Solar Transportation

Lesson 4: Designing a Solar Charger

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DESCRIPTION: In this lesson, students will further explore the potential and challenges related to using photovoltaics to supplement the power needed to charge batteries in BEVs. Students will be provided with a 12 V lead-acid battery and several 3 V, 1.5 A solar modules. Students will design a system of wiring the modules together as a means to charge the available battery. Students will then test their plan by wiring and connecting their modules to a “Watts-Up” energy meter, and ultimately, to the lead acid battery. Students will predict the accumulated charge over a 5-hour period based on the wiring strategy and compare their prediction to the actual energy supplied as determined by the Watts-Up meter. The following day, students will make predictions regarding the amount of time various items can be powered by the accumulated charge.

GRADE LEVEL(S): 10-12

SUBJECT AREA(S): Amperage, Voltage, Electricity, Power, Energy Storage, Battery Charging

ACTIVITY LENGTH: 4 days

LEARNING GOAL(S):

1. Students will explore the role of series and parallel wiring as they pertain to voltage and amperage.
2. Students will explore the processes involved with charging batteries and relate these processes to voltage and amperage.
3. Students will test photovoltaic modules to identify voltage and amperage outputs.
4. Students will design a system of wiring 3 V, 1.5 A modules together as a means to charge a 12 V lead-acid battery
5. Students will predict and test the effectiveness of their designed solar charger.

NEXT GENERATION SCIENCE STANDARDS:

- HS-ESS3-2: Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.
- HS-ESS3-4: Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
- HS-ETS1-1: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

- 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.
- HS-ETS1-3: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability and aesthetics, as well as possible social, cultural, and environmental impacts.
- HS-PS3-2: Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles and energy associated with the relative positions of particles.

COMMON CORE STATE STANDARDS:

- High School Mathematics:
  - BF-F-2: Write arithmetic and geometric sequences both recursively and with an explicit formula, use them to model situations, and translate between the two forms.
  - F-IF-6: Calculate and interpret the average rate of change of a function (presented symbolically or as a table) over a specified interval. Estimate the rate of change from a graph.

- High School ELA:
  - RST.11-12.3: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
  - RST.11-12.8: Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
  - RST.11-12.9: Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Materials List

- 30 x 3.0V, 1.5A solar modules (Solar Schoolhouse)
- Watt's Up Watt Meter and Power Analyzer
- 14 gauge wire
- Wire strippers*
- Crimper
- ANDERSON POWERPOLES 30 AMP (1 package)
- 12V, 35Ah Universal Lead-Acid Battery
- 1000 Watt Power Inverter (2x AC power outlets, 1x 2.1A USB port)
- 1 package 10A diodes

*Teacher Tip: Do NOT get the cheapest wire strippers that you might find at a grocery store. Good wire strippers are still inexpensive (maybe $14 vs. $8) and make a world of difference.

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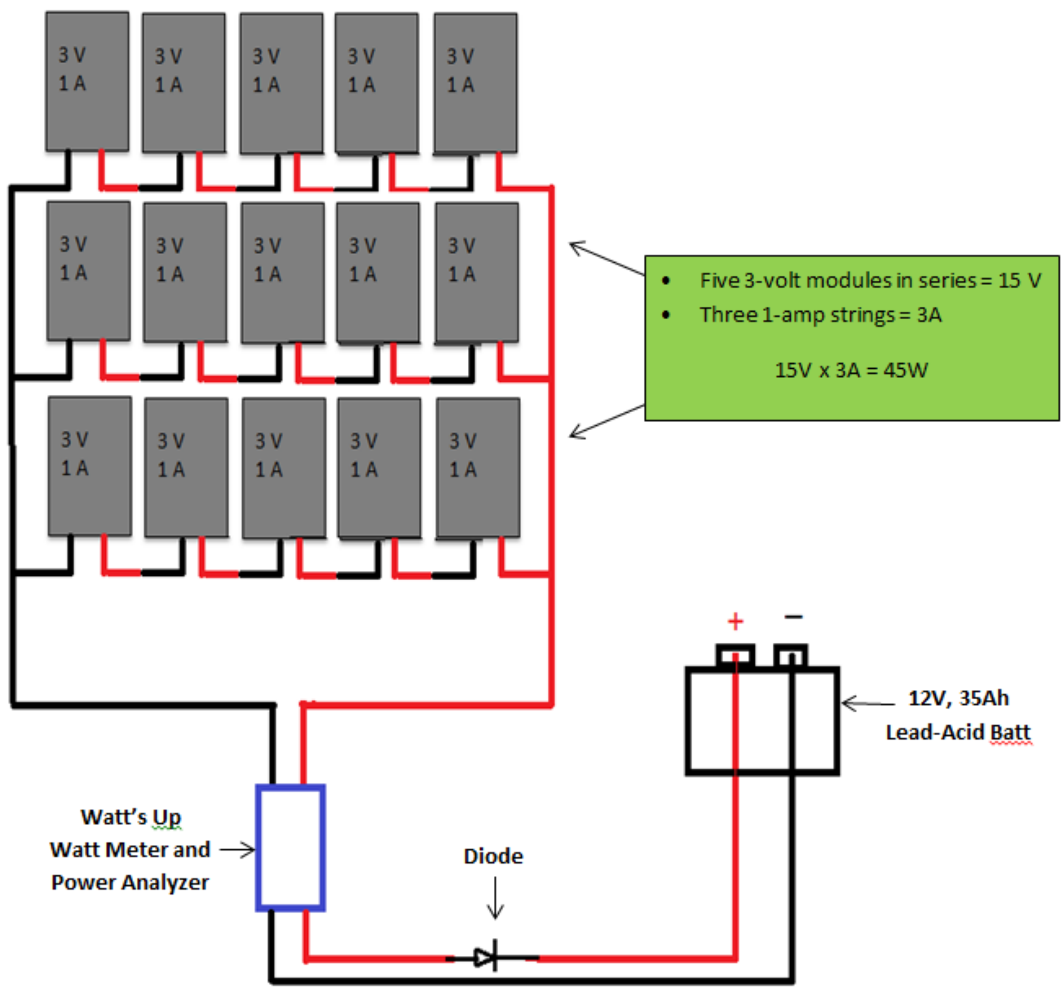
Lesson Details

Planning and Prep

If you are not particularly confident with wiring etc., DO NOT let inexperience deter you. With a little tinkering and some trial and error, even a complete novice can put this together. This lesson is designed to allow student groups to draw a plan for using the available materials to charge a lead-acid battery rated at 12 V and 35Ah (420 Wh). The battery, when fully charged, would theoretically be able to run a 100 W lightbulb for 4.2 hours. Students will likely not be able to fully charge the battery in a reasonable amount of time. However, during the school-day and if weather permits, they should be able to charge the battery nearly half way in about 6 hours. The following is the optimal wiring based on the number of modules indicated. You could easily increase the number of modules to increase the available current for charging.



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I engineered the wires used to connect the strings in parallel. I cut TWO pieces of wire to about 9" and a third piece at about 18". Using wire-strippers, I cut about 1 cm from each end of the wires. I then used the power poles and crimper tool to reconnect the wires together with connectors available for the alligator clips from the solar modules

Figure 1. From left to right: stripping 1cm from wire ends, power poles, using crimper tool, reconnecting wires.

I then connected the end of the wires to the Watt's Up meter by trimming the ends, twisting them together, then using electrical tape to secure it. Notice that these wires are connected to the "source" side of the meter.

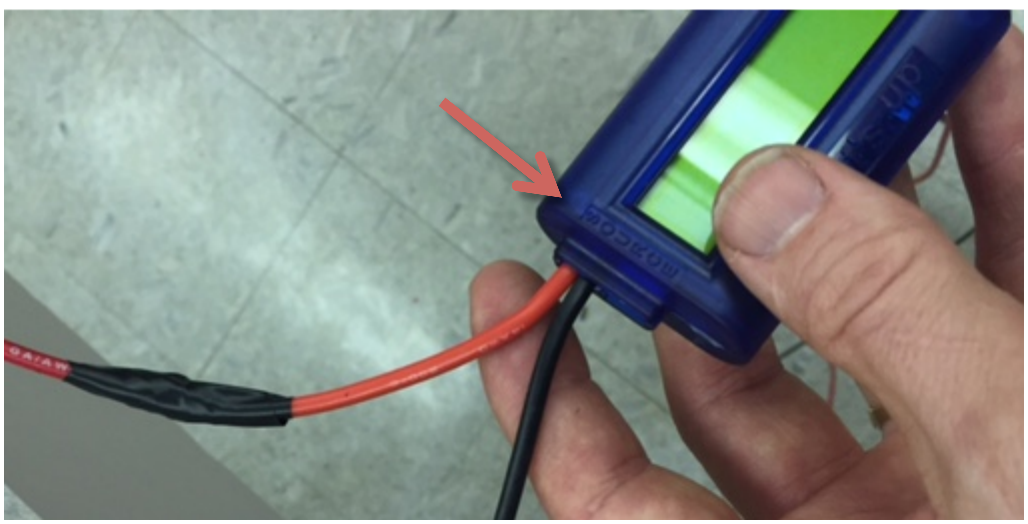

Figure 2. Watts Up meter source-side connection.

On the "load" side of the meter connect another 2-3 feet of wire to be used for connecting to the battery. The red wire should have a diode installed for safety as shown below:

Figure 3. Watts Up meter load-side connections with diode

To be safe, I would drain the battery of the majority of its stored energy before connecting to your solar charger. To do this, simply connect the inverter to the battery and plug-in a couple of lamps, a space-heater, or some other device that will use energy relatively quickly. The inverter will beep annoyingly when the battery output gets low.

Figure 4. Draining the 12 V battery.

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Finally, you should be ready to set-up the system and test the charging capabilities. This could be done overnight using lamps, or during the day using sunlight as intended. A picture of my final set-up is below is shown below.

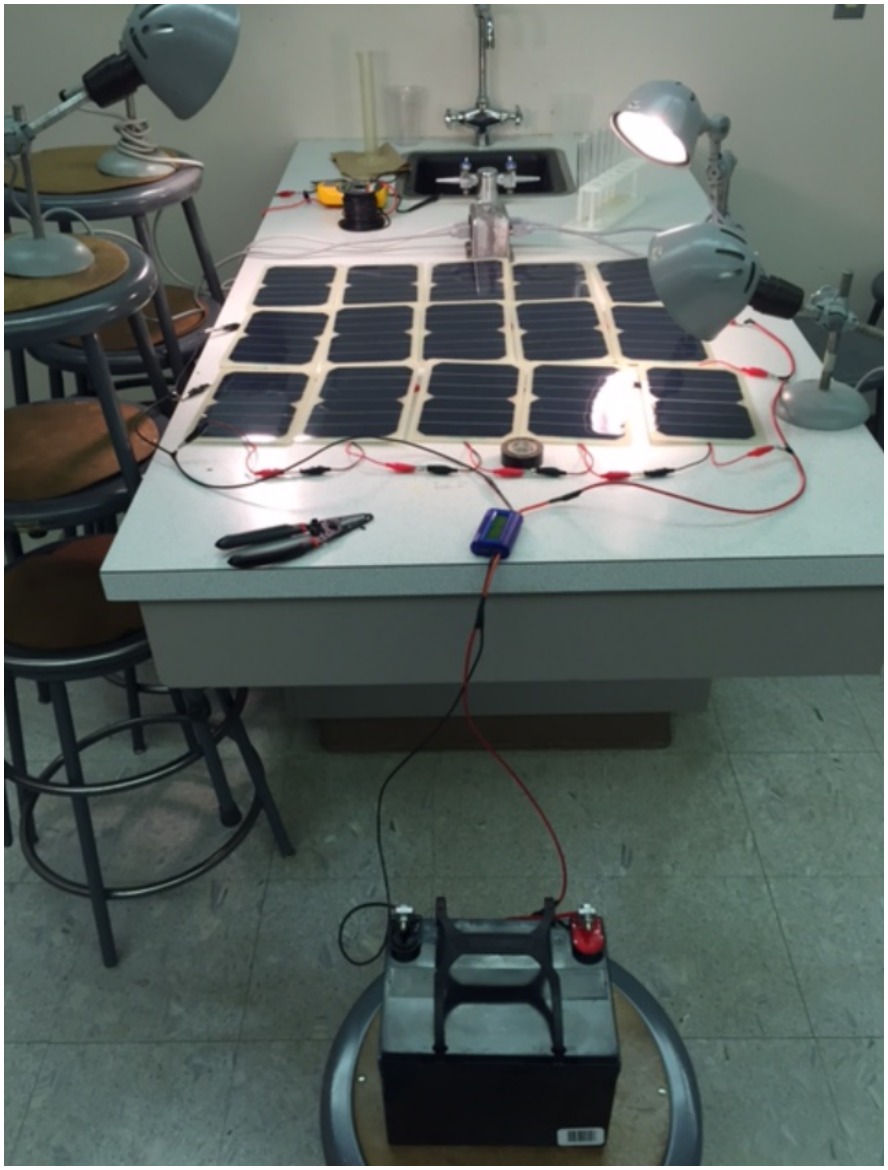

Figure 5. Testing system's charging capabilities.

Student Background

Students participating in this lesson should already be familiar with the following:

- How to connect solar modules using series and parallel wiring
- Calculating voltage, amperage, and watts based on different wiring strategies
- Voltage/amperage requirements for charging a battery

Lesson sequence (4 days)

Day 1:

Opening (10 - 15 minutes)

Show student the lead-acid battery with the inverter connected. Discuss the power and energy ratings of the battery.

Body (30 minutes)

Hand out Student Handout #8. Provide the students some time to make the calculations shown on the first section of the handout. Once finished, discuss the task for this lesson. Go over the list of materials available and the requirements for their solar charger.

Turn the student groups loose to begin developing their wiring diagrams. Be sure they are indicating series and parallel wiring, along with total voltage and amperage. Ideally, their diagrams will look something like the diagram I provided above. Teacher Tip: Unless your students are already familiar with diodes and watt meters, I would only expect them to come up with the portion of the wiring diagram that shows the solar modules.

Closing (5-10 minutes)

If time allows, have each group quickly present their wiring diagrams to the class.

Day 2:

Opening (10-15 minutes)

Follow-up on the wiring diagrams that each group developed yesterday. Discuss the relative merits of each diagram, and also determine whether each diagram will actually charge the battery.

Body (30+ minutes)

Show the students the diagram of the actual set-up and discuss why this diagram optimizes the materials available.

If weather permits, bring the materials outside and begin charging the battery. Have the students record the voltage and amperage indicated by the Watt's Up meter. Leave the charging station set-up in a safe location for the remainder of the day. Be sure to have students record the totals before they go home. If you have multiple classes of students, this is a great opportunity to share data across classes and discuss potential differences across the day.

Once the charging station is set-up and running, move back to the classroom to complete the remainder of section 2 of the student handout.

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<u>Conclusion: (10-15 minutes)</u>

Remind students to check the Watt's Up meter periodically throughout the day and especially at the end of the day before they go home. Students will get one more reading when they return to class the next day.

Day 3:

<u>Opening (10 -15 minutes):</u>

Give the students the final reading from the meter that you took before heading home on the previous day. Have them calculate the total amount of energy provided by the charger as it compares to the total energy the battery is capable of storing.

<u>Body (30-40 minutes):</u>

Have students complete section three from handout #8. Students will be working on the calculations during this time. I would encourage them to work together and make frequent progress and accuracy checks. The goal of this lesson is to get everybody "on the same page" with regard to both the limitations and the potential of PV technology as it pertains to meeting the demands of a BEV.

<u>Closing (5 minutes)</u>

Run a quick class discussion of their findings.

Day 4:

<u>Opening (10 -15 minutes):</u>

Have a few items ready to test some of the predictions made by the students in section three of the handout. There are inefficiencies all along this set-up, so be prepared to discuss why the appliances may not actually run for as long as predicted.

<u>Body (30-40 minutes):</u>

Connect the inverter to the battery and actually run the appliances. Have the students record the actual amount of time they were able to power whichever appliance you decide to connect. Students should complete the rest of student handout #8 with the results of the tests.

<u>Closing (5 minutes)</u>

Run a quick class discussion of their findings.

Lesson Extensions

If time and budget allows, you could connect a larger number of modules and attempt to charge the battery in less time. Students could make predictions similar to those on the handout.

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