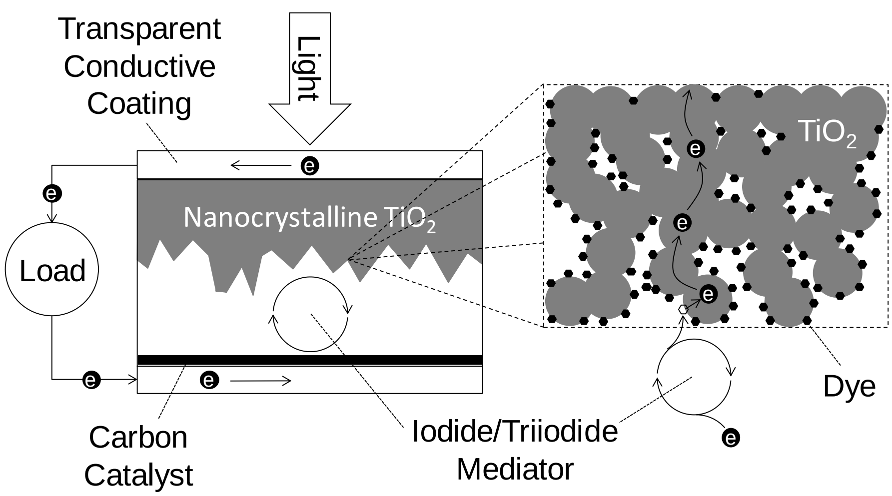
Dye-Sensitized Solar Cell (50 points)

Objective: The objectives of this online lab are to demonstrate and overview the procedures necessary to fabricate a photochemical cell and to characterize the photochemical cell using current voltage measurements.

The student will watch a series of videos pertaining to the DSC fabrication and characterization processes. These videos will provide detailed insight onto each step of the process. After watching the videos the student will be required to answer review questions on ANGEL.

Background:

Dye-sensitized solar cells (DSCs) are an example of a photoelectrochemical cell. This design relies on a photo-induced chemical reaction to facilitate the travel of electrons from one substance to another. The device construction and operation are illustrated schematically in the following figure.



DSCs consist of a nanostructured semiconductor film coated with organic dye molecules. The nanostructure intimately contacts an electrolyte solution that contains an iodide-triiodide mediator. The film and solution are sandwiched between two electrodes, which allow for electrical connections. One electrode (the one coated with nanocrystals) must be transparent, while the other should be coated with a carbon catalyst to facilitate reduction of the iodide-triiodide mediator.

<u>Characterization of Photovoltaic Devices</u>

Current density (J) is the current (I) divided by the area (A) of the device.

$$J(mA/cm^2) = \frac{I(mA)}{A(cm^2)}$$

The open circuit voltage (V_{oc}) is the voltage produced under illumination when no current is flowing (i.e., leads disconnected or under infinite resistance).

The short circuit current (I_{sc}) is the current that flows through an illuminated solar cell when there is no external resistance (i.e., when the electrodes are simply connected or short-circuited). The short-circuit current is the maximum current that a device is able to produce. Under external load, the current will always be less than I_{sc}. Short circuit current can be converted to short circuit current density (J_{sc}) by dividing by the area of the device.

Power (P) is current multiplied by voltage (V) or power density is current density multiplied by voltage.

$$P(mW) = I(mA) \times V(Volts) \quad \text{or} \quad P(mW/cm^2) = J(mA/cm^2) \times V(Volts)$$

The maximum power point is the point (V_{mpp}, I_{mpp}) on the I-V curve where the maximum power is produced. This point can also be identified on J-V curves as (V_{mpp}, J_{mpp}).

The power conversion efficiency (PCE) is the ratio of power produced by the device (at its maximum power point) to the total amount of power available in the incident light. The PCE can be calculated from device parameters as follows, where P_{in} = 100 mW/cm^2 at 1 sun illumination:

$$\text{Efficiency} = \frac{P_{out}}{P_{in}} = \frac{J_{mpp}V_{mpp}}{P_{in}} = \frac{J_{sc}V_{oc}FF}{P_{in}}$$

Here, the fill factor (FF) is the ratio of a photovoltaic cell's actual maximum power output to its theoretical power output if both current and voltage were at their maxima, I_{sc} and V_{oc}, respectively. The fill factor can be represented as:

$$FF = \frac{J_{mpp}V_{mpp}}{J_{sc}V_{oc}}$$

The fill factor is a key quantity used to measure cell performance. It is a measure of the "squareness" of the I-V curve.

Experiment:

In this lab, a dye-sensitized solar cell will be constructed. It is made of a layer of titanium dioxide (TiO_2) that is spread onto a glass slide. The TiO_2 will be bonded to an anthocyanin dye and sandwiched to another electrode with a carbon coating. The device will then be characterized utilizing voltage and current measurements. The data will be analyzed to determine the maximum power point, fill factor, and power conversion efficiency.

Step 1: Cleaning the substrates

The first step of this lab is to obtain two glass substrates and clean the substrates. On each of these glass substrates is an ITO layer that is conductive. The cleaning of these substrates can be seen in the following link.

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=2e4411da-5d64-49ea-9655-f

Step 2: Apply carbon shading to glass slide

A carbon coating is applied to the conductive side of a glass slide. This glass slide will serve as the anode of the device. The application of the carbon coating is shown at the video link below.

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=427e2f61-78a6-4526-ab80-e

Step 3: Coat conductive side of the glass slide with TiO_2

The next step of the fabrication process is to produce a thin film of TiO_2 on the conductive side of the glass substrate. A thin oxide layer is used to create this conductive surface on the glass substrate. A multimeter is used to determine which side of the glass substrate is conductive.

Next the TiO_2 layer is applied to the conductive surface of the glass slide. The glass substrate is taped down (conductive side facing up) so that 4-5 mm of the edge will remain clear of any TiO_2. The TiO_2 is placed on the substrate using a spatula and smeared over the surface using a glass rod. It is then baked on a hotplate to dry the layer. These steps are shown in the following video.

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=6406dcae-6ddf-4f00-9391-7

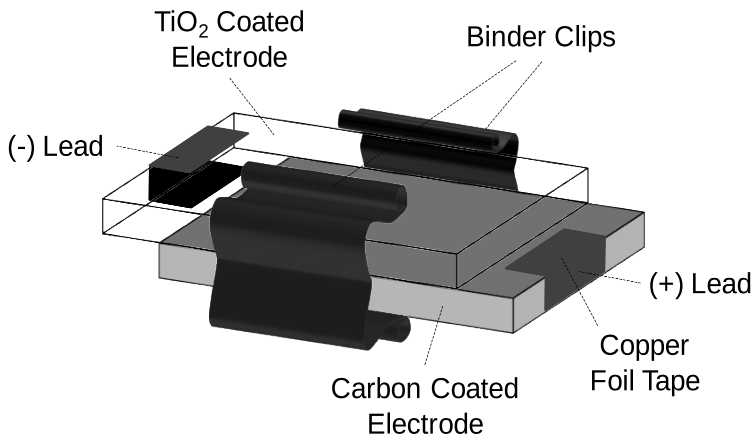
Step 4: Soak the TiO_2 with the anthocyanin dye

At this point the titanium dioxide thin film has been coated on the conductive side of another glass substrate. Next, the TiO_2 glass slide is placed into a petri dish and the anthocyanin dye is dispensed on the TiO_2. Once the staining is complete a drying step is completed. This glass slide will serve as the other electrode for the dye-sensitized solar cell. This step in shown in the video below:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=e287a121-8124-42db-83d0-c

Step 5: Combine the two electrodes and assemble the device.

The two electrodes of the solar cell are now complete. It is time to assemble the solar cell and introduce the electrolyte mediator. Binder clips will be used to hold the device together. The figure below depicts how the solar cell is constructed.



Watch the assembly of the solar cell at the link below:

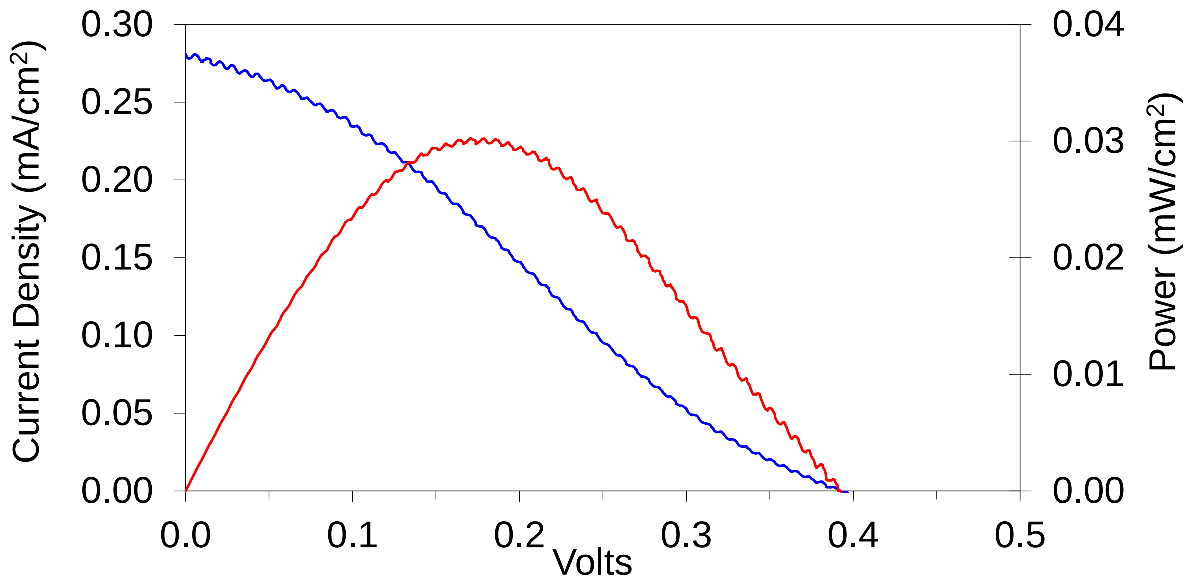
http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=2fe236d1-44ef-413e-a069-2

Step 6: Characterize the Solar Cell

Characterization of the solar cell was completed using a lamp and a VersaStat, which provides a variety of resistive loads to the solar cell circuit. This allows one to collect voltage and current characteristics of the device, which allows for determination of the properties of the solar cell. The properties determined from the VersaStat are shown in the table below.

Solar Cell Characteristics	
Open Circuit Voltage (V_{oc})	392 mV
Short Circuit Current Density (J_{sc})	0.281 mA/cm^2
Maximum Power Point (P_{mpp})	0.030 mW/cm^2
Voltage at P_{mpp} (V_{mpp})	171 mV
Current Density at P_{mpp} (J_{mpp})	0.177 mA/cm^2

The current density (blue) and power density (red) characteristic curves are shown in the graph below.



Questions to be answered on ANGEL (NO HARD COPY REQUIRED)

1. What type of conductive oxide is used in this lab?
2. What is the purpose of the conductive coating on the glass substrates?
3. In this lab, what setting on the multimeter was used when determining the conductive side of the glass substrate?
4. What is the purpose of the carbon layer in the DSC?
5. What mixture of chemicals did the titanium dioxide suspension contain?
6. What is the purpose of the taped slide in this lab?
7. How was the titanium dioxide layer spread across the surface of the slide?
8. What is the energy band gap of Titanium Dioxide and what type of light does it primarily absorb?
9. How long was the TiO_2 layer baked on the hot plate?
10. At what temperature was the TiO_2 layer baked on the hot plate?
11. What source was used for the anthocyanin dye?
12. How long was the anthocyanin dye allowed to soak into the TiO_2 layer?

13. After the dye was allowed to soak, the TiO_2 layer was then rinsed with what sequence of items (from first item of rinse to last item used)?

14. How was the excess anthocyanin dye removed in the experiment?

15. What is the purpose of the anthocyanin dye in the DSC?

16. What is the purpose of the electrolyte solution?

17. What is the purpose of the copper foil tape on the glass slides?

18. What was the approximate area of the solar cell device according to the video?

19. When exposed to ambient light, what was the open circuit voltage produced by the device?

20. From the characteristics obtained from the VersaStat, determine the fill factor of the dye-sensitized solar cell?
21. Assuming the incident light power density is 100 mW/cm^2, determine the efficiency in percent of the DSC?

22. If there is a 1000 W/m^2 of available power and a solar array is 12% efficient, what area of solar cells is needed in order to obtain enough electrical power for a typical home (1kW)?