Light Energy

Description

This lab will illustrate how aperture size and focal length affect camera images.

Objectives

- Students will model light intensity by the inverse square law.
- Students will compare the light intensity of various light sources.
- Students will estimate the energy collected by a solar panel.
- Students will convert light energy to electricity.

North Dakota State Standards

9-10.1.1 Explain how models can be used to illustrate scientific principles
11-12.1.1 Explain how scientists create and use models to address scientific knowledge
8.2.3 Use basic mathematics and statistics to interpret quantitative data
9-10.2.8 Analyze data found in tables, charts, and graphs to formulate conclusions

Schedule

11:00-11:30 Brief introduction/Cultural introduction
11:30-12:00 Start Activity 1
12:00-12:30 Lunch
12:30-1:00 Finish Activity 1, Complete Activity 2
1:00-2:00 Activity 3
2:00-2:30 Activity 4
2:30-3:00 Activity 5

Introduction

You know that the farther you are from a light source, the less light you receive. That's why when you read at night you sit by the light rather than across the room. This is also why the planet Mercury is somewhat warmer than the planet Earth which, in turn, is somewhat warmer than the place formerly classified as a planet: Pluto. In this lab we will look at the rules by which light intensity decreases.

Activity 1 – The Inverse Square Law

In this activity, we will see how light spreads out as it gets further from the source. This has a lot to do with the energy in light because the more spread out light is, the less energy it has. This explains in part why Earth is so comfortable, but some of the planets a bit closer to the sun are not so comfortable. In

the interests of completeness, it should be noted that Venus and Mercury are hotter than Earth for reasons besides being close to the sun.

Materials

Overhead projector on a wheeled cart, meter stick or tape measure, large sheet of paper or chalkboard, pencil, sheet of paper that covers the glass plate on the projector (with a small square cut in the middle of it)

Note: in the 21st century classroom it can be surprisingly difficult to find an overhead projector! An alternative is a flashlight that makes a roughly circular image. If you use a flashlight, you will need to replace the area formula in this activity with the formula for the area of a circle:

$$A = \pi r^2$$

Procedure

There is a table at the end of this section to help you with record keeping and recording calculations.

Project the image of the hole on the board. Then measure the distance from the projector to the board and trace out the image.

Move the projector back some distance. Repeat this process at least five times. Make sure one measure is taken at 1 m from the board and one other at 2 m from the board. The other measures are up to you.

Now measure the length and width of each rectangle (in centimeters) you traced on the board and calculate each area. Recall that for rectangles,

$$Area = length \times width$$

Now construct a scatterplot. On the x-axis put the distance of the projector from the board (in centimeters). On the y-axis, put the areas (in square centimeters). Plot your points and use a smooth, curved line to show the trend.

- Does moving the projector affect the amount of light that comes out of it?
- As you move the projector back (and make the image bigger), does each square centimeter get more or less light or does it stay the same?
- Is the image as bright if it were projected from the back of the room as it would be in the front of the room?

As you can see, this was an indirect measurement of the brightness of light. In physics, the brightness is often referred to as the light intensity (I). We indirectly measured the light intensity by measuring the area that the light covered. This lab illustrates an important concept about light and many other physical phenomena including gravity, electrical fields, magnetic fields, and radiation. The intensity of these fields does not drop off evenly. Instead, it drops quickly at first, but, once you are a certain distance away, the rate at which it drops off slows down. Mathematicians describe this as the inverse square law.

We say that the ratio of intensity to the square of the distance at one location is proportional to the ratio of the intensity to the square of the distance at another location. Light intensity decreases with distance.

$$\frac{I_1}{{d_1}^2} = \frac{I_2}{{d_2}^2}$$

A link which has a simulation is http://jersey.uoregon.edu/vlab/InverseSquare/index.html This can be used to quickly construct graphs with a variety of light sources.

Data Analysis

Consider your graph and table of results.

- Does the area illuminated increase in a straight line or is it a more complex pattern? Describe the relationship between area and distance from the source in words.
- Why are the lights in rooms with high ceilings often suspended from the ceiling?
- Could you explain why light gets dimmer as you move away from the source?

Distance from Light	Length (or diameter)	Width (or radius)	Area

Activity 2 -- Light Intensity Visualized

In this activity, we will model what happened in Activity 1 and visualize how the light travels.

Materials

Circles: 30 cm^2 and 120 cm^2; 10 pennies, possibly a calculator, graph and results from Activity 1.

Procedure

Look at your graph from activity 1. Select your measurements from 1 and 2 meters. Divide the area at 2 meters by the area at 1 meter. Round to the nearest whole number.

- What result do you get?
- If you were to take a measure at 4 m , what area would you expect?

Complete this sentence: “As the distance from the light source doubles, the area that the light hits increases _____ times.

So now, let's understand why the intensity of light decreases the further the source is from the screen. Imagine you are in a dark room with a flashlight. You stand 30 cm from the wall and shine your flashlight on the wall. The circle that the flashlight makes on the wall has an area of 30 cm^2.

Let's imagine that the pennies represent photons: individual particles of light. At the end of this packet are several diagrams of circles. Place your pennies on the 30 cm^2 circle to visualize.

- How many photons will fit inside the circle?

We will assume that this number of photons is how many are emitted by the flashlight. Now, let's suppose that we move back from the wall by doubling the distance to 60 cm.

- According to the rule you just developed, what should be the area of the circle the flashlight would make?

Locate this circle and put the pennies in it.

- What happens to the distance(s) between the pennies?
- If the pennies actually were photons of light, what would happen to the light intensity?

Now, suppose you move back to 120 cm.

- What should be the area of this circle?
- What will happen to the light intensity?

Activity 3 -- Light Intensity of Various Light Sources

Now that we have seen how distance from a light source affects its brightness (and thereby the amount of energy on a given area) we will turn our attention to how the actual brightness of the source can be compared, and we will look at methods of measuring the energy provided by the light.

Materials

Block of paraffin wax, knife, aluminum foil, scissors, tape, 2 light fixtures, 60 W incandescent bulb, other wattage light bulbs including a 60 W equivalent CFL.

Procedure

In this activity we will compare the brightness of various light. Due to the nature of the equipment we will use, we will need to compare intensities rather than measure them directly. This will involve the proportion we derived in the previous lab.

We will perform our observations with a device called a null-photometer. Cut your block of paraffin wax in half crosswise. Then construct a sandwich with the paraffin wax halves on either side as the “bread” and the aluminum foil in the middle as the “filling”. Wrap the edges of the sandwich with additional foil. You might wish to leave a small lip around the edge. Cut a window in one side of this wrapper so that you can see both pieces of wax and the foil in the middle.

This device does not measure light intensity directly. Instead, it enables us to compare the brightness of one light source with the brightness of another source. Set the photometer between two light sources. Then move it back and forth until both sides of the photometer are of equal brightness.

Since we don't have an absolute measure, we need to choose a scale. Let's use a 60 W bulb as our standard. This bulb should always be in one. We will measure its light intensity as 1.

Put a smaller bulb, such as a 40 W bulb into the other fixture. Move your null-photometer back and forth until the brightnesses are equal. Then, record the two distances.

Use this formula to calculate the light intensity of the smaller bulb.

$$\frac{I_1}{{d_1}^2} = \frac{I_2}{{d_2}^2}$$

Repeat the experiment with a 60 W equivalent CFL and again with a third type of bulb or, possibly, a candle.

Data Analysis

You might wonder why we are recording the brightness of a CFL and an incandescent light. The reason is that incandescent lights are inefficient. They give off a lot of their energy as heat.

Light bulbs are sold with a certain wattage written on them. Wattage is a measure of the amount of energy used by the bulb each second to produce the illumination. One way to calculate the efficiency of the bulb is to use the formula

$$Efficiency = \frac{Intensity}{Wattage}$$

- Which was the most efficient type of bulb?
- Which was the least efficient type of bulb?
- Where do you think the energy “goes” in the less efficient bulbs?

Light Source	Intensity of 60 W Bulb	Distance to 60 W bulb	Distance to other bulb	Intensity of other bulb	Efficiency (don’t forget 60W bulb)
	1				
	1				
	1				
	1				
	1				

Activity 4 -- Solar Power

You could repeat Activity 3 with sunlight as a light source. This was not written into the lab due to the very real possibility that you would be doing this lab on a cloudy day. However, you likely realize that sunlight is a very good source of energy, to the point that some have suggested the use of solar power to replace some current energy sources.

The sun delivers approximately 1380 W of power to every square meter on the surface of the Earth. This is written as $1380\ W/m^2$ and is sometimes called the intensity of illumination. A toaster requires between 800-1300 Watts in order to operate, so this sounds pretty good. Could a solar panel with an area of $1\ m^2$ power a toaster? Additional information on the power requirements of various appliances is available at http://www.altestore.com/howto/Reference-Materials/Power-Ratings-typical-for-Common-Appliances/a21/

To answer, let's take in some real world considerations. First, the solar panel will not have 24 hours of daylight. During winter the nights will be longer and during the summer the days will be longer, so let's average this out and assume 12 hours of daylight. This is a generous estimate. These estimates are all written to make the solar panel sound as good as possible.

- How much power will be delivered to this solar panel?
- Why did we divide the amount of power by 2?

In the morning and in the evening, the sun will provide a lot less illumination. This illumination will range from very little at the ends to quite a lot as the time is near noon. Let's be generous and take another quarter of the *original power* away.

- How much power will be delivered to this solar panel?
- Why don't we assume power will be provided equally all day?

All of our estimations so far assume that the days will be entirely cloudless and that the sky will be entirely free of dust. The atmosphere itself actually cuts quite a lot of power. It will cut the amount of energy in half yet again *from the amount you just calculated*.

- How much power will be delivered to this solar panel?
- Why did we make this additional calculation?
- Why is solar power frequently used for satellites orbiting the Earth?

One final complication is in the amount of power a solar panel can actually collect. A solar panel can typically only collect 20% of the energy that hits it. This is a really generous percentage. Most solar panels are even less efficient.

- How much power is generated by our solar panel?
- If solar panels were made more efficient, why would they still not collect the full $1380\ W/m^2$ provided by the sun?

The average house uses 50 kilowatt-hours. A kilowatt-hour is a measure of how much power is used in an hour, in other words the amount of energy used. This means it uses 2.1 kilowatts of power or 2100 watts.

- How many of these $1\ m^2$ solar panels would be required to power an average house?
- What complications can you see with total reliance on solar panels for power?

Activity 5 -- Solar Power

As our last activity today, we will see how a solar panel can collect power from light. The solar panel takes advantage of the photoelectric effect. When light strikes a metal, this causes electrons to be released from the atoms. This becomes electricity. Solar panels use the semiconductor silicon rather than metal. Also, to reduce the energy required to knock an electron loose, phosphorus is mixed in with the silicon

Obtain an empty soda can. Cut a styrofoam cup to use as a stand to insulate the can from the ground. Use scotch tape to attach a piece of stiff copper wire to the can so that it hangs out. Use more tape to suspend tinsel from the wire. This will serve as our electroscope.

Rub a charged object such as a balloon, comb, or ebonite rod through the tinsel. This will illustrate how our electroscope shows the presence of static electricity. The tinsel strands have the same charge, so they will repel each other. You should be able to discharge the electroscope by touching it.

Now, let's find out if light can create electricity. Sand a section of the aluminum can so that it is shiny and all of the oxide and paint is removed. Then, shine a UV light on the area. Tape a fairly stiff copper wire to the can so that the tape is outside the sanded area but the wire makes contact with the sanded area. (If you don't get a result, one place to start is to sand the wire itself.)

- What happens?
- What happens when you turn the light off?
- How does this show that light caused the electrons to move?
- How is steel different?
- How does this lab show that the electroscope does not work without UV light?
- What forms of energy does sunlight contain besides UV light?
- Why do you think solar cells are limited to 20% efficiency?

Activity 6 – Seasons (Optional – fits in after activity 3)

You have gotten a taste of several interesting features of light. You saw how light intensity decreases with distance from the light source and you have seen how light energy can become electricity. Finally, you saw the sizes of the solar panels required to generate electricity for a house. Let's now look briefly at some other applications of these concepts.

Seasons

What you learned about light intensity relates very closely to seasons.

First, let's think about our planet's place in the solar system. Earth is the third planet from the sun, located approximately 93,020,000 miles (149,669,180 km) from the sun. If you compare this to the distances we discussed in the lab, you can see that we worked with relatively small distances. Of course, the sun is also a lot brighter than the sources we worked with.

The Earth's orbit is slightly elliptical, so at times the Earth is further from the sun and other times it is closer. It would make sense that this might explain the seasons…only it doesn't. Winter in the Northern Hemisphere actually occurs when the Earth is closer to the sun. There must be a different explanation.

The answer is that the Earth is tilted on its axis. The light hits at different angles at different locations on the planet.

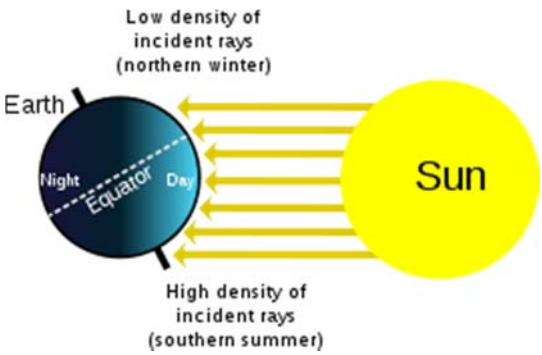

Figure 1 - The Earth is tilted on its axis, which causes the light to hit it unevenly. Here it is winter in the northern hemisphere and summer in the southern hemisphere. From http://upload.wikimedia.org/wikipedia/commons/1/12/Seasons.svg

You will recall that if a light source shines over a larger area, it is not as bright. We can investigate this very easily. Use a flashlight and a large sheet of graph paper. Put a dot in the middle of the paper. This represents a city. Hold the flashlight above the paper and shine it on the paper. Measure the distance between the dot and the flashlight. Shade in the area that is illuminated. Now, keep the flashlight the same distance from the dot, but at a 45 degree angle to the paper. Again, shade the area illuminated. Finally, hold the flashlight at a 20 degree angle to the paper but the same distance from the dot. Shade in the area illuminated.

- As the angle decreases, what happens to the area that is illuminated? (You can estimate this by counting squares that are shaded.)
- Look at figure 1 on this page. How does this relate to the amount of light hitting the Earth at greater distances from the equator?
- Look at figure 1 again. Why would the northern hemisphere be warmer in the summer (when the planet it tilted the other way) than the winter (as shown)?