A1 Electric current from solar cells – Let's build a dye-sensitized solar cell

1 Building a dye-sensitized solar cell

Building a dye-sensitized solar cell is not really difficult, but requires great attention to detail.

1.1 Apparatus and materials

- 2 clips (paper clips)
- Desk lamps, optional (halogen lamp, 20 W)
- 1 digital multimeter
- Fruit juice, optional (preferably dark red juice such as blackberry, raspberry, cherry, currant, elderberry)
- 1 glass electrode for dye cell (SnO, clear)
- 1 glass electrode for dye cell (TiO_2, white)
- Hibiscus tea (from the teacher)
- Iodine tincture (iodine/potassium iodide solution)
- 1 measuring cable assembly, banana plug to alligator clip, one red and one black for each
- Overhead transparency marker, felt-tipped pen, fiber-tip pen, or similar
- 1 pencil, soft (6B)
- 1 screw-on lid (for 100-ml cups)
- Syringe (conical tip), 5 ml (as pipette)

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

1.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions. The tea is not suitable for drinking. Avoid skin contact with iodine tincture (iodine is not particularly harmful, but some people are allergic to it).

1.3 Conducting the experiment

The experiment is normally conducted the first time with hibiscus tea as described below. Clarify with your teacher whether this applies to all groups, or whether you should immediately try out various other dyes (fruit juices).

1.3.1 Dyeing the negative electrode with a natural dye

- Arrange the materials at your workspace.
- Begin the experiment with the concentrated hibiscus pigment solution made from hibiscus tea. This will be provided by your teacher.

- Use the glass plate that is already coated with a layer of titanium oxide (white) as the negative electrode ("photoelectrode").
- Use the syringe to transfer approx. 6 ml of tea into the screw-on lid.
- Place the glass plate in the screw-on lid with the tea so that the entire surface is covered. Wait approx. five minutes. While you are waiting, you can already begin step 1.3.2.

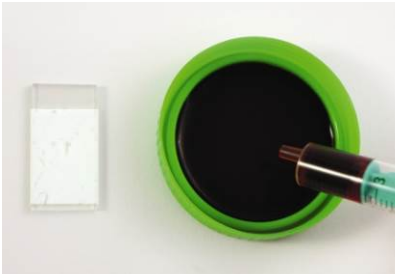

Fig. 1: The plate coated with white titanium oxide is placed in the hibiscus tea.

- Remove the glass plate from the lid and blot the surface dry with a paper towel. The formerly white titanium oxide should now be colored purple-red to blue-violet.

1.3.2 Coating the positive electrode

- Use the colorless glass plate with the layer of electrically conductive, yet transparent tin oxide as the positive electrode.
- With the multimeter, first determine which side of the positive electrode ("counter-electrode") is covered with the conductive tin oxide layer.
- Turn the multimeter's rotary switch to measure resistance (Ω) in the 200-ohm range and carefully hold the two test probes approx. 1 cm apart on the glass plate. If the meter indicates a very low resistance (approx. 30 ohms), you have identified the conductive side.

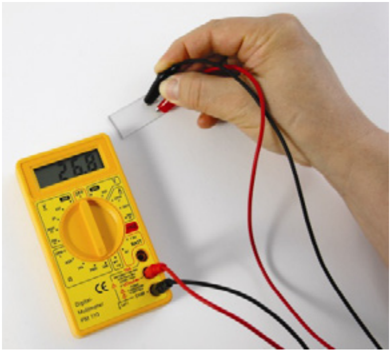

Fig. 2: The conductive side of the clear, transparent glass plate is determined by measuring the resistance.

- Shade the conductive side evenly with a soft pencil until the glass plate is uniformly gray.
- Mark the side with the layer of graphite with "+" using a fiber-tip pen.

Fig. 3: The conductive side is shaded with graphite using a soft pencil.

1.3.3 Assembling the cell

- Place the glass electrode with the white layer of titanium oxide on a paper towel.
- Wait for your teacher to apply a drop of iodine tincture (iodine/potassium iodide solution) on the titanium oxide/pigment layer as the electrolyte. (Using a paper towel, blot up any iodine tincture that runs to the side.)
- Now place the positive electrode on your workspace with the graphite layer (“+”) facing up.
- Then place the negative electrode on top of the positive electrode with the titanium oxide/pigment layer facing down.
- Make sure that a bit of the glass plate protrudes lengthwise to the left and right for tapping the current.
- Secure the two glass plates with the two binder clips.

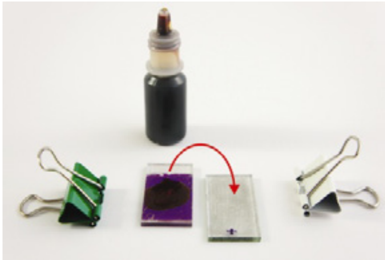

Fig. 4: After the drop of electrolyte is applied to the dyed layer, the two glass electrodes are placed on top of each other, slightly offset.

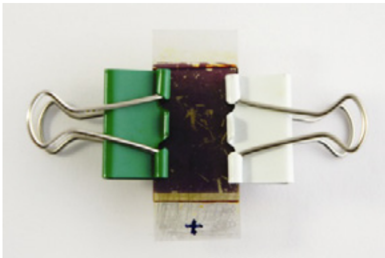

Fig. 5: The solar cell after being assembled and secured with the binder clips.

1.3.4 Determining the electrical power

- Place the dye-sensitized solar cell on your workstation with the dyed side (photoelectrode) facing up and connect the multimeter to the cell’s positive and negative poles using alligator clips.
- Make sure that the sun or a bright artificial light source shines directly on it.
- Set the meter to the 2,000-mV range and then the 2,000-µA range.

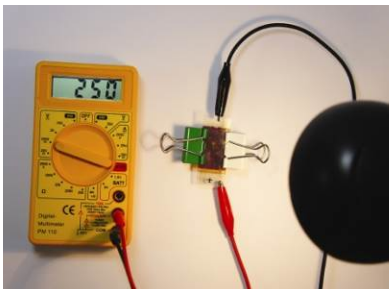

Fig. 6: Determining the no-load voltage under a halogen lamp.

1.4 Observation

- Determine the maximum values for no-load voltage (in V) and short-circuit current (in mA).
- Compare your values with those determined by your classmates.

1.5 Analysis

Power (P) is calculated from the measured voltage (V) and the current (I):
Power P = voltage V · current I
Example for 0.3 V and 0.2 mA $\Rightarrow$ P = 0.3 V · 0.2 mA = 0.06 mW
Make sure that the power determined from the no-load voltage (without conventional load, for example, an incandescent lamp) and the short-circuit current is not equivalent to the actual maximum power when a load is connected.

Create a table using the template below and enter the measured voltage and current of your cell and the values of your classmates. Then calculate the power:

Cell no.	Voltage in V	Current in mA	Power in mW

1.6 Questions

a) State reasons for the different power output of the individual cells.
b) A brief review of electricity basics: Explain why the power determined from the no-load voltage and short-circuit current is not equivalent to the actual power when a load is connected.
c) If you have already discussed photosynthesis in class: Compare the processes in the dye-sensitized solar cell with photosynthesis processes in plants.

2 Power output of the dye-sensitized solar cell at different illuminances

2.1 Apparatus and materials

- 1 complete dye cell
- Different light sources
- 1 digital multimeter
- 1 measuring cable assembly, banana plug to alligator clip, one red and one black for each
- 1 ruler

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

2.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.

2.3 Conducting the experiment

- Hold your cell for the same amount of time in the light of different light sources (daylight, artificial light, direct sunlight).
- Determine the maximum voltage and current and calculate the cell's power output.

2.4 Observation

Determine the cell's maximum values for voltage (in V) and current (in mA) for the different light sources.

2.5 Analysis

Enter the measured voltage and current of your cell with a notation of the light source in a table based on the following template and calculate the power:

Light source	Voltage in V	Current in mA	Power in mW

2.6 Questions

a) Select the best light source for generating power with a dye-sensitized solar cell and give reasons for your choice.
b) Explain what influence the brightness of sunlight has on plant growth. Take into account the varying illuminance from the sunlight over the course of a day and year.

3 Higher voltages through several dye-sensitized solar cells

To combine several cells, all student groups must work together.

3.1 Apparatus and materials

- Completed dye cells
- 4 connecting cables, alligator clip to alligator clip
- Desk lamp (halogen lamp, 20 W)
- 1 digital multimeter
- 1 measuring cable assembly, banana plug to alligator clip, one red and one black for each

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

3.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.

3.3 Conducting the experiment

An electrical device with a voltage requirement of 0.6 volts and a current requirement of 0.1 mA is to be operated with dye-sensitized solar cells.

- How many individual cells are needed?
- What light source should be used?

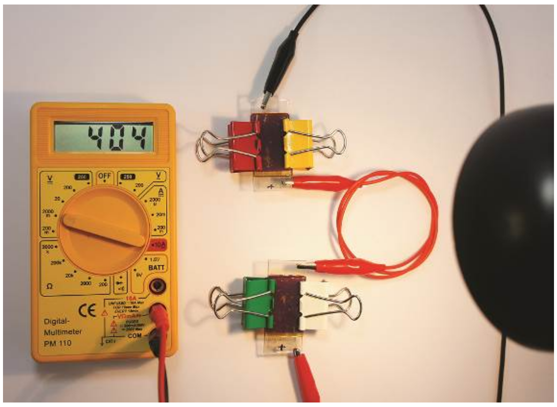

Fig. 7: Wiring for a series connection of two cells.

To conduct this experiment, you must work together with the other groups so that you can use all available cells.
Find out how the individual cells must be interconnected (in series or in parallel) to obtain a voltage of at least 1.2 volts.

3.4 Observation

Determine which type of connection and how many cells are needed to reach a minimum voltage of 1.2 volts.

Enter the measured voltages and currents into a table based on the following template:

Light source	Quantity of cells	Connection	Voltage in V	Current in mA
		In series		
		In parallel		

3.5 Analysis

a) Describe how the voltage and current behave when the cells are connected in parallel and in series.
b) Establish an analogy to the behavior of parallel and series connections of resistances learned in physics class.

3.6 Questions

a) Come up with applications in everyday life for which dye-sensitized solar cells could be used.
b) Describe what you would change in the dye-sensitized solar cell to improve the useful life and power output of the cell.