The Science of Photovoltaics and Solar Cells  
A module developed for hands on learning  

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Description: This document is a lesson plan for a short module covering:

1. What is a solar energy
2. Energy and wavelength of light
3. The concept of solar cells and how they work
4. The concept of photovoltaics

The module is readily adapted for students in grades 1-12. It was originally drafted for presentation to children aged 7-13 at the Rocky Mountain Camp for Dyslexic Children. The planned activities are therefore hands-on and do not rely on reading or writing skills.

Science Standards Addressed: (from the Colorado Department of Education)
https://www.cde.state.co.us/coscience/statetstandards

Standard 1- Physical Science

- High School
  - Outcome 6: Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system.
  - Outcome 9: Although energy cannot be destroyed, it can be converted to less useful forms as it is captured, stored and transferred.
  - Outcome 12: Multiple technologies that are part of everyday experiences are based on waves and their interactions with matter.

- Middle School
  - Outcome 6: Energy changes to and from each type can be tracked through physical or chemical interactions. The relationship between the temperature and the total energy of a system depends on the types, states and amounts of matter.
  - Outcome 8: A simple wave model has a repeating pattern with specific wavelength, frequency, and amplitude and mechanical waves need a medium
through which they are transmitted. This model can explain many phenomena which include light and sound.
  - Outcome 9: A wave model of light is useful to explain how light interacts with objects through a variety of properties.

- 4th Grade
  - Outcome 1: The faster an object moves the more energy it has.
  - Outcome 2: Energy can be moved from place to place.

1 Objective

This module serves to introduce students to some core concepts of photovoltaics. Specially, the idea that light is made up different energies which is why we see different colors and that this energy can be converted into usable energy through photovoltaic system. These ideas are demonstrated using solar cells and motors, solar powered toy cars, and different wavelengths of light (i.e. infrared, visible light, ultraviolet). Overall, students gain an understanding that light carries energy that energy can be transformed and utilized.

2 Background

Solar energy has been utilized for thousands of years to dry and cook food, produce textiles and chemicals, and heat homes and water. Many of these early applications relied on focusing sunlight with mirrors or situating homes such that their walls and windows faced the sun in order to passively collect heat during the day. Modern solar technology, though, produces electricity from sunlight with the help of photovoltaic materials. These materials produce electricity via the photovoltaic effect, which was discovered in 1839 by Edmond Becquerel. Becquerel discovered that light could increase the generation of electricity when directed at electrodes placed in conductive solutions. Almost 50 years later, in 1883, the first solar cell was created by Charles Fritts out of selenium wafers which took advantage of the photovoltaic effect to actively produce electricity when sunlight shone on the wafers. In 1954, the first silicon-based photovoltaic cell was created by Chapin, Fuller, and Pearson at Bell Labs. These silicon-based photovoltaic cells were more efficient than the selenium cells and were quickly adopted as the photovoltaic material of the future. Since the 1950’s much research has gone in to producing cheaper, more durable, and more efficient solar cells which could compete with non-renewable energy sources to provide clean and abundant power at scale using only the light of the sun.

Photovoltaic (or solar) cells are constructed from semiconducting materials- which are solid materials which conducts electrons better than insulators like rubber or glass, but not as well as metals like copper. Many modern solar cells are made of silicon because it is easy to dope (mix) the silicon with other materials to change its electrical properties. Solar cells are made up of a few layers, shown in Figure 1.
Figure 1: General structure of a silicon solar panel

The first layer of a solar cell is generally a glass cover which allows light to shine through it but protects the interior of the cell from water and dust. The second layer is an antireflective coating which allows light to pass into the cell but prevents it from being reflected back out of the cell by the silicon wafer. The third layer is made of a thin conductive material like copper or gold which is laid in a grid pattern to allow light to shine onto the silicon while acting as an electrical contact which collects the current and voltage produced by the cell and sends it to whatever is being powered (such as a light bulb). The fourth layer is the negative or n-type semiconductor. This layer is made of silicon doped with elements like phosphorous which have more electrons than the silicon. This creates a material which has extra electrons in its structure which can easily move through the material. The fifth layer is the positive or p-type semiconductor which is made of silicon doped with elements like boron, which have fewer electrons than silicon. This creates a number of silicon electrons that are unbound and looking for an electron to bind with. This missing electron is called a hole and can be thought of as a positive charge. The sixth layer is another conductive material bonded to the back of the p-type semiconductor to act as another electrical contact. The final layer is a rigid backing (like plastic) which supports the rest of the solar panel.

A solar cell is created when an n- and p- type semiconductor are sandwiched together, as in Figure 2. At the junction between the two, electrons from the n-type material fill the holes in the p-type semiconductor, creating a charged barrier between the two materials (the p-n junction). This barrier can be thought of as a one-way door which allows electrons to pass from the p-type semiconductor to the n-type semiconductor, but not the other way around. When light enters the cell, the photons can break apart some of the bound electrons. These electrons move to the n-type semiconductor which causes electrons to build up on the n-side and holes to build up on the p-side. If the solar cell is connected to an external circuit (such as wires through a light
bulb) the electrons flow from the n-side to the p-side to fill the holes. As the electrons pass through the circuit, they power whatever is connected to it whether that be a light bulb, a fan, a stove, or anything else that runs on electricity!

![Figure 2: Working cycle of a solar cell](image)

Solar cells are typically designed to produce optimal voltage and current at certain wavelengths of light. The cells absorb some of the energy from the light and produce electrons that can be passed through electric circuits to power anything from a television to a space satellite. The wavelength of light will determine how much energy is converted within the specific material, as the wavelength of light is tied directly to its energy. Light with shorter wavelengths (like ultraviolet light) has higher energy photons, but solar panels cannot convert all of these photons’ energy to electricity, and much is wasted as heat. This waste heat can degrade the solar panel materials and can cause the efficiency of the panel to drop. On the other hand, light with longer wavelengths (like infrared light) does not have photons of high enough energy to free bound electrons, and it passes through the panel without generating electricity. Most solar panels are designed to utilize a large portion of the visible light spectrum and a small portion of the infrared spectrum as these types of light are high enough energy to break electrons in silicon free and make up about 92% of the light that reaches earth from the sun.

In this exercise we will be looking at solar cells wired to a motor and fan to visualize the effect of exposing the solar cells to various types of light. This hands-on activity is designed for students to examine how photovoltaics work and to understand that light is made up of waves that carry different amounts of energy and that different forms of light will interact with solar cells differently.
3 Materials

- Small solar cells
- Wires
- Small low voltage motors
- UV lamp
- Color changing LED bulbs or flashlights
- Solar toy car
- White light
- IR light
- Voltmeter
- Solar powered calculator

4 Solar Cell Activity

Introduction:
Note: The following lesson plan encourages discussion and active participation. Class discussion questions are indicated by blue text.

Safety:
Activities will include the use of light sources including UV lamps. While our UV lamps use light emitting diodes and are not too intense, these lights should never be pointed directly in your own or anyone else's eyes. Lights should be pointed down and away from the face when in use and kept off when not in use.

Before the activity:
- Pre-activity picture-based questions on light, wavelength, and solar cells as part of assessment (See attached)
- Explain the solar cells
  - Who has gone outside on a sunny day and touched the sidewalk or a swing or your seatbelt in the car and it feels hot? Explain this is a form of solar energy.
  - Who has seen a solar cell before? Example in most school calculators
  - Here we have solar panel connected to a motor when it’s covered the motor does not turn, but when we expose it to energy in the form of light the motor begins to turn and spin the fan.
  - Today we are going to be looking at how we can convert light into usable energy through a photovoltaic system and how light carries different amount of energy based on it’s wavelength.
  - Explain that photovoltaics is converting light into electricity.
Does anyone have examples of other things that can be powered by photovoltaics? Students may say car or guide them and then demo solar toy car

**Activity**

**Preparation:** If teaching younger students prepare each of the solar cells and cars in advance

- Have each student make a photovoltaic system using the solar cells, wires, motor, and fan. This should only be done after safety instructions and demonstration on soldering. can be done by. Skip this step if assembly is performed in advance.
- Have each student test their solar cell either under overhead lights, lamps, or outdoors.
- Measure a solar cell with the voltmeter under the light source.
- What happens if we tilt the solar cells away or towards the light?
- Discuss white light being made up of all wavelengths of light. Does anyone know when we can see all the different colors of visible light? Rainbow
- In your pre assessment we asked which type of light do you think will work best for the solar cells what do people think and why? Discuss how different colors of light are made by different wavelengths that carry different energy. Explain how solar materials are designed to work best at certain wavelengths, typically for visible light.
- Bring out color changing LED bulb or pass out color changing flashlights.
- Turn off overhead lights and let students examine their solar cells under different colors of light.
- Measure solar cells with the voltmeter under the different colors of light.
- Explain how visible light is only part of the electromagnetic spectrum and we can go higher and lower in energy and wavelength.
- Bring out IR and Ultraviolet lights and have students examine if their motors spin faster or slower with these lights.
- Option to allow students to build their own solar powered cars or have preassembled cars.
- Can perform races with different light sources to demonstrate the different energies associated with different wavelengths of light.

**Post discussion:**

- Today we looked at how different energies of light interact with a photovoltaic system.
  - What made the motors turn? What would happen if we covered the solar panels for a long time?
  - What can we do to make the motor turn faster? Why do different lights make the motors turn at different speeds?
  - What types of light have the highest energy? What part of the electromagnetic spectrum can we see? What colors have the longest wavelengths?

- Post-activity picture-based questions on photovoltaics and solar cells as part of assessment same as the pre-activity assessment.

5 **Assessment**

This assessment is targeted towards dyslexic students and is designed so that the students do not need to read much or write.
Questions for Photovoltaic Activity

1. Photovoltaics convert what into electricity?
   - a. Wind
   - b. Solar energy
   - c. Steam

2. Which of these has the longest wavelength?
   - a. Infared
   - b. Visible light
   - c. Ultraviolet light

3. Which of these has the highest energy?
   - a. Green light
   - b. Blue light
   - c. Red light