LESSON INQUIRY QUESTION

How do solar photovoltaic cells convert photons to electric energy?

LESSON CHALLENGE

Create an effective explanation of how solar photovoltaic cells convert photons to electric energy.

Broad understanding

Students learn about the process that converts photons to electric energy in photovoltaic cells.

THINKING TOOLS

Background knowledge

- photons
- photovoltaic cells

Critical thinking vocabulary

- criteria

Criteria for judgment

- criteria for an effective explanation
  - » accurate
  - » appropriate
  - » clear
  - » comprehensive

Thinking strategies

- rating scale

Habits of mind

- attentive to detail

SUMMARY

In this lesson, students develop understanding of the process that converts photons to electric energy in photovoltaic cells. To begin, students rate the effectiveness of explanations of common daily tasks and processes. Students use these rating to co-develop the criteria for an effective explanation. Next, students examine explanations of how solar photovoltaic cells convert photons to electric energy. Guided by information about the key steps in the conversion process, students use the criteria for an effective explanation to rate each explanation. Students deepen their understanding of the conversion process by reworking ineffective explanations to better meet the criteria. To conclude the lesson, students create an effective explanation of the conversion process for a non-science audience.

MATERIALS

Activity sheets

- Rating Explanations (Activity sheet A)
- Rating Scientific Explanations (Activity sheet B)
- Developing an Effective Explanation (Activity sheet C)

Briefing sheets

- Explanations of the Solar Energy Conversion Process (Briefing sheet A)
- The Solar Energy Conversion Process (Briefing sheet B)

Assessment materials

- Assessing My Understanding of the Conversion Process (Assessment materials A)

LEARNING ACTIVITIES

Introduce the criteria

1. Organize students into pairs and provide each student with *Rating Explanations* (Activity sheet A). Instruct students to use the scale found on the activity sheet to rate the effectiveness of each explanation: an effective explanation would receive three stars, while an ineffective explanation would rate one (or no) stars.
2. Guide students' attention to the right-hand column of the activity sheet and ask them to identify the characteristics of each explanation that prompted its rating.
3. Encourage students to share their thinking with the class. As students share, present or co-develop the criteria for an effective explanation:
   - *Accurate:* The explanation precisely describes the important parts and steps of the process.
   - *Appropriate:* The reading level and style of the explanation matches the intended audience.
   - *Clear:* The explanation of the process is easy to understand.
   - *Comprehensive:* The explanation includes all the important parts and steps of the process.

   Consider recording and displaying the criteria for use later in this lesson.
4. Invite students to revisit their initial ratings for each explanation. Prompt students to use the criteria to assess each explanation. If time permits, consider asking students to revise each statement to make it a "three-star explanation."
5. Present students with the lesson inquiry question: "How do solar photovoltaic cells convert photons to electric energy?" Explain that they will respond to the question by creating effective explanations of how photovoltaic cells convert photons to electric energy.

Rate the effectiveness of explanations

1. Organize students into pairs and provide each group with *Explanations of the Solar Energy Conversion Process* (Briefing sheet A) and each student with *Rating Explanations of Solar Energy Conversion* (Activity sheet B). Explain that their first task is to rate the descriptions of how solar photovoltaic cells convert photons to electric energy.
2. Ask students to use the criteria to rate the explanations of the conversion process. Remind groups to identify the characteristics that prompted its rating. Groups could rate each explanation, or consider assigning individual explanations to groups.
3. Invite groups to share their ratings and reasons with the class.
4. Provide each group with a copy of *The Solar Energy Conversion Process* (Briefing sheet B) and explain that the next task is to revise statements to better meet the criteria.
5. Ask groups to suggest what revisions might make each explanation a "three-star explanation." Groups could provide suggestions for each explanation, or consider assigning individual explanations to groups. Prompt students to note their suggestions in the right-hand column of the activity sheet.
6. Encourage students to share their suggestions with another group, reminding them to use the criteria to guide their thinking about how explanations might be improved.

LEARNING ACTIVITIES

Respond to the lesson challenge

1. Provide each student with *Developing an Effective Explanation of Solar Energy Conversion* (Activity sheet C). Inform students that their final task is to respond to the lesson challenge: "Create an effective explanation of how solar photovoltaic cells convert photons to electric energy."
2. Invite students to suggest who might need to know about the conversion process. Student responses might include students new to the topic, homeowners considering the purchase of a home solar PV system, or a school council learning more about the potential benefits of a school solar PV system. Invite students to select one of the possible audiences, and then note it at the top of the activity sheet.
3. Prompt students to create their effective explanation, reminding them to use the criteria to guide their thinking and writing. If required, *The Solar Energy Conversion Process* (Briefing sheet B) can provide additional information.
4. Invite students to work with a partner to give and receive feedback on an initial explanation. Encourage students to use the criteria to frame their feedback.
5. Consider having students present or deliver their explanations to their suggested audience.

Assess the learning

1. Students may use *Assessing My Understanding of the Conversion Process* (Assessment materials A) to reflect on their learning and how effectively they responded to the lesson challenge.

Rating Explanations

Process	Explanation	Rating of explanation	Characteristics of explanation
How an egg fries	Eggs are made of protein. As the proteins in the egg are heated in a pan, they turn from liquid to solid and the egg is cooked. We call this a fried egg if the egg is broken into a flat pan coated with some kind of fat.	☆ ☆ ☆	
How ice melts	Ice is the solid form of water, which consists of one oxygen atom and three hydrogen atoms. In solid state the molecules of water are stacked in an arrangement and do not move very much. At temperatures above two degrees, the molecules heat up and move around more, releasing from their formation and flowing as liquid.	☆ ☆ ☆	
How teeth are cleaned	First, you put toothpaste on a toothbrush, and rub the toothbrush up and down across the surface of your teeth. The action of the toothbrush rubs the paste against your teeth. Both the contact of the brush against your teeth and the contact of the fine abrasive particles in the paste mechanically remove particles of food and bacteria that coat the surface of your teeth. Ideally, the paste, and removed particles are washed out of the mouth with water.	☆ ☆ ☆	
How cell phones work	A cell phone works by pushing a button to turn it on. Then you use it to make phone calls, text, or access the internet.	☆ ☆ ☆	

Rating Scientific Explanations

Explanation	Rating of explanation	Characteristics of explanation	Suggested revisions
1.	☆ ☆ ☆		
2.	☆ ☆ ☆		
3.	☆ ☆ ☆		
4.	☆ ☆ ☆		

Criteria for an effective explanation:

- ✓ *Accurate:* The explanation precisely describes the important parts and steps of the process.
- ✓ *Appropriate:* The reading level and style of the explanation matches the intended audience.
- ✓ *Clear:* The explanation of the process is easy to understand.
- ✓ *Comprehensive:* The explanation includes all the important parts and steps of the process.

Developing an Effective Explanation

My selected audience:

My effective explanation:

Criteria for an effective explanation:

✓ *Accurate:* The explanation precisely describes the important parts and steps of the process.
✓ *Appropriate:* The reading level and style of the explanation matches the intended audience.
✓ *Clear:* The explanation of the process is easy to understand.
✓ *Comprehensive:* The explanation includes all the important parts and steps of the process.

Explanations of Solar Energy Conversion

Explanation 1

Light is composed of photons, which are simply small bundles of electromagnetic radiation or energy. These photons can be absorbed by a photovoltaic cell–the type of cell that composes solar panels. When light of a suitable wavelength lands on these cells, energy from the photon is transferred to an atom of the semiconducting material in the p-n junction. Specifically, the energy is transferred to the electrons in the material. This causes the electrons to jump to a higher energy state known as the conduction band. This leaves behind a “hole” in the valence band that the electron jumped up from. This movement of the electron as a result of added energy creates two charge carriers, an electron-hole pair.

Explanation 2

A photovoltaic cell works because photons, or particles of light, knock electrons free from atoms, generating a flow of electricity. Photovoltaic simply means they convert sunlight into electricity.

Explanation 3

The way to positively dope a semiconductor so it will convert sunlight into electricity is to put in the crystalline structure atoms that have one less valence electron than their surrounding semiconductor atoms. And the way to negatively dope a semiconductor is to put in crystalline structure atoms that have one more valence electron than their surrounding semiconductor atoms. The intensity of the current produced by the cell, measured in milliamps, or amperes, will be directly proportional to the intensity of the flow of photons reaching the semiconductor (the north pole gets a lot less than the equator). This is measured in candelas, which comes from the number of candles historically, but there are different units. The efficiency of the solar cell will usually be inversely proportional to its thickness.

Explanation 4

Light behaves as an electromagnetic wave, and behaves like particles or packets travelling through space. When light strikes an electron it acts exactly like a particle hitting it, like a billiard ball transferring its energy to it, kicking the electron like the billiard ball it hits travelling across a pool table. Photovoltiac cells are a sandwich of two layers of silicon or other semiconductor, which are non-conductors that under certain conditions behave as conductors (a conductor conducts electricity; it is matter that lets the electrons flow). In a semiconductor, the electrons are bonded to the

Explanations of Solar Energy Conversion: Explanation 4 (Cont'd)

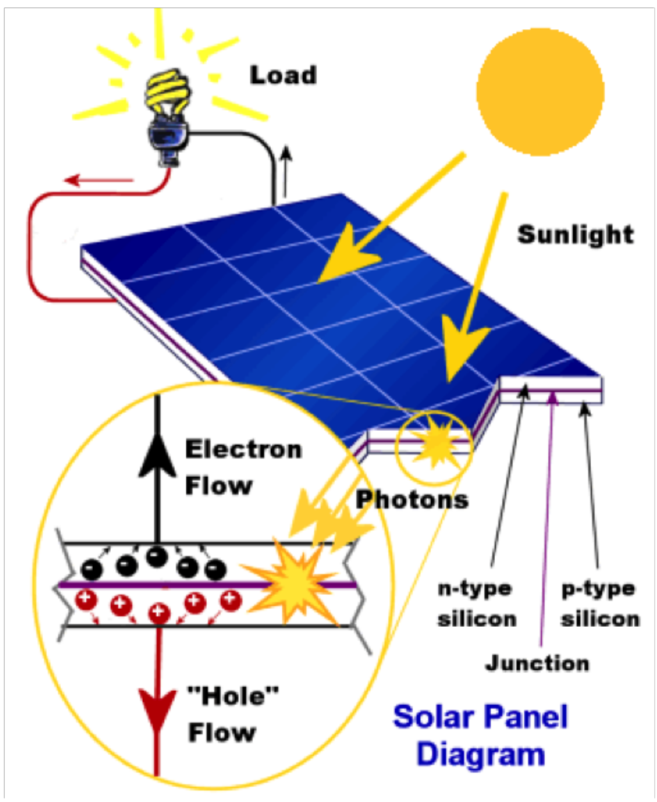
atoms tightly enough that they don't want to go from one to the other, but if you change some factors in them you will end up with substance that can conduct electricity. You will dope the semiconductor with a different element, dope one layer with extra electrons, P positive, and one with a less electrons, N negative, for example, doping silicon with boron–three valance electrons, doping positively, and phosphorus, with five valence electrons, doping it negatively. A phosphorus atom in the crystal structure of the silicon, and the surrounding atoms "feel" there is an extra electron. Dope with boron with three, and the atoms surrounding it "feel" like there is a hole next to them. When you put a negative layer in contact with a positive layer, negative charges are attracted to the holes and migrate to the surface of the contact junction, where there are missing electrons. And on the P side, the positive charges are attracted to the junction to the N side. You end up with a region, the depletion region, where the negatives will have crossed over, forming a region that is neutral between the two layers. The region of depletion acts as a nonconductor again, but you have the charges on both sides. So you have an electric field STILL, that would like to see the electrons move across, but because of the depletion region resisting the passage of the electrons, it doesn't move. But if photons of light come in, at speed of light with a quantity of energy, depending on the colour of the light, photon with the right amount of energy, it hits an extra electron that can't wait to jump over to the other side, and the photon kicks it off its place close to the boundary. With many photons, and many electrons flowing from the N side to the P side, you have an electric field, encouraging electrons to move toward the positive side. Billions of photons kicking off electrons, and a bunch migrate across. If you join the photovoltaic cell with wires, you end up with electrons moving in the direction out into the wire: an electric current.

The Solar Energy Conversion Process

Description of the process

The solar panels found on homes, schools, and other buildings consist of many photovoltaic (PV), or solar, cells. A typical 12 volt solar panel has 60 PV cells. PV cells convert energy from the sun into electrical energy, a process known as the photovoltaic effect.

A typical PV cell is approximately 0.5mm thick. A PV cell is a semiconductor device made of two very thin layers, usually silicon. The two layers have been specially treated, or "doped," to form an electric field, with a positive charge (p) on one side and a negative charge (n) on the other side. The two layers are connected with very thin wires made of conducting material, usually copper.



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The photovoltaic effect begins when light from the sun lands on a solar panel. After being absorbed by the PV cell, light photons collide with the electrons inside the semiconductor material. This "frees" the electrons from the bound position on their atoms. Because of the initial differences in charge, electrons move towards the p-type side. A positive charge

The Solar Energy Conversion Process (Cont'd)

develops on the n-type surface of the junction as the electrons leave the area, which forms holes. These holes move towards the negative n-type side. This causes a negative charge to develop on the p-type surface of the junction. The flow of the electrons across the p-n junction between the layers of the PV cell creates an electrical current. As long as sunlight continues to land on the solar panel, this process continues.

The electrical current generated in a solar panel can be collected by the conducting wires and sent to an inverter. The inverter changes the electrical current it from direct current (DC) into alternating current (AC). The AC current can then be used for electrical power.

Key terms

- **conductor:** a material that allows the flow of electrical current. Copper is often used as a conductor in PV cells.
- **semiconductor:** a material with electric conducting properties that can be altered in useful ways by introducing impurities into the crystal structure. Silicon (Si) is a commonly used semiconductor in photovoltaic cells.
- **doping:** the process of replacing atoms in the materials used to create PV cells. Solar cells are constructed from two layers of semiconductive material, usually silicon. One layer is n-type and the other is p-type:
  - » The n-type layer has a net negative charge due to addition of electrons by replacing a small amount of semiconductor (silicon) atoms with another element that has one extra valence electron such as nitrogen, phosphorus, arsenic, or antimony.
  - » The p-type layer has a net positive charge due to the lack of electrons by replacing a small amount of silicon atoms with another element that has one less valence electron, such as boron, aluminum, gallium, or indium.
- **p-n junction:** The contact surface between the n-type layer and p-type layer.
- **bound electron:** an electron that is in the outermost valence band of an atom (also called a valence electron).
- **free electron:** a valence electron that has absorbed the correct amount of energy to move across the junction from one layer of the photovoltaic cell to the another.

Assessing My Understanding of the Conversion Process

Name: ________________________________

1. Provide examples that show how you have met the success criteria.
2. Use the rating scale to indicate how well you have met the success criteria.
3. Describe the next steps in your learning.

Success criteria	How am I doing?
I can use criteria to identify an effective explanation. Examples:	1 2 3 4 **I'm still working on it.** **I've got it!** Next steps (e.g., use criteria, ask for help):
I can use criteria to develop an effective explanation of the conversion process. Examples:	1 2 3 4 **I'm still** **I've got it!** Next steps (e.g., use criteria, ask for help):
I can effectively explain the conversion process to a selected audience. Examples:	1 2 3 4 Next steps (e.g., use criteria, ask for help):