Solar Energy, Kit #5: Making a Dye Sensitized Solar Cell
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## Topic Template

<table>
<thead>
<tr>
<th>Topic</th>
<th>Solar Cells: A Comparative Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Associated Curriculum</td>
<td>Solar Energy</td>
</tr>
<tr>
<td>Associated Content</td>
<td>Photovoltaic Cells; Photosynthesis; Energy; Electricity; Electrochemistry</td>
</tr>
</tbody>
</table>
| Materials Required | • 6 grams colloidal titanium dioxide  
• 2 conductive, tin dioxide coated, transparent glass plates  
• acetic acid solution (pH 3-4)  
• clear dishwashing detergent  
• ethanol  
• deionized water  
• alcohol lamp/Bunsen burner/hot plate  
• Ring stand with ring and ceramic triangle or screen  
• Transparent tape  
• Glass stirring rod  
• Tongs  
• Petri dish or beaker  

| 5E Learning Cycle | • NEED ENGAGEMENT QUESTION  
• What plant dyes conduct the most electricity?  
• Why is solar energy still expensive?  
• Why does society need to find replacements to current forms of generating electricity?  
• How are photovoltaic cells similar to photosynthesis? How are they different? |
|-----------------|---------------------------------------------------------------------|
| Related NGSS Standards | **MSLS1-6.** Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.  
**MSPS1-3.** Gather and make sense of information to describe that synthetic materials come from natural resources and impact society. (Needs to be reworded to fit this standard better, see note below)  
**MSPS2-3.** Ask questions about data to determine the factors that affect the strength of electric and magnetic forces. (Same note as 1-3) |
<p>| Background/Why | Solar Cell technology has been transformed over the years to being closer to competing with nonrenewable of generating electricity. |
| Model 1 (Essential) | Photosynthesis (Photosynthesis drives the growth of a plant) |
| Model 2 (Essential) | Photosynthetic versus Battery versus Solar Cell Circuits (Photosynthesis is very similar to both solar cells and regular batteries in that it causes a flow of electrons) |
| Model 3 (Extension) | Comparison between photovoltaics and simplest form of the light reaction (Photosynthesis is very similar to solar cells in creating a flow of electrons.) |</p>
<table>
<thead>
<tr>
<th>Model 4 (Extension)</th>
<th>Energy Diagram for the Dye-Sensitized Solar Cell (Dye-sensitized cells utilize a photoreactive dye to create an electron potential)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 5 (Extension)</td>
<td>Measuring the efficiency of solar cell technologies (There are many different types of solar cells and over time they have increased efficiency)</td>
</tr>
<tr>
<td>Model 6 (Extension)</td>
<td>Photovoltaic Cells versus Gratzel Cells (Photovoltaic cells have similarities to Gratzel cells in that PV cells use two types of semiconductors to create an electric potential and Gratzel cells use a photoreactive dye)</td>
</tr>
<tr>
<td>Lab Protocol (Extension)</td>
<td>Making a Dye Sensitized Solar Cell (Creating a dyed solar cell which produces electricity from light)</td>
</tr>
</tbody>
</table>
Introduction – Solar Cells: A Comparative Analysis

WHY?
At the rate of combustion of fossil fuels by modern society, these reserves are nonrenewable. It is estimated that only a few hundred years supply of fossil fuels are available at our current rate of consumption and the rate is continually increasing. As the carbon dioxide concentration in the atmosphere increases due to fossil fuel combustion and the burning of forests, we are returning Earth to a higher carbon dioxide concentration. Some predictions suggest that over the next 50 to 100 years, the warming of the Earth due to the enhanced greenhouse effect, could allow sea levels to rise, agriculture and crops to fail, global climate to change, and economic development to be damaged. One method to avoid the undesirable consequences of the greenhouse effect involves conserving fossil sources of solar energy, also called conservation. There are however, alternatives to these fossil fuel energy sources. The most promising of these alternative energy sources are the renewable energy technologies. Photovoltaic cells and nanocrystalline solar cells are devices that convert solar energy into electricity and may help us to tap one renewable energy source.

Background:
Solar cells, also called photovoltaics (PV) by solar cell scientists, convert sunlight directly into electricity. Solar cells are often used to power calculators and watches. They are made of semiconducting materials similar to those used in computer chips. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. This process of converting light (photons) to electricity (voltage) is called the photovoltaic (PV) effect.

Solar cells are typically combined into modules that hold about 40 cells; about 10 of these modules are mounted in PV arrays that can measure up to several meters on a side. These flat-plate PV arrays can be mounted at a fixed angle facing south, or they can be mounted on a tracking device that follows the sun, allowing them to capture the most sunlight over the course of a day. About 10 to 20 PV arrays can provide enough power for a household; for large electric utility or industrial applications, hundreds of arrays can be interconnected to form a single, large PV system.

Thin film solar cells use layers of semiconductor materials only a few micrometers thick. Thin film technology has made it possible for solar cells to now double as rooftop shingles, roof tiles, building facades, or the glazing for skylights or atria. The solar cell version of items, such as shingles, offer the same protection and durability as ordinary asphalt shingles.
MODEL 1: Photosynthesis

1. What compounds are taken into the leaf during photosynthesis? What compounds are created?

2. What role does sunlight play in this reaction?

3. Knowing that the majority of a plant’s mass comes from carbon; can you deduce which compound taken in is responsible for the majority of a plant’s mass?
**MODEL 2: Photosynthetic versus Battery versus Solar Cell Circuits**

What is the source of energy in each system?

What type of energy transformation is occurring in each system?

In each system, what particle is responsible for doing the work?
MODEL 3: Comparison between photovoltaics and simplest form of the light reaction

Source: www.jccc.net/~pdecell
1. Low energy electrons in surface of photocell(left) and in photosystem(right)
2. Photons boost electrons to high energy level in photocell and in photosystem.
3. Electrons accepted by wire at photocell-wire junction(left) and by electron acceptor in light reaction.
4. Electrons passed along wire(4 left) to motor(5); Electrons passed (4 right) to hydrogen pump(5).
5. Motor turns producing mechanical energy(work) and heat(left). Hydrogen pump works to send H+ ions to the inside of the thylakoid and these are used to make ATP. Heat is given off as well.
6. The electrons having lost their energy(6) are sent to the photocell(left) and to the photosystem(right).
These replenish those lost by the photocell(left) and the photosystem(right).

What is the role of photons in both systems?

What type of work is completed by the electrons seen in Figure A and Figure B?

In Model 4, Figure A, the electrons lost by the solar cell must be replenished. How is this accomplished?

In Model 4, Figure B, the electrons lost by the pigments involved are replaced through what process?
MODEL 4: Energy Diagram for the Dye-Sensitized Solar Cell

Explain what is happening in the diagram.

How is this process like photosynthesis?

How is this process unlike photosynthesis?
Lab Protocol: Making a Dye Sensitized Solar Cell

Background:
Gratzel cells are dye sensitized solar cells that use a dye for directly converting sunlight energy into electrical energy. They were first invented in 1991 by Michael Gratzel and his researchers at the Swiss Federal Institute. In this lab, you will experience making your own Gratzel cell using various organic dyes. The cells are prepared from two pieces of glass that are pre-treated on one side with a thin layer of conductive material. One plate is coated with graphite and the other plate is coated with titanium dioxide. A dye is then adsorbed onto the titanium dioxide layer by immersing the plate in a dye solution. The plates are then sandwiched together and secured using binder clips. To complete the cell a drop of iodide electrolyte is added between the plates.

How Does it Work?

1) Sunlight energy passes through the titanium dioxide layer and strikes electrons within the adsorbed dye molecules. Electrons gain this energy and become excited because they have the extra energy.
2) Excited electrons escape the dye molecules and become free electrons. These free electrons move through the titanium dioxide and accumulate at the dyed titanium dioxide plate (-ve)
3) The free electrons then start to flow through the external circuit to produce an electric current.
4) To complete the circuit, the dye is regenerated. The dye regains its lost electrons from the iodide electrolyte. Iodide (I-) ions are oxidized to tri-iodide (I3-). The free electrons at the graphite plate then reduce the tri-iodide molecules back to their iodide state.
5) The dye molecules are then ready for the next excitation/oxidation/reduction cycle.
Materials
- 6 grams colloidal titanium dioxide
- 2 conductive, tin dioxide coated, transparent glass plates
- acetic acid solution (pH 3-4)
- clear dishwashing detergent
- ethanol
- deionized water
- alcohol lamp/Bunsen burner/hot plate
- Ring stand with ring and ceramic triangle or screen
- Transparent tape
- Glass stirring rod
- Tongs
- Petri dish or beaker
- Pipettes
- Cotton swabs
- Absorbent tissue paper
- Safety goggles
- Protective cloves
- Soft graphite pencil (no. 2)
- Various dyes: blackberries, raspberries, teas, etc.
- Filter paper
- 2 Binder Clips
- Iodide electrolyte solution in dropper bottle
- Copper foil tape
- Alligator clips
- Multimeter
- Mortar and pestle
- Zip-lock baggie

Procedure:
1. In 1-mL increments, add 9 mL of nitric or acetic acid solution to 6 g of colloidal TiO₂ powder in a mortar and pestle while grinding or mix with a spatula in a small beaker. Add each 1 mL addition of the dilute acid solution only when the previous mixing and grinding has produced a uniform and lump-free suspension with a consistency of a thick paint
2. To the TiO₂ paste, add a drop of a surfactant (clear dish detergent) in 1 mL of water. Do not grind or agitate after the surfactant is added.
3. Allow to equilibrate for at least 15 minutes for best results.
4. Obtain and clean two glass conductive plates by rinsing them in ethanol and then drying with a soft tissue.
5. Use a multimeter set to ohms to check which side of the glass is conductive; the reading should be between 10 and 30 ohms.
6. Orient one glass plate conductive side up. Turn over another glass plate so that the conductive side is face down. Place it adjacent to the glass to be coated.
7. Apply two 6-7 cm pieces of Scotch (3M) adhesive tape to the top faces of the glass plates in order to mask a strip not more than 1 mm wide on the two longer edges.
8. Apply another piece of adhesive tape along the top of the glass to be coated so as to mask a 4-5 mm strip. All tape should extend from the edge of the glass to the table in order to secure plates to the table.
9. To coat the glass, a thin line of the TiO₂ suspension is uniformly applied to the edge of the plate near the tape using the pipette. The amount of solution used is about 5 microliters per square centimeter.
10. Within five seconds after application of the TiO₂ suspension, slide a clean glass stirring rod (held horizontally) over the plate to spread and distribute the material. If the coating looks non-uniform, then the material can be wiped off the plate with a...
damp tissue and the deposition procedure repeated with a clean glass rod.

11. Carefully remove the tape. Place the plate in a petri dish and cover it. Allow the TiO$_2$ film to dry for one minute. Wash and dry the plate that was conductive side down and clean the glass rod.

12. Anneal the TiO$_2$ film on the conductive glass by using an alcohol or gas burner. Place the film on a ring stand at the tip of the flame for 10-15 minutes. During heating, the film may turn light brown and then back to white.

13. After the annealing is complete, allow the TiO$_2$ coated conductive glass to slowly cool to room temperature. This will take approximately fifteen minutes. Not allowing it to fully cool can result in cracking of glass or peeling off of TiO$_2$ film.

14. Make a strong glass of blueberry, passion fruit, raspberry, or another type of herbal tea.

15. Place the solution in a petri dish and then put the TiO$_2$ coated conductive glass in the solution face down for 15 minutes.

16. While the TiO$_2$ electrode is being stained the counter electrode can be made from the other piece of conductive glass.

17. Hold the conductive glass plate by the edges or with tweezers. Using a graphite (carbon) rod or soft pencil lead, apply a light carbon film to the entire conductive side of the plate. Be carefully not to miss any spots.

18. Wash the film, which should now be stained dark purple, in water and then in ethanol or isopropyl alcohol.

19. Gently blot dry the TiO$_2$ film with a tissue. If the stained electrode is not used immediately, then it should be stored in acidified deionized water (pH 3-4 acetic acid) in a dark-colored bottle.

**ASSEMBLING THE SOLAR CELL DEVICE**

20. Wash the TiO$_2$ coated conductive glass with water and then ethanol.

21. Gently blot the film dry with another piece of tissue paper.

22. Place the dried electrode on a flat surface with the TiO$_2$ film side face up.

23. Place the carbon-coated counter electrode on top of the TiO$_2$ film plate such that the conductive side of the counter electrode faces the TiO$_2$ film.

24. Gently lift the counter electrode and offset the two plates so that all of the TiO$_2$ is covered by the carbon-coated counter electrode and the uncoated 4-5 mm strip of each glass plate is exposed.

25. Carefully pick up the assembly while it is in this orientation and place two binder clips on the longer edges to hold the plates together.

26. Carefully place one or two drops of the iodide electrolyte solution at one edge of the plates.

27. Alternately open and close each side of the solar cell by releasing and returning the binder clips. The liquid will be drawn into the space between the electrodes. Make sure that all of the stained area is contacted by the electrolyte.

28. Wipe off the excess electrolyte from the exposed areas of the glass using cotton swabs and tissues dampened with ethanol. It is important that the electrolyte is completely removed.
from the two exposed sides of the cell.

29. Fasten alligator clips to the two exposed sides of the solar cell to make electrical contact to the finished device. As an option, two small pieces of copper foil tape can be placed on the exposed faces of the glass to facilitate electrical contact or allow wires to be soldered to the glass.

30. To place the copper foil tape, make sure that the glass surface is thoroughly clean. Place a 0.5-1 cm piece of the copper foil tape on the positive and negative sides of the cell. Wrap the excess foil over the edges of the glass. Once they are on the glass, press these pieces with a finger and then press them firmly using a glass rod or other hard object.

**MEASURING THE ELECTRICAL OUTPUT**

31. The negative electrode is the TiO\textsubscript{2} coated glass; attach the black wire of the meter to the TiO\textsubscript{2} coated glass. Attach the red, positive wire to the counter electrode.

32. Measure the maximum voltage by connecting the solar cell directly to a multimeter set to volts. Record this number on the data sheet.

33. Cover the cell with your hand or a piece of paper and record this number on the data sheet.

34. Measure the maximum current by connecting the cell directly to a multimeter set to mA (milliamperes). Record this number on your data sheet.

35. Cover the cell and record this number on your data sheet.

36. Take the solar cell various places and tilt in a variety of ways to see what the maximum voltage and current you can record with your solar cell is.
What solar cell technology is the most efficient? Which is the least efficient?

What is the difference in efficiency between the best dye-sensitized solar cell and the best photovoltaic crystalline Si cells?

According to Model 5, which solar cell technology has the most promise?

Based on this graph, why do you think Michael Graetzel was awarded the Millennium Prize for his research on dye-sensitized solar cells?

Extend: Do research on DSSC. What advantages might these have over silicon solar cells?
MODEL 6: Photovoltaic Cells versus Graetzel Cells

Figure 1. Typical Silicon Solar Cell. Light allows for separation of charges that creates electric current. The electrical load is connected to the top and back metal electrodes.

Figure 2. Dye-Sensitized Solar Cell. A single layer of dye (shown as black dots) adsorbing to the titanium dioxide nanocrystals in the nanocrystalline dye sensitized solar cell.

In a typical silicon solar cell, what serves as electrodes?

What are the necessary substances for the electrodes in the dye-sensitized solar cells?

How is the charge separation produced in the silicon solar cell? How is it produced in the dye-sensitized solar cell?

What is the role of the dye and electrolyte in the dye-sensitized solar cell?
Extension: Dying for Electric Power

In this activity you will use what you have learned about how pigments absorb light to design the best dye-sensitized solar cell.

Background:
Graetzel cells are dye sensitized solar cells that use a dye for directly converting sunlight energy into electrical energy. They were first invented in 1991 by Michael Graetzel and his researchers at the Swiss Federal Institute. In this lab, you will experience making your own Graetzel cell using various organic dyes. The cells are prepared from two pieces of glass that are pre-treated on one side with a thin layer of conductive material. One plate is coated with graphite and the other plate is coated with titanium dioxide. A dye is then adsorbed onto the titanium dioxide layer by immersing the plate in a dye solution. The plates are then sandwiched together and secured using binder clips. To complete the cell a drop of iodide electrolyte is added between the plates.

Procedure:
Part 1: Prepare your electrodes
1. Using what you have learned about how different pigments absorb different wavelengths of light, choose a pigment to dye your solar cell with, and obtain a sample from your teacher.
2. Place the pigment of choice in the pestle dish and mash it with the pestle if necessary.
3. Gently place the FTO/TiO2 electrode face-down into the pigment for about 10 min. (this is where natural dye molecules from the fruit will attach themselves to the white TiO2 nanoparticles producing a bright colorful electrode surface).
4. In the meantime (while the FTO/TiO2 is absorbing the natural dye) take the second piece of FTO conductive glass. Confirm using the multimeter which side is conductive.
5. Take this second piece of and rub it with a pencil lead to deposit carbon (graphite) directly onto the FTO surface. This will leave a black film of carbon on the FTO surface which will be used as our positive electrode.
6. Remove the TiO2 slide from the pigment and gently rinse with water. Allow to air dry (gently blot with a tissue if needed but do not damage the surface!).
Part 2: Build your Solar Cell Device

1. Wash the TiO2 coated conductive glass with water and then ethanol
2. Gently blot the film dry with another piece of tissue paper.
3. Place the dried electrode on a flat surface with the TiO2 film side face up.
4. Place the carbon-coated counter electrode on top of the TiO2 film plate such that the conductive side of the counter electrode faces the TiO2 film.
5. Gently lift the counter electrode and offset the two plates so that all of the TiO2 is covered by the carbon-coated counter electrode and the uncoated 4-5 mm strip of each glass plate is exposed.
6. Carefully pick up the assembly while it is in this orientation and place two binder clips on the longer edges to hold the plates together

7. Carefully place one or two drops of the iodide electrolyte solution at one edge of the plates
8. Alternately open and close each side of the solar cell by releasing and returning the binder clips. The liquid will be drawn into the space between the electrodes. Make sure that all of the stained area is contacted by the electrolyte.
9. Wipe off the excess electrolyte from the exposed areas of the glass using cotton swabs and tissues dampened with ethanol. It is important that the electrolyte is completely removed from the two exposed sides of the cell.
10. Fasten alligator clips to the two exposed sides of the solar cell to make electrical contact to the finished device.

Part 3. Measuring the Electrical Output

1. The negative electrode is the TiO2 coated glass; attach the black wire of the meter to the TiO2 coated glass. Attach the red, positive wire to the counter electrode.
2. Measure the maximum voltage by connecting the solar cell directly to a multimeter set to volts. Record the voltage in your data table.
3. Cover the cell with your hand or a piece of paper and record this number on the data sheet.
4. Measure the maximum current by connecting the cell directly to a multimeter set to mA (milliamperes). Record the current in your data table.
5. Cover the cell and record this number on your data sheet.
6. Take your solar cell to your teacher who will have a lamp. Use the lamp to see what the maximum voltage and current you can record with your solar cell is. Your teacher will write the class data on the board for you to copy.
7. Using the alligator clips and millimeter, connect your solar cell to the solar cells of other lab groups in a Series circuit. Record the voltage and current in your data table.
8. Using the alligator clips and millimeter, connect your solar cell to the solar cells of other lab groups in a Parallel circuit. Record the voltage and current in your data table.
**Data:**

<table>
<thead>
<tr>
<th>Trial #</th>
<th>Voltage</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Class Data:**

Record the data from each of the groups in the table below:

<table>
<thead>
<tr>
<th>Pigment</th>
<th>Voltage</th>
<th>Current</th>
<th>Series / Parallel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Draw a picture of your DSS Solar Cell above
Analysis:
1) How well did your solar cell’s voltage compare to other students? Why do you think it performed the way it did?

2) Write two paragraphs comparing and contrasting the wavelengths absorbed by the pigments with the voltage produced by the classes’ solar cells.

3) Construct an argument using the Claim-Evidence-Reasoning framework about why your solar cell did or did not perform well, compared to other students’ solar cells. Be sure to use absorption wavelengths as one of your pieces of evidence.

4) What pigments would you like to try in the future? Why?
Rubric:

This rubric was modified from McNeill, K. L. & Krajcik, J. (2011). Supporting grade 5-8 students in constructing explanations in science: The claim, evidence and reasoning framework for talk and writing.

<table>
<thead>
<tr>
<th>Component</th>
<th>Basic</th>
<th>Proficient</th>
<th>Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Claim</strong></td>
<td>Does not make a claim, or makes an inaccurate claim.</td>
<td>Makes an accurate but incomplete claim.</td>
<td>Makes an accurate and complete claim.</td>
</tr>
<tr>
<td>A statement or conclusion that answers the question asked or the problem posed.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Evidence</strong></td>
<td>Does not provide evidence, or only provides inappropriate evidence that does not support claim.</td>
<td>Provides appropriate, but insufficient evidence to support claim. May include some inappropriate evidence.</td>
<td>Provides appropriate and sufficient evidence to support claim.</td>
</tr>
<tr>
<td>Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Reasoning</strong></td>
<td>Does not provide reasoning, or only provides reasoning that does not link evidence to the claim.</td>
<td>Provides reasoning that links the claim and evidence. Repeats the evidence and/or includes some scientific principles, but not sufficient.</td>
<td>Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles.</td>
</tr>
<tr>
<td>A justification that connects the evidence to the claim. It shows why data counts as evidence by using appropriate and sufficient scientific principles.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Exemplary Student Response:
The Claim, Evidence, and Reasoning are color coded in the following model student response. This model response would be an Advanced level answer, according to my rubric.

```
Claim | Evidence | Reasoning

Our solar cell did not perform very well compared to other students' solar cells. We believe this is due to the absorption spectrum of our pigment, black tea. Black tea’s absorption spectrum is very broad and has no peaks. If there are no absorption peaks in our spectrum, that would mean that while everything is being absorbed, no wavelengths are being absorbed at a high enough level to excite the electrons enough to move. In addition, we noticed that students who had very high amperage outputs used pigments that had one or two very high peaks, compared to our pigment. This would further indicate a correlation between absorption peaks and electrical output. Given this evidence, we conclude that our electrical output was negatively affected by our broad absorption spectrum.
```
Steve and Shameka were learning about energy transformations in their science class. They learned that chemical energy is one form of energy, and it is stored in the bonds between atoms and molecules. It can be transformed into other forms of energy, such as heat, light or electrical energy.

They read on a website that a device can be powered by a battery made from galvanized nails, copper pennies and fruit. They wanted to try this out for themselves, to see if they could do it and to learn about electricity. They ordered a radio on the internet to run with their homemade battery. While they waited for it to arrive, they built a battery. They called it a “lemon battery”, even though they read that the chemical energy used in the battery is in the bonds of the coating on the nail.

Before the radio arrives, they need to figure out how many battery cells to include. They borrow their dad’s Volt-Meter to test voltage, and conduct the following investigation:

First, they build a 1-Cell Lemon Battery as shown. Second, they expand it to be a 2-Cell Lemon Battery, connected in series.

They continue by building a 3, 4, 5 and 6-Cell battery (all of them connected in series). They record their voltages in a data table, Figure 3.
**Data Table 1:**

<table>
<thead>
<tr>
<th># of Battery Cells (Lemons)</th>
<th>Voltage Reading on Volt-Meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.9 V</td>
</tr>
<tr>
<td>2</td>
<td>1.7 V</td>
</tr>
<tr>
<td>3</td>
<td>2.6 V</td>
</tr>
<tr>
<td>4</td>
<td>3.6 V</td>
</tr>
<tr>
<td>5</td>
<td>4.4 V</td>
</tr>
<tr>
<td>6</td>
<td>5.1 V</td>
</tr>
</tbody>
</table>

**Answer the following questions about Steve and Shameka’s Investigation.**

1. What is a testable question or problem that is the basis for this investigation? (1 point)

_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

Scoring Guide: The student correctly provides any reasonable testable question or statement of problem that:
- identifies what will be tested or measured
- will generate quantifiable data
- has a control or comparison inherent in the question

Exemplary responses take these appropriate forms:
- Does (independent variable) affect (dependent variable)?
- How does (independent variable) affect (dependent variable)?
- Will (independent variable) affect (dependent variable)?
2. Write an appropriate hypothesis for this investigation. (1 point)

_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

Scoring Guide: The student correctly provides any reasonable hypothesis based on the testable question or statement of a problem that predicts an effect, or the lack of effect, of the independent variable on the dependent variable. Exemplary responses take these appropriate forms:
• If (independent variable) (description of change in independent variable), then (dependent variable) (description of event).
• As the (independent variable) (description of changes), the (dependent variable) (description of observed changes in dependent variables).
• The (qualitative/quantitative change in independent variable) of (independent variable), the (quantitative change in dependent variable).

NOTE: Answer does not have to take the if/then form to be considered correct.

3. Identify the Independent Variable for this investigation. (1 point)

_______________________________________________________________________

Scoring Guide: Student correctly identifies the independent variable (the variable that is purposely changed by the investigator).

4. Identify the Dependent Variable for this investigation. (1 point)

_______________________________________________________________________

Scoring Guide: Student correctly identifies the dependent variable (The variable that changes in response to the independent variable and is observed (collected as data) is the dependent variable).

5. Identify two variables, other than the one investigated, that could have an effect on the voltage of a battery? (2 points)
1. ________________________________________________________________
2. ________________________________________________________________

Scoring Guide: The student correctly identifies two independent variables that could also influence the Voltage of the battery. (2 points)
The student correctly identifies just 1 independent variable that could also affect the voltage of the battery. (1 point)

6. Why is it important to hold some conditions constant during an investigation? (1 point)

_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

Scoring Guide: The student correctly identifies why it is important to keep some conditions constant during an investigation.

7. Identify two factors that should be held constant for this investigation. (2 points)
1. ________________________________________________________________
2. ________________________________________________________________
Scoring Guide: The student correctly identifies two constants for this investigation. Constants are factors that remain the same and have fixed values. Their purpose is to isolate the factor (independent variable) that can affect the results. (2 points) The student correctly identifies one constant for this investigation (1 point)

8. Use the data from Data Table 1 to draw a line graph on the grid below. Be sure to provide:
   - An appropriate title
   - Labeled axes with appropriate units
   - Appropriate number scales
   - Correctly plotted data.

Scoring Guide: One point for each of the following:
1. Appropriate title: a statement of the relationship between the independent and dependent variables or a statement of what is being tested
2. Both axes correctly labeled, with units if appropriate
3. Appropriate number scales labeled along each axis: numbers written on the grid lines, numbers that allow all data to be plotted, consistently scaled
4. All data points correctly plotted and connected by lines or line of best fit
9. When Steve and Shameka receive the radio they ordered in the mail, they see that it takes a 9-Volt battery. How many Lemon Battery Cells will they need to power their radio? Explain your answer using data from the table and/or your graph. (2 points)

Scoring Guide: 2 points – the student correctly identifies the number of battery cells and explains why this is correct using data from table 1 and/or their graph. 1 point – the student correctly identifies the number of battery cells but provides no explanation, an incorrect explanation or an explanation without data – OR - the student incorrectly identifies the number of battery cells but correctly explains how the data could be used to determine the number.

10. When sound comes out of the radio’s speakers, we know that it started out as chemical energy in the nails’ coating. Transformations take place when energy converts from one form to another.
   a. Complete the following energy flow diagram using the words from the word bank. (2 points)

   Word Bank: Thermal Energy (Heat) Electrical Energy
               Light Energy Mechanical Energy

   b. The Law of Conservation of Energy states that energy cannot be created or destroyed, but only changed from one form into another or transferred from one object to another. In this investigation, some of the energy is wasted and escapes the system. Describe where in the energy flow this takes place. (1 point)

Scoring Guide: 1 point for each of the following: Correct energy form in first box. Correct energy form in last box. Accurate description of wasted energy in the energy flow diagram/scenario.
11. A 9-Volt alkaline battery that is normally used to power a radio is made of six small Battery Cells connected in series. Based on what you learned from Steve and Shameka’s investigation, what is the voltage of each of those six Battery Cells? Explain your answer. If you need to show any work, it should be in the box provided. (2 points)

Scoring Guide: Student correctly identifies the number of volts per cell in a 9-Volt battery. (1 point) Student reasonably explains or shows how to determine a correct answer. (1 point) If the student gives a reasonable explanation but gives the wrong number of volts or makes an error in determining it they will earn 1 point.