# Enacting a P-N Junction

**Subject:** valance energy levels, holes and free electrons, changes in electrical charge and movement of electrons (production of current)

**Grade levels:** Upper elementary and higher

**Lesson length:** 30 to 40 minutes

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Participants kinesthetically enact the motion of electrons and photons to form a p-n junction, mimicking the production of electrical energy in a silicon solar cell.

Participants should come to this lesson with the following prior knowledge:

- Understand that a photon is energy and creates motion.
- Identify and label the process of generating electricity using a solar cell.
- Recognize that not all photons are the same. Photons have different amounts of energy. High-energy photons are blue; low energy photons are red.

## Objectives

➢ *Participants will understand how current is generated in a silicon solar cell.*

## Materials

- Colored plastic balls

- Colored tape (blue, red, yellow, gray/black)
- Signs with the following labels: electron, n-type silicon, p-type silicon, hole, current, PN junction

## Set up

Make an outline representing a side view of a solar cell as shown here (approximately 10 ft by 10 ft). Include a p-type layer, n-type layer, bus bars and fingers, back contact and circuit attached to an electrical device. The area or tape where the p and n silicon layers meet represents the PN junction, electromagnetic field, and band gap.

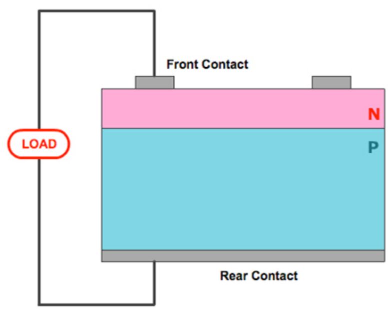

## Instructions

Review the process of electrons filling holes in the p-n junction. You might want to visit pveducation.org to review how current is generated in a solar cell. A good animation that explains this process can be found at

http://bit.ly/2o5uELC

Participants can complete definitions for relevant vocabulary words. Definitions could be completed in Flashcard Stash. Participants could be asked to add supporting visuals for each term if possible. Verify definitions found in flashcard stash as accurate based on our content, with the definition in

http://thesciencedictionary.org/




Word Bank

photovoltaic current circuit voltage electricity photon conductor

insulator semiconductor free carrier electrons hole absorption

electromagnetic field visible light spectrum

Students move through the cell as electrons. Each colored plastic ball represents that color of light, wavelength and energy. For the simulation, red will represent low energy or long wavelength radiation (i.e., near infrared to infrared radiation). Red balls will not excite the electrons enough to generate and conduct current. Student (electrons) who are tossed a red ball will not be able to move through the circuit. The teacher or designated students will toss one ball (photon) red or blue to each student (electron). The student (electron) will need to decide if they can move through the cell based on the photon they caught. In order to move thru the cell students will need to have a blue ball. (These high energy photons help create the electrons and holes, and the resulting electric field helps them move across the pn junction.) The electron will move up to, through the p-type layer, and through the circuit to the load and back to the n-type layer. Assign no more than 12 students as electrons and two students to toss photons at the electrons. Each electron should be tossed one photon one at a time. Observe each electron and hole as they move through the solar cell. After the first round, ask students observing to identify correct or incorrect electron movement.

Ask students to answer some of the following questions before continuing on to the final round and clarify any misinformation.

- Electrons have what type of charge?
- What overall charge does the region we call the hole have?
- What do the different colored balls represent?
- Why are electrons who are thrown a red ball not able to move and generate current?
- What causes the electron to separate from the hole and travel through the circuit?

Repeat the simulation but choose different students to be the electrons and photon throwers. As the instructor, you may want to recognize students who move through the cell model correctly. Assign all the observers to a team and ask them to identify and explain errors in the movement of electrons.

## Assessment

Students could answer questions below to check for understanding.

1) How is the p type silicon different from the n type silicon?
2) What causes the electron to move from the n-type layer to the p-type layer of the solar cell?
3) What is the relationship between electrons and holes?
4) What would cause current/voltage to vary in a solar cell or panel?
5) What factor(s) would affect the amount of electrical current produced by a solar cell or panel?

## Deepen Your Knowledge

Jigsaw activity: Assign groups one question to reflect upon by using the Kagan structure, Jot Thoughts. Independently, students will generate as many responses as possible by writing one response to the assigned question on a sticky note. (One response per sticky note). As a group they will pick out 2-4 essential responses to share with the class. Each group will choose a representative to share responses.

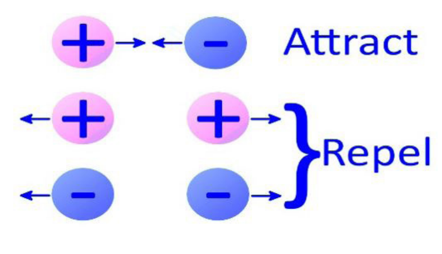
- What would happen to a PV cell if sunlight did not shine on it? Why?
- We know the light bulb won't turn on until the Sun light is shining outside. Why?
- What is the importance of creating a circuit when using a PV cell?
- Why is it important to learn about the process of making a PV cell? How does this process connect to the big picture of solar energy?
- How does creating a model of a PV Cell & acting out the process of how a PV cell works help you enhance your understanding of solar energy?
- How do we use energy in our daily lives? How can you replace those sources of energy with solar energy?

Participants could fill out a chart identifying things they found out, interesting observations, and questions they still have.

Alternative Version

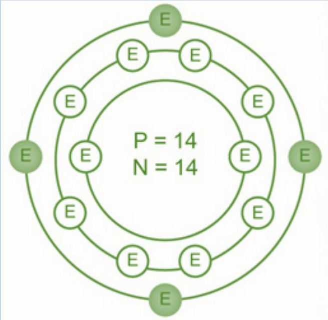
1) One student will stand at the right side of the box with 2 rectangular strips of aluminum foil (represents the metal wires/alligator clips) and a flashlight (represents the light bulb).
2) One student will stand outside to the upper left hand corner of the box with a sun (yellow construction paper of a Sun). Have a few or more students behind the Sun to act as photons.
3) Divide students into 3 equal groups – one group will stand in the N-Junction (extra electrons), another group will stand in the P-Junction (extra holes), and one group will stand behind the Sun (photons). Students should carry signs that represent their group.
4) The "Sun" students will shine light by holding up the paper sun. A "photon" student will walk over to tag the first student in the top section (N-junction/extra electron).
5) The "electron" students will link arms (across the horizontal line in the middle splitting the 2 sections) with a student labeled "hole". They will stay linked for one second then separate.
6) Once separated, the "electron" students will travel to the top & along the outside 'metal wire' line (conductors such as wire) and the "hole" students will travel down to the bottom of the P-Junction (bottom section).
7) Both "electron" students and "hole" students will link arms again (stay linked) showing the recombination of the hole and electron. They signal the flashlight holder to turn on the light which shows a complete circuit.
8) Continue this chain of movement until all students have been linked up and the energy (photons) has hit the last pair of students. Make sure that when each pair links back up again, they signal the flashlight holder to turn on the light, showing a complete circuit.
9) Students can continue this process until all the photons leave the Sun. Explain that, unlike this demonstration, the Sun never runs out of photons.

You can see a video of the game in action on the QESST Education website.




Atoms and their electrons are responsible for generating electricity. Atoms are made of three main subatomic particles. Protons and neutrons are located in the center of the atom called the nucleus. Protons have a positive charge and neutrons are neutral, they have no electrical charge. Electrons are located in the electron cloud and have a negative charge. Positively charged protons are attracted to negatively charged electrons. Opposite charges attract while same charges repel or push each other away. Atoms with an electric charge are called ions.

The electrons in the outer orbit of the atom are called valence electrons. When enough outside energy or force is present, a valence electron can escape the atom and become free. Free electrons can carry a charge and are responsible for the flow of electric current.




Elements with high conductivity can have a larger number of free electrons and are called conductors. Metals like copper, silver, and gold are usually the top choices for good conductors. An element's conductivity measures how tightly bound a valence electron is to an atom. Elements with low conductivity are called insulators. Insulators prevent the flow of electrons or electricity. Popular insulators include glass, plastic rubber, and air. A semiconductor is an element that can conduct electricity under some conditions but not others. Silicon is the most abundant semiconductor. Silicon can be altered by adding other elements (doping) allowing the flow of electrons to be controlled.

Electric fields provide the energy or force needed to generate a current flow. Within a photovoltaic cell, two semiconductor material layers are placed in contact with one another. One layer is an "n-type" semiconductor with an abundance of electrons, which have a negative electrical charge. The other layer is a "p-type" semiconductor with an abundance of "holes," which have a positive electrical charge.

Layering n-type silicon with excess electrons and p-type silicon with excess holes forms a pn junction that creates an electric field. When n- and p-type silicon come into contact, free electrons move from the n-type side to the p-type side. At the same time, the positively charged holes move in the opposite direction, from the p-type side to the n-type side. This results in the formation of the pn junction. This sets up an electric field around the junction. If there is no light being shone upon the device, then current due to electrons and holes cancel each other out and there is zero total current. When light is shone upon the device, the holes on the n side will actually try to go towards the p side.

When the PV cell is placed in the sun, photons (light energy) strike the electrons in the p-n junction and give them energy (kinetic), knocking electrons free of their atoms. Not all photons have the same level of energy; blue photons have the most energy while red have the least. Because some photons have more energy than others, not every photon is able to knock electrons free of their atoms to produce electrical current.

A simple circuit consists of a source of electricity, a path or conductor on which electricity flows (fingers and bus bars) and a device that requires electricity to operate. The flow of electricity is from the positive (+) surface of the cell through the bulb (lighting it up), and back to the negative (-) surface, in a continual flow.