Solar from Scratch Battery

Overview:

Solar cells are able to convert energy from the sun into usable electricity. Individual solar cells rarely produce enough voltage and current to be of use on their own, however, and must be wired together with other cells. The goal of the activity is to allow students to arrange the solar cells in a circuit that can produce enough power to charge their phones. Students will use the measured voltage and current to calculate the power of their proposed designs. Students should be familiar with the basics of circuitry, such as the difference between parallel and series, and Ohm's law. This activity would be great paired with an electronic circuits unit.

Essential Questions:

How do solar panels create clean electricity?
How are solar cells wired together to produce electricity in useful amounts?

Background:

Energy:

Energy can be defined as the ability to do work. The different forms of energy include heat, light, motion, chemical, gravitational, and electrical. We are able to change the form of energy to make it usable and accessible to us. **Clean energy** is energy that doesn't produce pollution into the atmosphere. Some sources of clean energy include the sun, wind, waves, and biomass. In this experiment, we will learn about one of these sources of clean energy, solar energy.

Photovoltaics and Solar Cells:

How do solar panels or **photovoltaics** actually convert sunlight into electricity? The term **photovoltaic** can be split up into two parts: photo meaning light and voltaic meaning electricity. Solar cells convert light energy into electricity through the use of photovoltaic materials called **semiconductors**. A **solar cell** consists of two different layers of semiconductor material, one that contains an excess of electrons and one that has an absence of electrons. The side with extra electrons floating around, called an **N-type semiconductor**, has a negative charge. The other side is missing electrons and thus has what are termed **holes** is called a **P-type semiconductor**. Between the two faces of each layer, the charge difference produces an electric field that forces electrons to travel from one side to the other externally through wires that are used to complete the circuit. When a **photon** with the right energy hits the semiconductor it will cause an electron to excite from the n-type side, creating a hole. That electron wants to go back and reconnect with the hole to get rid of it, but to do that, it has to travel through an external path provided. As it's traveling, we can use it as electricity. During this process, there are no harmful byproducts such as carbon dioxide produced. Multiple solar cells joined together form a **solar panel**.

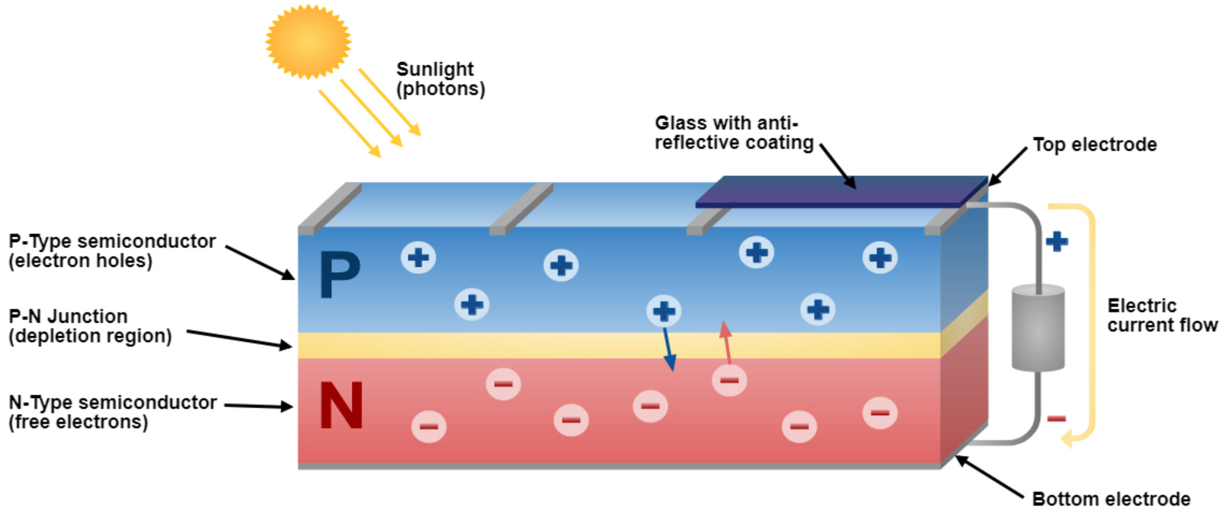

Figure 1. A basic photovoltaic cell construction, from [Apricus](#).

Circuitry with Solar Panels 101:

In a circuit, a solar cell can be thought of as similar to a battery. Each solar cell has a positive and a negative end. When multiple cells are arranged appropriately, the voltage and current can be increased to the desired outputs. A circuit arranged in **parallel** has the components connected across each other, forming two sets of electrically common points. A circuit arranged in **series** is connected from end-to-end, forming a single path for current flow.

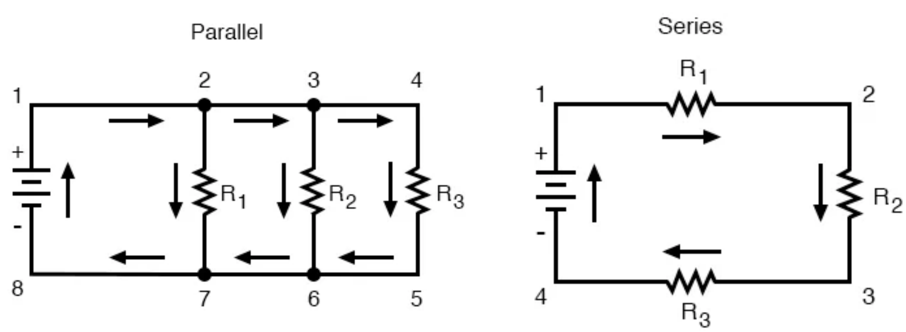

Figure 2. Schematic of circuits in parallel and series, from [All About Circuits](#).

We need to be able to calculate our expected **voltage** and **current** with our different arrangements, as well as the final **power** we will be able to output. The relationships between voltage (V), current (I), and power (P) can be described through Ohm's law. Ohm's law can be rewritten in many different ways, but the form most convenient for our application is:

$$P = IV$$

where voltage is in volts, current in amps, and power in watts.

The values used in this equation are the combined values of each component of the circuit. Before inputting the voltage into Ohm's law, the total calculated value of the voltage from the different solar cells must be accounted for first. The same should be done for the current. For cells in parallel, the voltage across each component is constant and the current is added across each component as:

$$V_{total} = V_1 = V_2 = V_3 = V_4$$

$$I_{total} = I_1 + I_2 + I_3 + I_4$$

For cells in series, the voltage is added across each component and the current is constant across each component - the opposite of the parallel circuit:

$$V_{total} = V_1 + V_2 + V_3 + V_4$$

$$I_{total} = I_1 = I_2 = I_3 = I_4$$

In this lab, the students will learn how to arrange the solar cells in various combinations of parallel and series circuits to obtain the ideal current and voltage for the target power output.

Research Connection:

Researchers have been working for years and continue working to improve the efficiency of solar cells so that smaller cells can produce more power (Figure 3). A material class called perovskites have been developed in the past few decades that show a lot of promise for quick efficiency improvement. Better efficiency means that solar panels will be more affordable, as less material is required to give the same output. As solar panels get cheaper, more people and businesses will be able to integrate solar energy into their houses and businesses. Other researchers focus on making solar panels lighter, stronger, and less likely to break. One approach to this is making solar cells out of organic polymers based on carbon atoms, similar to plastic bags or bottles. These cells can bend and twist without breaking, unlike traditional silicon cells or even perovskites which are still brittle.

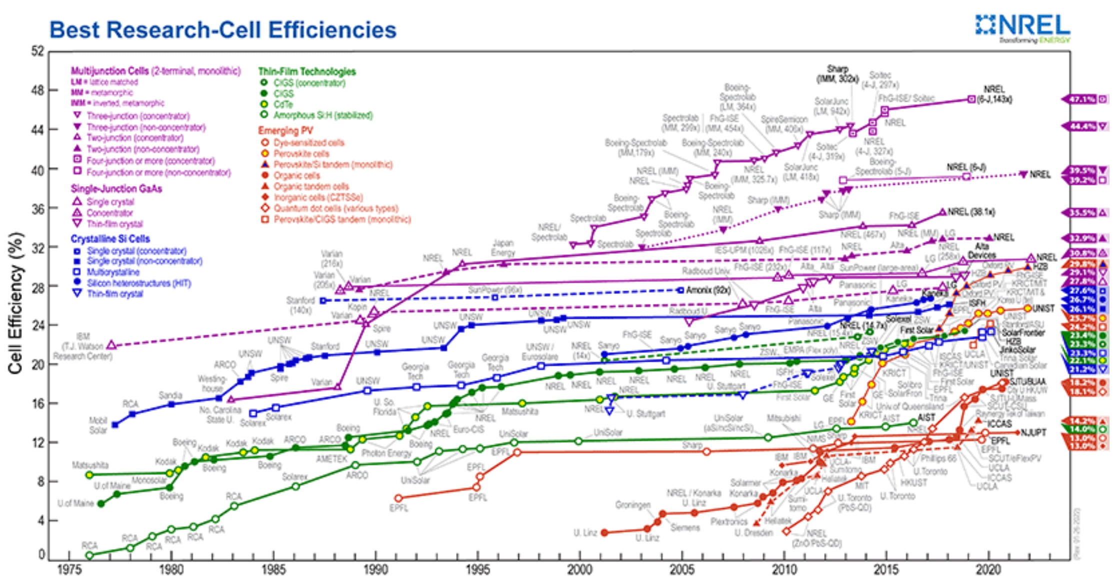

Figure 3: This fancy graph from the National Renewable Energy Laboratory has a lot of information in it, but the important thing to note is that efficiency is trending upward with time.

NGSS Standards:

Standard Number	Standard text
HS-PS3-3	Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
4-PS3-2	Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.
4-PS3-4	Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

Safety:

Heat guns can easily cause burns on the skin so caution must be used and any materials that can easily burn should be kept far from the front of the gun. While none of the materials are hazardous, students should still wear gloves to keep oil or other contaminants from their fingers off of their work. There is a poke risk from working with wires. Finally electricity can be dangerous, and though the cells recommended don't produce enough current or voltage to cause injuries when assembled as recommended, it is possible to get high enough voltage to get shocked if many cells are wired together in certain ways. Have students cover any exposed electrical wires at the end and remind them that, when in doubt, don't touch wires when the cells are in bright light.

Materials / Preparation:

- 3V, 600 mA solar panel x4
- Buck converter 5V output x1
- Wire (red for positive, black for negative)
- Butt connectors
- Shrink wrap and electrical tape to cover exposed electronics
- Fabric bag for case
- Glue (preferably a good epoxy)
- Multimeter for testing
- Heat gun for shrinking shrink wrap

Introduction:

1) Have the students read the introductory material and discuss together how solar cells convert sunlight to electricity (See student worksheet step #1)
2) To review parallel and series circuits, have students calculate the voltage and current of cells in parallel and series and discuss the results as a group (See student worksheet step #2)
3) Have the students brainstorm a more complicated system and potential methods to wire it. Share ideas and discuss any variations. See how many different ways of wiring that produce the desired outputs the class can come up with (See student worksheet step #3)
4) Tell students that today they will be building a portable solar panel charger from individual solar cells.

Main Activity:

1) Show the students the materials they will be using to build the solar panel charger (e.g., solar cells, buck converter, etc.) and explain the electrical pieces (i.e. the buck converter sets the voltage and current to a level their small electronics can use, the butt connectors are to connect wires together)
2) Hand out materials to students and give them time to examine and explore them.
3) Once students have had time to explore the materials, tell them that their next challenge is to use these materials to construct a portable solar charger with an output of the solar cells of 6V and about 1.2A. Encourage them to use their answers to student worksheet step #3, the equations, and their explorations to build. (See student worksheet step #4) The standard procedure for making the solar panel charger is as follows (there is also a powerpoint with images to help the students work through assembling the circuit):
    a. Lay out four solar cells face (bluish-black and curved side) down. Locate the positive (+) and negative (-) connections on each cell.
    b. Take two cells and connect a wire from the negative of one cell to the positive of the other using copper tape to hold the wire to the connections.
    c. Repeat with the other two cells.
    d. Now tape a wire to the positive or negative connection on each cell that does not have a wire attached to it using black for a negative connection and red for a positive connection (i.e. if you connected the positive of one cell, tape a wire to the negative connection point).
    e. Clip both of the negative wires in one alligator clip and attach the other end to a multimeter. Repeat for the positive wires and test what voltage and current the cell array produces in bright light. If no voltage is registering, check the connections. If you aren't getting >5V of voltage, check that the array is wired like the pictures above. If you aren't getting around 1A of current, make sure your lights are very bright or that you are out in the bright sun. Make sure that your voltage and current are what you want before attaching to the buck converter.
    f. Using a butt connector, put the two negative wires from the solar cells in one end and the negative wire from the buck converter on the other side. Crimp so the wires stay in place then use the heat gun to shrink the plastic and isolate the circuit.
    g. Repeat step e with the positive wires from the solar cells and the positive wire from the buck converter. If the converter is getting power, the LED on it will light up!
    h. Slide a heat shrink shield over the buck converter to make sure there are no exposed wires and shrink it with the heat gun.
    i. Test it! Try plugging in a small electronic device and putting the cells in bright light. Is it charging?

4) Before connecting the solar cell arrays to the buck converters, have students check their voltage and current by connecting alligator clips to their circuit and note the values whenever they try a new configuration (see step e of the standard procedure). Also have them measure the voltage and current in bright sunlight vs the ambient lighting of the classroom. Discuss why there may be a difference. (See student worksheet step #5)

5) Talk about the design and construction troubles as a group. Discuss what troubleshooting was successful and what didn't work so well. Brainstorm why some things worked and others didn't. Share any creative solutions to problems that arose (See student worksheet step #6)
6) Once students have a configuration that is capable of charging a small electronic device, have them design and assemble a way to package and transport the array securely (See student worksheet step #7). Reusable tote bags will be provided, but many other materials will work just as well. This is a place for students' creativity to really shine!
7) For an extended discussion solar panels and scaling up to powering buildings, see student worksheet step #8 and #9.

Summary:

Use one or more of the following questions with students to help them debrief the activity and demonstrate what they have learned.

- What voltage and current did you achieve?
- What happens if you reverse the wires coming from the solar cells?
- How can you increase the power output of the cells?
- Is there a limit to the power the solar cells you have can achieve?

Extensions

To help students further explore these concepts, consider the following extensions.

1) Rather than using butt connectors and copper tape, students could experiment with soldering the solar cells together. This creates a more permanent, robust connection. Be sure to use lead free solder.
2) Have the students try using their chargers in a variety of situations. Do they work in full or partial shade? Do they charge as fast if the panels aren't directly facing the sun?

Resources and References

1. Clean Energy Institute. "Solar Panel Workshop". https://www.cei.washington.edu/lesson-plans/solar-panel-workshop/
2. National Renewable Energy Laboratory, "Best Research - Cell Efficiency Chart". https://www.nrel.gov/pv/cell-efficiency.html
3. Footprint Hero. "DIY Solar USB Charger". https://footprinthero.com/diy-solar-charger
4. U.S. Sunpower. "How Many Solar Panels Do You Need: Panel Size and Output Factors". https://us.sunpower.com/how-many-solar-panels-do-you-need-panel-size-and-output-factors#:~:text=Typical%20residential%20solar%20panel%20dimensions,61.3%20inches%20by%2041.2%20inches.