Nanocrystalline Solar Cells

Learning Outcomes

- To gain a basic understanding of circuits and how solar cells work
- To build and test a solar cell made using nanocrystalline TiO_2 and juice from raspberries
- To understand how renewable energy benefits the environment
- To understand how nanotechnology can increase the efficiency of solar cells

Washington EALR Alignment

9-11 PS2A Atoms are composed of protons, neutrons, and electrons. The nucleus of an atom takes up very little of the atom's volume but makes up almost all of the mass. The nucleus contains protons and neutrons, which are much more massive than the electrons surrounding the nucleus. Protons have a positive charge, electrons are negative in charge, and neutrons have no net charge.

9-11 PS2G Chemical reactions change the arrangement of atoms in the molecules of substances. Chemical reactions release or acquire energy from their surroundings and result in the formation of new substances.

9-11 PS2I The rate of physical or chemical change may be affected by factors such as temperature, surface area, and pressure.

9-11 PS3A Although energy can be transferred from one object to another and can be transformed from one form of energy to another form, the total energy in a closed system remains the same. The concept of conservation of energy, applies to all physical and chemical changes.

9-11 ES2D The Earth does not have infinite resources; increasing human consumption impacts the natural processes that renew some resources and it depletes other resources including those that cannot be renewed.

9-11LS1A Carbon-containing compounds are the building blocks of life. Photosynthesis is the process that plant cells use to combine the energy of sunlight with molecules of carbon dioxide and water to produce energy-rich compounds that contain carbon (food) and release oxygen.

9-11 LS2A Matter cycles and energy flows through living and nonliving components in ecosystems. The transfer of matter and energy is important for maintaining the health and sustainability of an ecosystem.

9-11 LS2F The concept of sustainable development supports adoption of policies that enable people to obtain the resources they need today without limiting the ability of future generations to meet their own needs. Sustainable process include subsitituing renewable for nonrenewable resources, recycling, and using fewer resources.

Oregon Content Standards Alignment

H.2.P1 Explain how chemical reactions result from the making and breaking of bonds in a process that absorbs or releases energy. Explain how different factors can affect the rate of a chemical reaction

H.2 P.3 Describe the interactions of energy and matter including the law of conservation of energy.

H.2 L.2 Explain how energy and chemical elements pass through systems. Describe how chemical elements are combined and recombined in different ways as the cycle through the various levels of organization of biological systems.

H.2 E.1 Identify and predict the effect of energy sources, physical forces, and transfer processes that occur in the Earth system. Describe how matter and energy are cycled between system components over time.

H.2 E.4 Evaluate the impact of human activities on environmental quality and the sustainability of Earth systems. Describe how environmental factors influence resource management.

Idaho Content Standards Alignment

8 – 9 Physical Science, 8 – 9 Earth Science, 9 – 10 Biology

1.1.2 Apply the concepts of order and organization to a given system.

5.2.1 Explain how science advances technology.

5.2.2 Explain how technology advances science.

5.2.3 Explain how science and technology are pursued for different purposes.

8 – 9 Physical Science, 8 – 9 Earth Science, 9 – 10 Biology

9-10.B.5.1.1 Analyze environmental issues such as water and air quality, hazardous waste, forest health, and agricultural production.

9-10.B.5.3.1 Describe the difference between renewable and nonrenewable resources.

8 – 9 Physical Science

8-9.PS.2.3.1* Explain that energy can be transformed but cannot be created nor destroyed.

8-9. PS.2.3.2* Classify energy as potential and/or kinetic and as energy contained in a field.

8-9.PS.2.4.1 Describe the properties, function, and location of protons, neutrons, and electrons.

8-9.PS.2.4.4 State the basic electrical properties of matter.

8-9.PS.2.5.1 Explain how chemical reactions release or consume energy while the quantity of matter remains constant.

9 – 10 Biology

9-10.B.3.2.3 Show how the energy for life is primarily derived from the Sun through photosynthesis.

9-10.B.3.2.5 Show how matter cycles and energy flows through the different levels of organization of living systems (cells, organs, organisms, communities and their environment).

9-10.B.3.3.1 Identify the particular structures that underlie the cellular functions

11 – 12 Chemistry

11-12.C.2.4.3 Describe the relationship between the structure of atoms and light absorption and emission.

11-12.C.2.5.3 Describe the factors that influence the rates of chemical reactions.

11-12.C.5.1.1 Demonstrate the ability to work safely and effectively in a chemistry laboratory.

11-12.C.5.2.1 Assess the role of chemistry in enabling technological advances.

11-12.C.5.3.1 Evaluate the role of chemistry in energy and environmental issues.

Nanocrystalline Solar Cells

Background

Solar cells, or photovoltaics, convert light energy into electricity by converting photons into free electrons, which can flow through a circuit. When these electrons run through a circuit, electricity is produced (Fig. 1). To do this, solar panels must be made of several parts, including a material that can absorb photons and in turn lose electrons; a semiconductor that can accept the lost electrons; an electrolyte that replaces the dye's lost electrons; and a counter electrode that moves the electrons from the semiconductor into the circuit. The whole device has a negative charge on one side and a positive charge on the other allowing for the completion of a circuit. Silicon is a common semiconductor used in most commercial solar cells.

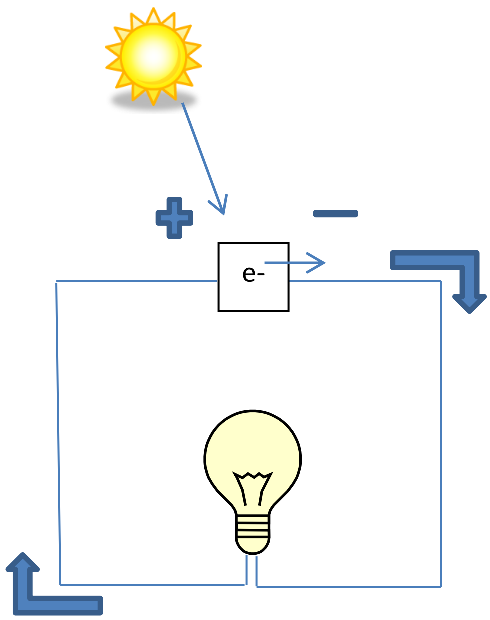

Figure 1. A simple circuit formed by a solar cell as photons are converted to free electrons.

In this experiment, the anthocyanin dye from certain berries – blackberries, raspberries, pomegranate seeds, or Bing cherries – loses electrons as it absorbs light. The semiconductor in this lab, titanium dioxide (TiO_2), then accepts the dye's lost electrons, before passing them on to the conductive plate. To make the solar cell more efficient the semiconductor, TiO_2, is a layer of nanoparticles. The nanostructure of the TiO_2 has a higher surface area to volume ratio than a flat surface of TiO_2. Since the dye coats the TiO_2, the dye has more surface area as well, allowing more photons to be absorbed, more electrons to be transferred to the TiO_2, and more electricity to flow. An electrolyte (iodide/triiodide in this lab) is used to replace the electrons lost in the dye (Fig. 2). The free electrons then move through the conductive SnO_2 coated glass plates, through an external circuit (potentially powering a device), and then back to the electrolyte through the counter electrode (Fig. 3). A thin layer of carbon is added as a catalyst to increase the rate of reaction.

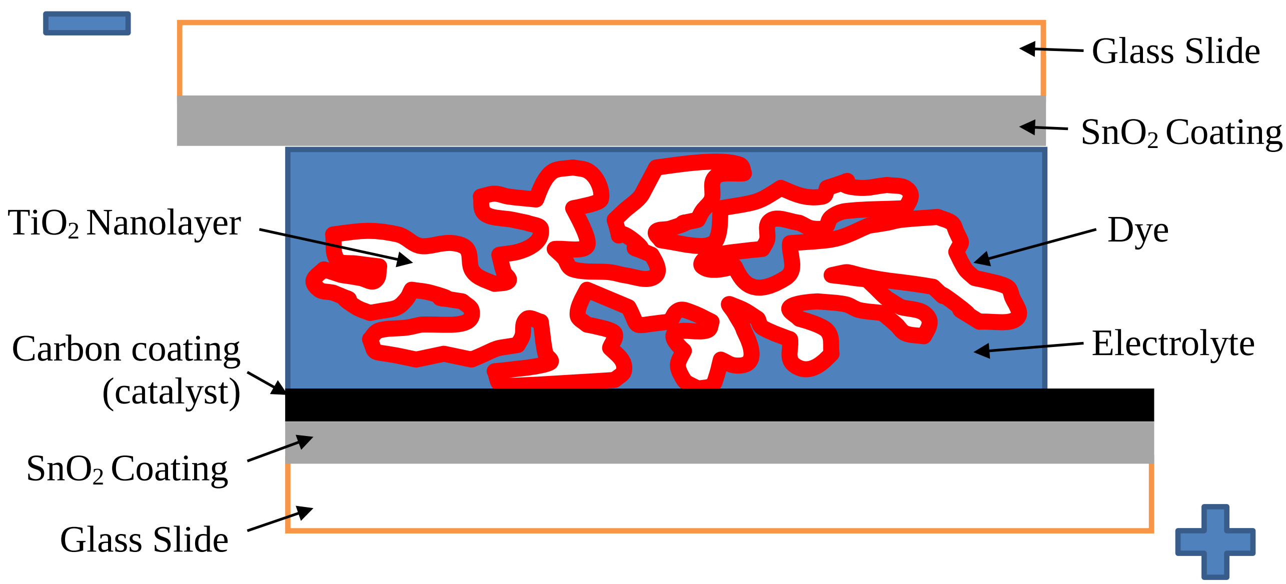

Figure 2. Parts of the nanocyrstalline solar cell.

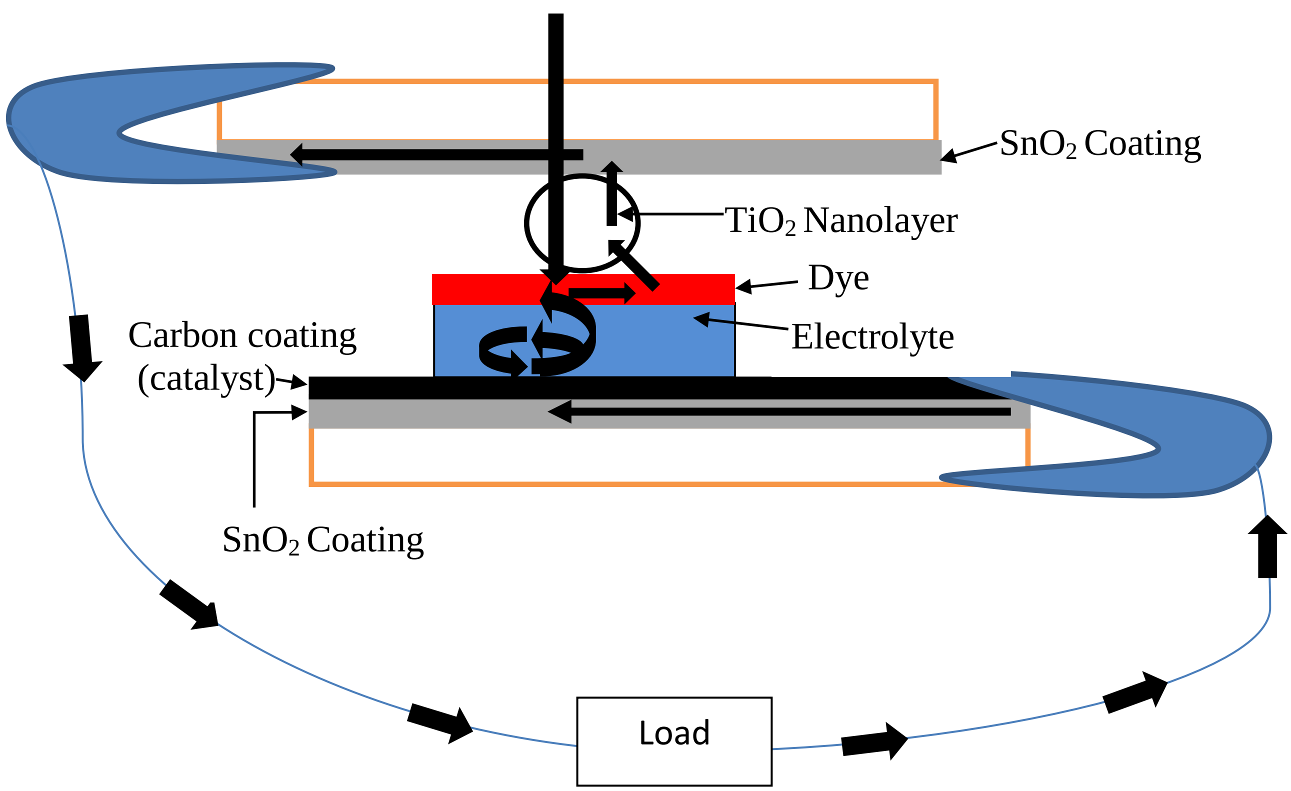

Figure 3. Flow of Electrons through the circuit.

Applications

- Electricity needs in space
- Calculators and small devises
- Traffic Signs
- Commercial electricity

Vocabulary

- Anneal
- Catalyst
- Circuit
- Counter Electrode
- Electrode
- Electrolyte
- Electron
- Load
- Nanocrystalline Structure
- Photon
- Photovoltaic
- Semiconductor
- Solar Cell
- Surfactant

Materials

For this lab, preparation of the TiO_2 can be done either before the lab by the instructor or during the lab by the students. There are two materials lists and lab instructions that follow. Version A is designed for the situation in which the instructor makes the TiO_2. The second set, Version B, is written for the students to make the TiO_2 solution. Below is a complete list of materials needed including those included in the kit and those that need to be provided.

Materials included in the kit

- Conductive (tin dioxide, SnO_2, coated) transparent glass
- Colloidal titanium dioxide powder
- Iodide electrolyte solution in dropper bottle
- Binder clips
- Dropper bottle
- Soft graphite pencil

Materials not included in the kit

- Surfactant (such as Triton X100 or clear dish detergent)
- 10 mL 0.1M Acetic Acid
- Mortar and pestle

- Transfer pipette
- Graduated cylinder
- Overhead projector with (integral) parabolic reflector
- Hot plate
- Ethanol in wash bottle
- Deionized water in wash bottle
- Blackberries, raspberries, pomegranate seeds, or Bing cherries
- Multimeter, capable of measuring amps, volts, and ohms
- Hookup wire (black and red)
- Alligator clips (large – should exert a large pressure when closed)
- Tongs
- Plastic tray
- Transparent tape
- Glass stirring rod
- Absorbent tissue paper (such as KimWipes)
- Cotton swabs
- Buchner funnel
- Safety goggles
- Gloves
- Aqueous waste container
- Organic waste container

MSDS/Safety

MSDS or other safety information sheets are provided at the end of this unit for all chemicals used. Waste materials should be collected in aqueous and organic waste container and then properly disposed of as hazardous waste. Students should wear gloves and goggles and use caution in working with the hot plate. Preparation of the TiO_2 should be completed in a hood or well ventilated area.