A photovoltaic cell, or solar cell, is an electronic device that converts solar light energy into electrical energy. How much energy depends upon environmental and electrical factors.
List of Materials Needed:
Each of the following is required per group:

- 1 solar cell
  - This cell is not very efficient and has a low fill factor, but it is very good for demonstrating the concepts, especially solar cell failure mechanisms since it isn’t of the highest quality. They are also extremely sturdy.

- Module equipped with load resistance and terminals for attaching solar cell and multimeter.
  - Pre-soldered modules are nice to have, but as long as you have a way to incorporate a resistor in series with the solar cell and meter for EXPLORATION 1 and then add a motor in series to that for EXPLORATION 2, it is fine. It will just require students to “break” the circuit in order to take current measurements and then put it back together to take voltage measurements across the load. This can get cumbersome and does take quite a bit longer.
  - The schematic to the modules that were made for the OU SEA 2010 is shown below, enabling the students to simply slide switches and rotate dials to take measurements.

- Variable light source
  - Incandescent lamps with dimmers work well.
  - Dimmers used for the SEA 2010 @ OU.

- Digital Multimeters
• Illuminance or Irradiance Meter
  o A 50,000 lux meter will work for all of the indoor explorations. A 100,000 lux meter is recommended for taking illuminance measurements of the sun. These meters can be expensive, so online auctions may be a good option.

• Ruler
• Protractor
• Calculators (1 for each student)
• Various low power objects than run off of DC current (example–motors)
  o The motors used for EXPLORATION 2:
    ▪ http://www.hometrainingtools.com/motor-electric-dc-0-5-6-volt/p/EL-MOTOR/

• Elenco produces a solar cell development kit which works well for most things. It can be tricky to make the base stable while taking measurement, but otherwise could be used with success for this lesson. It also includes many objects to power with the cell as well as provides the ability to link cells in series and parallel.
  o Can be found at Radioshack
    ▪ Elenco™ Solar Educational Kit
    ▪ Model: TR-30 | Catalog #: 277-011
    ▪ http://www.radioshack.com/product/index.jsp?productId=3526559

Activity Time Frame:
This activity can be completed in approximately six to ten hours.

Environmental Setting:
This activity will be conducted primarily in a typical classroom, but will require students to be outside for short periods of time.

PASS Standards:

PHYSICS
High School

Process Standard 1: Observe and Measure - Observing is the first action taken by the learner to acquire new information about an object or event. Opportunities for observation are developed through the use of a variety of scientific tools. Measurement allows observations to be quantified. The student will accomplish these objectives to meet this process standard.

1. Identify qualitative and quantitative changes given conditions (e.g., temperature, mass, volume, time, position, length) before, during, and after an event.
2. Use appropriate tools (e.g., metric ruler, graduated cylinder, thermometer, balances, spring scales, stopwatches) when measuring objects and/or events.
3. Use appropriate System International (SI) units (i.e., grams, meters, liters, degrees Celsius, and seconds); and SI prefixes (i.e. micro-, milli-, centi-, and kilo-) when measuring objects and/or events.
Process Standard 2: Classify - Classifying establishes order. Objects and events are classified based on similarities, differences, and interrelationships. The student will accomplish these objectives to meet this process standard.

3. Graphically classify physical relationships (e.g., linear, parabolic, inverse)

Process Standard 3: Experiment - Experimenting is a method of discovering information. It requires making observations and measurements to test ideas. The student will accomplish these objectives to meet this process standard.

1. Evaluate the design of a physical science investigation.
2. Identify the independent variables, dependent variables, and controls in an experiment.
3. Use mathematics to show relationships within a given set of observations.

Process Standard 4: Interpret and Communicate - Interpreting is the process of recognizing patterns in collected data by making inferences, predictions, or conclusions. Communicating is the process of describing, recording, and reporting experimental procedures and results to others. Communication may be oral, written, or mathematical and includes organizing ideas, using appropriate vocabulary, graphs, other visual representations, and mathematical equations. The student will accomplish these objectives to meet this process standard.

1. Select appropriate predictions based on previously observed patterns of evidence.
2. Report data in an appropriate manner.
3. Interpret data tables, line, bar, trend, and/or circle graphs.
5. Evaluate experimental data to draw the most logical conclusion.
6. Prepare a written report describing the sequence, results, and interpretation of a physics investigation or event.
7. Communicate or defend scientific thinking that resulted in conclusions.
8. Identify and/or create an appropriate graph or chart from collected data, tables, or written description.

Process Standard 5: Model - Modeling is the active process of forming a mental or physical representation from data, patterns, or relationships to facilitate understanding and enhance prediction. The student will accomplish these objectives to meet this process standard.

1. Interpret a model which explains a given set of observations.
2. Select predictions based on models.
3. Compare a given model to the physical world.

Process Standard 6: Inquiry - Inquiry can be defined as the skills necessary to carry out the process of scientific or systemic thinking. In order for inquiry to occur, students must have the opportunity to ask a question, formulate a procedure, and observe phenomena. The student will accomplish these objectives to meet this process standard.
1. Formulate a testable hypothesis and design an appropriate experiment relating to the physical world.
2. Design and conduct physics investigations in which variables are identified and controlled.
3. Use a variety of technologies, such as hand tools, measuring instruments, and computers to collect, analyze, and display data.
4. Inquiries should lead to the formulation of explanations or models (physical, conceptual, and mathematical). In answering questions, students should engage in discussions (based on scientific knowledge, the use of logic, and evidence from the investigation) and arguments that encourage the revision of their explanations, leading to further inquiry

Content Standard 1: Motions and Forces - The motion of an object can be described by its position, direction of motion, and speed. A change in motion occurs when a net force is applied. The student will engage in investigations that integrate the process and inquiry standards and lead to the discovery of the following objectives:

3. The electric force is a universal force that exists between any two charged objects. The strength of the force is proportional to the charges and, as with gravitation, inversely proportional to the square of the distance between them.

Content Standard 2: Conservation of Energy - The total energy of the universe is constant. The student will engage in investigations that integrate the process and inquiry standards and lead to the discovery of the following objectives:

1. Energy can be transferred but never destroyed. As these transfers occur, the matter involved becomes steadily less ordered.

Content Standard 3: Interactions of Energy and Matter - Energy (potential, kinetic and field) interacts with matter and is transferred during these interactions. The student will engage in investigations that integrate the process and inquiry standards and lead to the discovery of the following objectives:

1. Waves have energy and can transfer energy when they interact with matter. Sound waves and electromagnetic waves are fundamentally different.

NOTE: This lesson meets several of the PASS standard for Physical Science as well. However, most students in such a class do not have the necessary skills to perform this lab.

Lesson Objectives:
- Identify the relationship between solar irradiance and electrical power.
- Identify variables that affect irradiance at the Earth’s surface.
- Determine the effect of changing the angle of a solar cell’s surface with respect to incident radiation.
- Determine the current-voltage characteristics of solar cells.
- Employ arrays of solar cells in parallel and series connections to change output current and voltage.
- Determine the efficiency of solar cells.
- Students should be able to connect solar cells in an array appropriate for any load.
Students should be aware of many atmospheric effects that affect sunlight reaches the Earth’s surface.

**Vocabulary Terms:**
1. **Lumen (lm):** The fundamental unit of light.
2. **Illuminance (E):** The amount of light in lumens per unit of area. Lux and footcandle are the standard units. This value is corrected for the spectral response of the human eye.
   a. **Lux:** \( \text{lm/m}^2 \)
   b. **Footcandle (fc):** \( \text{lm/ft}^2 \)
3. **Irradiance:** Light power density in \( \text{W/m}^2 \).
4. **Luminous Efficacy:** A figure of merit for light sources. It is given as lumens of light per watt of electrical energy input and can be used as a conversion factor from illuminance to irradiance.

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From Lee Elizondo’s Renewable Energy: Solar EiP Lesson

**Electric Current:** Electric current is the flow of electric charge. Current is measured in the units of Amperes, A. 1 A of current is equivalent to the flow of 1 C of charge past a point per second. Electric current can either be direct or alternating.

**Electric Power -** The amount of energy produced per second. Electric power is the power produced by an electric current. Power is given in Watts (1 W = 1 A x 1 V).

**Electricity -** A form of energy characterized by the presence and motion of elementary charged particles generated by friction, induction, or chemical change.

**Electricity Generation -** The process of producing electric energy or the amount of electric energy produced by transforming other forms of energy, commonly expressed in kilowatthours (kWh) or megawatthours (MWh).

**Resistance:** The opposition posed by a material or a device to the flow of current. The SI unit of resistance is the Ohm, \( \Omega \).

**Solar Energy -** The radiant energy of the sun, which can be converted into other forms of energy, such as heat or electricity.

**Volt (V) -** The volt is the International System of Units (SI) measure of electric potential or electromotive force. A potential of one volt appears across a resistance of one ohm when a current of one ampere flows through that resistance.

**Background Knowledge:**

The sun has produced energy for billions of years. Solar energy is the sun’s rays (solar radiation) that reach the earth. The term “photovoltaic” comes from the Greek meaning “light”, and “voltaic”, meaning electrical, from the name of the Italian physicist Volta, after
whom the measurement unit volt is named. The term “photo-voltaic” has been in use in English since 1849.

Solar energy can be converted into other forms of energy, such as heat and electricity. In the 1830s, the British astronomer John Herschel used a solar thermal collector box (a device that absorbs sunlight to collect heat) to cook food during an expedition to Africa. Today, people use the sun’s energy for lots of things. The photovoltaic effect was first recognized in 1839 by French physicist Alexandre-Edmond Becquerel. However, it was not until 1883 that the first solar cell was built, by Charles Fritts, who coated the semiconductor selenium with an extremely thin layer of gold to form the junctions. The device was only around 1% efficient. Russell Ohl patented the modern solar cell in 1946 (U.S. Patent 2,402,662, “Light sensitive device”). Sven Ason Berglund had a prior patent concerning methods of increasing the capacity of photosensitive cells. The modern age of solar power technology arrived in 1954 when Bell Laboratories, experimenting with semiconductors, accidentally found that silicon doped with certain impurities was very sensitive to light.

This resulted in the production of the first practical solar cells with a sunlight energy conversion efficiency of around 6 percent. Russia launched the first artificial satellite in 1957, and the United States’ first artificial satellite was launched in 1958 using solar cells created by Peter Iles in an effort spearheaded by Hoffman Electronics. The first spacecraft to use solar panels was the US satellite Explorer 1 in January 1958. This milestone created interest in producing and launching a geostationary communications satellite, in which solar energy would provide a viable power supply. This was a crucial development which stimulated funding from several governments into research for improved solar cells.

In 1970 the first highly effective GaAs heterostructure solar cells were created by Zhores Alferov and his team in the USSR. Metal Organic Chemical Vapor Deposition (MOCVD, or OMCVD) production equipment was not developed until the early 1980’s, limiting the ability of companies to manufacture the GaAs solar cell. In the United States, the first 17% efficient air mass zero (AM0) single-junction GaAs solar cells were manufactured in production quantities in 1988 by Applied Solar Energy Corporation (ASEC). The “dual junction” cell was accidentally produced in quantity by ASEC in 1989 as a result of the change from GaAs on GaAs substrates to GaAs on Germanium (Ge) substrates. The accidental doping of Ge with the GaAs buffer layer created higher open circuit voltages, demonstrating the potential of using the Ge substrate as another cell. As GaAs single-junction cells topped 19% AM0 production efficiency in 1993, ASEC developed the first dual junction cells for spacecraft use in the United States, with a starting efficiency of approximately 20%. These cells did not utilize the Ge as a second cell, but used another GaAs-based cell with different doping. Eventually GaAs dual junction cells reached production efficiencies of about 22%. Triple Junction solar cells began with AM0 efficiencies of approximately 24% in 2000, 26% in 2002, 28% in 2005, and in 2007 have evolved to a 30% AM0 production efficiency, currently in qualification. In 2007, two companies in the United States, Emcore Photovoltaics and Spectrolab, produce 95% of the world’s 28% efficient solar cells.

Solar energy can be converted to thermal (or heat) energy and used to:

- Heat water – for use in homes, buildings, or swimming pools.
- Heat spaces – inside greenhouses, homes, and other buildings.
Solar energy can be converted to electricity in two ways:

- **Photovoltaic (PV devices) or “solar cells”** – change sunlight directly into electricity. PV systems are often used in remote locations that are not connected to the electric grid. They are also used to power watches, calculators, and lighted road signs.

- **Solar Power Plants** – indirectly generate electricity when the heat from solar thermal collectors is used to heat a fluid which produces steam that is used to power generator. Out of the 15 known solar electric generating units operating in the United States at the end of 2006, 10 of these are in California, and 5 in Arizona. No statistics are being collected on solar plants that produce less than 1 megawatt of electricity, so there may be smaller solar plants in a number of other states.

The major disadvantages of solar energy are:

- The amount of sunlight that arrives at the earth’s surface is not constant. It depends on location, time of day, time of year, and weather conditions.

- Because the sun doesn’t deliver that much energy to any one place at any one time, a large surface area is required to collect the energy at a useful rate.

The performance of a photovoltaic array is dependent upon sunlight. Climate conditions (e.g., clouds, fog) have a significant effect on the amount of solar energy received by a photovoltaic array and, in turn, its performance. Most current technology photovoltaic modules are about 10 percent efficient in converting sunlight. Further research is being conducted to raise this efficiency to 20 percent.

The photovoltaic cell was discovered in 1954 by Bell Telephone researchers examining the sensitivity of a properly prepared silicon wafer to sunlight. Beginning in the late 1950s, photovoltaic cells were used to power U.S. space satellites. The success of PV in space generated commercial applications for this technology. The simplest photovoltaic systems power many of the small calculators and wrist watches used every day. More complicated systems provide electricity to pump water, power communications equipment, and even provide electricity to our homes.

Some advantages of photovoltaic systems are:

- Conversion from sunlight to electricity is direct, so that bulky mechanical generator systems are unnecessary.

- PV arrays can be installed quickly and in any size required or allowed.

- The environmental impact is minimal, requiring no water for system cooling and generating no by-products.

Photovoltaic cells, like batteries, generate direct current (DC) which is generally used for small loads (electronic equipment). When DC from photovoltaic cells is used for commercial applications or sold to electric utilities using the electric grid, it must be converted to alternating current (AC) using inverters, solid state devices that convert DC power to AC. Historically, PV has been used at remote sites to provide electricity. In the future PV arrays may be located at sites that are also connected to the electric grid enhancing the reliability of the distribution system. Solar thermal (heat) energy is often used for heating swimming pools, heating water
used in homes, and space heating of buildings. Solar space heating systems can be classified as passive or active.

Passive space heating is what happens to your car on a hot summer day. In buildings, the air is circulated past a solar heat surface(s) and through the building by convection (i.e. less dense warm air tends to rise while more dense cooler air moves downward). No mechanical equipment is needed for passive solar heating. Active heating systems require a collector to absorb and collect solar radiation. Fans or pumps are used to circulate the heated air or heat absorbing fluid. Active systems often include some type of energy storage system.

Research is being done to place solar farms over the ocean. With oceans making up 70 percent of the earth’s surface, some people believe near the coasts would be a perfect place for solar farms. Currently, solar energy is used on offshore platforms and to operate remotely located equipment at sea. Solar energy is a renewable energy source, is free and does not pollute.

Resources:
http://www.learn.londonmet.ac.uk/packages/clear/visual/daylight/sun_sky/sun_calc.html
http://www.volker-quaschning.de/articles/fundamentals1/index.php
http://www.energysavers.gov/renewable_energy/solar/index.cfm/mytopic=50012
http://en.wikipedia.org/wiki/Luminous_efficacy
http://en.wikipedia.org/wiki/Irradiance
www.sunwize.com
www.solarenergy.org
www.eia.doe.gov/kids/glossary/index.html
www.eia.doe.gov/kids/energyfacts/index.html
http://www.nrel.gov

Activity Procedures:
- Students will gather current and voltage data and calculate the electrical power output of the solar cell for various light intensities.
- Next, they will determine the I-V characteristics of a solar cell under varying loads and lighting conditions.
- They will then determine the power output of the photovoltaic cell at various angles with respect to a light source.
- Students will work through some application questions to make sure that they have a good grasp on the practical aspects of the lab.
- They will then be work through an authentic assessment where they will explore various aspects of solar panel installation and solar systems planning.

Technology Component:
Students will use illuminance and/or irradiance meters, digital multimeters, and photovoltaic cells in this laboratory exercise.
Engineering Application:

Students will be given the opportunity to use solar cells to provide power to various electric devices and utilize basic electrical engineering tools to determine the power requirements of those devices. They will also be involved in a field activity whereby they consider the factors affecting the design and installation of a solar panel array.

Assessment Tools:
Coincides with the engineering application.

Additional Sections:

**Photometric and Radiometric Units (Needed for Efficiency Section)**

- Power is normally measured in watts (W).
- The illuminance meters that we have been using measure light in “lux”.
- A “lux” is a lumen (lm) per square meter.
- A lumen is the perceived power of light by the human eye.
- If we look at the graph to the right, we can see that the human eye responds best (or is more sensitive to) green light.
- This means that as humans 10W of green light will look brighter than 10W of red light or blue light.

<table>
<thead>
<tr>
<th><strong>Illuminance is measured in units of lux. Lux = lm/m^2.</strong></th>
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</thead>
<tbody>
<tr>
<td>Solar cells have their own response curves, but in order to get a grasp on how well a cell converts light to other forms of energy we need to know the actual amount of light power in watts that the cell is receiving per square meter.</td>
</tr>
<tr>
<td><strong>However, we need to know the “irradiance” or how much light we have in watts per square meter! Irradiance = W/m^2</strong></td>
</tr>
</tbody>
</table>

A simple way to do this is to use what is called the “luminous efficacy”, which is the ratio of the perceived light power in lumens to the actual power in watts, to convert between illuminance and irradiance.  

\[
\text{Luminous efficacy} = \frac{\text{lm}}{\text{W}}
\]

<table>
<thead>
<tr>
<th>Chart 1: Luminous efficacy of some common sources of light.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Category</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Incandescent</td>
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<td></td>
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<tr>
<td>Light-Emitting Diode</td>
</tr>
<tr>
<td>Fluorescent</td>
</tr>
<tr>
<td>LASER</td>
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<tr>
<td>Sunlight</td>
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</table>
Example: If we measured 500 lux from a 32W Fluorescent bulb, what is the light bulb's irradiance?

\[ 500 \text{ Lux} = 500 \frac{\text{Im}}{\text{m}^2} \quad \Rightarrow \quad \frac{500}{75} \frac{\text{Im}}{\text{W}} = 6.66 \frac{\text{W}}{\text{m}^2} \]

**CONCEPT EXPLORATION: Efficiency**

1. Measure and record the length (L) and the width (W) of your solar panel in centimeters.

   **Solar Cell dimensions**
   
   Length (L) = ______________ cm
   
   Width (W) = ______________ cm

   - For the OWI-608, L = 12.7 cm and W = 6.4 cm.

2. Why do you think surface area is essential to know for our efficiency calculation?

   - The area is needed to normalize our data. This means we need to know how much power we are receiving per square unit of surface area from the cell. The same solar cell that is 1 sq. ft. will produce half the power as one that is 2 sq. ft. If we didn’t scale by the area, it would appear as if the larger panel is more efficient, which it is not.

**CONCEPT DEVELOPMENT: Efficiency**

3. Calculate the surface area of your solar cells and record the value below in square centimeters.

   **Solar Cell surface area**
   
   Surface Area (SA) = __________ cm²

   - Again, for the OWI-608, SA ~ 81 cm²

The energy conversion efficiency defined as the percentage of power that is absorbed as light that is converted to electrical power. It is given as follows:

\[ \text{Energy conversion efficiency, } \eta = \frac{\text{Maximum power point (W)}}{\text{Irradiance (W/m}^2\text{)} \times \text{Surface Area (m}^2\text{)}} \times 100\% \]
4. Using the data we collected in EXPLORATION 1 for the brightest lighting condition, calculate the solar cell’s efficiency with a lamp as a source indoors. NOTE: The following calculations will not reflect the actual quoted efficiency of the solar cell. Special conditions must be in place to yield the actual quotable efficiency of a solar cell.

Solar Cell Efficiency for 500 lux: ________________________________

- For 500 lux, our maximum power point is roughly 13.9 mA @ 1.13 V. This is 15.707 mW = .015707 W of power output.
- Using Chart 1, we see that for a 100 W incandescent lamp that 500 lux is equivalent to an irradiance of 28.57 W/m².
- Our area is 81 cm² = .0081 m²
- Putting it all together, we calculate an efficiency of roughly 6.8%.

Solar Cell Efficiency for 2,000 Lux: ________________________________

- For 2000 lux, our maximum power point is roughly 41.5 mA @ .9 V. This is 37.35 mW = .03735 W of power output.
- Using Chart 1, we see that for a 100 W incandescent lamp that 2000 lux is equivalent to an irradiance of 114.3 W/m².
- Our area is 81 cm² = .0081 m²
- Putting it all together, we calculate an efficiency of roughly 4%.

5. What could be some things that one could do to improve solar cell efficiency?

- Use different materials to make the solar cell out of.
- Make sure the angle of the surface of the cell with respect to the sun rays is optimized. (at a perpendicular angle)
- Make sure panels are placed where there will be no shadow cover from objects throughout the year.
- Make sure the load resistance is optimized.

ENVIRONMENTAL FACTORS

Rather than provide information on environmental factors after the section on how solar panel orientation (angle) affects power output in a lecture format, the following activities could be employed to help teach that content.

Let’s use the internet to try to understand, further. The following website should give some insight as to why your data differs from the solar constant. You can also search for “solar radiation” to obtain additional information.

Please provide at least 4 variables that affect how much light reaches the surface of the Earth.

1. Time of day.
2. Time of year.
3. Local factors such as trees and clouds.
4. Geographic location on Earth.

Now let us explore how each of those factors affects solar radiation.

**Environmental Factors**

**Reason #1:** We have an atmosphere! There are two primary contributing factors to the attenuation (loss of magnitude, opposite of “gain”) of light power in our atmosphere.

**Reason #1a:** *Optical airmass:* Simply put; the distance light has to travel through our atmosphere. The more molecules and particles the light interacts with on the way to the Earth’s surface, the more light scatters and is absorbed. The amount of atmosphere light has to pass through on the way to the surface depends on the time of day, the time of year, and the exact location that the light hits the surface. The scattering itself also increases the length of the shortest path it takes for light to reach Earth.
1. To model this effect, we will consider the atmosphere and the surface of the Earth to be rectangular “slabs” of matter. This is actually a very good approximation for a given local area throughout most of the day.
   a. You have been given a sheet of paper labeled as such.

2. Please place your lux meter facing your light source as shown to the right.

3. Measure the distance that the light is traveling through the “atmosphere” and record your data in Table 4.

4. Also record the illuminance at this point in Table 4.

5. Next, keeping the lux meter in the same position, move the light source such that it is 9 cm from the top of your “atmosphere” at a 30° angle (You are allowed to rotate the meter so that it still faces the light source.) (Shown below)

6. Repeat the measurements in 3 & 4 and record your data in Table 4.

7. Finally, repeat 5 and 6, but with the light at a 20° angle with respect to the top of your atmosphere.
CONCEPT DEVELOPMENT

1. The first measurements we took with the light source perpendicular (90°) to the atmosphere represented light from the sun having to travel through 1 optical airmass in order to reach the surface of the Earth.

2. For what time of year and location on Earth do you think that light would travel through 1 optical airmass to reach the surface of the earth?

- **At true Zenith (zenith angle = 0 degrees and azimuth = 90 degrees)** This occurs on the equator at solar noon during the summer solstice.
3. Based upon your observations, can the optical airmass ever be less than 1?

YES or NO

4. Where on the Earth would you expect the highest optical airmass?
   a. Norman, USA
   b. Mexico City, Mexico
   c. Vancouver, Canada

5. What time of day would you expect to see the highest optical airmass?
   a. 9 AM
   b. 12 PM
   c. 5 PM
Which of the locations above is at the higher latitude?

- The top picture. The data is actually for Berlin, Germany (top) and Cairo, Egypt (bottom).

**Reason #1b:** Atmospheric Extinction Coefficient: This is the actual loss of power due mostly to the scattering of light by air molecules and aerosols and molecular absorption. This data depends upon the same parameters as the optical airmass and a few others.

1. Can you think of anything else that might limit the irradiance that directly hits the surface?

- Any pollutants or local environmental factors such as trees and cloud cover.

**Reason #2:** Local environmental factors such as clouds, trees, and mountains.

1. Using the experimental setup found in Exploration 1 and the materials supplied, design and execute an experiment to determine to what extent local geographical and meteorological factors affect sunlight reaching the Earth’s surface. Please report your findings below.
   a. For instance, you may want to model cloud cover as sheets of paper.