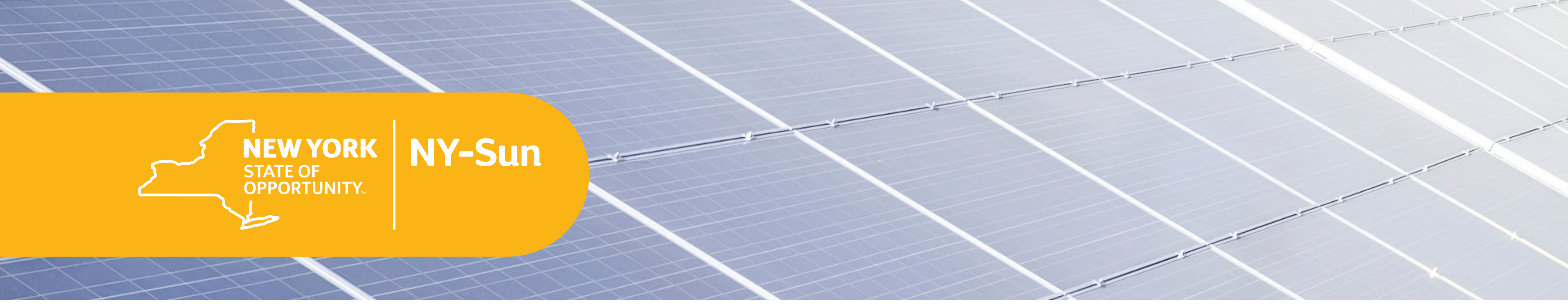


How Photocells Work

Suggested Level: Middle school/high school

LEARNING OUTCOME

Following participation in a game, students are able to relate how electrons are energized in a photovoltaic cell and pass through a circuit to provide energy that runs an appliance.

LESSON OVERVIEW

In the context of a game format, students learn how photovoltaic cells work. Students are exposed to the p-n junction between two types of semiconductors and learn how it relates to the production of electricity in a photovoltaic cell.

MATERIALS

- Student handout
- Dice (three per group)
- Electron tokens (four per player—small squares of colored poster board are appropriate)
- Energy tokens (one for each electron token— pennies would suffice)

SAFETY

There are no particular safety precautions for this lesson.

TEACHING THE LESSON

Begin by explaining the structure and operation of photovoltaic cells, covering the information in the student handout and drawing from the background information below. Then have students—in groups of two to four—play the game.

ACCEPTABLE STUDENT RESPONSES

Because this is a game that follows a prescribed set of "rules," students are expected to follow them.

BACKGROUND INFORMATION

Photovoltaic cells are named for what they do: convert light ("photo") to electricity ("voltaic"). They are made from the same materials as the well-known transistors of solid-state electronics—the class of substances called semiconductors. A semiconductor is so named because it conducts an electric current slightly when connected to a battery but not nearly as well as a metal. A metal is a good conductor of electricity because a few electrons in its atoms are free to move and produce an electric current when a battery is connected. The corresponding electrons in the atoms of a semiconductor are not free to move unless they first acquire a certain amount of energy. They can acquire this energy from light shining on the semiconductor in a photocell.

The semiconductors in a photocell are "doped" by replacing some of the atoms with others with a different number of electrons. If these substituted atoms have more electrons, the extra electrons increase the negative charge among the electrons, and the result is called an n- type semiconductor. It is important for comprehension to note that n-doping does not result in a negatively charged semiconductor because all atoms—the semiconductor atoms and the doping atoms—are electrically neutral. However, the doping atoms have one more electron in their outer layer that cannot form bonds with the other semiconductor atoms, and this creates a structural imbalance. Structural balance could be regained by removing the extra electrons. If the substituted atoms have fewer electrons, there is a decrease in the negative electron charge (equivalent to an increase in positive charge), and the result is called a p-type semiconductor.

The “deficiency” of electrons in a p-type semiconductor is described in terms of electron “holes.” The same is true for the p-type semiconductor as for the n-type semiconductor. The p- type semiconductor is not positively charged by itself, because all its atoms are neutral. However, because the doping atoms have one less electron in their outer layer, some of the bonds in the semiconductor lattice are missing, resulting in a structural imbalance. Structural balance could be reestablished if extra electrons were made available, filling the “holes.”

Photovoltaic cells are made from a piece of n-type semiconductor joined to a piece of p-type semiconductor. The region where the two types of semiconductor are joined is called a p-n junction. Because of the above-mentioned structural imbalance, some of the surplus electrons in the n-type semiconductor—near the boundary—naturally migrate to the p-type semiconductor, cross into it, and line up along the junction. The atoms that accept these electrons now have more electrons than protons and so have a net negative charge. This buildup of negative charge also keeps further electrons from the n-type semiconductor from moving into the p-type semiconductor. The electrons that migrated from n-type to p-type semiconductor naturally result in a positively charged region on the n-side of the junction.

p-type -

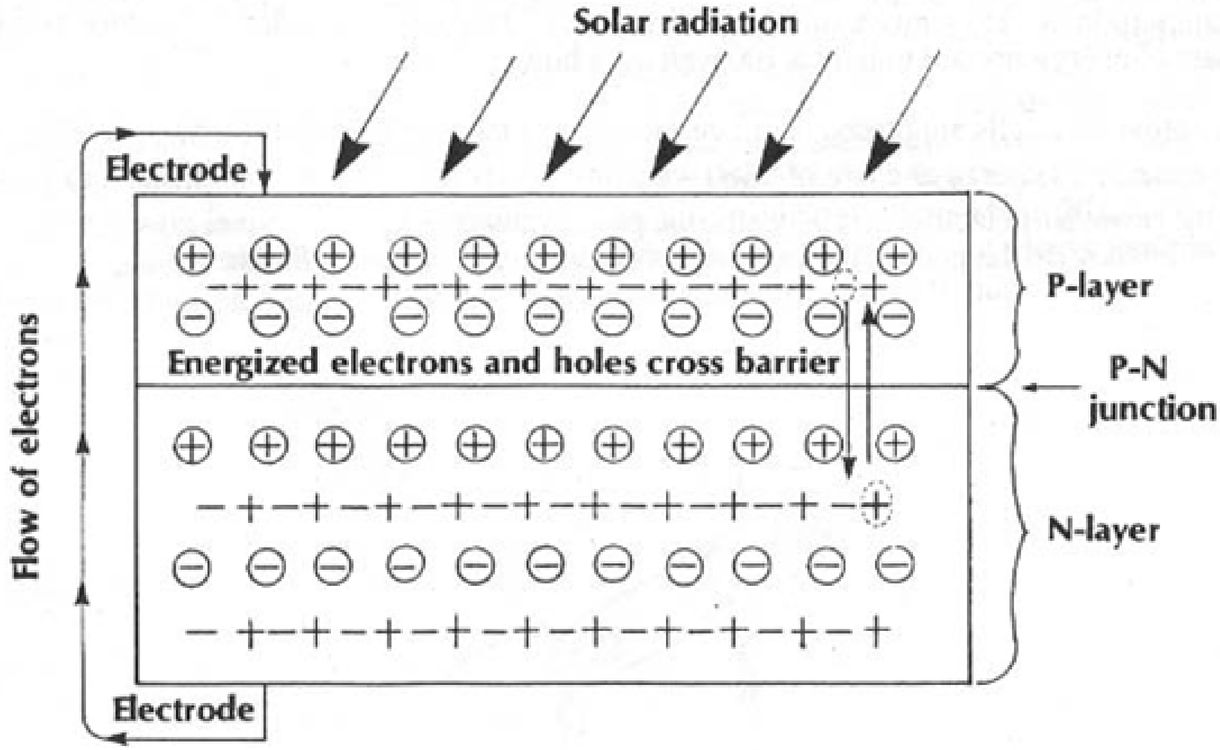
n-type +

This electrical discontinuity forced by the structural n-p discontinuity is often referred to as a potential barrier.

Now, let the sun shine on the photovoltaic cell. In reacting with the photocell, the sunlight behaves as if it were made of bundles of energy called photons, so that the greater the frequency of the light, the greater the energy of its photons. If the photon energy is great enough, it can energize an electron and release it from its covalent bond. This produces an electron that is free to move and leaves behind a hole in the covalent bond that can accept another electron. If this freed electron is in the p-n junction region, it will be pulled across the junction into the n-type semiconductor by the small voltage at the junction. A freed electron in the p-type semiconductor will then fill the hole in the p-n junction that it left behind. This electron will leave its own hole, which will be filled by another freed electron from deeper in the p-type material.

In this way, electrons from the p-type material move across the p-n junction into the n-type material. This leaves behind an increased number of holes in the p-type material. This causes the solar cell to develop a negative charge in the n-type material and a positive charge in the p-type material—just like in a charged battery. To enable electrons on the p-side of the p-n junction to cross the junction into the n-type semiconductor, they become free to move and produce an electric current. If the sunlit photocell is connected to an electric circuit, the electrons will flow from the n-type semiconductor through the circuit back to the p-type semiconductor of the photocell, just as they would in flowing from the negative terminal of a battery to the positive terminal. And the energy they have gained from the sunlight is just like the energy that electrons get from a battery.

Cross Section Diagram of a Photovoltaic Cell



(STUDENT HANDOUT FOLLOWS)

Name Date

How Photocells Work

A photovoltaic cell converts light into electricity. It is made of two types of material called a semiconductor. It is called a **semiconductor** because, when it is connected to a battery, it conducts just a little electric current, far less than a metal would.

The two types of semiconductor are called “n” and “p.” The *n*-type semiconductor is so named because some of its atoms have extra electrons, which have a negative charge. The opposite is true for a *p*-type semiconductor: some of its atoms have fewer electrons (and the opposite of negative is positive).

The production of electricity in a photovoltaic cell begins where the two types of semiconductor are joined together. It is called the ***p-n junction***. Some of the extra electrons in the *n*-type semiconductor are attracted to the *p*-side of this junction. When the right type of light hits the photovoltaic cell, electrons on the p-side of the *p-n* junction gain energy that allows them to move across the junction into the *n*-type semiconductor. This is like the chemical reactions that provide energy to electrons in a battery. In both cases the electrons that have gained energy can pass through an electric circuit and thus produce an electric current. When these electrons pass through the circuit, they give the energy they have gained to a light bulb or other electric appliance.

DEVELOP YOUR UNDERSTANDING

To follow how electrons get energized in a photovoltaic cell and pass through a circuit to provide energy to light a light bulb, play the following game for two to four players according to these rules:

1. Each player begins with four electron tokens at the *p-n* junction in the photovoltaic cell. (These can be cutout squares of colored poster paper with a different color for the tokens of each player.)
2. Each player takes a turn, in a predetermined order, by throwing three dice.
3. The number on each die enables a player to do the following:

   a) Each “6” allows a player to move an electron token from the *p-n* junction to one of the spaces on the *n*-side of the photovoltaic cell. When this happens, an energy token is placed atop the electron token.

   b) Each number on a die allows a player to move an electron token that number of spaces from the *n*-side of the photovoltaic cell into the wire or along the wire, subject to the following restrictions:

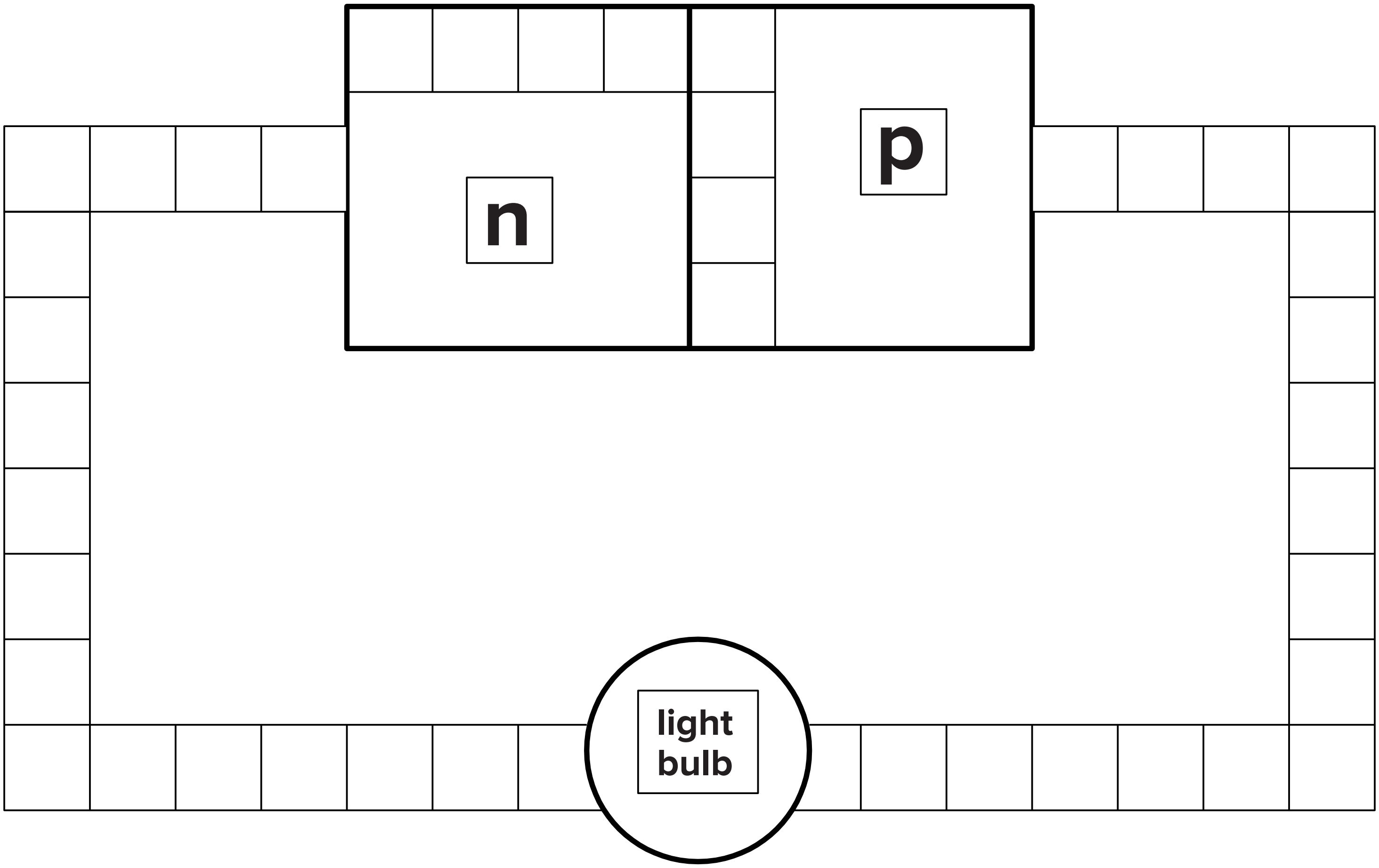
      (1) In order for an electron to energize the light bulb, the number on a die must exactly match the number of spaces to land exactly on the light bulb space. When this happens, the energy token is removed from the electron token and placed in the player’s energy container.

      (2) An electron token can move into the *p*-side of the photovoltaic cell only if the number on a die exactly matches the number of spaces to the *p*-side space. Electron tokens returning to the p-side space are placed in one of the spaces at the *p-n* junction to await reenergizing by throwing a “6.”

      (3) Except for spaces along the *p-n* junction at the beginning of the game and the light bulb, only one electron token may occupy a space.

      (4) If a token may not be moved the number of spaces shown on a die, the movement allowed by that die is forfeited.

4. The game can end at any time. When the end of the game is called, the winner is the player with the largest number of energy tokens in her/his energy container.


n
p
light
bulb