# Solar Panel Construction, Orientation and Use

**AUTHOR:** James Mulanax

**DESCRIPTION:** For this extended task, students will track the sun's altitude and Azimuth to determine the best position for their hand-built solar panel, learn solar cell operation basics, solar panel construction, series and parallel circuitry and basic array sizing.

**GRADE LEVEL(S):** 9-12

**SUBJECT AREA(S):** Applied physics: physics / principles of technology / engineering / applied math. English: text types and purposes, production and distribution of writing, research to build and present knowledge. Mathematics: statistics and probability, modeling.

**ACTIVITY LENGTH:** In Class Activities: 16hrs. 40min. Homework Activity: 8-9 hrs.

**LEARNING GOAL(S):** Modeling and data analysis

**STANDARDS MET:**

- CLAIM #1: Concepts & Procedures: “Students can explain and apply mathematical concepts and interpret and carry out mathematical procedures with precision and fluency.”
- CLAIM #2: Problem Solving: “Students can solve a range of complex well-posed problems in pure and applied mathematics, making productive use of knowledge and problem solving strategies.”
- CLAIM #3: Communicate Reasoning: “Students can clearly and precisely construct viable arguments to support their own reasoning and to critique the reasoning of others.”
- CLAIM #4: Modeling and Data Analysis: “Students can analyze complex, real-world scenarios and can construct and use mathematical models to interpret and solve problems.”

**Common Core**:

- MATH: CCSS.Math.Content.HSS-MD.B7: Analyze decisions and strategies using probability concepts. (e.g., product testing).
- ENGLISH: CCSS.ELA-Literacy.WHST.11-12: Conduct short as well as more sustained research projects to answer a question or to solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

## Student Background:

**Stimulus/Source:**
Students will have access to panels and brochures completed by other students from previous semesters. Their work may or may not be correct. The purpose of the available work is to provide a "visual" of what is to be expected of the student by the teacher.

## Educator Background:

**Scaffolding Techniques:**
- Frequently clarify lecture and notes.
- List objectives for the day in a place where students can see them.
- Begin each class with a review and short vocabulary.
- Demonstrate proper tool use to prevent damage to equipment and self.
- Have on-hand completed sub-assemblies and working PV Module.

During this assignment, it will be considered reasonable to help the students to set up the testing equipment, to allow some students to work together, to praise where credit is due, and to correct student usage of measuring tools and other tools related to the solar panel construction and testing. However, it is the students' responsibility to collect data, arrange data, and compile the data into a presentable brochure. The point of this experiment is to use the collected data and experiences gathered from their solar technology exercise to develop a logical and presentable persuasive brochure about their solar panel design. The brochure should mimic their proficiency on the subject.

## Science Kit Materials List:

- Multimeter (1 per 2 students)
- Single Solar Car Kit (1 per class)

## Other Materials List:

- "Handouts for Mulanax Solar Panel Project"
- PV Cells (4 per student) 125mm x 125mm quasi-square crystalline
- Calibrated Solar Cell (1 unit per 4 students)
- Tab Ribbon & Bus Ribbon (one (1) roll will serve 25 students) 3/16" wide and 3/32" wide ribbon each in a 50 foot roll
- Aluminum Bar-Stock (1/4" x 1" x 6' per student)
- May substitute 1/4" x 1" x 6' Fir wood stock for cost reduction
- Aluminum Sheet (1 sheet will serve 36 students), 1/8" x 4' x 8' sheet
- May substitute 1/8" x 4' x 8' door-skin or fiberboard for cost reduction
- Polycarbonate (1 sheet will serve 36 students), 1/8" x 4' x 8' sheet

- Nylon or Plastic Screen (1 roll will serve 36 students), 4' x 8' roll
- Layout Board (1 sheet will serve 36 students), 1/8" x 4' x 8' door-skin or fiberboard
- Bolts (16 nuts and bolts per student), 1/4" x 1/2" National Coarse grade five machine screws/bolts
- Solder (1 roll per soldering iron/gun station), One pound electronic 60/40 x 0.050" solder roll
- Flux Pen (1 pen per soldering station)
- Clear Silicone (Two (2) tubes per 25 students), Standard 2" x 8.5" caulking gun tube
- Junction Box (1 per student)
- 2-Position Dual Row Barrier Strip (1 per student)
- Electrical Tape (1 roll per 6 students)
- Digital Soldering Gun w/chisel tip (1 per 4 students)
- May substitute lower quality soldering gun for cost reduction, but students will have a difficult time controlling heat.
- Caulking Gun (2 per 25 students)
- Paint Brush (1 per student). Low grade 2" disposable bristle brush
- Book: Build Your Own Solar Panel: Generate Electricity from the Sun by Phillip Hurley. ISBN 978-0-9837847-1-5
- Book: Teaching Solar by Rahus Institute
- Hacksaw (1 per 6 students)
- Exacto Knife (1 per 6 students)
- Screwdriver (1 per 6 students)
- Pencil (1 per student)
- Ruler (1 per 2 students)
- Drill (1 per 12 students)
- Electrical Wire (1 roll per 4 students), One (1) 25' roll of 12-gauge automotive, multiple strand insulated copper wire
- Clear Semi-Hemisphere and Compass Card (1 per student)

## Vocabulary:

- AC (alternating current): Typical household electricity; electrical current that flows alternately in two directions. The positive and negative switch back and forth 60 times per second in the United States. This rate (hertz) varies from country to country.
- AM (air mass): The relative thickness of air that solar radiation must pass through to reach the earth's surface.
- Array: A complete photovoltaic power-generating system.
- Azimuth angle: The horizontal angle between where the sun is relative to due south (in the northern hemisphere).
- Battery: A collection of electrochemical cells that are contained in the same case in such a way to produce a desired voltage.
- Battery bank: A group of batteries connected together in such a way to produce a desired voltage.
- Current-voltage (I-V) characteristic: The basic electrical output of a PV device.
- DC (direct current): Electrical current that flows in one direction only.
- Doping: The process of adding small amounts of impurities to semiconductors to alter their electrical properties.

- Load: A piece of equipment that consumes electricity.
- Maximum power current ($I_{mp}$): The operating current on an I-V curve where the power is at maximum.
- Maximum power point ($P_{mp}$): The operating point on an I-V curve where the product of current and voltage is at maximum.
- Maximum power voltage ($V_{mp}$): The operating voltage on an I-V curve where the power output is at maximum.
- Module: A PV device consisting of a number of individual cells connected electrically, laminated, and packaged into a frame.
- N-type semiconductor: A semiconductor that has free electrons (negative).
- Open-circuit voltage (VOC): The maximum voltage on an I-V curve and is the operating point for a PV device under infinite load or open-circuit condition, and no current output.
- Photon: A unit of electromagnetic radiation.
- Photovoltaic cell: A semiconductor device that converts solar radiation into direct current electricity.
- Photovoltaic effect: The movement of electrons within a material when it absorbs photons with energy above a certain level.
- Photovoltaics: A solar energy technology that uses unique properties of semiconductors to directly convert solar radiation into electricity.
- Photovoltaic (PV) system: An electrical system consisting of a PV module array and other electrical components needed to convert solar energy into electricity usable by loads.
- P-N junction: The boundary of adjacent layers of p-type and n-type semiconductor materials in contact with one another.
- P-type semiconductor: A semiconductor material that has electron voids (positive).
- Radiation: Energy that emanates from a source in the form of waves or particles.
- Reference (calibrated) cell: An encapsulated PV cell that outputs a known amount of electrical current per unit of solar irradiance.
- Semiconductor: A material that can exhibit properties of both an insulator and a conductor.

# Lesson Details:

## Part 1 (20 Minutes): The Reason for the Seasons

(Pg. 5) (Teaching Solar / Rahus Institute)

***Passive Solar*** (does not change) the ***collector surface angle remains fixed***.

Most solar energy is received when the ***cell array faces directly towards the sun***.

***Proper solar panel orientation for maximizing input requires*** an understanding of how the sun tracks across the sky in your particular area both daily and yearly (see Fig. pg. 5, Teaching Solar).

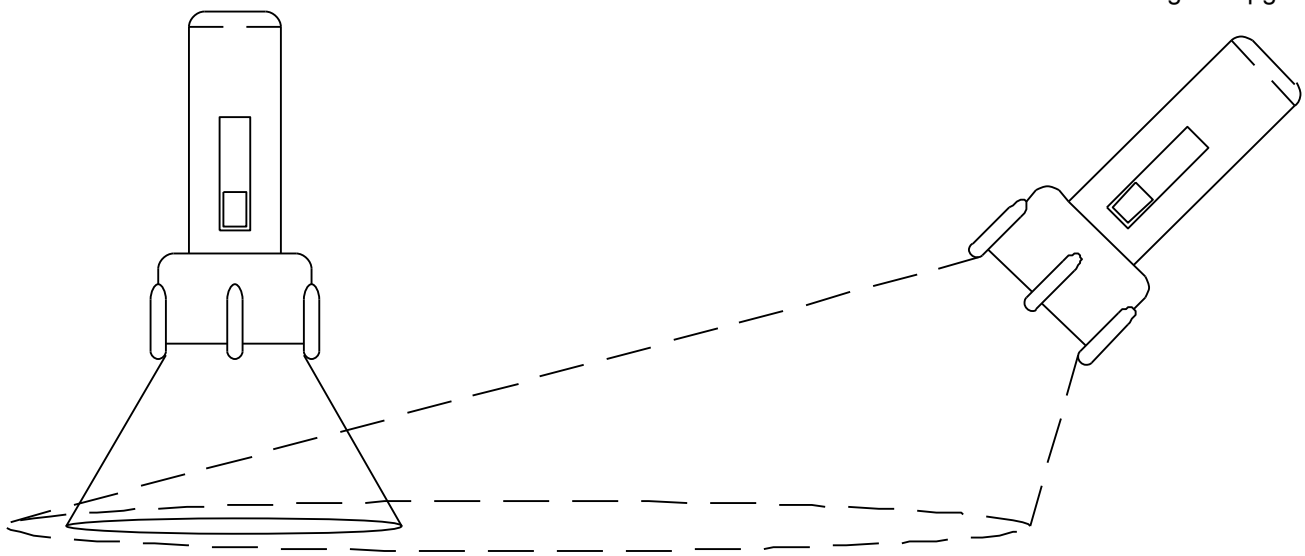
Seasonal differences and the maximum height and minimum height of the sun are caused by the earth's position as it orbits around the sun. The tilted axis of the earth is fixed (see Fig. pg. 5, Teaching Solar).

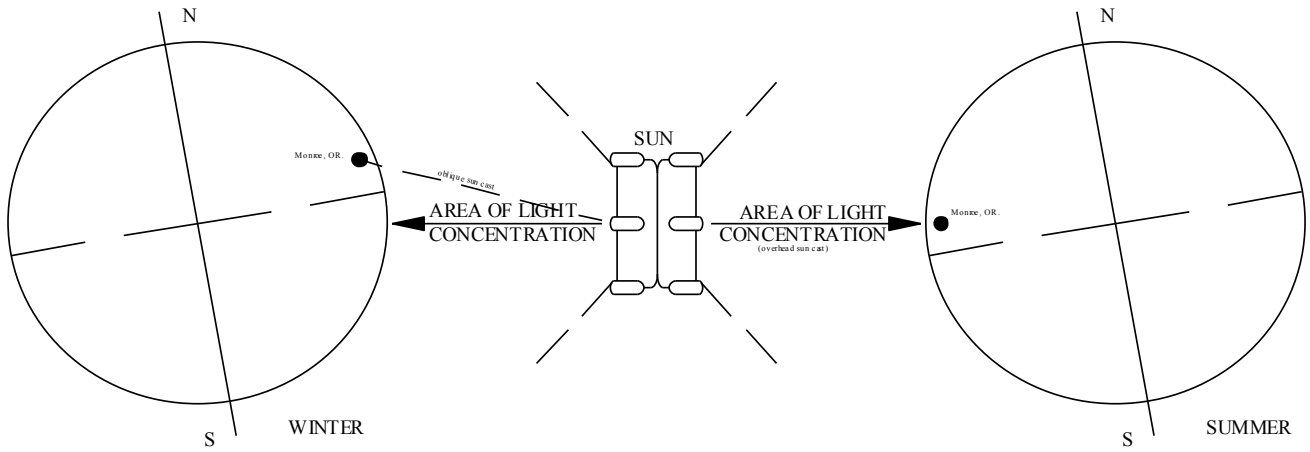
## Part 2 (20 minutes): How the Sun's Position Affects Available Solar Energy/Brilliance

(Pg. 8 Teaching Solar)

- Using a good quality flashlight, demonstrate how the sun casts its light on the ground when directly overhead and at an oblique angle.
- An overhead will produce a circular pattern that is bright (concentration of light per area is at its greatest).
- An oblique angle (45 degrees) will produce a dimmer light but cast light over a larger surface (concentration of light is minimized per area). The power density of the light is shared over a larger area. (The intensity of the flashlight can also be demonstrated by shining the light directly in a person's eyes or obliquely.)
- Use this demonstration to show how the earth's tilted axis can affect the "quality" of the light and the angle the sun shines on the earth (summer versus winter) in relation to where we are on the planet.

Use Figs. on pg. 8.



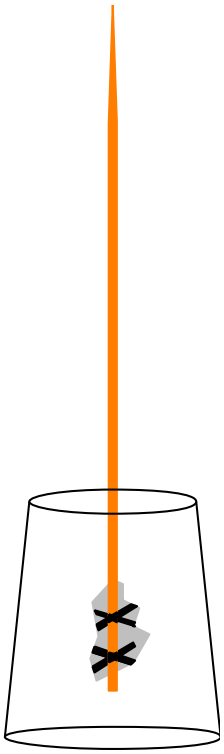



## Part 3 (20 minutes): Finding True North and South Without a Compass

(Pg. 7 Teaching Solar / Rahus)

Demonstrate how to find "true north" using the method below. Assign students homework to create a compass on the ground of their yard or driveway to be used when they proceed with their sun tracking exercise.

- Use shadow tracings. Use a paper cup and supported/weighted skewer. Show students how to create a simple system by taping small rocks to a wooden skewer and pushing the skewer through the bottom of the cup from the inside. Place the cup open-mouth down with the skewer in the air and demonstrate its use, as per instructions below.
- Trace shadow at a given time and label "W" for west.
- Trace shadow again 1-2 hours later and label "E" for east.
- Draw a line from the top of both shadows.
- Stand on the line with "E" to your right – you are facing "true north."



## Part 4 (80 minutes): Measuring the Sun's Position (Altitude & Azimuth)

(Pg. 8 Teaching Solar / Rahus)

**Altitude:** Sun's height above the horizon (Fig. pg. 9 Teaching Solar).
**Azimuth:** Sun's direction on a compass as measured from due south (Fig. pg. 9 Teaching Solar).

### ALTITUDE

- TEACHER: Construct paper altitude finder located on page 86 of Teaching Solar.
- Teacher then demonstrates proper and safe use of the altitude finder (**do not look at the sun!**) as explained by Rahus Institute.
- Be sure to remind students that zero degrees is at/on the horizon.
- STUDENTS: Students then construct altitude finder, go outside to a designated spot and measure the sun's altitude at the present time.

### AZIMUTH

- TEACHER: Reiterate finding the sun's Altitude and then demonstrate finding the sun's Azimuth using a clear hemisphere as per Rahus instructions (Fig. pg. 9 Teaching Solar).

- Start this exercise by drawing north, south, east, and west on a piece of paper large enough to place under the clear semi-hemisphere. The direction of the rough compass card can be approximate for demonstration purposes.
- Continue this exercise by showing how to pinpoint the sun's location on the plastic semi-hemisphere. Draw its location with a small point using a non-permanent marker.
- Then, draw a line straight down from the sun's location on the clear semi-hemisphere to the horizon on the compass card. From that point to true north (angle in degrees) is the sun's Azimuth (Fig. pg. 9 Teaching Solar).
- STUDENTS: Students will go outside to practice measuring the sun's Azimuth with their clear semi-hemispheres and ready-made compass cards. The teacher needs to observe, correct and praise as the students will later take their units home and track the sun over a given number of hours.

## Part 5 (20 minutes): Tracking the Sun

(Pg. 11 Teaching Solar / Rahus)

**TEACHER: NOTES TO SHARE:**

- Bulk of solar energy is delivered between 9 am and 3 pm.
- Sun's track during the summer months is higher due to earth's tilted axis and orbit around the sun. (Highest on June 21st).
- Sun's track during the winter months is lower due to earth's titled axis and orbit around the sun. (Lowest on December 21st).
- Solar window occurs vertically between 9 am and 3 pm and horizontally between December 21st and June 21st.
- Demonstrate development of solar window on clear hemisphere (Fig. pg. 15 Teaching Solar).

## Part 6 (20 minutes): Review

Using a clear hemisphere, review the sun's altitude, Azimuth, tracking and the solar window that is created based upon the notes shared above.

## Part 7 (8-9 hours): Charting the Sun’s Path

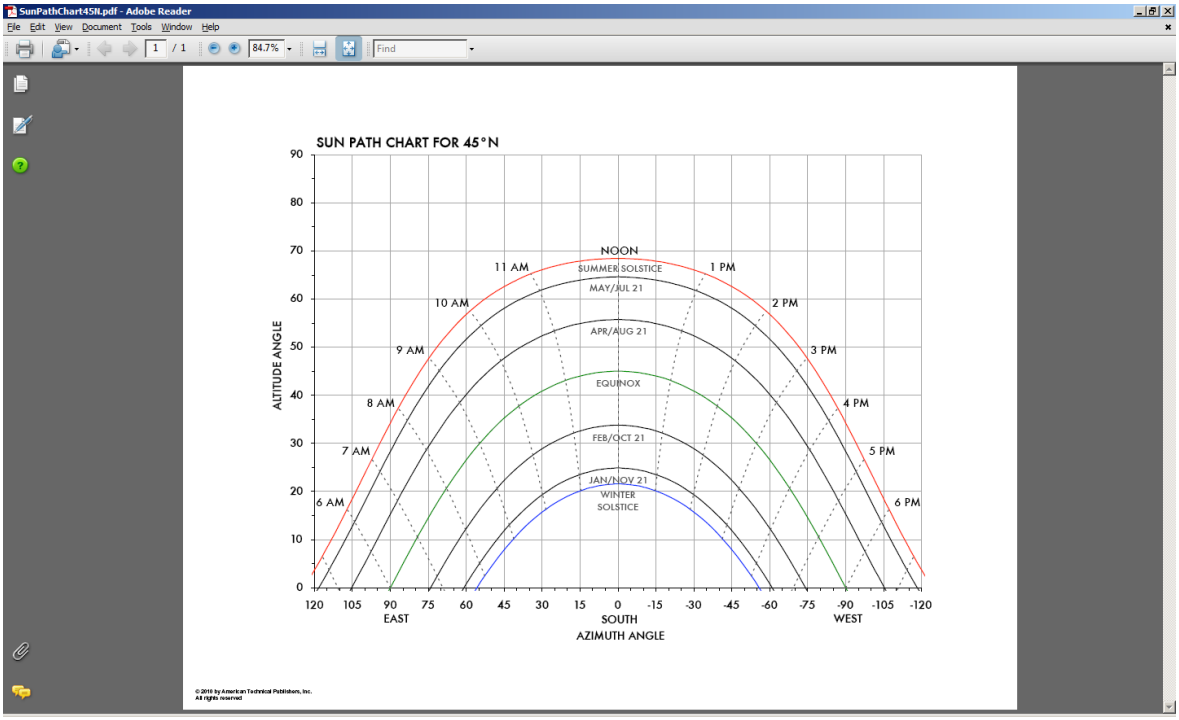
(Pg. 15 Teaching Solar / Rahus)

- STUDENTS: Homework, as per handout
- Students will set up their north, west, south, and east compass grid on their driveway at home or in their yard.

- Students will track the sun for one day from 8 am to 4 pm in one hour increments at home using a clear semi-hemisphere. Students must use a NON-PERMANENT marker for this exercise.
- Upon return from the weekend, review findings with students by comparing their semi-hemispheres. (They should all be the same.)

## Part 8 (120 minutes):

- Use figure on page 15 after students complete their sun tracking exercise to show what their tracking data would look like after a full year of data is spread out flat. http://solardat.uoregon/SunChartProgram.html
- Chart reading exercises. Present handout of local sun chart and have students work together to solve related questions.



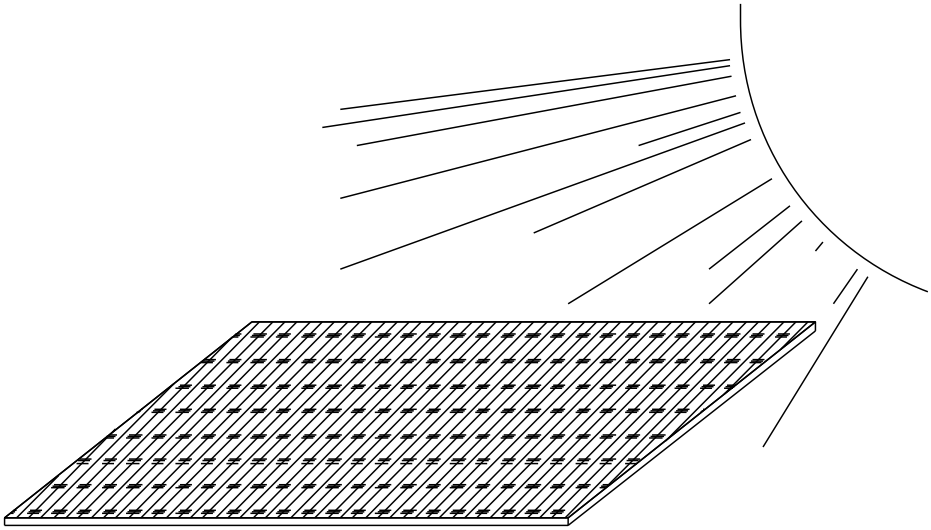

(example)

## Part 9 (20 minutes): Solar Cell Basics

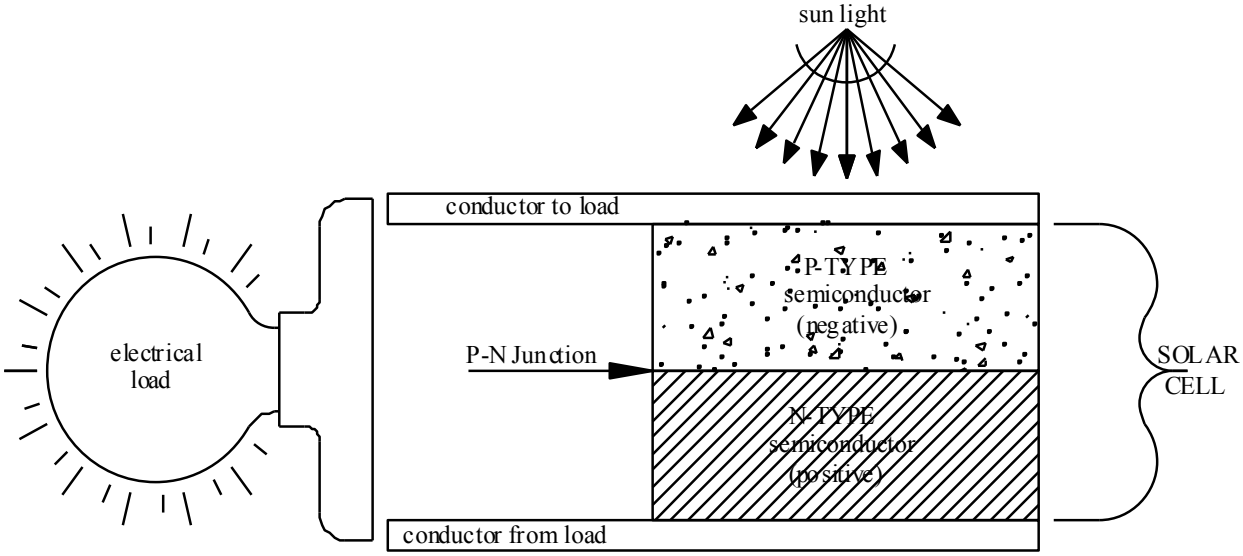
(Pg. 1 Build Your Own Solar Panel / Phillip Hurley)

The sun, as an energy source, produces billions of megawatts per second. The sunlight that feeds solar cells travels 186,282 miles per second to reach the earth in 8.4 minutes. Even though 1,368 Watts/$M^2$ is released at the top of the Earth's atmosphere and reduced due to water vapor, ozone and

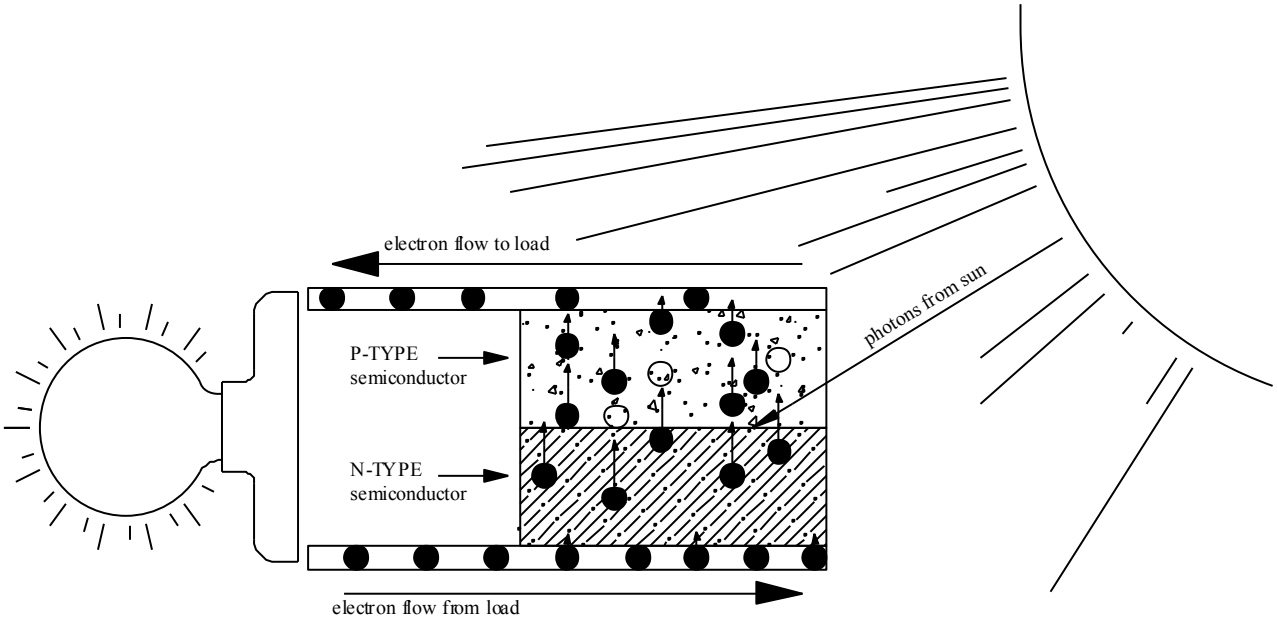
scattered air molecules, it is free energy. You do not have to go to the solar station to purchase energy and a dark lid will not be placed over your home when your bill is overdue.



**BASIC ARRANGEMENT OF A SOLAR CELL**



**HOW IT WORKS (Photovoltaic Effect):**




1. The sun's photons hit the P-N junction (acting like a switch) causing "electrical" flow by increasing the potential energy between the P-Type and N-Type semiconductors. *There is an electrical charge difference between the top of the P-Type semiconductor and the bottom of the N-Type semiconductor initiating electron movement*.

2. N-Type semiconductor has extra electrons and they move up to the P-N when photons hit the P-N junction.

3. P-Type semiconductor has "holes" or electron “voids” and they carry the extra electrons from the N-Type semiconductor.

4. Electrons flow from the P-Type semiconductor to the electrical load. When the electron carriers are emptied, the "voids" return to the bottom of the P-Type semiconductor and await a free-electron.

5. Electrons *from* the electrical load flow into the conductor and head towards the N-Type semiconductor and the process starts over.



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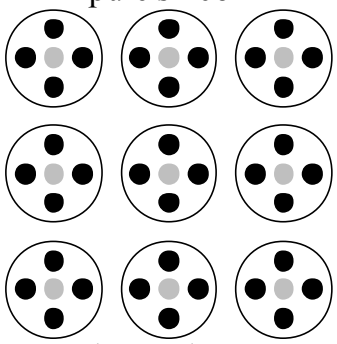
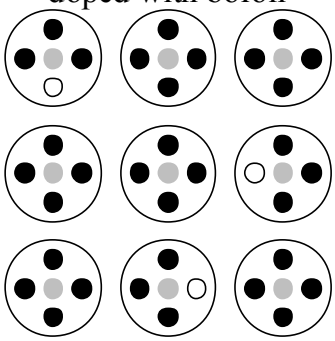
**P-TYPE and N-TYPE SEMICONDUCTORS ("DOPING") at the ATOMIC LEVEL:**

pure silicon



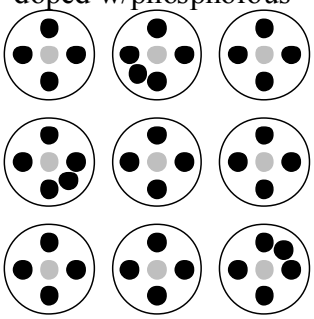
4 valance electrons

(P-Type) silicon
doped with boron

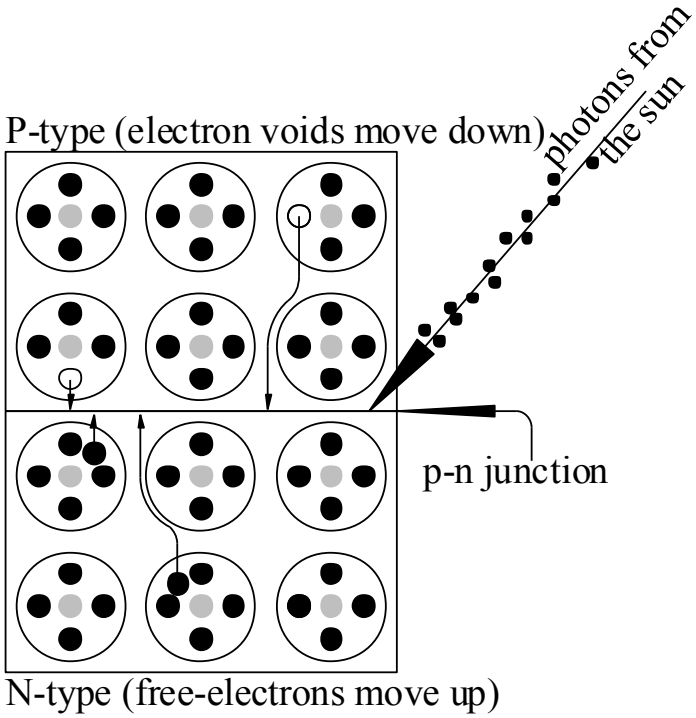


boron has 3 valance electrons and an electron "void"

(N-Type) silicon
doped w/phosphorous



phosphorous has 5 valance electrons with the 5th being a "free electron"



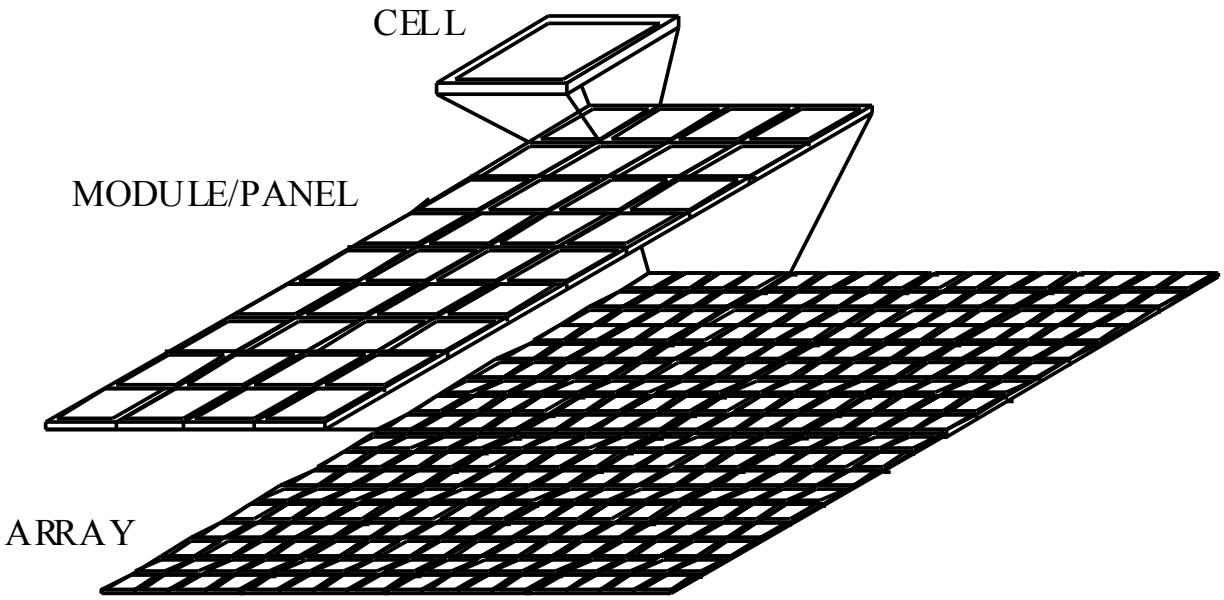

1. When the sun's photons hit the P-N junction, electron and electron-void movement occurs within the two semiconductors. This separation of electrons and electron-voids creates an electrical charge difference between the top of the P-Type semiconductor and the bottom of the N-Type semiconductor. When there is a potential charge difference, electrical flow occurs (electricity).
2. The P-Type semiconductor has voids or electron carriers that move down to gather free or extra electrons from the N-Type semiconductor.
3. N-Type semiconductor has extra or free-electrons and move up through the N-Type semiconductor to the waiting electron-carriers in the P-Type semiconductor.
4. Electrons are released from the carriers at the top of the P-Type semiconductor into the conductor and flow to the electrical load.
5. Electrons leave the electrical load via a conductor to the N-Type semiconductor. These "extra" electrons now flow up through the N-Type semiconductor due to a potential difference in charges. These electrons flow towards the electron-carriers. The process starts anew.

Pass around the handout for students with copy of electron flow: students will put into their own words the photovoltaic effect and turn in to the teacher.

## Part 10 (10 minutes): Video of Photovoltaic Cell and Panel Production

Show video: Photovoltaic Module Manufacturing (Located in CD of Photovoltaic Systems book by James P. Dunlop)

## Part 11 (1 minute): Solar Cell Nomenclature



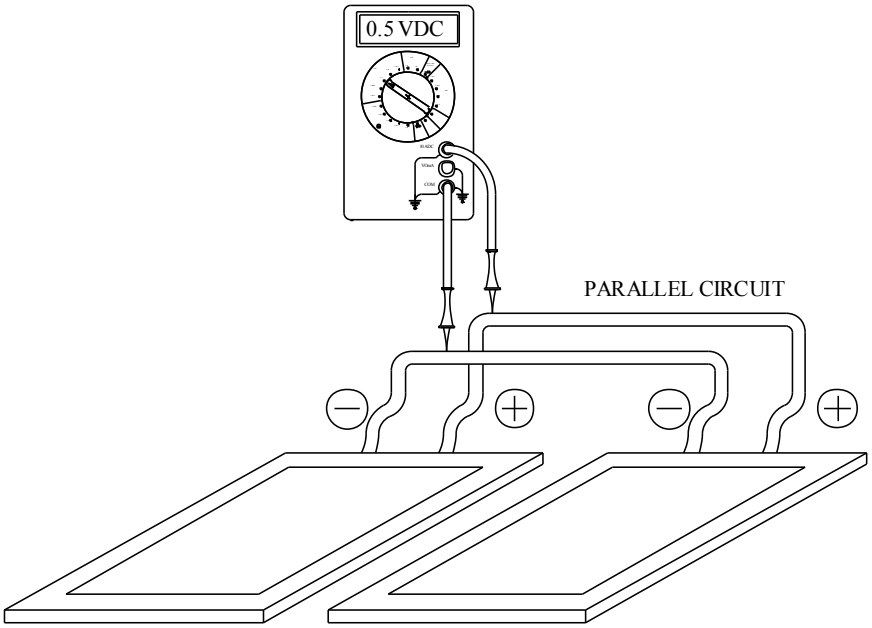

## Part 12 (10 minutes): Solar Cell Output

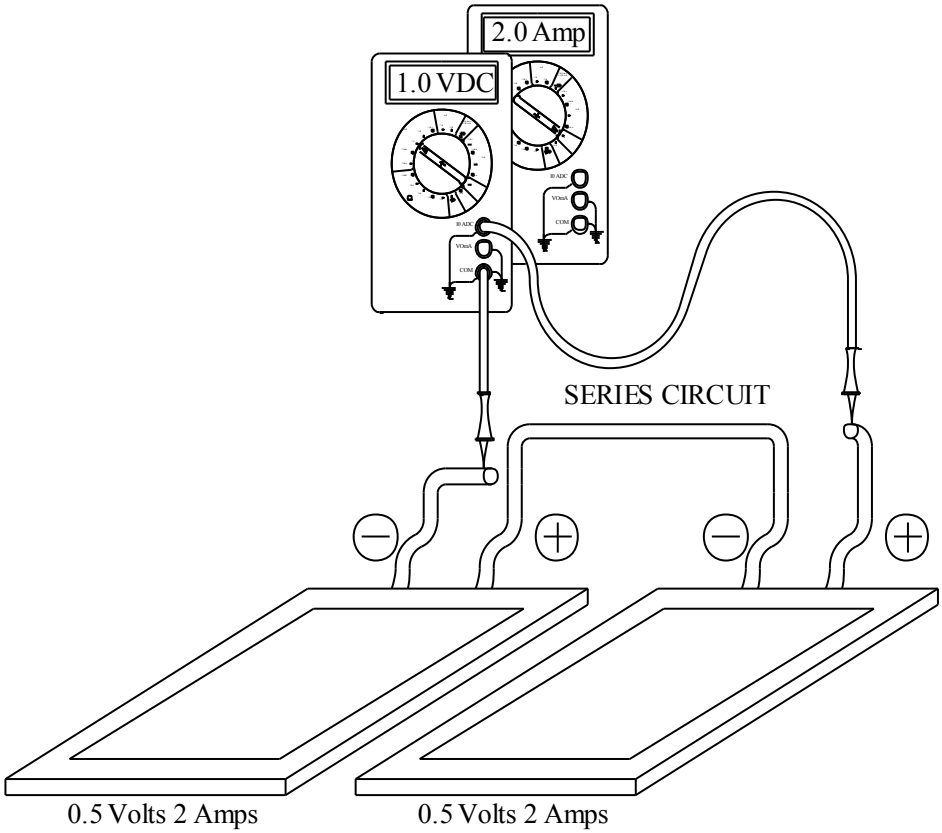
- Solar cells produce about 0.5 Volts (more or less) regardless of how large they are. Cells produce 0.5 volts per P-N junction, and cells have only one P-N junction.
- Size of solar cell do effect Current flow (Amperes).
- Solar cells are "rated" by a combination of the two by Watts.

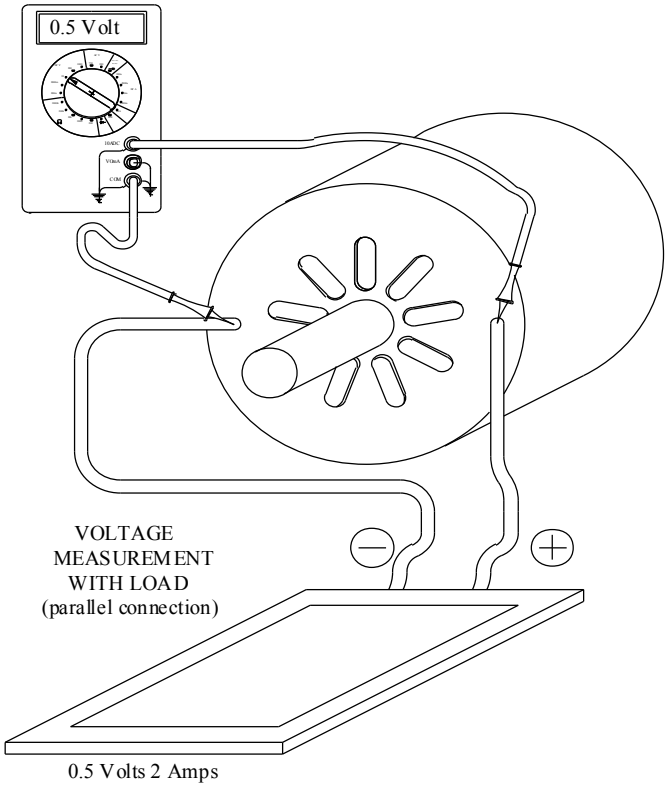
  - ✓ Volts: An electrical "force".
  - ✓ Amperage: The flow of electrons past a given point in time. One ampere is equivalent to 250 billion, billion electrons flowing past a given point in 1 second.
  - ✓ Watts: Volts times amperes.

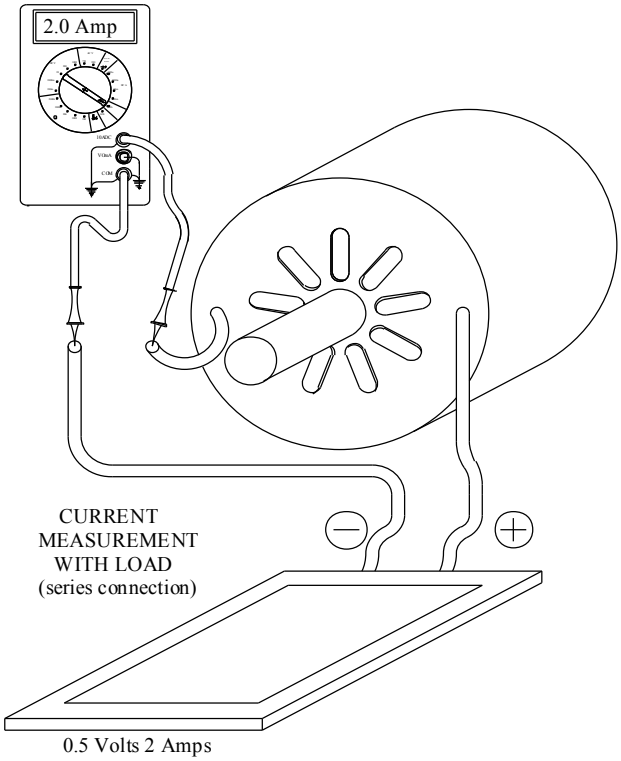
ex: **0.5 Volts x 4 amperes = 2 Watts**

# Part 13 (20 minutes): Series and Parallel Circuits

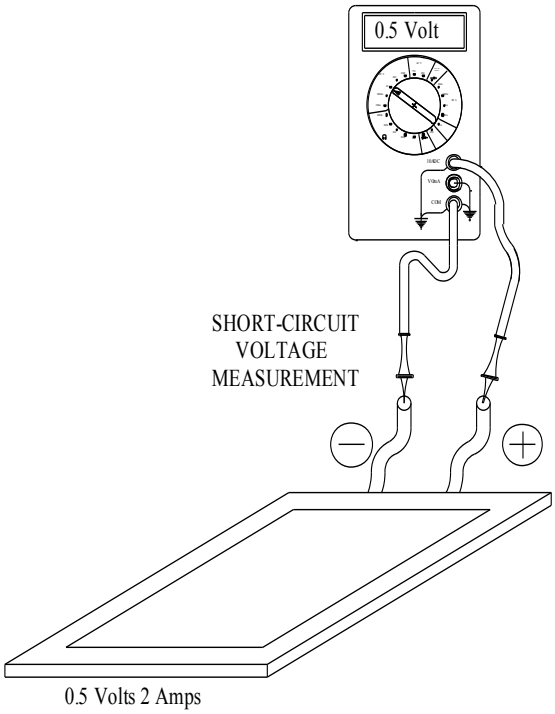


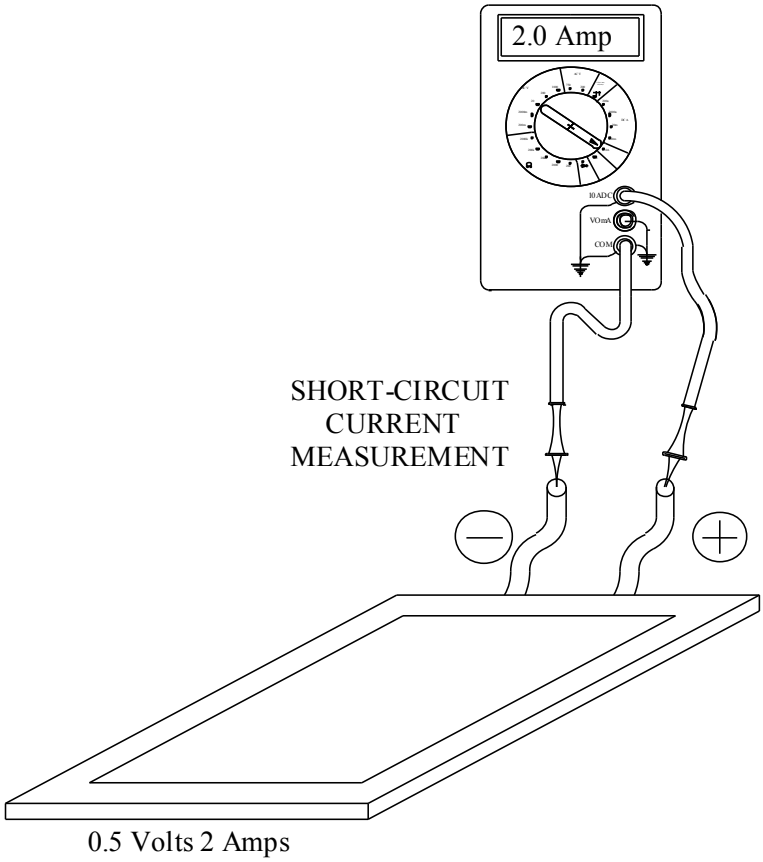




0.5 Volt
VOLTAGE
MEASUREMENT
WITH LOAD
(parallel connection)
0.5 Volts 2 Amps




## Part 14 (20 minutes): Measuring Solar Cell Capacity






## Part 15 (20 minutes): Series / Parallel & Volts / Amperage / Watts Check-Point

1. Hand out series / parallel exercises for students to complete.
2. Hand out shop-made electrical boards to study series and parallel circuits along with Amperage, Volts, and Watts and the proper/safe use of a multi-meter. Students will read instructions and fill-in handout.

## Part 16 (30 minutes): Testing Solar Cells

(NOTE TO TEACHER: At this point, students will be getting close to actually creating a photovoltaic (PV) module, however, the cells the students will be using may or may not be close to their tested outputs. Therefore, it is very important that the cells are "matched" relatively closely for construction purposes. This is a real concern and a common procedure in the industry. The teacher should demonstrate once again the procedure of measuring the short-circuited voltage test. Once the students have selected four nearly identical cells for their project, you should show the students a finished tabbed set of cells so they can "see" their next steps. Teach them how they are to "wield" the

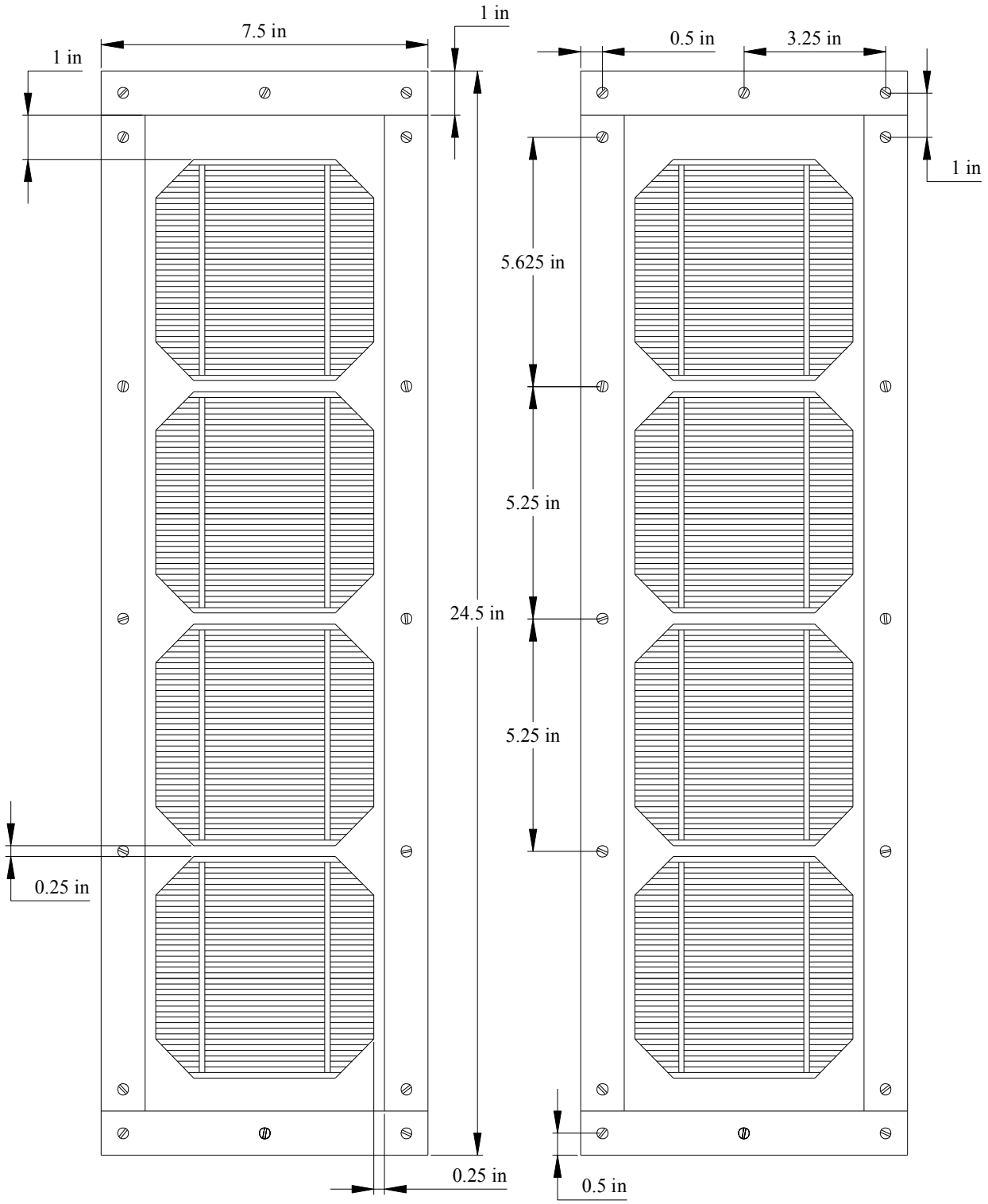
soldering gun to accomplish this tabulation process. (Tip: It is imperative the students practice soldering first or you may have a lot of botched cells and disgruntled students.)

**TEACHER NOTES TO SHARE:**

- All cells are tested under artificial light at what is called Air Mass Condition 1 (AM1).
- At AM1, the light is directly overhead. Air Mass has to do with how much atmosphere the sunlight travels through before hitting the earth. Obviously, when the sun is directly overhead, the AM level is at its lowest.
- Each student should test their solar cell under the same light, angle and distance as per "PART 14" discussion. Exchange cells with other students until each student has four cells relatively close in voltage. This is critical.
- If one cell's output in a module is of lower value than the rest, the entire module will behave as if all the cells are rated low.
- Students compare their cells to the "calibrated cell" to determine the "quality" of their cell group. The calibrated cell is tested at AM1 and the value is printed on the back.

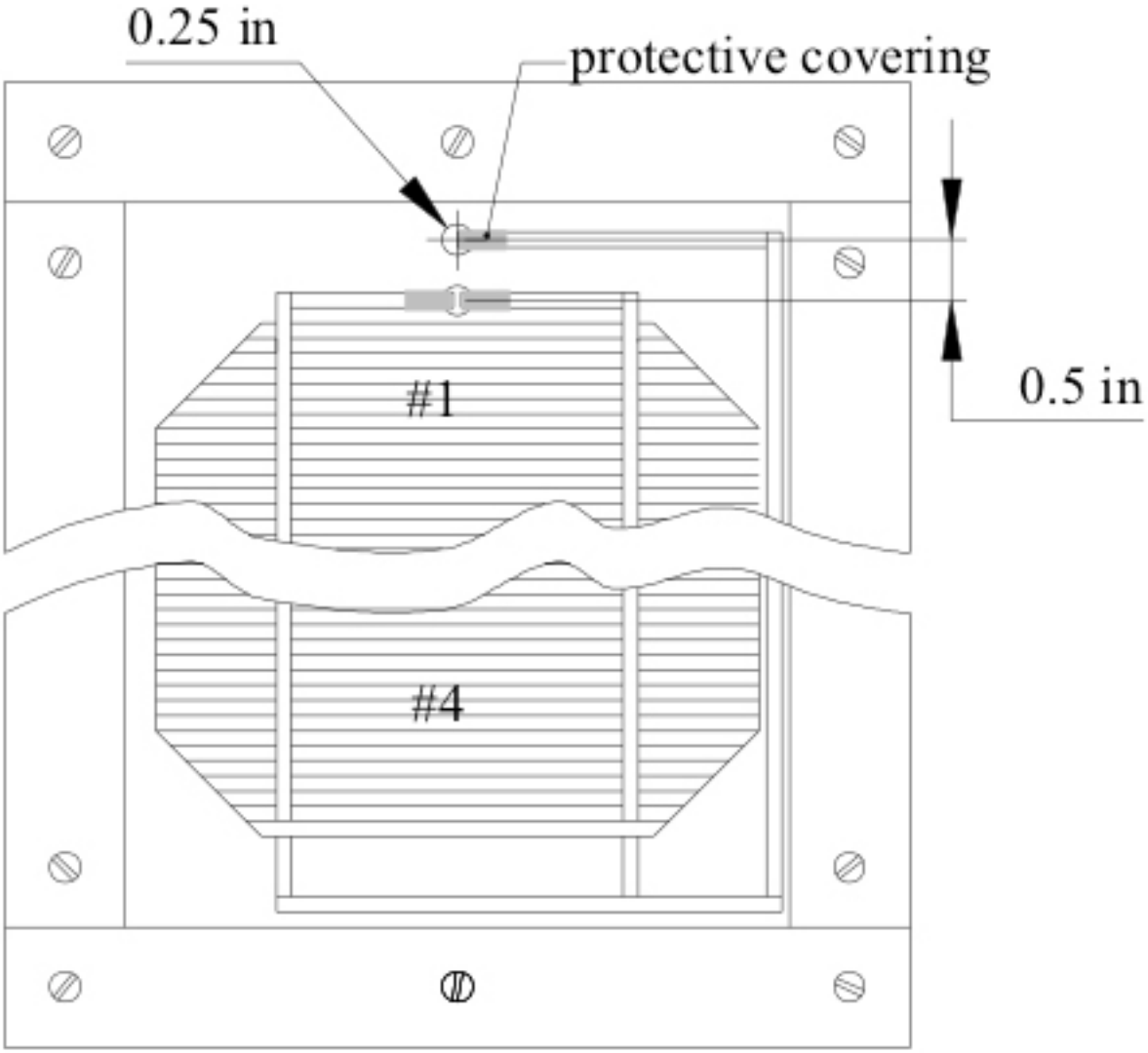
## Part 16 (180 minutes): Solar Cell Panel Plans

(NOTE TO TEACHER: It is imperative that the teacher have completed "sub-assemblies", completed assembly and concise instructions with minimal wordiness and lots of pictures on hand for the students to assist them in their construction phase of the PV module.)



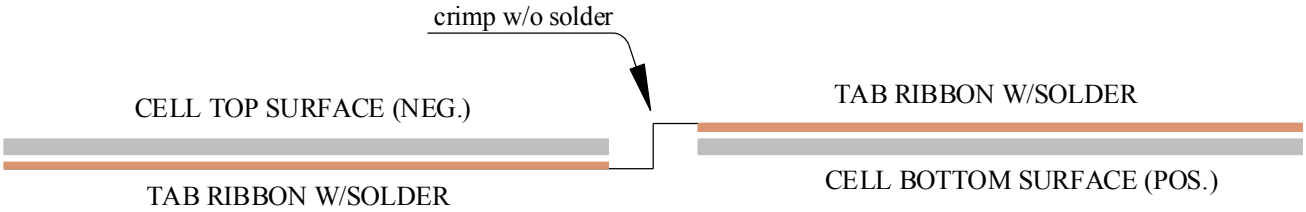

- Back panel: 1/8" x 7-1/2" x 24-1/2"
- Clear Face Polycarbonate Cover: 1/8" x 7-1/2" x 24-1/2"

- "Bar Stock": all pieces are 1/4" thick x 1" wide and cut to above specifications.
- Space cells apart according to specifications.
- Drill 1/4" diameter holes as per plan specifications and use nuts, washers and bolts provided for the project.



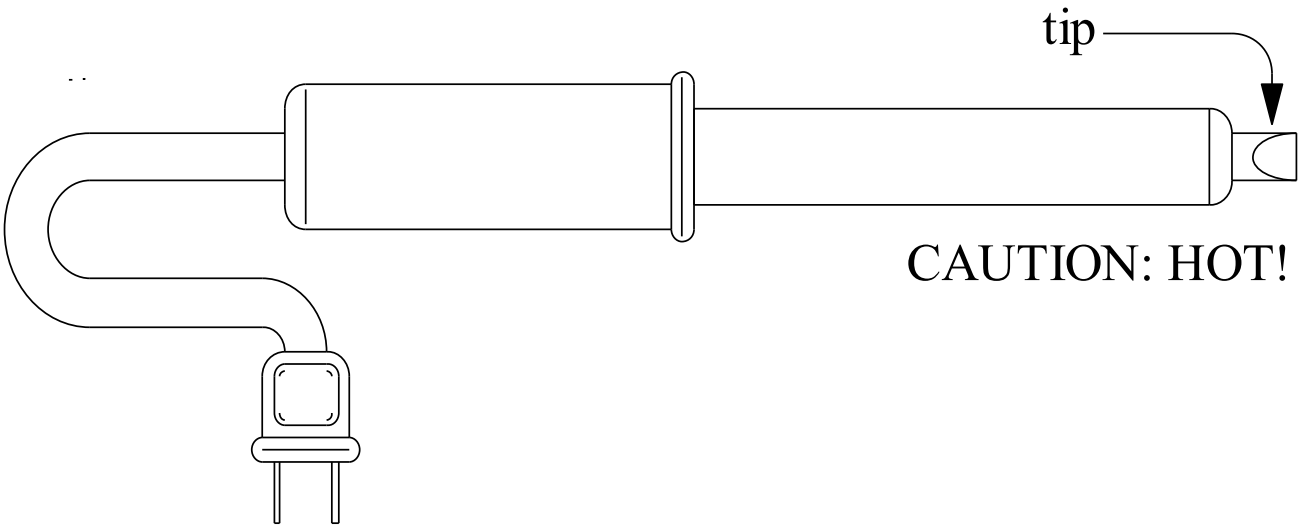

- Junction box holes drilled 1/4" diameter.
- Hole spacing for junction box is 1/2"
- Junction box mounted on back.

## Part 23. 90 minutes (dependent upon the number of students and soldering irons): Preparing Tab Ribbons




Length of ribbon is two times the length of a solar cell plus 1/2" for the crimp. You will need six completed tab ribbons for this project.

**TINNING / SOLDERING**




Before Use:

- iron is hot!
- wipe tip with damp sponge
- coat tip with solder

After Use:

- iron is hot!
- wipe tip with damp sponge
- coat tip with solder

**TINNING the RIBBON (applying solder)**

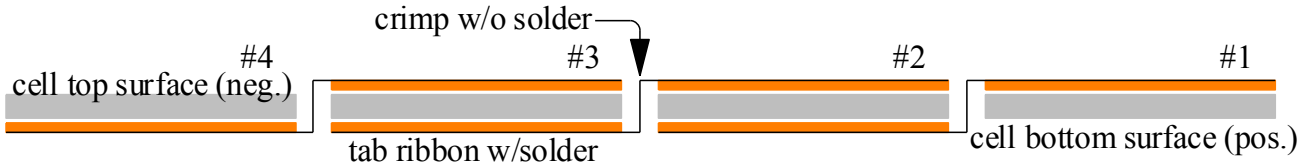
1. Set iron to 376$^0$F (solder turns to a liquid at 374$^0$F).
2. Cut ribbon to the proper length.
3. Flux one-half of the ribbon on one side only (leave 1/2" in the center not fluxed for crimping).
4. Immediately place cap back on the flux pen!
5. With a smooth, continuous motion of the iron, apply solder (tinning) to tab.
6. Wipe the iron tip with a damp sponge.
7. Coat the tip with solder.
8. Flux the other half of the ribbon on the opposite side only (leave 1/2" in the center not fluxed for crimping).
9. Immediately place cap back on the flux pen!
10. With a smooth, continuous motion of the iron, apply solder (tinning) to tab.
11. Wipe the iron tip with a damp sponge.
12. Coat the tip with solder.
13. Turn off iron unless another person is going to use it.

**SOLDERING the RIBBON to the SOLAR CELL**

Tinning and crimping of six ribbons are completed as the picture above indicates.

1. GENTLY, GENTLY, GENTLY flux the negative (face) of the solar cell along the connection point(s).
2. Immediately replace cap on flux pen.
3. GENTLY, GENTLY, GENTLY apply the solder side of one ribbon to the solar cell face.
4. GENTLY, GENTLY, GENTLY with a smooth, gentle, continuous motion of the iron melt the solder on the ribbon to the solar cell face. Hold the ribbon to the surface of the solar cell with a small wood block (do not apply pressure).
5. Repeat this process with the second ribbon.
6. Repeat this process with two more solar cells for a total of three tabbed cells. (A tabbed cell is a cell with soldered electrical connections.)

Soldering of two ribbons to the solar cell is completed.




1. Place the three tabbed solar cells face down on your panel backing board.
2. Gently place unused tabs from each cell on the back of the next cell.
3. Place the remaining cell on its face and unused tabs of the third cell on the back of cell number four. (See drawing, which is of the finished product, so it is upside down for your current purposes).
4. Flux the backs of the cells where the tabs will rest.

5. Align the solar cells one last time making sure the spacing is equal and correct. GENTLY, GENTLY, GENTLY with a smooth, gentle, continuous motion of the iron, melt the solder on the ribbon to the solar cell back. Hold the ribbon to the surface of the solar cell with a small wood block (do not apply pressure).
6. Repeat this process with the remaining ribbons.
7. Using another panel backing board (ask instructor for extra boards), place over finished work and gently flip over and add additional tabbing as instructed in the next step.

**ADDITIONAL TABBING for JUNCTION BOX (positive and negative junctions)**

- Additional tabbing must be soldered in place to permit capturing electrical energy produced by the solar cells.
- The negative sets of tabs are required to run from the top of the first solar cell and through a small hole to a junction box.
- The positive tab is required to run from the bottom of the fourth solar cell, up the side spacing and through a small hole to a junction box.
- These holes and the junction box are already in place on the panel.

1. Cut ribbons to length, tin and solder in place.
2. Place shrink tubing over tabs as a protective covering and gently place ribbon into holes for mounting inside junction box.
3. With dry fit confirmed, carefully remove solar cell assembly and set aside.
4. Coat the inside of the panel where the solar cells rest with a thin layer of silicon; this will adhere the cells to the inside of the panel.
5. Reinstall the cells.
6. When completed, place three plastic buttons in between the cells. This will prevent the cover from touching the cells.
7. Install the plastic cover and screws.



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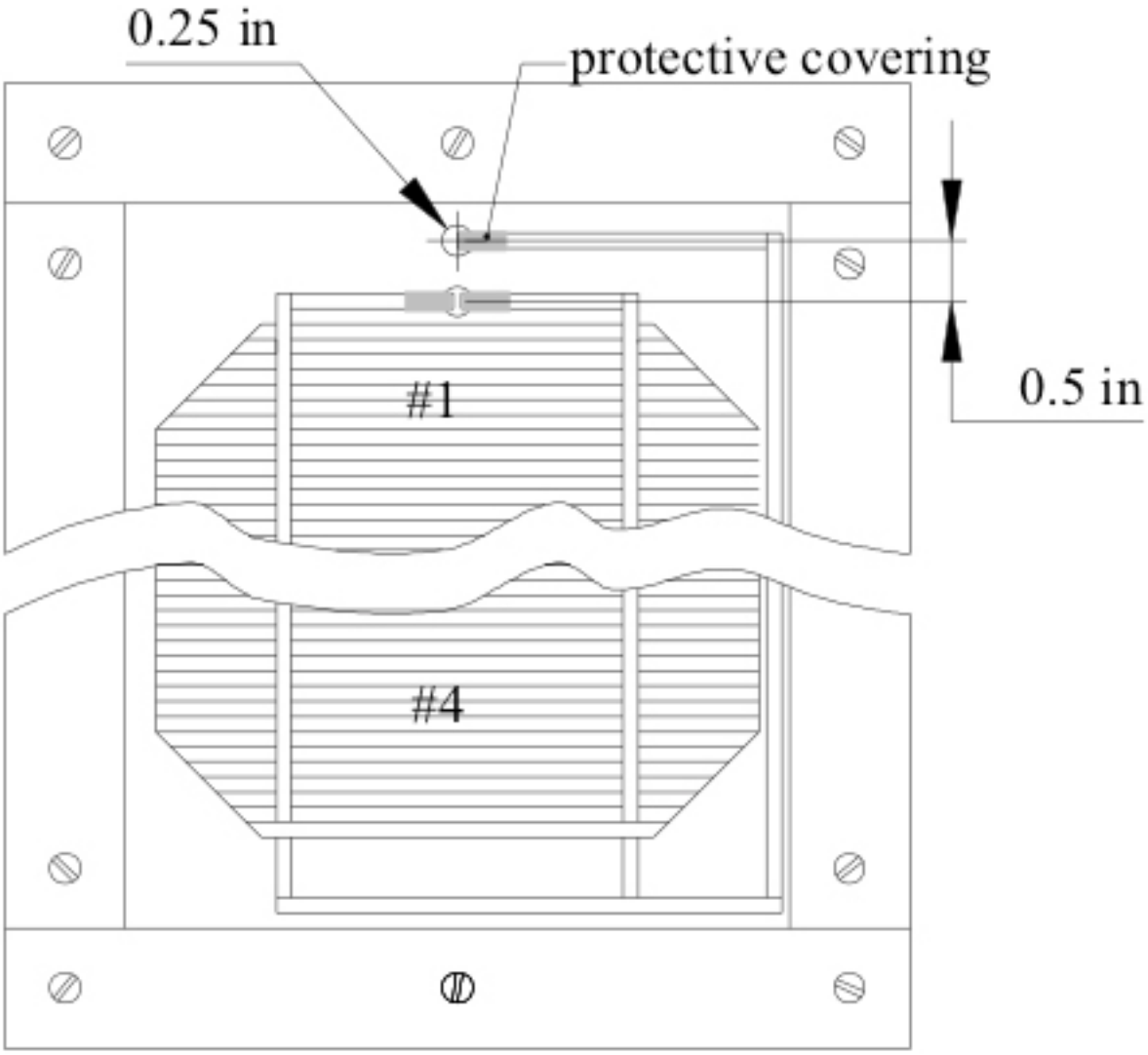
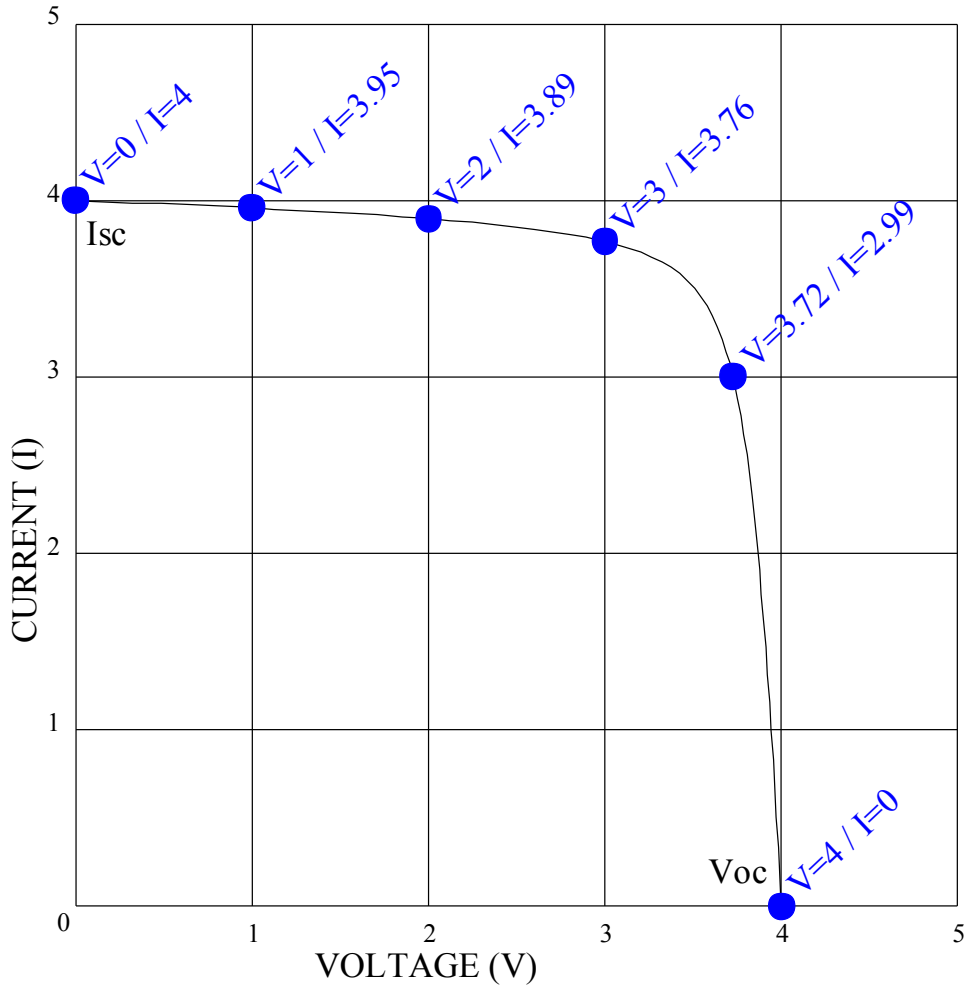



## Part 25 (90 minutes): Testing Your Solar Panel (creating an I-V curve)

- The current-voltage (I-V) characteristic is the basic electrical output profile of a Photovoltaic device.
- The I-V characteristic represents all possible current-voltage operating points and power output for a given PV device at a specified condition.
- Certain points on an I-V curve are used to rate panel performance and are the basis for design of arrays.
- A PV device can operate anywhere along its I-V curve depending upon the electrical load.
- Temperature and irradiance both affect panel output.




To create an I-V curve, you will need a multi-meter, testing clips, paper, resistors (these act like an electrical load) and a pencil/pen. Graph your results on an Excel spreadsheet and turn in. Be sure and save your file for later use.

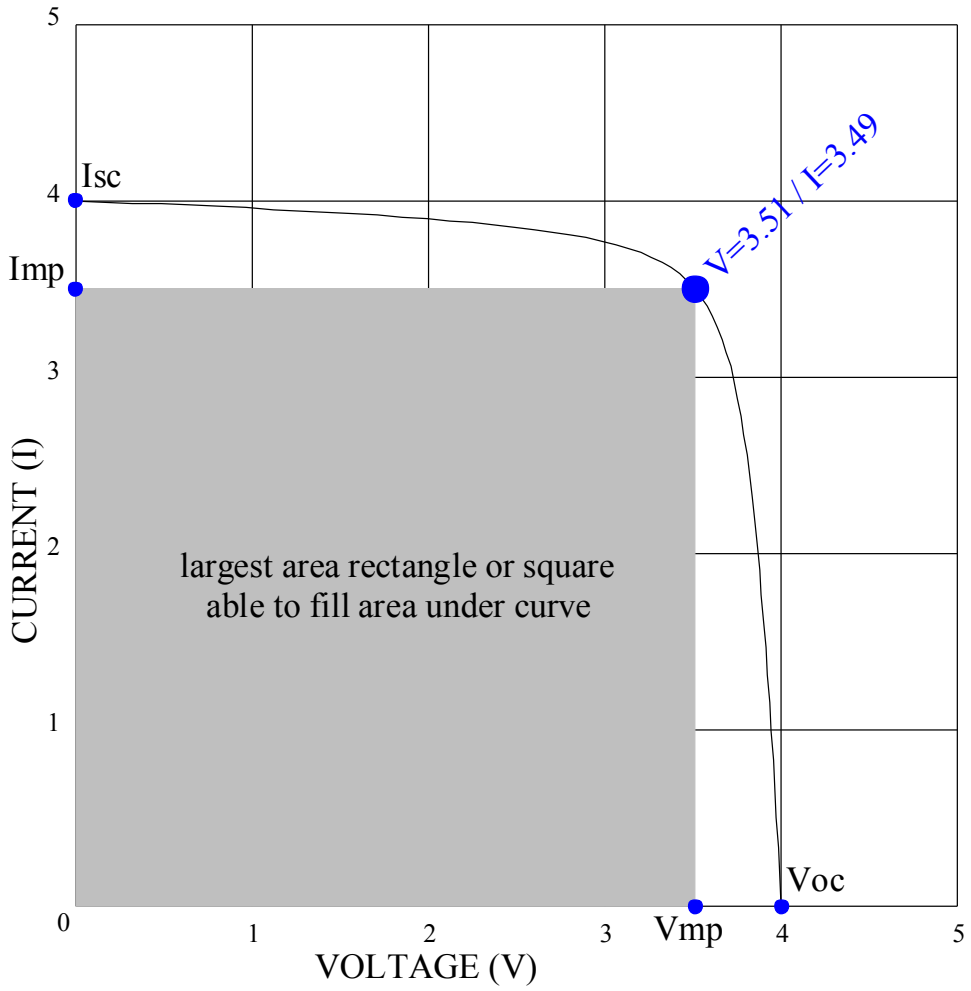
You will measure the performance of your module at six points.

- Point 1 will be short circuit amps ($I_{sc}$).
- Points 2-5 will require four different resistors provided by the teacher. (*Values subject to change.*)
  - resistor #1 (.253Ω/3.95W)
  - resistor #2 (.514Ω/7.78W)
  - resistor #3 (.798Ω/11.28W)
  - resistor #4 (1.244Ω/11.12W)
- Point 6 will be a voltage open circuit test.

Using the graph to rate your module:

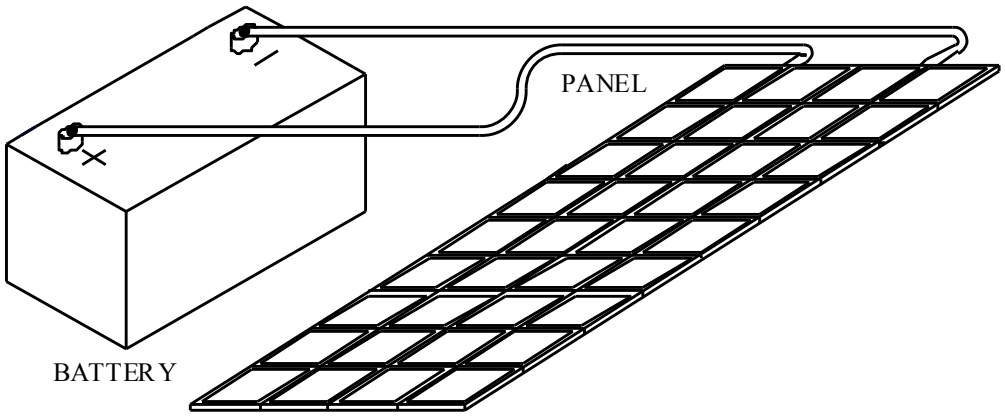
The largest square area able to be drawn under the curve will represent the Voltage Maximum Power ($V_{mp}$) and the Amperage Maximum Power ($I_{mp}$) your module should be able to produce under normal circumstances. Again, temperature and irradiance will affect output.

You will use the graph you created along with all the values generated in your final assignment of creating a brochure of your module's capabilities.

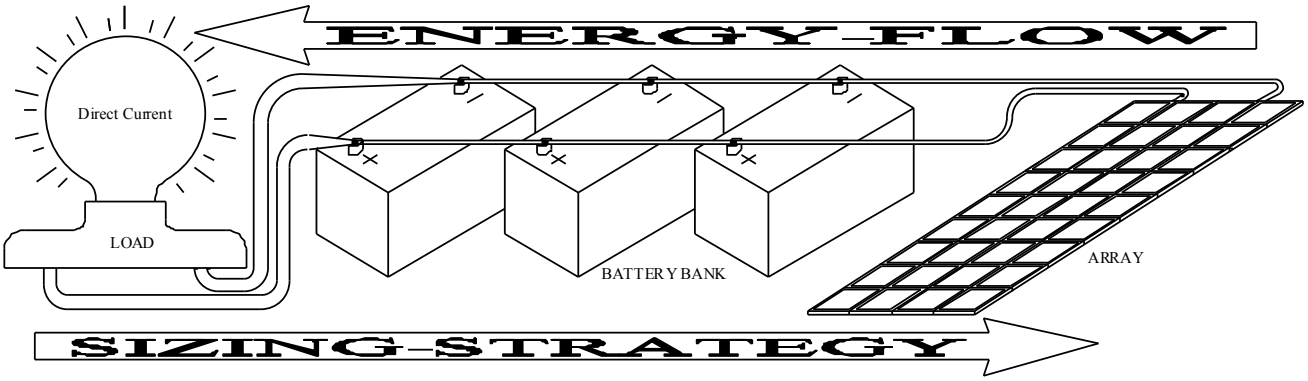



## Part 37 (30 minutes): Solar Array Sizing

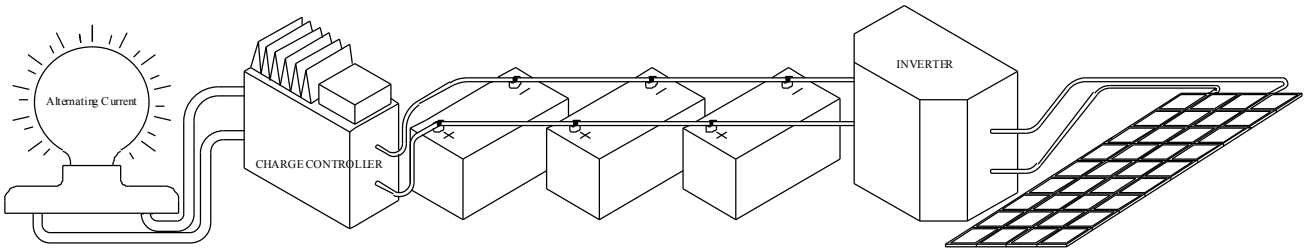
For simple systems such as a solar-powered battery charger, a solar panel can charge a battery and maintain it as long as the panel's designed voltage does not exceed the rating of the fully charged battery. The length of time required to charge the battery depends upon the panel's maximum amperage output and the amperage rating of the battery. A diode — a one-way electrical "valve" — is wired to the panel and will prevent cases of reversed energy flow. If the battery voltage is higher than the solar panel voltage, energy can flow from the battery to the panel and ruin it. Such cases can occur when the sunlight is blocked or one forgets to disconnect the battery during the night.



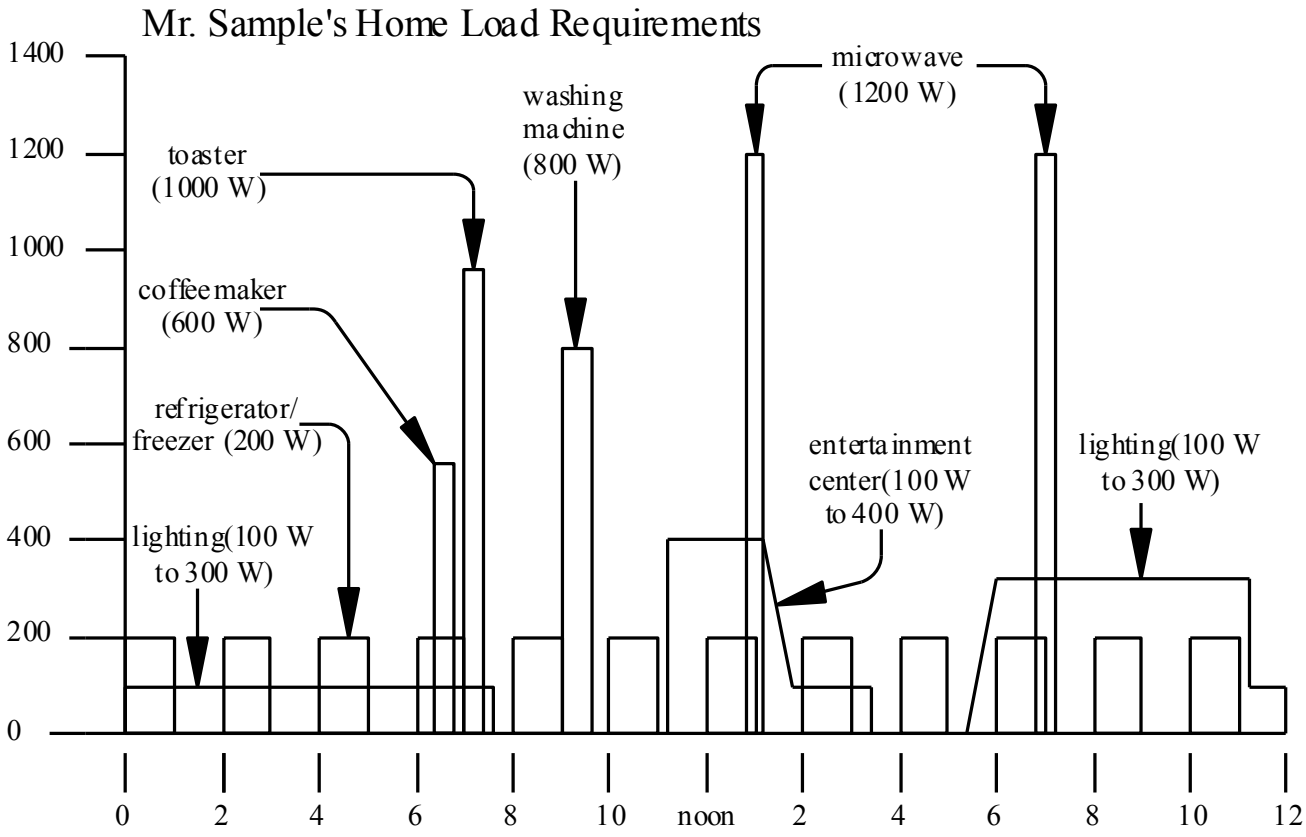

When designing an array to power a load, the maximum load is determined first and the array is designed to meet the needs of the load. This process is complicated and there is software available to help the engineer to design a system. It is pointless to design a system too small and not be able to have enough energy to supply your needs. A system too large is costly. There are buy-back programs available from the power companies to purchase your excess electricity, but not all utility companies actually do this. Determine your needs and do your research. We are going to keep the array sizing process simple for our needs.




The above drawing is a Direct Current example. For most homes, an inverter (shown on next page) is required to convert Direct Current (DC) into Alternating Current (AC). The inverter is not 100% efficient. Some energy is lost to heat. When designing your system, you must account for energy losses. In actuality, a large battery bank is required to supply the energy demand and the array recharges the batteries. The batteries provide the intermittent peak source requirements of energy for your home and the sun recharges them continuously.




Mr. Sample wants to consider an array to power his home. First, an assessment is done to determine how much energy Mr. Sample uses in his home. The assessment should be complete. In this example, Mr. S. uses a washer, but what about a dryer, heating and cooling? Also, a history of his monthly electric bills can prove useful. Likely, he will find energy consumption at its highest during the winter months. Remember, the sun's irradiance is lowest during the winter months.




After all the load requirements are determined, a total energy demand or load analysis can be determined. From here, an appropriate battery bank is designed to supply the energy requirements for the home and then the solar array output determined to recharge the batteries.

# LOAD-ANALYSIS

Month: August

AC LOADS

| Load Description | Qty. | Power Rating (W) | Operating Time (hr/day) | Energy Consumption (Wh/day) |
|---|---|---|---|---|
| Refrigerator/Freezer | 1 | 200 | 10.0 | 2000 |
| Mocrowave | 1 | 1200 | 0.5 | 600 |
| Toaster | 1 | 1000 | 0.05 | 50 |
| Coffeemaker | 1 | 600 | 0.25 | 150 |
| Washing Machine | 1 | 800 | 0.29 | 232 |
| Entertainment Center | 1 | 200 | 3.0 | 600 |
| Computer System | 1 | 100 | 2.0 | 200 |
| Plug Loads | 1 | 200 | 1.0 | 200 |
| Water Pump | 1 | 800 | 0.33 | 264 |
| Ceiling Fans | 2 | 50 | 24.0 | 2400 |
| Fluorescent Lighting | 4 | 15 | 6.0 | 360 |
| Fluorescent Lighting | 4 | 32 | 4.0 | 512 |
| | | | | |
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| | | | | |
| DC LOADS | | | | |
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| | |
|---|---|
| Total AC Power | 5388 W |
| Total DC Power | 0 W |
| Total Daily AC Energy Consumption | 7568 Wh/day |
| Total Daily DC Energy Consumption | 0 Wh/day |
| Weighted Operating Time | 11.2 hr/day |
| Inverter Efficiency | 0.90 (90%) |
| Average Daily DC Energy Consumption | 8409 Wh/day |

## Part 38 (90 minutes): Array Size

Given the above load analysis:

- Calculate how many of *your* solar panels will be needed to provide 8500 Wh/day if your ideal solar window is 5 hours long per day. (Assume the irradiance is constant during your 5 hour period and year 'round.)
- As the input power required for the DC to AC inverter is 48 Volts, draw a clear schematic of a segment of your 48 Volt array. Start with the individual cells and work your way up until a clear picture is developed of what you must do to achieve 48 Volts. Do not forget amperes in your array design.
- If your solar array should lay flat (which it will not), how large of an area will you need to provide enough power?
- Include all relevant data and show your calculations.

## Part 39 (90 minutes): Research Essay

Assemble a brochure of your solar panel to sell to the public. Include your I-V curve, a picture or two, cost, and any other performance characteristics you feel will be helpful to entice a possible customer to buy your product over another.

### College and Career Connections:

With the successful completion of this exercise, students can collect data, analyze real-world scenarios and use mathematical models to develop a sound conclusion through productive use of problem solving strategies. The process of this task mimics the multitude of projects engineers and scientists perform in the “real-world” every working day.



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