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Solar Cells – Part 1

Lesson created by: UTeach Outreach, Fall 2010
Description of the class: 6th grade after-school Science Olympiad Club
Adapted by: Laura Sanders, Environmental Science Institute, January 20, 2011
Length of lesson: 60-90 minutes

Source of the lesson:
http://science.howstuffworks.com/solar-cell1.htm
http://science.howstuffworks.com/question5011.htm
http://www.solideas.com/solrcell/ICE_98_001_NanocrystalllineSolarCellKit.html
http://www.allaboutcircuits.com/vol_1/chpt_2/1.html
http://tonto.eia.doe.gov/kids/energy.cfm?page=solar_home-basics
http://www.nrel.gov/docs/gen/fy01/30927.pdf

TEKS addressed:
6.1(A) The student demonstrates safe practices during laboratory and field investigations as outlined in the Texas Safety Standards.
6.2(D) Construct tables and graphs, using repeated trials and means, to organize data and identify patterns
6.4(B) Use preventative safety equipment, including splash goggles, aprons, and gloves, and be prepared to use emergency safety equipment, including an eye/face wash, a fire blanket, and a fire extinguisher.
6.7(A) Debate the advantages and disadvantages of using coal, oil, natural gas, nuclear power, biomass, wind, hydropower, geothermal, and solar resources.
6.7(B) Design a logical plan to manage energy resources in the home school or community.
6.9(A) Investigate methods of thermal energy transfer, including conduction, convection and radiation.
6.9(C) Students demonstrate energy transformations such as energy in a flashlight battery changes from chemical energy to electrical energy to light energy.

I. Overview
Students will begin by learning about nanoscience and reviewing photosynthesis. Students will learn about TiO_2 and its practical uses. Students will make a solar cell and understand the process of solar energy. They will review concepts visited in Metals and Nonmetals: conductors, resistance and what is necessary for a circuit to work. Students will complete an activity that focuses on the importance of renewable resources.

II. Objectives
1. Students will describe and demonstrate the process of energy transformation by solar cells.
2. Students will collect data, make calculations, and create graphs to display scientific data.
3. Students will compare methods used for transforming energy in devices.
4. Students will identify solar energy as an inexhaustible resource.

III. Resources, materials and supplies
Per group of four students:
- Multimeter
- Mortar and pestle
- Craft stick or dropper
- Cut transparency/piece of plastic with two pieces of glass taped down on it
- 6 mL Acetic acid
- 4 g TiO_2 powder
- 0.66mL dish soap solution
- Glass rod
- Timer

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- Styrofoam
- Centrifuge Tubes

Per pair of students:

- A bag/container
- 90 of one type of bean and 10 of another

IV. Advanced Preparation – Gather all materials before the lesson begins.
Measure 0.5 ml of soap water and pour into the centrifuge tube. Place tubes in the Styrofoam for later use.

V. Supplementary worksheets, materials and handouts

- "Solar Cell Background Information" handout
- "What is a nanometer?" powerpoint
- "Solar instructions" powerpoint

VI. Vocabulary & Definitions:
For Secondary Students:

1) Solar cell or Photovoltaic cell – commonly called a solar cell or PV, is the technology used to convert solar energy directly into electrical power.
2) Electrons – an elementary particle consisting of a negative charge.
3) Amps – used to measure the rate of current in a substance.
4) Current (A) – a flow of electric charge.
5) Multimeter – an instrument for measuring the properties of an electrical circuit such as resistance, voltage, or current.
6) Resistance (R) – a material's opposition to the flow of electric current.
7) Ohms (Ω) – a unit of measure for resistance.

For Elementary Students:

1) Solar energy (la energia solar) - the sun's rays (solar radiation) that reach the Earth.
2) Solar cell or Photovoltaic cell (de celulas solares) – a kind of battery that gets its energy from the sun.
3) Electrons (electrons) – negatively charged particles.
4) Amps (amperios)– unit of measurement for current.
5) Current (la corriente electrica) – a flow of electric charge.
6) Multimeter (multimetro) – a device that is used to measure resistance, current, or voltage.
8) Semiconductor (semiconductores) – any of a class of solids whose electrical conductivity is between that of a conductor and that of an insulator.
7) Resistance (resistencia) – opposition to the flow of electric current.
8) Chlorophyll (clorofila) – green pigment that enables plants to carry on photosynthesis.

VII. Safety Considerations:
Students must wear safety goggles, gloves and masks at all times during the exploration.
Students must handle the glass squares with care as the edges are sharp.

VIII. 5-E Lesson Plan

Engagement **Time: 5 minutes**		
What the Teacher Will Do	**Probing Questions**	**Student Responses** **Potential Misconceptions**
Hold up a plant.	*How do plants eat?*	Plants make their own food from

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		sunlight! [Misconceptions: They don't need food. Water is their food.]
	What do plants use to change the sun's energy into their own?	Chlorophyll; the leaves. [Misconception: The plant's roots.]
Right, plants use chlorophyll to take in the sunlight and make its own energy.	*Why are plants green?*	Chlorophyll is a green pigment.
The chlorophyll in plants makes them green! In our experiment, we will be using anthocyanin dye. Anthocyanin dye is a bluish color while chlorophyll is green. **Write chlorophyll and anthocyanin on the board and show pictures of them.**	*What similarities do you see between these two molecules?*	They both have rings. Various answers. [Misconception: Not knowing what a molecule is; not understanding the diagram.]
They both have similar structures.	*Do you think they will behave the same way because they have similar structures? Do you think that anthocyanin dye could help perform photosynthesis like chlorophyll?*	Yes/No. Discuss.
We are going to find out. Today we are going to be nanoscientists!! Nanoscientists study things that are 100 nanometers or smaller! ***Nanometer PowerPoint slide show*** *A nanometer is tiny. A leaf is about 10 cm. A leaf is a tenth of a meter, which is about ten centimeters or 100 millimeters.* **Next slide.** *A thumb tack is about a tenth of a leaf which is about 1 cm or 10 mm.* **Next slide.** *One strand of hair is one hundredth of a thumb tack. This means one hundred strands of hair can fit across a thumb tack. One strand of hair is about 90,000 nanometers which is about 0.09 millimeters. We will be working with something that is about 50,000 nanometers!!* *Even at 50,000 nanometers, it's still smaller than a hair from your head!*		
Exploration **Time: 40 minutes**		
What the Teacher Will Do	**Probing Questions**	**Student Responses**

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		Potential Misconceptions
Pass out worksheets. *A solar panel is a sheet that uses solar energy and converts it into electricity. A solar panel is made up of many solar cells and is also called a photovoltaic cell. The prefix photo- means "light" and voltaic means "electricity."* **(Write on board.)** *Now record this on your worksheets.* *Today, as nanoscientists, we are going to make a solar cell, which is a form of nanotechnology. Let's go over the rules first.* *1. Safety is number 1! Just like scientists in a lab, we must always wear safety goggles and gloves when experimenting with chemicals.* *2. Follow directions!! This is extremely important. If you don't follow instructions carefully, your solar cell won't work.* *3. Be scientists and work together!* **Pass out safety equipment first. Then pass out the job cards/instruction sheets.** *Safety equipment is extremely important for our experiment so we will not continue until everyone has it on. Also, if we see anyone taking any of it off, they will not be allowed to participate in the rest of our experiment.* **Students should divide into groups of four.** *One person from each group should pick up an experimental kit for their group.*	*Have you ever heard of a solar cell? Have you ever seen a solar panel? Where?* *What does a solar panel do?*	Yes/No. Various responses. It uses solar energy. It powers things with electricity.
Exploration (continued) **Time: <u>40 minutes</u>**		
What the Teacher Will Do	**Probing Questions**	**Student Responses**

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		Potential Misconceptions
Now get out the container and stick (mortar and pestle) *from the kit. Also, you will get a powdered chemical inside of a container. This white powder is called nanocrystalline* TiO_2. (**Write on board and show pictures of** TiO_2 **products)** TiO_2 *is found in things such as toothpaste, white paint, and even sunscreen. Now, are any of these items harmful to you? They would be if you eat them right? So these items can be harmful if you eat them, and you aren't supposed to breath in too much of the paint's smelly fumes. So we have to be careful with the* TiO_2 *powder and can't eat it or breath it in. because it can be very harmful just like these items. For this experiment, we are going to wear masks when we are working with the* TiO_2. **Write acetic acid on the board.** *Acetic acid is also called vinegar and is found in everyday items such as salad dressing.* *After we add the* TiO_2 *powdered chemical, person number 2, will add the acetic acid solution with the dropper while number 1 mixes the solution with the stick in a crushing motion.* ***Listen carefully to directions before you continue.*** *You must add the acetic acid slowly while crushing and mixing it. Number 2 will add one milliliter, which is marked on your pipette. After 30 seconds, you will add another milliliter until you have added 3 milliliters. Then Number 3 will add 1 milliliter of acetic acid every 30 seconds until you have added 3 milliliters. You may begin.* **Walk around and help students as needed.**		
Exploration (continued)		

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Time: 40 minutes		
What the Teacher Will Do	**Probing Questions**	**Student Responses Potential Misconceptions**
Now if you have the timer **(Number 4)**, *you will restart the timer for the next part. Each of you will be mixing the solution for one minute, starting with number 1 and rotating to the next number. Ready, go!* **While students are mixing continue with the questions until they finish. Once the students are done, pick up the acetic acid and pipette.**	*Tell me, what is TiO_2?*	Nanocrystalline.
Right! It's a nanocrystaline, which means it's made up of tiny particles.	*Why are we still mixing our solution? Why can't we just skip this step of everyone taking turns mixing?*	Various answers.
Well, remember how small a nanometer is? We are working with nanocrystalline TiO_2 which means there are tiny crystal-like structures that are really tiny. This means even though the solution may look like it is mixed up, it still needs to be mixed at the nano level to break up all of the crystals since they started out in clumps from the powder. ***(*Show the picture on the slide of the crystals in TiO_2)**		
While you are mixing the solution, you will be working in your groups and answering a few questions on your worksheet. You must list at least three different answers for each question. Be sure to keep track of the timers and taking turns mixing the solution.	What are some objects that we could power with solar energy? What could we power with one solar cell? What other products do you think have nanocrystals in them?	Various answers.
When students finish answering the questions or when they finish mixing, whichever comes first, go over some of their answers.		
Number 1 will add 0.5 milliliters of dishwashing soap and water solution to the bowl while number 4 is mixing it. ***Before you add the soap solution, there are some instructions on how to do this.***		

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Exploration (continued)
Time: 40 minutes

What the Teacher Will Do	Probing Questions	Student Responses Potential Misconceptions
Write "soap solution" on the board. Underneath it you will list "slow," "gentle," and "bubbles" with an "x" through "bubbles" or follow along on the PowerPoint. Pass out the soap and pipette after you explain the safety rules. *When Number 1 adds the soap solution, Number 4: make sure you mix very gently and slow. You don't want to form ANY bubbles or your solar cell won't work properly.* **Demonstrate while you are explaining. Let the students follow along with you.** *Now, we have to let the mixture sit for about 15 minutes. If you have a timer, go ahead and start those while we come around and pick up your mixtures. We will put them in containers labeled with your group number on them.* **Be sure there assigned group numbers and keep them in order. One person will put them in the containers while the other continues with the lesson.**		
While we are waiting, we will continue with the next part. One person take out the square glass and the multimeter.	*What are some safety considerations for working with multimeters?*	Only touch the item being tested. Do not touch other people. We are not testing each other.
A multimeter is a device that measures voltage, current, and resistance. We will be measuring the resistance of each side of the glass. We saw multimeters a few weeks ago when we were studying metals and nonmetals.	*What is resistance? What does resistance mean?*	It stops something from happening.

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Exploration (continued) **Time: <u>40 minutes</u>**		
What the Teacher Will Do	**Probing Questions**	**Student Responses** **Potential Misconceptions**
Resistance means "to oppose" or to make it harder for something to move. In this case, we are talking about electrons moving across the glass surface. *The multimeter forms a closed circuit with the two probes. Then it measures resistance, or ability for the free electrons on the surface to move.* *When we use the multimeter to measure the resistance, we want to see a lower number. If the number is too high, the multimeter will read OL, which means overload.* **(write on board)** *If the number is low enough, you will see a number on the multimeter.* *Number 1 will use the multimeter and put both of the probes on one side of the glass. Be sure to notice and remember which one reads "OL" for overload and which one has a number reading on the multimeter.* **Have the multimeters on the right setting before handing them out to groups. Walk around and make sure the students find the right side. The right side should be about 10-30 ohms. Demonstrate.** *You should have the piece of glass with the number reading at the top with the tape around three edges.*	*When I use this multimeter and put its two tips on the glass, what am I creating?* *In order to get the best solar cell, would we want a higher or lower resistance? Would we want the electrons to be able to move slower or faster?*	A closed circuit! [Misconceptions: Students may have no idea if circuits have not been previously covered, so this concept may need to be addressed.] The resistance should be low so the electrons can move faster.

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Exploration (continued) **Time: 40 minutes**		
What the Teacher Will Do	**Probing Questions**	**Student Responses Potential Misconceptions**
Now we are ready for our final step. Number 2 will need to get the craft stick and scoop up the mixture on the top edge piece of tape. You will place it on the piece of taped-down glass and dispose of the stick properly. Number 3 will get the rod from the kit and spread out the mixture evenly on the glass very carefully by grabbing both ends of the rod and sliding the stick back and forth one time. **Demonstrate and walk around to guide the students. If it doesn't look smooth enough then have them clean off the glass and start over.** *This is the end of making our solar cell today. We will finish making them next week!! Be sure to label the plastic sheets with your group number and remember your number for next time.* **You want the glass to dry before stacking them to avoid smearing and scratching.**		

Explanation **Time: 7 minutes**		
What the Teacher Will Do	**Probing Questions**	**Student Responses Potential Misconceptions**
	In your own words, explain to your group what a mulitmeter is. Then, tell me.	It measures different things. [Misconception: it only measures resistance and/or voltage.]
The multimeter measures resistance, voltage, and current. We used it to measure the resistance of the glass.	*What did the mutlitmeter test?* *What is resistance?*	Resistance. [Misconception: Voltage] A measure of an object's opposition to the flow of electrons. [Misconception: Students confuse voltage with resistance because

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	Why did we have to measure the resistance of the glass?	both are measured with the same multimeter.] To make a better solar cell by ensuring that the resistance was low.

Explanation (continued)
Time: 7 minutes

What the Teacher Will Do	Probing Questions	Student Responses Potential Misconceptions
We had to measure the resistance of the glass to see if the free electrons on the glass surface could move.	*What was necessary for us to measure the movement of electrons?*	A circuit and/or a closed loop.
Right! We used the multimeter to make a closed circuit so the electrons were able to move and we could get a resistance measurement.	*What is a conductor?*	Something that electricity can travel through easily.
	Would a good conductor have a high or low resistance?	Low. [Misconception: High because a lot of electrons need to flow. Students tend to confuse the word high with meaning "a lot."]
A good conductor will allow electrons to flow through it so it would have a low resistance.	Do you think glass is a good conductor? Why or why not?	No. [Misconception: yes because we are using it for our solar cells.]
Glass isn't a good conductor because the structure doesn't allow electrons to move around easily. Now you are probably wondering, if glass isn't a good conductor, why did we measure the resistance and why was the resistance different on the opposite sides? Glass by itself isn't a conductor, but our piece of glass was coated with a chemical that is a good conductor. This allows the electrons to move more freely and will help our solar cell to work.		

Elaboration
Time: 15 minutes

What the Teacher Will Do	Probing Questions	Student Responses Potential Misconceptions
Continue with this activity if time		

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permits.	What is a renewable/nonrenewable resource is? Is solar energy renewable or nonrenewable?	Renewable resources can be easily replaced and nonrenewable can't be replaced. Renewable. [Misconception: Nonrenewable because we have to make more solar cells all the time.]
Elaboration **Time: 15 minutes**		
What the Teacher Will Do	**Probing Questions**	**Student Responses** **Potential Misconceptions**
Scientists are constantly working to find more renewable sources of energy such as solar energy so it won't be a problem when we run out of nonrenewable sources of energy. *In the early 1970s it was predicted that we would run out of natural gas by the late 1980s. Although many predictions are made, no one can be completely sure. We are going to do an activity showing the decreasing availability of nonrenewable sources.* **Divide students into pairs and pass out a blindfold and a container: 90 of one type of bean and 10 of another.** *Recent studies show that the total renewable energy percentage is about 10%. The U.S. depends on nonrenewable energy everyday and because the population is growing, more and more energy is needed each day.* *One of you will put the blindfold on and take beans from the container. The beans represent energy, 90% nonrenewable and 10% renewable. If you take out renewable energy, you can replace it back in the container each year. Record the amount of renewable and nonrenewable energy used each year as well as how many beans are left in the container or how much energy is left.*	What are some nonrenewable energy resources? Can we predict about when we will run out of nonrenewable sources? When do you think we will?	Fossil fuels. Coal. Natural gas, etc. Ten years? Twenty? One hundred? [Misconception: Never, because we have lots of things on earth.]

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Be sure students are recording each year in their worksheets. *Now that we saw how nonrenewable sources are limited, let's brainstorm some ways we can conserve energy in our homes, school or in Austin.*		
Evaluation **Time: 5 minutes**		
What the Teacher Will Do	**Probing Questions**	**Student Responses Potential Misconceptions**
Pass out the quiz question sheet.		

Solar cell directions

Nano Scientists 1, 2, 3, 4

Step one
1: You will start with the mortar and the pestle
4: You will be timing to make sure number 2 & 3 add acetic acid every 30 seconds.
2: You will add one milliliter of acetic acid every 30 seconds until you have added 3 milliliters.
3: You will add one milliliter of acetic acid every 30 seconds until you have added 3 more milliliters for a total of 6.

STOP!

Step two
1: One of you will return the acetic acid to the front.
2: Each of you will mix the solution for one minute, rotating in numerical order starting with number 1.

STOP!

Step three
1: Add 0.5 milliliters of the soap solution to the mixture
4: Gently, slowly, very carefully mixes the mixture after 1 adds the soap solution.

STOP!

Step Four
1: Return the tray with all your materials.
You must be careful when handling the next equipment because it is glass and has sharp edges.

STOP!

Step five
1: Measure the resistance of both pieces of glass using the multimeter. Remember which one is "OL" for overload and which one had a number on the multimeter when you finish.

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2: You will spread out a small amount of the mixture along the piece of tape at the top of the piece of glass that had a number reading or with tape around three edges.
3: As soon as 3 puts the mixture on the glass, you will use the rod to spread it out onto the glass. You will hold both sides of the rod and use a sliding motion, going back and forth one time.
4: You will label the sheet with your group name or number and take the photo cell to the front of the classroom with all the other materials.

Group Name:____________________________ Date:___________

I am a Nanoscientist!!

Directions: List at least three different answers for each question as a group.

1. What are some objects do you think we could power with solar energy?

   A. ____

   B. ____

   C. ____

2. What about one solar cell?

   A. ____

   B. ____

   C. ____

3. What other products do you think has nanocrystals in it?

   A. ____

   B. ____

   C. ____

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Name: ____ Date: ______________________

Renewable vs. Nonrenewable Energy in the World

Directions: One person will be blindfolded and will be taking out the beans. You will take turns for each year and record your results. Remember, if they are renewable you can put them back in the container, if they are nonrenewable, once you take them out they have to stay out.

Years:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total:
# Beans Remaining																
#Renewable																
# Nonrenewable																

What happened to the renewable resources between years 1 and 15?

____

____

What happened to the nonrenewable resources between years 1 and 15?

____

____

What are at least three ways to conserve energy in our everyday lives?

1. ____
2. ____
3. ____

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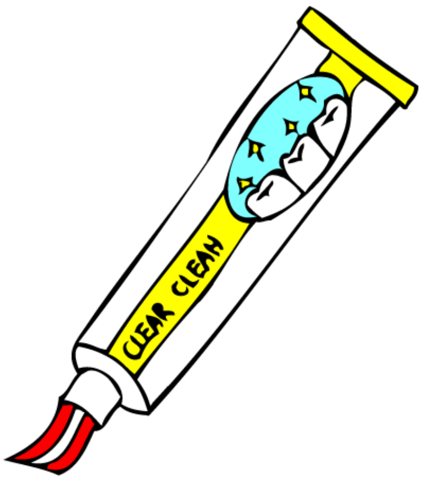
TiO_2 PICTURES



Titanium dioxide is the most widely used white pigment because of its brightness. It's employed as a pigment to provide whiteness and opacity to products like toothpaste and paints.

Titanium dioxide is found in almost every sunscreen with a physical blocker because of its high refractive index, its strong UV light absorbing capabilities and its resistance to discoloration under ultraviolet light.

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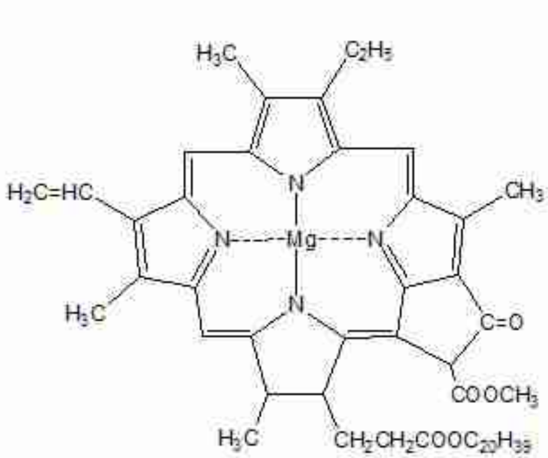
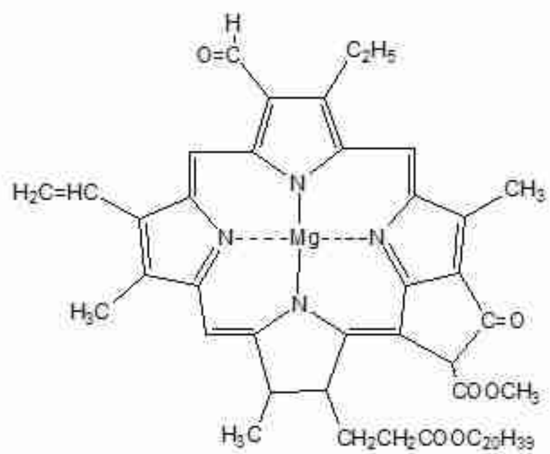
CHLOROPHYLL



Chlorophyll a



Chlorophyll b

ANTHOCYANIN

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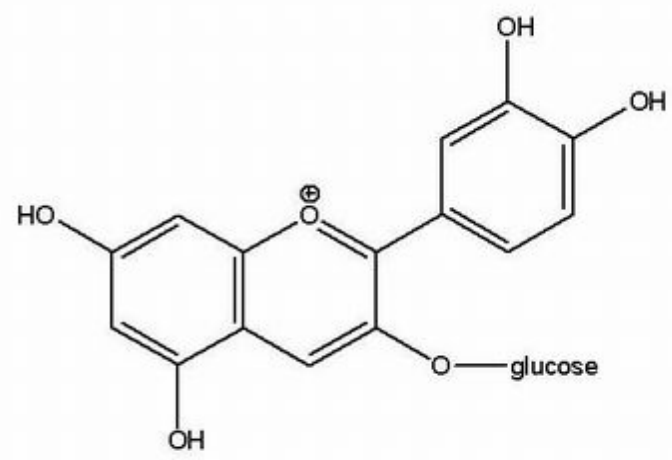

anthocyanin with sugar

Name: ______________________________________ Date: ____________________

Solar Cell Quiz

1. A photovoltaic cell is
   a. the same as a solar cell.
   b. something that takes up energy from the sun and turns it into electricity.
   c. something that uses a renewable source of energy.
   d. all of the above.

2. A renewable source of energy is
   a. a type of energy that will eventually will run out.
   b. a type of energy that will never run out.
   c. natural gas.
   d. fossil fuels.

3. In a solar cell, the resistance should be
   a. low, because you want the electrons to be able to move around easily, forming a circuit.
   b. low, because you want the electrons to stay still.
   c. high, because you want the electrons to be able to move around easily, forming a circuit.
   d. high, because you want the electrons to stay still.

4. Anthocyanin dye and chlorophyll have similar structures. This means they should react the same. This means that the anthocyanin dye should be able to
   a. take up water just like leaves do.
   b. be green because chlorophyll is green.
   c. absorb light from the sun and transform it into energy.

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d. grow in plants.

Name:_____________________________

Recipe for a Solar Cell

Ingredients

Bowl and Stick	2 glass squares
3 millimeters of Acetic Acid	One minute
0.5 millimeters of soap solution	Multimeter
Glass Rod	Low
TiO_2 Powder	Nanocrystals
Tape	Bubbles

Step 1: First, take the ____________________________ and add the white ______________. Then, two different people in the group will each add _____________________________.

Step 2: Now everyone will take turns mixing the solution for _______________. You must mix the solution, even if it looks like it is mixed, because the __________________ are so small that we can't see that they aren't fully mixed yet.

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Step 3: Then you will add __________________ to the mixture, and mix very slowly and gently to make sure there are no ____________. After mixing, the solution has to sit for about 15 minutes.

Step 5: Then, someone will use the _________________ to measure the resistance of the ________________. To get the best solar cell, you want the resistance to be ______.

Step 6: Finally, spread out a small amount of the mixture along the piece of _________ at the top. Use the _________________ to spread the mixture evenly on the glass using a sliding motion. Now your solar cell is ready for next week's experiment!

Solar Cell Background Information

Elyse Zimmer, UTeach Outreach, Fall 2010

Solar Cell Lesson #1 Background Information:

College Level

I. Introduction:

The purpose of a solar cell is to convert one form of energy, sunlight or solar radiation, into another form of energy, electricity. Solar radiation is composed of elementary particles called photons. Photons carry energy. Solar cells themselves do not store electricity, so they are often attached to a solar electric system.

When photons hit a solar cell the energy of the photons is converted into electric current, or the movement of electrons. A solar cell by itself does not create much electric current so often solar cells are arranged into solar panels. The electrons do not disappear when the solar cell is struck by photons and instead just lose their energy, in the form of volts to create a voltage. The de-energized electrons flow back through the solar cell and are re-energized by photons. As long as there are photons present this process continues.

There are two types of solar cells: Silicon Solar Cells and Dye Sensitized Solar Cells.

II. Silicon Solar Cells

Resources:

- Excellent Video: http://www.youtube.com/watch?v=3Zpg5yLFKnI
- Explanation by GE: http://www.gepower.com/prod_serv/products/solar/en/how_solar_work.htm

The majority of solar cells are composed of silicon. The reason that silicon makes a great material for solar cells is because it is a semiconductor and it is a metalloid. Silicon is an insulator, like nonmetals, and also has metal properties. Silicon is often used in solar cells because the energy needed to ionize a silicon electron matches the typical energy of photons coming from the sun.

A pure silicon crystal is almost an insulator, meaning very little electricity will flow through it because the charge, in the form of electrons, in the crystal is not mobile. Silicon crystals can be turned into conductors, meaning electricity flows through the substance, by adding a small amount of impurities often in the form of boron or phosphorous. This process of doping is explained in:

- http://www.youtube.com/watch?v=K76r41jaGJg
- http://ffden-2.phys.uaf.edu/212_spring2005.web.dir/george_walker/howtheywork.htm

Through the process of doping two materials are created: n-type and p-type. The p-type material can be thought of having “holes” where electrons are missing because the material is positive. The n-type material is negative so it gives electrons to the p-type material to fill “holes.”

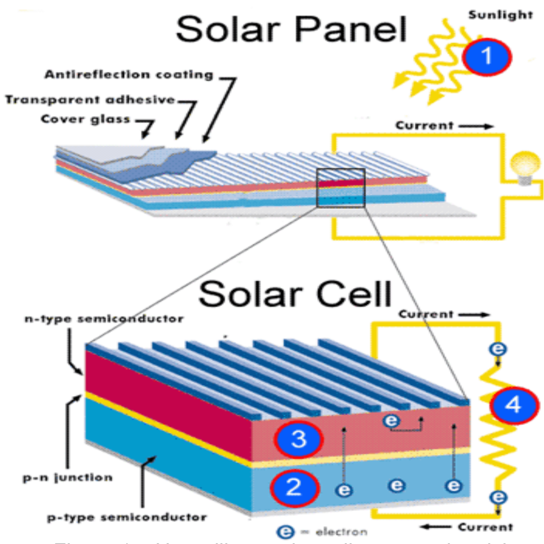


Figure 1 – How silicon solar cells create electricity

Brief Overview:

1. A photon hits the solar panel.
2. An electron is released in the p-type semiconductor.
3. The electron travels to the n-type semiconductor through the p-n junction.
4. The electron then travels through a wire to the p-type material and electrical current is created.

III. Dye Sensitized Solar Cells (DSSC)

Resources:

How Dye Sensitized Solar Cells work:

- Excellent Video: http://www.youtube.com/watch?v=YCLHI0FoTp0
- More advanced: http://www.youtube.com/watch?v=AQIUNu5Mi40
- Gratzel, Michael, "Dye-sensitized solar cells," Journal of Photochemistry and Photobiology 4 (2003), pages 145 – 153. <http://photochemistry.epfl.ch/EDEY/DSC_review.pdf>
- Dahl, Julie et al. "Dye-Sensitized Solar Cells – Using organic dyes to generate electricity from light," Center for the Advancement of Mathematics and Science Education. <http://www.camse.org/scienceonthemove/documents/DSSC_manual.pdf>

Although silicon solar cells have dominated the market for solar cell production, recently Dye Sensitized Solar Cells (DSSC) cells have emerged. These cells are in their early stages of development but show great promise as an inexpensive alternative to silicon solar cells. DSSCs use organic dye that is extracted from plants. They imitate the manner in which plants convert sunlight into energy.

A DSSC does not operate the same as a silicon solar cell. Silicon acts as both the source of photoelectrons and provides the electric field to separate the charges. It also creates electric current because there is both a n-type and p-type material. In the DSSC model, the semiconductor is used for charge transport and the photoelectrons are provided from a separate dye.

With TiO_2 acting as a semiconductor in DSSCs, the p-type material does not exist. When a DSSC is hit by photons only extra electrons are created by TiO_2. It is possible for the free electrons to recombine with the dye, which would act like a p-type material, but this process is very slow. Manufacturers have introduced an electrolyte to allow the dye to regain an electron at a much faster rate.

Diagram of a DSSC:

Glass
Conductive Coating
TiO_2
Dye
Electrolyte
Graphite – acting Catalyst
Conductive coating
Glass

Figure 2 – Structure of DSSC solar cell *Note* Different materials can be used for electrolyte, catalyst, etc.

A photon hits a dye molecule on the surface of the solar cell. This is absorbed by a TiO_2 molecule and results in a loss of an electron or oxidation. This electron then exits through the conductive layer. The electron releases energy (in the form of volts) as it passes through the solar cell to the bottom conducting layer. With the help of the catalyst layer the electron then enters the electrolyte and interacts with a tri-iodine molecule. With another electron an iodide ion is formed. This then makes its way to the activated dye molecule and transfers an electron back to the dye. The dye molecule the goes back to its initial state and the process continues. This process happens many times per second and creates an electrical current.

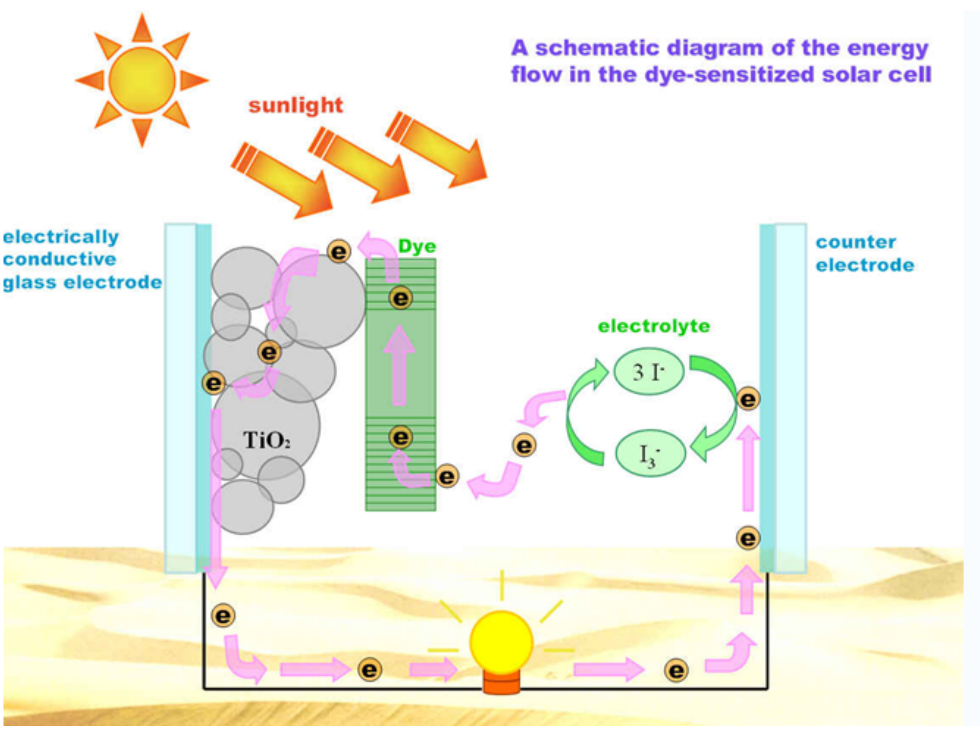


Figure 3 – How a DSSC creates electricity

IV. Solar Cell Efficiency – Overview of Electronics

Resource:

- Ohm's Law: http://hyperphysics.phy-astr.gsu.edu/hbase/electric/ohmlaw.html#c1

The efficiency of the solar cell relies on the amount of photons it receives. When there is little or no sunlight hitting the solar cell then no electric current is produced. Because of this often solar panels are attached to solar systems that store electricity until more photons hit the solar cell.

A solar cell is not composed only of semiconductors or dyes; it also has resistors and other circuit elements to ensure its high efficiency. At times the resistance, or blockage of the flow of electrons, can be too high and the solar cell will produce little or no electric current.

The circuit elements follow Ohm's Law which shows the relationship between total voltage, current and resistance.

$$V=IR$$

Where V=Voltage measured in volts, I=Current measured in amps, R=Resistance measured in Ohms

By Ohm's law, voltage is directly proportional to current if resistance is constant. Resistance is inversely proportional to current, which means that the higher the resistance of the circuit is the lower the current and subsequently voltage is present. If there is no electric current then there is no resistance and no voltage meaning that the circuit is "off" or not operating. This happens at the absence of photons.

Middle School Level

I. Introduction

The sun releases solar radiation in the form of sunlight. Sunlight is composed of elementary, very small, particles called photons. Photons contain energy and when captured properly, in the form of a solar cell, can produce electricity to power anything imaginable. Solar cells are also called photovoltaic cells. The term can be broken down into photo- which means light and voltaic- which means electricity.

When photons hit a solar cell the energy of the photons is converted into electric current, or the movement of electrons. A solar cell by itself does not create much electric current so often solar cells are arranged into solar panels. The electrons do not disappear when the solar cell is struck by photons and instead just lose their energy, in the form of volts to create a voltage. The de-energized electrons flow back through the solar cell and are re-energized by photons. As long as there are photons present this process continues.

There are two types of solar cells: Silicon Solar Cells and Dye Sensitized Solar Cells.

II. Silicon Solar Cells

A semiconductor is a substance that can conduct electricity. Many solar cells are made of silicon because silicon is an excellent semiconductor. Silicon is a metalloid. This means that it has both nonmetal and metal properties. Silicon is often used in solar cells because it can operate at high temperatures. The energy necessary to ionize a silicon electron matches the energy of a photon so this makes silicon an excellent solar cell material.

Silicon crystals are almost insulators, meaning very little electricity in the form of electrons can flow. In order for silicon to be used in solar cells additional impurities must be added. The process in which a silicon solar cell converts sunlight into electricity involves different types of materials forming a junction. There are two layers to a silicon solar cell: n-type (negative) and p-type (positive). These layers work together to create an electrical current when supplemented with photons.

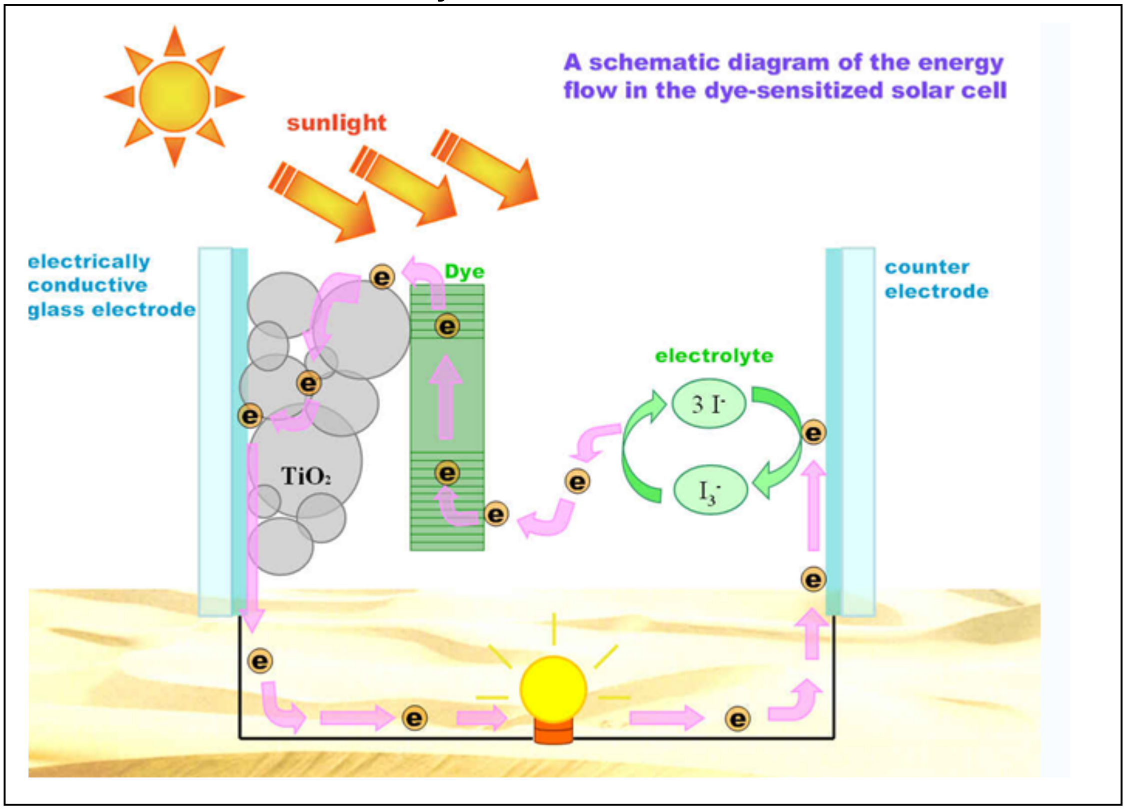
III. Dye Sensitized Solar Cell (DSSC)

Silicon solar cells are very expensive to manufacture. As a result, dye sensitized solar cells have provided a low-cost alternative. In the experiment conducted in this lab, DSSCs are made using different fruit juices as dyes. The cells imitate the manner in which plants convert sunlight into energy. Diagram of DSSC to be created in experiment:

Glass
Conductive Coating
TiO_2
Dye
Electrolyte
Graphite – acting as catalyst
Conductive coating
Glass

Figure 1 – Solar cell schematic diagram

III. How a DSSC creates electricity



1. A photon hits the surface of the solar cell
2. The photon is absorbed by a TiO2 molecule that loses an electron.
3. The electron releases energy as it passes through the solar cell to the bottom conducting layer.
4. With the help of a catalyst, the electron enters and interacts with an electrolyte
5. Another ion is formed which varies depending on electrolyte used.
6. The ion then transfers an electron to the dye.
7. The dye then transfers an electron back to a TiO_2 molecule and the process continues.

IV. Electronics Overview

To be able to form an electric current, a low resistance should be present. Resistance opposes the movement of electrons. To form an electric current, the electrons must be able to flow through a conductor, in our case this is the conductive coated glass. To understand how much the conductive coated glass will resist the flow of current we can measure the resistance. In this lesson we will be measuring resistance using a multimeter.

A multimeter can be used to measure more than just resistance. Later in the experiment multimeters will be used to measure the voltage created by our solar cells after exposure to light.

V. Additional information for lesson – Nanometers

A nanometer is .000000001 meters. The wavelengths of light are commonly measured in nanometers.

<u>Solar Cell Lesson #2 Background Information:</u>

College Level

I. Introduction

Solar cells depend on the amount of photons received. In order to understand how solar cells convert photons into energy, a basic understanding of the electromagnetic spectrum is necessary.

Light can be described as both a particle and a wave. Light is composed of elementary particles called photons that contain various amounts of energy. The energy that a photon carries is dependent upon its unique wavelength, the speed of light in a vacuum and Plank's constant. The speed of light is constant regardless of the medium it travels through.

The relation:

$$E=\frac{hc}{\lambda}$$

Equation 1 – Energy photon relation. Where c=speed of light in vacuum, h=Plank's constant, λ=wavelength, E=energy

The amount of energy that a photon carries is inversely proportional to the wavelength it has.

The wavelength of a photon can be measured in many ways. It is the distance between any two similar points on the wave when looking at in a two dimensional plane.

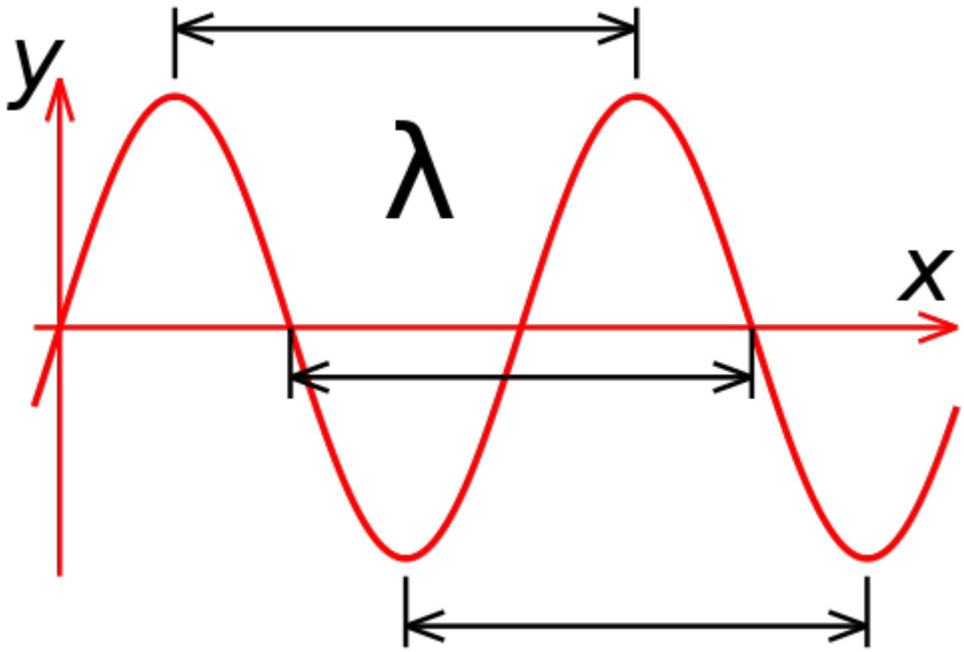


Figure 1 – Image of wave

The electromagnetic spectrum contains all the various wavelengths, and thus energies, photons can be composed of.

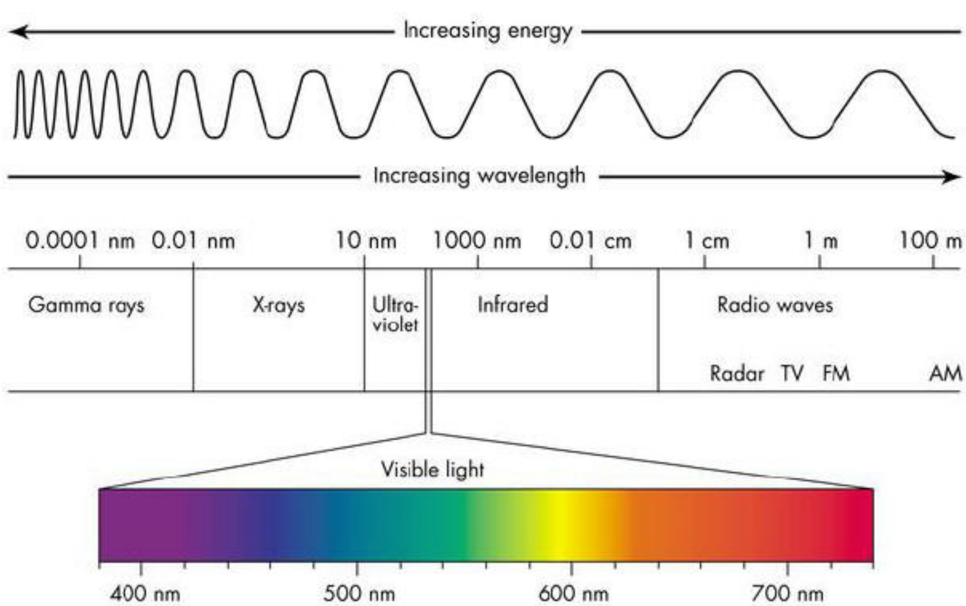


Figure 2 – Electromagnetic Spectrum

Electromagnetic radiation link:

- http://imagine.gsfc.nasa.gov/docs/science/know_l2/emspectrum.html

The main difference between Gamma rays and Radio waves is the amount of energy that the photons carry. Low energy photons, such as, radio waves behave more like waves. High energy photons, such as, X-rays behave more like particles.

Humans can only see visible light. These have wavelengths between 390 and 750 nm. Human eyes are able to detect wavelengths in this range because of the properties of photoreceptors in the eyes. Other animals, such as, bees and some birds can see in other parts of the electromagnetic spectrum. This includes seeing in ultraviolet which can help the animals find food and distinguish between males and females.

White light contains all the colors of visible light. These can be split by a prism to view all of the colors.

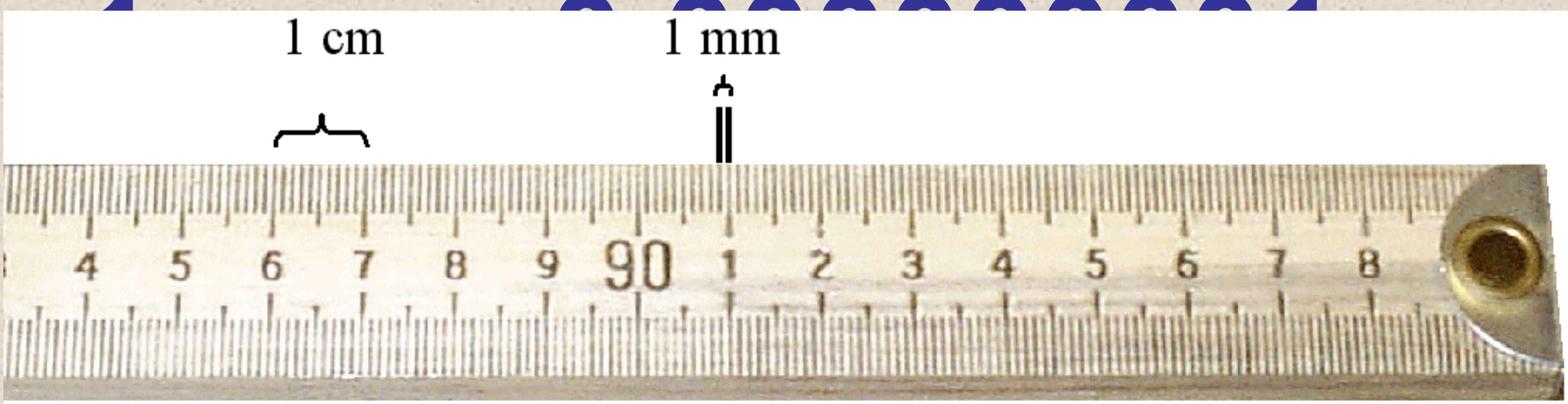
II. How the Electromagnetic Spectrum can affect solar cells

Some of the photons that hit the solar cell will not carry enough energy to cause TiO_2 to lose an electron. When the energy present in a photon matches the amount of energy to cause the TiO_2 to lose an electron a solar cell is capable of producing electricity. Many photons with different energies hit solar cells constantly but only those that fall within the allowed band gap for TiO2 will allow for electricity to be produced.

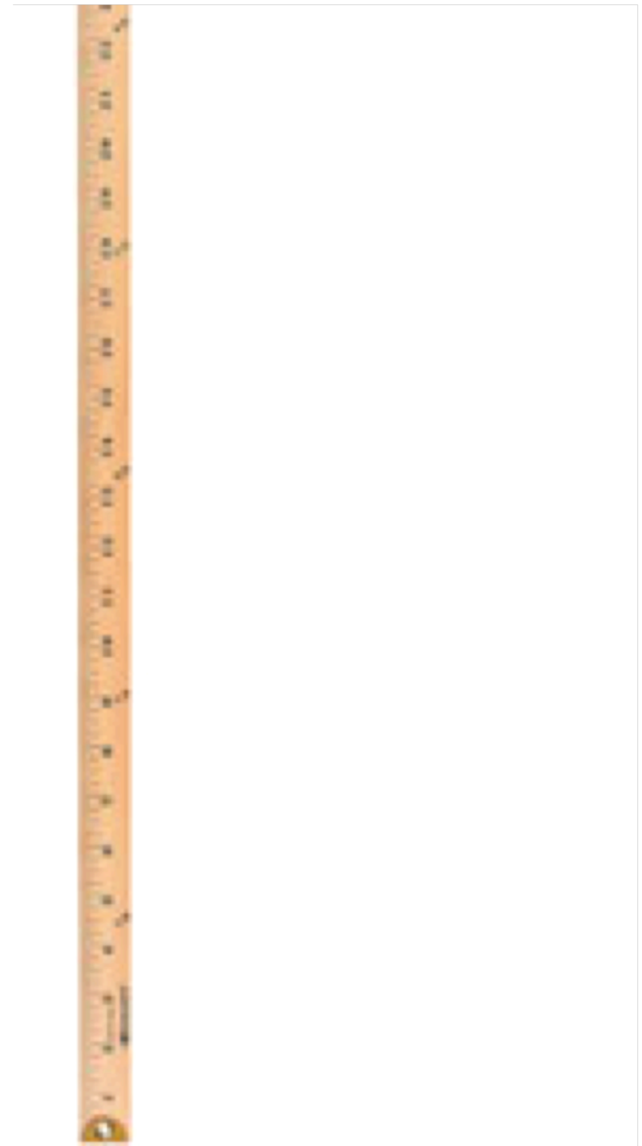
The color present in the dye placed on a solar cell affects the amount of photons it will absorb. The color affects the absorption and reflection of photons. A dye that is closer to black in color than white will absorb more photons of different energies. Objects that are white in color will reflect all the colors of visible light.

How Small Is A Nanometer?

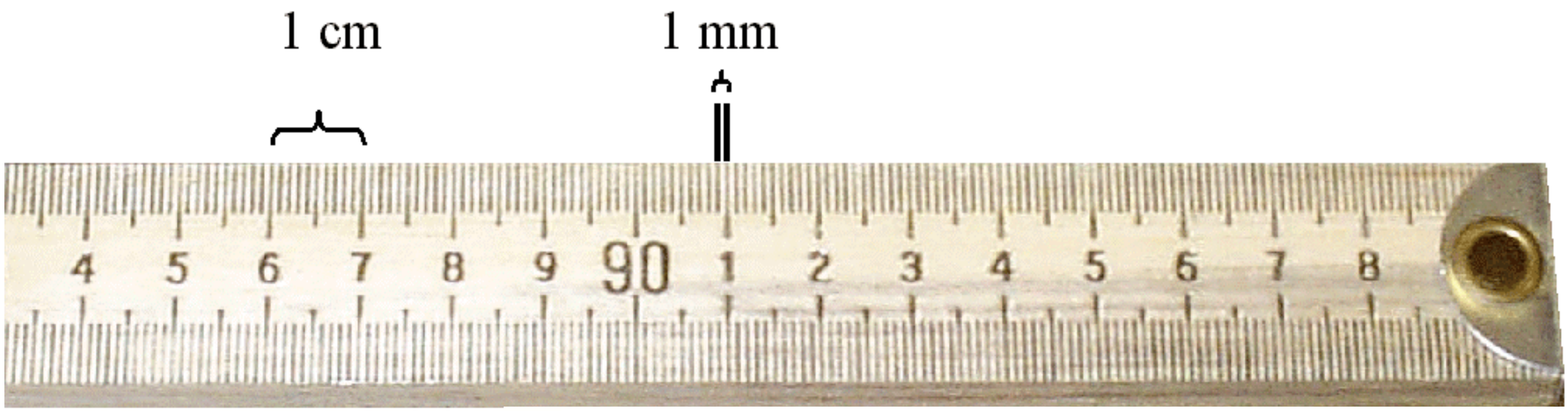
A nanometer (nm) is one billionth of a meter.



This plant is about one meter.

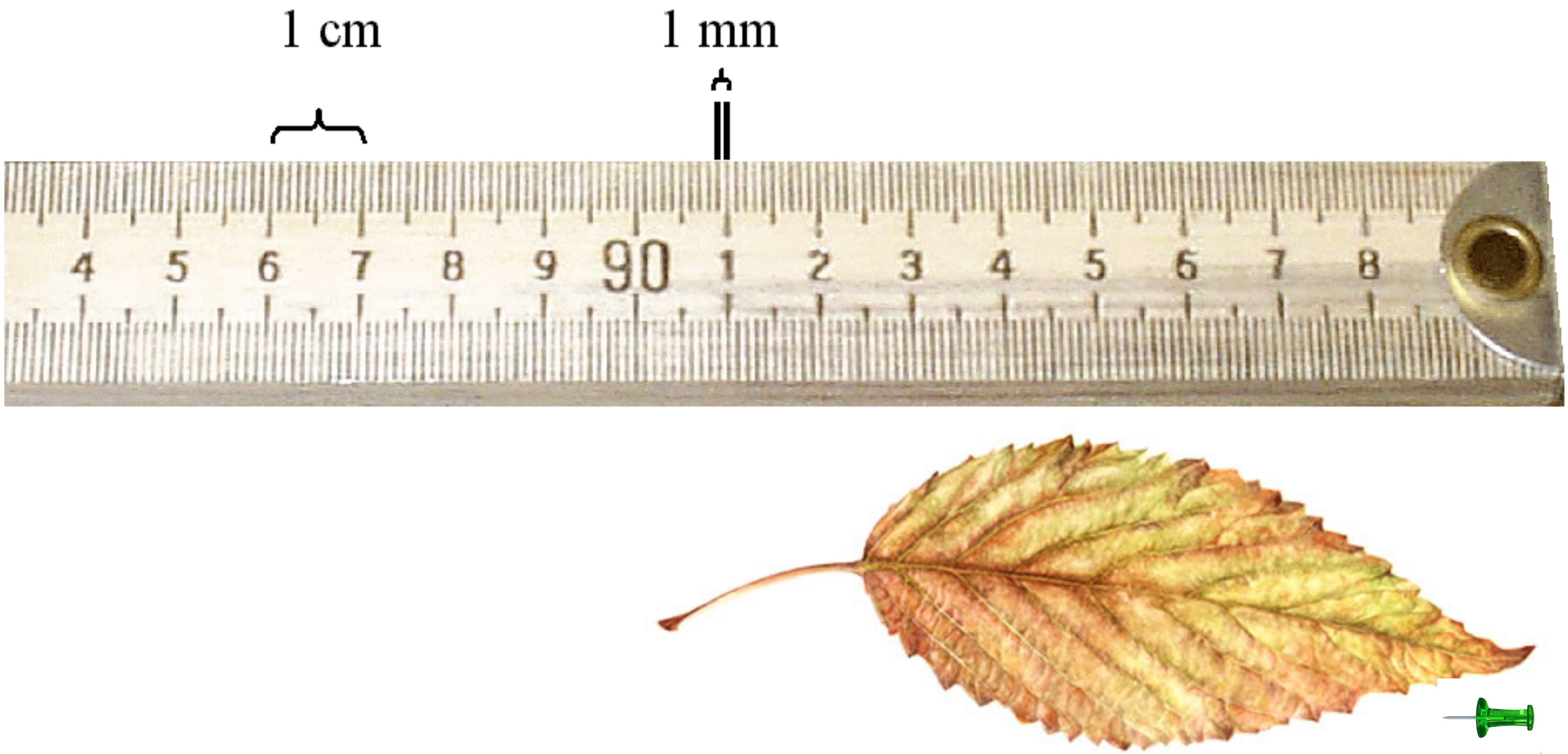


1 meter stick



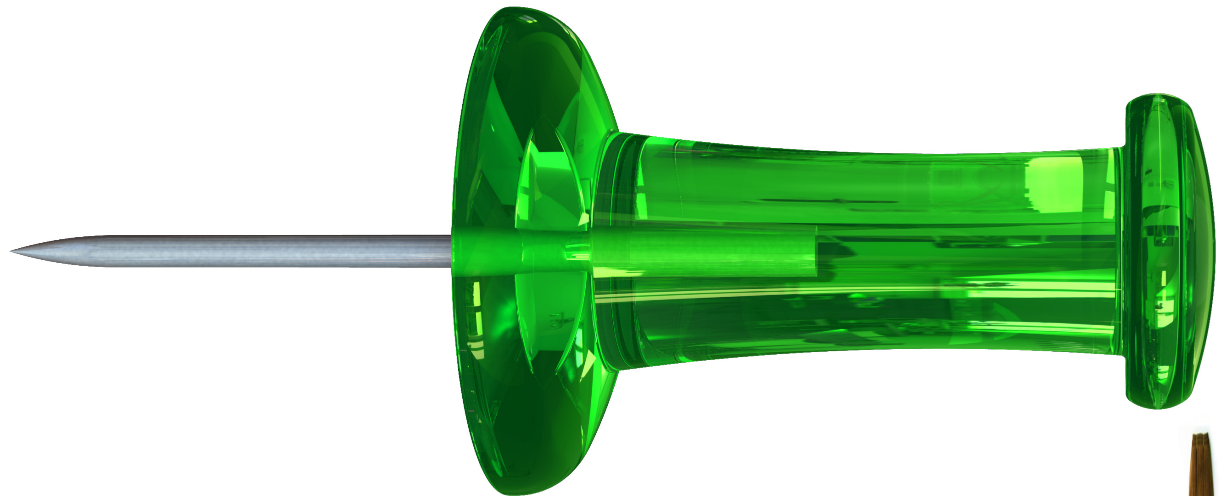
A leaf is a tenth of a meter.

10 cm = 100 mm



A thumb tack is about a tenth of the leaf

1 cm = 10 mm



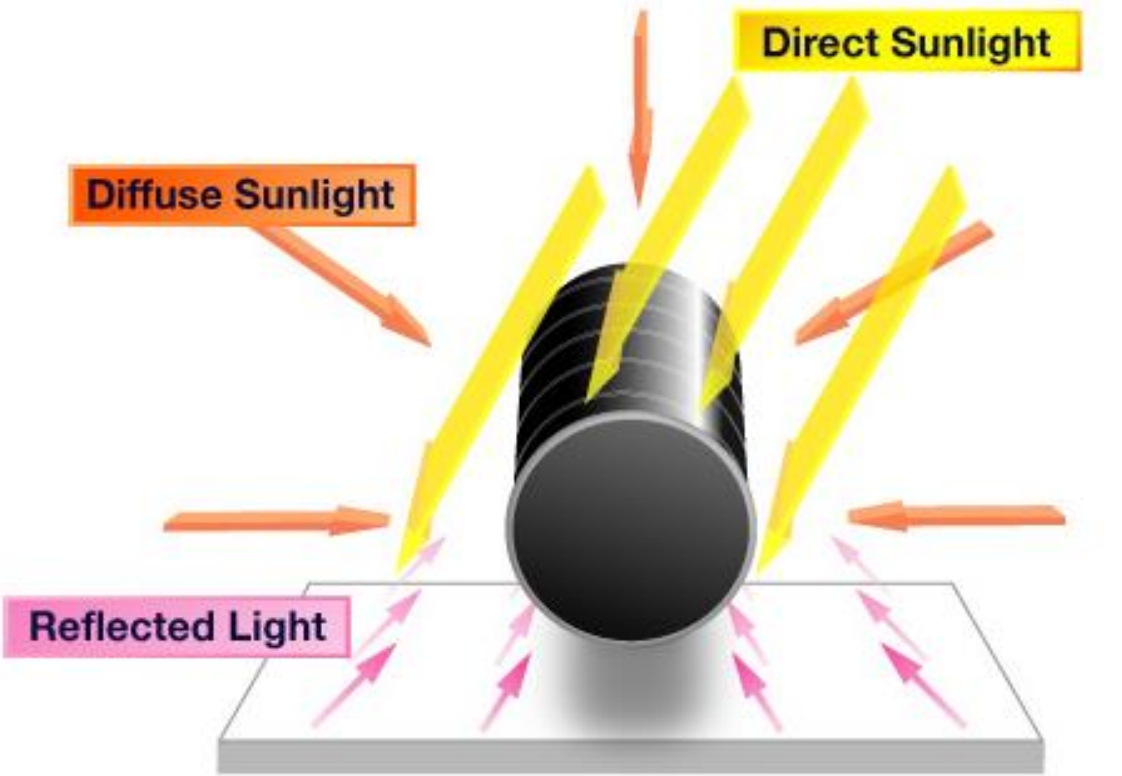
Hair strand →

One hair strand is one hundredth of a thumb tack

90,000 nm

We will work with something that is about 50,000 nm, which is smaller than the thickness of one strand of hair!!

Solar Cells



Safety Rules

- 1. Just like scientists in a lab, we must always wear safety goggles and gloves when experimenting with chemicals.
- 2. Follow directions!! This is extremely important. If you don't follow instructions carefully, your solar cell won't work.
- 3. Be scientists and work together!

Steps in Making a Solar Cell

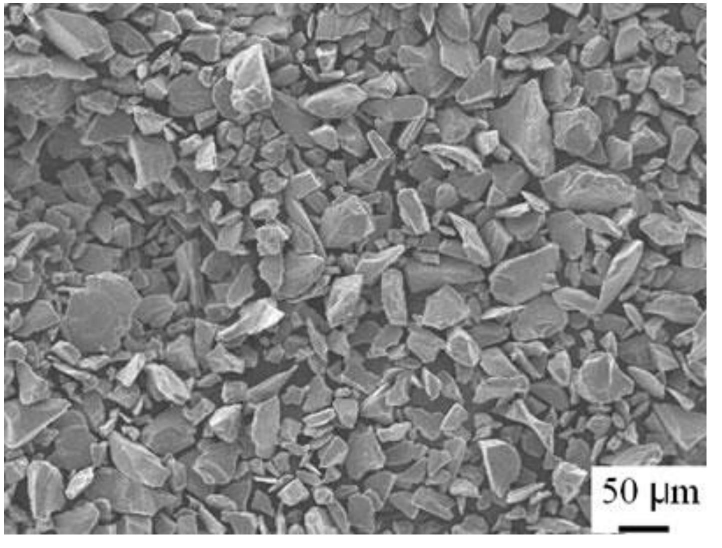
1. Take out the mortar and pestle (white container and stick) from the kit.

2. Add the TiO_2 to the white container.

Caution: TiO_2 powder can be harmful!

3. Add the solution labeled Acetic Acid to the powder, one milliliter at a time, while another person mixes.

4. After all of the Acetic Acid is added, you will take turns mixing the mixture for one minute each.



One crystal = 50,000 nanometers or 0.05 millimeters

5. The next person will add half of a milliliter of soap solution.

- Mix slowly and gently.
- No bubbles allowed!!

6. Let the solution sit for 15 minutes.

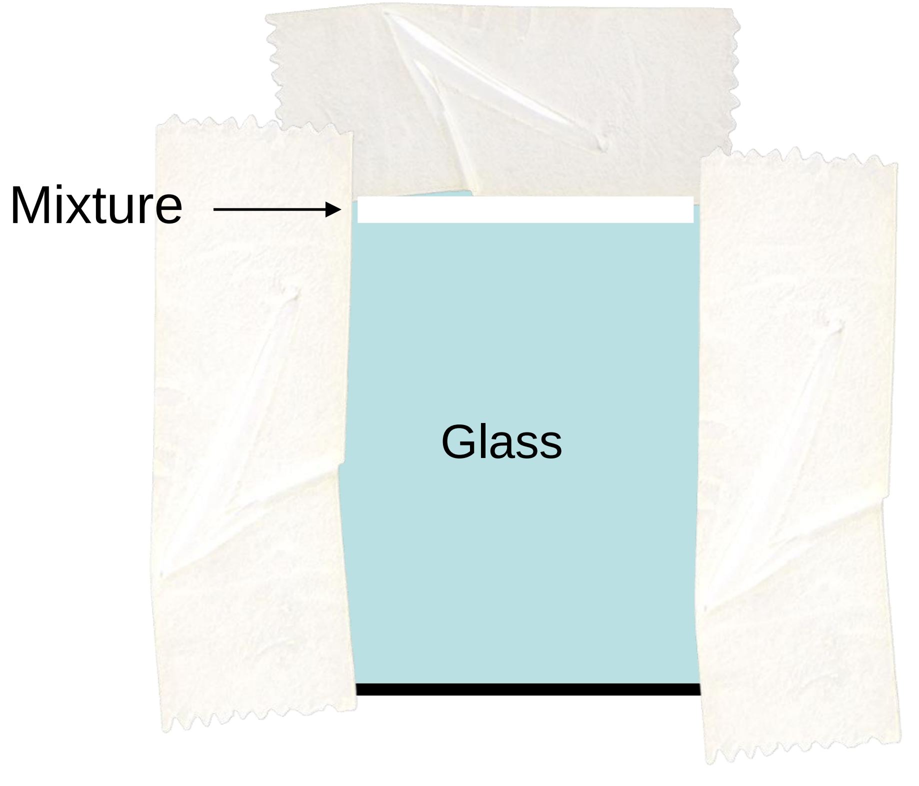
7. Locate the plastic sheet with two pieces of glass taped down.

Multimeter: *a device that measures voltage, current, and resistance. We will measure the resistance of each side of the glass.*

Resistance: *to oppose or make it harder for something to move. In this case, electrons moving across the glass surface.*

8. The next person will put both of the probes of the multimeter on one side of the glass. Remember which side is OL and which side shows a number.

9. Place the mixture on the top of the glass that is taped to the paper.

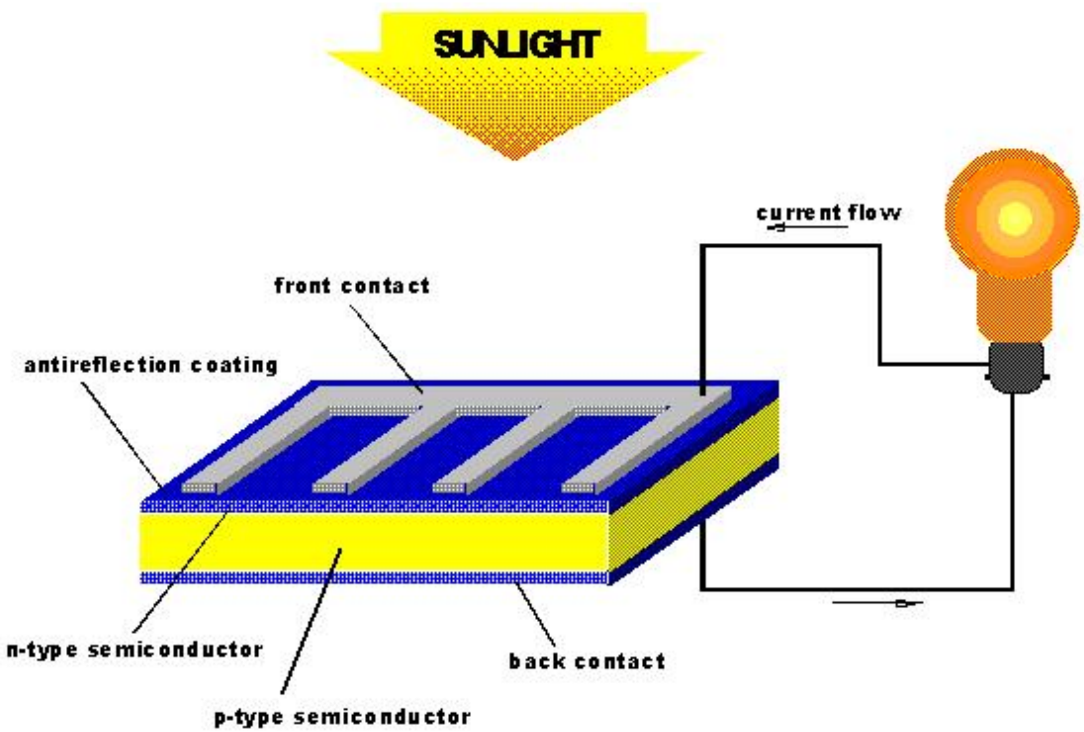


10. Spread out the mixture evenly on the glass VERY CAREFULLY.

Like rolling dough with a rolling pin!

Hold on to the edges of the rod and slide the rod down and up ONCE.

Solar Cells
The Sequel!



Safety Rules

- 1. Just like scientists in a lab, we must always wear safety goggles and gloves when experimenting with chemicals.

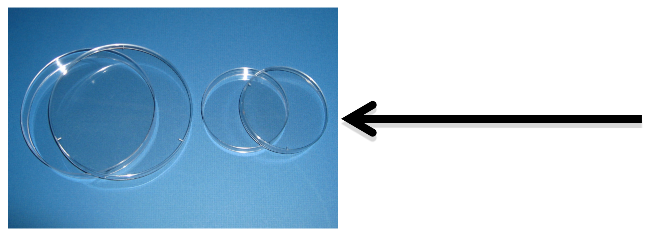
- 2. Follow directions!! This is extremely important. If you don't follow instructions carefully then your solar cell may not work properly.

- 3. Be scientists and work together!

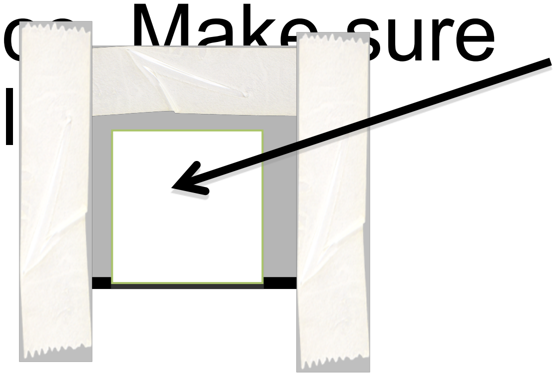
Steps for Completing Your Solar Cell

#1. Come to the front and grab your tray of materials

#2. Slowly pour your juice into the small petri dish



#3. Use the tweezers to slowly place your glass (white side face up) into the juic Make sure your juice covers your solar cel

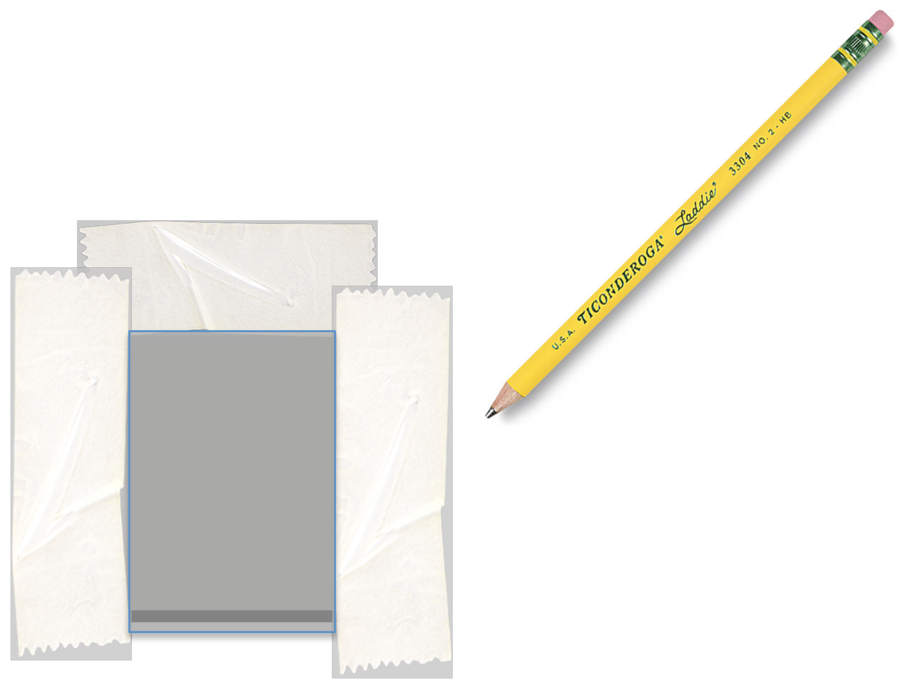


#4. Measure the resistance of the second piece of glass. Make sure you have the conductive side face up. (Is that the side with low or high resistance?)

#1. Hold the glass still while #4 is measuring the resistance

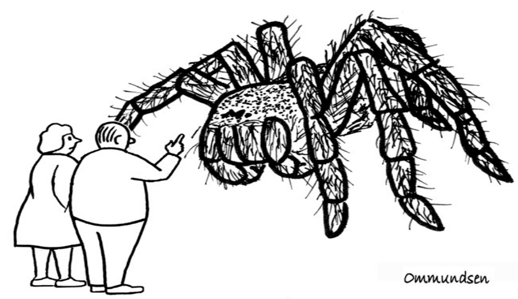
#2. Use the graphite pencil to color all of the glass.

(Remember to hold the glass in place, #1)



Make Your Hypothesis

- There are 3 different dyes
  - 100% Blackberry
  - 100% Blueberry
  - Mixture of both
- Question: Which one will perform better in this experiment?
  - Fill in your hypothesis
    - In a complete sentence
    - With attitude!!
    - Include why you are correc



"I've narrowed it to two hypotheses: it grew or we shrunk."

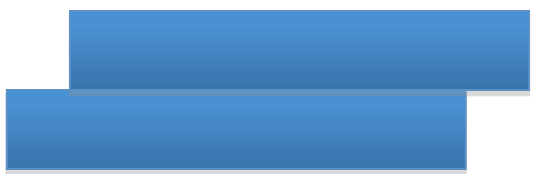
The Dyeing Process is Finished!!!

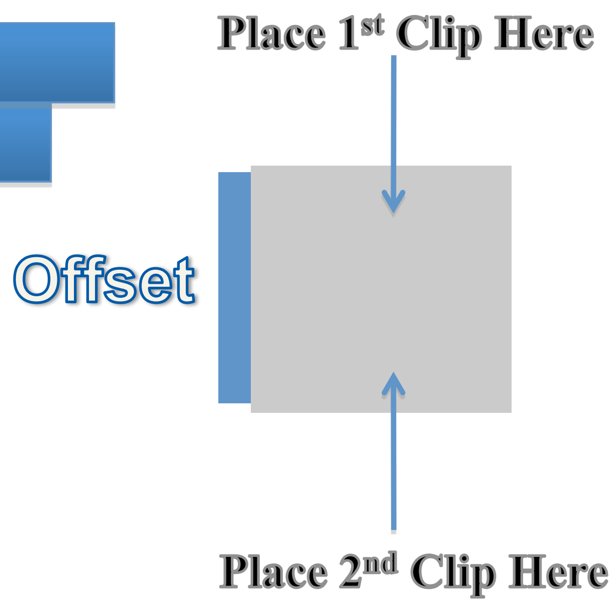
#3. Use the tweezers to grab the solar cell out of the dye (Make sure you DO NOT touch the part with the dye) and wash it with **ONE DROPPER FULL** of water.

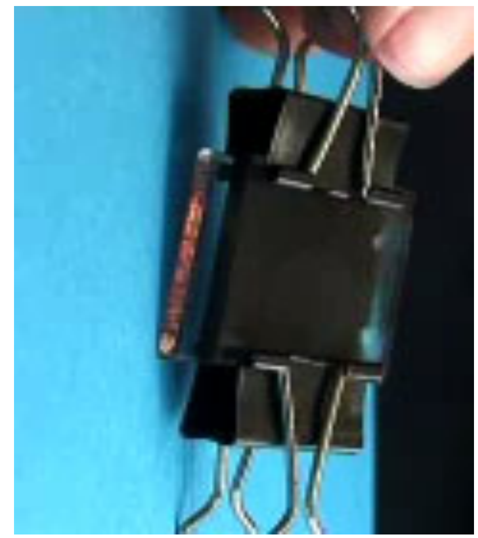
#4. Hold up your solar cell and wait for us to come around to wash it with alcohol. (This will give it an extra wash, as well as help it dry faster.)

Let’s Put It Together!!!!

- #1. When the solar cell is dry, put the solar cell together like a sandwich (with the “stuff” on the inside) with the edges out and place the binder clips on the outside







- #2. Hold your solar cell up and wait for us to come around with the final solution or electrolyte (something to get the electrons moving)
- #3. Clean the extra solution from the outside of the solar cell with a q-tip, then place it in the middle of your table

Now Let's Test Our Solar Cells

#4. Place the alligator clips on each "overhanging" side of your solar cel 

(If the number is negative, flip them.)

Now you will need to change the settings on your multimeter to Volts!

Now you are ready to test your solar cell!

Data Collecting

While you're waiting:

Record your voltage

- in shade (hand covering)
- room lighting

When called to the light station:

Team members bring the following to the light station:

#1: Solar Cell

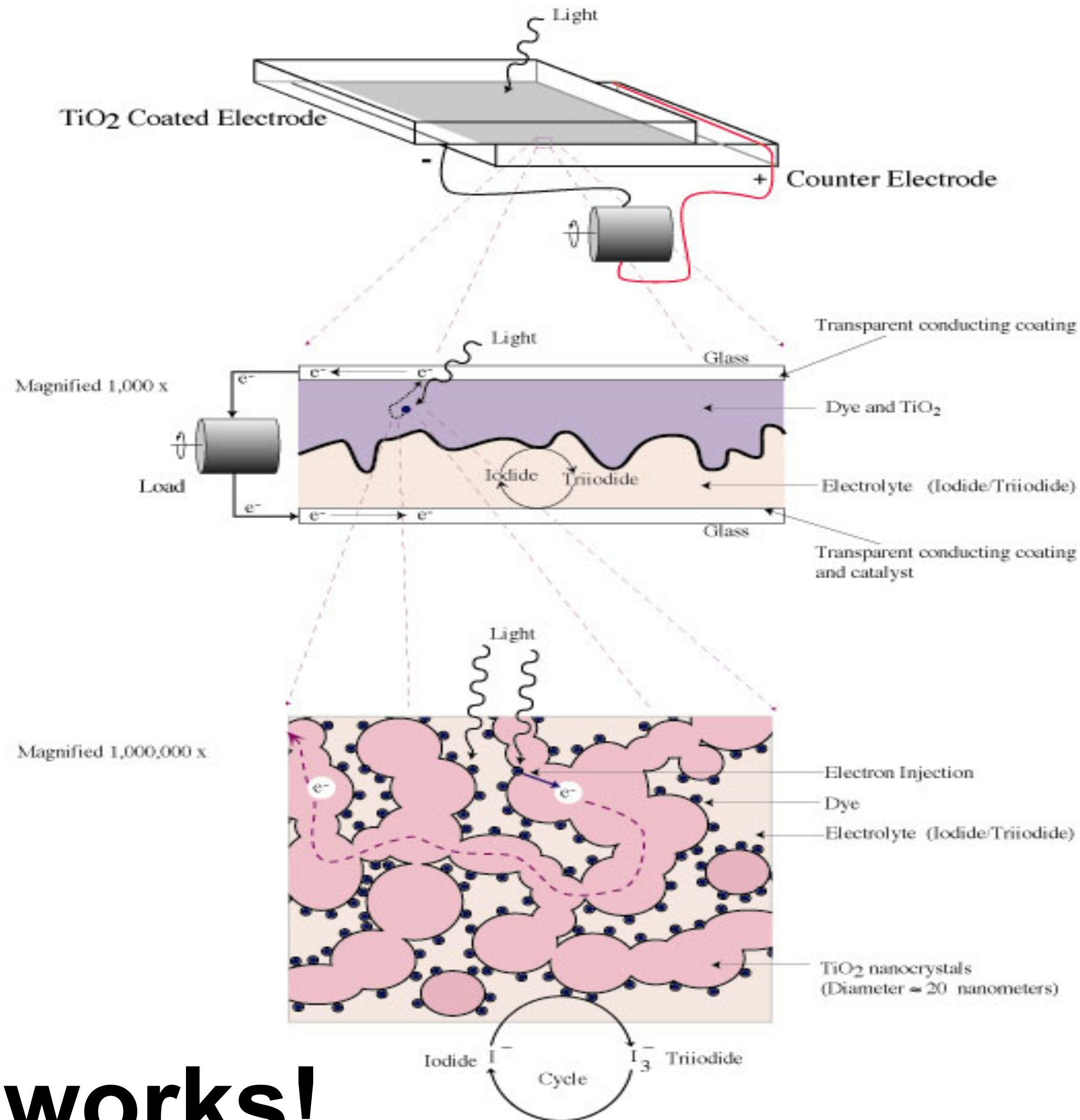
#2: Mulitmeter

#3: Data Sheet

#4: Pencil

Record your data and prepare to share.

Rainbow:
raindrops refract the sunlight



How it all works!

Annual Solar Energies