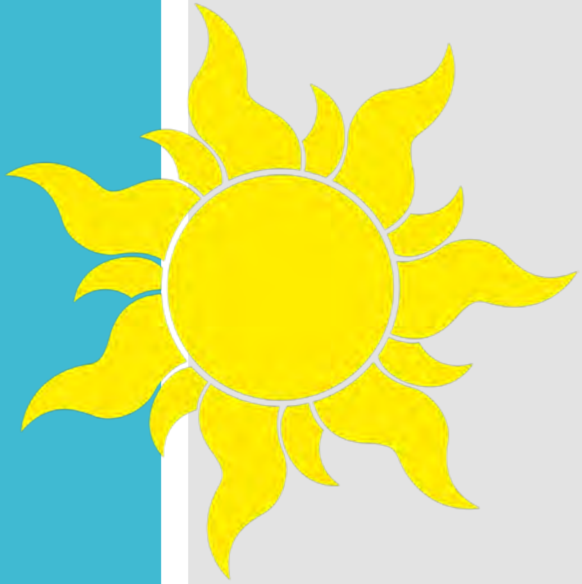
Making a Nanocrystalline Solar Cell Recreating Photosynthesis



Laura Wommack - Potlatch Jr-Sr High

From Seattle's SHINE Institute

And the Institute for Chemical Education

Overview

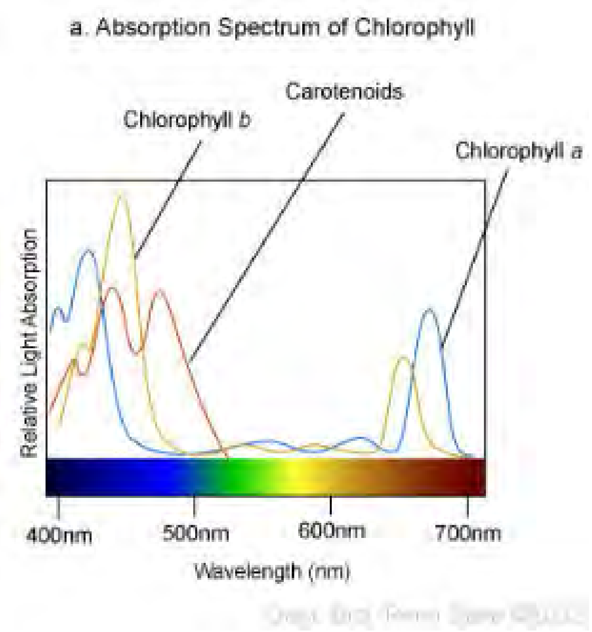
- This activity uses natural dyes extracted from plants to make a solar cell.
- It is most appropriate for high school and college-age students but could be adapted for middle school with support.
- The kit and manual can be obtained from Seattle's SHINE Institute. http://www.seattlenano.org/

When to use this lab

- This laboratory activity supports curriculum units of:
  - Energy
  - Alternative Energy
  - Photosynthesis
  - Electricity and Current
  - Nanotechnology

Background Students Should Have

- Basic knowledge of photosynthesis and the role of pigments.
- Basic understanding of electricity including voltage and current.
- Awareness of basic related scientific vocabulary



Objectives Addressed

- The student will demonstrate operating principles of a nanocrystalline solar cell.
- The student will be able to explain the relationship between their constructed solar cell and the role of pigments in photosynthesis.
- The student will be able to verify that the solar cell functions by determining voltage and power output.
- The student will be able to explain the relationship between electrons, electron excitation and flow of current.
- The student will be able to follow a complex series of instructions to create a functioning model.

Materials

- There is an extensive list of materials in the instruction booklet including:
- Tin dioxide-coated glass
- Colloidal titanium dioxide powder
- Graphite pencils
- Binder clips
- Potentiometer
- Organic dyes made from berries

Planning Considerations

- This lab will take at least three periods to create and test the solar cells.
- The first day should be spent in preparing students in terms of background information and carefully reviewing and demonstrating how the lab will be performed.
- The procedure used is VERY complex; you may want to create a simplified student procedure.
- More time will be required if a formal lab write up is done.
- The first step is deposition of TiO_2 film and curing; second step is staining the TiO_2 with anthocyanin dyes. Next the device is assembled and tested.
- The pigment could be created in advance by the teacher or by teams of students but they are prepared 24 hours in advance. Refrigerate or they will ferment.

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Lesson Materials "Teacher Background"

Materials and Supplies

What follows is a comprehensive list of materials and supplies necessary to complete all portions of the Nanocrystalline Dye Sensitized Solar Cell Kit. The list is divided into those materials that are included in the Solar Cell kit, those that are needed but not included, and those that are optional.

Those materials that are marked with a star ✸ are available for separate purchase from ICE. We have also listed other suppliers for materials that may become depleted but are difficult to obtain (but remember, part numbers may change).

Equipment and Supplies: Required and Included

✸ ❑ **Conductive (tin dioxide coated) transparent glass, in glassine envelopes** ***(10 pieces included)***
Two (2) pieces of glass are used per solar cell. Pre-cut commercial (2.5 cm × 2.5 cm) TEC 8 or TEC 10 glass can be purchased from several suppliers including: Hartford Glass Co., P.O. Box 613, Hartford City, IN 47348; 765/348-1282; fax: 765/348-5435; e-mail: hartglas@netusa1.net; or Pilkington North America Inc., P.O. Box 799, Toledo, OH 43697-0799; 419/247-3731; fax: 419/247-3821; http://www.pilkington.com. [10 additional slides may be purchased from ICE]

✸ ❑ **Colloidal titanium dioxide powder, AEROXIDE® TiO_2 P 25** ***(20 g included)***

Materials Included

These materials are included with the ICE Nanocrystalline Solar Cell Kit.

Additional components and replacement parts marked with an ✸ are available from ICE. To order components, contact us by email, phone, or fax using the information on the back cover.

Lesson Materials "Teacher Background"

Photosynthesis

Three and a half billion years ago, the Earth was much different than it is today. The first photosynthetic organisms were simple, pigmented, one-celled chemical factories [7, 8]. They were probably descendants of early **chemosynthetic organisms** whose importance in our *biosphere* and in geology was only recently realized [7, 9]. The early photosynthetic organisms used hydrogen sulfide, H_2S, and *organic* compounds and sunlight to produce energy-rich materials, sugars, carbohydrates and building materials for themselves and those that fed on them. To convert chemicals into living material, these organisms used pigments like *chlorophyll*. The electrons removed from an electron donor such as hydrogen sulfide, via the action of light on chlorophyll, reduced the abundant carbon dioxide, CO_2, in the Earth's early atmosphere. This resulted in the production of *carbohydrates* that were used by living organisms as stored energy and food (the general formula for a carbohydrate is $[C(H_2O)]_n$) (see Figure A).

Chemosynthetic Organisms. Living organisms capable of the biological process of energy utilization in which simple chemicals like hydrogen or H_2S are used to produce organic molecules. It is believed that this form of life occurred on the early Earth before photosynthesis and exists today at deep ocean vents and deep within the Earth itself.

Did You Know...

An electron donor is also called a reducing agent; the substance receiving the electron is called an oxidizing agent.

Oxidation is the loss of electrons.

Reduction is a gain of electrons.

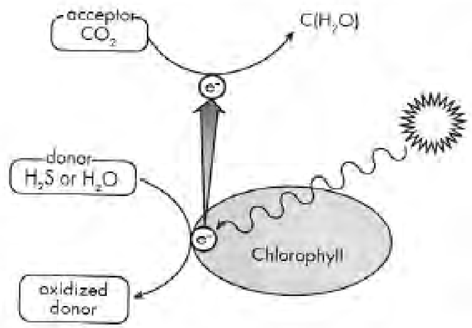


Figure A. Anaerobic photosynthesis uses H_2S as an electron donor, while aerobic uses H_2O. Both produce carbohydrates $[C(H_2O)]$.

Lesson Materials "Teacher Background"

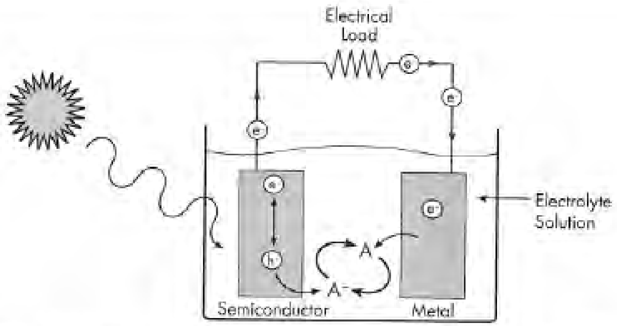


Figure F. A Photoelectrochemical cell is a device in which a photo-driven reaction induces electrons to travel from one substance to another. In this example, electrons move through the load from the illuminated electrode to the unilluminated electrode. A mediator in the electrolyte completes the circuit.

over 100 million watts of conventional solar cells are currently produced each year for these applications, no solar cell technology has produced an efficient, reliable, and cost-effective solar module that can be widely used to replace fossil fuel energy sources.

In contrast to conventional solar cells, the nanocrystalline dye sensitized solar cell is a photoelectrochemical cell. It resembles natural photosynthesis in two respects: 1) it uses an organic dye like chlorophyll to absorb light and produce a flow of electrons, and 2) it uses multiple layers to enhance both the light absorption and electron collection efficiency [2–4, 13–15]. Like photosynthesis, it is a molecular machine that is one of the first devices to go beyond microelectronics technology

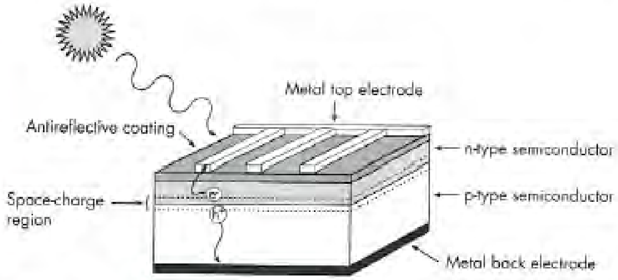


Figure G. Typical Silicon Solar Cell. Light allows for the separation of charges that creates electric current. The electrical load is connected to the top and back metal electrodes.

Lesson Materials "Student Materials"

6. To coat the glass, a thin line of the TiO_2 suspension is uniformly applied to the edge of the slide near the tape using the dropper bottle or a pipet. The amount of solution utilized is approximately 5 microliters per square centimeter ($\mu L/cm^2$).

7. Within five seconds after application of the TiO_2 suspension, slide a clean glass stirring rod (held horizontally) over the slide to spread and distribute the material (see Figure M). The most successful technique for achieving a uniform film is to use a rapid sweeping motion of the rod towards the bottom of the setup and then back over the film in the opposite direction.

   Repeat two or three times without lifting the rod. If the coating looks nonuniform, then the material can be wiped off the slide with a dampened tissue and the deposition procedure repeated (with a clean glass rod).

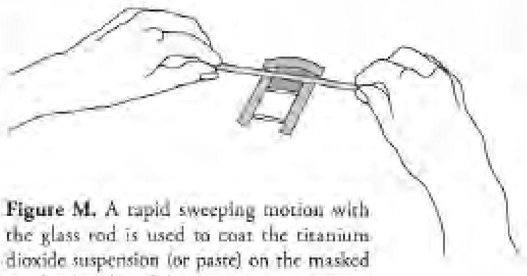


Figure M. A rapid sweeping motion with the glass rod is used to coat the titanium dioxide suspension (or paste) on the masked conductive glass slide.

8. After deposition of the suspension, carefully remove the tape. Place the slide in a petri dish and cover it. Allow the TiO_2 film to dry for one minute. Wash and dry the slide that was conductive side down and clean the glass rod.

9. Anneal the TiO_2 film on the conductive glass by one of the following methods (see Figure N):
   - **Option 1.** A simple tube furnace can be made from a hot air gun or paint stripper gun if it has a low air flow setting and will reach a temperature of 450 °C. The outer plastic casing at the base of the nozzle may have to be removed to prevent it from melting. The

Lesson Materials "Student Materials"

Day Two, Part One

Staining the TiO_2 with Anthocyanin Dye

Anthocyanin. The pigment responsible for the red or blue coloring in flowers and other areas of the plant.

1. Crush 5–6 fresh (or freshly thawed) blackberries, raspberries, pomegranate seeds, or Bing cherries in 2 mL of deionized water, and filter. The filtered solution is an **anthocyanin** dye solution [15, 16].

- Optional: Place the TiO_2 film face down on top of the filtered crushed berries to which a tablespoon of water has been added (see Figure O). Move the TiO_2 coated slide around until all the white film is coated with juice.

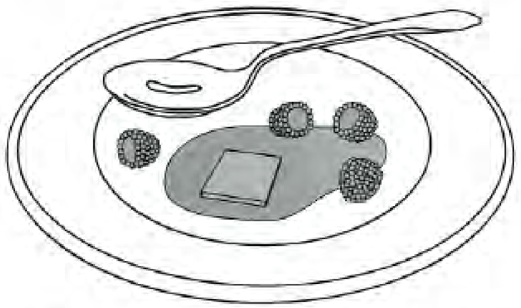
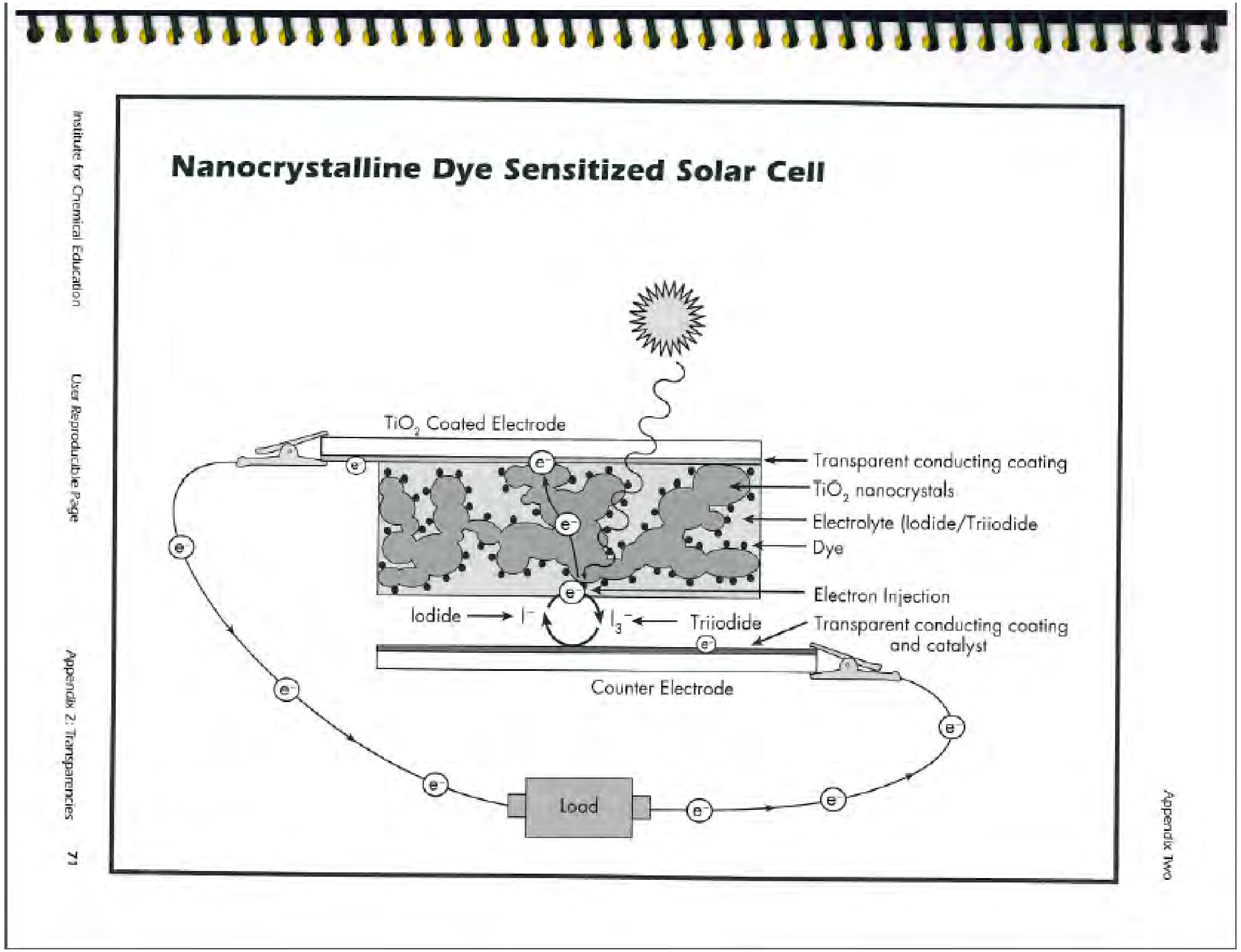


Figure O. Placement of the titanium dioxide coated conductive glass slide in the anthocyanin-containing solution.

- Optional: The water obtained from soaking red Hibiscus tea leaves at room temperature may also be used as well as cranberry juice, but produces varying results depending on the source and nature of the material.
- Optional: The anthocyanin may also be purified by crushing 2 or 3 berries in 10 mL of methanol/acetic acid/water (25:4:21 by volume) and filtering the product to obtain a clear red liquid. One can then either use this solution to stain the TiO_2 or, as an option, purify it further by passing the filtered extract through a Sephadex LH 20 (Pharmacia) column using the above mentioned solvent [15]. If the collected fractions are divided into fifths (2–10 mL each), the middle fractions are >98% pure anthocyanin and can be used to stain the TiO_2 film.

Lesson Materials "Transparency Masters"



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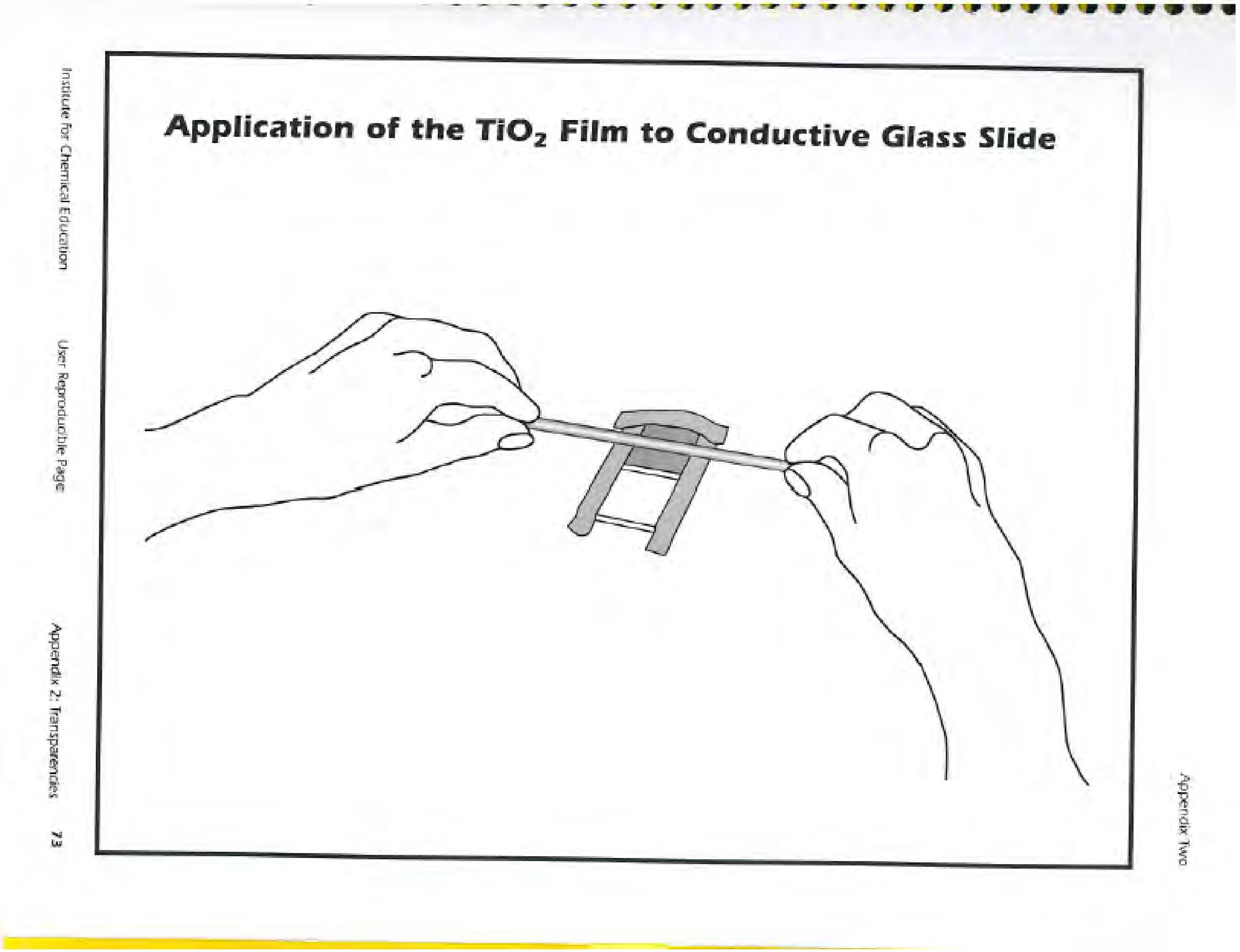

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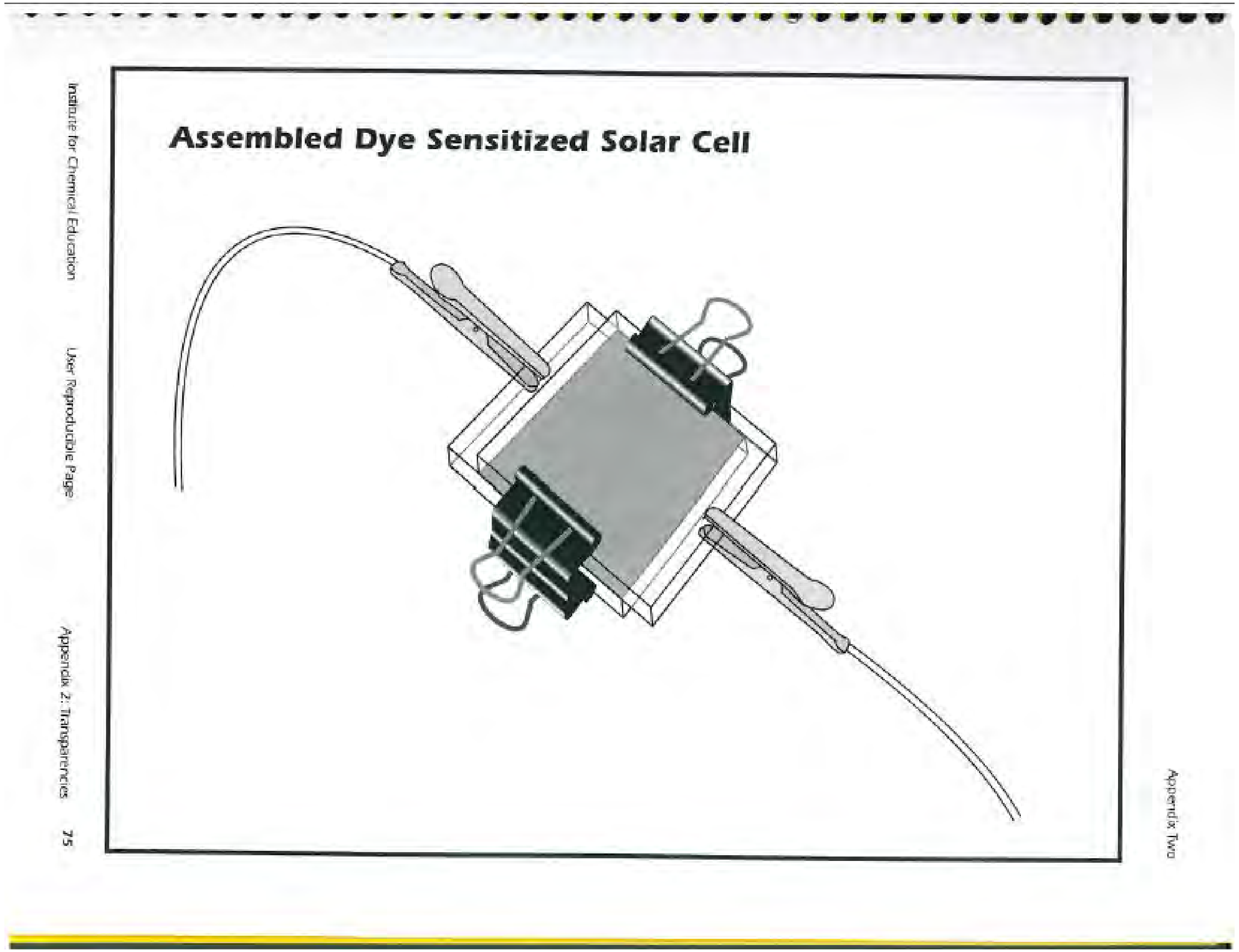

Extensions

- I prefer inquiry-based labs rather than recipe style.
- I ask students which pigments they believe will conduct more electricity.
- They make their own pigments, two or three cells and test the conductivity of different pigments.
- Then they research the pigments to determine if the conductivity they got is supported by research.
- They draw a conclusion as to whether their data reports the research or where they may have made errors.
- Time for a formal presentation to the class may or may not be given but data on the same pigments could be shared across groups to determine if there are differences.

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Resources

- Seattlenano.org
- Nanocrystalline Solar Cell Kit from Instiitute for Chemical Education by Linda Fanis, Editor, et.al.
- http://ice.chem.wisc.edu/