



Ella the Electron

Subject: How charged electrons fill holes to form a p-n junction between semiconductors in a solar cell.

Grade Levels: 8th grade through high school

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This lesson pre-supposes that students have completed a unit on atomic structure. The activity was originally developed for a classroom unit on types of energy, as part of a sub-unit on solar. This activity should only be used with participants who already have background knowledge of how solar cells convert energy from the sun to usable energy; this lesson can help them consolidate and extend that knowledge. Participants interpret an original story of “Ella the Electron” through texts and pictures, engaging in substantive interaction with peers to negotiate their understanding and refine their knowledge of how charged electrons fill holes to form a p-n junction between semiconductors in a solar cell. Participants then connect the story to an actual solar cell given an overview of the cell’s structure and vocabulary terms. Students can be assigned to groups, with each group assigned a scene from the story, following by whole-group discussion.

Outreach leaders may use this lesson in conjunction with other outreach activities that first introduce students to how current is generated in a solar cell (e.g., construction paper solar cells).

Objectives

- ➔ *Participants will be able to explain how the electrons of an atom produce energy. In so doing, they will refine their knowledge of how charged electrons fill holes to form a p-n junction.*

Materials

Each group or individual needs the following materials:

- Ella the Electron story
- Blank paper, pencils, color pencils or pens for drawing
- Solar vocabulary worksheet
- Ella the electron worksheet
- A diagram of a silicon solar cell

Instructor Content Background Information

For a quick guide to a PV cell in action, see Richard Komp's TedEd video, How Do Solar Panels Work?

<https://youtu.be/xKxrkht7CpY> (~4 minutes)

You might show this explanation and animation of the ideal short circuit flow of electrons and holes at a p-n junction:

<http://pveducation.org/pvcdrom/light-generated-current>

Explanation for operation of solar cells with simple diagrams and animations:

<http://www.pveducation.org/pvcdrom/light-generated-current>

An animated illustration of how the p-n junction is formed:

<http://www.pveducation.org/pvcdrom/formation-of-a-pn-junction>

Instructions

Part 1: Review

Review with participants how a solar cell converts the sun's energy to usable energy. Use the online resources above to help students recall relevant prior knowledge. Use the vocabulary worksheet to aid the review process. Working in groups, participants could create their own definitions and explain their understanding based on content knowledge or life experience. Groups could then compare and contrast their definitions, decide which is best (most accurate and concise), and further refine a collective definition for all or some of the vocabulary. In deciding, students explain reasoning for what they include and what they exclude. The outreach leader should facilitate the discussion. Allow students to lead, only interject to keep them on topic and make them elaborate or justify weak claims.

Note: The worksheet found at the end of this lesson is filled in with definitions. It can be used when time is limited. Outreach coordinators can also use the definitions to seed the conversation among participants.



Part 2: Ella the Electron.

Participants read, draw, and discuss *Ella the Electron*, a five-part story of how the electrons travels to produce energy in a solar cell. In an outreach setting, this is probably best accomplished in small groups. Divide participants into five groups. Each group should be assigned to draw and label each scene for one part of the *Ella the Electron* story. Group members should read the entire story together before drawing their

section. When all groups have completed their drawing, they explain their drawing to the whole-group, taking turns sequentially through the story. The drawings can then be collected into a book. Each participant can be given a copy of the book to take home. A copy can also be donated to elementary or middle school classrooms!

Part 3: Consolidate knowledge

Participants connect the story to a diagram of a silicon solar cell, given an overview of the cell's structure and vocabulary terms. Using their illustrations for *Ella the Electron* and the worksheet provided, participants connect the story to the parts and processes of a silicon solar cell, identifying the pathway of the electron and purpose of each layer and important processes that occur.

A possible extension to the activity is to explore with the students what effect the following changes would have on a solar cell.

- 1) Use a metal instead of a semimetal for the wafer.
- 2) Use copper instead of silver as the metal for the fingers and busbars.
- 3) Use an inorganic material for the dye-sensitized cell.
- 4) Increase the thickness of the glass of the dye-sensitized cell.

Connect beyond the classroom

Why is necessary to harness solar power in a usable form?

Deepen Your Knowledge

This lesson is part of a high school classroom unit called *Energy in Action*, created by high school science teacher, Rebecca Hooper. You can find the full unit on the QESST Education website.

In Part 3 of the lesson, students could also compare *Ella's* story and a silicon solar cell with a dye-sensitized solar cell.

Vocabulary

- Absorption - The transfer of energy of a wave to matter
- Texturing - Roughing the surface of a substance by etching along along the face. Results in a surface of pyramids in silicon.
- Sunlight - Energy emitted by the sun incident on the earth
- Electron - Sub-atomic particle that holds a negative charge and makes up the outer volume of an atom
- Recombination - When an excited electron stabilizes to a lower energy state, removing a hole
- Photon - Packets or particles of energy that sum to the total energy of light
- Energy - The ability to do or perform work
- Electricity - A form of energy generated by the accumulation of movement of charged particles
- Busbars - Metallic top contacts necessary to collect current generated by the cell
- Fingers - areas of metallization, which collect current for delivery to the busbars
- Conductor -Material that allows electrons to flee freely or allows the flow of electrical current
- Semiconductor - A solid whose conductivity lies between that of an insulator and a metal
- P-Type - Group III elements with three valence electrons to interact with silicon's four, which results in one less electron, thus creating a hole
- N-Type - Materials made of Group V elements that have valence electrons to bond with silicon 4 and the extra electron can participate in conduction
- P-N junction - Area where a p-type and n-type meet so that electrons diffuse from the p-type to the n-type
- Wafer - A slice of semiconductor material used in electronics for solar cells
- Doping - The process of adding different add-ons to a silicon wafer in order to shift the balance of electron and holes
- Efficiency - Ratio of energy output from the solar cell to input energy from the cell
- Holes - The area of a p-type material where there is a missing electron
- Current - The flow or movement of electrical charge in a circuit
- Voltage - Measurement of the potential energy of a charge within an electric circuit at a given point

Ella the Electron : The Story

PART 1

Let's explore a world that has potential to change everything about our own world and possibly save it, starting with one little girl named Ella... Ella the Electron has a pretty normal unexciting life in Silicon Villa, a place with citizens who are referred to as particles. Before getting to know the people, here is a little history on the place, Silicon Villa. Once a flat smooth land long ago, one day a rain descended that was so heavy it was as if someone had dipped the entire villa into a tub of water. But this rain was not just ordinary water; it had other special additives. The rain eroded the land leaving an uneven mountainous terrain. Two additional periods of similar, but unique types of rain created new lands on either side of Silicon Villa, but we will share more about those areas later. Every home in Silicon Villa was exactly the same as each other, but unlike any home you would be familiar with. For example, they didn't even call a home a "home"; they called it an atom. Here's more explanation...

Every home and its land was referred to as a Silicon atom, each with the exact same floor plan and members. Every household was made of the "mothers of the house" called Neutrons. Typically, there were around fourteen Neutrons, very rarely you would see a house with one more or one less. Every house had fourteen girls, referred to as Electrons, and fourteen boys called Protons. The Protons were a very positive group of boys, they remained in the house taking care of household tasks, along with the Neutrons. Together the Protons and Neutrons made up the center of the atom, often referred to as the Nucleus. The Electrons were a different story. Despite being much smaller, they were equally as strong a force as the Protons, but had negative attitudes specifically with each other. Despite their negativity, they were vital to the structure of the atom, so instead Electrons took care of the outside of the house. They would work quickly making sure to stay out of each other's way. In fact, they worked so quickly that it was difficult to see them independently; they just looked like a cloud of Electrons. It was tough work, but each Electron had a strong loyalty to the Protons, and together with the Neutrons, they maintained the stability of the home – or as we now know, the atom.

Not every Electron was exactly the same; some electrons had greater energy than others and were able to travel farther from the house than the others. The most loyal of the electrons remained closest to the nucleus and often questioned the loyalty of those who wandered farther away. Now it's time to introduce Ella the Electron. Four of the electrons had the highest energy of them all - and Ella was one of them. They frequently roamed on the outskirts of the property line, called the Valence line. The electrons that dared to reach the valence line were, of course, referred to as the Valence Electrons. Ella the Electron had a secret desire to explore the other lands she suspected were beyond Silicon Villa, but she could never quite muster up enough energy to leave.

PART 2

One day, Ella the Electron was working around the house as normal and she noticed a bright white light in the distance just as she made it to the valence line. She noticed this white light was made of individual packages of varying colors and sizes. As she continued to work with the light shining down, she started to notice more and more of these packages. But they never quite came close enough for her to understand what they were. Ella overheard one of the other valence electrons mentioning seeing these packages as well; at least she knew she wasn't just seeing things. One day, one of the green packages got closer and closer, close enough that Ella the Electron was able to see that it was in fact a package and that on it was printed the word "PHOTON". But still, the object remained out of reach.

The next day, Ella the Electron saw in the distance, coming towards the valence line, one of the blue packages. It was getting closer and closer, close enough to grab. She could have kicked herself for not being in the right spot at the right time! Right in that instant, one of the other valence electrons snatched the package. Ella the Electron witnessed her sister receive a great burst of energy and sprint beyond the valence line, vanishing in the distance. As she continued to work, Ella the Electron's mind spun with the possibilities of what could have happened to the other electron. She wondered if her sister would ever return to the atom. The loss of a negative attitude left a positive atmosphere throughout the atom, so no one searched, no one inquired. But Ella the Electron was still curious.

Things continued to get even more bizarre. As Ella the Electron continued to work, she noticed something approaching the valence line in the distance. At first, she thought it was another package, but quickly she realized it was a different electron returning to the atom. Ella the Electron watched as the electron approached with the same unusually high amount of energy the other electron that left had received from the photon, but as she approached, the electron seemed to be losing that energy. Once the electron reached the valence line, she returned to a normal level of energy and started picking up the work the other valence electron had left behind. Despite the addition of another negative attitude, the work needed to be done. So the atom returned its neutral state with the same number of electrons and protons. The number of questions swimming through Ella the Electron's mind was staggering, but electrons never stopped working and hated to be near each other. So the idea of approaching and asking those questions was, well...repulsive. So, Ella the Electron kept her questions to herself and became determined that she would have her own experience. At the next possible chance, she would not hesitate to grab one of those photons herself.

PART 3

Ella the Electron did not have to wait long. The next thing she knew, she was at the valence line, wrapping her hands around her own package. As soon as she got the package open, she felt a surge of energy she had never experienced before. She took off past the valence line, leaving the atom behind. Ella the Electron let the energy take her to places she had never been before. She even passed other valence electrons who had grabbed their own packages. She had to be careful though. As she passed other positive silicon atoms she felt a slight attraction to get back to work and fill in the empty spot they left behind. It

was difficult battling the natural urge to be with an atom. But the photon had given her the strength and energy to fight her nature.

To remove the temptation, Ella the Electron searched for a different way to get by the atoms. Unfortunately, there were so many electrons in this negative place that she kept bumping into others. It was nearly unbearable! The only saving grace was that the electrons all seemed to be moving along. Since she was in the situation, Ella the Electron took the opportunity to ask a fellow electron what was going on. The stranger she asked looked just as unhappy to be in the conversation, but complied and proceeded to answer her questions. As suspected, Ella the Electron's atom was not the only one that started seeing these colorful packages. The stranger had been on this journey multiple times since the packages first started appearing, when the bright white light shown on the land.

As Ella the Electron guessed, the key to leaving the valence line was getting the right colored package, one with a photon with the right energy, at the right time. When Ella the Electron inquired why all the electrons were huddled together heading in the same direction, the stranger replied that the discomfort they had to endure through this portion of this journey would be worth what's on the other side. They were heading towards Phosphorous Farms, one of the lands that formed after a heavy rain. Any extra electron is doing what they can to get out and travel to the other side. The atoms in Phosphorous Farms were very similar to those in Silicon Villa, except they had one extra electron, proton, and most likely neutron for a total of fifteen each. This made for a hectic border where Phosphorous Farms and Silicon Villa met, with extra electrons everywhere. At least this explained the crowdedness and discomfort. With the extra electrons from the phosphorous atoms and the addition of electrons leaving their atoms thanks to the packages, the negativity was overwhelming and many electrons fought to get out. Ella the Electron had more questions, so she did her best to keep up with the stranger as they made their way through the farms.

A shiny road in the distance caught her attention as the stranger headed straight for it. The stranger urged Ella to be ready to pick up the pace because travel on the road speeds up drastically. Once there, Ella the Electron automatically fell in line swiftly picking up the pace to travel north, but not before sensing a great source of heat as she got in line. Not sure what to think, since it was gone as fast as it was there, Ella the Electron continued in line. Unfortunately, much to everyone's distaste, it was still crowded. But the electrons were not nearly as crowded as they had been in the farms, and at least they were moving quickly. As much as electrons hated being near each other, something about this road overcame that force. So they lined up closer than any one of them truly desired to be in order to continue on their journey.

The stranger picked up their conversation, calling the road they were on Silver Fingers, one of many that could lead them to a greater purpose. As soon as the stranger mentioned this greater purpose, it seemed the reason Ella the Electron had been moving forward with this group of electrons was explained. There was a task she was meant for, they were all meant for; to carry the energy they received from the photon to produce something great. She understood why the electrons would be willing to endure such a close, negative atmosphere. Another feeling of great heat distracted her, just like when she first got in line. Looking around, Ella noticed that an electron who had been behind her was gone, off the Silver Finger. The stranger saw her confusion and explained that, despite having the additional energy, some atoms lose patience and doubt. Feeling the pull of the comfort of returning

to a Silicon atom to continue the work they were used to doing. So, they go and recombine with another atom. The stranger explained that it is disappointing and pitiful, as they waste that energy. Ella the Electron wondered why they would come all this way just to return to their normal state without serving their true purpose. She hated inefficiency.

PART 4

At that time, the line turned and merged with other electrons onto a larger road. The excitement in the stranger's face was contagious; Ella the Electron asked what was going on. The stranger explained they just turned from the Silver Fingers to the Silver Busbars, so they must be getting closer. The task they were going to complete was so great and included so many electrons with energy that they required a larger road to transport them all. As they travelled, Ella the Electron grew more and more anxious to get to their destination to serve their purpose. But she was bumping into so many other electrons trying to move forward that she worried she would lose all her extra energy before she even got there. The stranger reappeared next to her and told her she would have to fight to get to the port. Before Ella the Electron had the chance to reply, she looked up and saw the sign for "Port of Electrode Out", giving her a new motivation.

As they got closer, Ella the Electron concentrated on her calling to serve her purpose and make sure the energy she obtained was used for something greater than herself. So, she repelled, collided, and fought her way closer and closer to the sign. Finally, she had made it to where the port oddly dropped off and the electrons funneled into a narrow dark corridor. They continued for a long way, what seemed like forever to Ella the Electron, being joined by other electrons along the way. Again, sensing her question, the stranger explained that their entire planet was just one of many modules that come together to serve the same greater purpose. All of the planets were made in the same way with the heavy rains and silicon atoms. Their combined task was initiated when the light shown and the packages, photons, started arriving.

They were continuing in dark silence when suddenly the stranger warned her that they were approaching the moment when they would serve their true purpose. Ella the Electron waited with anticipation as she got closer and saw the slightest hint of light ahead and where the corridor stopped, she couldn't wait to get closer. Electron after electron was drawn up and out of the corridor to somewhere she could not see. The stranger told her to get ready right as she herself was drawn up. Ella the Electron started to ascend, then quickly entered what felt like a roller coaster. Up and around, loops and spins, Ella the Electron was transported through in what probably was less than a millisecond, but felt like an eternity. In that split millisecond, as if time slowed down, she saw the most magnificent, brilliant light she had ever seen. It reminded her of the light she witnessed when the packages started to arrive. Ella knew somehow it was all connected and she was serving her purpose. Abruptly, she landed into another corridor, not exactly sure what had happened. All she knew was that she felt drained of the extra energy she had received from the package. She continued down the corridor with the other electrons that had just gone through what she had. Fortunately, the stranger was nearby and explained that the light she witnessed was in fact that bright and magnificent because of the energy the electrons were giving as they went through that roller coaster ride. This explained why she felt back to her normal self. The

photons were a special gift from that light that everyone had seen back in Silicon Villa, each gift containing just the right amount of energy to meet the right electron at the right time. However, this energy was not for them to keep, but to give to provide energy for another light, a light for our world. This energy was not limited to providing light, but could also be used for cooling or heating homes, charging phones, and anything else that requires energy. The shortest moment of Ella the Electron's life turned out to be the most significant.

PART 5

Ella the Electron tried to process this information as she and the stranger continued to the end of their journey. But she realized she had no idea what was next. The stranger explained that her journey did not have to end. She could continue to serve her purpose, but she would have to make it back to Silicon Villa to start again. Before she could ask how she would get back home, the corridor opened up and the electrons exited a different port, Port of Electrode In. Ella the Electron asked how in the world she would do that if she had no idea where she was and in what relation to Silicon Villa. With a dramatic roll of the eyes, the stranger stated they were in Aluminum Alley. All she had to do was head north - but that would be the easy part. The hard part would be resisting the urge to stay. Ella the Electron couldn't imagine not wanting to go through that empowering experience again. She was already missing that extra energy after having returned to her normal self. At the same time, she did feel a sense of comfort from Aluminum Alley that tempted her to find an atom and get to work. Maybe she would stay a while... As if sensing her turmoil, or at least now beginning to anticipate and predict her many questions, the stranger turned to explain. The stranger warned her not to lose sight of her purpose. The attraction of Aluminum Alley helps a lot of electrons return from the light, but it is not the end goal. It's an alley for crying out loud, meant to be a passageway, not a home. The Aluminum houses have great appeal in that, unlike Phosphorous Farms, each atom has one less electron, proton, and usually neutron for a total of thirteen each. Since there are fewer electrons and a lot of positivity, weak-willed electrons would get distracted and remain. To the stranger, it was just another way for them to recombine to an atom and waste their potential.

Ella the Electron knew she had to resist that weakness and again fight her way back to Silicon Villa. But before she could make a move, the light, the source of the packages, disappeared. Chaos ensued as electrons returned to their normal energy, trying to find a home, any home to go to. Ella the Electron felt a push. She turned to see the stranger who urged her to find a home as well. She did as told, landing at an atom and getting to work immediately. Although Ella the Electron was okay where she was and could be content, she had a feeling it wasn't over. For some reason, she knew the light would be back, packages would start coming in again and she would have an opportunity to continue to serve the greater purpose... It was just a matter of when the white light would return.

Ella the Electron Worksheet

Directions:

Read through the story or your group's portion of the story. Draw an illustration of what's happening, like a picture or comic book.

Use the Solar Vocabulary handout with definitions to fill in the chart below connecting Ella's journey to the structure and function of a silicon solar cell.

	Ella's Journey	Silicon solar cell
ABSORPTION		
TEXTURING		
SUNLIGHT		
ELECTRON		
RECOMBINATION		
PHOTON		
ENERGY		
ELECTRICITY		
BUSBARS		
FINGERS		
CONDUCTOR		
SEMI CONDUCTOR		
P-TYPE		
N-TYPE		
P-N JUNCTION		
WAFER		
DOPING		
EFFICIENCY		
HOLES		
CURRENT		
VOLTAGE		

Fill in the chart below, connecting Ella's journey to the structure and function of a silicon solar cell. Comparison may not be exact as long as they relate.

	Ella's Adventure	Silicon Solar Cell
Wafer structure		
Atomic structure		
How the electron receives energy		
Where the electron goes		
Electron powering a light bulb		
Electron returning		

