



The Solar Energy Activity Lab (SEAL)

User's Guide

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For assistance setting up the SEAL kit or help troubleshooting any problems that may arise, please contact Michelle DeBoever at mchansen@caltech.edu or (626) 395-2829.

1. Preface

The Solar Energy Activity Lab (SEAL) enables users—in collaboration with university scientists—to conduct research directed at solving the greatest technological problem of our time: using sunlight to meet the world’s growing demand for consumable energy. This user manual is not simply a set of instructions; it is a comprehensive guidebook. We outline the motivation of this specific line of research, the function of the kit, the experimental design, and the scientific principles at play.

A second motivation for this guide is the establishment of a common protocol for these experiments. A standard protocol will help maximize the productivity of participants and facilitate the analysis of data. In any scientific effort, it is important to be rigorous in maintaining a standard procedure that limits unintentional variation from experiment to experiment. Such an approach allows the direct comparison of data collected by researchers using many different SEAL units.

This guide has been written to be accessible to anyone who has taken a high-school class in chemistry. For curious and advanced readers, we suggest additional reading materials that discuss concepts in more depth than is practical here.

2. NGSS Alignment

As the SEAL kit is often used in the high school classroom or as an after school project for advancing STEM learning, we have decided to include a list of NGSS standards that the SEAL project addresses. We hope that the SEAL kit will be a valuable resource for high school teachers as they implement new curriculum that includes crosscutting concepts and science and engineering practices.

NGSS #	STANDARD DESCRIPTION	Alignment with SEAL
HS-PS1-6	<i>Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.</i>	In the clarification statement, it says “Examples of designs could include different ways to increase product formation including adding reactants or removing products.” Different combinations of metal oxides are attempted by the students to find the best material. Students must balance the cost of the material, relative abundance, and overall activity.
HS-PS3-3	<i>Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.</i>	In the clarification statement, it says “Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.” Students being by creating different model systems of mixed metal oxide semiconductors. These systems are constrained by factors such as abundance, activity, cost, light absorbing capability, ease of use, and stability.
HS-ESS3-2	<i>Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.</i>	The students will be able to compare their current materials to ones in the database or the internal standard, while evaluating the usage of different metal precursors based off of their earth abundance. Additionally, the method of water splitting can be compared to other methods such as PV technology.
HS-ESS3-4	<i>Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.</i>	The projects goals to produce oxygen and hydrogen from sunlight using an inexpensive, earth abundant material providing another option for renewable energy. The students will be able justify their choices of precursors vs. earth abundance and compare the current results to the results within the projects. Also, students will able to hypothesize ways to make the projects work on a large scale, then compare their idea to the current technologies and how those technologies can impact natural systems.

3. Introduction

3.1. Motivation: Global Energy Demand and the Need for Solar Power

The world is facing an energy crisis. Our society's demand for consumable energy is increasing under the stresses of a growing population and escalating industrial development. At present, the vast majority of the world's energy needs are satisfied by the combustion of fossil fuels. Common examples of this technology include powering vehicles with gasoline and generating electricity by burning coal. There are two principal reasons why the present system is unsustainable in terms of meeting the world's growing demand for consumable energy. First, the supply of fossil fuels is not limitless, and in the future, hydrocarbon reserves will be more difficult to access unless we develop new methods for doing so. Second, the extraction and combustion of fossil fuels harms the environment. Carbon dioxide is an unavoidable byproduct of burning hydrocarbons, and CO₂ is a greenhouse gas that contributes to global warming.

We need to find alternative means for powering our planet that rely on sources of energy that are inexhaustible and don't pollute the environment. The main alternatives to fossil fuels are nuclear, wind, hydroelectric, hydrothermal, biomass, and solar technologies. Each of these methods brings its own advantages and disadvantages, which are briefly summarized in Table 1.

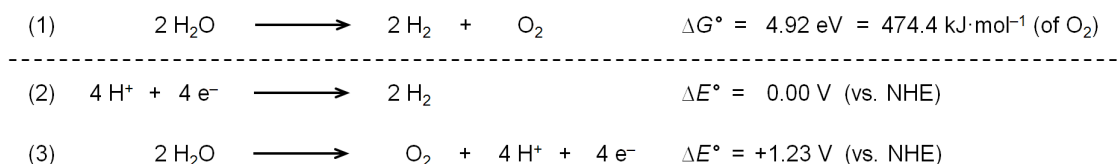
Technology	Capacity	Advantages	Disadvantages
Fossil fuels	>5000 TW·yr	<ul style="list-style-type: none">• Existing technology• Existing infrastructure• Inexpensive	<ul style="list-style-type: none">• Produces CO₂• Not renewable
Nuclear	100 TW·yr	<ul style="list-style-type: none">• Existing technology• Produces no CO₂	<ul style="list-style-type: none">• Generates hazardous waste• Ltd. supply of radioactive ore
Biomass	7 TW	<ul style="list-style-type: none">• Renewable	<ul style="list-style-type: none">• Uses agricultural land• Inefficient
Hydroelectric	1.6 TW	<ul style="list-style-type: none">• Effectively inexhaustible• No pollution	<ul style="list-style-type: none">• Very limited capacity• Floods land, affects wildlife
Hydrothermal	11 TW	<ul style="list-style-type: none">• Effectively inexhaustible• No pollution	<ul style="list-style-type: none">• Limited capacity• Low energy density• Limited infrastructure
Wind	4 TW	<ul style="list-style-type: none">• Effectively inexhaustible• No pollution	<ul style="list-style-type: none">• Limited capacity
Solar	600 TW	<ul style="list-style-type: none">• Effectively inexhaustible• High capacity	<ul style="list-style-type: none">• Expensive (at present)• Limited infrastructure• No output at night or when cloudy

Table 1. Summary of some of the main advantages and disadvantages of various sources of consumable energy. The values for capacity—very rough estimates for the maximum global output of each technology—have been taken from Lewis and Nocera.¹ Capacity estimates are given in units of (remaining) energy for non-renewable sources and power for renewable sources.

It appears that solar technology is the only option that can meet the world's growing demand for energy—estimated at 27 TW by the year 2050—without disastrous environmental consequences. For solar energy to become a practical alternative to fossil fuels, we must find efficient and economical methods for using sunlight to produce fuels that can be stored and transported easily. The storage of solar energy in chemical fuels is of critical importance, because people want to be able to power their vehicles and other mobile devices wirelessly, as well as to use electricity at night, when the Sun does not shine.

3.2. Our General Approach

There are many approaches to harvesting the energy in sunlight. At CCI Solar, we are especially interested in using sunlight to split water (H_2O) into hydrogen (H_2) and oxygen (O_2). The idea is that the oxygen gas can be vented—it already constitutes 21% of our atmosphere—while the hydrogen gas that is produced can be stored and used to generate electricity when needed by a standard hydrogen fuel cell.



Equation (1): *Water Splitting*; **Equation (2):** *Proton reduction*; **Equation (3):** *Water oxidation*

Equation (1) is the balanced chemical reaction for splitting water. This overall reaction is the sum of two electrochemical half-reactions: the reduction of protons to form hydrogen (2) and the oxidation of water to form molecular oxygen and protons (3). Figure 1 depicts a model photoelectrochemical cell for the photolysis of water. It consumes water and sunlight to generate H_2 and O_2 . The cell shown below is only a model in the sense that we know what generic components we'll need and the tasks we want them to perform, but not what specific materials can be used to build these components. That is the point of our research—we are still working to determine the best materials to build this system. With your SEAL experiments, you will contribute to this research effort.

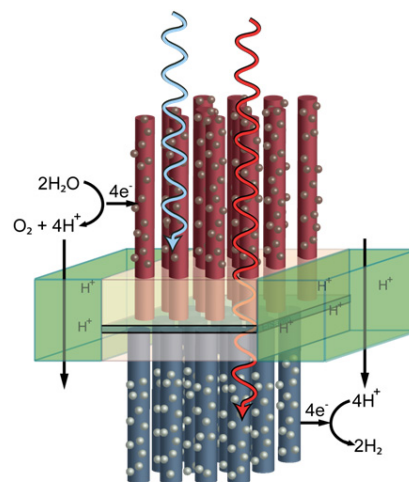


Figure 1. *A model photoelectrochemical cell for splitting water into hydrogen and oxygen with sunlight.*

Image credit: Elizabeth Santori.

The model cell has two main compartments: one for hydrogen evolution by the reduction of protons at the cathode, and one for oxygen evolution by the oxidation of water at the anode. The compartments are separated by a membrane that keeps each half-reaction contained but allows protons generated at the anode to pass to the cathode, where they react to form hydrogen. The membrane also keeps the H_2 and O_2 gases that are produced from mixing. Section 3.3 discusses the components of the electrochemical cell in greater detail.

Catalysts are substances that speed chemical reactions. In the construction of the model cell in Figure 1, the electrodes need to serve two key purposes: (i) to absorb photons capable of providing

the energy to split water, and (ii) to catalyze the half-reactions at the surface of the electrodes. Metal oxides are the class of materials we will study in our experiments. These materials can serve both purposes in our system.

Our experiments entail screening metal oxides for the photoelectrolysis of water. This effort builds on the pioneering work of Bruce Parkinson and coworkers at the University of Wyoming.² Their team constructed a system to screen combinations of metal-oxide semiconductors, and then simplified the system such that it could be distributed as a kit—the Solar Hydrogen Activity Research Kit (SHArK)—to be assembled locally for use in high schools and colleges. Winkler and Winkler developed a second-generation system—the Solar Materials Discovery (SMD) kit—that cut the screening time down from hours to minutes and introduced a multitude of other improvements.³ This system was renamed the Solar Energy Activity Lab (SEAL) and is the system you will use to search for catalysts to split water.

3.3. A More Detailed Look into the Photoelectrochemical Cell for Splitting Water

Building the photoelectrochemical cell shown in Figures 1 and 2 is the overarching goal of the NSF CCI Solar Center headquartered at Caltech. We believe it holds promise as *the* solution to the world's energy needs, but before we can build it, we must research what materials and methods we can use to produce each component. Figure 2 identifies these components and their functions.

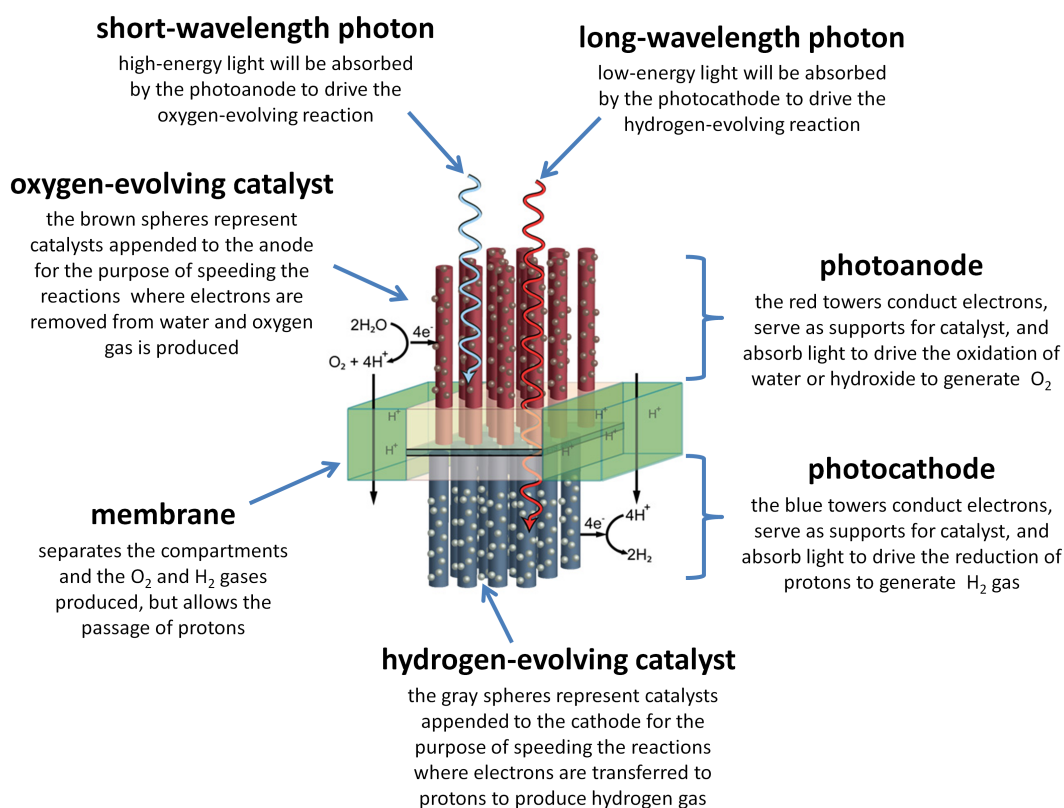


Figure 2. A diagram of the photoelectrochemical cell we wish to construct to split water into hydrogen and oxygen gases. Each component is labeled with its function in the system.

The system depicted in Figure 2 probably does not look like the electrochemical cells you've studied in chemistry textbooks. Figure 3 is the equivalent cell drawn as a common H-cell, a depiction that may seem more familiar to you.

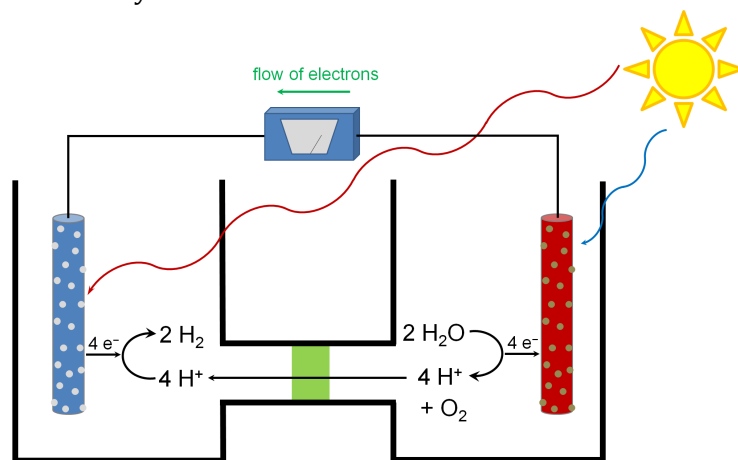


Figure 3. A diagram of the photoelectrochemical cell for splitting water drawn as a common H-cell. While this depiction is a useful learning tool since it is similar to the electrochemical cells most commonly encountered in general-chemistry textbooks, it is not practical for the mass production of consumer devices.

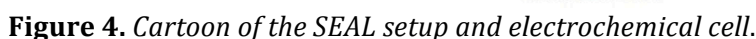
3.4. How the SEAL Experiments Work

While final target system for our collective research appears in Figure 2, we will focus on one piece of the puzzle: investigating metal-oxide semiconductors as materials that can both absorb light and catalyze the production of H₂ or O₂ gas from water. In our work, metal oxides will serve the combined roles of the towers and balls on the electrodes in Figure 2. Since we are focusing on this single aspect of the system, we need not construct the complete electrochemical cells drawn in the figures above. Instead, we can introduce shortcuts and simplifications to speed our experiments:

- *Examine one half-reaction at a time.* To keep things simple, we will only study catalysts for one half-reaction at a time, either equation (2) or (3). The electrode corresponding to this reaction—either the anode or the cathode—will be the “working” electrode. The other electrode will be replaced by a simple graphite rod that serves as a counterelectrode to provide a source or sink for electrons that avoids the accumulation of charge. By making this simplification, we need only construct a cell with one compartment—a simple glass dish.
- *Use a glass plate as a substrate for the working electrode.* Whereas you might normally associate an electrode as a piece of wire or metal foil, we will use 3” x 3” glass plates with a conductive fluorine-tin oxide (FTO) coating on one side. The fact that glass and FTO are transparent allows us to irradiate the spots (with light) through the electrode, such that the photons are absorbed where the samples come in contact with the conductive plate. The large surface area of the electrode will allow us to study multiple samples on one plate, which will help to speed the process of screening them for activity.
- *Potentiostat.* Perhaps the most important component of the SEAL kit is a potentiostat—a device that can apply a constant potential (i.e., voltage) across an electrochemical cell. We will apply a small bias potential to our system to help “push” the reactions along.

- $$E_{cell} = E^0 + \frac{RT}{nF} \ln \left(\frac{[Ox]}{[Red]} \right)$$

In our experiments, we are going to build a modified version of the electrochemical cell shown in Figure 3, in a fashion that is designed to study the specific reactions in which we are interested. The SEAL electrochemical cell is drawn in Figure 4; you will notice that our physical system looks very different from the target system in Figure 1.



3.5. How Semiconductors Work

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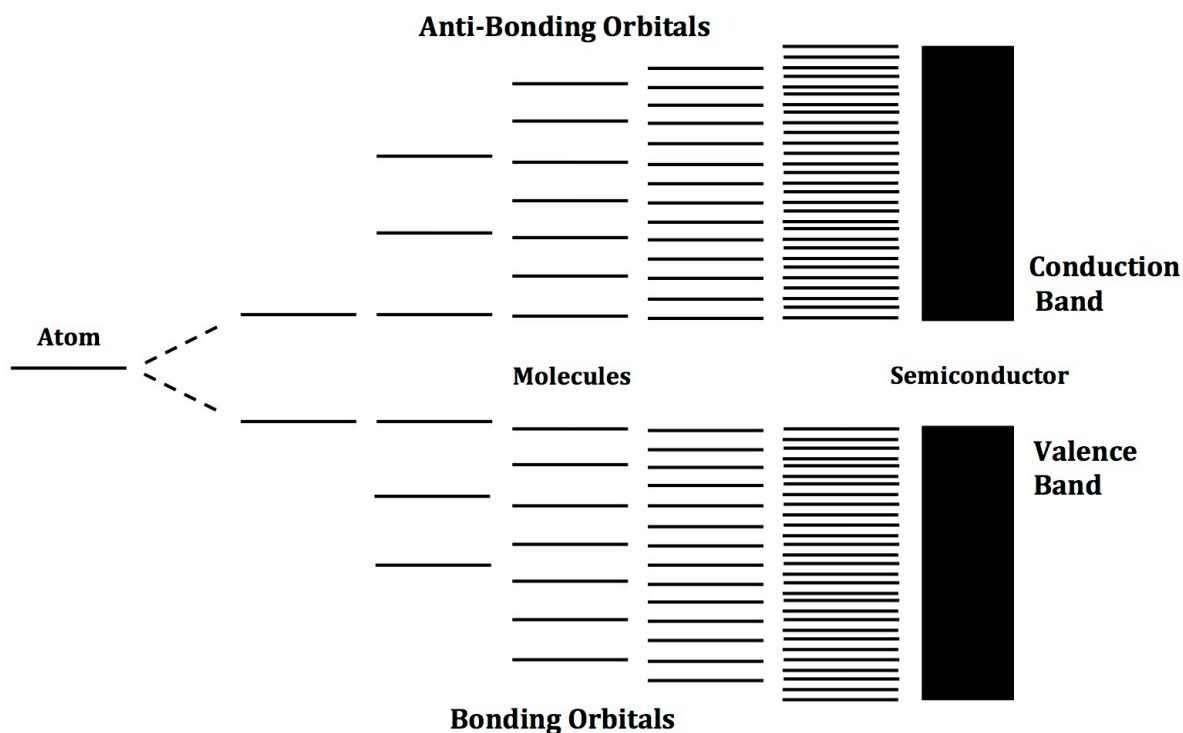


Figure 5: *Bonding and anti-bonding orbitals combining to form the valence band and conduction band of a semiconductor respectively*

The electrons are naturally more stable in the lower-energy valence band, but while they are here, they are not very mobile. This lack of mobility presents a problem to us, because we want to catalyze reduction–oxidation reactions that require the exchange of electrons. Energy is required to promote electrons into the conduction band, where they are more mobile.

4. Materials List

Items included with the kit:

- USB Flash Drive with National Instruments hardware drivers, standalone SMD software, excel templates and User's Guide
- LED Array Unit (black box)
- Current Integrator (aluminum box, with electrode leads)
- Digital Voltmeter/Multimeter (small red box)
- CAT 5 ethernet cable (connects LED to integrator)
- USB Cable (connects integrator to PC)
- BNC Cable (connects integrator to voltmeter)
- 5 FTO-coated glass slides, 3" x 3" square (Hartford Glass, #TEC 15 (765) 348-1282)
- Pre-spotted iron oxide sample
- Copper Tape with Conducting Adhesive (McMaster-Carr: 76555A712, 1/2" wide)
- 5-min Epoxy (Devcon 20845 5-min epoxy)
- Insulated Wire (McMaster-Carr: 8054T22, stranded wire)
- 2 Graphite Rods (Wale Apparatus: 12-1201, 1/8" x 12")
- Spotting Template
- User's Guide

Required items not included with the kit:

- Computer running Windows XP or 7 operating system (NOT Windows 8 or Mac)
- Pyrex glass crystallization dish, 125 mm x 65 mm or larger
- Sodium Hydroxide, 0.1 M aqueous solution
- Isopropanol or acetone
- Micropipette (5-25 μ L range) and disposable tips (Cheap version with 25 μ L range: <http://www.flinnsci.com/store/Scripts/prodView.asp?idproduct=18990>)
- Jewelry kiln (Good, cheap version: Paragon SC2 - http://www.clayking.com/kilns/paragon_kilns/paragon_sc2.html)
- Scotch tape

5. Plate Preparation

- 1) Clean your glass slide (both sides!) with water and isopropanol or acetone. Next, dry the slide.
- 2) Test for the conductive side of the glass using your multimeter on the 2000 Ω setting. The side with a measurable resistance is conductive (will measure in the 20-100 Ω range).
- 3) Place the glass plate conductive side up on top of the plate-spotting template. These circles will be the area in which to deposit the solutions.
- 4) Using a micropipette, deposit between 5-10 μL total of solution per spot. If using more than one solution, be sure to calculate ratios of metal salts based on both their molarities and volumes deposited.
- 5) When the spotting is complete, the solutions need to evaporate. It is optional to warm the glass plate on a hotplate set at 80-100°C (typically setting 2-3) for several minutes until spots evaporate. This method is faster and will help avoid the “coffee ring effect” which often occurs from air-drying, but is not absolutely necessary. Once the spots are evaporated, fire the plate at 500°C for approximately 3 hours. A small jewelry kiln works very well for this.
- 6) Cut a ~5” piece of wire and strip ~0.5” of insulation off of each end. Once the plate is fired and cooled back to room temperature, attach one end of the wire to the top left (1,1) corner of the plate using the copper tape. Be sure to splay the wire strand onto the plate to make as much contact as possible. Then cover all of the copper tape and exposed wire with 5 min epoxy. If any copper or wire is exposed, the circuit will short and the plate will not work.

5.1. Decision of Metals to Spot

You might think that any element on the Periodic Table is fair game for us to use in our research. While many of these elements are of interest to us, practicality forces us to exclude the following elements:

- *Non-Metals.* We will focus on the study of metals, elements that typically lose electrons and form stable oxides. Most non-metallic elements do not form oxides useful as catalysts for splitting water.
- *Radioactive elements.* We do not wish to use highly radioactive isotopes of elements because: (i) they emit harmful radiation and (ii) radioactive elements decay to other elements over time. Some elements that we will not use include U, Pu, and Th.
- *Precious metals.* We want to identify catalysts made from inexpensive, earth-abundant materials such that the construction of the final photoelectrochemical cell is economical. Elements that are probably too rare for our purposes include Ru, Pd, Rh, Te, Ir, Os, Re, Pt, and Au.

Just about all of the other elements are fair game, but you are encouraged to attempt experiments with different materials than those already studied. To see what mixtures have already been studied, you can access the Solar Materials Discovery database at: <http://www.bilrc.caltech.edu/solmatdisc/>

Remember to consult a Materials Safety Data Sheet (MSDS) before you handle any chemical with which you are not familiar. Safety first!

5.2. Suggestions for spotting

When spotting to survey mixtures of elements, it is considered efficient to test gradients of your mixtures. In these patterns, the spots are mixtures of the same elements in slightly different proportions, usually arranged such that the concentration of an element steadily increases or decreases as you move down a column or across a row.

If you decide to use a gradient, it may be easiest to follow the pattern shown below in Figure 6. This pattern is built into the software such that you can inform the program of the elemental composition of each spot in relatively few keystrokes (data entry, while important, can be monotonous).

COL ROW	1	2	3	4	5	6	7	8
1	0 : 90 : 0	0 : 80 : 10	0 : 70 : 20	0 : 60 : 30	0 : 50 : 40	0 : 40 : 50	0 : 30 : 60	0 : 20 : 70
2	10 : 80 : 0	10 : 70 : 10	10 : 60 : 20	10 : 50 : 30	10 : 40 : 40	10 : 30 : 50	10 : 20 : 60	10 : 10 : 70
3	20 : 70 : 0	20 : 60 : 10	20 : 50 : 20	20 : 40 : 30	20 : 30 : 40	20 : 20 : 50	20 : 10 : 60	20 : 0 : 70
4	30 : 60 : 0	30 : 50 : 10	30 : 40 : 20	30 : 30 : 30	30 : 20 : 40	30 : 10 : 50	30 : 0 : 60	
5	40 : 50 : 0	40 : 40 : 10	40 : 30 : 20	40 : 20 : 30	40 : 10 : 40	40 : 0 : 50		0 : 10 : 80
6	50 : 40 : 0	50 : 30 : 10	50 : 20 : 20	50 : 10 : 30	50 : 0 : 40		10 : 0 : 80	0 : 0 : 90
7	60 : 30 : 0	60 : 20 : 10	60 : 10 : 20	60 : 0 : 30		80 : 0 : 10		
8	70 : 20 : 0	70 : 10 : 10	70 : 0 : 20		80 : 10 : 0	90 : 0 : 0		10 μL Fe^{3+}

Figure 6: Gradient spotting pattern

If you are running experiments under non-standard conditions, you will want to spot one or more 0.05M $\text{Fe}(\text{NO}_3)_3$ samples on every plate as a standard

Note that a small amount of light from one LED can spillover into the adjacent spots on the slide. It is often is a good idea to leave a blank space between spots, forming a checkerboard-like pattern.

6. Assembly of the Instrument

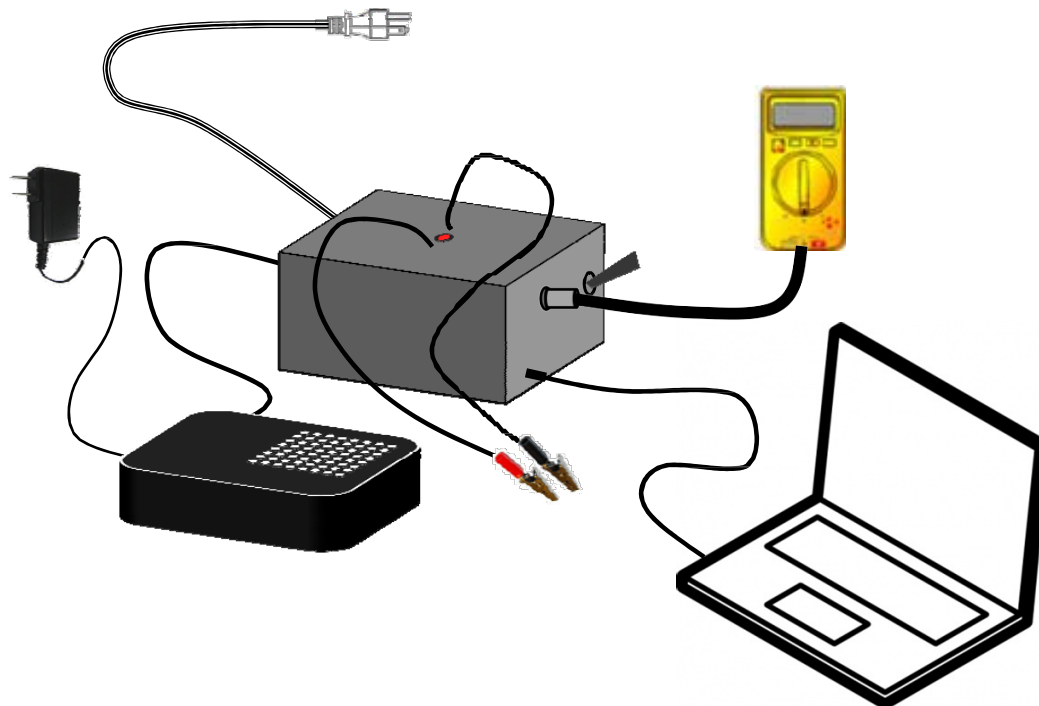


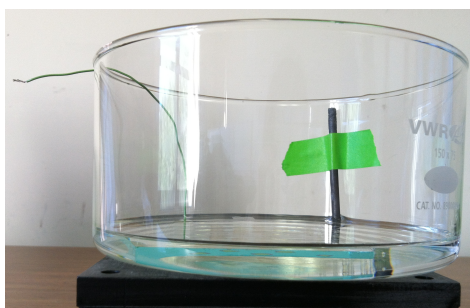
Figure 7. Schematic diagram showing the connectivity of the SMD instrument.

SAFETY: Always wear eye goggles and gloves when working with chemicals. The electrolyte solution (0.1 M NaOH) will burn skin and eyes. Flush eyes or skin with water for 15 min in case of accidental contact. Avoid skin and eye contact with epoxy resin. Can cause irritation and bonding of skin to itself or other materials.

- 1) Connect the components of the instrument as shown in Figure 7. Do not yet connect the leads to the electrodes (the sample plate and the graphite rod counter electrode). It is generally good practice to plug the silver Current Integrator electronics box (the box that connects to the voltmeter) and the LED array (black plastic box) into different outlets. The LED array may light up depending on the order the devices are connected. This is perfectly fine. The “ground” lead (black) of the BNC cable connects to the “COM” port of the voltmeter and the other lead (red) into the “VΩmA” port. Reversing the leads will make all the voltages read the same numerical value, but with opposite sign.



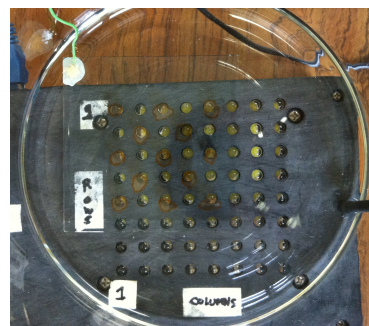
- 2) Use tape to secure the graphite rod (counter electrode) to the side of the crystallization dish. The rod should be vertical on the side of the dish with the bottom of the rod touching the bottom of the dish. Be sure the tape is at least an inch above the bottom of the electrode so that the electrode makes contact with the sodium hydroxide solution (next step) in the dish. Place the plate in the bottom of the dish with the metal-oxide spots (with epoxied wire) facing upwards.

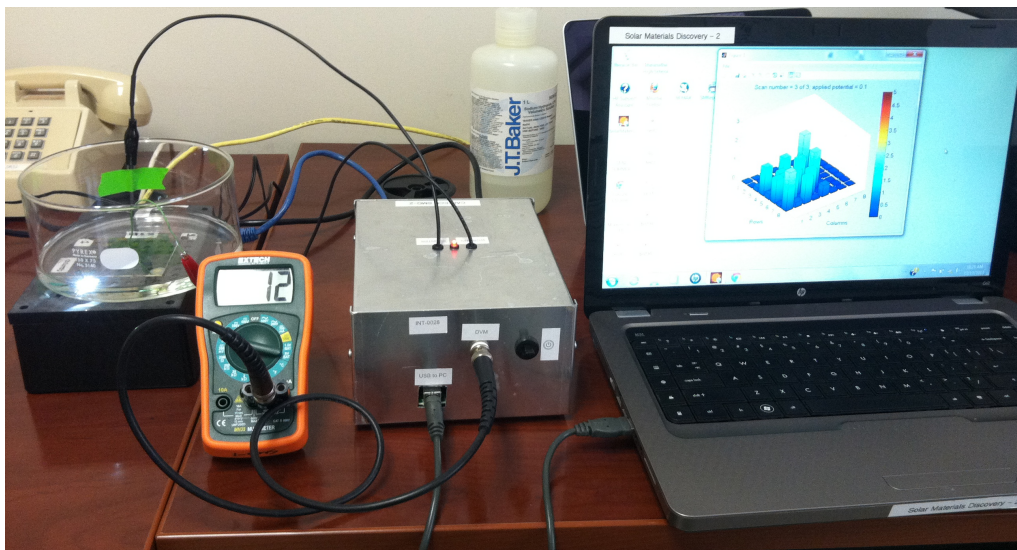


- 3) Fill the glass dish with electrolyte (e.g., 0.1 M NaOH) so that the plate is completely immersed and that some part of the graphite rod is submerged. A large quantity of electrolyte beyond this minimum is not required. The level of electrolyte should NOT be so high that the alligator clips will come in contact with electrolyte; the clips should only attach to the dry parts of the electrodes.
- 4) Make sure that the alligator clips have still not been attached yet, then activate the power (toggle) switch on the current integrator box. The LEDs might activate and blink at this step. (Note: Having the alligator clips attached and the circuit completed when powering on the current integrator may cause too high of a voltage to pass through the system and fry the electronics).
- 5) Activate the voltmeter. Set the voltage switch to 20 DCV range.
- 6) Start the Solar Materials Discovery program by clicking on the Solar Materials Discovery shortcut. Select "yes" to override any warnings that pop up. The program takes several seconds to start up as various drivers are loaded.
- 7) Eventually, you will see a prompt in the open window asking for the reading on the voltmeter. This step is intended to calibrate the applied voltage, and set the equipment to a zero position before beginning any experimental work. You should enter the voltmeter reading in units of volts (e.g., "0.035" V corresponds to 35 mV). After entering the value, the voltmeter should read 0.000 V (or within a few mV of this value). If it does not read close to zero, you may have incorrectly entered the voltage reading. Exit the program and try again.
- 8) Now connect the leads to the electrodes: connect the counter electrode (the graphite rod) to the black alligator clip; connect the working electrode (the conducting glass sample plate) to the red alligator clip.
- 9) You will notice the LEDs turn on and off. This is an initialization sequence; wait for it to complete. A menu will open when the process is complete.

7. Scanning a Plate

- 1) Click on the button “Apply Voltage” to set the bias potential in volts. For general scanning for water oxidation, enter “0.100” to set the bias potential to +100 millivolts. Wait a few moments and note that the voltmeter now reads +0.100 V (within ± 0.02 V). If the voltmeter does not read close to the value that you entered, there may be a calibration problem. Exit the program and try again.
- 2) Click on the button “Check Dark Current” (also referred to as rest current). This will generate a plot of volts vs. time on the screen and should stabilize to a low value (<0.5). The y-scale is volts because there is a current-to-voltage conversion within the equipment itself. Please remember that the units of current are typically microamps. Continue to periodically click on this button until the points stabilize around a common value. Ideally, the points will be low on the plot (<0.5). This process can take a little waiting (1-10 minutes), but you can periodically recheck the dark current as many times as you like over this period. If the rest current is large, try reducing the applied voltage to (0.05–0.10 V). High rest currents decrease the signal-to-noise ratio during the light-driven experiment that forms the basis of the results obtained from the kit, so the lower the Dark Current, the better your results will be!
- 3) Make sure the glass plate (i.e., the working electrode) has its spots aligned properly over the LED array and in the proper orientation relative to the row/column pattern you have used for spot composition. Improper orientation of the plate will result in mismatch errors when the data are reported for the semiconductor materials. Note: the cone of light emitted from any one LED may overlap with an adjacent spot if the spots are not well defined and sharp. This can lead to some “cross-talk”. With experience, you will be sufficiently adept at pipetting to form the individual spots that this will not be a major problem.
- 4) Click “Perform a Scan”. Enter the number of cycles that will be averaged for this scan (e.g., “3”). Each cycle takes 1–2 minutes. If you were to input “3”, then each spot will be scanned three times, and the responses for each spot will then be averaged by the software to give a single final value. Note that the LEDs will blink and the progress of the scans is reported in real time on the monitor in 3D. The menu will re-open when the scanning is complete. Note: you can rotate the chart in 3D by clicking the rotation option on the toolbar (looks like a curvy arrow).





8. Saving and Uploading Data

- 1) On the menu, click “Save Data to a File” and then on “experiment information” in the next pop-up window. Enter the appropriate information as prompted by entries, from top to bottom (LED color will be white).
- 2) The next pop-up will allow you to edit the “experiment information” again or “load chemical and pattern information from excel” or “manually load chemical and pattern information”. To load from a file, simply select the Microsoft Excel template that has been filled out with the chemical and pattern information previously and then verify the pattern is correct.
- 3) Finally, either “save data to a file” or go back and edit experimental information or the file chosen if necessary.
- 4) To manually load chemical and pattern information, follow the sequence of menus presented. First enter how many total elements were used on the plate. Select each element using the crosshairs on the periodic table. Be sure to note the order the elements were chosen. Then enter which metal salt was used for each element as well as the concentration of that solution.
- 5) On the next menu, click “manually load pattern information” (or go back and edit experiment information or chemical information if desired). Pick a preexisting pattern or customize a blank template using the cross hair tool. Be sure to not click outside of the window while editing or the program may crash.
- 6) Finally, either “save data to a file” or go back and edit experiment, chemical or pattern information.
- 7) Data will be saved locally as *.smd files that can be uploaded to the Caltech Solar Materials Discovery online database- <http://www.bilrc.caltech.edu/solmatdisc/index.php>, as *.fig files that can be opened from a graphics window in the data collection program, as *.bmp bitmap images and as *.xls excel spreadsheet. The spreadsheet is especially useful since it contains the data as numerical values for easy manipulation later.
- 8) Click on “Go to Solar Materials Discovery website” in the main menu to log-on to the website and

upload data. The website also has downloads of the user guide, templates, software and other resources available. A temporary guest log-on is:

Username: smdvisitor

Password: SolarPhoton (case sensitive)

If you do not yet have your own password, please contact Michelle DeBoever by email at mchansen@caltech.edu to request one.

9. References:

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