Environmental Science Institute
THE UNIVERSITY OF TEXAS AT AUSTIN

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Solar Cells – Part 2

Lesson created by: Kim Cao and Rachita Patel, UTeach Outreach
Date of lesson: Week of April 5, 2010
Description of the class: 6th grade after-school Science Olympiad Club
Adapted by: Laura Sanders, Environmental Science Institute, January 19, 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://science.jrank.org/pages/2368/Electromagnetic-Spectrum.html
http://www.sciencegeekgirl.com/activities/Blackberry%20solar%20cell.pdf
http://www.nrel.gov/docs/gen/fy01/30927.pdf
http://science.howstuffworks.com/light6.htm
http://www.good-science-fair-projects.com/reflection-1.html
http://eosweb.larc.nasa.gov/EDDOCS/Wavelengths_for_Colors.html
http://www.physicsclassroom.com/Class/light/U12l2e.cfm
http://stainsfile.info/StainsFile/dyes/dyecolor.htm

TEKS Addressed:

6. (2) Scientific investigation and reasoning. The student uses scientific inquiry methods during laboratory and field investigations. The student is expected to:

(A) Plan and implement investigative procedures including asking questions, formulating testable hypotheses, and selecting and using equipment and technology.

(B) Collect data by observing and measuring

6. (7) Matter and energy. The student knows that some of Earth's energy resources are available on a nearly perpetual basis, while others can be renewed over a relatively short period of time. Some energy resources, once depleted, are essentially nonrenewable. The student is expected to:

(C) Research and describe energy types from their source to their use and determine if the type is renewable, non-renewable, or inexhaustible.

I. Overview

Students will complete the creation of a solar cell by using juice as dye. Students will use technology to test the solar cells. As they complete their solar cells, students will learn about voltage and conductors, review properties of light, and learn how these properties relate to their solar cell. Students will learn the difference between fossil fuels and renewable sources. They will also learn different applications of solar cells to help the environment.

II. Objectives *(learner outcomes)*

1. Students will complete a solar cell and test its voltage using a multimeter.
2. Students will explain how humans are able to see colors.
3. Students will explain how wavelengths of light interact with dye in order to make the solar cells work.

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III. Resources, materials and supplies

Per class:

- Ethanol
- Solar calculator
- Battery powered calculator
- 2-6 heat lamps

Per group (designed for groups of four students):

- Tray
- Juice for dyeing the solar cells
- Petri dish
- Small amount of water and alcohol
- Graphite rod or soft pencil lead
- Tweezers
- Multimeter
- Paper towels and/or tissues
- Square glass from previous lesson
- Binder clip
- 4 cotton swab
- 4 ziplock bags
- 4 pair of gloves
- 4 pair of goggles

IV. Advanced Preparation:

Prepare dyes from juices prior to lesson. Pre-package supplies into baggies.

V. Supplementary worksheets, materials and handouts – See attached.

VI. Background information (2 - 3 pages total)

COLLEGE LEVEL

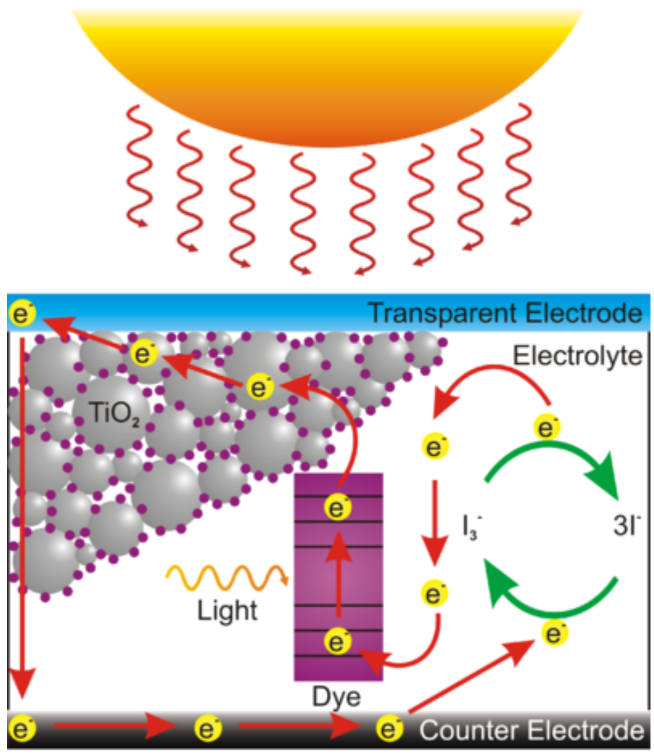
Properties of Light and the Solar Cell:

Light can be quantified in the both particle and wave form. This is the basic concept of the particle-wave duality of light principle. Particles of light, called photons, contain various amounts of energy that correspond to the different wavelengths of the solar spectrum. Solar cells use photons as energy to allow the free electrons to move and form a circuit to generate electricity.

Visible light is only part of the electromagnetic spectrum. Electromagnetic radiation is made up of a range of different wavelengths. The wavelength of a light wave is a measure of the distance between peaks of the wave. Waves corresponding to photons with higher energy have smaller wavelengths than waves with lower energy. Gamma rays have the shortest wavelengths and therefore have the most energy, whereas radio waves, with wavelengths between 1 cm and 1m, have much less energy. Humans can see wavelengths between 390nm and 750 nm. Our eyes are able to detect wavelengths in this range because of the properties of the photoreceptors in our eyes. White light contains all of the visible colors of light, which can be seen in the form of a rainbow. Each color visible corresponds to a different wavelength of light. Other animals, such as bees and some birds, can see light waves outside of the visible spectrum. Some can see in the ultraviolet region, which can help them find food and also be used to distinguish between males and females of a species based on body markings visible only in this region.

Since the light that hits solar cells has photons of a wide range of energies, some of the photons won't have enough energy to form an electron hole in a solar cell. These types of photons will simply pass through the cell. Photons can have too much energy as well. In this case, the cell will use the energy needed to knock an electron loose and form a hole, and the extra energy will be lost. The energy needed to knock an electron loose is called the band gap energy.

The band gap also determines the strength or voltage of the electric field in a solar cell. Lowering the band gap energy by using a different type of material will lower the electric field as well. If the band gap is too low, then there will be extra current but a smaller voltage. The power, or rate in which energy is converted, is equal to the current multiplied by the voltage. Optimal band gap is around 1.4 eV.



TiO2 is a wide band gap semiconductor. The gap is so wide that energy from sunlight can't excite electrons enough to make them conduct; however, sunlight can excite the electrons in the blackberry dye. Those excited electrons are transferred from the blackberry dye to the TiO2, which transfers it to the electrode, producing electricity.

In this lesson, a nanocrystalline dye sensitized solar cell will be made. We will be testing different colors of dyes to see how the colors affect the voltage produced by the cells. Changing the color of light a solar cell is absorbing will vary the amount of energy the cell is receiving. Looking at a visible light spectrum, red has the longest wavelength and violet the shortest. The energy of electromagnetic radiation or the photon is inversely related to the wavelength so the longest wavelength will have the lowest energy. In solar cells, shorter wavelengths of visible light will have a greater current than longer wavelengths.

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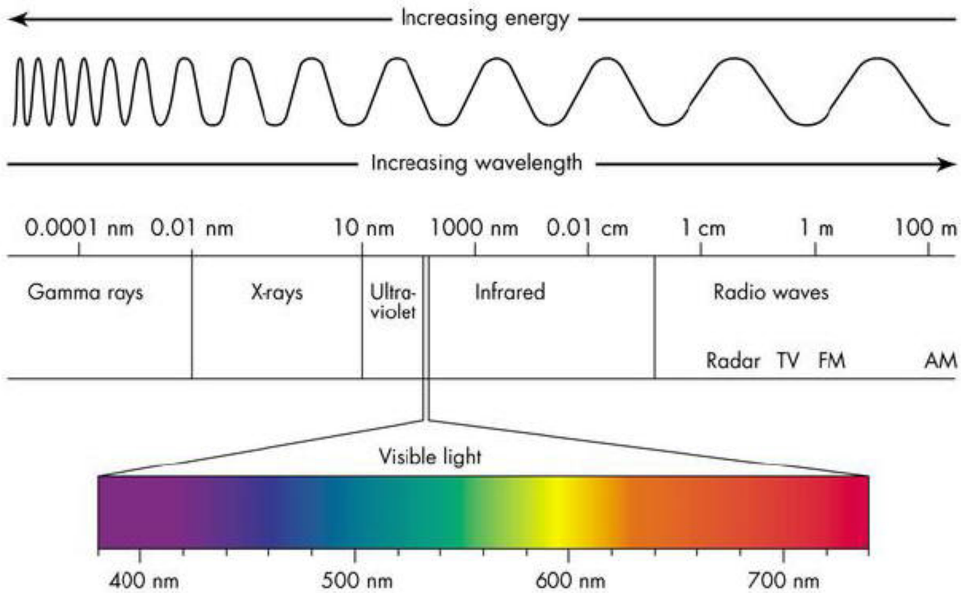
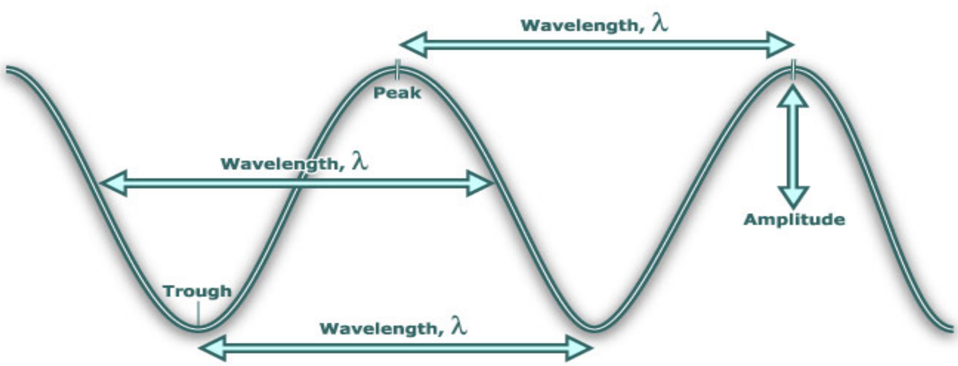
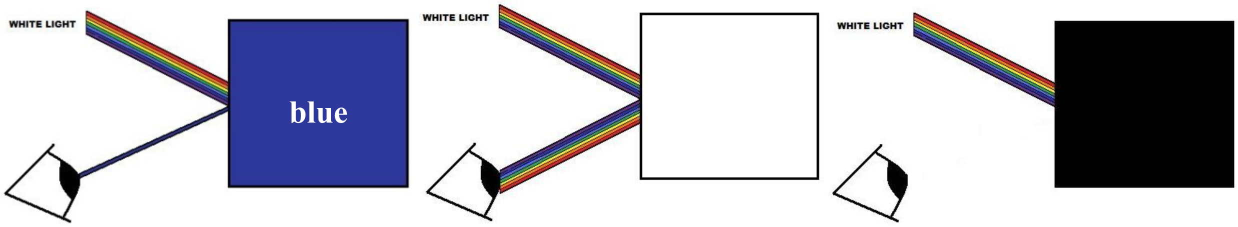
The Electromagnetic Spectrum





How we see color:

The color of an object is based on the absorption and reflection of different wavelengths of light. For most objects, the color we see corresponds to the wavelength or combination of wavelengths reflected off of the surface of the object. All other colors of light are absorbed by the object. As previously mentioned, white light contains all of the visible wavelengths. White objects do not absorb any wavelengths of the visible spectrum, reflecting all of them back to our eyes, causing us to view the object as white. Black objects, however, absorb all of the colors in the visible spectrum, and therefore no light is reflected to our eyes. The absence of this reflected light is what makes us view the object as black. Wavelengths that are not reflected do not play a role in what color we see and are absorbed by the object. Absorbed light is converted to heat. This explains why a person wearing a black shirt in the summer under the hot sun will cause them to be hotter than someone wearing a white shirt, as white reflects the visible light rays, decreasing the amount of energy converted to heat.

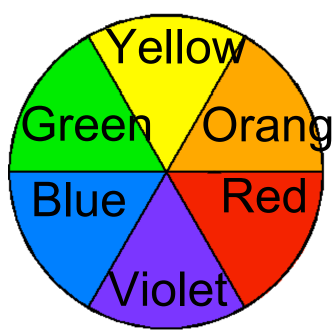


A blue object absorbs all other colors but blue, which is reflected back toward the eye. A white object reflects all colors, whereas a black object absorbs all visible wavelengths.

The basis for this relationship lies in the properties of the atoms that make up the object. Electrons in atoms vibrate a certain distinct frequencies. If a light wave hits an electron with the same frequency as its natural frequency of vibration, the electron will become excited, and transfer energy to surrounding atoms as thermal energy. The energy is therefore absorbed by the object, not reemitted as a light wave. If the light wave frequency does not match the frequency of the electrons it comes into contact with, the do vibrate, but the light is emitted as a light wave instead of being absorbed by the object. This is the light that is reflected back to our eyes allowing us to perceive a color.

Dyes produce color via a different pathway. Dyes absorb one color of light and reflect its complementary color. Complementary colors are colors on opposing sides of a color wheel.

COLOR WHEEL



For example, a red dye will absorb green light and reflect red light. Dyes contain structures called chromophores. The presence of a chromophore moiety on a dye molecule allows the dye to absorb electromagnetic radiation at a certain wavelength. Electron resonance in the structure also allows the dye to reflect the complementary color of the light absorbed.

Anthocyanin is a dye that can appear as red, violet, or blue, depending on the pH of the surrounding solution. This is because of conformational changes in the molecule that occur at different pH's. Anthocyanin appears more red in lower pH, and is more blue in solutions with high pH. This means that at low pH, anthocyanin absorbs wavelengths in the green range of the visible light spectrum, and at a high pH it absorbs orange light.

ELEMENTARY LEVEL:

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Light behaves as both a particle and a wave. Particles of light are called photons. Energy in waves of light is measured by the distance between the peaks of the wave. When light hits a solar cell, photons transfer their energy to electrons in the cell, causing them to move around. The movement of electrons creates a current in the cell. The energy converted using the solar cell is directly related to the energy of these photons.

Visible light makes up only a small fraction of the total spectrum of light waves. Light waves of different energies are listed on the electromagnetic spectrum. Humans can see wavelengths between 390nm and 750nm. Other animals can see outside of this range, but we can't because we don't have receptors in our eyes that respond to those wavelengths.

Light waves with more energy have shorter wavelengths; therefore, purple light waves have more energy than red do, because light has a wavelength around 400 nm and red has a wavelength around 730nm. If a solar cell absorbs light with shorter wavelengths, there is greater flow of electrons, and more solar energy is converted to electricity.

We see color because of the reflection and absorption of light waves on objects. An object will absorb certain colors and reflect others, depending on the contents of the surface. The light that is absorbs by the object is converted to heat, but the light reflected reaches our eyes. The color of the object that we see is the color of the wavelength or wavelengths of light reflected from the object; however, dyes are different from other objects. Dyes absorb one color of light and reflect its complementary color. Complementary colors are colors on opposing sides of a color wheel. Dyes can do this because of a chemical structure in the dye molecule that alters the way molecule absorbs light waves and reflects light waves.

VII. Vocabulary & Definitions:
For Outreach 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; it is a nonmechanical device usually made from silicon alloys.
2) Photons: carry solar energy in different wavelengths. Upon hitting a solar cell photons can be absorbed, reflected, or pass through. The photons that generate energy are the ones that are absorbed.
3) Electrons – an elementary particle consisting of a negative charge.
4) Amps – amperes, used to measure the rate of current in a substance.
5) Current – a flow of electric charge through a conductor.
6) Multimeter – an instrument for measuring the properties of an electrical current such as resistance, voltage, or current.
7) Semiconductor – the term for the broad category that solar cells fall into. Electrons are free to move in semiconductors when photons get absorbed.
8) Resistance – a material's opposition to the flow of electric current and is measured in ohms.

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) Photons (fotones) – carry solar energy in different wavelengths.
4) Electrons (electrons) – fast-moving, negatively charged particles.
5) Amps (amperios) – current is measured in amps.
6) Current (la corriente electrica) – a flow of electric charge.
7) Multimeter (multimetro) – 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.
9) Resistance (Resistencia) – opposition to the flow of electric current.

VIII. Safety Considerations:
Students must wear safety goggles and gloves at all times. Avoid spilling the juices as can dye clothes. Goggles and gloves are used to protect from getting dyes and ethanol on the skin or in the eyes.
Wipe tables when complete. Students must wash hands when complete.

Five-E Lesson Plan Organization

ENGAGEMENT **Time: 7 minutes**		
What the Teacher Will Do	**Probing Questions**	**Student Responses** **Potential Misconceptions**
Idea: Introduce basic solar cells we see in everyday life, like simple calculators, watches. Teachers can show how they don't work when you cover the solar panel (on the calculator). *Today we have two calculators.* **Take out two calculators, one that uses batteries and another that uses solar panels. Be sure every student can see the calculators, by passing them or walking around the class with them. As a class, make a chart to detail the noticed differences between the two calculators.** **Demonstrate by covering the panel.**	*1. What are the differences between these two calculators?* *2. How do you think the other calculator works?* *3. Yes, solar panels. Where are the solar panels located on here??* *4. What would happen if I cover up the panel?* *5. What are some other examples of solar powered things?*	1. One is larger than the other, one is black, one has a lot of buttons, one uses batteries [Potential Misconception: The one with batteries works better] 2. Solar panels! [Magic, a tiny battery] 3. On the inside, on the front 4. It won't work anymore! [nothing] 5. Watches. The blinking school light outside. *Only things outside can use solar power.
EXPLORATION **Time: 40 minutes**		

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What the Teacher Will Do	Probing Questions	Student Responses Potential Misconceptions
If you remember from last class, we started making solar cells and today we are going to finish making them! *First we must go over the rules:* *1. Wear safety equipment at all times!* *2. Follow directions carefully.* *3. Be careful not to spill the dye anywhere because it will stain. Notify one of us if it does spill.* *4. Be careful when using ethanol. It can be dangerous if swallowed or if it gets in your eyes. It is NOT water.* *5. Be scientists and work together!* *Turn to your neighbor and take turns repeating one safety rule.* **Pass out the safety equipment. For this lesson, the safety equipment the students are required to wear at all times are goggles and gloves. Make sure students are in groups of four, assign numbers 1-4 to the members of each group. For groups of less than 4, assign one student two roles. Show .ppt throughout this session.** *We will be using blackberry and blueberry juice as dyes to create our solar cell, and we will test to see which juice will make the solar cell absorb the most energy.* **Each group will test one dye, so assign groups to test either 100% blackberry dye, 50/50 blackberry and blueberry dye, and 100% blueberry dye.** **Write the word Ethanol on the board and explain the safety precautions.** *Make sure not to touch the*		

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Ethanol on the slide or you might accidently rub your eye or touch your face! *Now would person #1 from each group come up and get their kit and a direction sheet for your group.* *Follow along with the PowerPoint on your instruction sheet. For the first step, person #2 will pour the juice into the petri dish.* *Now person #3 will place the square glass from last week into the petri dish face up* **(coated side down)**. *Make sure you put it the right way.* **Walk around and guide students.** *It must soak up the dye from the fruit juice, so we have to wait about ten minutes.*		
Have students slowly push the tray to the center of the table so they do not play with the equipment while waiting. Be sure to do this slowly so it doesn't spill. Hand out the second piece of glass.	1. *What is a conductor?* (Guided Notes Question)	1. Something that can move electrons. Electrons move freely in it.
We will move on while we are waiting. Now this piece of glass is the other part to your solar cell. You have to be very careful with this part or your solar cell won't work.	2. *What is the difference between semiconductors and conductors? Do you think semiconductors conduct better or worse than conductors?*	2. One is half of another. [Students should explain WHY they think one works better than the other.
Write the word "Conductor" on the board. *Remember that the glass we are using for this lab is a type of conductor called a semiconductor.* **Once you explain that the glass we use is a semiconductor, add "Semi" to the beginning of "conductor."** *First, we have to measure the*	3. *How can we tell which side of the glass is a good conductor?* (Then call on a student that hasn't spoken up yet.) 4. *Why do we want the resistance to be low?*	3. The shiny side. The scratched side. The side with the lowest resistance. Measure it with a multimeter. 4. That means there is less of a force opposing the flow of the electrons.

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conductive side of the glass. Then call on a student that has not spoken up yet. **Write the word "resistance" on the board. Also add resistance low = good energy flow** *Right! We have to use the multimeter to measure the resistance. We want the side with the lowest resistance because that means that electrons can move more easily which will make our solar cell work.* (Guided Notes Question 4) *Person #4 will use the multimeter to measure the resistance. Pick up the multimeter from the tray and measure the resistance by putting both probes on the ends of the glass* **If this becomes difficult, the rough side of the glass slide is the side that is conductive.** *Now, person #1 will hold the glass piece down with some tweezers. Person # 2 will color the surface in with the pencil lead. Be sure you do not touch the surface directly.* **While waiting for the ten minutes, have students create a hypothesis for this experiment on their worksheet. Make sure they don't use phrases like "I think _________ will happen." Instead, have them write "The __________ dye will produce more energy." These instructions are also on the PowerPoint. UTeach students should walk around and engage the students, ask questions to get them thinking about how it works. And asking them to explain back to the coach the terms that you think they should know by now. They can**		

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write down terms they can explain on their Testing Solar Cells worksheet. Remind them that they will be investigating their hypothesis by the end of class. *Now that is has been about ten minutes, everyone check your piece of glass in the dye and make sure there is no white showing.* **Make sure there is no white on the surface. If there is, they must soak it for about five more minutes, if not they can move on.** *Person #3 needs to hold up the glass with tweezers. Person #4 is now going use a pipette to rinse the TiO2 side of the slide with one dropper of water. Then, we will walk around and wash your glass with ethanol.* *So while _________, is walking around with the ethanol. We are going to talk about what Ti02 is.* *TiO_2, or titanium dioxide, is a pigment that can be found in paint, sunscreen, toothpaste, and food coloring* (see pictures). *We are going to be using to create a porous structure on the glass. The pores will help keep the dye in a thin layer on the glass.* **Make sure the slides are dry before moving on.** *Next you will put the two parts together.* *Person #1 will very carefully set the two pieces of glass on top of each other. Make sure you place the two sides that are colored on top of each other like a sandwich. Also, make sure you leave a little room on the edges at the top and bottom of the glass.* **Demonstrate and guide students. Show the students**	5. *What is the chemical formula of potassium iodide?* (Students may look at the periodic table.)	5. KI. *[Misconception: the first letter is capitalized and the second isn't. Potassium is represented by the letter P.]

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the pictures in the ppt. **Write the words "Potassium Iodide" on board.** *Potassium Iodide is going to make us able to conduct electricity. It is an electrolyte substance containing free ions that make the substance electrically conductive.*		
EXPLORATION (Continued)		
What the Teacher Will Do	**Probing Questions**	**Student Responses Potential Misconceptions**
Add "helps conduct electricity" to "Potassium Iodide" on the board. *Now you can clip the pieces together.* **Demonstrate.** **Dump out the juice and take away the Petri juice so that the students do not play with it or spill it. The only thing on the table at this point is the paper plate and the solar cell.** *Then person #2 will hold up the solar cell and the COACH will put two drops of the potassium iodide on the edges that are hanging out. Wait for a minute while the liquid travels to the middle.* G**o to each group and loosen the clips, one side at a time, to allow the potassium iodide to cover the cell.** *Now person #3 will use the cotton swab to wipe the edges you just put the drops on so the edges are clean.* *Congratulations! You just made a solar cell! Now put it in the middle of the table while we go over instructions for the next part of the lab.* **Write the word "voltage" and the definition on the board.** *Voltage is the force that helps the electrons to flow in a circuit to*	*What does voltage measure?* *Why are we testing our solar*	Electricity! To see how much electricity it

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create electricity. *Now we are going to collect some data and test your solar cells. We are going to measure the voltage of each cell in the shade (when covered with a hand), in room lighting, and under the heat lamp. We will call each group up to the heat lamp, but you should be recording the voltage of the other 2 settings as you wait.*	*cell's volts?*	holds. To see if it works.
EXPLORATION (Continued)		
What the Teacher Will Do	**Probing Questions**	**Student Responses Potential Misconceptions**
NOW call groups up to each heat lamp as they begin recording data. One lamp per four students minimum. You can have two heat lamps per coach as long as they are right together and watched carefully. *Person # 4 will take the solar cell, and attach the clips from the multimeter to the two overhanging sections of the glass on the solar cell. We will shine this heat lamp on them. Then person # 4 will write down the voltage their solar cell had.* *The light from the sun uses UV rays, which are what gives us a sun tan when we sit out in the sun for too long. The sun provides more photons when it shines, making it a better source of light for a solar cell. And a light bulb can only produce a little bit of photons, making it not as good as the sun. Everyone repeat - "the sun provides photons"* **Hold the heat lamp over the solar cell. Shine the light on the dyed slide of the solar cell. Be sure to remember to change the setting to volts. THE MULTIMETER MUST BE SET TO READ ON DC (see ppt).**	*Do you think the light that comes from this lamp is the same as the light that comes from the sun?*	Yes. It is yellow and heats like the sun.

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EXPLANATION Time: 20 minutes		
What the Teacher Will Do	**Probing Questions**	**Student Responses Potential Misconceptions**
Fill in the table provided on the butcher paper with the voltages the kids measured- Ask a representative from each group to record the type of dye they used and the voltage measured. This way all of the students can get the information about each of the dye readings.		
Pass out copies of the guided notes and ask probing questions.	1. *Which dye had the highest voltage?* (Guided Notes) 2. *Which one had the lowest voltage?* (Guided Notes)	1. The dye from the blackberries. 2. The dye from the blueberries.
Note that the mix of the two dyes had a voltage in between these two.	3. *Did the results agree with the hypothesis you made during the experiment? Explain.*	3. Yes or no, depending on what they put.
So now we are going to find out why the dye from the blackberries produced higher voltage than the one made from the blueberries in our solar cells.	**Check TIME here and decide if you want to go further or not.**	**Check TIME here and decide if you want to go further or not.**
Check TIME here and decide if you want to go further or not.		
The solar cells use light to create energy, so we need to learn about some of the properties of light to understand how this happens.	4. *Has anyone seen a prism refracting light? What happens?*	4. Yes, we see all of the colors of the rainbow.
That's right! A prism separates or refracts white light so that we can see all of the colors it contains. (Guided Notes question)		
Click to which has a picture of a prism.		
Light from the sun is white light, which contains all of the colors. It has energy that is transferred as particles, called photons.		

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Write photons on the board. *Photons can have different amounts of energy. These different amounts of energy correspond to different colors of light waves. (Light also travels in waves.)* *Each of the colors we see has a different amount of energy based on how much energy the photons have.* **Click to show the visible spectrum-. Powerpoint.** *This is a picture of all of the colors that we can see. It's called the Visible Light Spectrum.*		
EXPLANATION (continued)		
What the Teacher Will Do	**Probing Questions**	**Student Responses Potential Misconceptions**
Click the mouse, the name will appear on the spectrum on the Powerpoint. Have the class repeat term (Guided notes question). *Red has the least amount of energy out of all of the colors, and violet light has the most energy. (Guided Notes Question)* **Click the Powerpoint twice, this info will appear at the bottom of the spectrum.** *The amount of energy in the colors increases from the red side of the spectrum to the violet side.* *That's right. Green light has more energy than yellow light.* **Ask more questions about which color has more energy to ensure the students understand this point as needed.** *Waves of light are measured by something called a* ***wavelength****.*	5. *Do red and yellow have the same amount of energy?* 6. *Which has more energy: yellow light or green light? Why?* 7. *What is a wavelength?*	5. No, all of the colors have different amounts of energy. 6. Green, because it is closer to the violet side of the spectrum. 7. The thickness of the wave, how big the wave is, and the length of the wave.

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Write wavelength on the board, then draw a wave *This is what a wave of light looks like.* *The wavelength of a light wave can be measured as the distance between the peaks in the wave.* **Draw this on the wave.** *Draw what a wavelength is on your guided notes. The differences in wavelength make some light waves have more energy than others. Light waves with shorter wavelengths have more energy than light waves with longer wavelengths.*	8. *From what you just learned, does red light have a longer or shorter wavelength than violet light?*	8. Longer, shorter, the same.
Yeah, red light has a longer wavelength. The reason red light has less energy than violet light is because the violet light has a shorter wavelength.		
Click on the Powerpoint, the words "shorter wavelengths" and "longer wavelengths" will appear on the visible spectrum. UV light will be to the right of violet on the spectrum on the Powerpoint. *So UV light has a shorter wavelength compared to the visible light spectrum, meaning it has more energy than visible light.* **Infrared light will be to the right of red on the spectrum.** *Infrared light has a longer wavelength, meaning it has less energy.* ***You might have noticed the difference in energy between UV and infrared light. If you stand in UV light which the sun and tanning beds emit, you get***	9. *UV light is also on the electromagnetic spectrum. Does it have more or less energy than visible light?* 10. *What about infrared light? Does it have more or less energy than visible light?*	9. It has less energy since you can't see it. It has more energy. 10. It has less energy since you can't see it. It was more energy.

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tanned or sunburned after long exposure. If you stand near infrared light, like a fireplace, you can get comfortably warm. Therefore, UV light has more energy than infrared light.		
So now let's talk about ENERGY! ***Click to the next slide, titled "how is light used…."*** *The energy from the waves of light hitting the solar cell knocks electrons from the dye loose so that they will be able to move through the conductive surface of the glass. The circulation of electrons is what produces the current in our solar cells, which is what creates energy in the cell. (Guided notes question)* **Click powerpoint once to show the atom/electron, then once to show a text box about the electrons moving, then once to show the animation.** **If you don't have a powerpoint presentation, draw a diagram of a wave of light hitting the dye/solar cell and electrons moving around on the board to help explain this, or show a print out.**	11. *Let's discuss what was happening when we put the leads of the multimeter on the solar cell. What do you think the positive and negative meant?*	11. The positive and negative signs show in what direction the electrons are flowing; negative is bad and positive is good.
So, now that we know how light is used to create energy in the solar cell, let's talk about how we are able to see different colors of light. *When white light, containing all of the colors, hits an object, each of the colors can be reflected off of its surface or they can be absorbed by the object.*	12. *Do you think the colors we see are reflected or absorbed by objects? Talk with your groups for a minute and then we will discuss what you think.* (Teachers may need to give students an example, such as ____'s shirt is red, so are red wavelengths reflected or absorbed by this shirt?)	12. Reflected. Absorbed. Don't know.
Right, we see the colors that are of light that is reflected back from the surface of an object. So, if someone is wearing a red shirt,	13. *We don't see black on the visible spectrum. What do you think happens when we see black?*	13. None of the colors were reflected.

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the shirt is absorbing all other colors of light and is reflecting red, which we see. **Draw a diagram of this on the board or in ppt.**	14. *What colors are reflected off of an object we see as white?*	14. All of them.
When an object absorbs all of the visible colors, we see black. NO light is reflected to our eyes, so we don't see any color. Black corresponds to the absence of light. *White light contains all of the colors, so white objects reflect all of the colors in the rainbow back to our eyes.* **Pause for questions- make sure the kids understand this before moving on.**	15. *Do you remember anything about complementary colors?*	15. They are on opposite sides of the color wheel.

EXPLANATION (continued)

What the Teacher Will Do	Probing Questions	Student Responses Potential Misconceptions
Click to show Slide 4 of the powerpoint presentation, which has a color wheel. *Right! Complementary colors are on opposite sides of the color wheel.*	1. *What color is complementary to red? Yellow? Blue?*	1. Green. Violet. Orange.
Dyes, like the one used to make our solar cell, absorb and reflect light a little differently. A dye absorbs a certain color and reflects its complementary color. (Guided Notes) **Click the powerpoint, a list of the complementary colors appears.** *So, using this information, fill in the diagram on your Guided Notes. You need to label what color light hits the solar cell, what color is absorbed by the dye on the cell, and what color is reflected back to our eyes.*	2. *If a dye is red, what color light is it absorbing?*	2. Green.
The dye made with blueberries had a more blue color than the	3. *The blackberry dye we used*	3. Yellow.

violet color of the blackberry dye. It would be in this part of the color wheel. ***Click on the powerpoint.*** *If we look across the color wheel, we'll see that the complementary color for the blueberry dye is more of an orange color. So that means that the blueberry dye absorbs a more orange color than the blackberry dye.*	*today was violet. Since the color of the dye we see is the complementary color to the color of the light absorbed, what color was absorbed for the blackberry dye?* 4. *Looking at the visible light spectrum, does yellow or orange light have more energy?*	4. Yellow.
Click on the powerpoint, another slide of the light spectrum. *Yes, yellow light has more energy. Let's compare this to the results of our experiment.*		
*Let's look at the diagram we have on the board about how energy is created in a solar cell***.** *Light with more energy will make the electrons in our solar cell move around more. This creates more energy in the solar cell.*	5. *Using this information, can anyone explain to the class why the blackberry dye produced a higher voltage?* (Students may discuss in groups as needed.)	5. Because the blackberry juice absorbed yellow light, it absorbed more energy.
The blackberry dye produced a stronger voltage because there was more energy in the yellow light than the orange light absorbed by the blueberry dye.		
Remember that it is light that has the wavelength not the juice. **Pause for questions.**	6. What process do plants use to create energy using sunlight?	6. Photosynthesis.
The sunlight is indeed absorbed by the dye. Sunlight is used to create energy in other things besides a solar cell.		7. Green.
Chlorophyll is the pigment used in plants for photosynthesis. The fact that it is a dye explains why grass stains are so hard to get out of your clothes.	7. What color are chlorophyll pigments? 8. Therefore, what color are they reflecting? What color are they absorbing?	8. Green. Red.
When plants don't get enough light from the sun to produce		

food, they stop producing chlorophyll and become dormant. So, when chlorophyll isn't in the leaves anymore, other colors that were always in the leaf are visible. We can see the yellow and orange that was in the leaf because it isn't hidden by the green chlorophyll anymore. *Last time we saw that the structure of the dye ANTHOCYANIN was similar to chlorophyll.* ***Write anthocyanin on the board and have the class repeat it.***	9. *What dye did we talk about during the last lesson (besides chlorophyll)?* 10. *What role do you think anthocyanin had in making our solar cell work?*	9. Various guesses. Answer: anthocyanin. 10. It absorbed the sun light.
The blackberries and blueberries contained the dye anthocyanin. The anthocyanin absorbed yellow or orange light, causing excited electrons to move throughout the cell. *This experiment shows that anthocyanin absorbs light to excite electrons in a similar way that chlorophyll does during photosynthesis.*	11. *Which dye created a larger voltage on the multimeter?* 12. *What does the larger voltage mean in terms of how much energy is absorbed?*	11. Blackberry dye. 12. More energy was absorbed.
Let's review what we've learned today. *The purple dye absorbed more photons of light, which made the voltmeter show a higher voltage.* **Read over the guided notes as a class to be sure the students understand all of the answers.**		

ELABORATION **Time: <u>15 minutes</u>**		
What the Teacher Will Do	**Probing Questions**	**Student Responses** **Potential Misconceptions**
So let's talk a little about our solar cell and how it worked. Here's a diagram of our solar cell. **The diagram is included in the packet; put it on the doc cam or draw it on the board. Remember to label everything**		

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and verbally reiterate components (ex. This rectangle is our top piece of glass, this is TiO_2, this is our multimeter, etc) before moving on. *$TiO_2$is drawn here. Remember that TiO_2 are nanocrystals, so the layer of TiO_2 we put on the glass actually has tiny little pockets in it like a sponge.* *The dye is taking up all of the space in the TiO_2 "sponge." The dye doesn't leak out of the "sponge" because we have the piece of glass under the TiO_2 layer as prevention.* *When we used our solar cell, we measured the flow of electricity to make sure it was working.*	1. Since TiO_2 is like a sponge, what do you think it soaked up in its holes? 2. What do you need to confirm about your circuit before anything can be measured? Can we test the solar cell by itself?	1. The dye. *[Misconception: water, the electrons.] 2. That it's complete. You have to complete the circuit before testing. *[Misconception: You can test before completing the circuit.]
ELABORATION (continued)		
What the Teacher Will Do	**Probing Questions**	**Student Responses Potential Misconceptions**
Right, it's important to make sure that the circuit is complete so the electrons can flow. If the circuit isn't complete, the electrons won't move, and we won't get a reading! *The multimeter is how we closed the circuit – it connected the two ends of the solar cell to make a pathway for the electrons to flow through.* *So now let's look at where the electrons flowed in our circuit. The electrons actually come from our potassium iodide solution.* *It's the electrolyte! When light – in this case, the light from our heat lamp – hits our solar cell, it helps the electrons from the potassium iodide solution move. The dye actually helps move the electrons from the solution to the*	3. What did we use to complete the circuit of our solar cell? 4. What was our potassium iodide solution serving as? 5. Do electrolytes help us conduct electricity? Or do they hinder conduction?	3. The multimeter. *[Misconception: the light, the KI solution (technically a part of the solar cell.)] 4. The electrolyte. *[Misconception: the conductor) 5. They help us conduct electricity.

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TiO2 layer. *The electrons then move from the TiO_2 layer to the glass plate that it's touching. It then moves along the circuit, through the multimeter, onto the other glass plate, and back into the potassium iodide solution.* *The electrons will keep moving through the circuit as long as it's closed and light is still being supplied!* *Solar energy is a renewable resource which means we can't ever run out of it. But right now we use the burning of fossil fuels) to power steam engines that generate energy.* **Write renewable resources on board under solar energy.**	6. Once the electrons get back into the potassium iodide solution and there's still light being applied to the cell, what do you think they'll do? 7. Why do you think solar energy is important?	6. Keep moving through the circuit. 7. So we don't use a lot of batteries. So we save energy because it is renewable. So we save the environment.
ELABORATION (continued)		
What the Teacher Will Do	**Probing Questions**	**Student Responses Potential Misconceptions**
Write fossil fuels on board. **Write nonrenewable on board under fossil fuels and make sure they understand the difference between to two, by making a chart and listing the types of resources that fall under each category.** *Here are some examples of how solar panels are used in today's society.* **Show pictures in handouts.** *Solar panels can be used in cars, houses, and even space units.* *Solar cars use something called PV cells, panels that convert light directly into electricity.* *Solar panels also help heat water in homes instead of using natural gas or electricity.* *The solar panels used in space*	8. What are fossil fuels? 9. Why are fossil fuels important when we consider the environment? 10. How could solar cells help with the problem that comes with using up our fossil fuels?	1. Coal, natural gas, or petroleum. 2. They are non-renewable resources. They create pollution. Global warming. 3. You could use them to get energy instead of fossil fuels or batteries or generators.

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can power robots to explore different planets. *Solar panels are ideal in space because satellites switch between being in direct sunlight to being in none at all (in the earth's shadow). Solar panels allow for satellites to store energy for later use. Plus, it costs millions of dollars to send a satellite into space in the first place so sending up new batteries is not feasible.* *Expalin that lots of experiments are going on at UT to make solar cells more efficient as a mater of fact that's where our solar lab equipment came from today. Manufactures cells are better than ours aren't they but we had to start somewhere. Maybe you will be the nano scientist that doubles the efficiency.*	11. Why do you think solar panels are important to use in space?	You can't change the batters if they die in space. They can store energy there. They still have access to the sun.

EVALUATION **Time: <u>7 minutes</u>**		
What the Teacher Will Do	**Probing Questions**	**Student Responses** **Potential Misconceptions**
It's time to show off what you learned today and see how ready we are for Science Olympics. Work with your groups to answer these four questions. Make sure all your team members know the concepts. **Pick 2 questions from the quiz bowl sheet and write them on the board.** *Write down your answers in your interactive journal them when you are done.*		

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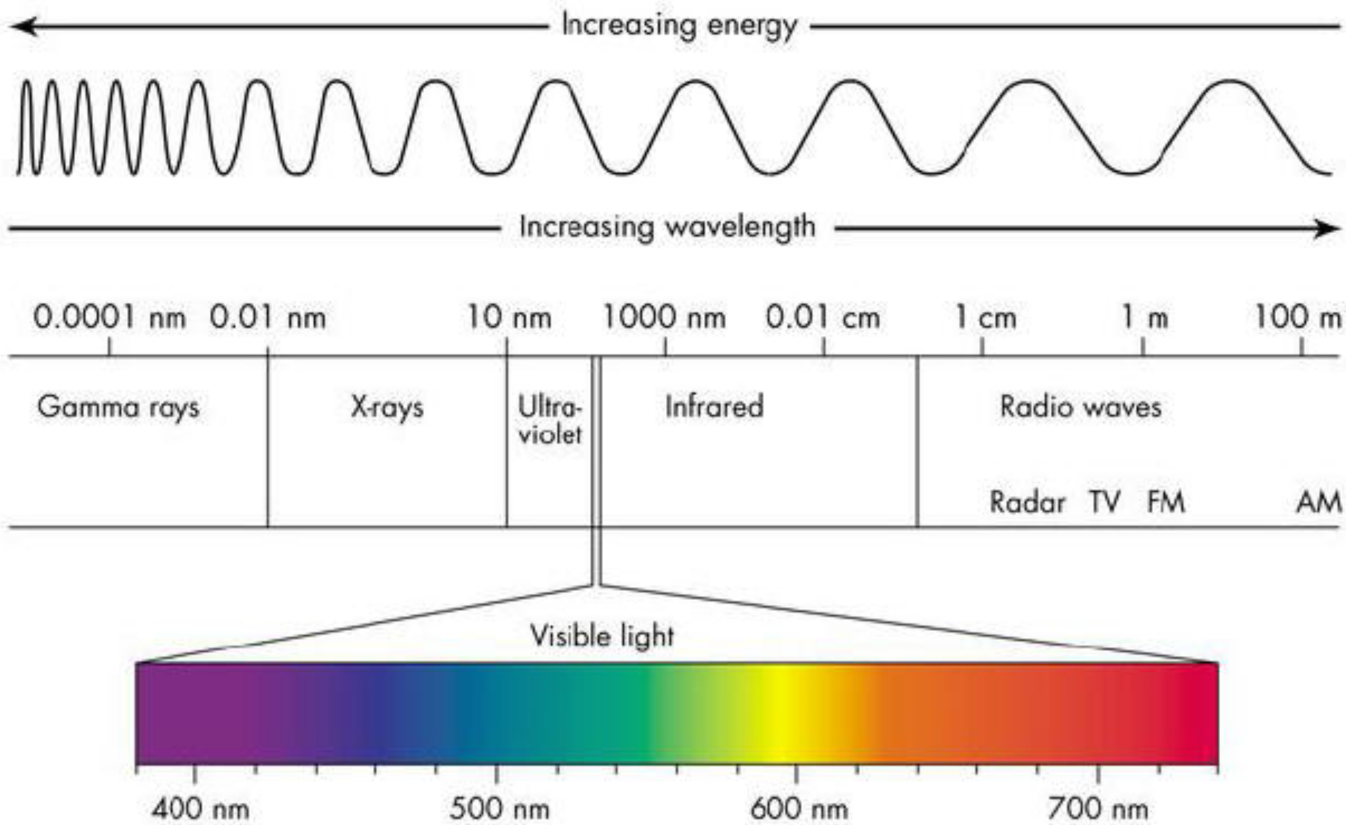

Name: ______________________________________ Date: ____________________________

Testing Solar Cells

Hypothesis:____
____
____
____

Percent of Each Juice Used (Blackberry/Blueberry)	Voltage Shaded (Hand covering solar cell)	Voltage at Room Lighting	Voltage with Heat Lamp

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________/__________			
________/__________			
________/__________			
________/__________			
________/__________			
________/__________			

Conclusion:

____

____

____

Which dye produced the most voltage?

____

Why do you think this dye had the highest voltage?

____

Which light source produced the highest voltage for your solar cell?

____

____

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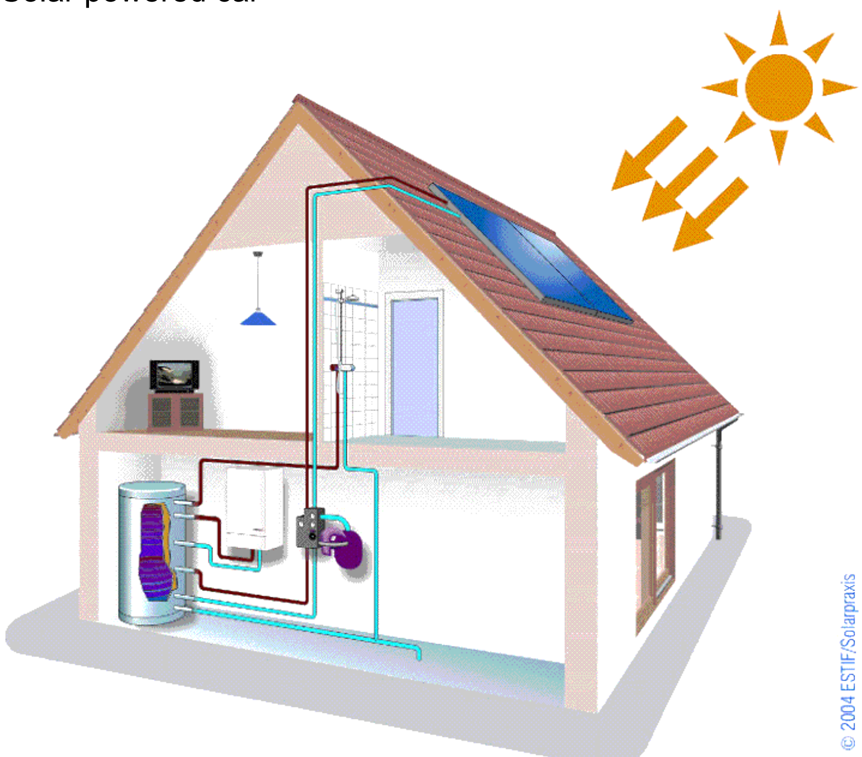
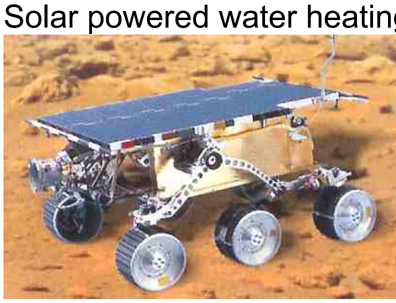
Solar powered car



Solar powered water heating system



Solar powered Mars rover

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Evaluation Questions, Solar Cell 2

1. What did we use to test which side of the glass was a good conductor?
   a. Multimeter
1. What are photons?
   a. Particle of light
2. What are Electrons?
   a. Negatively charged particle
3. What is a Current?
   a. A flow of electric charge
4. What is resistance a measure of?
   a. Force against the flow of an electric current
5. What two things does light act like?
   a. A wave and a particle
6. Which dye had the highest voltage and why?
   a. Blackberry juice, absorbed more energy
7. What does a prism do to light?
   a. Separates it into different colors from white light
8. Does anyone know at what wavelengths we can see light?
   a. 390 to 750 nm
9. What is this region of light called?
   a. Visible Light Spectrum
10. What are 2 examples of wavelengths of light that we cannot see?
    a. Microwaves, UV, x-rays
11. What does the larger voltage mean in terms of how much energy is absorbed?
    a. more energy absorbed
12. What is the complementary color of purple?
    a. Yellow
13. What other type of energy comes from the sun besides electricity?
    a. Heat
14. Based on what we've learned today, what color shirt would keep you the most cool if you had to stay outside on a summer day?
    a. White
15. Why would a black shirt make someone hotter on a summer day than if they wore a white shirt?
    a. More energy is absorbed.

Solar Cells 2 Guided Notes

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A ______________________ (1) is any material that allows electrons to move freely in an object. The glass used for our solar cells is a ____________________ (2). The conductive side of the glass has the least _____________________ (3), which means that the electrons are able to move more freely.

A ____ (4) is used to measure the resistance.

We tested the energy created by our solar cells by measuring the _____________________ (5), which is a potential energy that exists to move electrons from one point to another.

Which juice created the highest voltage for the solar cell? ________________________ (6)

Which juice created the lowest voltage for the solar cell? _________________________ (7)

A ______________________ (8) is used to separate white light into all the colors.

The energy input for our cells came from __________________________ (9), which excite _____________________ (10) in the solar cell.

____________________ (11) is the force that helps the electrons to flow in a circuit. It is also the relationship between the flow of electrons and the resistance to that flow.

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Guided notes KEY

A **1) conductor** is any material that allows electrons to move freely in an object. The glass used for our solar cells is a 2) **semiconductor**. The conductive side of the glass has the least **3) resistance**, which means that the electrons are able to move more freely. A **4) multimeter** is used to measure the resistance. We tested the energy created by our solar cells by measuring the **5) voltage,** which is a potential energy that exists to move electrons from one point to another.

6) Which juice created the highest voltage for the solar cell? **Blackberry**

7) Which juice created the lowest voltage for the solar cell? **Blueberry**

8) A **prism** is used to separate white light into all the colors.

9) Current is the force that helps the electrons to flow in a circuit. It is also the relationship between the flow of electrons and the resistance to that flow.

	Group #	**Volts**
Blueberry (100%)		
Blueberry/Blackberry (50/50%)		
Blackberry (100%)		

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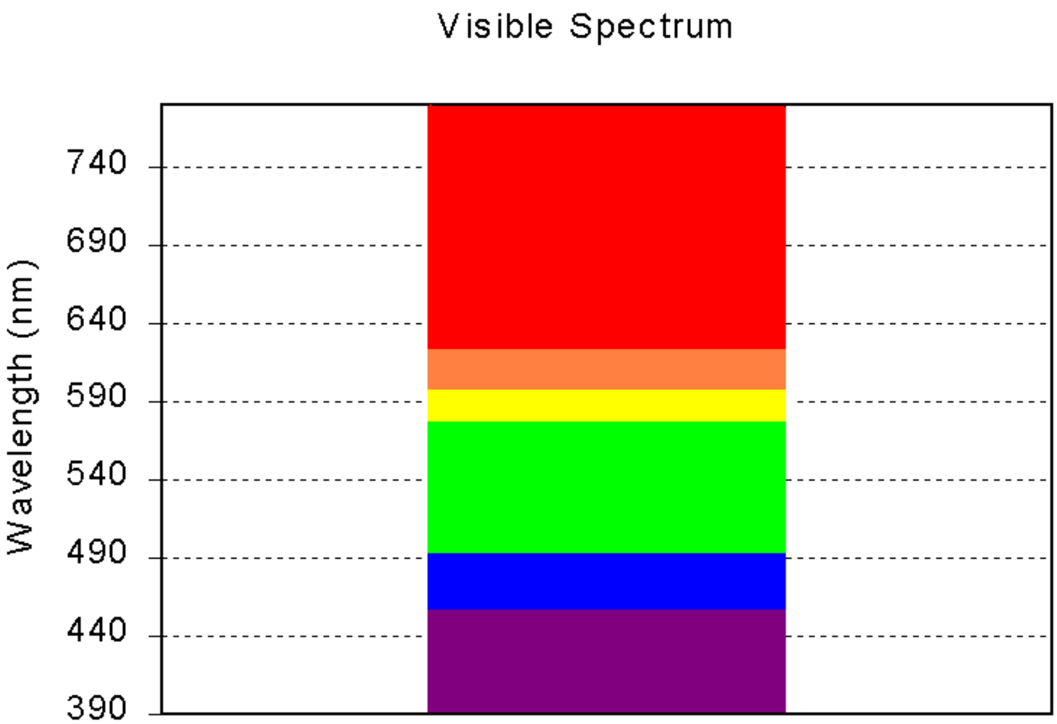

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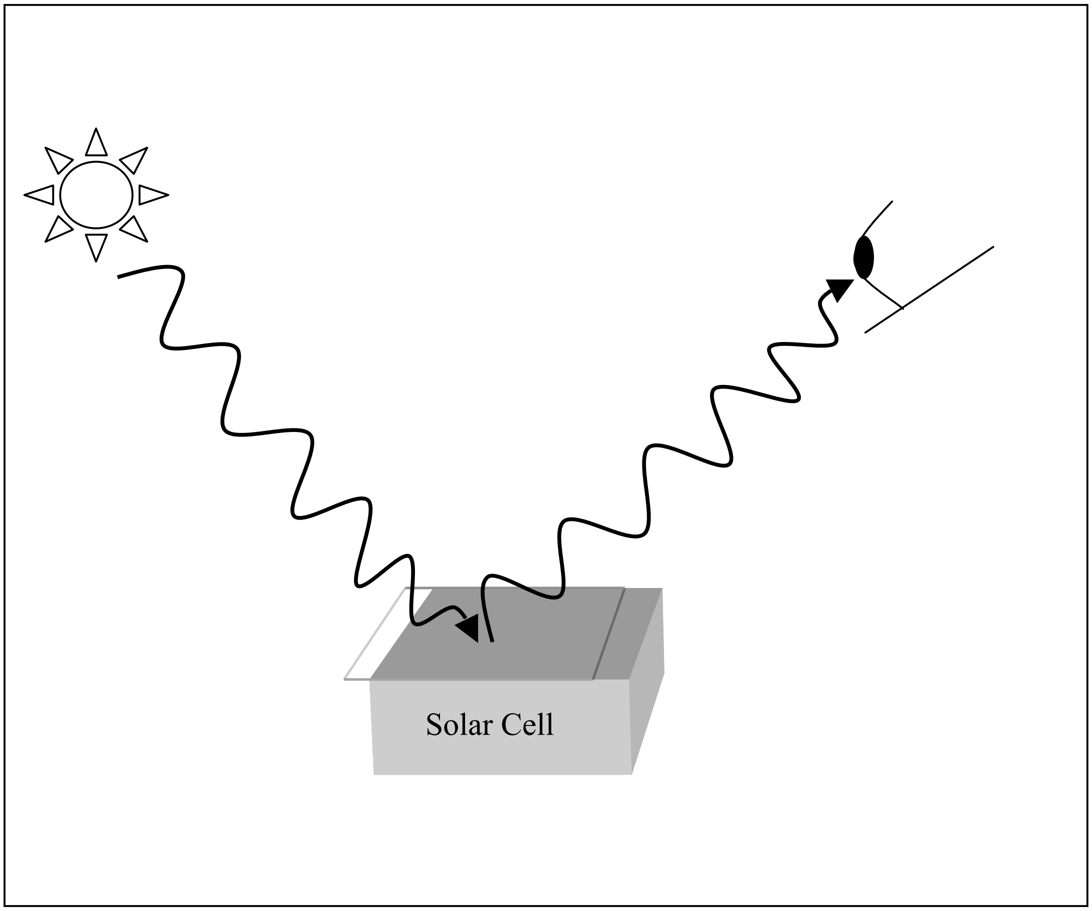

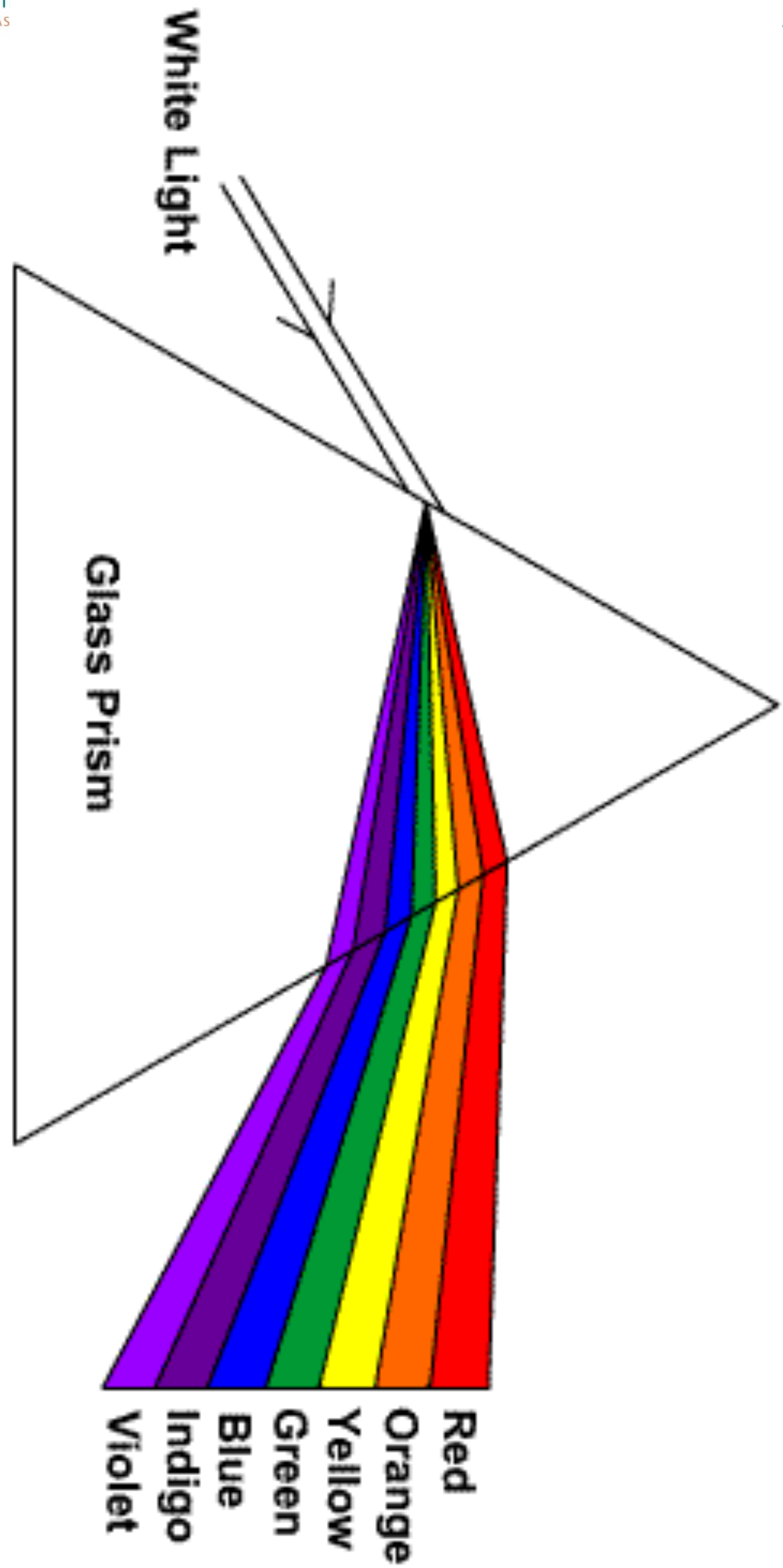
White Light
Glass Prism
Red
Orange
Yellow
Green
Blue
Indigo
Violet