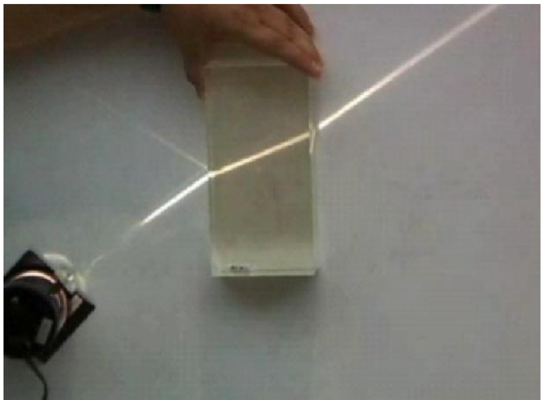

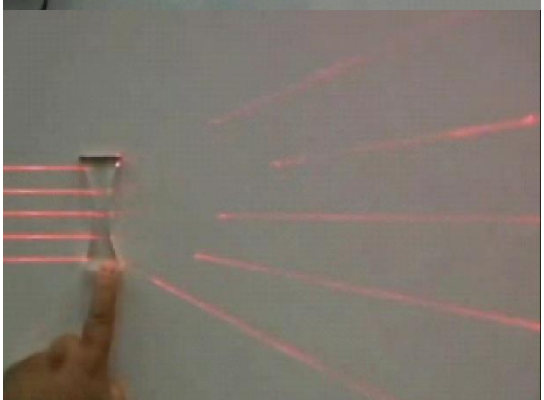

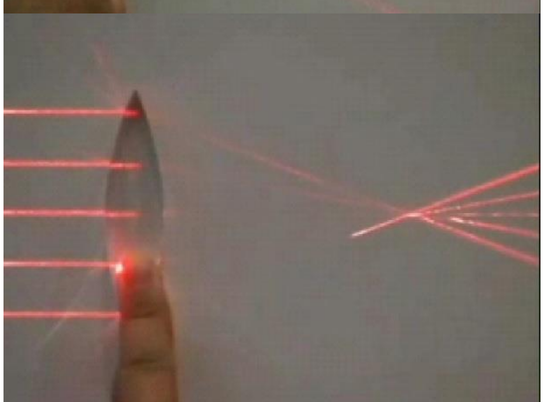

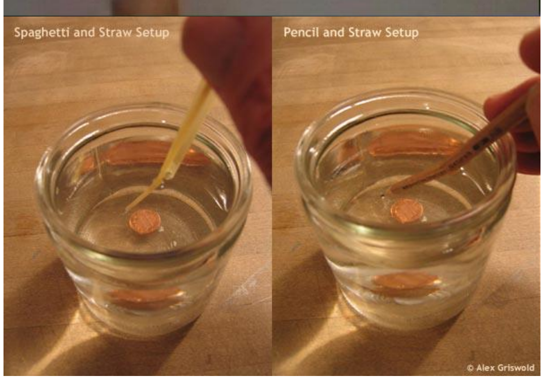

How Light Moves

More Lessons from the Sky

Satellite Educators Association

https://SatEd.org

Please see the Acknowledgements section for historical contributions to the development of this lesson plan. This form of "How Light Moves" was published in November 2015 in "More Lessons from the Sky," a regular feature of the SEA Newsletter, and archived in the SEA Lesson Plan Library. Both the Newsletter and the Library are freely available on-line from the Satellite Educators Association (SEA) at https://SatEd.org.

Content, Internet links, and lesson resources available online from the SEA Lesson Plan Library revised and updated, July 2023.

SEA Lesson Plan Library Improvement Program

Did you use this lesson plan with students? If so, please share your experience to help us improve the lesson plan for future use. Just click the Feedback link at https://SatEd.org/library/search.htm and complete the short form on-line. Thank you.

How Light Moves

Invitation

What is light? How does it move? In this media-rich lesson, learners conduct simple experiments to investigate how light travels. They examine the paths that light takes with different materials and observe shadows, reflection, and refraction.

More Lessons from the Sky endeavors to present original lesson plans and highlight lesson plans already published that enhance student understanding of space-based technologies especially satellites and the use of satellite-based remote-sensing environmental data. In this lesson, the spotlight is on **How Light Moves** originally published by PBS Learning Media online.

Coupled with **Light and Color**, this lesson can be presented as the first of a two-lesson set in which grades 4-5 learners develop an understanding of the nature of light and color especially as it relates to satellite remote sensing and digital imaging of various components of our Earth systems.

Grade Level:	4-5
Time Requirement:	2 class periods
Prerequisites:	None
Relevant Disciplines:	Physical Science

Student Learning Outcomes

By the end of this lesson, students should be able to do the following:

1. Describe how light travels (in a straight line)
2. Examine how light can be reflected by a mirror or refracted by a lens
3. Explore how light is reflected off an object and demonstrate that the angle of the outgoing light is equal to the angle of the incoming light (the law of reflection)
4. Explain that light follows the law of reflection when it reflects off smooth objects (like a mirror) and rough objects (like a piece of paper)
5. Explain that when light reflects off rough surfaces, it is scattered in all directions, which prevents the formation of an image
6. Explore how light changes direction when crossing the boundary between two different transparent materials in a process called "refraction"

Lesson Description

The lesson can be described in three parts – Part I: Exploring How Light Travels; Part II: Exploring Refraction; and Check for Understanding.

Part I: Exploring How Light Travels

1. Before the first day of the lesson, using the **Light and Shadow Walk** worksheet, students should have taken a light and shadow walk around their neighborhood. On the day of the lesson, begin by having students discuss their light and shadow walks. Where did they see shadows? Did the shadows change? Under what circumstances?

Students may indicate different light sources (the Sun, the Moon, or a streetlamp) depending on where and when they took their walk. Do all shadows have to have something that blocks light, thus creating the shadow?

2. Ask students to suggest some "rules" about how light moves based on their observations from the light and shadow walks. Write some of these rules on the board. Whenever possible, try to demonstrate the suggested rules. For example, if someone suggests that light travels in a straight line, you can test this by doing the following demonstration. Darken the room and have one student hold an index card while another student shines a flashlight at the card. Then have a third student hold a pencil so that it casts a shadow on the card. Ask the student holding the pencil to slowly move it to the left or right, and challenge the student with the index card to keep the shadow of the pencil on the card without moving anything but the card. As the student with the pencil moves around the room, observe what the student with the card has to do as the shadow "keeper." If time permits, have all students try this experiment in their small groups with different objects.

   Next, learners view another demonstration of how light travels in straight lines in the short video **How Light Travels**. Project the video or have each student team visit https://ca.pbslearningmedia.org/resource/lsps07.sci.phys.energy.lighttravel/how-light-travels/.

3. Tell students that they will now explore what happens when light shines on different kinds of objects that are opaque, clear, or shiny. Ask learners to use **Flashlight Predictions** from the Student Activity pages and pretend they have a flashlight they can shine on various objects. Have students discuss and record on paper [in their science notebooks or on the Flashlight Predictions document] what they think they would see if they shone the flashlight on the objects as shown. They should pay particular attention to where the light would go after it hits the object and record this for each object. With equity in mind, if students have not ever had a chance to explore with a flashlight before making these predictions, the lesson may need to be expanded to allow time for these explorations.

4. In a darkened room, have students test out their predictions. Students should shine flashlights on each object and record how the light interacts with the objects, starting with the paper and the rock. They should note [by writing in their science notebooks or the Flashlight Predictions document] that on opaque objects, there will be definite shadows. On shiny objects such as the mirror, some of the light will be blocked from its original direction, making a shadow. Some of the light will be redirected in a beam. This beam will be noticeable if there is dust in the path of the light. It can also be seen if the flashlight is placed flat on a table along with the mirror that is mounted on the block of wood, so that some of the light spills onto the table. On clear objects, the light will pass right through. [Then learners write in their science notebooks a descriptive example of light traveling in a straight line.]

5. Next, have students work in pairs or small groups to explore the properties of the mirror more precisely. Students should begin by placing their mirror (mounted on a wood block so it can stand upright) in the middle of the lab table on top of a piece of white paper. Then they should place their flashlight on the table so that it shines directly at the mirror. Ask students to observe and trace with a pencil the ray of light

from the flashlight to the mirror, as well as its reflection. They should put arrows on their lines showing the direction in which the light is traveling. Ask students what they think would happen if they turn the mirror. Then have students turn the mirror and trace the path of the light and its reflection using a different colored pencil, again adding arrows to show the direction in which the light is traveling. Does the reflection move with the mirror? Finally, have students turn the mirror one more time and trace the lines in a third color. Ask students to reflect on the following questions [in their science notebooks]:

   a. Turn off the flashlight, aim it at the mirror, and draw the incoming light line and your predicted path of reflected light. How do you think the light reflects when entering the mirror and leaving the mirror? Write a general rule.
   b. Were you able to measure the angle of reflection compared to the angle of light coming in? Remember, you are measuring the angle between the flashlight beam and the mirror on one side, and the angle between the reflection of the flashlight beam and the mirror on the other side.
   c. If you trace the path of the light on the paper and on the edge of the mirror, how do the two angles compare? (Note: Younger students can color in the wedges and see that they are the same shape and area, while older students can measure the angles with a protractor.)

6. Ask students to place an index card in front of the mirror. Then have them point the light at the index card and observe the ray of light across the table. They should notice how the ray continues beyond the card as it did with the mirror. Ask students whether or not they think the index card is reflecting light.

7. Show students the **Light and the Law of Reflection** video by projection or at each student computer. Ask students what they think determines whether or not there is a reflection. [Then learners write in their science notebooks an explanation of what happens to light when it reflects off an object with a smooth surface and off an object with a rough surface. Inclusion of drawings is encouraged.] Find the video at https://ca.pbslearningmedia.org/resource/lsps07.sci.phys.energy.lightreflect/light-and-the-law-of-reflection/.

Part II: Exploring Refraction

8. Students will now work on the Spear Fishing Challenge. Set up the equipment by putting the penny in the container of water. Cut the straw in half lengthwise so that the pencil can slide down it. Alternatively, you can use a thin piece of dry spaghetti instead of a pencil so that there is no need to cut the straw. You may also want to display the **Spear Fishing Challenge** image from Student Activity pages or online at https://ca.pbslearningmedia.org/asset/lsps07_img_lpachallenge/ (project video or provide to student computers or student visit directly) so learners can see an example of the activity setup. Then, have each group do the following:
   a. Stand beside the container and look at an angle through the water to the penny. Hold the straw to your eye like a telescope so that you can just see the penny. Without moving the straw, insert the pencil and release. What happened? Did you spear the penny fish? If you were not successful, rethink your strategy and try again. Where do you need to position the straw to be able to hit the penny with the pencil? Try hitting the penny from directly above the water.
   b. Construct a diagram of what you think is happening with light that makes it

difficult to spear the penny. Include arrows to indicate direction.

9. Darken the room. For each group of students, place a sheet of paper on the lab tables. Then place a glass of water on top of the paper. Ask students to move the flashlight around until they can pass most of the light through the glass of water. Where do they see light? Can they draw the path of the light from the flashlight through the water and out again?

   For a visualization of how the glass bends light, use the video **Observing Refraction of Light** at https://ca.pbslearningmedia.org/asset/lsps07_vid_lightrefract/.

10. Have students try to shine light through the eyeglass lens onto the paper. Does the light hitting the paper change depending on how the eyeglass is held? Can they find a spot where the light is the most concentrated?

Check for Understanding

After students put away their lab materials, discuss with the class what they learned from the Refraction of Light Demonstration Flash Interactive. Can they predict how the light will bend as it enters or leaves a transparent material?

Darken the room, and ask for a student volunteer to stand close to a piece of white poster board. Direct the class to closely observe the student's face as you turn a flashlight pointed at the poster board on and off. (Note: Do not let any of the light from the flashlight hit the student's face directly.) Ask students to observe the student's face as the flashlight changes, and then draw arrows representing the path of the light from the flashlight to their eyes in their journal [or science notebook]. [Take some time with this. A well-drawn diagram will take into account the reflection of light by opaque objects as well as the Law of Reflection. This can truly serve as the summative assessment for the reflection portion of the lesson.]

Important Terms

Shadow	Lens	Reflection	Refraction

Assessment

Formative assessments include the responses on the Light and Shadow Walk worksheet, the quality of participation in group and class discussions, predictions and records noted in science notebooks. The Check for Understanding can serve as a summative assessment if the diagrams are carefully inspected for inclusion of reflection of light from an opaque object (the student volunteer’s head/face) and application of the Law of Reflection related to the direction of the light ray arrows drawn in the diagram. The Your Turn activity at the end of the Student Activity pages asks students to apply what they learned to a new situation by explaining the “disappearing” beaker in the short video clip. They can work in groups and write the explanation in their science notebooks.

Next Generation Science Standards

The following Next Generation Science Standards are addressed in this lesson.

Performance Expectations & Disciplinary Core Ideas

Grade 4: Waves and Their Applications in Technologies for Information Transfer

PE- 4-PS4-2 – Develop a model to describe that light reflecting from objects and entering the eyes allows objects to be seen.

DCI- 4-PS4.B – An object can be seen when light reflected from its surface enters the eyes.

Grade 5: Matter and Its Interactions

PE- 5-PS1-1 – Develop a model to describe that matter is made of particles too small to be seen.

DCI- 5-PS1.A – Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means.

Science & Engineering Practices

– Develop a model to describe phenomena.

Crosscutting Concepts

– Cause and effect relationships are routinely identified.

– Natural objects exist from the very small to the immensely large.

Preparation

The online lesson plan lists these material needs for each part of the lesson:

Part I

For each group of two to three students:

- Flashlight Predictions document
- Mirror—cosmetic mirror or 3-inch square of silvered Plexiglas, fastened with tape or elastic to a small wooden block so it can stand upright
- Paper
- Rock
- Pane of glass (or clear plastic), 3-inch square
- Glass of water
- Eyeglass lens (convex, such as used for reading up close)
- Flashlight
- Index cards
- Scissors
- Video or computer for playback of resources
- Clear plastic container
- Straws

Part II

For each group of students:

- Container of water (best with transparent sides)
- Penny
- Straw
- Pencil or 2-3 strands of dry spaghetti
- Scissors
- Spear Fishing Challenge image

Duplicate the Light and Shadow Walk worksheet and Flashlight Predictions. Distribute one copy of Light and Shadow Walk worksheet to each student. Distribute one copy of Flashlight Predictions to each student or each student team.

One video must be downloaded; view the others online. Determine your method ahead of time: project the video from a teacher's computer for the entire class to see, or provide the link to learner teams at each student computer. Projection is recommended as it allows the teacher to stop, start, discuss, and repeat the video as needed. If desired, the teacher can download each video from PBS Learning Media by registering a free account. It is free, painless, and takes little time.

The one video not available from PBS is the **Disappearing Beaker** needed for the Your Turn extension activity. There are many versions produced and posted by numerous demonstrators especially on YouTube. A reasonable, 51-second, video from Educational Innovations can be projected or viewed directly on student computers at https://www.youtube.com/watch?v=9NBTwyDvVvE. A quick Internet search for "disappearing beaker video" will offer other possibilities if desired.

The Spear Fishing Challenge image can be downloaded and printed or projected (preferred method – uses less paper) for reference by learners during set up in Part II: Exploring Refraction. Either access and project the image from an Internet-enabled computer or download the image and project it. To download the image in Windows, right-click the image and select "Save image as." To download the image on a Mac, Ctrl-click the image and select "Save target as" or simple drag the image to the desktop.

The Refraction of Light Demonstration is best projected from an Internet-enabled computer. A browser with Shockwave Flash plug-in activated is required.

These Teaching Notes are presented in portable document file format (.pdf) requiring an acceptable PDF reader such as Adobe Reader (https://get.adobe.com/reader/) or equivalent. The Student Activity pages are offered in Microsoft Word document (.doc or .docx) format so the teacher can more easily adapt these pages to meet the particular needs of students, curriculum, and classroom situation.

Background

Electromagnetic radiation is energy that radiates, or travels out, from its source in the form of transverse magnetic and electric waves. It includes all visible light as well as infrared, ultraviolet, radio waves, microwaves, and X-rays among others.

A little history…
In 1678, Christiaan Huygens professed light was composed of waves based on his observations of the behavior of visible light in a prism. To the contrary, in 1704, Isaac Newton described light as particulate and furthered that notion by mathematical application of his three laws of motion.

This wave vs. particle controversy continued for more than two hundred years. Then, in 1900, Max Plank explained black-body radiation (the energy radiated from an object as it is heated) by postulating that the emitted radiation was directly proportional to its frequency, a property of waves, in the equation $\mathbf{E = h\nu}$, where $\mathbf{E}$ is energy, ν is frequency, and **h** is a constant of proportionality equal to $6.626x10^{34}$ J/Hz (now called Plank's Constant). Plank thought the radiated energy consisted of small indivisible units of $\mathbf{h\nu}$ he called energy quanta. Albert Einstein called each $\mathbf{h\nu}$ quantum a "photon" in his description of the photoelectric effect in 1903. When photons of light struck a metal plate, electrons were emitted from the plate and collected on another plate when a voltage was applied between them. The energy of each electron was the energy of the absorbed photon. This was a fairly clear demonstration of the particle-like nature of photons. Then, in 1905, Einstein formulated the special theory of relativity in which his famous $\mathbf{E=mc^2}$ described matter and energy in a proportional relationship with the velocity of light in a vacuum, ***c***. With matter, or mass, represented by **m**, this, too, is a distinctive statement of the particle-like nature of photons. Additionally, Einstein believed the velocity of photons in a vacuum (the "speed of light"), 299,792,458 m/s (usually $3.0x10^8$ m/s) was a universal constant unrelated to the observer's perspective and was the upper limit of velocity in the universe.

Louis de Broglie, in his 1923 doctoral thesis, hypothesized a dual nature for light, both particle-like and wave-like, and not just for photons but for all matter. A simplified way to visualize this connection is by equating Plank's $\mathbf{E=h\nu}$ with Einstein's $\mathbf{E=mc^2}$. If energy, **E**, is the same in each equation and both ***h*** and ***c*** are constants, then a simple substitution and rearrangement shows frequency, $\boldsymbol{\nu}$, a wave property, inversely proportional to momentum, **m*c*** (or **mv**), a particle property. Experimental evidence to support de Broglie's hypothesis was found by Davisson and Germer at the Bell Labs within a few short years. So, photons travel like waves and impact matter like particles.

The following brief essay on the nature of light once appeared on PBS Learning Media's page about the refraction of light:

> "One of the most well-known properties of light is *c*, the speed of light in a vacuum (approximately 300,000 km/s). However, the speed of light is slower when traveling through a transparent material. For example, the speed of light traveling through glass is about two-thirds its speed in a vacuum. Depending on the material, the speed of light will vary. This occurs because the light is absorbed and reemitted by the electrons in the material, causing a delay. This slowing can be described by the 'index of refraction,' defined as the ratio of the speed of light in a vacuum divided by the speed of light through the material; the higher its index of refraction, the slower the speed of light will be when traveling through that material.
>
> "When light crosses the boundary between two transparent materials that have different indices of refraction (such as air and glass), it may also undergo a change in direction. If the light approaches the boundary at an angle not along the normal line (perpendicular to the boundary), the change in speed causes it to bend. This bending due to the change in speed is called refraction. If the light enters into a material with a higher index of refraction, it bends towards the normal line as it slows down in the new material. If it enters into a material with a lower index of refraction, it bends away from the normal line as it speeds up in the new material.
>
> "The refraction of light as it passes from one material to another is the foundation for many optical devices, including magnifying glasses, eyeglasses, microscopes, [telescopes,] and cameras. These devices control the path of light through the use of lenses—transparent objects, usually made from glass or plastic, that are specially shaped and designed to refract light in specific ways. There are two basic types of lenses: converging and diverging. When parallel rays of light pass through a converging lens [such as a

convex lens], they meet at a common point. Conversely, when parallel rays of light pass through a diverging lens [such as a concave lens], they spread apart.

"In a typical human eye, light from an object enters the eye and passes through a lens that focuses the light on the retina. However, for some people, light does not focus on the retina and they have trouble seeing images clearly. A nearsighted eye focuses the image in front of the retina; eyeglasses made with diverging lenses correct for nearsightedness by diverging the light just enough so that the image comes into focus on the retina instead of in front of it. Alternatively, a farsighted eye has the image coming into focus behind the retina; eyeglasses made with converging lenses correct for farsightedness by converging the light and moving the focused image forward and onto the retina." (PBS Learning Media)

Acknowledgements

More Lessons from the Sky is pleased to shine the spotlight is on **How Light Moves** originally published by PBS Learning Media online and produced by WGBH with funding from the National Science Foundation. Although this specific lesson plan is no longer available from PBS Learning Media, a large number of topic-related lessons and resources are offered at https://ca.pbslearningmedia.org/.

There were many contributors to the development of this lesson as published by PBS Learning Media. Though too numerous to be listed here, they can all be identified by perusing the PBS Learning Media web site listed above. Of particular significance are the contributions by the Harvard-Smithsonian Center for Astrophysics, the University of Massachusetts, Rutgers University, and the WGBH Educational Foundation.

This lesson module, including this edition of Teaching Notes and the arrangement of these lesson components, was developed by J.P. Arvedson as part of *More Lessons from the Sky* for the non-profit Satellite Educators Association. *More Lessons from the Sky* has its roots in an original collection of more than fifty lessons compiled by Satellite Educators Association, Inc. and published in *Lessons from the Sky,* © 1995 by Amereon, Ltd. *More Lessons from the Sky* is a regular feature of the free, on-line Satellite Educators Association Newsletter. More information about the Satellite Educators Association, its annual Satellites & Education Conference for teachers, international student environmental research collaborative, and access to the Newsletter can be found at https://SatEd.org.

All *More Lessons from the Sky* lesson plans are archived in the on-line SEA Lesson Plan Library available at https://SatEd.org. The web site features a description of the library contents, Next Generation Science Standards addressed, several search tools for finding lessons easily, separate resource files for lessons where needed, and the library's Analysis Toolbox.

When duplicating or otherwise using any portion of this lesson or its associated materials, full credit to all contributors to the lesson and its associated materials must be included.

Resources

Note: All of these URLs were current and active as of this writing. If any are unreachable as printed, the use of on-line search engines such as DuckDuckGo, Ask, or Google is suggested to find current links.

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How Light Moves

Introduction

What is light? How does it move? In this media-rich lesson, learners conduct simple experiments to investigate how light travels. They examine the paths that light takes with different materials and observe shadows, reflection, and refraction.

Activity

Follow your teacher's directions. Use the following worksheets and picture.

Light and Shadow Walk

Take a light and shadow walk around your neighborhood. Observe how the available light sources create shadows. Answer the following questions:

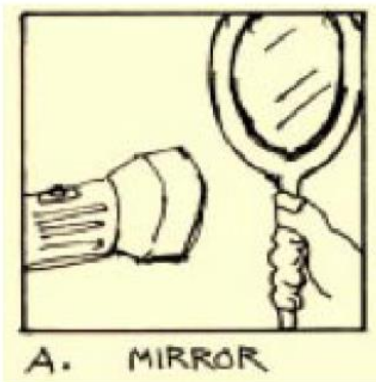
1. Where are the shadows?
2. What shapes are the shadows?
3. Are there any shadows that overlap?
4. What causes the shadows?
5. Are they always the same?

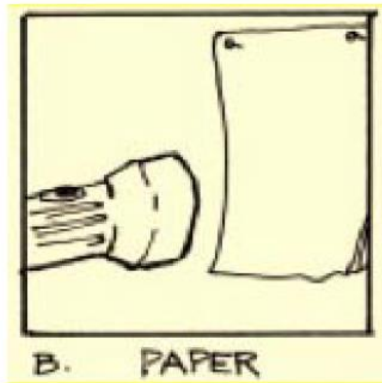
Then use a flashlight to create your own shadows. Answer the following questions about your observations:

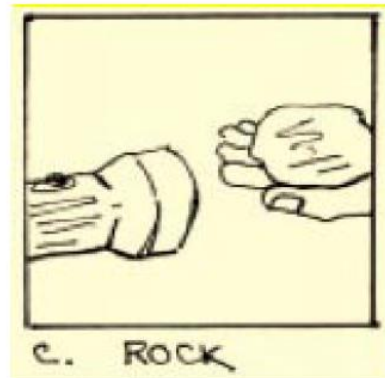
1. How do the shadows change when you move the flashlight?
2. How are the shadows created with a flashlight similar to or different from shadows created with other types of light sources?
3. On the back, draw some of the shadows that you have seen.

Name____ Date________________

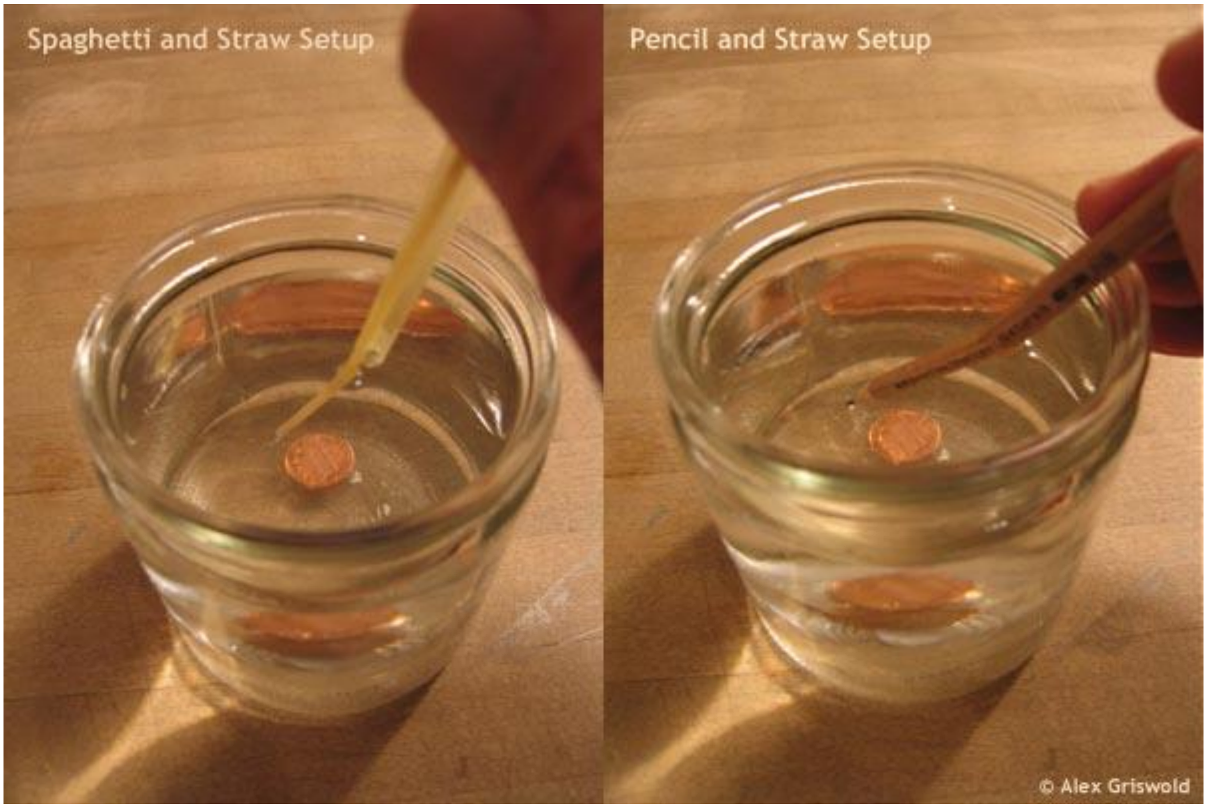
Flashlight Predictions







Spear Fishing Challenge



Your Turn

- Your teacher will tell you the best way to view the Disappearing Beaker video found at this web site: https://www.youtube.com/watch?v=9NBTwyDvVvE. Watch the video about the disappearing beakers. Discuss what you see with your teammates. Remember what you have learned about reflection and refraction. Can you explain what you see in the video? Write your explanation in your science notebook.