CLEAN ENERGY INSTITUTE
UNIVERSITY of WASHINGTON

Teacher Guide for SunDawg Bag Lessons

These additional instructional notes will help you get the most out of your SunDawg lessons. A typical instructional sequence would be to introduce the activity to the whole class with a discussion to bring up prior knowledge about solar energy. Then demonstrate the cars under a light or in the sun. You may choose to purchase additional cars so that several small groups of students can each have a car. Otherwise have the groups take turns with the two cars and work at different stations such as car body, reflector, filters, sun angle and design your own experiment.

1. **Shakedown Drive-**

- Start with a discussion. What is solar energy? What is a solar car? How does a solar car work? What are the parts of the car (a solar cell, a motor, wheels, and some gears). How is a solar car different from an electric car (no battery)? How many types of energy are involved with a solar car (light, electricity, energy of motion).
- The cars work best in full sunlight. They also work well under a high power incandescent work light (500 watt) or a spot light shown directly on the car. With a hand-held spotlight you can actually follow the car around the room watching it scoot ahead as the beam hits it. Other lights such as fluorescent or LED may not be powerful enough or have the right color to make the silicon solar cell work. In addition to the visible light silicon solar cells can use energy in the near infrared, radiant heat.
- Students can try designing their own paper car bodies following the basic design provided. The center cut out and slit are used to attach the body to the car. Ask students to be very careful when they attach the body because the wires connecting the solar cell to the motor are very small and are easy to break. You could also open the activity up to decorate the cars creatively with feathers, or animal shapes or whatever as long as the solar cell is exposed and the wheels don't rub.

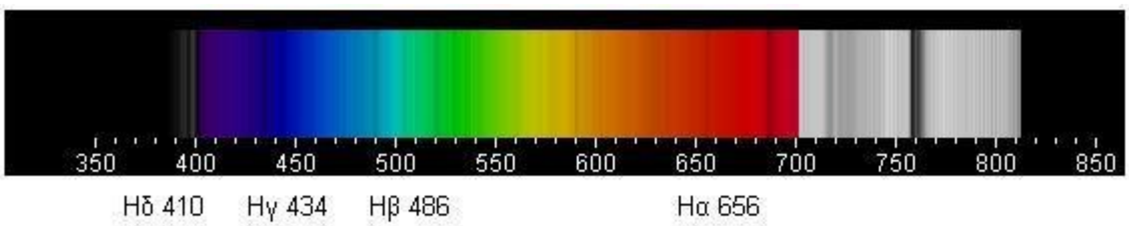
2. **To the Races**

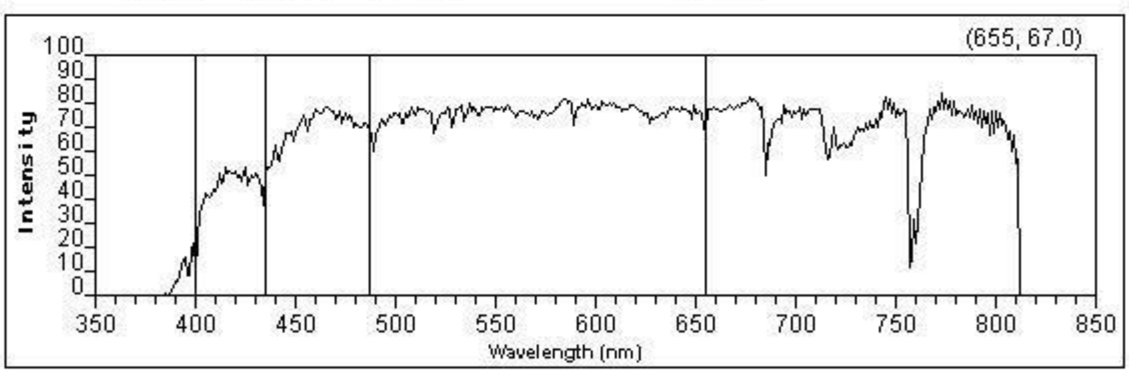
- If you didn't make different color car bodies you might what to add a sticker to identify the cars. Often one car will be faster than the other. Repeat the race several times. Ask one student to keep track on the chalkboard.
- Discuss the results. Which car seemed to be faster? Any ideas why this might be? Why was it important to repeat our experiment several times? Was this a "fair test" or not? This is good chance to reinforce some basic principles of scientific research. We need to **repeat experiments** to improve the **accuracy** of measurements. **Multiple trials** allows us to see trends and not get fooled by random problems like the wheels getting stuck. A "**fair test**" is a simple way of thinking about **experimental controls**. Starting the race by exposing the cars to light at the same time with a blocking card eliminates the problem of one student releasing the car before the other. Students might notice that cars directly under the light do better than those farther to the side. This variable could be controlled by either placing

then the same distance, or by switching places during trial so each has the same chance. If you have stop watch on your phone you could try collecting time data rather just counting wins or losses. Now that you know how your two cars behave you can move on to the next set of experiments in which one car will be the control and the other the experiment.

3. Fun with filters

- Start with a discussion about color and light. Pass the filters around and let the student look around at objects in their classroom or outside. Where do colors come from? How do filters change the way the things look? What happens when light shines on differed colored objects?
- Explain that white light is composed of all colors mixed together but we don't see them separately. A rainbow (or rainbow diffraction stickers) splits the white light into its colors so you can see different kinds of light there. Objects can **absorb** and **reflect** light of different colors. If an object is white it means it is reflecting all the colors equally, if it is red that means that it is reflecting back only red light but is absorbing the others. A black object is absorbing all colors equally. The filters work the same way except the filter is **transparent**. A red filter lets red light through but blocks all other colors. A blue filter makes red colors behind disappear. (Try looking at a red LED on a charger or phone with a blue filter). Colored filters will block some light so unfiltered light is always the strongest. The graph below shows the intensity of light from the sun at each wavelength. The little dips in the graph or dark lines in the spectrum are colors that are absorbed by chemicals in the atmosphere. For example the big dip at the wavelength 760 nm is a color absorbed by oxygen.





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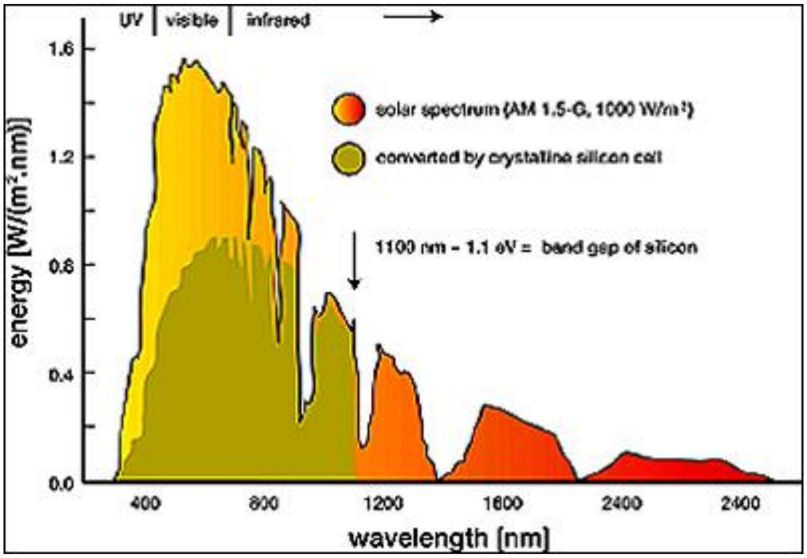
- Solar cells are sensitive to the color (**wavelength**) of light they are exposed to. They are even able to use energy beyond the visible spectrum. In the graph below notice that the green curve of crystalline solar cell extends beyond 700 nm which is the end of the visual spectrum. Also notice it doesn't work very well below 450 nm which is blue to violet light.

- 

- Ask the students to design an experiment to test which color of light is best for the solar cars. Ask them to make a **hypothesis** about what results they will see. Try to get them to volunteer a reason for their hypothesis. For example, "yellow will do best because it is lightest or looks most like the sun". A good hypothesis is more than a guess, it connects the results to a rule or theory you are trying to prove. Students race cars with different colors of filters and compile the results after multiple trials. Was this a fair test? Students may notice that some filters are much darker than others. This might explain why your results do not match the absorption chart for silicon. Also the differences between the cars might outweigh the effect due to color of light. Read more http://www.suntoy.co.za/downloads/ColourFilters_KatieFitzgerald.pdf

4. Angles of light

- This activity helps students think about the idea of incoming solar power and how solar cells respond. The angle of sunlight with respect to the surface determines how much of the available power at that moment hits the surface. We are only considering the effect of angle and not the secondary phenomena about the power changing over the course of the day as it sunlight goes through more or less atmosphere. The sun at noon feels more powerful that the sun at dawn even when you face it directly. On clear day the sun should provide 1 kilowatt of energy per square meter of area it hits at 90 degrees. You may want to discuss with students the idea of power the watt- a measure of energy used or produced per unit of time. A cell phone uses 2 watts when charging, an oven uses 3000 watts.
- http://www.wholesalesolar.com/solar-information/how-to-save-energy/power-table

- What time of day does the sun feel the hottest? When does the sidewalk feel the hottest? What time of day do solar cells work the best? Does it make a difference if the sunlight hits the solar cell directly or if it hits the panel at a low angle? To answer this question through experimentation the students will need to have a movable light source such as a spot light, or they will need to try the cars in sun a noon and in early morning or late afternoon.
- As students design an experiment they need to define **what they will measure**, what **they will change** and **what they will keep the same**. These represent the **dependent variable**,

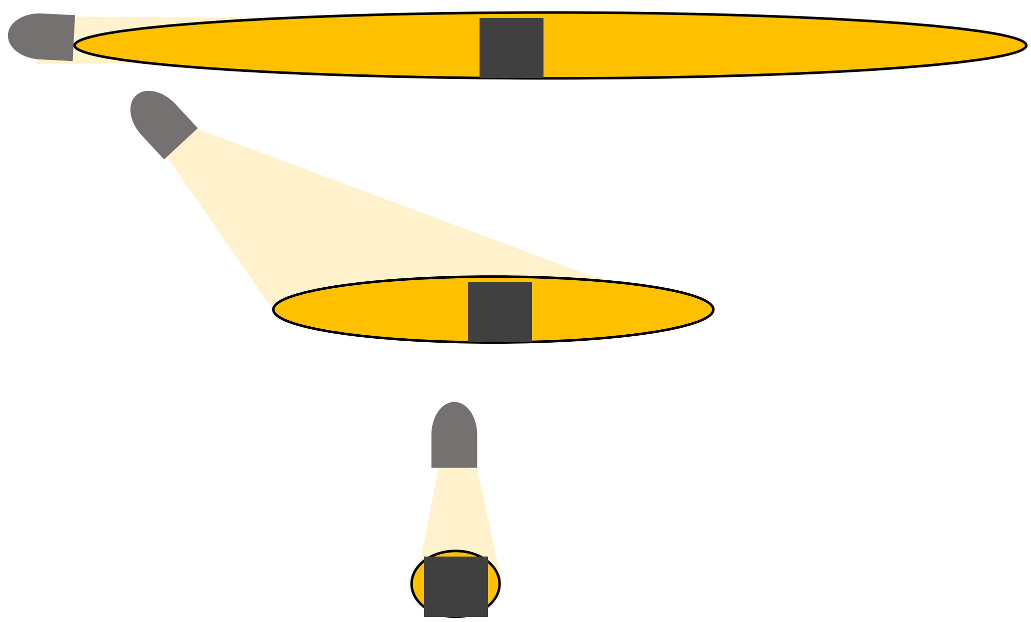
the **independent variable** and the **controlled variables**. Measure the cars speed by observation, (eg, slow, fast, fastest) or by timing race using a stopwatch. Another method would be to measure at what angle of light the car first starts to move. The independent variable you are controlling and changing is the angle of the light. Cut out and use the protractor to measure the angle of the light as it is changed, or of the sun at different times of the day. The things to keep the same are a) the cars b) each test should be run on the same track. Tilting the race track is not a good idea because it introduces the variable of gravity. You could hold the car and tilt it and record the angle when the wheels begin to spin or stop spinning.

- After sharing class data ask students what they concluded. (90 degrees with respect to the sun is best). Ask them to explain this. Use a flashlight to illustrate. The flashlight provides a certain amount of light in the area of its beam. Regardless of how you point it the flashlight is always producing the same amount of light. Draw a circle around the area the beam is lighting up. Now move the flashlight to a lower angle and outline the area, repeat. Now draw a square in the first circle about the size of the circle; this represents a solar cell that is collecting all the power the flashlight is producing. Now compare the situation when the angle is 45 degrees. The solar cell is only covering half of the area that light is shining on. So it must be collecting less than half the power of the flashlight. At the lowest angle the beam is covering a huge area but the solar cell is only catch a small portion of the light.

0 degree angle

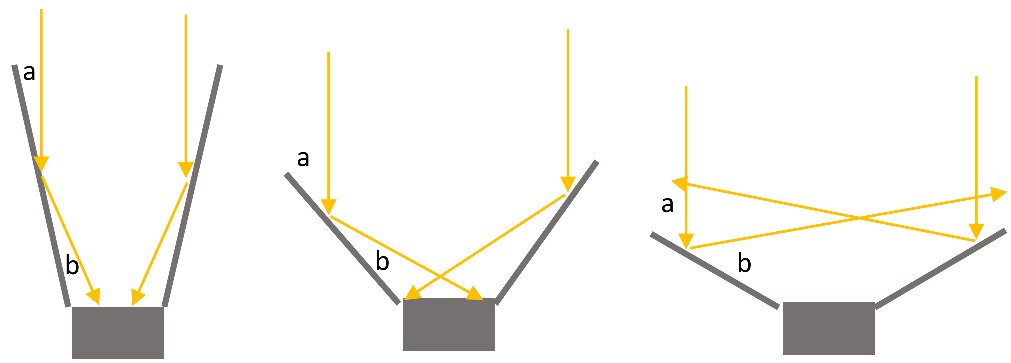
45 degree angle

90 degree angle



5. Concentrators

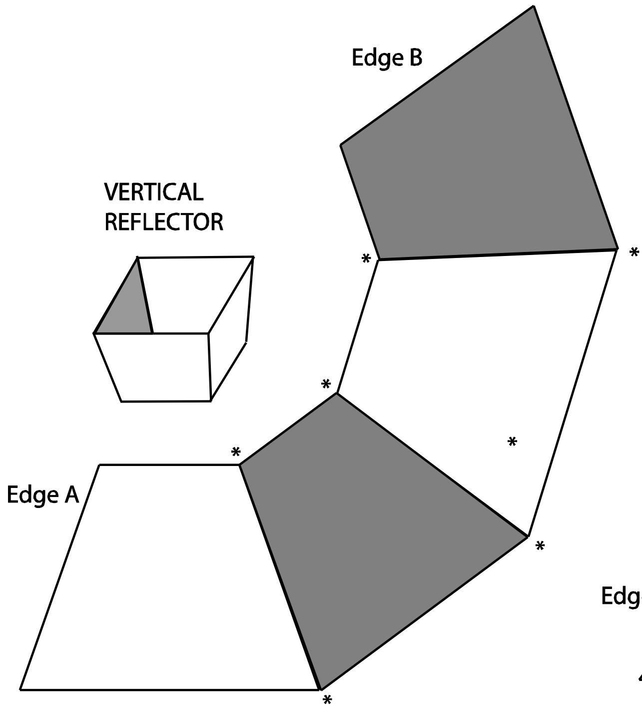
- Another strategy to improve solar cell output is to provide more sunlight by using concentrators such a lens or mirrors. Mirrors can help offset the effect of an incorrect angle. Demonstrate this by using a piece of the mirror card to reflect low angle light on the car. Multiple mirrors can also be used to intercept a larger area of light and focus this to small area. Let students try design their own concentrators. This is a good activity for the **engineering** part of STEM learning. Engineering design is similar and different from the scientific process.

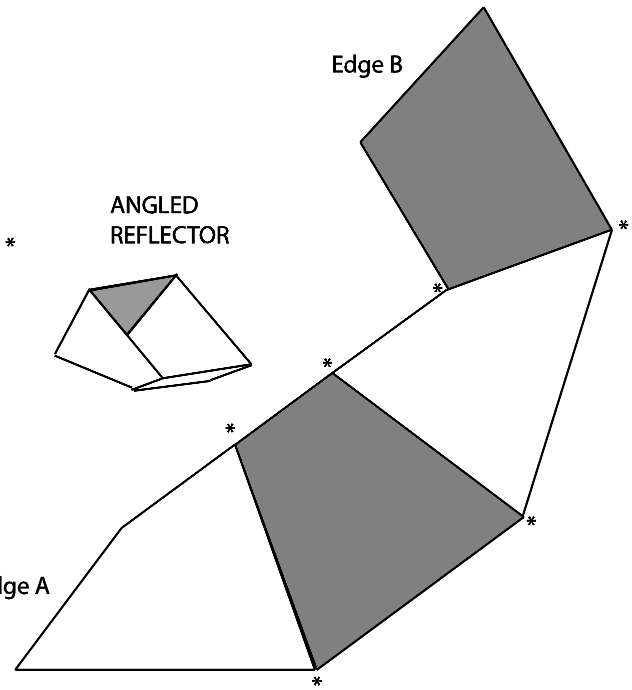
- What is an engineer? How is an engineer different from a scientist? How are they the same?
- An engineer creates a design that solves a problems. In this case the challenge is "how can we get more light on the solar cells to make them work better". Students will work to create a **prototype**. In the process of exploring reflectors they will make some discoveries that will help them with future designs. The reflector has to be at the correct angle to direct light on the panel. A shallow angle of less than 45 degrees will not work. Show them how to draw a ray diagram. Show that the rule of reflectors is that the **angle of incidence** (a) equal to the **angle of reflection** (b). If the angles are correctly reflecting the area of entire opening is focused on the cell, boosting the power by the ratio of the area of the opening to the area of the cell.
- 

  - Students can make a sketch of their design and then build the reflector. Another discovery students might make is that reflectors have to face the light source straight on or they won't work. If your students get really excited they might try to create a curved collector. Ask your own questions

The speed of the cars represent a fun way to measure power from solar cells and to perform experiments for science and engineering. See what questions of their own they can ask and then answer through experiments.

A simple reflector box can be assembled using the following plans. The straight version is good for noon sun directly overhead. The tilted one is good when racing towards a low sun. Students can practice basic geometric constructions. The ideal reflector angle and size directs all the light coming in the opening towards the target.





1) Copy and cut out outline of the reflector
2) Trace outline on the back of the reflective material- or line with foil
3) Cut out the shape in the reflective material
4) Use a straight edge to fold at lines marked *
5) Join Edge A to Edge B with tape
6) Place the reflector around the solar cell and secure with tape