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SOLAR ENERGY WORKSHOP

Learning for Clean Energy Innovation:
A Professional Development Opportunity for Connecticut Teachers

9th Grade Science Frameworks

CLEAN ENERGY. LET'S MAKE MORE.

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* Content information compiled from HowStuffWorks.com and Conceptual Physics by Paul Hewitt.

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INTRODUCTION

As teachers, we want students to learn about energy – what it is, how we use it, and where it comes from. It is important for students to become aware of both renewable and nonrenewable forms of energy resources so, as they grow into adults, they can have the knowledge necessary to become responsible, contributing citizens and make good choices about the resources they use.

One renewable resource that many of us use today is solar energy. Solar energy is used in residential homes, industrial application, central power stations, and commercial buildings. The activities from today's workshop will fit easily into classroom lessons involving scientific inquiry and the scientific method. They will help address several of the *9th Grade Content Standards of the Connecticut Core Science Curriculum Framework* including:

9.1 Energy cannot be created or destroyed; however, energy can be converted from one form to another.

D3 – Describe energy transformations among heat, light, electricity and motion.

9.2 The electrical force is a universal force that exists between any two charged objects.

D4 – Explain the relationship among voltage, current and resistance in a simple circuit.
D5 – Explain how electricity is used to produce heat and light in incandescent bulbs and heating elements.

9.3 Various sources of energy are used by humans and all have advantages and disadvantages

Alternative energy sources are being explored and used to address the disadvantages of using fossil and nuclear fuels.

D9 – Describe the availability, current uses and environmental issues related to the use of hydrogen fuel cells, wind and *solar energy* to produce electricity.

During our time together we will not only have the opportunity to DO each of the activities presented in the workshop, but we will also take time to discuss how these activities can fit into your established curriculum, what prior knowledge is required for each activity, and make suggestions for modifications and extensions to these activities. We will also preview software that is being developed especially for the Communities Program that will help you educate your students about solar energy.

Suggested Sequence of Classroom Lessons

Lesson 1: Batteries and Bulb Activity

Lesson 2: Simple Circuits and How a Light Bulb Works

Lesson 3: Ohms Law and Power Calculations

Lesson 4: Measuring Current and Voltage Activity

Lesson 5: Solar Cells

Lesson 6: Factors that Effect the Power Output of a Solar Cell Activity

Lesson 7: Discussion of Solar Energy as an Alternative Energy Source

Note: “Lesson” is not meant to imply 1 class period or 1 day of instruction.

Vocabulary

Ampere (A) – a unit of electric current; 1 ampere is the flow of 1 coulomb per second

Battery – an energy storage device that converts chemical energy to electrical energy

Circuit – continuous path through which electric charge can flow

Coulomb (C) – a unit of electric charge

Current – the flow of charged particles; in an electric circuit the charged particles are electrons; current is measured through a circuit

Electron – subatomic particle of small mass and negative charge found in all atoms

Energy – the ability to do work; property capable of causing changes in matter

Light –a form of energy that can exist as either a particle or a wave (visible light has a wavelength between 400 and 700 nanometers)

Multimeter – device used to measure current, voltage and resistance in a circuit

Ohm (Ω) – a unit of resistance; 1 volt per ampere

Photon – a particle of light

Power – the rate at which work is done; the amount of energy that passes a point in a circuit each second

Resistance – ratio of voltage across a device in a circuit to the current that flows through it; resistance impedes the flow of current

Solar Cell – device that converts light energy into electrical energy

Voltage – the difference in electric potential energy between two points; higher voltages cause increased current; voltage is measured across circuit devices

Volts (V) – a unit of voltage

Watts (W) – a unit of power; 1 joule per second

BATTERIES AND BULBS

You have been given a battery, a wire, and a light bulb. Your task is to light up the bulb and to document the different battery/bulb/wire configurations you test.

A. Show, as completely as you can, **4 different** arrangements that DID NOT light the bulb.

B. Show, as completely as you can, **4 different** arrangements that DID light the bulb.

ANALYSIS QUESTIONS

1. Based on your observations, list as many rules as possible that must be followed in order to light up the bulb.

2. Based on your observations of what worked and what did not work, what do you think the wiring inside of a light bulb looks like? Draw an outline of the light bulb, and inside of it, show what you think the wiring might look like.

3. Explain how your rules relate to your idea of what the wiring inside a light bulb looks like.

4. Think about the arrangements that worked. What do you think would happen if the wires you used were much longer – would it take the bulb more time, less time, or the same time to light up compared to when the wire was shorter? Explain why.

The Structure of a Light Bulb*

Light bulbs have a very simple structure. At the base, they have two metal contacts, which connect to the ends of an electrical circuit. The metal contacts are attached to two stiff wires, which are attached to a thin metal filament. The wires and the filament are housed in a glass bulb, which is filled with an inert gas, such as argon.

When the bulb is hooked up to a power supply, an electric current flows from one contact to the other, through the wires and the filament. As the electrons zip along through the filament, they are constantly bumping into the atoms that make up the filament. Energy from the electrons transfers to the atoms, causing them to vibrate. In other words, the current (moving electrons) causes the atoms to gain thermal energy.

The filament in a light bulb is made of a long, incredibly thin length of tungsten metal. In a typical 60-watt bulb, the tungsten filament is about 6.5 feet (2 meters) long but only one-hundredth of an inch thick. The tungsten filament is wound up to make one coil, and then this coil is wound to make a larger coil so that it all fits into a space of about an inch long!

If the vibrating electrons in the tungsten filament get enough energy, they may “jump” temporarily to a higher energy level. When they fall back to their normal levels, the electrons release the extra energy in the form of photons (tiny packets of light). Metal atoms release mostly infrared light photons, which can’t be detected by the human eye. But, if they are heated to a high enough level -- around 4,000 degrees Fahrenheit (2,200 degrees C) as in the case of a light bulb -- they will emit a good deal of visible light.

Most metals will actually melt before reaching such extreme temperatures -- the vibration will break apart the rigid structural bonds between the atoms so that the material becomes a liquid. Light bulbs are manufactured with tungsten filaments because tungsten has an abnormally high melting temperature. But tungsten *will* catch on fire at such high temperatures, if the conditions are right. Combustion is caused by a reaction between two chemicals, usually between oxygen in the atmosphere and some heated material. In order to prevent combustion, the filament in a light bulb is housed in a sealed, oxygen-free chamber. The chamber in the light bulb is actually filled with an inert gas, typically argon. Since inert gases normally don't react with other elements, there is no chance of the elements combining in a combustion reaction.

Cheap, effective and easy-to-use, the light bulb has proved a monstrous success. It is still the most popular method of bringing light indoors and extending the day after sundown. But by all indications, it will eventually give way to more advanced technologies, because it isn't very efficient. Incandescent light bulbs give off most of their energy in the form of heat-carrying infrared light photons -- only about 10 percent of the light produced is in the visible spectrum. This wastes a lot of electricity. Cool light sources, such as fluorescent lamps and LEDs, don't waste a lot of energy generating heat -- they give off mostly visible light. For this reason, they are slowly edging out the old reliable light bulb.

Ohm’s Law*

Electric “current” is the flow of electric charge. In a solid conductor (like a wire) the electrons carry the charge through the circuit because they are free to move throughout the atomic network. These electrons are sometimes called “conduction electrons”. Protons, however, are bound inside the nucleus of an atom and cannot move in the circuit. When a circuit is complete, negatively charged electrons move through an atomic network composed of positively charged atomic nuclei. In ordinary situations, the number of electrons in a circuit is always equal to the number of protons in the circuit – the number of electrons entering one end is the same as the number leaving the other end.

Charges do not flow unless there is a potential difference. Something that provides a potential difference is called a “voltage source”. The electric potential energy available per charge is the “voltage”. Voltage causes current – it is measured *across* a circuit or device, while current is measured *through* a circuit or device. The more voltage that is present, the more current there will be – it is a direct relationship. Current, however, also depends on the “resistance” of a circuit. The more resistance in a wire, the less current there will be – it is an inverse relationship. The resistance of a wire depends on material used (how well it allows charge to move) and also on the thickness, length, and temperature of the wire. Wires that are thin, short, and at a high temperature all tend to have an increased electrical resistance. Taken all together, the relationship between current, voltage, and resistance is seen in Ohm’s Law: current = voltage/resistance.

Power – It’s All in the Watts! *

Light bulbs are ranked by their power (measured in watts) -- the amount of light energy they put out in a certain period of time. Power is equal to the amount of energy produced divided by the amount of time it takes (power = energy/time). Since voltage is the amount of energy per charge (voltage = energy/charge) and current is the amount of charge passing through a point in a certain amount of time (current = charge/time), power calculated by multiplying current by voltage ([charge/time] x [energy/charge] = [energy/time] = power).

Bright, Brighter, Brightest*

A three-way bulb has two filaments of different wattage -- typically a 50-watt filament and a 100-watt filament. The filaments are wired to separate circuits, which can be closed initially using a special three-way socket.

The switch in the three-way socket lets you choose from three different light levels. On the lowest level, the switch closes only the circuit for the 50-watt filament. For the medium light level, the switch closes the circuit for the 100-watt filament. For the brightest level, the switch closes the circuits for both filaments, so the bulb operates at 150 watts.

MEASURING CURRENT AND VOLTAGE

Make a working simple circuit using one battery, some connecting wires, and a motor. Place the battery in the battery holder and connect one wire (using the alligator clip) to each side of the battery. Then, connect each 'free end' of the wire to a wire coming out of the motor (again, use the alligator clips). It *does not* matter which side of the battery is connected to which wire on the motor.

1. Using the multimeter, measure the voltage across the battery. Record the voltage in the table below.
2. Measure the current through the circuit. Record the current in the table below.
3. Calculate the resistance of the circuit using Ohms Law (I=V/R). Record the resistance in the table below.
4. Calculate the power output of the circuit (P = IV) Record the power in the table below.

Add a second battery to your circuit.

1. Measure and record the voltage across the two batteries.
2. Measure and record the current through the circuit.
3. Calculate and record the resistance of the circuit.
4. Calculate and record the power output of the circuit.

Remove the batteries from your circuit. Replace them with a solar cell. Using the light source provided, shine light on your solar cell so that the motor runs.

1. Measure and record the voltage across the solar cell.
2. Measure and record the current through the circuit.
3. Calculate and record the resistance of the circuit.
4. Calculate and record the power output of the circuit.

Voltage Source	Voltage (V)	Current (A)	Resistance (Ω)	Power (W)
1 Battery				
2 Batteries				
1 Solar Cell				

ANALYSIS QUESTIONS

1. What happened to the current in your circuit when a second battery was added? Why did this happen?

2. What do you think would happen to the current in your circuit if the number of batteries (or solar cells) remained the same but more motors were added?

3. How is a solar cell like a battery? How is it different?

4. Compare the power output of the solar cell to the power output of the battery.

5. What are the advantages and disadvantages of using a solar cell to power your motor instead of a battery?

6. What factors do you think might effect the power output of a solar cell?

Solar Cells*

The solar cells that you see on calculators and satellites are sometimes called photovoltaic cells. Photovoltaic (PV) cells convert one form of energy, light, into another form of energy, electricity. PV cells are made of special materials called semiconductors; the most commonly used is silicon. When light strikes the cell, a certain portion of the light is absorbed within the semiconductor material. This means that the energy of the light is transferred to the semiconductor. The energy knocks electrons loose from their atoms, allowing them to flow freely. This flow of electrons is called current. By placing metal contacts on the top and bottom of the PV cell, that current can be used externally to run other devices. For example, the current can power a calculator. This current, together with the cell's voltage (which is a result of its built-in electric field), defines the power that the solar cell can produce.

In solar cells the most commonly used semiconductor material is silicon. Silicon has some special chemical properties, especially in its crystalline form. An atom of silicon has 14 electrons, arranged in three different shells. The first two shells, those closest to the center, are completely full. The outer shell, however, is only half full, having only four electrons. A silicon atom will always look for ways to fill up its last shell (which would like to have eight electrons). To do this, it will share electrons with four of its neighbor silicon atoms. It's like every atom holds hands with its neighbors, except that in this case, each atom has four hands joined to four neighbors. That's what forms the crystalline structure. But, pure silicon is a poor conductor of electricity because none of its electrons are free to move around the crystalline structure – they are locked in place! Instead, a solar cell has silicon with impurities -- other atoms mixed in with the silicon atoms. We usually think of impurities as being undesirable, but in the case of PV cells these impurities are actually put there on purpose.

Consider silicon with an atom of phosphorous here and there, maybe one for every million silicon atoms. Phosphorous has five electrons in its outer shell, not four. Phosphorous still bonds with its silicon neighbor atoms, but the phosphorous has one extra electron that doesn't have anything to "hold hands with". It doesn't form part of a bond, but it is held there in place because of the positive proton in the phosphorous nucleus. Now, when energy is added – in the form of light - one of the "extra" phosphorous electrons can break free and move through the crystalline structure. The process of adding impurities on purpose is called doping, and when doped with phosphorous, the resulting silicon is called N-type ("n" for negative) because of the "extra" free electrons. N-type doped silicon is a much better conductor than pure silicon is, but it is only one part of the solar cell.

The other part is of the cell is made of P-type doped silicon. This type of silicon is doped with boron, which has only three electrons in its outer shell instead of four. Instead of having an extra electron, this type of silicon ("p" for positive) has an extra space, called a "hole". Holes are just the absence of electrons, so they carry the opposite (positive) charge, but they move around just like electrons do.

The interesting part starts when you put N-type silicon together with P-type silicon. Every PV cell has an electric field that forms when the N-type and P-type silicon are in contact with each other. Without this electric field, the cell wouldn't work. When light, in the form of photons, hits our solar cell, its energy frees electron-hole pairs in the silicon.
Each photon with enough energy will normally free exactly one electron, and result in a free hole as well. The electrons are sent to the N side and holes are sent to the P side. But, if an external path is provided, electrons will flow through the path to unite with holes on the opposite side. The electron flow provides the current, and the cell's electric field causes a voltage. With both current and voltage, the cell’s power (which is the product of the two) can be calculated.

FACTORS THAT EFFECT THE POWER OUTPUT OF A SOLAR CELL

The object of this experiment is to investigate the factors that affect the power output of a solar cell.

You may have seen solar cells and modules on people's homes and businesses or even your school. These cells are capturing the sun's energy and changing it into electricity for us to use. You may be asking yourself why we would want to use the sun's light for electricity when we have so many other energy resources. The answer is that every day more solar energy falls to the Earth than the total amount of energy the planet's 6.1 billion inhabitants would consume in 27 years! In other words, there is plenty of sunlight to go around and we won't run out of it until the sun dies (which is not expected to happen for another 4.5 billion years!). This makes the sun a renewable resource. Every day scientists are researching ways to make solar energy easier and less expensive to use. They want to find ways to make energy from the sun more economical for us to use in our communities so that we can decrease our nonrenewable energy use. Thus, scientists are continually investigating ways to increase the efficiency and power output of solar cells.

The first step in this investigation is for your group to brainstorm what factors you think might affect the power output of a solar cell. Some factors you may wish to consider are the distance of the cell from a light source, the wattage of the light source, the wavelength of the light source, or the angle at which the light hits the cell. You may also think of other ideas! After you have decided what you think will make a difference, your group is going to test your predictions. Remember that once you have determined that one factor does make a difference, there is no reason to test it again with the next factor. For example, if you found that color does or does not make a difference, there is no reason to test the next factor that you think has an effect for all the different colors, because you already know the effect of color.

Your experiment should include:

- A clear problem statement that includes the independent and dependent variables in your experiment.
- A description of the experiment you carried out. Your procedure should be clear and complete so that someone else could easily replicate your experiment.
- The results of your experiment. All data tables and/or appropriate graphs should be properly labeled.
- Conclusions from the experiment. All of your conclusions should be clearly supported by data.
- Comments about the validity of your results. Any factors that contribute to confidence (or a lack of confidence) in your results or conclusions should be discussed. Also indicate ways that your experiment could be improved if you were to do it again.