



Solar Battery Charging

AUTHOR: Luke Robbins, Seaside High School

DESCRIPTION: Students will become familiar with circuits, cells, batteries, and photovoltaic cells, then plan, build, test, modify, and re-test a small solar battery charger designed to maintain batteries from a particular device.

GRADE LEVEL(S): Basic: 7th-8th; Intermediate: 9th-12th

SUBJECT AREA(S): Physical Science, Physics, Earth Science, Integrated Science, Environmental Science, Chemistry, series circuit, parallel circuit, current, resistance, voltage, diodes, polarity

ACTIVITY LENGTH: 5-10 class periods

- Background content instruction: 2-3 hours
- Background skills: 1-3 hours
- Lab Activity: Setup 1-3 hours
- Follow up data collection and battery use: 20 min. x 2-4 sessions.

LEARNING GOAL(S):

Students will build series, parallel, and parallel series circuits from a schematic diagram. Students will master the basic concept of battery charging. Students will be able to plan and build solar battery chargers for a given battery system. Intermediate students will calculate time to charge a depleted battery to its full capacity given specifications of a solar module. Students will be able to explain how a solar cell works with diagrams and words. Students will use a digital multi-meter to measure voltage, current, resistance, and diode polarity.

NEXT GENERATION SCIENCE STANDARDS:

- MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

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- MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.
- 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
- HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*
- HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

COMMON CORE STATE STANDARDS:

- CCSS.ELA-LITERACY.RST.6-8.7. Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).
- CCSS.ELA-LITERACY.RST.9-10.7. Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.
- CCSS.ELA-LITERACY.RST.11-12.4. Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.

UNIT:

- Day 1: Electricity Notes and Inquiry
- Day 2: Circuit Schematics and Wiring – Series, Parallel, and Parallel-Series
- Day 3: Measuring Voltage, Resistance, and Current with a Digital Multimeter
- Day 4: How Photovoltaic Cells Work
- Day 5: Planning Solar Charging Systems
- Day 6: Plan and Set Up Solar Charging Systems
- Day 7: Test, Collaborate, and Revise Systems

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Student Background

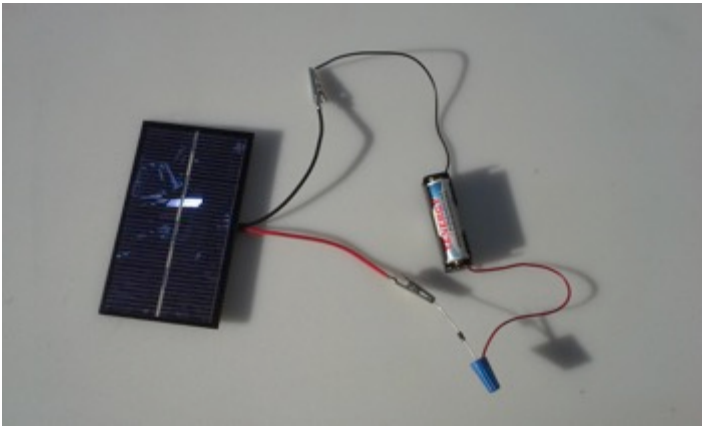
(Check for understanding and build as needed).

- Electricity is the flow of electrons.
- Electrons have a negative charge and may move from atom to atom.
- For electrons to flow there must be a complete circuit.
- Electrons will move away from a net negative charge and toward a net positive charge.
- Conductors can easily carry electrons, similar to water in a hose.

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- Insulators such as plastic coatings on wire have a high resistance to electron flow and may be analogous to the outer casing of a garden hose.
- Current, measured in amperes (Amps) is how fast electrons flow through a circuit.
- EMF (Electromotive Force) commonly referred to as Voltage is measured in volts, and is analogous to water pressure.
<https://www.youtube.com/watch?v=EJeAuQ7pkpc>
- Photovoltaic Cells (Solar Cells) transfer energy from the sun into electric current.
- Diodes permit electrons (and therefore current) to flow in only one direction.
<https://www.youtube.com/watch?v=AqzYsuTRVRc>
- Batteries may be charged by being hooked up to a higher voltage source with a diode, positive (+) to positive (+) and negative (-) to negative (-). The silver or gray line on the diode will need to face the + (red) of the battery pack.
- Given several solar modules a variety of voltages and currents may be made with different wiring configurations.



(A 2 volt 200mA solar module charges a AA battery).

Educator Background

In addition to the student background...

- (Ideally all the students will know this at the end of the lessons).
- Photovoltaic (PV) cells use the sun's electromagnetic waves in the light spectrum to make electrons flow in a circuit.
<https://www.youtube.com/watch?v=m4t7gTmBK3g>
- PV cells are made of two layers, a net positive layer and a net negative layer. In between is the P-N junction. When the two layers are connected with a conductor electrons may flow in the presence of light. Ideally one electron flows for each photon that strikes the surface of the cell. See link below.
<https://www.youtube.com/watch?v=x2zjdtxrisc>

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- PV cells can be made from certain elements known as semiconductors and their neighboring elements on the periodic table. . They are found on and near the staircase toward the right of the periodic table and include Silicon, Gallium, Boron, Phosphorus, Germanium, and Arsenic. Silicon and Germanium in Group 14 are both semiconductor materials in their pure forms because they have 4 valence electrons. Semiconductors are more conductive than insulators but less conductive than metals and, also unlike metals, their resistance decreases as they heat up.
- The two main layers of a photovoltaic cell are made by doping Silicon with Boron and Phosphorus. Respectively this results in “holes” or electron spaces on the P side, and “extra” electrons on the other, N, side of the junction.

<https://www.youtube.com/watch?v=SOuyZWqhINU>

Materials List (For a class of 30)

Below is a table of battery packs and the PV modules that could charge them. It shows the total battery bank charge, the voltage plus 0.5 Volts for the diode, then the recommended PV module(s). It is intended as a starting point for a teacher to assemble the materials. Fewer combinations makes a simpler, shorter duration activity. There are many combinations that will work. Diodes, finger-safe connectors and connecting wires are also recommended.

- (1-2) 250-Watt Halogen Work Lamps (for rainy dark, cloudy days)
- 20 diodes
- 100 connectors
- Wires (red and black)
- 50 LEDs
- 50 2-Volt mini incandescent bulbs cut from a string of Christmas lights
- Solar cell fragments at least 1 cm²
- 16 Digital multi-meters or one for every two students
- Extra fuses for the multi-meters (usually 5 x 20 mm 250mA)

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Suggested PV module/Battery pairings					
Student Pair	Battery	qty.	Total Voltage	PV module >	series modules suggested PV
1	AAA	1	1.2	1.7	4 @ 0.5
2	AAA	1	1.2	1.7	4 @ 0.5
3	AA	1	1.2	1.7	4 @ 0.5
4	AA	2	2.4	2.9	2 @ 1.5
5	C	2	2.4	2.9	2 @ 1.5
6	D	2	2.4	2.9	2 @ 1.5
7	AAA	2	2.4	2.9	2 @ 1.5
8	AAA	3	3.6	4.1	2 @ 2
9	AA	3	3.6	4.1	2 @ 2
10	AA	4	4.8	5.3	1 @ 6
11	C	2	2.4	2.9	2 @ 1.5
12	D	2	2.4	2.9	2 @ 1.5
13	AA	2	1.2	1.7	1 @ 2
14	AA	4	2.4	2.9	2 @ 1.5
15	9V	1	9	9.5	2 @ 5

Lesson Details

Planning and Prep

Teacher will need to prep by having the materials, planning groups, keeping things organized and set up. **Important note: Make sure that students remove batteries from battery packs after each day of use – short circuiting a battery and melting a battery pack is a very real potential hazard.**

Day 1 - Electricity Notes and Inquiry

Light a bulb with a battery or two and a wire

1) Warm Up: Create mixed groups of 4 students. Assign 2 scribes and 2 speakers. They will alternate participation. Students will use small white boards or paper and pencil to answer the questions, and then share responses with the class.

1. What is electricity?
2. What is an electron?
3. List examples of conductors.
4. List examples of insulators.

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2) Inquiry: Light some small holiday lights with one or two cells (battery to normal people).

Safety Try to avoid short circuits. If anything starts to heat up disconnect it immediately and try another configuration.

Alternately do this classic bulb, wire, and battery activity.

- Use a small 2 Volt incandescent bulb without a socket, one battery, and one wire.
- Pass out the materials and challenge the class to light the bulb as many ways as possible, drawing any setups that you try, whether they work or not. There will be four.
- See link for full lesson and illustrations.
<http://www.physicsclassroom.com/class/circuits/u9l2b.cfm>
- Make sure all students have a chance to see all of the 4 different ways to light the bulb.

3) Brainstorm “What are the requirements for the bulb to light?”

Answer: There must be a path for electrons to get from one side of the battery to the other via each contact of the bulb.

Additionally, you could challenge students to light two bulbs or give them two batteries, using more wire as well, to require series and/or parallel circuit construction and promote an initial discussion of the differences.

Day 2 - Circuit Schematics and Wiring

Simple Circuit Symbols, Diagrams and Circuit Wiring: Series, Parallel, and Parallel-Series

Learning Objective: Students will build series, parallel, and parallel series circuits from a schematic diagram.

1) Warm up: What are the requirements for an electric circuit?

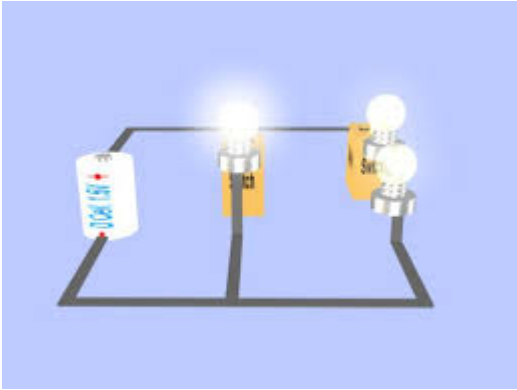
2) Draw Circuits: Show symbols for wire, bulb, battery, switch, resistor, LED, and diode.

- Draw a series circuit with a 2-cell battery, a switch, and 2 bulbs. Have students draw this circuit.
- Draw a series circuit with a 2-cell battery, a switch, and 1 LED. Have students draw this circuit.
- Students build the two circuits. Many will notice that the LEDs have to be put in the right way to work.

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- Draw a parallel-series circuit with a three cell battery, a master switch, a single bulb and two bulbs in parallel with one another. (Similar to diagram below but with 3 cells).

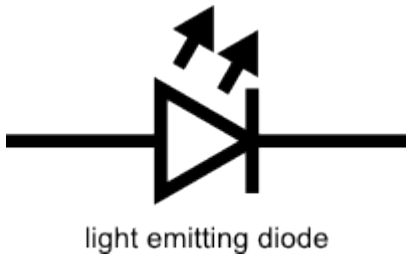
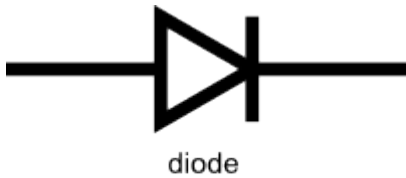


Screen shot from www.virlab.virginia.edu

3) Show Make Magazine clip on What is a Diode?

<https://www.youtube.com/watch?v=AqzYsuTRVRc>

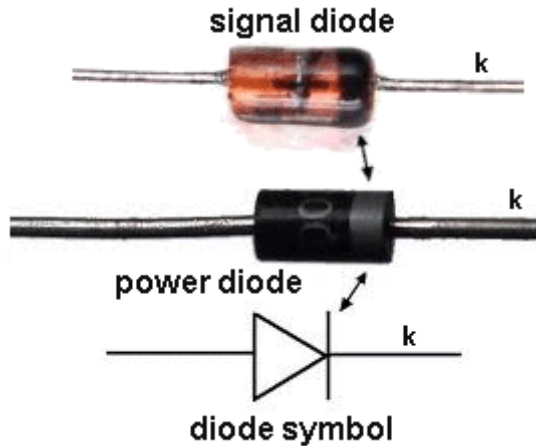
- Highlight the difference in the symbols of the Diode and the Light Emitting Diode.



- Ask: What do the two arrows symbolize? (Light being emitted)
- Ask: What is the significance of the direction of the “play” arrow in the diode symbol? (It shows the direction of electron flow).

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- How might a diode be useful in charging batteries? (It keeps the battery from discharging when there is no sun). It could be useful to review the structure and function of batteries here for your students.

Day 3 - Measuring Voltage, Resistance, and Current with a Digital Multimeter

Today the students will become familiar with the digital multimeter. They will build prescribed circuits from the day before, and then measure the voltage across all components such as batteries, bulbs, and wires. As they record values on the diagrams from yesterday they will search for patterns in the numbers.

They will also make their first parallel circuit and measure and record the voltage across components.

Make sure students set the meters to 20 DCV for voltage measurements that the 10 Amp socket is not used for voltage measurements.

Show how to move the meter dial gently, not quickly.

Have students preview the two following sites as homework:

- <http://eugbug.hubpages.com/hub/Using-a-Multimeter#> (has text, photos, and diagrams)
- https://www.youtube.com/watch?v=zb7WHaL_dz8 (9 minute tutorial)

You could show them in class too or begin with an easy assessment in which they take quick open circuit measurements from a battery to gauge understanding.

“We will not test the wall outlets today though.”

Ask: What are three big differences in your setup when testing the current?

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(The meter is in line with the circuit, the dial is set on the 10Amp setting, and the red test lead is moved over to the 10A socket).

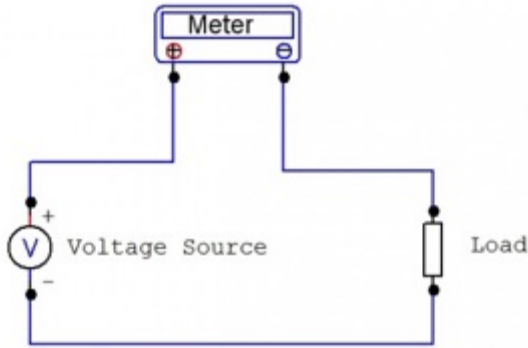


Figure 3-1 **Multimeter testing voltage**
(note PARALLEL setup)

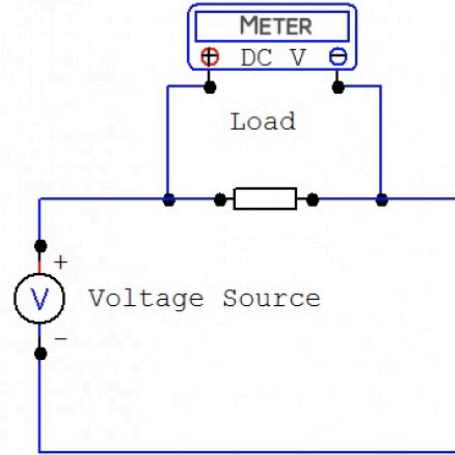


Figure 3-2 **Multimeter testing current**
(note SERIES setup)

Students will get a worksheet showing the circuits to build.

Circuit diagram work sheet will show:

- bulbs in series with one cell.
- bulbs in parallel with one cell.

There will be blank spaces to write voltage, current, and resistance next to each symbol. Measure voltage, current, and resistance at all required locations

The worksheet will ask students to make observations about the relationship between current and voltage as well as resistance. This leads nicely into a discussion of Ohm's law (Voltage = Current x Resistance or $V=IR$). Students should be able to observe that different loads have different resistances and that the amount of resistance in the circuit will dictate the amount of current. In series circuits, resistances add while in parallel circuits, resistance decreases as given below.

Resistance in series:

$$R_s = R_1 + R_2 + R_3$$

Resistance in parallel:

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

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Day 4 - How Photovoltaic Cells Work

1) Opener: Pass broken PV chips to all students, have them write and share observations.

2) Show and pass several different solar module types including Silicon solar cells, amorphous, flexible, big, and small. Pass DVMs and test voltage and current of chips as well as several different panels. ****It is hoped that students will recognize that each PV cell creates a potential difference of about 0.55V from bottom side to topside regardless of the size of the cell.

- Ask: When measuring on the chip what is needed to get a reading from the DMM? (Touch front and back with the red and black leads).
- Ask: Which side is the positive side? (bottom, gray/silver, or back side) How do you know? (Negative numbers if voltmeter leads are switched).

3) Show 1+ minute video: <https://www.youtube.com/watch?v=x2zjdtxrisc>

- This explains briefly how they work. This is a great opportunity to make linkages to chemistry and atomic theory where possible, depending on the age group of your students.
- Any Questions?????

4) Next show how they are made: <https://www.youtube.com/watch?v=SOuyZWqhINU>

- Any Questions?????

5) Use remaining time to let the students explore hooking up the panels to different small lights, LEDs, motors, fans, voltmeters, ammeters, multimeters, etc. You will need a sunny window, the outdoors, or some bright lights. A shop light works great. This might also be a good time to reinforce measuring current (milliamps) to see how much current different components such as lights, motors, or resistors require. Show students to first set up the simple circuit then disconnect and insert the digital multimeter in series with the component in question. See Figure 3-2. As a precaution for the DVMs you can set the dial to current 10A and switch the red wire lead to the 10 Amp hole.

You can also provide students with the additional challenge of powering different battery-powered toys and gadgets such as radios or handheld games with the solar modules. This provides additional examples in which students can visualize circuits in their daily lives as well as power requirements of various devices.

Allow adequate time to show how all of the equipment needs to be put away.

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Day 5 - Planning Solar Charging Systems

1) Warm up: Have you ever had a battery run out when you really needed it? Share a story in groups of 4.

2) Brainstorm: What items do we rely on that require batteries? What types of batteries are there? Sizes?

3) Show diagrams and photos of off grid systems. See handout “Off-Grid Systems”

- The first set of pictures shows a solar photovoltaic powered greenhouse. To extend growing season with warmer temperatures and 2-4 hours of extra light per day in the late Fall and early Spring.
- The second set is an off grid home in Northern Vermont. The cost of installing the Solar PV system was half the cost of running utility lines to the remote property.



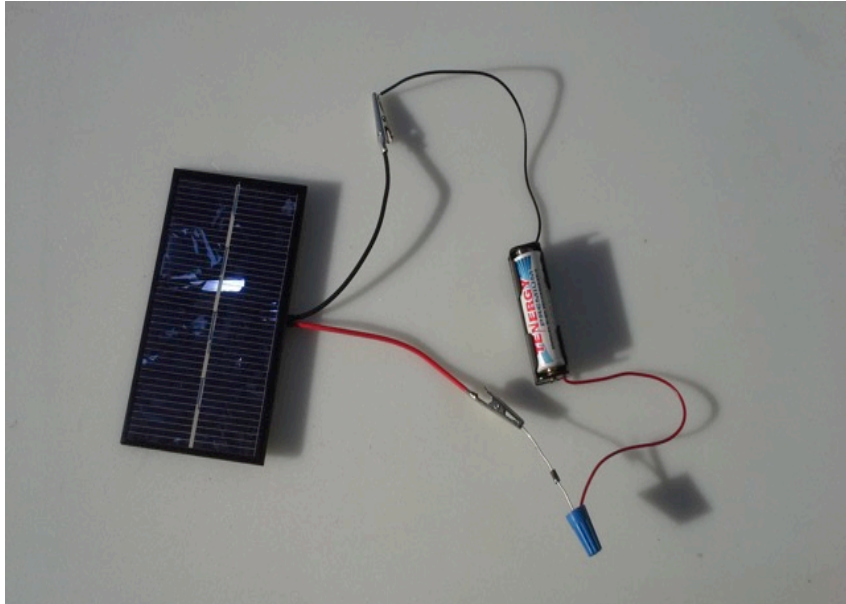
Solar Powered Greenhouse with 2 refurbished 64-Watt Photovoltaic modules. See “Off-Grid Systems Handout” for photos of the two off-grid systems.

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4) INTRODUCTION TO SMALL SOLAR CHARGERS: Discuss purpose of components (solar module, battery, diode, wires). Remind students to avoid short circuits.

- Show the most basic system: 2-Volt PV module charging 1 AA cell



- All pairs will get one solar panel, a diode, long wires and a battery pack with AAs, AAAs, 9 Volts, Cs, or Ds. Initial voltage will be tested. Diodes need to be oriented correctly as shown in diagram and picture. When circuits are completed and inspected by the teacher the students will bring panels out in the sun. Have students monitor and record battery voltage every 5 minutes. Use data sheet provided. (Solar Battery Charging Data Sheet). Some of the systems will charge very slowly, such as small panel with a larger battery (3 Volt / 70mA panel charging a 1.2V 10,000mAh “D” cell).
- Class returns with 20 minutes to go and shares data in last 5 minutes of class before a 5-minute cleanup. Which batteries were easiest to charge? Which were slowest to charge? Have students record their reasoning for why they believe they received these results or work through this out loud.

5) Introduction for Battery Storage or Capacity: This is a good opportunity to discuss the amount of charge a battery can hold and the units of measurement (Milliamp-hours). The units of measurement lead to charge:

$$\text{Current} = \text{Charge}/\text{time} \quad \text{so} \quad (\text{charge}/\text{time}) \times \text{time} = \text{charge}$$

With units it looks like this...

$$1 \text{ Ampere} = 1 \text{ Coulomb} / 1 \text{ second}$$

So when we multiply by time (hours) we are left with Coulombs. (After converting from hours to seconds).

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*****The key to effective battery/solar module pairings requires that the more massive batteries (ex: 5000 mAh “C” cell) are paired with the higher current modules (ex: 3 Volt 200mA solar module) to ensure faster charging.**

Day 6 - Plan and Set Up Solar Charging Systems

1) Assign battery packs with cells. Help students decipher and record information on batteries, especially mAh, Voltage, and NiMH. “milli-Amp-hours” is an estimate of time that the battery (cell) would provide the current at the given voltage. For example a 1.2 Volt battery with a charge of 2000mAh could provide a circuit with 200mA for 10 hours or maybe 100mA for 20 hours, or 10 mA for 200 hours! NiMH stands for Nickel Metal Hydride. Please see handout at end of document “Battery Pack Data Table.” Please modify to suit your needs. It looks like this.

Cell type	Number of cells	Voltage	Storage (mAh)

- What are some possible ways to partially drain your battery?
- How long will it take to charge them back up?
- If you had a battery that ran a light at 2.8 Volts and 1 amp for 2 hours how many Amp hours did you use?
- If you were to charge the battery back up with a 4 Volt solar panel that had a maximum current of 0.5 amps, how long should it take to charge?

2) STUDENTS MAKE A PLAN: After testing some panels and finalizing choices student teams will wire circuits, with diodes, measure and record initial voltages then set their panels in the sun to charge batteries. One or more class periods on sunny or at least bright days should be allotted for monitoring various setups in full sun at 5 or ten minute intervals. These data should be graphed (Excel or Google Sheets work well, or students could create their own axes to develop their conception of scale) with clear titles for each setup. (Example: Battery Voltage as a Function of Time: 6-Volt panel charging 4 AAs)

- **Options:** Depending on the amount of equipment being used by the class or multiple classes you could have teams pool data for all of the possible combinations, troubleshooting the ones which do not work as well as others. Each day of electrical lab work could start with a class sharing session of what worked/did not work the previous day. If the classroom has southern exposure then multiple day charging should be done to verify that substantial charging is occurring. Student pairs can commit to different PV/battery pairings and daily recordings can be made.
- **Potential Outcome:** Students will recognize that the somewhat depleted batteries will charge more quickly than the nearly full charge batteries. Also voltage gains for more massive cells will be modest if even measurable over short periods of time. For example a 1.2 Volt “C” cell with 5000 milliAmp hours (mAh) will charge much more slowly than a 9

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V battery which typically has only 200 mAh. Once full voltage (1.38 V per cell or so) is gained they may run the batteries down with a variety of electronic devices. Small motors, incandescent bulbs, or home made electromagnets might do the job quickly. Multiple devices wired in parallel will deplete the batteries more quickly. Some battery chargers have a discharge function on them too.

3) Graph and compare results using shared Google docs or open office spreadsheets. Analyze which systems worked best and why. Challenge students to make a graph that overstates the charging system's performance. Test and recharge.

Day 7 - Test, Collaborate, and Revise Systems

Multiday testing : Test, collaborate, and revise systems. Consider setting up individual challenges for students to explore. During this phase, students should be finding the plateau's that are reached regarding speed at which batteries can be charged, promoting a further discussion of electric potential in batteries and perhaps their structure and use in more detail.

Extensions

Students choose and make a charging project. Ideas might include:

- Phone, i-Pod, tablet, chargers, small reading light or fan system, standard 5V USB charging system, or soldering a charge controller circuit.
- If you look at the specifications on the manufactured charger you can match or build a system to meet the voltage and current requirements. Many excellent plans are online and there are intermediate kits too. (Try searching "Minty Boost" "Instructables" or "DIY Solar _____ Charger", "Make Magazine" is a great resource too).
- Many USB charged devices have specific voltage and current required on the inner two pins, (pins 2 and 3) and charging specs for pins 1 and 4. The inner pin specs can be matched with the right resistors.

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