Light & Darkness in Space

**Grade Level** 3rd

**Time Required:** 60 minutes

**Group Size:** Whole class and small group experiment teams

**Summary:** Students will explore the property of light essential to understanding the natural phenomena we study in this unit – light propagates in straight lines until reflected or scattered by objects in its path. They will also find that we “see” the world by collecting light that enters our eyes.
The first fact leads to the existence of shadows. Students will understand this and probe the way in which an object's size, shape, position, and orientation determine the shadow it creates given a light source. They will characterize an object's shadow as the region from which a light source is not visible because the object obstructs the line of sight. The second fact means that if no light enters our eyes from a particular direction we perceive that direction as dark. This is less obvious than it seems: in the classroom, once lights are turned on no direction appears dark as we are surrounded by reflecting objects – the walls and everything else in the room – so that light is impinging on our eyes from all directions. In the emptiness of space, light (from the Sun) may be present, but absent objects to reflect it to our eyes we see darkness.

Keywords

Light: A form of energy, produced by heating or otherwise exciting matter. In the absence of matter, light propagates in straight lines at a fixed velocity of about 186,000 miles per second (or 670 million mph). Light is understood as an electromagnetic wave; in quantum mechanics it also has a dual description as a beam of massless, chargeless particles called photons.

Reflection: When light hits a collection of matter, some of the energy “bounces off” the edge of the object, as a reflected beam. Most objects reflect light in all directions pretty equally, no matter what the direction of the incoming beam. Many reflect light of a particular color more than light of other colors. Some materials, such as metal or glass, can be polished to cause the reflected beam to leave the surface at an angle to the normal equal to that of the incoming beam. This allows mirrors to create images. See the notes for Additional Activity 1, Mirror Mazes, for more information on this.

Absorb: A second possible outcome when a beam of light hits an object is absorption, in which some of the energy of the light beam is retained in the object, heating it up. The reflected beam is then less intense than the incoming beam. An object which absorbs most of the light hitting it will thus appear dark.

Transmit: Finally, some objects allow some of the light incident on them to continue through the object.

Scatter: The collective, random reflection of light from multiple, small, objects, as in a cloud of dust or a plume of smoke, is called scattering. In general, a beam of light incident on such a collection will be scattered so that there is a diffuse glow in all directions.

Shadow: The region in space which light beams from some light source cannot reach due to the interfering presence of an object is the object's shadow with respect to that source. In general, when there are multiple light sources (or a large source each small part of which can be considered a source) an object will create multiple partial shadows, in regions where the light from some part of the light sources cannot reach. The shadow will be darker in regions obscured from more light sources. If there is one small (or distant) light source, shadows with respect to this source will be very dark.

Educational Standards

- **Science:**
  - Objective 3.01 Observe that light travels in a straight line until it strikes and
object and is reflected and/or absorbed.

- Math:
  - Objective 3.01 Use the appropriate vocabulary to compare, describe, classify two and three-dimensional figures.

Pre-Req Knowledge

Students most likely have experimented with their own shadows in kindergarten or first grade although few understand the principles behind how shadows are formed and that shadows are not just the darken shaded space on the ground. Entering this activity with little understanding is fine as the students will discover and begin to piece together some of the basic principles and properties of light and darkness.

Learning Objectives

After this activity, students should be able to:

- Understand how the fact that light travels in straight lines allows an object to hide another.
- Explain how an object obscuring a light source from a particular location causes a shadow at that location.
- Understand how an object's shadow is determined by the object's shape, size, and orientation.
- Demonstrate how one object can create different shadows by changing its orientation, and how objects of different shapes can create the same shadow.
- Understand that a shadow is a region in space, distinguish this from its projection on a “screen” to make it visible (shadow exists in absence of screen!).
- Explain why astronauts in space seem to be surrounded by darkness even when the Sun is shining brightly so that the astronauts and their equipment appear to glow.

Materials List

Teacher needs:
- 1 or 2 Overhead projector
- Lamp with 250W bulb in center of class

Each pair needs:
- Sheet of white paper
- Sheet of black construction paper
- Two pencils of different lengths
- If desired, other objects for shadow games – geometrically shaped blocks are great for this.
- Styrofoam ball

Background:

In this activity we deal with the properties of light. As was the case with gravity in “The Earth is Round,” for example, a discussion of the nature and properties of light in general is a very natural extension. If you wish to pursue this, you will need to prepare this. For our purposes here, the essential facts are these:
Light is a form of energy. It is often generated heating matter (converting heat energy to light) as is the case for incandescent light bulbs (with a thin wire inside which is heated by the electric current until it glows), flames (where the gases heated by the burning fire glow in various colors) and stars (whose interior, heated by thermonuclear reactions, in turn heats the gas on their surface, producing the glow we see as starlight or, in the case of our nearest star, Sunlight.) There are other ways to generate light, such as by exciting electrons within gases. This is how fluorescent lamps work, and is the source of some of the light created by lightning.

Once generated, light is emitted from a source, in general in all directions. The energy in a light beam travels in a straight line at a fixed speed so long as it is in vacuum (in space). In most gases, such as air, light propagates in the same way as in vacuum – in a straight line at the speed of light (about 186,000 miles per second).

When it encounters some forms of matter, light can be reflected, absorbed, or scattered. Most objects reflect light from their surface in all directions, no matter what direction it is incident from, though some, like polished glass or the calm surface of water, have special reflective properties that allow an image to form in a mirror. In most cases, only part of the light is reflected, while some is absorbed in the object. Often, light of a particular color is more readily reflected than other colors, so that white light (containing essentially all colors) falling on an object causes light of a particular color to be reflected. (There is some oversimplification in this description but it captures what we need). Objects that reflect most of the light falling on them appear bright; objects that absorb most of the light and reflect little appear dark. An (ideal) object that reflects no light at all would appear pitch black.

Our eyes collect light that falls upon them. They distinguish colors, and essentially report to the brain a “map” of the color and intensity of light that they receive from each direction in front of us. This is the information the brain uses to construct a picture of the world. So when I am standing in a classroom illuminated by lamps, looking at a blue book, white light from the lamps hits the book, is reflected in all directions – which is why the book is visible from any direction – including, if I look towards it, into my eyes. My eyes see blue light from a particular direction, and my brain interprets the shading and color as a book. In directions from which little light is coming, we perceive darkness, or black.

The above may well seem like a long lecture on the obvious. The point is to make explicit our implicit, intuitive, understanding, so that we can clearly apply them in less familiar, less intuitive situations.

An object that absorbs or reflects light can hide another object from our view if placed in such a way that any straight line from our eyes to the target object is broken by the hiding object.

An object placed between our eyes and a light source can likewise prevent us from seeing the light source. This means there is a region behind any object where light from the source cannot reach. Another object placed there will not be reached by light from the source so will appear dark. This region is what we call the object's shadow. Often, we use shadow to describe what happens when a screen (wall, ground, etc) is placed behind objects. There is then a part of the screen which, lying in the object's shadow, is dark because light is not reaching it, and we call this part a shadow.

The shape and size of the shadow produced on a screen, and indeed of the shadow region itself, are determined by shape, size, and orientation of the object producing the shadow. For a small (or distant) light source, the edge of the shadow is found by extending straight lines from the light source to the edges of the object. The area covered by the shadow grows as one proceeds farther.
behind the object. Mathematically, for a small source, if we hold the object at a constant distance from the source, the size of the shadow formed on a screen is proportional to the distance between the screen and the light source. In other words, moving the screen so that its distance from the light doubles, without moving the object, will cause the shadow on the screen to double in size.

- By rotating the object, the edge presented to the light source will change, changing the shape of the shadow on a screen. Also, since the shadow depends only on the edge presented to the light source, objects of different shapes can produce identical shadow shapes. Understanding the way shadows are created and playing with attempts to recognize shapes by their shadows, etc. are all good ways to reinforce students' understanding of the way light propagates.

- The idea that light travels in straight lines is in conflict with our everyday experience on Earth, because we are surrounded by reflecting and scattering objects. Indoors, walls reflect light so that light produced by a source will in fact be impinging on us from all directions. Outdoors, the daytime sky is not dark because impurities in the atmosphere scatter light. This makes it difficult to understand why, for example, the Moon glows so brightly in the night sky, if it is just a rocky ball in sunlight. We cannot take students to space but will examine the way things appear when placed in a bright light against a dark background (black construction paper to represent the darkness of space). We will use the overhead projector's beam as a bright light source, as well as our 250W bulb. Unfortunately, while an overhead projector works fine for shadow production if objects are placed on the surface, the beam itself, after passing through the lens, is not so good for producing the shadow effects we want because it is collimated (parallel beams of light rather than beams originating in a small pointlike source) so shadow will not grow with distance behind the object in the same way.

**Preparation:** Prepare the 250W light bulb in the center of the room. This activity, as well as several others in this unit, work best if the classroom can be made quite dark, with the only light coming from the 250W bulb. If possible, close window shades and try to block skylights or unshaded windows with construction paper or some similar solution. Distribute the materials to student groups. If desired, set up the overhead projector so the beam projects across an open area of the classroom, where students will be able to put objects in its path. A screen is not needed.

**Procedure:**

1) Introduce the activity with the following **Motivation / Challenge:** Ask students to look at the photograph at the top of the first page of this activity. You can reproduce this as an overhead slide to share with them, in which case you will need the overhead projector directed at a screen. (To find the picture in color, go to [http://www.nasa.gov/images/content/152331main_s121e06583.jpg](http://www.nasa.gov/images/content/152331main_s121e06583.jpg)). The image shows astronaut Piers J. Sellers spacewalking outside the International Space Station. The questions students should try to answer is: Is Mr. Sellers in light or in darkness? How does he see what he is doing? If he looked up, could he see the Sun? If so, where do you think he should look to see it? What is the bluish circle behind him? What is the black thing filling the rest of the frame? Allow students to brainstorm and record their ideas in their science notebooks.
2) Lead a discussion of what we mean by “seeing,” and how this relates to light. To see something, we need light from it to enter our eyes. What if something gets in the way? Why can't we see it then? Bring up the difference between a light source, which produces light, and is visible even in otherwise total darkness (a firefly at night, for example) and objects we see because they reflect light produced by other sources which hits them, so they are invisible in total darkness. So there are two ways to make a non-luminous object invisible to us: hide it, so that the light it reflects can't reach our eyes, or place it in total darkness so there is no light for it to reflect. Which of these would work with a luminous object?

3) Darken the classroom and turn on the 250W bulb. Ask students, working in pairs, to use a pencil to create shadows of various shapes and sizes on their white paper. They should solve the following puzzles, and write their conclusions in their Science Notebooks.

- With the pencil and paper in a fixed position, find the orientation of the pencil for which the shadow produced on the paper is longest, and the orientation for which it is shortest.

   ![The orientation of the student’s pencil in relation to the white paper will change the shadow’s size. The light source is out of view in the center of the class.]

- With the pencil held to produce the longest shadow, move the paper, first placing it right behind the pencil, and progressively moving it farther away. What happens to the shadow as the paper is moved farther?

- With pencil held to produce the longest shadow and paper in a fixed location, try to tilt the paper and see if you can make the shadow longer this way.

- If desired, provide students with objects of various size and shape so they can experiment with the shadows of various objects. As a simpler version, have them take the two pencils of different lengths and find a way to make them produce identical shadows; this can be worked as a game, with one partner holding the pencils and challenging the other, looking only at the shadows, to find which is which.

4) Turn on the classroom lights, turn off the 250W bulb, collect students for a discussion to summarize their findings. What determines the size and shape of the shadow? Can we determine the size and shape of an object just from its shadow? What is the shadow? What was going on when the paper “screen” was not there? The shadow covers all the points from which the pencil would prevent us seeing the light source, by obstructing our line of sight. Whether the paper is there or not, these points are darker than points the light can reach.
5) If we place an object in the shadow, will we be able to see it? Were the students able to see the parts of the paper that were in shadow? How? If no light reaches a sheet of paper, can we see it (for example, if the paper were in a completely dark cave)? If the pencil prevented light from the light bulb reaching the paper, how were we still able to see it? Light is reaching the paper, even where the pencil hides the light, because light is reflected off the classroom walls, leaks in through windows, etc. If there were no walls, if the light bulb were the only source of light, the part of the paper in the shadow would be not just darker, but completely dark and invisible!

6) In the second set of activities, students will use the black construction paper as a screen and background. In space, there are no walls, and essentially nothing to scatter or reflect light. We cannot produce this situation in the classroom, but since the black paper reflects little light, it will make things look more like they would in space than would the white paper. We can make the contrasts even stronger by using a brighter light source such as our overhead projector. Darken the classroom, turn on the 250W bulb. As you lead the class through these investigations determine what questions you want your students to answer in their science notebooks.

- Place the pencil in front of the black paper so that it is illuminated by the bulb. Replace the black paper by the white paper. How does the pencil's appearance change? Can you see the pencil's shadow on the black paper? Does it look different from the shadow on the white paper?

- Put the black paper back, now use your hand to produce a shadow. Place the Styrofoam ball so that it is hidden by your hand. Explain what’s happening to allow the ball to be hidden. Put the styrofoam ball between your hand and the paper, so that part of it is in the shadow of the hand. What does the shadow on the ball tell you about the shape of your hand? How does the part of the ball in the shadow look different than the part of the ball outside the shadow? How would this change if you really were doing the experiment in space?

- Again place the ball half way in the shadow of your hand. Move your hand to make a different sized shadow. Move it to make a different shaped shadow. How many different shadow shapes could you create with your hand? Place the ball in between the light and your hand. What does the shape of the ball’s shadow on your hand tell you about the shape of the ball?

- If you have the time, turn off the 250W bulb and allow students to repeat the experiment using the beam from the overhead projector as a light source. The brighter light, with less reflections from walls etc because the light is directed in one direction, should make the contrast stronger. If possible try to borrow an additional overhead projector and split the class into two groups.
Safety Issues

- When setting up the bright light in the center of the room, it is important to find a way to connect the power cord so that students can move about the classroom without tripping over it and knocking the light over. We will often use the light bulb in this central location so this is a problem worth solving thoroughly.
- Warn students not to look directly into the light beam. Unlike the Sun, this source will not cause permanent eye damage, but it will temporarily blind them since it is so bright, and students who can't see where they are going are not a good thing.

Assessment

**Pre-Activity Assessment**

After you have introduced the Challenge/Motivation the students’ drawings and writings in their Science Notebook act as a pre-assessment. This pre-assessment is based on their prior knowledge of light, shadow and their relationship.

**Activity Assessment:**

How does turning the pencil in a different direction change the size of its shadow on the paper? Draw and explain how this works in your science notebook.

What happens to the shadow on the paper when it is moved farther behind the pencil? Draw and explain how this happens in your science notebook. Include in your drawings the light source, the pencil, the paper, and the paths of some light rays from lamp to paper.

In her science notebook a student has drawn an illustration describing how she produced a larger shadow. As the distance between her screen and pencil grows larger her shadow’s size grows larger.

What happens behind the pencil when there is no white paper there? Is there a shadow when there is no screen? How would you find it?

Replace the black paper by the white paper. How does the pencil's appearance change? Can you see the pencil's shadow on the black paper? Does it look different from the shadow on the white paper?

What does the shadow on the ball tell you about the shape of your hand? How does the part of the ball in the shadow look different than the part of the ball outside the shadow? How would this change if you really were doing the experiment in space?

How many different shadow shapes could you create with your hand? What does the shape of the ball’s shadow on your hand tell you about the shape of the ball?
If you have the time, turn off the 250W bulb and allow students to repeat the experiment using the beam from the overhead projector as a light source.

**Post-Activity Assessment**

Look again at the picture from space from our Motivation/Challenge. Is Mr. Sellers in light? In darkness? Can he see what he is doing? Why is the sky behind him dark? Looking closely, can you find which direction the Sun would be in this picture?

In the picture, there is clearly a part of his helmet that is in the shadow of another part. Why is it not completely dark, then, since he is in space? In other words, where is the light coming from by which we see the top of his helmet? (Could be the Space Station near him, or else the more distant but larger Earth itself.)

Look at the part of Earth visible behind him. Would people living there be able to see the Sun? Would they be in light? In darkness?

**Activity Extensions**

**Astronauts’ Shadows on Moon Photos:**

Additional photos of astronauts on the Moon will test your students’ ability to determine where the Sun is located based on the shadow’s size, shape and direction. Also you can discuss why is the sky black if the Sun is shining?

Many of the NASA’s Moon photos can be found at NASA’s NIX site:

http://nix.ksc.nasa.gov/search;jsessionid=7ri1tfhqr659

Individual photos are located at


**Geometric Shapes Activity:**

Allow your class to classify various geometric solids (rectangular and triangular prisms, spheres, cones, and cylinders). Discuss what the shape’s shadows will look like. What will the shadows look like if the objects are resting on paper? What if they were in Space with no screen? They will notice that some objects can make two different shaped shadows. Discuss how they can prove the object’s shape. Lastly, have them examine the sphere and its shadow by turning it. Discuss and prove the sphere’s differences to a quarter or coin’s shadow that is both flat and circular.

**More Shadow Play:**

Can you make two objects that are very different sizes appear to be the same size? Allow your students to experiment with different sized coins and other similar objects and see how and why they can make their shadows appear to be identical. Students will learn more about the connection between a shadow’s size and distance from the light source.
Interactive Websites with fun Light & Shadow Activities:

BBC’s Educational website offers activities and assessment for your students:
http://www.bbc.co.uk/schools/scienceclips/ages/7_8/light_shadows.shtml

A wonderful site teaching about what we can learn about an object’s size and shape from its shadows is found at a site teaching about how CAT Scans work:

After your students have experimented with geometric solids let them have a go at using multiple light sources to further understand the relationship between an object & its shadow and the light source at

References:
