least 6" in width and depth
- Water
- Flour
  A small amount (half spoonful) of flour or substance with similar consistency (e.g., baby powder or talc)
- Laser pointer
- Paper & pencil
- Cell phone camera

Preparation of Materials

Reflection (Experiment 1)

1. Polish your metal spoon with a damp cloth to make it shiny enough to reflect an image that you can easily recognize
2. Have a pencil and paper or a cell phone camera ready to record what you see

Refraction (Experiment 2)

1. Make sure your large glass or plexiglass container is clean so that the laser light can be easily seen through its walls
2. Fill the container with water to approximately half an inch from the top
3. Add a small amount of flour to the water (half teaspoon of flour for every gallon of water)
   Note: Flour in the water scatters the laser light, allowing you to see the light more easily – only a small amount of flour needs to be added to the water. Milk has the same effect and can be added instead of flour; again, only a small amount is needed.
4. Stir just before doing Experiment 2 to make sure the flour particles are suspended in the water
5. Have a cell phone camera ready to record the laser light

Procedure

Experiment 1: Reflection

1. Hold the metal spoon in front of you so that the inwardly curved side (the side that you use to scoop things up) is facing you and you can see your reflection in the spoon (**Fig. 1**).

Note: *The inwardly curved surface is referred to as* ***concave****. You can think of concave surfaces as curving inward, much like a cave.*

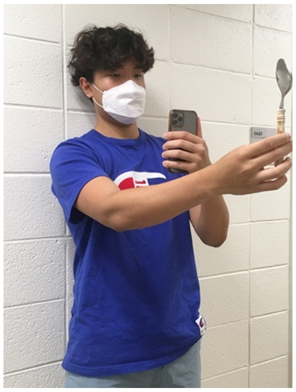

Fig. 1 Hold the spoon so you can see your image.

2. Using your pencil and paper, draw the image of yourself that you see and label it "*Concave side*". Instead of drawing your image, you could take a photo with your cell phone camera.

What do you observe about the image of you that you see? Is it right-side up or upside-down? Is the image the same as you would see in a snapshot or a mirror?

3. Now turn the spoon around so that the side that curves outward is facing you.

Note: The outwardly curved surface is called ***convex****. Convex is the opposite of concave; here the curved surface extends outward.*

4. Position the spoon so that you can see your reflection on the convex side of the spoon. Draw the image of yourself that you see on your piece of paper and label it "*Convex side*" or take a photo with your cell phone camera to compare with your image on the concave side of the spoon.

What do you observe about the image that you see? Is it right-side up or upside-down? Is the image the same as the one you saw in the concave side of the spoon – if not, how does it differ? Note that one of the images – the one on the *concave surface – will be inverted and the other will be upright. For an explanation of why the images differ, see **Note 1**.*

Experiment 2: Refraction

1. Prepare the large container of water as described above and have your laser pointer ready, along with your paper and pencil or cell phone camera to record your findings. Give the water a quick stir to make sure the flour is suspended in the water, rather than settled on the bottom of the container. Hold the laser pointer at an angle above the container and to the right (or left) of the container (**Fig. 2A**). When the laser is turned on, the laser light should be *parallel* to the front of the container.

Position your cell phone parallel to the front side of the container. Make sure that your camera flash is OFF for the image. Then turn off the room lights and turn on the laser light. Take an image – your photo should look like **Fig. 2B**, but without the white line, which we added to show the laser light path in air; the line was extended into the water to show the difference between the light path in air and water.

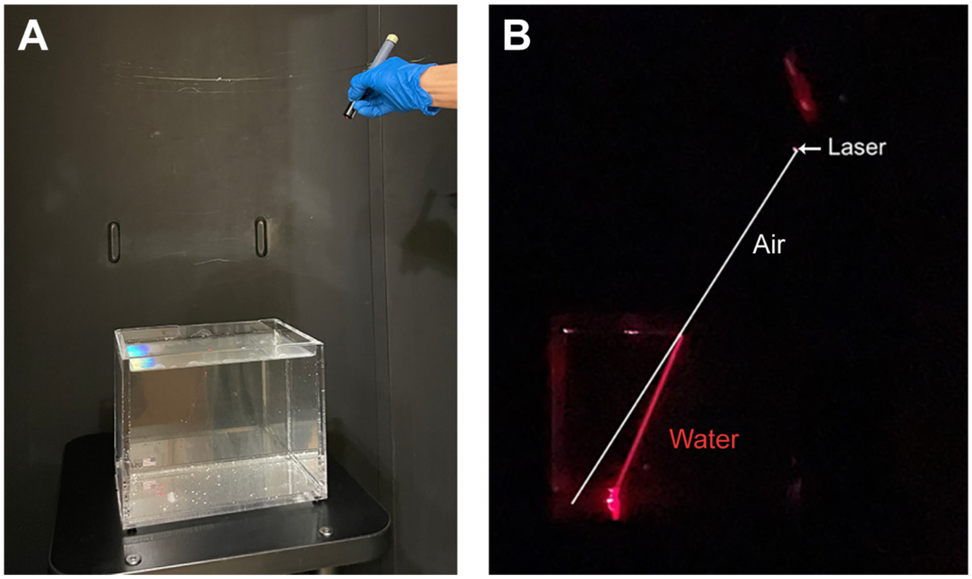

Fig. 2 A) Hold the laser pointer above the container of water so the laser light hits the water at an angle. **B**) Laser light in the dark. The laser light starts in air (top Right, arrow) and is visible in water as a red line (bottom). Laser light path in air (white line) and water (red line).

We will use the image in **Fig. 2B** to measure the bending of the laser light by the water and to calculate the index of refraction of water (see **Advanced Topic 1** below).

Now that you have seen what the laser light looks like in water after adding flour, what do you think would happen if we didn't add flour? Note that the small flour particles in the water scatter the laser light, making it possible to easily follow the direction and path of the light. Try this experiment using water without adding flour to see the difference!

Notes

1. When light is reflected from a surface, the angle at which the light strikes the surface, called the **angle of incidence**, is equal to the angle at which it bounces back, or the **angle of reflection** (**Fig. 3A**). For curved surfaces, such as the two sides of a spoon, the angle of incidence and the angle of reflection are also the same, but because of the curvature, the incident and reflected angles differ for each point on the spoon surface (**Fig. 3B**).

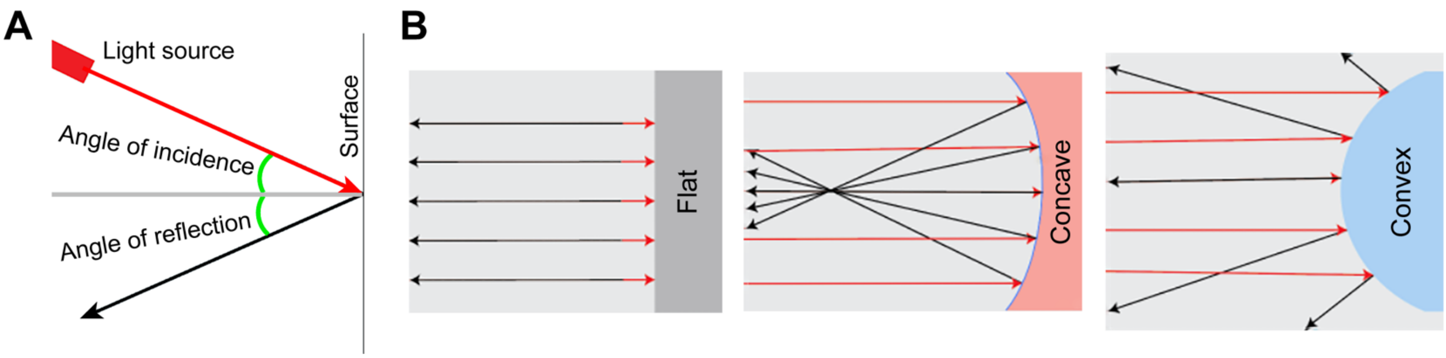

Fig. 3 Reflection of light. **A**) Light is reflected from a surface at the same angle as it strikes the surface. **B**) Light rays (red lines) are reflected (black lines) at the same angle for each point of a flat surface (Left), but the angles differ for each point of curved surfaces (Middle, Right). Note that for each point on either a flat or curved surface, the angle of incidence is the same as the angle of reflection.

Because of the differences in angles of light reflected from flat and curved surfaces, the images formed by the surfaces differ (**Fig. 4**). For flat surfaces, an upright image is formed of the same size as the object (**Fig. 4A**), whereas concave surfaces form a small inverted image of the object (**Fig. 4B**) and convex surfaces form a small upright image of the object (**Fig. 4C**).

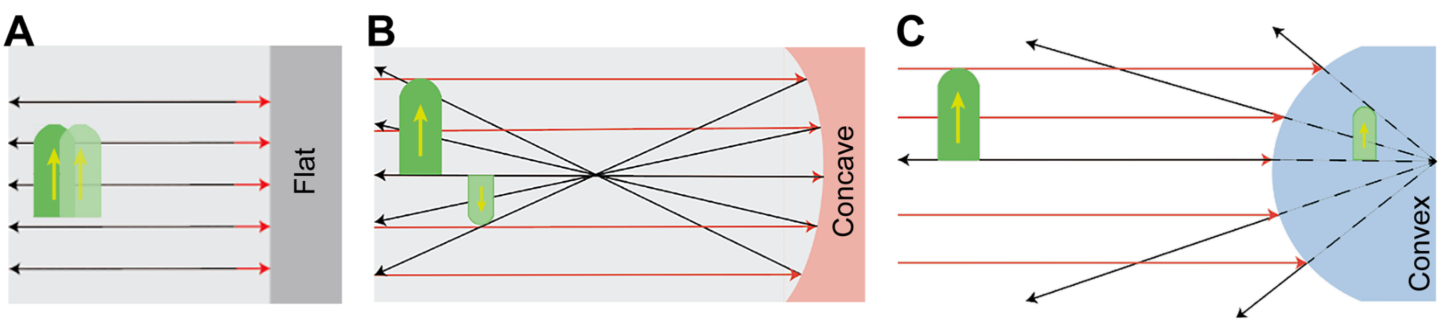

Fig. 4 Images formed by flat and curved surfaces differ due to reflected light. **A**) Flat surfaces reflect light from the object (green) that forms a same-sized upright image of the object (pale green). **B**) Concave surfaces reflect light from the object that forms a small inverted image of the object. **C**) Convex surfaces reflect light from the object that forms a small upright image of the object.

The images that you observed in the two sides of the spoon in Experiment 1 can be explained by the difference in light reflection by the two curved surfaces!

2. **Advanced topic 1**: Determining the index of refraction. We can use our results from Experiment 2 to calculate the index of refraction of water. The index of refraction, *n*, is defined as the ratio of the speed of light without the substance (e.g., in a vacuum), *c*, and the speed of light in the substance, *c'*, and can be stated as *n=c/c'*. We can calculate the index of refraction for water using the speed of light – but light is fast! The velocity of light is estimated to be 300,000,000 meters per second. This is fast enough to travel nearly 80% of the distance to the moon in one second! Although we could easily measure the speed of light in water with special equipment, we can determine the index of refraction of water using a much simpler method.

We can use Snell's Law, which states that when light passes between two substances, the product of the index of refraction and the sine of the angle the light makes with the surface stays constant. This can be stated as

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

where n_1=index of refraction of the first substance, n_2=index of refraction of the second substance, θ_1=the angle of incidence, and θ_2=the angle of refraction (see **Fig. 5**).

This equation can be rearranged as

$$n_2 = n_1 \sin \theta_1 / \sin \theta_2$$

For Experiment 2, we recorded the bending or refraction of light as it traveled from air into water, so we can take air as substance 1 and water as substance 2. Air has a refractive index of n=1.0003 and we can calculate the refractive index of the water in the container from θ_1, the angle of incidence and θ_2, the angle of refraction, both of which are angles of right triangles (**Fig. 5**). The sine of an angle of a right triangle is the length of the line opposite the angle (**Fig. 5**, L_{Opp}) divided by the length of the hypotenuse (**Fig. 5**, white line for θ_1 and red line for θ_2). Our measurements gave $\sin \theta_1$=0.6160 and $\sin \theta_2$=0.4404. Entering these values into the equation above for Snell's Law, together with n_1=1.0003 for air, we can calculate the index of refraction for water, $n_2 = n_1 \sin \theta_1 / \sin \theta_2$=1.399!

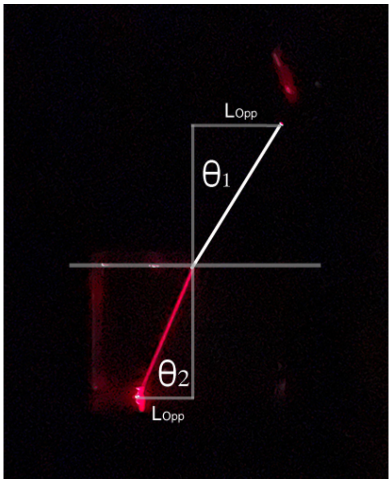

Fig. 5 For Experiment 2, the index of refraction for water, n_2, can be calculated from the angle of light incidence (top, θ_1) and the angle of refraction (bottom, θ_2).

How close is this to actual index of refraction for water? The index of refraction for water is 1.333. We find that our result was close! It's not the same though, so we need think about what caused the difference. It could be caused by several different things. First, our water was tap water, rather than a purer form of water, and different solutes in the water can lead to differences in the index of refraction, although the changes caused by impure water are usually very small. Second, our measurements might not be exact because our camera may not have been exactly parallel to the front of the container of water, although it was placed as parallel to the container as possible. This would affect the angles of the incident and reflected light that we measured from our photos. Finally, our measurements of the lengths of the lines that form the right triangles in **Fig. 5** from the photos that we took could have been inaccurate, which would affect the estimated index of refraction. Repeating Experiment 2 using purer water, ensuring the camera is parallel to the container, and measuring from larger photos would probably give values for *n* closer to the actual index of refraction for water.

3. Refraction of light can also be observed by putting a pencil (or straw) in a glass of water so that it is partially submerged. The pencil will appear to be bent as it enters the water from air – this is caused by the refraction of light in water compared to air.

4. Earlier, we said that light slows down when it enters water, and we found the index of refraction of water to be 1.399 in our experiment. This means that the speed of light in water is 1/1.399, or around 70% of what it would be in a vacuum. Can you think of a reason why light travels more slowly in water compared to air? What properties does water have compared to air that make it difficult for light to travel? *Hint: Remember that molecules in water are closer together or denser than in air – this is the reason that water is heavier than air. Light hits the water molecules, causing it to slow down in water compared to air. This is like walking through a crowd of people – can you walk faster through a crowd or an empty room?*"

Acknowledgements

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