Center for Renewable Energy Advanced Technological Education

Name: ________________________________
Date: ____ / ____ / ____ Class Hour: ____

SOLAR PV:
WATTS FROM THE SUN

Produced from nuclear fusion within the sun, sunlight travels away from the sun in all directions. Because of this, only a tiny fraction of the sun's light ever reaches our little planet, eight minutes and 93 million miles later. Then only a small fraction of that fraction ever makes it through our atmosphere to strike the earth's surface. While passing through the atmosphere, sunlight is absorbed, scattered, and reflected by molecules in the air, clouds, dust, smoke, and atmospheric pollutants. Naturally the sunlight reaching where we stand is also governed by local weather, our location on the globe, the season of the year, the time of day, and our local landscape.

All of that, and some people calculate the sunlight reaching the surface of our planet each hour of the day is more than the energy used by all humans across the earth each year. That's amazing!

Solar photovoltaic panels are able to turn some of that sunlight into clean, renewable electricity that can be used by humans across the earth. That's amazing too.

Now it's time for you to do some common measurements and calculations on the electricity produced by the sunlight hitting a solar panel. You'll measure basic solar panel performance characteristics to determine how much electricity a classroom solar panel produces. Then you'll use your solar panel production data to project how large a solar panel array would be needed to satisfy different electrical load requirements. You'll be working today in a place where electricity and solar science meet practical application—a place those in the solar industry work all of the time. Is it a place you can see yourself working in the future?

Materials:

Classroom-use solar panel

Digital multimeter wired with alligator clip leads

Magnifying glass

Strong light source--***caution!***

Ruler or meter stick

In this lab exercise, you'll work with and learn Ohm's Law, named after a German Physicist Georg Ohm. It's used everywhere and all of the time in the electrical industry. Ohm's Law states that:

The POWER, **P**, flowing through an electrical circuit is the product of the CURRENT, **I**, multiplied by the ELECTRIC POTENTIAL, **E**

$$\boldsymbol{P = I\ x\ E}$$

This can be remembered as Power is "easy as PIE"

P is **POWER**	**I** is **CURRENT**	**E** is **ELECTRIC POTENTIAL**
It's measured in units of **Watts (W)** and power is sometimes referred to as wattage It is the rate at which work is done (and energy is used) in an electrical circuit $1\ Watt = \frac{Joule}{second}$ *Students may also recall from physics class that Power = Work / time*	It's measured in units of **Amps (A)** and current is sometimes referred to as amperage It is the rate at which electrons flow through an electrical circuit $1\ Amp = \frac{Coulomb}{second}$ *The symbol **I** comes from the French phrase "**i**ntensité de courant" (intensity of current).*	It's measured in units of **Volts (V)** and electric potential is sometimes referred to as voltage It is the amount of potential energy available to push electrons through an electrical circuit $1\ Volt = \frac{Joule}{Coulomb}$ *Electric potential in some older texts was referred to as **E**lectromotive Force (**E**MF). This is technically not correct, since electric potential is not a force.*

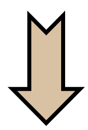
A historical note: Ohm's Law states that for a given resistance (R), the current in a circuit is given by I = E/R. It was James Prescott Joule, not Georg Simon Ohm, who first discovered the mathematical relationship between power dissipation and current in a circuit. Joule's discovery, published in 1841, is properly known as Joule's Law. However, the power equation is so commonly associated with the Ohm's Law equation relating voltage, current, and resistance (I=E/R) that it is frequently credited to Ohm.

Procedure:

1. Examine your classroom-sized solar panel with a magnifying glass. The sun-facing, upper, dark side of your solar panel contains thinly sliced, semi-conducting silicon. If yours is a faithful mimic of a commercially-used solar module, it's covered with non-reflective and protective coverings. Dark and shiny, the silicon just below this surface is the semi-conducting element used to convert sunlight into useful electricity in almost all commercial solar modules.

There are electrical contacts above and below the silicon layer of your solar PV panel. The silver grid patterns you see running through the silicon are the electrical contacts for the top of the panel. You probably can't see it, but a layer just below the silicon in your panel is coated with a thin, continuous sheet of metal. Together, these two sets of contacts complete an electrical circuit. When sunlight strikes your solar PV panel, electrons flow through that circuit, producing renewable electrical energy you can use.

1a. Take a photo of your classroom-sized solar panel. Insert it into this document just below the arrow.



2. In inches, measure the solar-usable length and width of your classroom-sized solar panel. Typically, this will be the glass top surface of your solar panel. Multiply these two measurements together to determine the solar-usable surface area of your panel in inches^2 (in^2). Take that value and divide by 144 in^2 / 1 ft^2. This number is the solar-usable surface area of your solar panel in ft^2.

Post these measurements and values into **Table 2**. Before posting your values, check with your teacher. Your teacher may want everyone in the class to use the same agreed upon measurements at this stage of the lab.

Table 2

Instruction	Exercise
Post a unit label after each measure or number. Do it throughout the entire exercise.	$\overline{Length}\ x\ \overline{Width} = \overline{Surface\ Area, in^2}\ \overline{Surface\ Area, ft^2}$

3. Follow your teacher's directions for connecting a classroom solar PV panel to a digital multimeter to properly read Current. Current is measured in units called amps. It is the rate at which electrons flow through an electrical circuit.

Caution! You will use a strong light source in this part of the investigation. Do not look directly at the light source. Looking directly at the light source can cause eye damage.

Now follow your teacher's directions for holding your classroom PV panel in front of a strong light source. Hold the panel close to the light source.

3a. Record the distance of the panel from the light source and current reading at that distance in **Table 3**, below. Then increase the distance of the PV cell from the light source. Record the distance from the light source and the corresponding current reading in **Table 3**. Keep varying the distance and recording the current reading.

Table 3

Distance (express with unit)	Current, I (amps, A)	Electric Potential, E (volts, V)	Power (Watts, W)

3b. State or explain the trend that emerges from your Current data.

***Answer**

4. Now follow your teacher's directions for connecting a classroom solar PV panel to a digital multimeter to properly read Electric Potential. Electric Potential is measured in units called volts. It is the amount of potential energy available to push electrons through an electrical circuit.

4a. Repeat step 3a, this time recording Electric Potential in **Table 3**, above.

4b. State or explain the trend that emerges from your voltage data. Does voltage show the same trend as current?

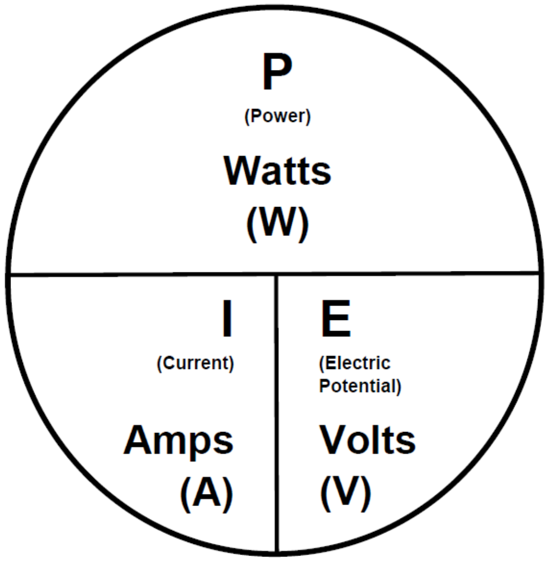
***Answer**

5. Now you'll work with Ohm's Law, as promised earlier. Ohm's law states that:

The POWER, **P**, flowing through an electrical circuit is the product of the CURRENT, **I**, multiplied by the ELECTRIC POTENTIAL, **E**

$$\boldsymbol{P = I\ x\ E}$$

This can be remembered as Power is "easy as PIE"



Perhaps you've seen or used a math relationship circle like the one above. If you know any two of the measures in the "PIE" circle, you can determine the third.

Put a finger over the variable you need to know. The line between the two measures you know, will tell you what to do to get the answer. A vertical line between the two indicates a multiplication operation. A horizontal line means division.

If you don't care for circles, the mathematical relationships between these three variables are expressed below

POWER (Watts, W) = CURRENT (Amps, A) x ELECTRIC POTENTIAL (Volts, V)

CURRENT (Amps, A) = POWER (Watts, W) / ELECTRIC POTENTIAL (Volts, V)

ELECTRIC POTENTIAL (Volts, V) = POWER (Watts, W) / CURRENT (Amps, A)

You'll be using these math relationships throughout the rest of this lesson.

5a. Calculate the electrical Power generated by your solar panel at each of the distances you worked with in **Table 3**, above. *It's easy as PIE.*

5b. Select the distance that produced maximum voltage and current readings for your classroom solar PV panel. Highlight all of the values in that row of **Table 3**.

5c. What is your panel's maximum Power output? Record the value below in **Table 5**.

Table 5

Instruction	Exercise
Highlight the number you put into this table.	____________________ Maximum Power output for my solar panel

6. Calculate and use the Watts / ft^2 at maximum Power for your classroom solar PV panel.

6a. Using the maximum Power output above, and your panel's area in ft^2, calculate the Watts / ft^2 your panel will produce at maximum Power. **Table 6a**, below.

Table 6a

Instruction	Exercise
Show your math work completely. Highlight your answer with its correct unit label.	

6b. Let's say you want to install a solar PV system on your roof capable of producing 2 kW (2000 Watts) of electricity at maximum power. How many square feet of area will you need to make available on your roof for solar panels like these to produce 2 kW of electrical power in full, direct sun? Do your calculation in **Table 6b**, below.

**Note: No one would ever install small, classroom-size, educational solar panels on their roof. For a variety of reasons, they are not suited for this purpose. However, "sizing" calculations just like these are very real.

Table 6b

Instruction	Exercise
Show your math work completely. Highlight your answer with its correct unit label.	

6c. Divide your answer to the last question by ten. Write your result on the blank in

Table 6c. At 10 feet tall, this result is the length of a fixed-tilt, rooftop solar PV system needed to generate 2 kW of electricity at maximum power production.

[“Fixed-tilt” means the panels are fixed in place throughout the day and year. Some other PV systems include sensors and motors that allow the panels to move in relation to the sun all day--a “tracking” system. Tracking systems produce more electricity but are more expensive to install and have maintenance costs.]

Table 6c

Instruction	Exercise
	_________ feet X 10 feet.

Summarize and **S**how What You Know

S1. ***Power is "easy as PIE"***:

S1a. What does P stand for? ***Answer**

S1b. What is the definition for P? ***Answer**

S1c. What units is P measured in? ***Answer**

S1d. What does I stand for? ***Answer**

S1e. What is the definition for I? ***Answer**

S1f. What units is I measured in? ***Answer**

S1g. What does E stand for? ***Answer**

S1h. What is the definition for E? ***Answer**

S1i. What units is E measured in? ***Answer**

S1j. Describe the mathematical relationship behind the phrase, *Power is "easy as PIE"*? *

S2. ***Power is "easy as PIE,"* practice, practice practice:**

Typically, each electric utility supplies 120 volts of Electric Potential to homes in the United States. 120 V is the voltage on each electrically "hot" wire in your home with respect to neutral (or ground). With this in mind, practice some simple PIE calculations with the lighting information supplied in **Table S2**.

Four different lighting technologies are described on the left side of **Table S2**, below. The first, a typical incandescent light bulb, is the oldest and most common lighting technology in use. Somewhat more efficient incandescent light bulbs began replacing them over time. Then compact fluorescent (CFL) lights were introduced in the marketplace. You may know that the most recent lighting to hit the market is light emitting diode (LED) technology. LED lighting is much more efficient at converting electricity to light. But LED's are not only more efficient. LED lighting is more versatile, lasts longer, and is becoming less and less expensive.

Table S2

Lighting technologies supplying approximately 800 lumens (~60 W equivalent)

Lamp Type:	**S2a. Stat line:**	**S2a. Calculation with math work for PIE:**	**Calculation with math work for cost:**
Typical Incandescent Light Bulb (lasts 1000 hours)	**20 Volts** **_______ Amps** **60 Watts**		60 Watts x 1k hours = 60 kiloWatt hours = 60 kWh x $0.15 / kWh = **$9.00**
Efficient Incandescent Light Bulb (lasts 2000 hours)	**120 Volts** **0.36 Amps** **_______ Watts**		
Compact Fluorescent Light Bulb (CFL) (12,000 hours)	**120 Volts** **_______ Amps** **14 Watts**		
Light Emitting Diode (LED) (25,000 hours)	**120 Volts** **0.1 Amps** **_______ Watts**		

S2a. From the “stat line” posted next to each lighting technology in **Table S2**, calculate (showing work) the variable that remains. Highlight your answer. *It’s easy as PIE*!

S2b. What is the trend for how long the lamp will last as you move down the table--as you move toward more and more efficient lighting?

***Answer**

S2c. What is the trend for Watts of power as you move down the table--as you move toward more and more efficient lighting?

***Answer**

2d. Whether you've noticed it or not, you have an electric service panel or service box where you live. Many people call it the "breaker box," because it contains numerous circuit breakers for your home. A circuit breaker is an OCPD--an **O**ver **C**urrent **P**rotection **D**evice. For electrical safety, a circuit breaker is designed to stop, break, or "trip" current flow that goes over the current limit for that breaker. After turning off at least some of the appliances in the tripped circuit, a circuit breaker can be reset. Typical residential circuit breakers limit current flow to and through their electrical circuit to either 15 amps, or 20 amps.

More and more people today are switching away from incandescent light bulbs to more energy efficient lighting technology. LED lighting has attractive features consumers want, and of course, it saves energy and money. An added bonus? Circuit breaker limits aren't exceeded as often as they used to be in older homes. Using data from **Table S2**, explain why people living in older homes don't "trip" circuit breakers as often as they used to.

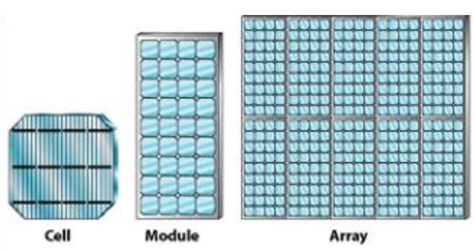
***Answer**

2e. What is the cost to use each type of lighting technology for 1k hours (1000 hours)? Show your math work in the space provided in **Table S2**. An example is illustrated using an electricity price of $0.15 / kWh. Use that price unless your teacher gives you a more specific price for your region. Your teacher will tell you how much math work needs to be shown. Highlight your final answer with its correct unit label in yellow.

2f. What is the trend for cost per 1000 hours of use as you move down the table--as you move toward more and more efficient lighting?

***Answer**

S3. Cell to module to array



S3a. In full, direct sunlight, a 6 inch by 6 inch solar PV cell on a typical residential solar panel will measure 9.0 amps and 0.5 volts. In **Table S3** below, calculate power for the single 6 inch by 6 inch cell described. You may want to check your answer with your teacher before going to the next question.

Table S3

In each box, show your math work completely. Highlight your answer with its correct unit label.

Summary	**Math Work**
S3a.	**____________________ / Solar PV cell**
S3b.	**____________________ / Module**
S3c.	**____________________ Modules / 6 kW residential array**
S3d.	**____________________ = Minimum roof area required to install a 6kW rooftop array**
S3e.	**______ feet = length of a 6 kW fixed tilt PV array that is 10 feet tall**

S3b. A typical residential solar PV module (solar panel) often has 10 rows of 6 solar cells, or 60 cells in all. Calculate how many watts of power this solar panel will produce in full, direct sunlight in **Table S3**, above.

S3c. The average residential solar PV system installed in the US produces 6 kW (6000 Watts) of electricity at maximum power. How many typical solar PV modules will be required to deliver

6 kW of electric power? Show your work and post your answer in **Table S3**, above. Round your answer to the nearest whole number.

S3d. The typical 60-cell module from the last question measures 39 inches wide by 65 inches tall, or 2536 in^2. Divided by 144 in^2 / 1 ft^2, it occupies an area of 17.6 ft^2. How many square feet of area will you need to make available on your roof for these solar modules to produce a total of 6 kW of electrical power in full, direct sun? Post your answer in **Table S3**, above.

[Solar PV systems don't have to be installed on rooftops. Roof mounted systems are common for obvious reasons. Solar arrays may be installed on poles, awnings, and can be mounted to racks on the ground, just to name a few.]

S3e. Divide your answer to the last question by ten. Write your result on the blank in **Table S3**, above. At 10 feet tall, this result is the length of a fixed-tilt solar PV system needed to generate 6 kW of electricity at maximum power production.

S3f. Your answers to the last two questions assume that you may place a 6kW solar array just about any place on your roof. Describe at least three rooftop characteristics that must be in place--that must be "right"--in order to make your investment in sun, solar, and renewable energy make sense:

S3f-1. *Answer

S3f-2. *Answer

S3f-3. *Answer

S4. The big picture

S4a. Sometimes a homeowner is using less than 6 kW of electricity during a time of maximum sunlight. What is a sensible thing for such a homeowner to do with this "excess" electricity?

***Answer**

S4b. Sometimes a homeowner needs more than 6 kW, or needs electricity when their solar PV system is not producing (night), or generating below maximum (cloudy). What is a sensible thing for such a homeowner to do when more electricity is needed than the system can provide?

***Answer**

S4c. A homeowner who has installed a solar PV system has been heard to say, "We try to match our lifestyle to the capacity of our home to produce electricity." Consider your answers to the previous two questions and what you've learned in this lesson. What meaning is this homeowner trying to convey:

***Answer**