National Renewable Energy Laboratory

Photovoltaics (PV) in the Classroom Workshop

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PV in the Classroom Workshop

Introduction to Power and Energy

Electricity is the most common type of energy used in US households. While ubiquitous, it is also mysterious to most of us. We hear to terms power and energy used frequently, seemingly interchangeably, though they are quite different. We pay our monthly electricity bills, but may not be sure what the 158 kiloWatthour we been charged for really is, whether paying 8 cents per kiloWatthour is cheap or expensive, or how best to approach reducing our electricity use to lower our bills. We may read of power plants that are built to megaWatt size, yet we get charged for kiloWatthours of usage. If the utility asks us to reduce our electricity usage to avoid a brownout or blackout, we are not sure if the best way to do this is to turn off the air conditioner, the oven, a light or the radio.

We buy appliances or devices like a 100 Watt light bulb or an electric tool that requires 120 Volts or a vacuum cleaner that uses 8.8 Amps. We tend not to notice or worry about these things and we are very confident that when we plug a device into our wall socket, it will work – and it usually does.

However, since we rely heavily on electricity and energy for so many of the daily activities we undertake and since we are all impacted heavily when energy prices rise, it is important to have a basic understanding of energy, what it is, how it works, how we pay for it, where it comes from, etc..

The purpose of this booklet and the workshop that it is designed to be used in conjunction with is to provide teachers with useful information for teaching electricity, solar geometry, photovoltaics, and data analysis.
This booklet is used as part of a workshop for teachers' that addresses several important topics, including: basics of electric power and energy; basics of photovoltaics and solar geometry; basics of data analysis for school photovoltaic demonstration projects.

Power & Energy Estimation – First Try

First, let’s see what we know about electricity that we use in our home.

Rank the following in terms of how much power (1 for highest power consumption, 6 for lowest) and energy (1 for highest energy consumption, 6 for lowest) they consume in a typical day. If possible, try to determine the actual power and energy requirements:

Appliance	**Hours per day of use**	**Amps**	**Rank**	**Power** [Watts]		**Rank**	**Energy** [kiloWatthours]
TV	2 hrs	0.8					
Computer	1 hrs	0.33					
Lamp	8 hrs	.83					
Toaster	0.05 hr (3 min /60 min/1 hr)	11.67					
Fan	4 hrs	1.9					
Blender	0.033 hr (2 min /60 min/1 hr)	2.2					

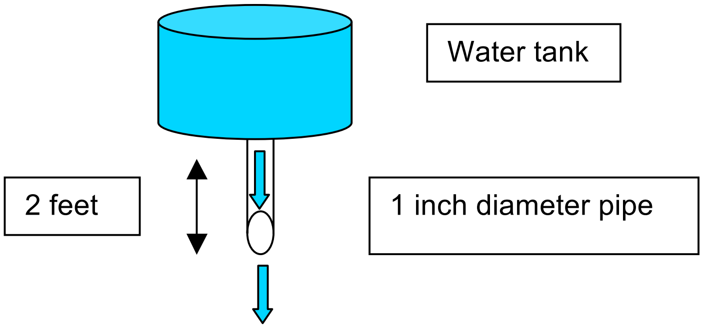
This little exercise may help us realize that we do have some things to learn about electricity.

Power and Energy Concepts

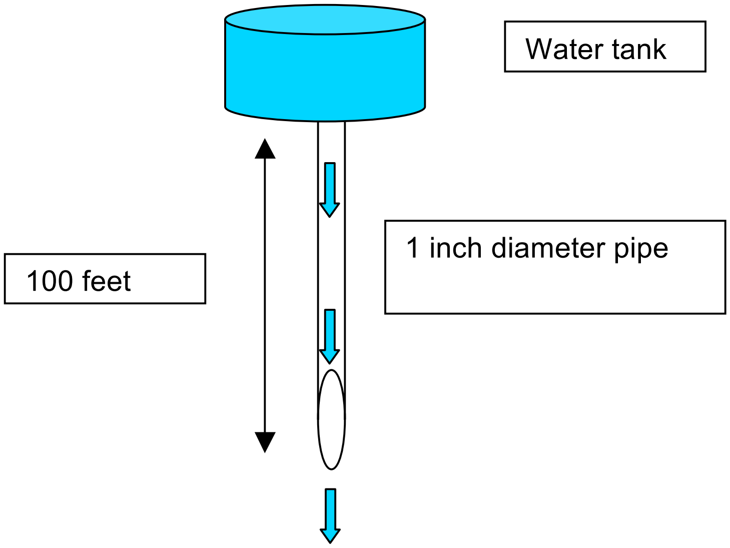
Components of electrical power can be confusing. We will introduce them using water analogies. Voltage, current, resistance, power and energy can be described using common concepts more typically associated with water, but reasonably adapted to electricity terminology (especially as aids to understanding).

Voltage

The concept of voltage can be described using water pressure and water pressure potential. If a tank full of water is suspended 2 feet above the ground with a 1 inch pipe coming out of the bottom, would students feel comfortable putting their head under the water stream? The water coming out would be similar (same order of magnitude) to the force of a shower they take at home.



If the same full water tank were suspended 100 feet above the ground with the same 1-inch pipe coming out of the bottom, the force of the water hitting the ground would be much greater than before. So much greater that the students might have difficulty standing up in the falling stream of water, and even if they could stand up under it, the force of the water would likely hurt them or give them a headache. If you doubt the difference in voltage pressure with this analogy, try another. Imagine yourself on a stool 2 feet above the ground. Now jump off. What is the force of your body hitting the ground, great or small? This should be easily manageable for most of us. Now imagine jumping of a building ledge that is 100 ft. above the ground. The force with which you would hit the ground would be immense and survival unlikely. The same thing is happening to the water in the 100 ft. pipe.



Voltage (V) is a measure of the amount of pressure, or electromotive force, applied to electrons to make them move. **A Volt is the unit of electromotive force that will force a current of one ampere through a resistance of one ohm.** After we learn about current and resistance, this definition will make more sense. **Voltage** is measured in units of **Volts (V).**

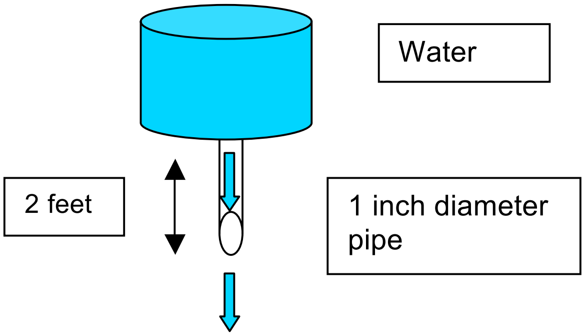
Just as the tank suspended 100 feet would apply a higher water pressure than a tank suspended 2 feet, a power supply at 100 volts would apply a greater electromotive force or voltage pressure than a power supply at 2 volts. For voltage discussions, a more commonly used term is **potential** (i.e., voltage potential), which is reasonably analogous to pressure for our purposes.

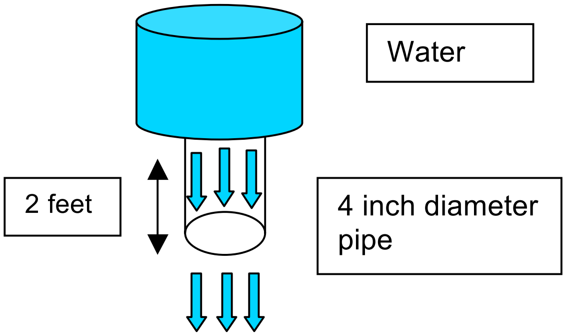
AA batteries are 1.5 Volt – they apply a small amount of voltage or pressure for lighting small flashlight bulbs. Your car has a 12 Volt battery – it applies quite a bit more pressure or voltage to push current through circuits in your car to operate the radio or defroster. At home, we operate with 120 Volts being the standard voltage that comes out of the wall outlets – that is a dangerous amount of voltage! And, your electric clothes dryer is typically wired at 240 volts – again, a very dangerous amount of voltage.

Current

Electrons can be likened to molecules of water. In stationary water, the molecules are relatively stationary and will perform no work. In moving water (small river or a vertical pipe), the molecules are moving, analogous to electrons moving in a closed circuit. In water, the current of the water would vary directly with the number of molecules flowing by a fixed point, just as electrical current would vary directly with the number of electrons flowing by a fixed point. **Current (I)** is the measure of electron flow in a conductor between two points having a difference in potential (voltage). **Current** is measured in units of **Amperes or Amps (A).**

Using our tank full of water suspended 2 feet above the ground, imagine how much water would flow if the same 1 inch pipe were attached to the bottom.
Then asked, what would happen if the 1-inch pipe were replaced with a 4-inch pipe? Or a ¼ inch pipe?





With the larger cross-sectional flow area, the water flow would be increased and, hence, the flow of current would be increased. Conversely, the smaller the cross-sectional flow area of the pipe (the ¼ in. pipe), the less water would flow.

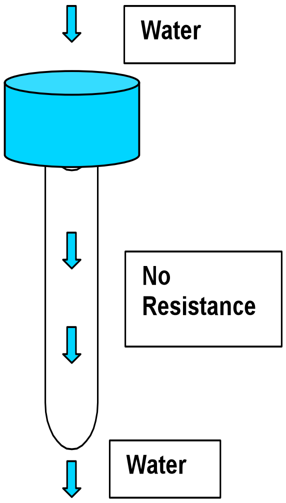
With electricity, conducting wires take the place of the pipe. The bigger the cross sectional area of the wire, the more current it can allow to flow through it. The smaller the cross sectional area, the less current it can allow to flow through it. As current flows through a wire, the rapidly moving and vibrating electrons cause the wire to heat up. Small wires with lots of current flowing through it will heat up, melt the protective coating and potentially cause a fire. The same current flowing through a much larger wire, though it would heat up, would do so to a much lesser degree and not pose a fire threat. It is important to size wires according to the amount of current expected to flow through them to avoid over-current problems. Similar to the over-current problem in wires, trying to force too much water through too small a pipe may cause the pipe to burst.

For electrical current to flow, the conductor (wire) must form a complete or **closed circuit**. If there is a break in the conductor, no electricity can flow and it is called an **open circuit**.

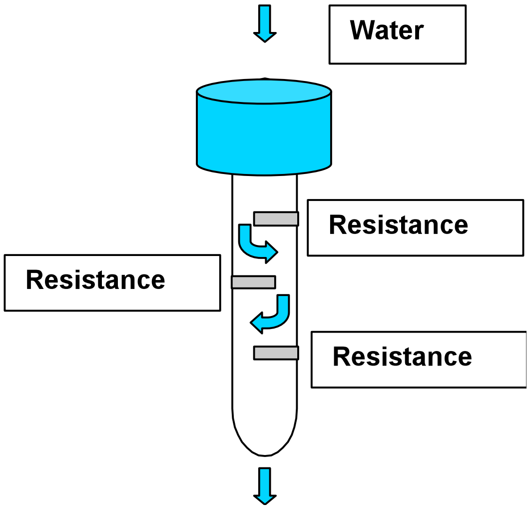
The direction of current flow in a circuit is determined by the **polarity** of the voltage source. The conventional current direction describes current flowing from the positive terminal of the voltage source through a resistance or load to the negative terminal of the voltage source. (Point of interest: The actual direction of electron flow is the opposite of this – the electrons flow from the negative terminal through the resistance to the positive terminal. We will only use the conventional current direction description.)

Resistance

With water in a pipe, resistance can be thought of as impediments to water flow such as a smaller pipe or fins extending across the flow area on the inside of the pipe, thereby restricting and slowing water movement. For conducting wires, the resistance of the wire is actually a constant that is dependent on the conductor material (the wire may be made out of copper, aluminum, silver – all have different resistance properties) and the size of the wire (diameter). Resistance (R) is measured in units of Ohms (Ω). There are electrical devices, called resistors, designed with a specific, built-in resistance to be placed in a closed circuit to reduce or control the current flow. The load or appliance that we are operating with electricity has a built-in resistance as well.



No Additional Resistance



Additional Resistance using Water Analogy

The example on the left can be thought of as a circuit with no load or appliance connected to it (you will see this when you use the Genecon generator that is not connected to anything). On the right, electrically, the resistances could be several of the lights that you have in one room at home that are all connected to the same circuit.

Ohm's Law

Ohm's Law is an experimental, rather than physical, relationship between voltage (V), current (I), and resistance (R). This means that this relationship was observed to happen consistently and the Law was derived from the observations, rather than the Law being derived from theoretical physics and then "proved" through experimentation.

Ohm's Law states:

$V = I * R$ [Units: Volts = Amps * Ohms or $V = I * \Omega$]

or Voltage = Current x Resistance

From basic Algebra, if we can solve for V by multiplying I and R, we should be able to work backwards to find R if we know V and I simply by dividing V by I.

$R = V / I$

or Resistance = Voltage / Current

Ohm's Law Calculations

Let's try a few examples:

* At home, if we used 2 A (Amps) of current to operate a lamp that had a resistance of 60 Ω (Ohms), what would the voltage of the circuit be?

$V = I * R$

or Voltage = Current x Resistance

so $V = 2\text{ A} * 60\ \Omega = 120\text{ V}$

* In your car, we use a 12 Volt battery. If the radio requires 0.5 Amps of current, what is the Resistance of the radio in Ohms?

$R = V / I$

or Resistance = Voltage / Current

so $R = 12\text{ V} / 0.5\text{ A} = 24\ \Omega$

* In a small flashlight, AA batteries are typically used. These are 1.5 V batteries. If the resistance of one bulb is 3 Ω, how much current is needed to operate the flashlight?

$I = V / R$

or Current = Voltage / Resistance

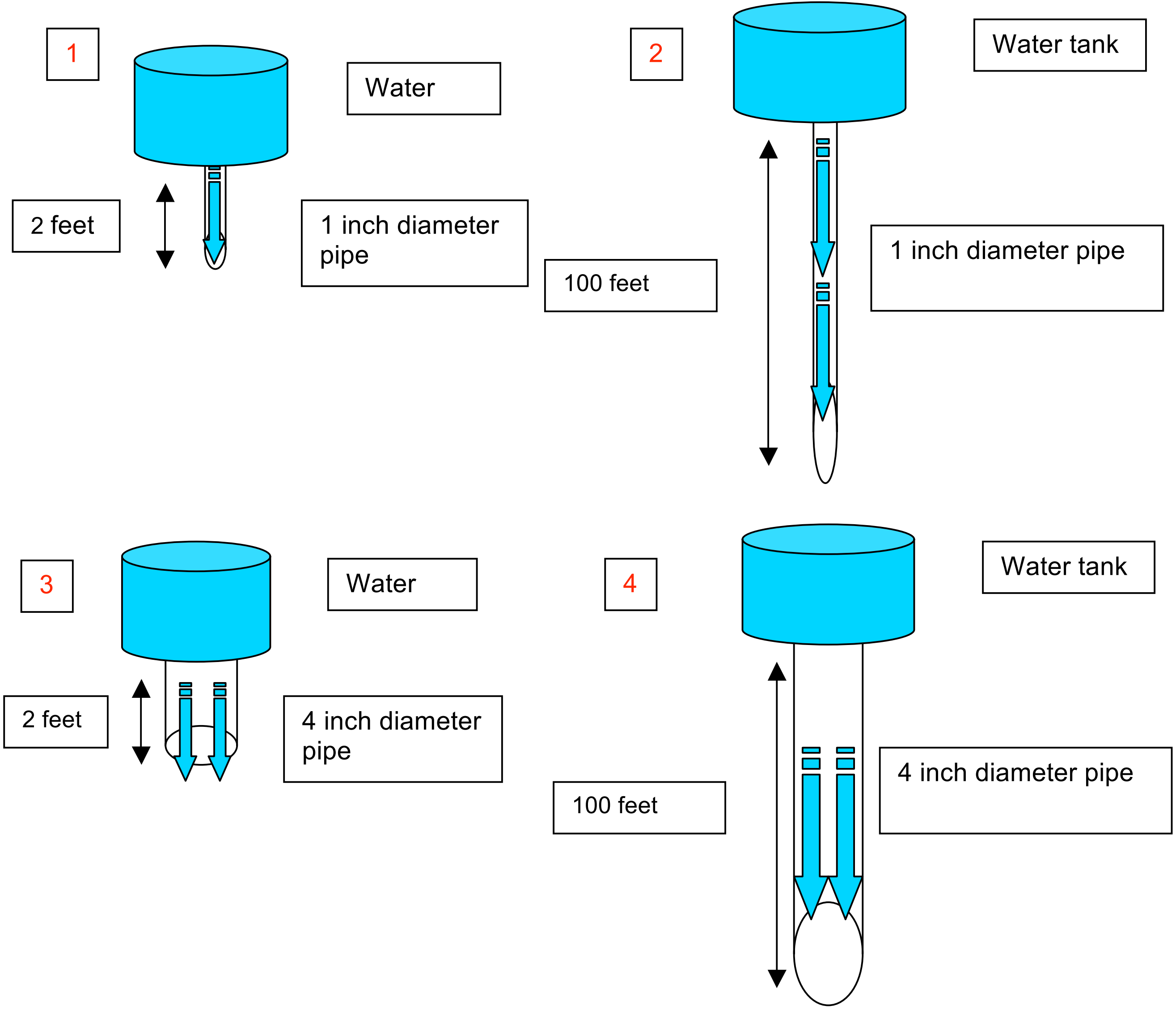
so $I = 1.5\text{ V} / 3\ \Omega = 0.5\text{ A}$

Now fill in the following table using the relationships above:

Voltage	=	Current	*	Resistance
1.5 V	=	_____ A	*	2 Ω
_____ V	=	3 A	*	4 Ω
120 V	=	1.5 A	*	_____ Ω

Electrical Power

Continuing with the water analogy, electric power is the combination of the water pressure (voltage) and the rate of flow (current) that results in the ability to do work. The power of water falling through a 2-inch pipe that is 2 feet high is considerably less than that of a 4-inch pipe that is 100 feet high.



As we compare the pipes, pipe #2 has a much greater potential (due to water falling 100 feet instead of 2 feet) that pipe #1. Pipe #3 has much more water flowing through it than #1 or #2 because the pipe has a 4-inch diameter instead of only 1 inch. However, considerably more work could be accomplished by moving water by using the pipe at the bottom right (# 4) – it has both **more water (current)** flowing and it is being pushed with a **greater pressure (voltage potential)** – it produces more **water power** than the any of the other 3 pipes.

Of course, controlling the power or transforming it into more useful forms of power become very important issues in both generating and using power.

What is Electrical Power?

Electrically, **power** is the **rate** at which energy is converted or the **rate** of doing work. **Power (P)** is measured in units of **Watts (W).** When talking in terms of **Watts**, we are talking about the **rate** that electricity is being produced or consumed.

One of the ideas that causes confusion with Power is that it does **NOT sound** like a rate and Watts does **NOT sound** like a rate – there is no "something **per** something" which is what we usually think of when we say "rate".

Let's look at a more familiar example. We often talk of traveling at 60 **miles per hour** – that is a **rate of traveling**. Or our car gets 30 **miles per gallon** – that is a **rate of gasoline consumption.**

Power is calculated from the amount of current flowing due to an applied voltage. The basic relationship is:

$P = V \times I$ [Units: Watts = Volts × Amps or W = V × A]

or $Power = Voltage \times Current$

Power is the amount of electricity it takes to turn a light bulb ON or the amount of electricity needed to operate a drill. It is the electricity required to start or to instantaneously operate a device. It might be best thought of the amount of electricity to run a device for 1 second.

The general confusion about units of electricity often begins with power and energy. The reason is that electricity is a somewhat generic, all-encompassing term that usually includes power, energy, voltage and current, among others. There is both electrical power and electrical energy, and many people often use them interchangeably. Unfortunately, they represent entirely different concepts using entirely different units of measure and they **are not** interchangeable. Since we all have experience with what electricity **does**, we tend to not pay attention to exactly what it **is**. The following 7-8 paragraphs will attempt to clarify the difference between power and energy.

In talking about power, the term Watt is often a confusing one – a Watt is **not** a quantity of work performed (though it seems to **'sound like one'**). A Watt is the **rate** at which work is performed or electricity is produced or consumed. Technically, 1 Watt is the rate of doing work when 1 Joule of energy is expended in 1 second (1 Watt = 1 joule/second). In this form, 1 joule per second, 1 Watt does appear to be a rate because it is energy expended per time interval (1 second). But, when it stands alone, 1 Watt does not 'seem' like a rate, **though it is one.**

A 50-Watt light bulb uses electricity or electrical power at a **rate** of 50 Watts. We could say it is consumed at a **rate of 50 joules per second** and **it would look like a rate** and we would be happy. However, the conventional language uses only Watts and we must accept that Watts is a rate.

Before going any further, let's do some calculations with Voltage (Volts), Current (Amps), and Power (Watts).

Power Calculations

The following calculations will help to clarify the relationship between voltage, current, and power. Again, using basic Algebra, we can work forward or backward through the power equation as long as we know two of the three variables.

- Using a 6 V car battery that pushes 2 A of current through a light bulb, how much power does the light bulb require?

  $P = V \times I$

  or $Power = Voltage \times Current$

  Power = 6 V x 2 A = 12 W

- At home we typically have 120 V coming out of our outlets. If a blender requires 3 A of current to operate, how much power does it need?

  $P = V \times I$

  Power = 120 V x 3 A = 360 W

To test if we really understand this algebraic relationship, we will work backwards through similar calculations to find that the basic power equation could be used to find current or voltage, as well as power, with simple algebraic manipulation.

- If a refrigerator was using power at a rate of 600 W while connected to a 120 V outlet, how much current is required to operate the refrigerator?

  $P = V \times I$

  600 W = 120 V x $\boxed{?}$ A = or

  re-arrange so I = P / V

  Current = 600 W ÷ 120 V = 5 A

Fill in the following table using the relationships above:

Power	=	Voltage	*	Current
20 W	=	1.5 V	*	_____ A
_____ W	=	120 V	*	1.5 A
45 W	=	_____ V	*	3 A
_____ W	=	240 V	*	12 A

Conversions for Large or Small Quantities of Power

The last example reminds us that we need to review some better ways of representing large numbers. What is a kilogram? How do we convert 2380 grams to kilograms? We use conversion factors, like kilogram/1000 grams, as follows:

2380 grams x 1 kilogram / 1000 grams = 2.38 kilograms (kg)

Notice, the unit **grams** cancels out of the numerator (top) and denominator (bottom) of the terms on the left of the equal sign. We do this conversion because it is a lot easier to talk about 340 kg of a steak needed to feed the Super Bowl teams during Super Bowl week than it is to talk about 340,000 grams of steak. The same thing applies if when talking about meters and kilometers (1000 meters).

We do the same thing when talking about electricity in units of power and energy. Usually, if we are over 1,000 Watts, then we will apply the conversion factor and add the prefix “kilo”, as follows:

240 V x 12 A = 2880 W

2880 W x 1 kiloWatt / 1000 Watts = 2.88 kiloWatts (kW)

How many kilowatts of power will it take to operate an arc welder that uses 15 Amps of current at 240 Volts?

Voltage	*	Current	=	Power [Watts]	÷	1000 Watts / kiloWatt	=	KiloWatts
___ V	*	___ A	=	_____ W	÷	1000 W / kW	=	____ kW

We will apply this same type of conversion (factor of 1000) when talking about energy because energy often turns into very large quantities very quickly.

We should also look at converting to a smaller scale because many small appliances or battery-powered devices do not require Amps to operate, they only require a fraction of an Amp, or a milliAmp, to operate. The prefix *milli* tells us that it will be one one-thousandth of an Amp.

Here, the conversion factor we use will make the quantity useable in smaller units. If we have 0.25 Amps, we multiply by a conversion factor of 1000 milliAmps / 1 Amp as follows:

0.25 Amps x 1000 milliAmps / 1 Amp = 250 milliAmps (mA)

Also, in instances when we are dealing with rather small quantities of electrical power, typically less than 1 Watt, we use the conversion factor and apply the prefix “milli” to both our current (or sometimes to the voltage) and to the calculated power.

1 V x 1 mA = 1 mW
1 Volt x 1 milliAmp = 1 milliWatt

Note: if we used capital M, then this unit would be MegaWatts, which is 1,000,000 Watts!! So it makes a BIG difference whether it is a lowercase m or uppercase M.

How much power does a small flashlight consume that uses 1 AA, 1.5 V battery with mini-light bulb in it drawing 0.35 Amps. Starting with the 0.035 Amps, we convert it to milliAmps as follows:

0.035 Amps x 1000 milliAmps / 1 Amp = 350 milliAmps (mA)

Voltage [Volts]	*	Current [milliAmps]	=	Power [milliWatts]
___ V	*	___ mA	=	_____ mW

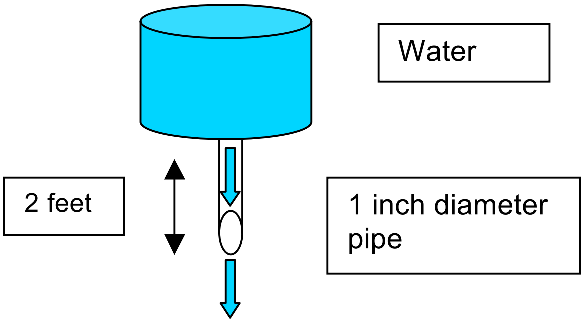
We could do the same calculation using Amps and then convert after we have found Power in Watts.

Voltage [Volts]	*	Current [Amps]	=	Power [Watts]	÷	1000 milliWatts / Watt	=	milliWatts
___ V	*	___ A	=	_____ W	÷	1000 mW / W	=	____ mW

Electrical Energy

Electrical **energy** involves simply introducing the **time** dimension to electrical **power**. In the water analogy, it would be how much work could be done with water falling continuously through the 12-inch pipe that is 50 feet high **over a period of time** such as an hour or a day.

If a certain amount of water is falling through the pipe at this instant (i.e., one second), then you would expect much, much more water would fall continuously through this pipe over the course of an hour. Although we might accomplish some useful work with the power of the water flowing through the pipe this instant, it is more likely that much more useful work could be accomplished using this power over the course of an hour. When we talk of using **the power over the course of an hour**, we really are talking about using **energy**. Using our water example of before, rather than trying to feel the power of the water as it hits our head this instant, we are looking at how much **work** can be done by the water in the **time** that it takes for the tank to empty.



The electrical energy that an appliance consumes can only be determined if you know how long (**time**) it consumes electrical power at a specific **rate** , let's say 50 Watts. To find energy consumed, we multiply the rate of consumption times the amount of time (usually hours) that it is being consumed.

$E = P \times t$	[Units: Watt-hours = Watts x hours or Wh = W x h]
or Energy = Power x Time	[or kiloWatt-hours = kiloWatts x hours or kW h = kWxh]

We will address this soon, but first let's look at more familiar examples of **rate**. One of the confusing aspects of **power** is that it does not **sound** like a rate. Let's look at another rate that you know – **rate of speed when traveling.**

Another way to look at the power vs. energy difference is with an analogy to traveling. If a person travels by car at a **rate** (r) of 40 miles per hour, to find the total **distance** (d) traveled you must multiply the **rate** of travel by the amount of **time** (t) spent traveling at that rate. We use:

If a person traveled for 1 hour at 40 miles/hour, he/she would have traveled 40 miles.
40 miles/hour x 1 hour = 40 miles

If a person traveled for 2 hours at 40 miles/hour, he/she would have traveled 80 miles.
40 miles/hour x 2 hours = 80 miles

If a person traveled for 3 hours at 40 miles/hour, he/she would have traveled 120 miles, and so on.

The basic equation we use is:

Rate	x	Time	=	Distance
(miles/hour)	*x*	*hours*	=	*miles*
30 miles/hour	x	4 hour	=	120 miles

Remembering our Algebra, we **cancel out the hours of time** from our RATE with the **hours** used in TIME, then the only unit left for DISTANCE is **miles**. This distance traveled represents the work done by the car.

Let's try a few:

* If you travel at 60 miles per hour (mph) for 3 hours, how far will you have gone?

Rate	x	Time	=	Distance
60 mi/hr	x	3 hr	=	?? mi
60 mi/hr	x	3 hr	=	180 mi

* If you traveled 80 miles in 4 hours, how fast were you traveling?

Rate	x	Time	=	Distance
?? mi/hr	x	4 hr	=	80 mi
20 mi/hr	x	4 hr	=	80 mi

* If you traveled at a rate of 45 mi/hr (or mph) and you went a total of 157.5 mi, how long did it take you?

Rate	x	Time	=	Distance
45 mi/hr	x	?? hr	=	157.5 mi
45 mi/hr	x	3.5 hr	=	157.5 mi

When talking in terms of **power** and **Watts**, we are talking about the **rate** that electricity is being produced or consumed. When talking about **energy**, we find that **energy is analogous to distance traveled** in our previous rate problems.

Basic Equation	Rate	x	Time	=	Distance
Units	(miles/hour)	x	hours	=	miles
Example	*30 miles/hour*	*x*	*4 hour*	=	*120 miles*

Basic Equation	Rate	x	Time	=	Energy
Electrical Equation	***Power***	***x***	***Time***	**=**	***Energy***
Units	Watts	x	hours	=	Watt-hours
Example	*30 Watts*	*x*	*8 hours*	=	*240 Watt-hours*

A person would not typically say he/she took a '**40 mile per hour trip'** because 40 miles per hour is **rate**. The person might say he/she took a '40 mile trip', an '80 mile trip', or a '120 mile trip'. We describe the trip in terms of **distance** traveled, **not rate** traveled. The **distance** represents the total amount of **work** done in traveling, not the **rate** of traveling.

The same applies with electricity. You would not say you used 30 Watts of electricity to listen to your stereo for 8 hours because the **30 Watts represents the rate that you used electricity**, not the total quantity used. The total quantity of **energy** used would be calculated by multiplying the **rate** of electricity consumption (30 Watts) by the amount of **time** (8 hours) the stereo was operating, as above.

To find the energy used by the stereo over 8 hours, we use:

Basic Equation	Rate	x	Time =	Energy
Electrical Equation	Power	x	Time =	Energy
Units	Watts	x	hours =	Watt-hours
Example	30 Watts	x	8 hours =	240 Watt-hours

Another confusing aspect of power as a rate is that there is no common unit that is cancelled out when we multiply power by time as in the “rate x time = distance” problems. But, we can see from the example above, that there are no units to cancel and the units of energy are a combination of two units being multiplied, Watts and hours, as we would expect.

Now, re-examining energy, to find **energy** consumption or production, take the **power** and multiply it by the **time** that power is expended, or produced. **Energy** (E) is measured in terms of Watt-hours (Wh) or, more commonly, due the relative magnitude of energy consumption and production, kilowatt-hours (kWh).

Energy is calculated simply by:

$E = P \times t$ [Units: Watt-hours = Watts × hours or Wh = W × h]

or $Energy = Power \times time$

From the example above:

$E = P \times t$

240 Watt-hours = 30 Watts x 8 hours

The quantity of **energy** consumed over 8 hours would be 240 Watt-hours, the **rate** of consumption would be 30 Watts for every second of that 8 hours.

When we talk of electrical **energy**, due to the large quantities we produce and consume it in, rather than using Watt-hours, we use kilowatt-hours. This is the unit that utilities use when billing residential customers. For most residential customers, utilities charge for the amount of **energy** used, not the **rate** at which it is used.

To find kilowatt-hours from Watt-hours, simply multiply Watt-hours by a conversion factor of:

1 kilowatt-hour / 1000 Watt-hours

The common abbreviation used is **kWh** for **kilowatt-hour.**

Now let’s try some examples:

- How many kilowatt-hours are in 12,800 Watt-hours?

  — 12,800 Wh x 1kWh/1000 Wh = 12.8 kilowatt-hours = 12.8 kWh

- If a refrigerator requires 600 Watts of power to operate, how much energy does this refrigerator consume in 1 hour of operation? In 24 hours?

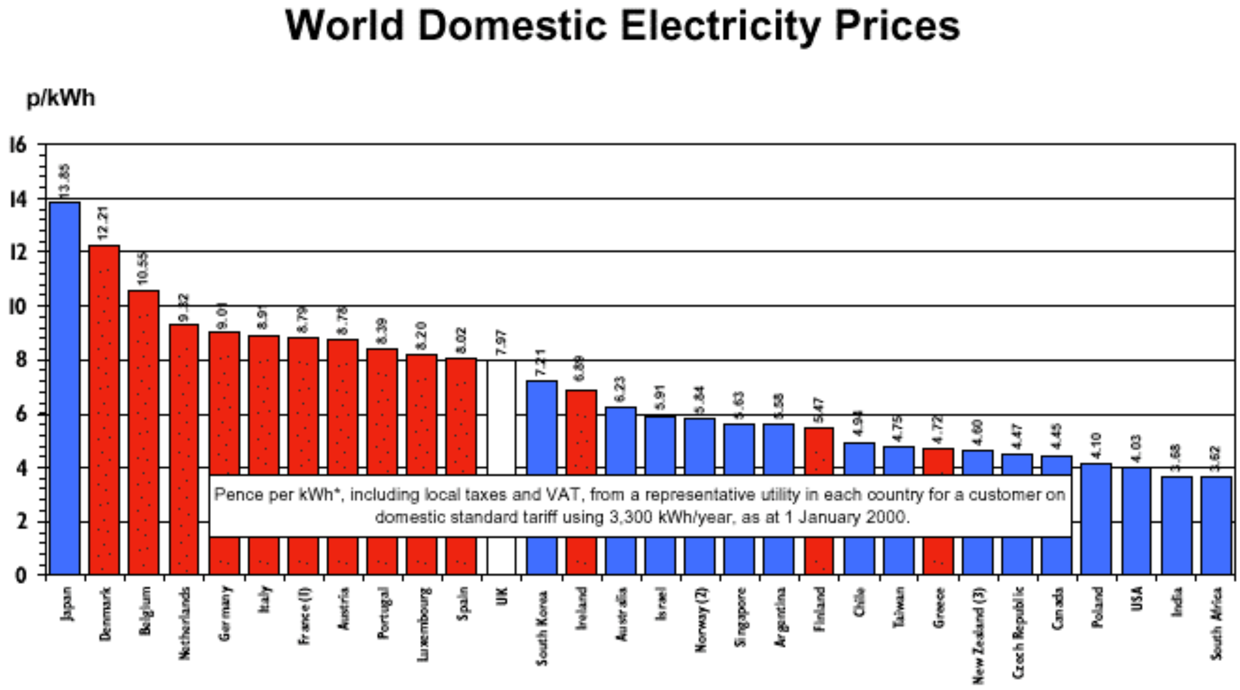
  Rate x Time = Energy
  600 W x 1 h = 600 Wh

  Rate x Time = Energy
  600 W x 24 h = 14,400 Wh = 14.4 kWh

Cost of Electricity

One other very important concept regarding electricity involves the calculation of the cost for using electricity with various appliances.

Cost of electricity varies across the country and around the world. The graph below shows the cost of electrical energy per kilowatt-hour in a number of countries around the world.



* Converted using 30 December 1999 exchange rates.

(1): 1999 data.
(2): 1997 data.
(3): 1998 data.

Source: http://www.electricity.org.uk/uk_inds/pricesla.html

Using 8 cents per kilowatt-hour as our basis (what a local utility typically charges for electrical energy for residential customers), compare the power, energy, and cost of running a toaster oven, 100 W lamp, TV, computer, and a blender on a “typical” day. We will use a “typical” day that includes: 5 minutes of toaster oven use, 8 hours of light bulb use, 2 hours of TV, 1 hour of computer, and 2 minutes of blender use. We will use a chart and we will fill it in with your input to help clarify the relationships developed thus far and to determine and compare the power, energy, and cost of using these appliances on a typical day.

Power, Energy and Operating Cost of Appliances

Local electricity cost per kilowatthour (kWh) = 8 ¢ /kWh = $0.08 / kWh

Appliance	Typical Voltage		Rated Current		Calculated Power		Hours of Operation		Energy Consumed	Energy Consumed		Cost per kWh		Daily Cost
[Type]	[Volts]		[Amps]		[Watts]		[Hrs/Day]		[Watt-hours]	[kiloWatt-hours]		[$/ kWh]		[$/day]
TV		X	0.8	=		X		=			X	0.08	=	
Computer		X	0.33	=		X		=			X	0.08	=	
Lamp		X	0.83	=		X		=			X	0.08	=	
Toaster		X	11.67	=		X		=			X	0.08	=	
Fan		X	1.9	=		X		=			X	0.08	=	
Blender		X	2.2	=		X		=			X	0.08	=	
		X		=		X		=			X	0.08	=	
		X		=		X		=			X	0.08	=	
		X		=		X		=			X	0.08	=	
		X		=		X		=			X	0.08	=	

Power & Energy Estimation - Second Try

Rank the following in terms of how much power (1 for highest power consumption, 6 for lowest) and energy (1 for highest energy consumption, 6 for lowest) they consume in a typical day. If possible, try to determine the actual power and energy requirements:

Appliance	Hours per day of use	Amps	Rank	Power		Rank	Energy
				[Watts]			[kilowatt-hours]
TV	2 hrs	0.8					
Computer	1 hrs	0.33					
Lamp	8 hrs	.83					
Toaster	0.05 hr (3 min /60 min/hr)	11.67					
Fan	4 hrs	1.9					
Blender	0.033 hr (2 min /60 min/hr)	2.2					

Hopefully, this table was easier to fill out the 2nd time around. Do note that this table is missing several columns that would make the calculations easier. If you were able to do this table easily now, you have developed a strong understanding of what electrical power and electrical energy are and how to calculate them, and have mastered the difference between electrical power and energy.

AC vs. DC

The concepts of **AC, or Alternating Current**, and **DC, or Direct Current**, are important in the electrical world, especially with PV. We will not examine them in detail now, but will simply differentiate between the two.

Direct current is produced when current flows constantly in one direction. It's abbreviated as "**DC**". Since direct current flows in one direction only, its electrical pressure or voltage is always oriented in one direction, or "polarity".

Interestingly, the first commercial electrical systems set up by Thomas Edison and others were direct current systems. But, for economic reasons, these were later changed to alternating current or AC systems, and are described in the Alternating Current section of this program.

Today, batteries, solar panels, fuel cells and special DC generators such as wind turbines produce direct current. Batteries supply the power for our most common DC-powered devices. Examples include: automobile battery, flashlight battery, watch battery, or Walkman battery. Batteries for flashlights, radios and toys are typically cylindrical and operate at 1.5 Volts. Small rectangular batteries typically operate at 9 Volts. In using our multimeters, we will **only** be measuring DC voltage and DC current (and calculating power and energy).

Residential and commercial electrical systems typically operate with **Alternating Current**, or **AC**, electricity. We rely on this kind of power in our homes, businesses, and industries. That's because AC power is much more economical to produce and use than DC power.

The first commercial AC power was set up by George Westinghouse in 1886. At that time, Edison was still providing DC current to homes, but the range of power transmission was about one mile from his plant in New Jersey. Because AC power was found to be much cheaper to distribute over longer distances, it became the obvious preference.

The primary characteristic of AC power that makes it so economical is the ability to change the voltage levels by using transformers. The voltage can be stepped up or down as the need arises. This allows the power to be distributed as widely as needed. Unlike DC voltage and current, which remain steady, AC voltage and current changes -- or cycles -- 60 times per second in North America. AC power in Europe cycles 50 times per second.

Common uses of AC power include: TV, washer, stereo, computer, and most household appliances. Most of our home appliances need 120 V to operate with an electric dryer being the most common exception – it requires 240 V (hence the big, three-prong plug it typically has). In using the Watts Up Meter, we will be only measuring AC power and energy.

There is much more to AC and DC electricity than this, but for our purposes, a little information might be better than too much.

Watts Up Meter

A **Watts Up Meter** enables you to see a digital readout of exactly how much power an appliance requires to operate. By setting the cost of electricity per kilowatt-hour, it can also display the cost of running the appliance over time. Additionally, it will keep track of exactly how much energy the appliance consumes over time. To operate the Watts Up meter, simply plug it into a wall receptacle and plug the appliance into the outlet in the meter.

We can use the Watts Up meter to calculate the operating current that appliances need. Remember, we find power to be the product of voltage and current.

$P = V \times I$ [Units: Watts = Volts × Amps or W = V × A]

or $Power = Voltage \times Current$

If we already have the power and know the voltage to be 120V since we are operating on a normal household or commercial electrical circuit, simply divide both sides of the equation by voltage to rearrange it to solve for current, as follows:

$P \div V = I$ [Units: Watts ÷ Volts = Amps or W ÷ V = A]

or $Power \div Voltage = Current$

Suppose we have a blender that the Watts Up meter shows to use 440 Watts of power on low speed. How much current is it using on low speed? Assuming it is running on household circuit with AC power, we can expect that the blender requires 120 Volts to operate. To solve:

$I = P \div V$ [Units: Amps = Watts ÷ Volts or A = W ÷ V]

or $Current = Power \div Voltage$

Current = 440 Watts ÷ 120 Volts

Current ≈ 3.7 Amps

Watts Up Meter Worksheet

Let’s use the Watts Up meter to calculate the current used in various appliances, then compare the calculated current to **the nameplate rating** that you find on it. On most appliances and tools, you will find the nameplate rating that will tell you the required voltage, operating or maximum current, and/or the power consumed by operating the device. It will also usually state that the device needs a frequency of 60 Hz (Hertz) to operate.

Appliance	**Measured Power**	÷	**Voltage**	=	**Current**	**Rated Current**
	[Watts]		[Volts]		[Amps]	[Amps]
Overhead Projector		÷	120	=		
Lamp		÷	120	=		
Toaster Oven – Low		÷	120	=		
Toaster Oven – High		÷	120	=		
Fan – Low Speed		÷	120	=		
Fan - High Speed		÷	120	=		
Blender – Low Speed		÷	120	=		
Blender – High Speed		÷	120	=		

Using the Multimeter

An **ammeter** is a device that measures the current flowing in a circuit. A **voltmeter** is a device that measures the voltage potential across the terminals of a source electromotive force.

A **multimeter** is a handy tool in that it combines both the features of an ammeter and a voltmeter and can be used to measure the current, voltage, or resistance (among other measurements) in an electric circuit or in parts of a circuit.

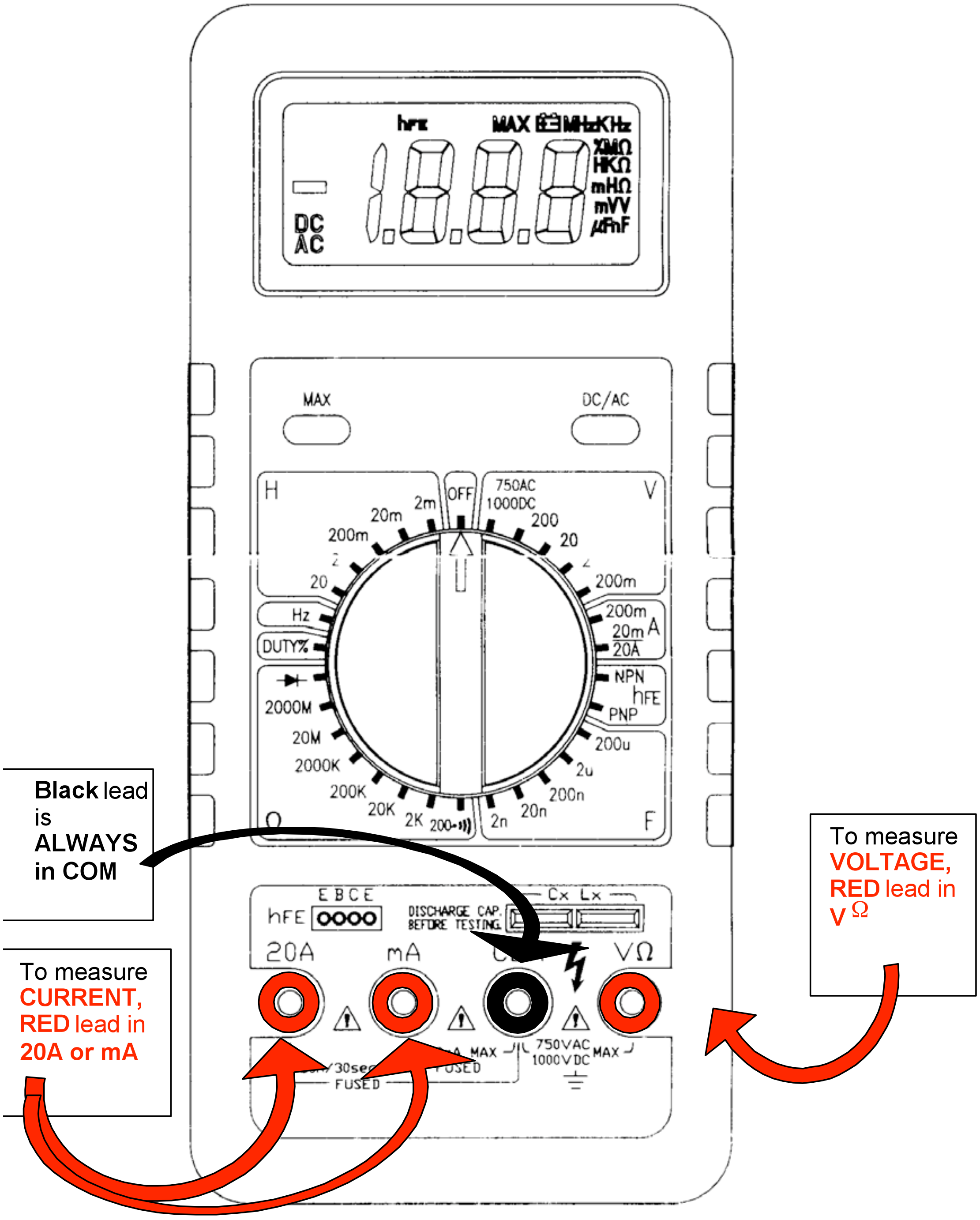
We will use a multimeter to help us learn more about current and voltage and how they behave in circuits when power sources in a circuit are wired in **series**, in **parallel**, or **both series and parallel**.

The black lead **ALWAYS** goes in the black terminal labeled '**common**'. The red lead will go into the red terminal on the right of the black terminal (on our Kelvin 400 LE multimeters) if measuring voltage. To measure voltage, always measure across two main terminals of the power-producing device.

To measure current in a circuit, the red lead will go into **one of the 2 red terminals on the left of the black terminal.** The red terminal on the far left is for measuring current at 1 amp or more. The red terminal immediately to the left of the black terminal is for measuring small amounts of current typically less than 1 amp. This measurement is usually in milli-amps. To measure current, the multimeter must be included as part of the circuit.

To measure the voltage of a battery, turn the multimeter on, make sure the dial is turned to DC Voltage (V with a solid bar over it, not a sine wave ~, the V with a ~ over it is for measuring AC Voltage), take a size C battery (or A, AA, AAA or D) and put the red lead onto the positive terminal (+) and the black lead onto the negative terminal (-). You should get a reading between 1.55 – 1.63 V. If the reading is below 1.5 V, your battery may be in need of a re-charge (if a re-chargeable battery) or in need of replacement.

OPERATING INSTRUCTIONS
KELVIN 400LE
DIGITAL MULTIMETER



Black lead is **ALWAYS in COM**

To measure **CURRENT, RED** lead in **20A or mA**

To measure **VOLTAGE, RED** lead in **V** Ω

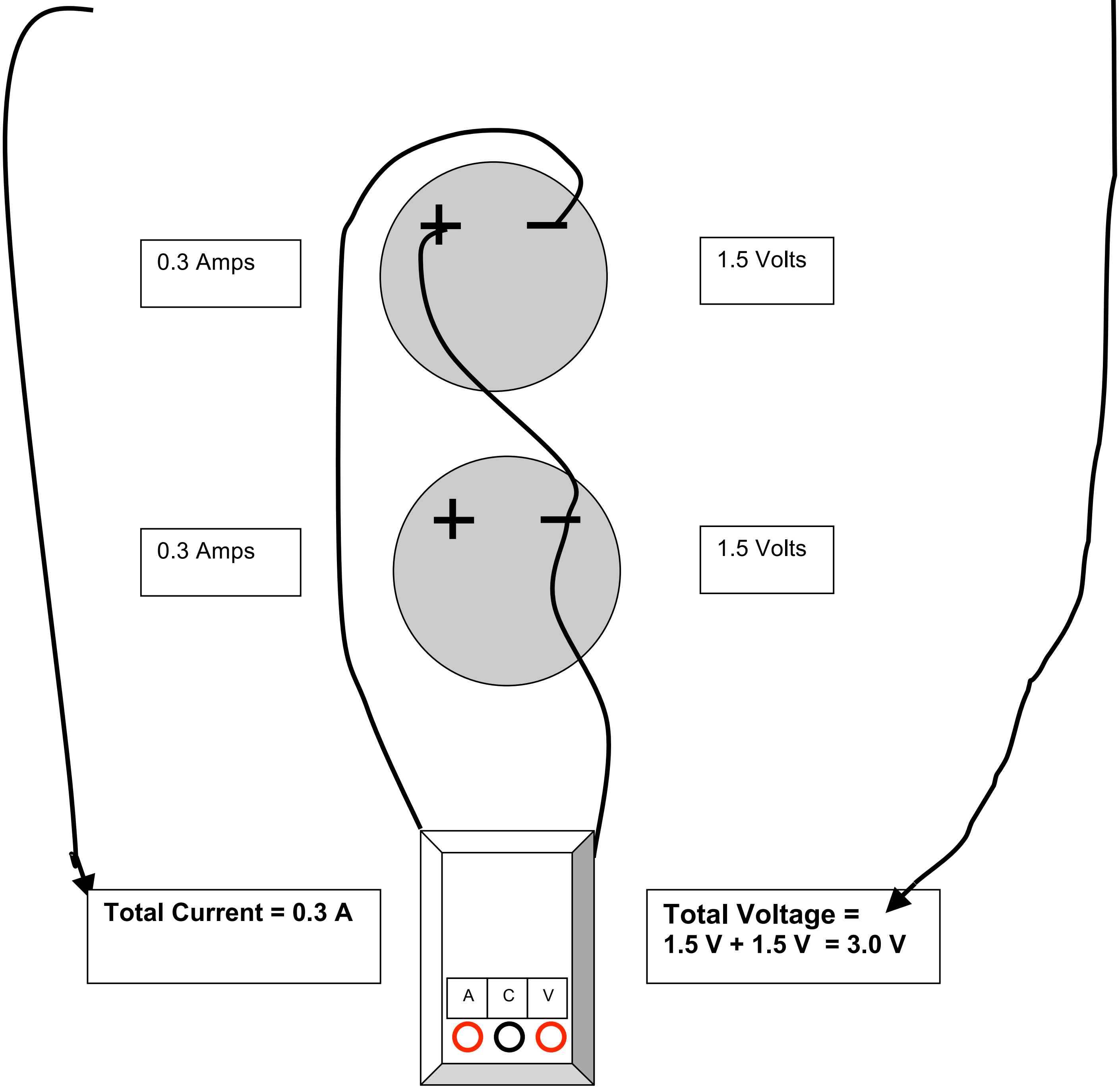
Series Wiring

To combine batteries or PV cells in series, connect the positive of one battery to the negative of the next. The way we normally insert batteries into a flashlight does this – the nipple end of one battery goes into the receptor end of another. When voltage sources are aligned in series, the voltages of each respective source is added to the others to find the total voltage across the terminals of the circuit.

The Voltage ADDS ($V_1 + V_2 + V_3 + \ldots V_x = V_{Total}$)

Current <u>stays the same</u> ($I_1 = I_2 = I_{Total}$)

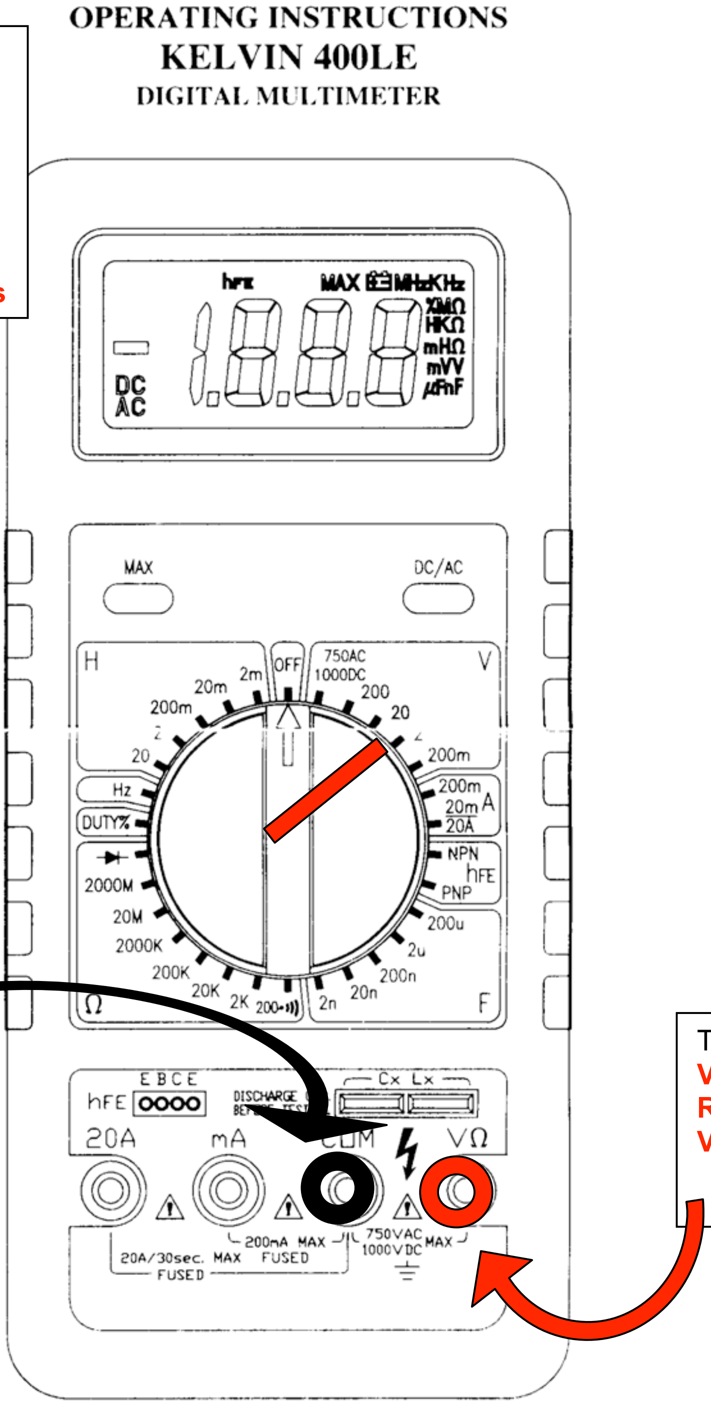
Note: If the Currents are not all the same, the Total Circuit Current will be equal to the lowest



current among the current sources in the circuit.

To measure **Voltage,** leave the **black lead in COM:**

1. Place the **RED lead in VΩ**
2. Turn the dial to **2 Volts or 20 Volts**



Black lead is **ALWAYS in COM**

To measure **VOLTAGE, RED** lead in **V Ω**

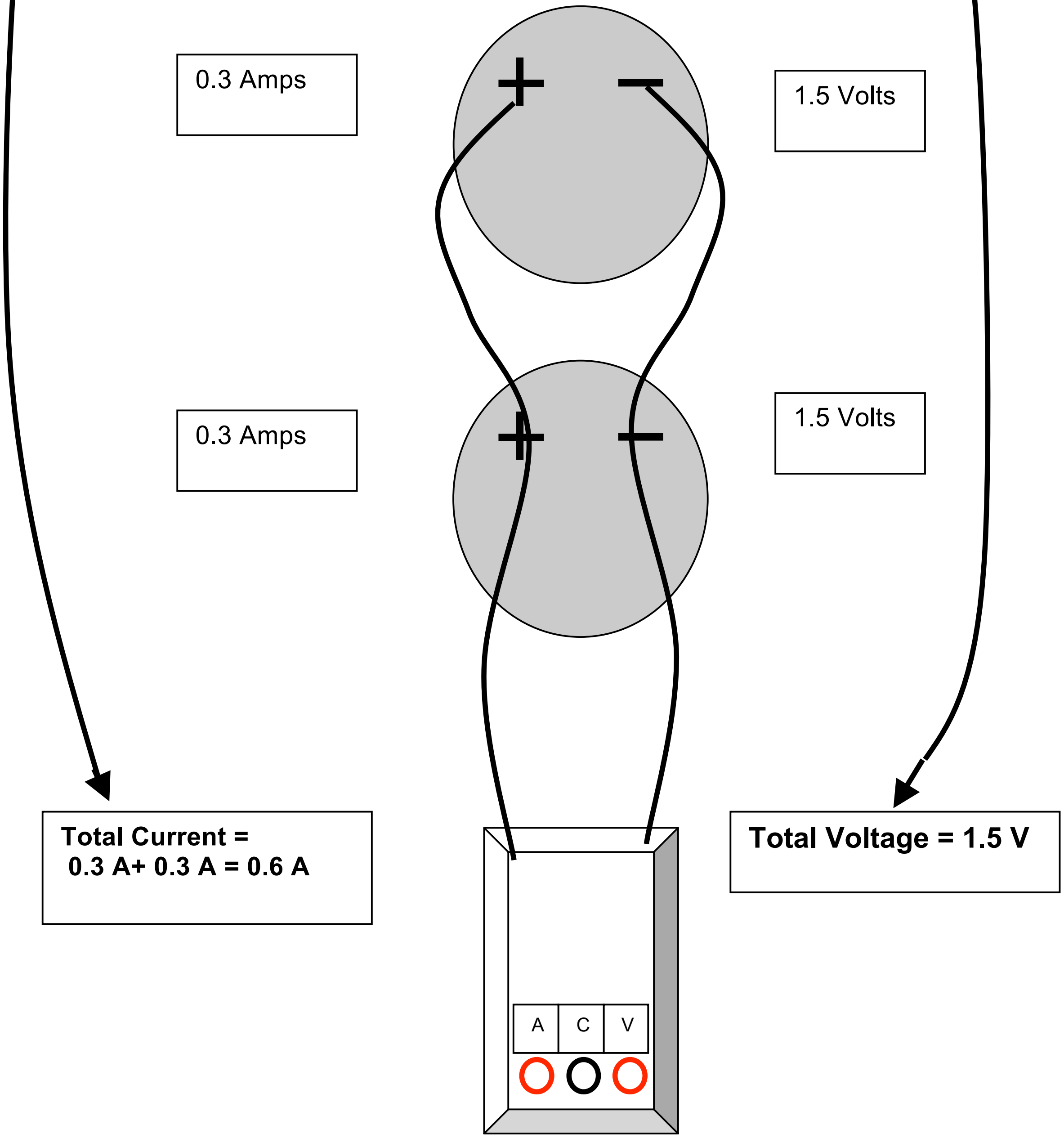
Parallel Wiring

To combine batteries or PV cells in parallel, connect the negative terminal of one battery to the negative terminal of the next battery and so on. Do the same procedure with the positive terminals. When a circuit has power sources wired in parallel, the source current adds through the circuit, but the voltage remains the same.

The Current ADDS ($I_1 + I_2 + I_3 + \ldots I_x = I_{\text{Total}}$)

Voltage stays the same ($V_1 = V_2 = V_{\text{total}}$)

Note: If the Voltages are not all the same, the Total Circuit Voltage will be equal to the lowest voltage among the voltage sources.



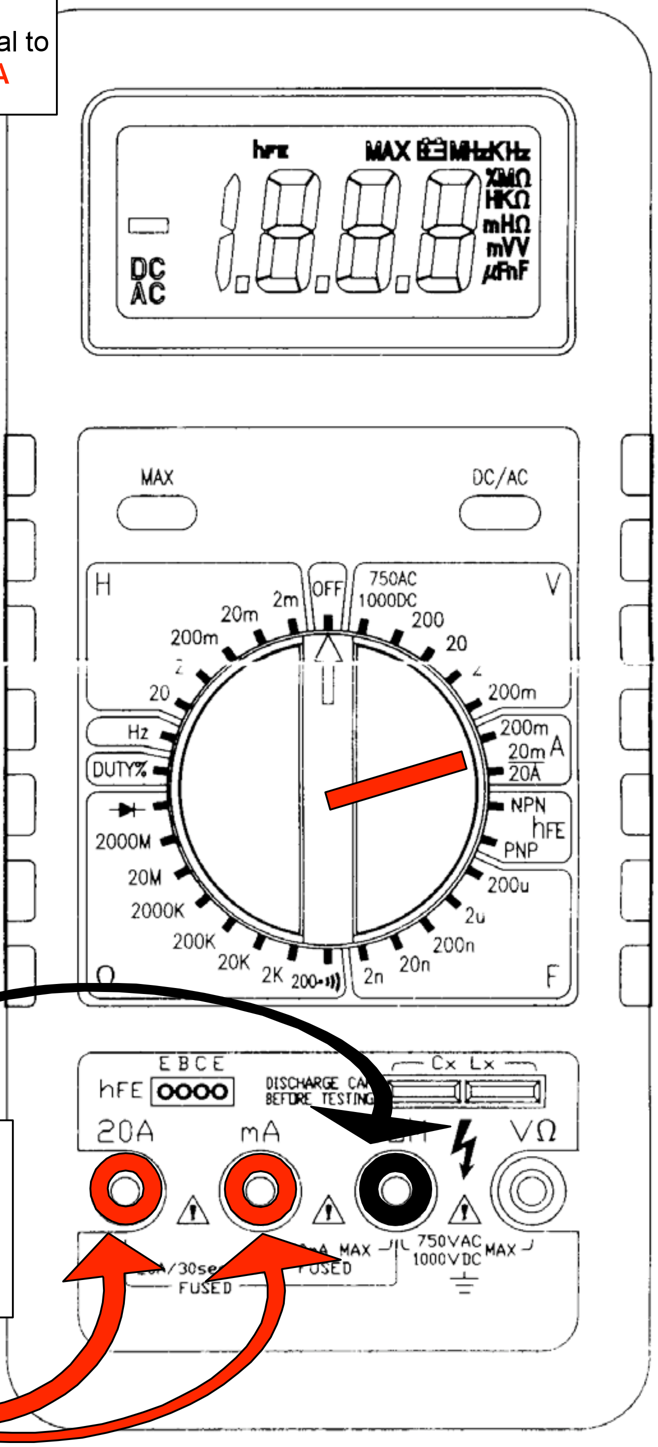
Total Current = 0.3 A+ 0.3 A = 0.6 A

Total Voltage = 1.5 V

OPERATING INSTRUCTIONS
KELVIN 400LE
DIGITAL MULTIMETER

To measure **Current**, leave the **black lead in COM:**

1. Place the **RED lead in 20A or mA**
2. Turn the dial to **20mA / 20A**



Black lead is **ALWAYS in COM**

To measure **CURRENT, RED** lead in **20A or mA**

Genecon Electricity Experiments

Introduction to the Genecon Generator

The Genecon generator is a very effective, hands-on tool for safely teaching many principles of electricity. It is a hand-crank DC generator that produces current up to 1200 milli-Amps through voltages of approximately 6-9 Volts by rotating a coil of copper wire in a magnetic field to create electricity.

The Genecon provides a good opportunity to work in small groups (2 – 5 students) with each student being able to: generate electricity, complete circuits using alligator clips and conducting wires, test for conductivity, see what effect polarity has on a circuit, feel the effect of additional loading of a circuit, wire circuits in parallel and series and see the effect on current and voltage, etc..

With the Genecon, you can safely learn the basics of electricity that you will need in later activities. Do pay attention to the principles of using the multimeter and connecting wires.

You will work the following experiments to develop a better understanding of several important electricity concepts. The following activities are adapted with permission from NADA Scientific, www.nadasci.com. NADA Scientific has available a booklet with 24 hands-on, minds-on activities for students using the Genecon generator.

Activity #1: Getting to know your Genecon

Materials:

Genecon generator
1 bulb with socket and leads

Key Concepts:

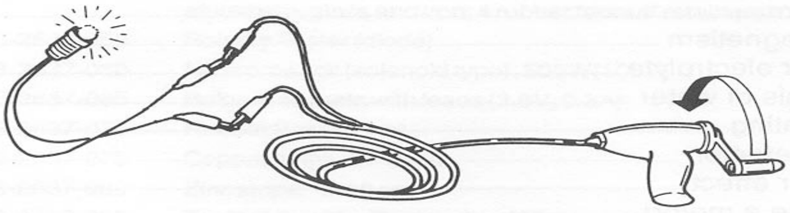
1. A generator converts mechanical energy (the energy of moving parts) into electrical energy (the flow of electrons through a conductor).
2. The brightness of the bulb is directly related to the voltage of the current passing through it.

Procedure:

1. Connect the leads of the Genecon to the leads of the bulb socket as shown in the sketch below.
2. Slowly turn the Genecon handle with increasing speed until the bulb lights.

Thought Questions:

- Why does the bulb become brighter as the Genecon is turned faster?



Activity #2: Testing for Polarity

Materials:

Genecon generator
Polarity Tester

Key Concepts:

1. Electricity is the flow of negatively charged particles, called electrons, through a conductor.
2. Electricity flows from the negative electrode (where there is a surplus of electrons) to the positive electrode (where there is a shortage of electrons).
3. The polarity of an electrical source refers to the location of the positive and negative electrodes.
4. Incorrect polarity may cause certain appliances to work improperly or become damaged.

Procedure:

1. Connect the Genecon leads to the terminal leads of the multimeter to measure the voltage. Point the white arrow to the 20V setting.
2. Turn the handle of the Genecon in a clockwise direction. If the voltage reading is positive, the lead of the Genecon attached to the red multimeter lead is positive. If the voltage reading is negative, the lead of the Genecon attached to the red multimeter lead is negative.
3. If necessary, readjust your leads so that rotating the handle in the clockwise direction gives a positive voltage.
4. With the Genecon correctly connected to the multimeter rock the handle back and forth.

Thought Question:

1. What happens to the voltage when the Genecon handle is rocked back and forth?

Procedure (continued):

5. Take the red terminal lead out of the voltage connector in the multimeter and put it into the 20A connector. Switch the white arrow so it faces 20mA/20A.
6. Rotate the handle of the Genecon clockwise. The reading is the current produced in milliAmps. It should indicate the same polarity as you had after adjustments with the voltage.
7. With the Genecon correctly connected to the multimeter rock the handle back and forth.

Thought Question:

2. How is current affected by rocking the handle?

Activity #3: Conductor or Insulator?

Materials:

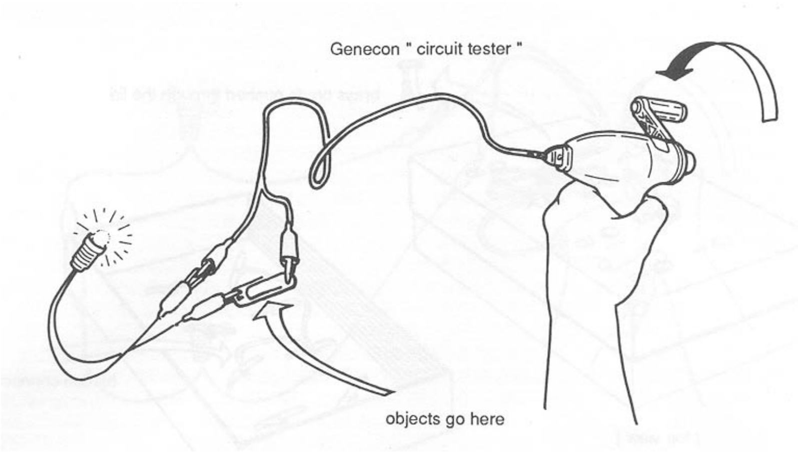
Genecon generator
1 bulb with socket and leads
Variety of objects: paper clip, rubber band, steel wool, balsa wood, and plastic straw

Key Concepts:

1. Materials, which allow an electric current to pass through them easily, are called conductors.
2. Materials, which do not conduct electricity very well, are called insulators.

Procedure:

1. Connect one of the Genecon leads to one of the bulb leads.
2. Have one student operating the Genecon while another student touches the two loose leads together. The bulb should light when this is done.
3. Separate the leads and place each testing material between them as shown in the sketch below.



4. Fill in the following chart for each material tested.

Material	Conductor or Insulator
Paper clip	
Rubber band	
Steel wool	
Balsa wood	
Plastic straw	

Thought Questions:

1. What effect does touching the two loose leads have on the circuit?
2. What types of materials are better conductors?

Activity #4: Bulbs in Series

Materials:

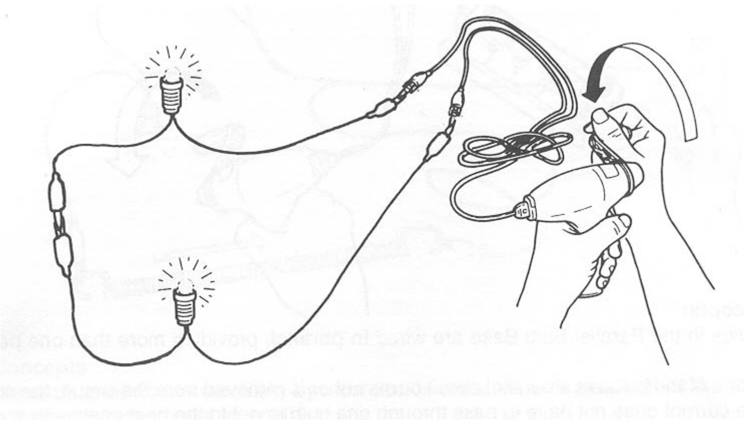
Genecon generator
4 bulbs with sockets and leads

Key Concepts:

1. In a series circuit bulbs are wired one after the other providing only one path for the current.
2. As bulbs are added to a series circuit, there is an increase in resistance and a corresponding decrease in current.

Procedure:

1. Connect one of the bulbs to the Genecon and light it up to a moderate brightness.
2. Add another bulb to the circuit by inserting it between the first bulb and the Genecon as shown in the sketch below.



3. Light both bulbs by rotating the handle at the same rate as before.
4. Add a third and then a fourth bulb in a similar manner as above.
5. While one student is operating the Genecon with the four bulbs in series, another student should unscrew any bulb in the circuit.

Thought Questions:

1. When additional bulbs are added, what happens to the brightness of the bulbs?
2. If a bulb is removed from the series or burns out, what happens to the flow of electricity?

Activity #5: Bulbs in Parallel

Materials:

Genecon generator
Parallel Bulb Base
Four bulbs

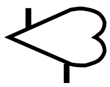
Key Concepts:

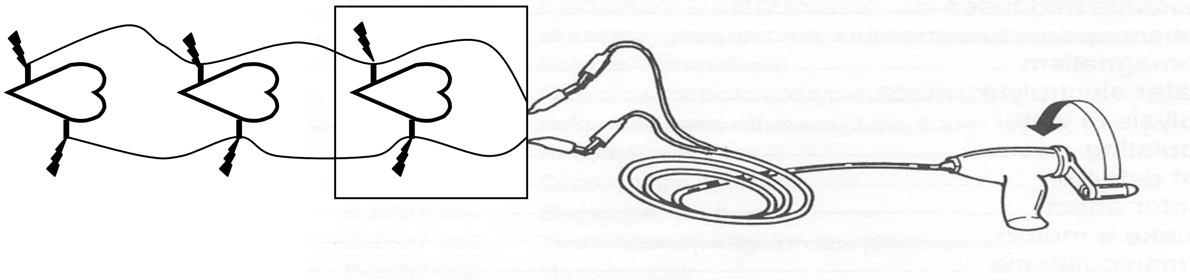
1. Bulbs in a parallel circuit are wired in parallel, providing more than one path for the electricity.
2. Current does not have to pass through one bulb to get to another.
3. As bulbs (or other loads) are added to a parallel circuit, there is a decrease in resistance and a corresponding increase in current.

Procedure:

1. Connect the leads of the alligator clips from the connector on the base of one lamp to the same connector on the base of another. Use another pair of alligator clips to connect the base of one of these lamps to another lamp (3 total).
2. Use another pair of alligator clips to connect the opposite connector of both lamp bases. Then connect the Genecon leads to the connectors of one lamp base. (Three lamps are shown connected below as a reference for adding more lamps – do it for 4 lamps).

The heart-shaped symbol below represents one of the light bulbs with the two connectors on the lamp base. The symbol on the right is an alligator clip.





3. Unscrew the bulbs from all except the closest lamp to the Genecon.
4. Rotate the handle of the Genecon enough to light the bulb
5. As one student continues to rotate the handle at a constant speed, another student should screw in the next bulb down the circuit.
6. Continue by screwing in another bulb.
7. Repeat the process, by taking one bulb at a time out of the circuit.

Thought Questions:

1. As additional bulbs are added to the circuit, what effect does the Genecon operator feel?
2. What effect is felt as bulbs are removed from the circuit?
3. If a bulb is removed from the circuit or burns out, what happens to the flow of electricity?

Activity #6: Short Circuits and Fuses

Materials:

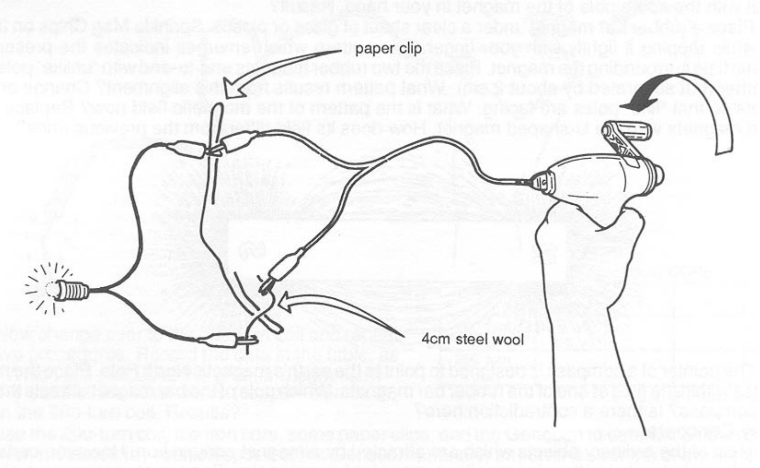
Genecon generator
1 bulb with socket and leads
One paper clip
Strand of steel wool, medium grade

Key Concepts:

1. A short circuit is created when accidental contact occurs between wires of opposite polarity in a circuit before the electricity reaches the intended appliance or load.
2. Short circuits offer very little resistance to the flow of electricity, which causes wires to get hot and possibly cause a fire.
3. Fuses are designed to melt when they get hot, which shuts down the circuit.

Procedure:

1. Connect the leads of the Genecon to the leads of the bulb socket.
2. Disconnect one of the leads and insert the strand of steel wool.
3. Have one student generate enough current to light the bulb brightly.
4. Then have another student lay a straightened paper clip across the two leads from the bulb for a few seconds as shown in the sketch below. (CAUTION: do not touch the steel wool as it will get hot.)



5. Remove the paper clip.
6. Repeat the shorting-out process, as above, but hold the paper clip on for a few more seconds. The steel wool wire should get red hot and then burn through.

Thought Questions:

1. What happens to the brightness of the bulb when the paper clip is placed across the two leads?
2. What happens to the circuit when the steel wool burns through?
3. What component of a circuit is the steel wool acting as?

Learning About Photovoltaics - Overview

Grade Level - Subject

6-12th Grade – Math, Science, and Technology Education (see specific activities for appropriateness for 6-8th or 9-12th grade).

Overview

In this lesson students will explore and learn:

- What are photovoltaics?
- How photovoltaics work
- Advantages and disadvantages of photovoltaics
- Types of photovoltaic cells
- Photovoltaic terminology
- Photovoltaic system components
- Photovoltaic ratings of modules and specifications for Jicarilla modules
- History of photovoltaics

Purpose

The purpose of this lesson is to introduce students to the concept of photovoltaics, common uses, common materials used in fabrication, terminology, ratings, and history. These concepts will provide the foundation for the other photovoltaic lessons in this notebook.

Learning Objectives

After completing this lesson, students will be able to:

- Describe what photovoltaics are and are not
- How photovoltaics work
- Identify three common types of photovoltaic cells
- Photovoltaic terminology
- Main components of photovoltaic systems
- Historical information about photovoltaics

Vocabulary

photovoltaic
poly-crystal
cell
array
PV
thin film
module
single crystal
efficiency
panel

Resources & Materials

rooftop pv system
computer with web access

Preparatory Activities & Prerequisite Knowledge

This is meant to be the first introduction to photovoltaics for your students, so no special preparation is needed. Concepts learned from this unit will be re-used throughout the notebook and its lessons and activities.

Discussion and Analysis of Photovoltaics

Teacher leads students through introduction and discussion of photovoltaics. Students should be encouraged to do further research using web-based sources mentioned or other sources on the web or in the library.

PV - Basic Information

Photovoltaic (or **PV**) **systems convert light energy into electricity**. The term "photo" is a stem from the Greek "**phos**," which means "**light**." "**Volt**" is **named for Alessandro Volta** (1745-1827), a pioneer in the study of electricity. "**Photo-voltaics**," then, could literally mean "**light-electricity**."

Most commonly known as "solar cells," PV systems are already an important part of our lives. The simplest systems power many of the small calculators and wrist watches we use every day. More complicated systems provide electricity for pumping water, powering communications equipment, and even lighting our homes and running our appliances.

The physics and chemistry behind PV technology are both very fascinating and exceedingly complex. This lesson will provide a very brief introduction to photovoltaic cells/modules and attempt to provide basic information in an understandable form. It is not meant to be comprehensive, but rather to give you some useful background information for understanding photovoltaics and how they work. Topics are covered in more detail in accompanying materials in the notebook and through web sites listed throughout the text.

Solar Electric vs. Solar Thermal

There are two fundamentally different kinds of solar panels that can be commonly seen on rooftops throughout many parts of the United States – solar thermal and solar electric panels. **Solar thermal panels** take the sun's light energy and changes it to heat energy that is transferred to some other material for immediate use or storage for later use. The heat energy can be used to heat air in buildings or water for domestic use (showers, swimming pools, etc.). **Solar electric panels**, more commonly referred to as **photovoltaic, or PV, panels**, take sunlight and convert it directly into electricity. The electricity is used to run appliances and electrical devices or stored in batteries to be used later. The panels on your school are photovoltaic or solar electric panels.

Solar Thermal Panels

Residential and Commercial Water Heating

Solar water heaters use the sun to heat either water or a heat-transfer fluid in collectors. That water is then stored for use as needed, with a conventional system providing any necessary additional heating. A typical system will reduce the need for conventional water heating by about two-thirds, minimizing the cost of electricity or fossil fuel and the environmental impacts associated with their use.

Solar collectors are at the heart of most active solar thermal energy systems. The collector absorbs the sun's light energy and changes it into heat energy. This thermal energy can then be used to provide heated water for residential or commercial use, to provide space heating or cooling, or for many other applications where fossil fuels might otherwise be used.

Solar buildings technologies use the non-polluting power of the sun to help heat, cool, and power our buildings. Because buildings now use one-third of the energy currently consumed in this country, the potential markets for using solar buildings technologies in place of conventional ones is substantial.

Collectors

Solar thermal collectors are the key component of active solar systems, and are designed to meet the specific temperature requirements and climate conditions for the different end-uses. There are several types of solar collectors:

Flat-plate collectors
Evacuated-tube collectors
Concentrating collectors
Transpired air collectors

Residential and commercial building applications that require temperatures below 200°F typically use flat-plate or transpired air collectors, whereas those requiring temperatures greater than 200°F use evacuated-tube or concentrating collectors.

For more information regarding solar thermal systems, please see:
http://solstice.crest.org/renewables/re-kiosk/solar/solar-thermal/index.shtml
http://www.mrtc.org/~mist/solar.html

Solar Electric or Photovoltaic (PV) Panels

The "**photovoltaic effect**" is the basic **physical process through which a PV cell converts sunlight into electricity**. Sunlight is composed of **photons**, or **particles of solar energy**. Imagine that these little particles of energy are microscopic “bullets” of light that literally “rain” on earth wherever sunlight is shining. Billions upon billions of these light bullets are hitting the earth every second. These photons contain various amounts of energy corresponding to the different colors of the solar spectrum.

When photons strike a PV cell, they may be reflected, **absorbed**, or they may pass right through. **Only the photons that are absorbed generate electricity**. Which photons get absorbed is a function of their wavelength (what color they are in the solar spectrum) and the properties of the materials used in the PV cell (they are designed to absorb photons with a particular wavelength). When a photon is absorbed, the energy of the photon is transferred to an electron in an atom of the PV cell. With its newfound energy, the electron is able to escape from its “normal” position associated with that atom to become “free.”

The freed electron will move most easily along a conductor. The PV cell is really a semiconductor device (yes, similar to the semiconductors used in your computer!). Freed electrons move and become part of the current in an electrical circuit.

As millions of photons strike the PV cell, millions of electrons are “freed” to move along the conducting wires. The freed electrons in the semiconductor become part of the **current** in an electrical circuit. The thin wires that you see in solar cells and modules are conducting wires for an electrical circuit. The PV cells have a built-in electric field to provide the voltage needed to drive the current through an external load (your radio, for example).

Each cell produces a small amount of current. By connecting many cells together and placing them on larger panels, the electric current produced can be significant.

For more details of how a PV cell works, please see:
http://www.eren.doe.gov/pv/pvmenu.cgi?site=pv&idx=1&body=aboutpv.html

For more information about how PV cells are made, how a built-in electrical field is developed, and what the n- and p-layers do, please see:
http://www.eren.doe.gov/pv/pvmenu.cgi?site=pv&idx=1&body=aboutpv.html
http://www.eren.doe.gov/pv/pvmenu.cgi?site=pv&idx=1&body=aboutpv.html

Other excellent sites that can cover the whole breadth of PV research can be found at:
http://www.nrel.gov/photovoltaics.html

http://www.nrel.gov/ncpv/

http://www.nrel.gov/ncpv/pvmenu.cgi?site=ncpv&idx=3&body=infores.html

PV Advantages and Disadvantages

PV has many features that make it a wonderful technology to use to solve many electrical needs. Although, like any technology, it has it drawbacks as well.

Some of the main advantages of PV include:

High Reliability

PV cells were originally developed for use in space, where repair is extremely expensive, if not impossible. So reliability has always been an important benefit of PV modules. PV still powers nearly every satellite circling the earth because it operates reliably for long periods of time with virtually no maintenance. PV modules have long useful operating lives on earth as well – typically 20-30 years.

Some homeowners are connected to the electric utility grid **and** have a PV system (often with back-up battery pack for energy storage) at their home. When there is a utility power outage, they can simply turn on the PV system and have a reliable source of power ready to meet their needs.

Low Operating Costs

PV cells use the energy from sunlight to produce electricity—the fuel is free. With no moving parts, the cells require little upkeep. These low-maintenance, cost-effective PV systems are ideal for supplying power to remote railway crossings, navigational buoys at sea, or homes far from utility power lines.

PV systems are especially useful for mountaintop communication repeater stations or remote monitoring stations where using the electric grid is prohibitively expensive and environmentally damaging to extend. Compared to the difficulties faced by other potential power systems, such as the delivery of fuel for and maintenance of a diesel generator on a remote mountaintop with extremely harsh winter conditions, the low maintenance, high reliability of PV systems make them an attractive choice for these difficult to reach locations.

Environmental Benefits

Because they burn no fuel and have no moving parts, PV systems are clean and silent. This is especially important where the main alternatives for obtaining power and light are from diesel generators and kerosene lanterns. As we become more aware of "greenhouse gases" and their detrimental effects on our planet, clean energy alternatives like PV become more important than ever.

The 2400 Watt PV system on your roof reduces greenhouse gases equivalent to not driving your car 6,700 miles this year (and every year the system operates).

Modularity

A PV system can be constructed to virtually any size based on energy requirements. Furthermore, the owner of a PV system can enlarge it if his or her energy needs change. For instance, homeowners can add modules every few years as their energy usage and financial resources grow.

Portability

A PV system can be set up on a trailer and moved from location to location as needed. This is especially useful in seasonal applications such the Forest Service personnel, campground personnel, ranchers, boaters, etc..

Ranchers can use mobile trailer-mounted pumping systems to water cattle as the cattle are rotated to different fields. Portable PV systems can be used as a source of power following natural disasters that cripple the **electric grid** and our normal sources of electrical power.

Least Cost Alternative

In some cases, installing a PV system to meet the specific needs of an electrical load is cheaper than using conventional electricity sources – i.e., bringing in the electric grid. PV-powered emergency telephone call boxes or lighting for signs on remote stretches of highways are two examples where a PV system is more cost effective than conventional electricity sources to solve a problem. In other instances, like putting in lighting on a traffic island at the entrance to a campground, it can be less expensive to install a PV lighting system than to dig up the roadway to bury electrical wires for the lighting system.

Some of the main disadvantages of PV include:

Expensive Technology

The manufacturing process for making PV cells is still expensive in spite of great reductions in cost over the past 30 years. Depending on where you live in the U.S., it can be **2-5 times more expensive** than electricity provided by electric utilities. If there is no electric grid available, the cost of paying to bring in the grid can be more expensive than installing a PV system. But, the grid is already available in most areas that people live in and, in those areas, PV systems are often more expensive than the grid.

Weather and Climate Dependent

While the PV cells themselves are fairly reliable, the sun's rays are not always a very predictable resource in some areas. PV modules need sunlight to produce electricity. Consequently, they do not produce electricity at night. Though PV modules can produce electricity on cloudy days, the amount of electricity produced will vary depending on the density of the cloud cover as it has a direct effect on the amount of sunlight striking the PV modules. Geographic areas that have cloudy climates or high humidity will require more PV modules to produce a given amount of electricity than in dry, sunny locations like New Mexico.
Smog, dust, and other airborne particles can affect the amount of sunlight striking the PV modules and, hence, the amount of electricity produced.
Geographic areas closer to the poles (North and South) have very long days in one season (summer for areas near the North Pole, winter for areas near the South Pole) and very short

days during the opposite season.

All of these are factors that can potentially prevent a PV system from being a reliable source of electricity. Battery packs are often used to improve the reliability of PV systems. They add cost to the system, but help to provide a continuous source of power when needed.

Space Requirements

To provide enough electricity for an entire household, a good deal of the roof must be used, or equivalent space on the ground, and it must have good "solar access" -free from shading effects of nearby trees, mountains, or buildings.

Other Necessary Equipment

Depending on the type of PV system and its intended use, there may be need for an inverter (device that converts DC electricity produced by the PV modules to AC electricity which is commonly used in homes and businesses) or for a battery pack or both. Either of these will add significant cost to a PV system.

Types of Materials Used in PV

There are a number of different semiconductor materials used and different manufacturing processes used in the production of solar cells. Some of the common materials include:

- Single-crystal silicon (Si)
- Polycrystalline silicon (Si)
- Amorphous silicon (a – Si)

These materials are chosen for a variety are their specialized effects or properties, such as:

- Electronic material properties
- Absorptivity
- Band Gap
- Cost

Some metals, such as copper, aluminum, platinum, gold and silver, are known as excellent **conductors** of electricity because their atoms hold their outer electrons loosely or with a weak attractive force. This means that they can be dislodged more easily than in other materials. Dislodged electrons move rapidly along a conductor and, in the case of a copper wire, can be made to follow a complete electric circuit.

Most wires used in homes and businesses are copper, though aluminum is sometimes used. Copper costs more than aluminum, but it is a better conductor so smaller wires can be used. Aluminum is used by utilities for the transmission wires strung on high towers because it is lighter in weight than copper so it can handle the large spans between poles and it is more economical for the long transmission distances. Platinum, gold and silver are too expensive to use for these applications.

Some materials, like plastic, rubber, wood, or glass hold their outer electrons tightly or with a strong attractive force. These materials are known as **non-conductors** because they do not readily conduct electricity.

Other materials have conductive properties somewhere in between conductors and non-conductors. They are called **semiconductors**. Elements such as silicon (Si) and germanium (Ge) and compounds such as cadmium telluride (CdTe) and Cadmium Indium Diselinide ($CuInSe_2$) are semiconductors used in photovoltaics (though silicon is the most commonly used in commercial applications).

There are two types of semiconductors: n-type and p-type. N-type semiconductors involve movement of negative charges – electrons. P-type semi-conductors involve positive charges (or absence of electrons commonly called “holes”). These two kinds of semiconductors are made into a “sandwich” in a PV cell. The area where they touch is called the p-n junction. So, solar cells are made up of both n-type and p-type semiconductors.

Comparison of Common Types of PV modules

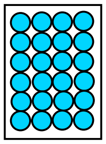
Silicon is a material commonly used in commercial PV modules. It is the second most abundant element in the Earth’s crust, oxygen is the most abundant. Silicon occurs most frequently in nature as silicon dioxide (silica, SiO_2) and as silicates (compounds containing silicon, oxygen, metals, and maybe hydrogen). Sand and quartz are two of its most common forms. However, sand is generally too impure to be processed into silicon.

High-grade deposits of quartzite can be almost 99% pure silica, but will still be less than 90% silicon. The silica must be processed to become silicon. To become semiconductor-grade silicon it must be processed and purified until it is 99.9999% pure silicon! This process, as you might expect, is very expensive.

The computer industry uses purified silicon for manufacturing its computer chips.

Single crystal silicon

(the Siemens modules on your roof are single crystal silicon)

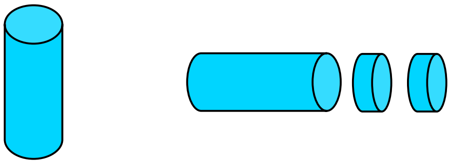


Advantages

- Well established and tested technology
- Stable conversion efficiencies over the life (20-30 years) of the module
- Highest efficiencies of silicon solar cells

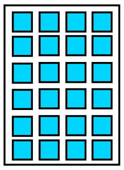
Disadvantages

- Expensive manufacturing process
- Uses expensive single crystal and other materials
- Round crystals have less packing density (single crystal silicon ingots are pulled from molten silicon as cylinders that are sawed into wafers)



Polycrystalline Silicon

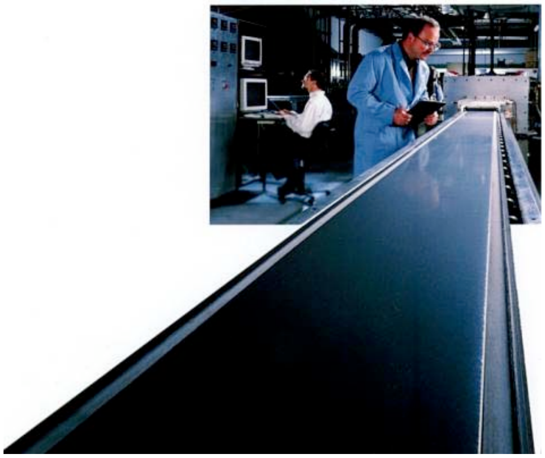
Advantages



- Well established and tested technology
- Stable conversion efficiencies over the life (20-30 years) of the module
- Square cells for better packing density

Disadvantages

- Uses expensive materials (though less expensive than single crystal silicon)
- Expensive manufacturing process
- Slightly less efficient than single crystal silicon



Amorphous Silicon

Advantages

- Low material use because the films are microns thick
- Potential for automated production
- Potential for low cost
- Less affected by shading due to long, thin cells – harder to shade a single cell
- Thinness contributes to use in specialized applications, i.e. calculators and watches (where small amount of power is required)
- Can be incorporated into windows and roofing tiles or shingles in building-integrated PV systems (the electrical generation system is part of the building *skin*)

Disadvantages

- Lower efficiencies than single and polycrystalline silicon
- Larger areas needed for same power output as single or polycrystalline silicon due to lower efficiencies

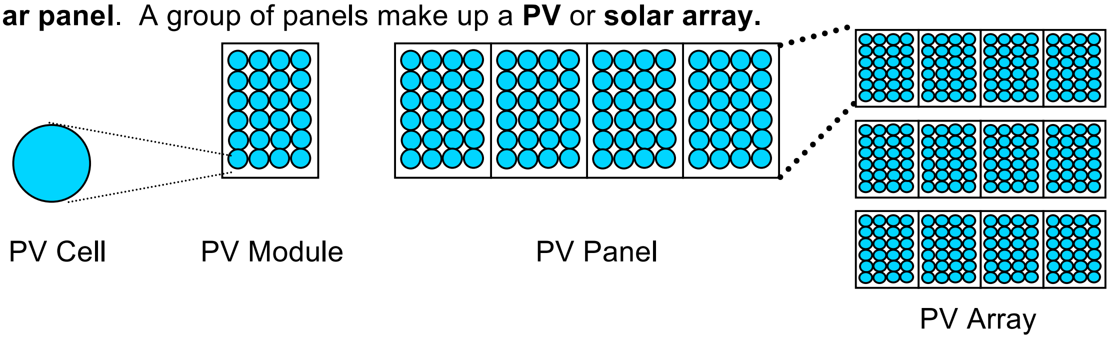
The cost per unit area (cost/area) of silicon solar cells increases with the size of the crystals. This means that a smaller area of single-crystal cells is required to generate 100 W of power. The cost of a panel that will generate a 100 W may be more constant than the size.

Other Materials for PV Cells

Other materials are being researched for both their electrical generation potential and commercial feasibility, including: Copper Indium Diselenide, Cadmium Telluride, and Gallium Arsenide. These compounds may become the PV material of choice in the future.

Photovoltaic Terminology

A **PV** or **solar cell** (used interchangeably) is the smallest production unit of PV systems and it is the building block of larger systems. Common single crystal silicon (a typical type of semiconductor material used) solar cells produce about 0.5 Volts.
A group of cells wired together form a **module**. With single crystal silicon, 36 solar cells are often grouped together and wired in series to produce 18 Volts.
A number of modules grouped together and attached to a mounting frame form a **PV panel** or **solar panel**. A group of panels make up a **PV** or **solar array.**



There many different materials used for PV modules and different ways of configuring modules. Consequently, there are many different sizes (Watts) and voltages available in commercial modules. Effective PV system design allows the user to meet a wide variety of electrical loads.

PV System Components

A PV power system consists of several components, though the exact list may vary with the application. A remote water pumping system may utilize a DC water pump and be designed to operate only during the day when there is sun and the components may be the PV array (or panel or module depending on size of the load), a controller to regulate current and voltage, and the water pump, or load. A grid-tied system, like the one at your school, consists of the following components:

- PV array
- Inverter – converts DC electricity generated by the PV array to AC electricity fed into a building electrical panel (or sub-panel) (Note: a controller is built into the inverter)
- Emergency disconnects – allows for the PV array or the inverter to be disconnected
- DAS – Data Acquisition System – monitoring instruments (anemometer, temperature thermistor, pyranometer, and AC watt-hour meter) that display readings real-time on classroom computer

PV systems that are designed to provide useful energy even when the sun is not shining will have two additional components – a battery bank that stores the excess electricity produced until it is needed and a charge controller that regulates the amount of current and voltage allowed to be fed into the battery bank.

Power Ratings of PV Modules

PV modules are tested and rated at Standard Test Conditions (STC) in a laboratory. NREL provides expert service to rate modules for a number of manufacturers. Standard Test Conditions include:

- Cell temperature of 25 °C
- Sun intensity of 1000 W/m^2
- Spectral distribution at AM 1.5 (Air Mass 1.5)

Also, typically included in power ratings may be items such as the rated power of the module, current and voltage at typical load, short circuit current, open circuit voltage, and the dimensions of the module.

PV History

1800's

The "photovoltaic effect" was first described by the French physicist Edmond Becquerel in 1839. Becquerel found that certain materials would produce a small amount of electric current when exposed to light.

During the latter part of the 19th century, research by Heinrich Hertz and others led to the development of selenium PV cells (sometimes called "solar" cells) that could convert light into electricity with efficiencies of 1-2%.

Selenium was also used in light measuring devices for the burgeoning photography industry. Light meters are needed in photography to ensure that the correct shutter speed is used to achieve optimum exposure for the photo.

1900's

In 1954, scientists at Bell Laboratories developed the first crystalline silicon PV cell. With efficiencies as high as 4%, it marked a significant improvement over selenium PV cells.

The developing space program (1950's – 1970's) provided opportunities to utilize PV technology where a never-ending source of electricity was needed to power satellites and scientific instruments in space. The cost for this renewable energy technology was very high from the outset, but worthwhile for the space program due to the advantages of PV over other sources of electricity and their fuel requirements.

Through research and development in private, public, and university sectors, the cost of PV technology has declined steadily over the years. However, during the past 20 years, the effective cost (inflation-adjusted) of conventional electricity has actually declined. Consequently, PV-produced electricity is still an expensive option in many cases, especially if conventional electricity is readily available. However, for many specific types of applications (livestock watering, remote roadway phones, wristwatches, calculators, etc.), it is the most cost effective way to satisfy the need for electricity.

A good website with interesting information regarding the history of photovoltaics, please see:
http://www.techreview.com/articles/july95/Smith.html

On-line PV information and quiz can be found at:
http://www.eren.doe.gov/pv/pvmenu.cgi?site=pv&idx=1&body=aboutpv.html

Solar Angles and Geometry

Determining the Effect of Angle of Orientation on PV Module Output

Grade Level - Subject

6-12th Grade – Math, Science, and Technology Education (see specific activities for appropriateness for 6-8th or 9-12th grade).

Overview

In this lesson students will explore and learn:

- How to orient a PV module for maximum electricity production through data gathering and analysis
- How to take current and voltage measurements of a PV module using a multimeter
- How to determine the effect of angle of orientation on PV module output

Purpose

The purpose of this lesson is to introduce students to the concept of how to maximize the solar resource, how to take measurements of the electrical output of a PV module and put the measurements into a more useful, graphical form.

Learning Objectives

After completing this lesson, students will be able to:

- Identify "normal" orientation for a PV module
- Be able to take current and voltage measurements and calculate power from them
- Use a multimeter to take a series of sequential measurements for performance analysis
- Understand how to interpret a graph for determining optimum angle of orientation

Vocabulary

maximum
voltage
power
angle of orientation
current
volt
watt
photovoltaic module
amp
multimeter
normal

Resources & Materials

Groups of 3-5, each group should have:

PV module (5-20 Watts)
protractor
graph paper
paper towel roll
multimeter
compass
ruler
one 30-foot string
calculators
pencils/markers

Preparatory Activities & Prerequisite Knowledge

Students should already know or be familiar with the following:

protractor
independent variable (x)
dependent variable (y)
current
power
angles
how to read a graph (x and y axes)
how to plot/construct a graph (x and y axes)
voltage

Before the first day of this lesson, students should have some familiarity with photovoltaic modules and systems, how they work, and why we use them. They should also have completed the unit on Appliance Power and Energy and the unit of Power and Energy Basics so they will be able to attach meaning to the DC electrical power output of the PV module. Teacher should have some familiarity with a multi-meter and taking current and voltage readings with it. Students should also be comfortable with the safe use of a multi-meter. **NOTE: A small module of 5 – 20 Watts is preferred for these exercises.** There is no need for a 50-100 Watt module, no need for a high voltage or high current module. Safety is paramount, and the smaller the power source, the less need to worry even if a student is not taking working with electricity very seriously.

Discussion and Analysis of Orienting PV Panel

Teacher leads students through introduction and discussion of maximizing the available sunlight (solar resource) through orienting the panel so that it faces the sun directly.

Solar Geometry and Its Effects on Electric Power

In order to measure the power produced by a solar electric or photovoltaic (PV) module, students need some background information on the sun, its rotation, its intensity, the photoelectric process, and the importance of module orientation for producing maximum electricity. Students then take measurements of the current and voltage produced by the PV module. With this information, they can calculate the power.

Angle of Orientation

For maximum solar electricity production, solar panel orientation is important. Students will be able to determine exactly how important orientation is through testing the PV power production at various angles of orientation.

Group Work – Outside

Students should be in groups of 3-5 and most of what follows should take place outside (except for the data analysis done on a computer) preferably on a reasonably sunny day. After students are comfortable working with the multimeter and taking measurements, doing similar testing on a cloudy, partly cloudy, rainy or snowy day may provide students greater insight as to the effects of these meteorological conditions on PV output. It is preferable that each group has a full set of supplies to do this activity.

Teacher-led Questions, Answers, and Discussion

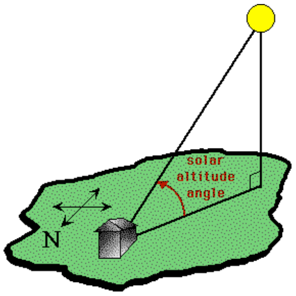
Ask students for information about the path of the sun during the day and during the year. It should be agreed that the sun moves (appears to move) from east to west across the sky daily and is higher in the sky at noon on June 21st than on December 21st . The explanation for the yearly change in the sun's path across the sky has to do with the earth's axis tilt and how it affects the relative position of the sun in our sky view.

Introduce the idea that sun's daily highest point it the sky – the sun's **altitude angle – occurs at solar noon each day**. The altitude angle is measured from the **horizon up to the sun**. The sun does not honor Daylight Savings Time and solar noon is relatively constant (varies by a few minutes seasonally, but not by an hour as we change it with Daylight Savings and Standard Time).

During the Winter Solstice at solar noon, the sun will be at its lowest solar noon point in the sky for the entire year. The sun's altitude angle will be **23° less during the Winter Solstice than at the Equinox** (it is at about 55° at solar noon on the Equinox). So, 55° - 23° = 32°. The sun will be 32° above the horizon at noon on the Winter Solstice. During the Summer Solstice at solar noon, the sun will be at its highest solar noon point in the sky for the entire year. The sun's altitude angle will be 23° more than at the Equinox. So, 55° + 23° = 78°. The sun will be 78° above the horizon at noon on the Summer Solstice.

Altitude Angle

The altitude angle (sometimes referred to as the "solar elevation angle") describes how high the sun appears in the sky. The angle is measured between an imaginary line between the observer and the sun and the horizontal plane the observer is standing on. The altitude angle is negative when the sun drops below the horizon. In this graphic, replace "N" with "S" for observers in the Southern Hemisphere.



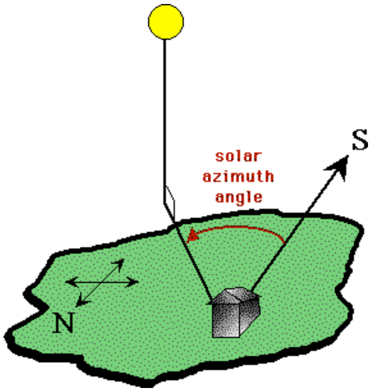
The altitude angle is calculated as follows:

$$\sin(Al) = [\cos(L) * \cos(D) * \cos(H)] + [\sin(L) * \sin(D)]$$

where:
Al = Solar altitude angle
L = Latitude (negative for Southern Hemisphere)
D = Declination (negative for Southern Hemisphere)
H = Hour angle

Source: Christopher Gronbeck; Christopher@susdesign.com; http://www.susdesign.com; 509-493-3486; World Steward, Inc., Highland Farm, 101 Highland Orchards Road, Underwood, WA 98651; http://www.worldsteward.org

Azimuth Angle



The solar azimuth angle is the angular distance between due South and the projection of the line of sight to the sun on the ground. A positive solar azimuth angle indicates a position East of South, and a negative azimuth angle indicates West of South.

Note that in this calculation, Southern Hemisphere observers will compute azimuth angles around +/- 180 degrees near noon. Comments would be appreciated concerning whether or not this should be modified such that solar noon is associated with an azimuth value of 0.

The azimuth angle is calculated as follows:

$$\cos(Az) = (\sin(Al) * \sin(L) - \sin(D)) / (\cos(Al) * \cos(L))$$

where:
L = Latitude (negative for Southern Hemisphere)
Az = Solar azimuth angle
D = Declination (negative for Southern Hemisphere)
Al = Solar altitude angle

The sign of the azimuth angle also needs to be made equal to the sign of the hour angle when using the above equation.

Source:
Christopher Gronbeck; Christopher@susdesign.com; http://www.susdesign.com; 509-493-3486; World Steward, Inc., Highland Farm, 101 Highland Orchards Road, Underwood, WA 98651; http://www.worldsteward.org

Christopher Gronbeck has created an interesting web site that will do all of your solar angle calculations for you: http://susdesign.com/sunangle/

Magnetic Declination Angle

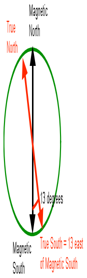
If the sun were at solar noon, it would be in our southern sky at 13° east of magnetic south. We could orient our solar panel to face directly at the sun, 13° east of magnetic south easily.

Students should be asked to find **magnetic south** and **true south** using a compass. The compass will point to **magnetic north**, 180° opposite that will be magnetic south. **13° east of magnetic south** will be **true south**. The PV panels on the roof of your school were mounted facing as close to true south as the support structure of the roof would allow.

Magnetic Declination and Earth Rotation

1. In few places on Earth does magnetic north equal true north.

   In Denver, true north will be 13 degrees west of magnetic north, so true south will be 13 east of magnetic south. When you go outside, use your compass to find magnetic south, then go 13 degrees east to find true south.



2. For maximum output, we like the sun's rays to be "**normal**" to the PV module. **Normal means perpendicular**, but for 3-D objects, perpendicular is more difficult to determine. We can make something **"normal"** to the sun's rays by having it face the sun directly **so it casts <u>no shadow</u> (or a minimal shadow).**
3. The earth rotates 360 degrees each day (one full circle), causing the sun to appear to revolve 360 degrees around the earth each day. How many degrees across the sky does the sun move in 1 hour?

Sample Problems Using Magnetic North/South and Sun Rotation

Here are several simple calculation problems to ensure that students understand magnetic declination and the rotation of the earth.

- How many degrees across the sky does the sun move in 1 hour?

  Use a simple proportion: 360 degrees / 24 hours = x degrees / 1 hour == now solve. First multiply both sides by 1 hour, the hours will cancel out on the left, then divide 360 degrees by 24 and you will get:
  X = 15 degrees in one hour, the sun moves across the sky 15 degrees in one hour.

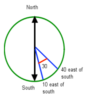
- How many degrees per hour does the earth rotate?

  15 degrees.

- How many degrees does the earth rotate in 3 hours?

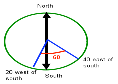
  3 x 15 degrees = 45 degrees.

- If the sun is at 40 degrees east of south at 10:00 a.m., where will it be in 2 hours?



2 hours * 15 degrees / hour = 30 degrees
So, sun will be 10 degrees east of south.

- If the sun is at 40 degrees east of south at 10:00 a.m., where will it be in 4 hours?



4 hours * 15 degrees / hour = 60 degrees
So, sun will be 20 degrees west of south

- If the sun is at 95 degrees east of south at 6:30 a.m., where will it be at 5:00 p.m.?

How many hours are we talking from 6:30 am to 5:00 pm**?**
5.5 + 5 = 10.5 hours
How many degrees will the sun rotate in 10.5 hours?
10.5 hours * 15 degrees / hour = 157.5 degrees

The sun will use 95 of those degrees to get to south (157.5 - 95 = 62.5)
So it will continue westward another 62.5 degrees and be 62.5 degrees west of south

Magnetic Declination and Earth Rotation Worksheet

1. In few places on Earth does magnetic north equal true north. **In Denver, true north will be 13 degrees west of magnetic north, so true south will be 13 east of magnetic south. When you go outside, use your compass to find magnetic south, then go 13 degrees east to find true south.**

2. For maximum output, we like the sun's rays to be **"normal"** to the PV module. **Normal means perpendicular**, but for 3-D objects, perpendicular is more difficult to determine. We can make something **"normal"** to the sun's rays by having it face the sun directly **so it casts <u>no shadow</u> (or a minimal shadow).**

3. The earth rotates 360 degrees each day (one full circle), causing the sun to appear to revolve 360 degrees around the earth each day. How many degrees across the sky does the sun move in 1 hour?

4. How many degrees per hour does the earth rotate continuously?

5. How many degrees does the earth rotate in 3 hours?

A sketch may be helpful on the next 3 questions.

6. If the sun is at 40 degrees east of south at 10:00 a.m., where will it be in 2 hours?

7. If the sun is at 40 degrees east of south at 10:00 a.m., where will it be in 4 hours?

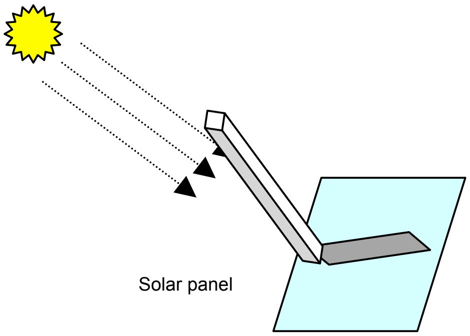
8. If the sun is at 95 degrees east of south at 6:30 a.m., where will it be at 5:00 p.m.?

“Normal” to the Sun

Ask students to face the PV module directly at the sun so it will maximize electric power output. It may be difficult for students to tell if they truly are facing **directly** at the sun. To determine if we are facing directly at the sun, we need another form of measurement. We need to determine if the tilt angle of our solar panel is optimized so that it is completely “flat” relative to the sun’s incoming rays.

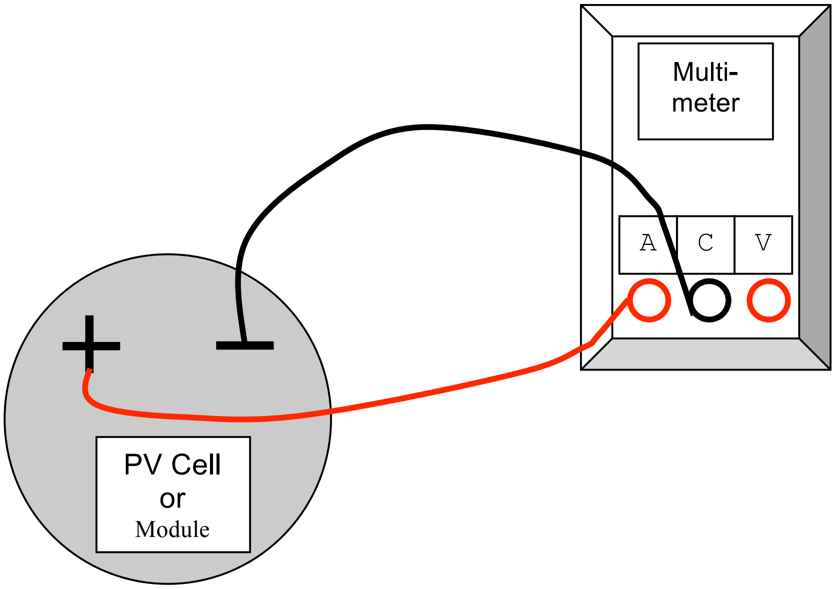
The concept of “normal” or being perpendicular in 3 dimensions, not just perpendicular in 2 dimensions like in plane geometry, should be introduced. The easiest way to get across this somewhat abstract concept is with a hollow tube, e.g.. a cardboard paper towel tube. If you orient the tube so that you have full circle on sun shining through to the ground (with no shadow being cast by the tube), then the tube is “parallel” to the sun’s rays.

On a sunny day, if the PV module is facing “**normal**” to the sun, the maximum amount of **direct beam sunlight** will be striking the surface of the PV module.
A similar way of obtaining “normal”, and one that will help to properly orient the solar panel, is to place a 1 x 1 x 12 piece of wood (or a cardboard paper towel tube) on the panel surface to that one of the small, square ends is flush against the panel. It will probably cast a shadow. Keeping it flush against the panel, adjust the panel so that the wood casts no shadow. At that point, the panel will be “normal” to the sun.



Students should be asked to orient their solar panel “**normal**” to the sun to maximize electrical output. If a cylinder or rectangular prism is placed upright with its base flush on the surface of the module and it casts no shadow, it is “normal.” The module will probably be angled to the east or west of true south and be tilted up to some degree to achieve “normal.” Of course, exactly how will vary depending on your location (latitude), time of year, and time of day. Once students have found the proper orientation, they should try to maintain the exact same “tilt” angle for the module for the rest of the measurements to be taken.

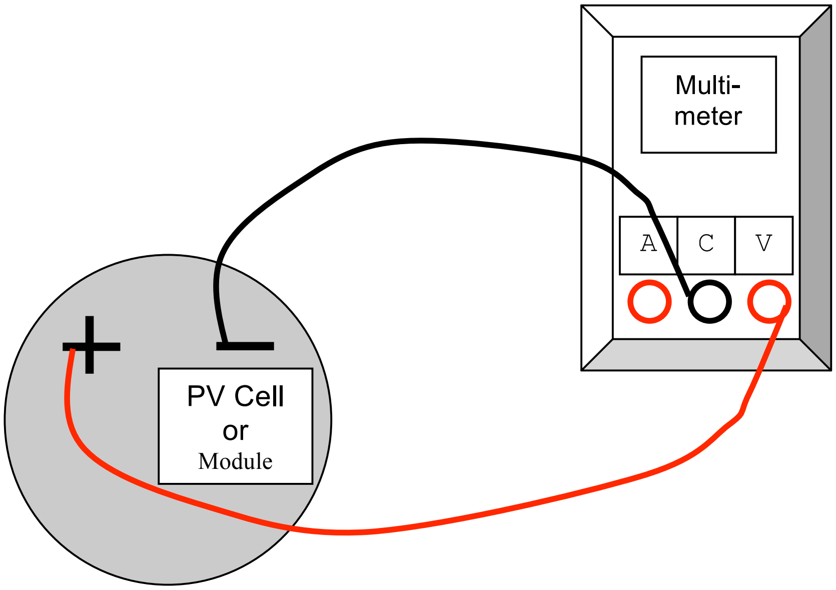
Once “normal to the sun” is found, that direction pointing to the sun will be considered the reference point. Let’s call it **0°.** Using the **multimeter**, students take a current reading (be sure the multi-meter has the black lead in the COM port and the red lead in CURRENT or A for Amp) to determine how much current (in amps) the PV module is producing while facing directly normal to the sun. Have a student record the reading under Current at **0°** in the worksheet (three pages hence).



To measure current, make the PV module or cell part of a complete circuit.

Then, remove the red lead from Current and put it into the VOLTAGE port or V port. Using the multimeter, students take a voltage reading (be sure the multi-meter has the black lead in the COM port and the red lead in VOLTAGE or V port) to determine how much voltage (in volts) the PV module is producing while facing directly normal to the sun. Be sure to change the leads on the multimeter and the type of measurement being made (Voltage). Have a student record the reading under Voltage at 0° in the worksheet (two pages hence).

To measure voltage, measure the potential across the PV cell terminals.

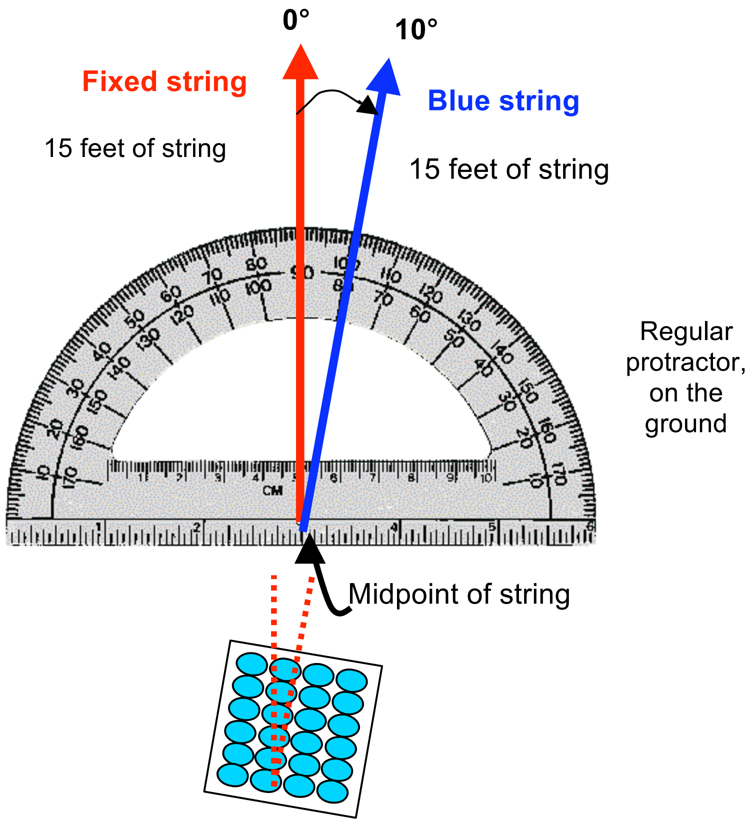


Students have now taken one current and one voltage measurement with the PV module facing “normal” to the sun. Power can be calculated by multiplying current x voltage (I x V = P). See the Power and Energy Unit for a detailed explanation.

To determine the effects of angle of orientation, students will take a series of measurements with the angle of orientation changing by **10°** increments for each measurement (from **0 – 90°**). Trying to determine exactly how far to turn the PV module to represent a **10°** increment can be challenging. Present the problem and see what your students come up with. Below is one method that works reasonably well.

A protractor is a useful tool for determining angles, however, it seems rather small for determining angles of the PV module relative to the sun. Using a protractor and one 30-foot length of string, we can "enlarge" the protractor as a tool to serve the purpose.
Lay the protractor on the ground as shown on the next page. Have a student hold the middle of the string in place on the center point of the protractor (at the zero point on the horizontal bar). Extend one end of the string along the **90°** axis that is perpendicular to the horizontal bar – let's call this the "**fixed string**". It is the **red string** in the diagram on the next page. Keep the protractor and this string permanently in this position as this will serve as the reference point for all the other measurements.

Extend the other end (let’s call it the **blue string** to be able to tell them apart here) of the string **10°** west of the **90°** axis or along the **100°** line. With the string extending out 15 feet from the protractor, one can more easily see how far to turn the PV module to be **10°** west of “normal” (**10°** east of “normal” would work just as well).

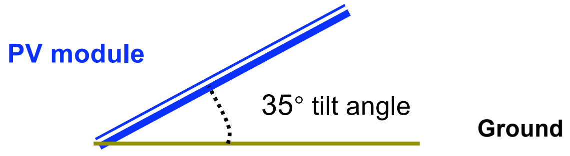


PV module, not drawn to scale, turned or facing **10°** off of **normal**.

Use the blue string to establish “line of sight” to be able to effectively shift the PV module 10° west of the original measurement. With the PV module now 10° west (or east) of normal, have students take current and voltage measurements again with the multimeter (remember to change the ports the red lead is in for current and voltage measurements) and record them on the worksheet on the next page.

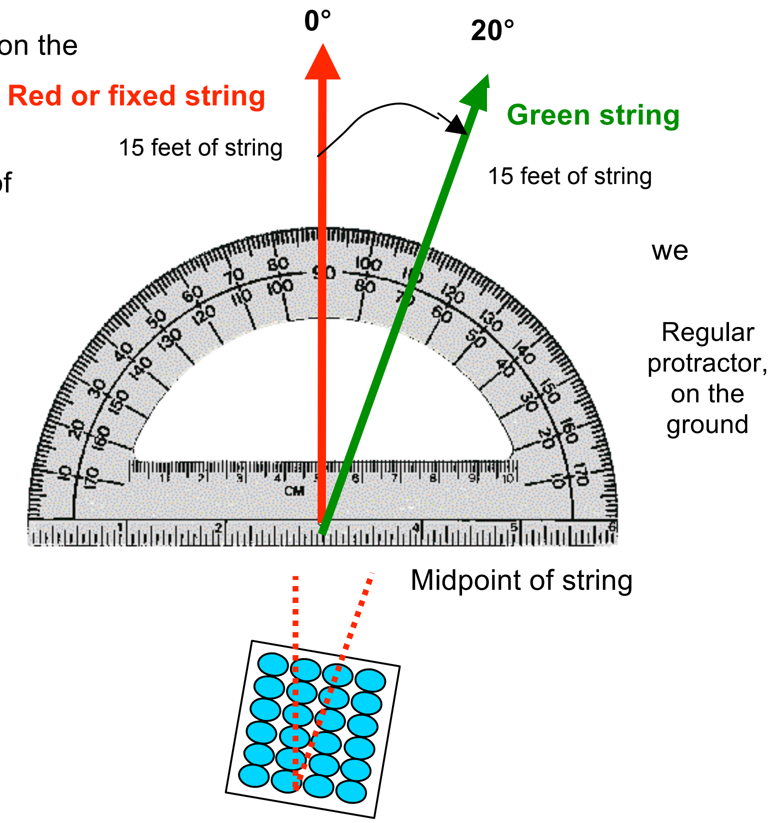
Tilt Angle

It is important to try and maintain the same “tilt” angle (i.e., how much the module is tilted up from the ground) for all of the measurements taken. The tilt angle is called the “Beta” (β) angle in solar engineering applications.



Bear in mind, for the results to be meaningful in terms of the effect of angle of orientation on PV power production, the weather conditions need to be stable. A clear day with steady sun is best. A cloudy day with mixed cloud cover or changing cloud thickness will make it difficult to obtain meaningful or consistent results.

Keeping the protractor in the same place (on the ground), and the **fixed string** on the same line, extend the "blue" half of the string to **70° or 20° off of "normal".** Re-align the PV module to follow the line of sight of the new line from the "**green"** string. Let's call it the "green" string so we can differentiate in this text. (First measurement was **10°** and we called it **blue**, 2nd measurement was **20°** and we called it **green**). From this 2nd line of sight, the **green** string, students will again take current and voltage measurements that will show the power output when facing **20°** off of "normal."



PV module, not drawn to scale, turned or facing **20°** off of normal.

Have students continue this process taking measurements at 30° off of normal, 40°, 50° and so on through to 90°. Students can even continue taking measurements beyond 90° off of normal, in other words, facing "away" from the sun. Measurements can be taken all the way to 180° away from normal – this is facing directly away from the sun. Students can continue to take measurements every 10° or they could simply do 90°, 135°, and 180° for illustrative purposes (as no one would ever orient a PV module 135° away from the sun for power production). Students may be surprised at how much power the PV module can generate while facing away from the sun.

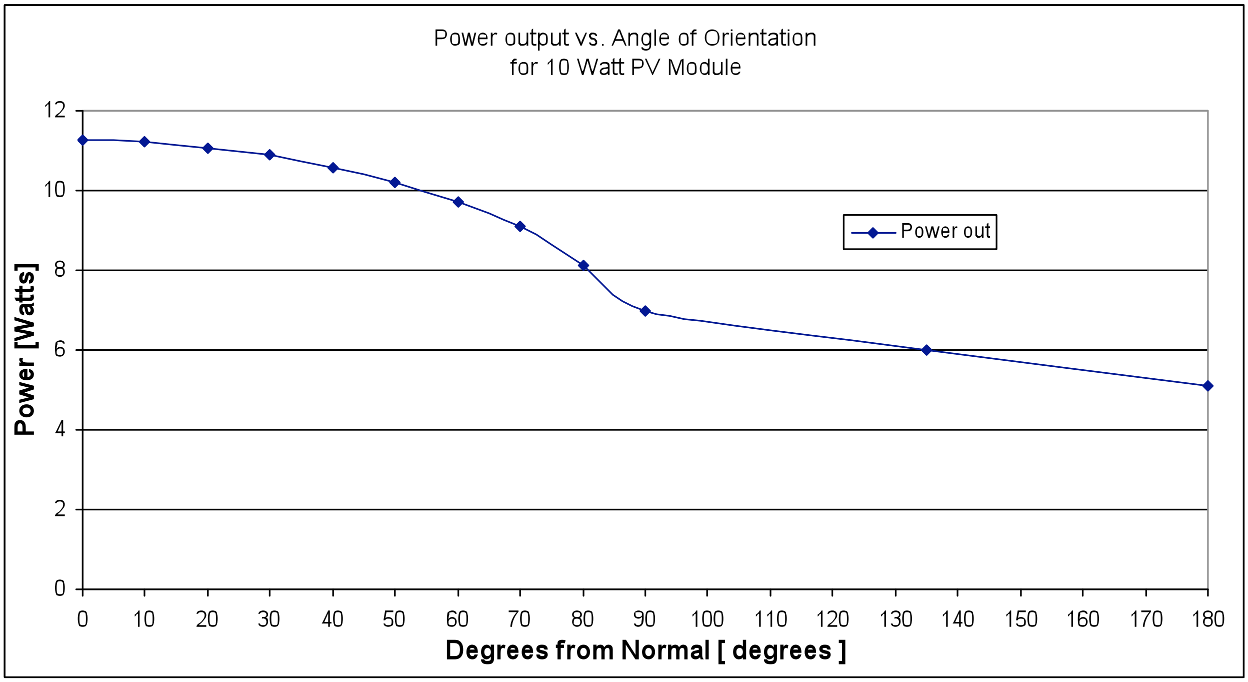
Students can also take measurements with the PV module laying horizontal on the ground (tilt angle of 0°) and with the module vertical (perpendicular to the ground) while facing 0° or directly in the direction of the sun but with a tilt angle of 90°. The results of these measurements can be seen in summary form below.

Reminder on finding power

Do you remember how to find Power?
To find the amount of power the module is producing, we need voltage and current:
Power = Voltage * Current or P = V * I
[Watts] = [Volts] * [Amps]
Sample PV Worksheet

Calculating PV Power Output from Voltage and Current Measurements

Test #	Normal (degrees from true south)	Degrees from "Normal"	Voltage	x	Current	=	**Power out**
	[degrees]	[degrees]	[V]	x	[A]	=	[Watts]
1	22	0	6	x	1.88	=	11.3
2	22	10	6	x	1.87	=	11.2
3	22	20	5.99	x	1.85	=	11.1
4	22	30	5.98	x	1.82	=	10.9
5	22	40	5.97	x	1.77	=	10.6
6	22	50	5.96	x	1.71	=	10.2
7	22	60	5.92	x	1.64	=	9.7
8	22	70	5.88	x	1.55	=	9.1
9	22	80	5.81	x	1.4	=	8.1
10	22	90	5.73	x	1.22	=	7.0
11	22	135	5.62	x	1.07	=	6.0
12	22	180	5.41	x	0.94	=	5.1

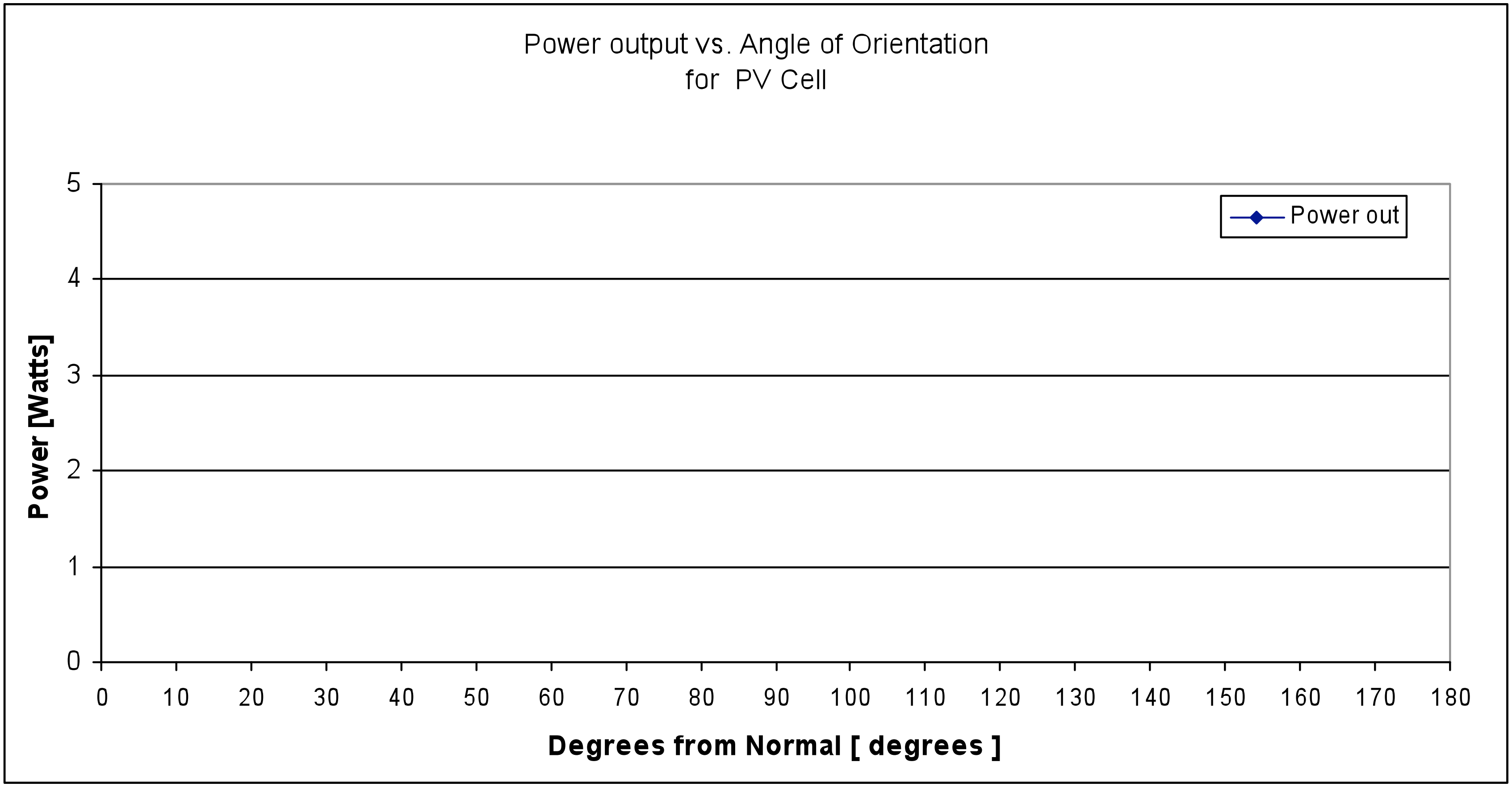


Blank Worksheet for PV Power Output Activity

Calculating PV Power Output from Voltage and Current Measurements

Test #	Normal (degrees from true south)	Degrees from "Normal"	Voltage	x	Current	=	**Power out**
	[degrees]	[degrees]	[V]	x	[A]	=	[Watts]
1		0		x		=	
2		10		x		=	
3		20		x		=	
4		30		x		=	
5		40		x		=	
6		50		x		=	
7		60		x		=	
8		70		x		=	
9		80		x		=	
10		90		x		=	
11		135		x		=	
12		180		x		=	

Blank Graph for PV Power Output



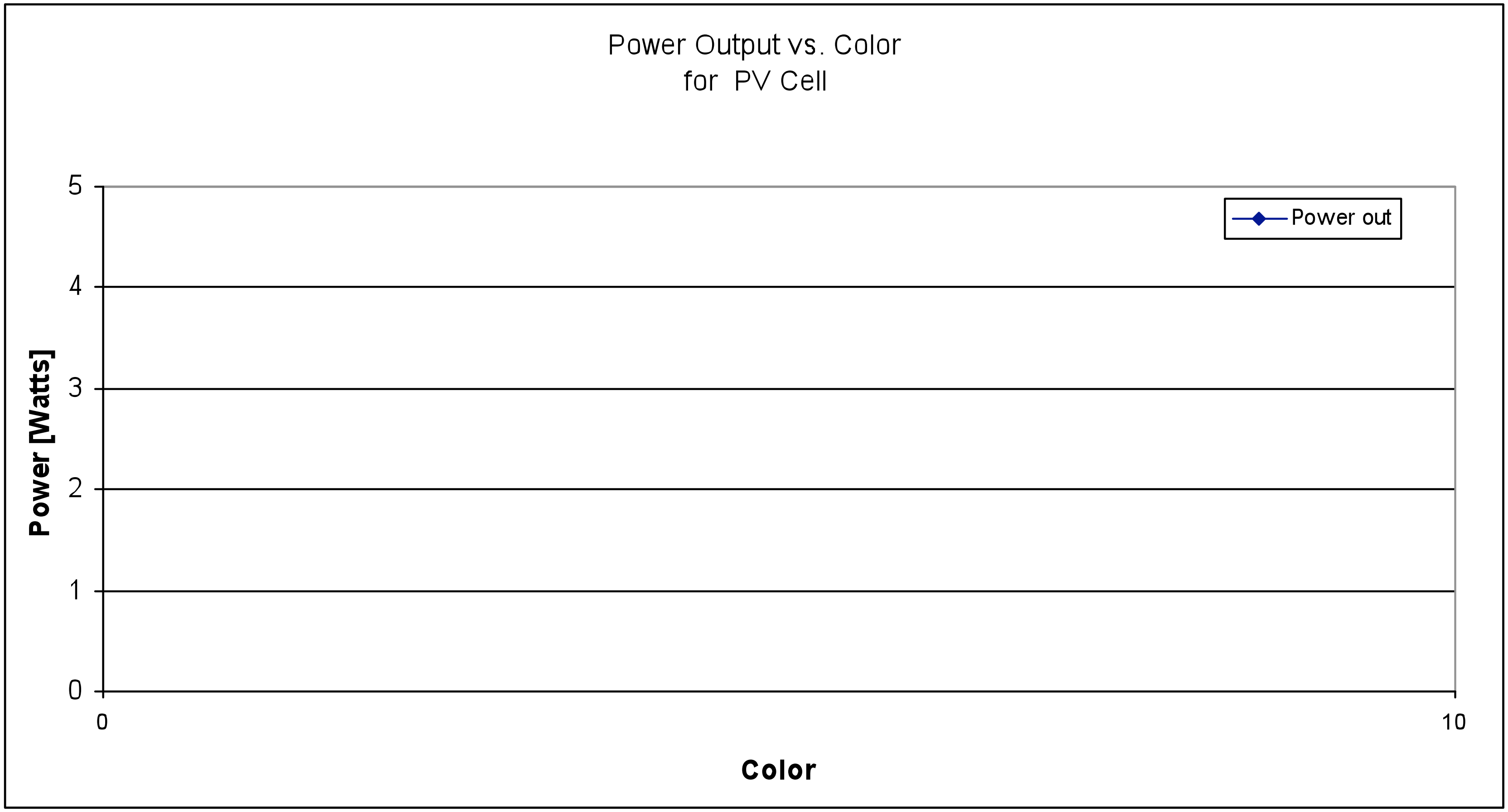
Effect of Color Filters on Power Output and Efficiency

Another activity that can be done as an extension and combination of the previous two activities is to measure the voltage and current, calculate the power and efficiency of your solar cell while facing directly at the sun (“normal”) while using various color transparencies.

Blank Worksheet for PV Power Output Affected by Color Activity

Calculating the Effects of Color on PV Power Output from Voltage and Current Measurements

Test #	Normal (degrees from true south)	Color of Filter Paper	Voltage	x	Current	=	**Power out**
	[degrees]	[color]	[V]	x	[A]	=	[Watts]
1		Red		x		=	
2		Orange		x		=	
3		Yellow		x		=	
4		Green		x		=	
5		Blue		x		=	
6				x		=	
7				x		=	
8				x		=	
9				x		=	
10				x		=	
11				x		=	
12				x		=	


Power Output vs. Color
for PV Cell
Power out
Power [Watts]
5
4
3
2
1
0
0
10
Color

Calculating the Effects of Concentration on PV Power Output from Voltage and Current

Test #	Normal (degrees from true south)	Number of Additional Reflectors	Voltage	x	Current	=	**Power out**
	[degrees]	[number]	[V]	x	[A]	=	[Watts]
1		0		x		=	
2		1		x		=	
3		2		x		=	
4		3		x		=	
5		4		x		=	
6				x		=	
7				x		=	
8				x		=	
9				x		=	
10				x		=	
11				x		=	
12				x		=	

Concentrating Solar Power Activity

Another variation to the PV Power activity is to use additional reflective surfaces to make your solar cell into a concentrating solar cell. Test the effect of adding 1, 2, 3, and 4 concentrators on the power output and the efficiency.

Conversion Efficiencies

The conversion efficiency of a PV cell is the proportion of sunlight energy that strikes the cell that is converted to electrical energy. This is very important when discussing PV devices, because improving this efficiency is vital to making PV energy more cost competitive with more traditional sources of energy (e.g., fossil fuels). Naturally, if one efficient solar panel can provide as much energy as two less-efficient panels, then the cost of that energy (not to mention the space required) will be reduced. For comparison, the earliest PV devices converted about 1%-2% of sunlight energy into electric energy. Today's PV devices, depending on materials and manufacturing methods, convert 7%-17% of light energy into electric energy.

Definition of Efficiency

Manufacturing a PV cell is expensive no matter which material or manufacturing method is used, though some materials and methods are more expensive than others. Of critical concern is getting the most electricity out of a given amount of PV material.

As an example to help understand efficiency, when you take a 100 question test, the maximum possible correct answers is 100 – that is the "Total Available Questions". If you were to get 87 correct, your score would be 87 correct out of 100 available or possible. To find your percentage score, we ***divide*** **number of correct answers** by **number of questions available**. We might call your percentage score your **efficiency of taking the test**.

Percentage Score = Number Correct / Number Available
87 % = 87 Correct / 100 Available

To find the efficiency of a PV cell, take the **electrical power output** and ***divide by*** the **solar power input**. This is a measure of **solar cell efficiency**.

Efficiency = Power Out / Power In

Power In = Solar power from the sun [Watts Input]

Power Out = Electricity [Watts Output]

Efficiency [%] = Watts Output / Watts Input

This has been simplified to eliminate the size of the PV cell in this calculation. We usually use the size (collector area) of the PV cell (or module) and unitize the solar input to a square meter basis (i.e., Watts / m^2). Standard Test Conditions for PV modules uses the reference value of 1000 W/m^2 for the Solar Power Input from the sun.

As an example, if a $1m^2$ PV module is receiving 1,100 Watts of solar energy input. And, the PV module is producing enough electricity to light an 100 Watt light bulb, we would calculate the efficiency of the module as follows:

Efficiency of PV Module = 100 Watts Output / 1100 Watts Input = 9.1 % Efficiency

9.1% of the solar energy is getting converted into electricity. We say this module has an efficiency of 9.1%.

Another example, this time using typical irradiance readings, find the efficiency of a module producing 78 Watts of power while the sunlight intensity is 1024 Watts/m^2. The size of the module is 80 cm x 120 cm.

First, we need to calculate the area of the PV module. Remember, to find area, we multiply length times width.

Length x Width = Area
120 cm x 80 cm = 9600 cm^2
9600 cm^2 x 1 m^2 / 10000 cm^2 = 0.96 m^2

Then we will use the Efficiency Equation, although this time we will include the area in both the numerator and the denominator. The units will cancel each other out, but this method, using the collector area and the solar input on per square meter basis, enables us to calculate the efficiency for any sized PV cell, module, panel or array.

Efficiency of PV Module = (Watts Output ÷ Area of Collector) ÷ (Watts Input ÷ Unit area)

Efficiency of PV Module = (78 Watts Output ÷ 0.96 m^2) ÷ (1024 Watts Input ÷ 1.0 m^2)

Efficiency of PV Module = 81.25 ÷ $1024 \approx 0.079 \approx 7.9\%$

Notice all units will cancel and we end up with a unitless number, which we should when calculating efficiencies.

Learning How to Read and Use the Strip Chart - Irradiance

Grade Level - Subject

6-12th Grade – Math, Science, and Technology Education

Overview

In this lesson students will explore and learn:

- how to read and interpret the strip chart feature of the software that interacts with the rooftop photovoltaic (PV) system and displays the irradiance striking the PV array
- how to re-group the data to highlight different kinds of information

Purpose

The purpose of this lesson is to introduce students to the concept of obtaining useful information from a graphical representation of data while learning about the type of data represented in the graph. Students will extract a variety of data from the real-time strip chart and categorize it into useful forms. Students will also compare archived data for a specific time period to the graphical representation of the data in the strip chart to verify the accuracy of the strip chart and its sensors.

Learning Objectives

After completing this lesson, students will be able to:

- Identify maximum and minimum data points and supply plausible reasons for this behavior.
- Identify trends and disturbances to trends and supply plausible reasons for this behavior.
- Understand how the scale of a graph or chart can influence interpretation of that data.
- Realize that the length of day varies during the year and that that affects the number of hours during which the PV system is generating electricity
- Realize that a set of data can have more than one explanation
- Realize that measurement is not precise. Measurement can be a source of error.
- Understand the concept of correlation.

Vocabulary:

maximum
y-interceptquantitative data
time scale
source of error
minimum
x-intercept
error
light meter (pyranometer)
trend
qualitative data
correlation
photovoltaic system

Resources & Materials:

rooftop pv system
archived data
graph paper
pencils/markers
real-time computer monitor output
handouts on PV system, strip charts, archived data
rulers
calculators

Preparatory Activities & Prerequisite Knowledge:

Students should already know or be familiar with the following:

independent variable (x)
dependent variable (y)
how to read a graph (x and y axes)
how to plot/construct a graph (x and y axes)

Before the first day of this lesson, students should have some familiarity with photovoltaic modules and systems, how they work, and why we use them.

Discussion and Analysis of Irradiance Strip Chart

Teacher leads students through introduction and discussion of data collection devices and strip chart information.

Introduction

Provide background information on (review from previous lessons):

- PV systems

Provide background information on:
Data collection devices, how and when we use them, why we use them.

Can you name some data collection devices you use everyday? We use a thermometer to tell us what the air temperature is, we use a speedometer to tell us how fast we are traveling (in a car or by bike), we use a rain gauge to tell us how much rain has fallen, etc.. [note: a clock is a device that tells us what time it is, but not by collecting data, it is a mechanical device that displays the effects of counting discrete time intervals continuously].

The PV system on your roof has a pyranometer and where the system is connected to schools electric system there is a kilowatt-hour meter.
A **pyranometer** measures the intensity on the light (in this case, sunlight), which strikes its surface. It measures the sunlight in units of Watts/meter^2. So it is measuring the **power available** (Watts) in the sunlight **per unit of area** (in this case, square meter).
A standard reference for sunlight intensity is **1000 Watts/meter^2** (W/m^2). This is considered "**1 full sun**" of sunlight on earth. In most parts of the country, achieving 1000 W/m^2 is considered to be an indication of a bright, sunny, clear day. In New Mexico, with your high altitude, dry air, and generally low pollution levels, you may find that the sunlight intensity routinely goes up to about 1200 W/m^2 during the middle of the day. Yes, the sunlight in New Mexico is really that intense!

A **kilowatt-hour meter** is a device that you probably have at your home or apartment. It measures how much electricity (electrical energy) you use. The amount of electricity you use is measured in kilowatt-hours. The electric utility (who makes the electricity) keeps track of how much you use and charges you based on how many kilowatt-hours you have used (see the lesson on Appliance Power and Energy for more information on how to use kilowatt-hours).

Real-time data

Real-time data is data that is being collected and displayed instantaneously. In Altair's system, you are able to watch the computer monitor and see the exactly the intensity of the sunlight shining on the PV system, what the ambient air temperature at the PV system is, what the wind speed at the PV system is, and how much AC power the system is producing. The data is collected, averaged and displayed on the other computer display pages (we will go to those later).

For this lesson, we will concern ourselves only with the intensity of the sunlight shining on the PV system and how much AC power the system is producing. These are the two graphs available on the Strip Chart display page. The graphs represent all the data collected by the pyranometer and kilowatt-hour meter during the time period shown on the chart (1 week is showing when you first turn it on). The strip chart data gets updated every 15 minutes.

Teacher-led Questions, Answers, and Discussion

Turn on the classroom computer and bring up the real-time strip chart for the rooftop PV system. Have students examine the charts and discuss what the graph is showing/telling them.

Use the following questions to spark a discussion of the strip charts and the information they provide.
Look first at the **"Irradiance" strip chart.**

What is irradiance? Irradiance is a measure of the amount of radiation that the sun gives off that actually makes it to earth. It travels through space 93 million miles, through the atmosphere – with clouds, pollution, etc., and to the photovoltaic system. It represents the "intensity" with which the sunlight is striking the PV system.

What does "Plane of Array Irradiance" or POA Irradiance refer to? The pyranometer is NOT measuring exactly how much sunlight is falling on the PV array. It is ONLY measuring how much sunlight is falling on the PYRANOMETER. **In most cases**, whatever sunlight is striking on the pyranometer is also striking on the array. However, that is NOT ALWAYS the case.

Can you think of some instances when this might not be true (that the sunlight striking the PV array does not equal the reading on the strip chart)? If a bird does "birdie-do" on the pyranometer, it will read, even on a full sun day, some rather low values (maybe in the 2-600 Watts/meter^2 range. It may be that "full sun" is falling on the PV array (1000 Watts/meter^2), but the pyranometer may be indicating that only 400 Watts/meter^2 (for instance) is striking the array. So, 1000 Watts/meter^2 is striking the array, 400 Watts/meter^2 is striking the pyranometer, but the strip chart is indicating that POA Irradiance is 400 Watts/meter^2 and that is NOT TRUE. This is called "erroneous data" or you might say your data has an "error". The source of the "error" is that the measurement device (pyranometer) is not exactly the same as the PV array even though the pyranometer is attached to one of the PV modules and shares the same tilt angle and direction as the PV array..

What units are used to measure irradiance? Irradiance is measured in Watts/meter^2. The Watts(W) represents the power of the sunlight that is striking the PV system. A square meter (m^2) is a real standard unit used in measuring irradiance.

On the Y-axis, what is the scale used to measure irradiance? The scale goes from 0 W/m^2 to 1400 W/m^2.

On the X-axis, what is the variable being used? What units are being used? Time is being measured in units of hours.

Looking at the strip chart as it first comes on the screen, how many hours or days does it represent? It represents 168 hours or 7 full days (7 days x 24 hours/day = 168 hours).

What do you notice during those seven days? Are there any patterns? There appears to be seven “humps” across the screen. They seem to coincide with 7 days as there is roughly 1 hump per day. (Note: If you have had very variable weather patterns during the past week, you may not have 7 smooth humps, you might not even have any if it has been very cloudy and stormy. But, if it has been sunny, you should have 7 humps.).

What do you think the humps might represent? The humps represent the maximum intensity of sunlight that shines every day.

Since the sun is almost always bright in New Mexico, why are there dips that go down to 0 W/m^2 on the Y-axis? When do these dips occur? The dips to 0 W/m^2 represent night-time (check the hours that this occurs). There is no sunlight at night, so the pyranometer reads 0 W/m^2.

Why do the humps vary in size, shape, etc..? The sunlight reaching the earth varies in intensity due to factors like time of day (affecting the angle that the sunlight strikes the panels), cloud cover, air pollution, time of year, etc..

Looking at the strip chart, can you tell which day had the most intense sunlight? It is the day that the graph reaches the highest point relative to the Y-axis. This highest point is called the maximum. It represents the maximum value of the Y variable (in this case, sunlight intensity).

What time of day was the most intense sunlight? The most intense sunlight was usually close to 12 noon. This is when the sun is most directly facing the PV panels.

Is that surprising? No, the sunlight usually feels the most intense around noontime.

How intense was the sunlight? From the chart, take the reading. It might be anywhere from 1000 W/m^2 to 1250 W/m$^{2.}$.

What causes the dips to 0 W/m^2 on the chart? When there is no sunlight, the graph goes to 0 W/m^2. This is what happens at night, when there is no sunlight. These 0 values represent the minimum value of the Y variable (in this case, sunlight intensity).

Why does it happen so frequently? The earth rotates every day, so there is time every day when we are not facing the sun and we have no direct sunlight shining on us. We experience day and night every 24 hours.

On most days, the irradiance graph will have a nice smooth, curved “*bell-shape*” to it. *Do you see any sudden dips in your daily **bell curves**?*

What do you think causes the sudden dips in the bell curves? Changes in the weather, like clouds moving in and shadowing the PV system. Snow falling on the PV system could also make the curve dip. Someone covering part of the PV system could also cause the curve to dip. Some dips will be more extreme, depending on what has caused it (gradual weather change vs. big, dark cloud suddenly blocking the sun).

ZOOM IN ON THE STRIP CHART SO YOU ARE ONLY LOOKING AT 2 DAYS WORTH OF DATA.

By looking at a smaller time frame (2 days instead of 7 days), we can obtain more detailed information from the strip chart.

Can you tell what time the sun came up on the first day? Can you tell what time the sun set? Answers will vary depending on your chart.

Which day had the most intense sunlight? Answers will vary depending on your chart and recent weather.

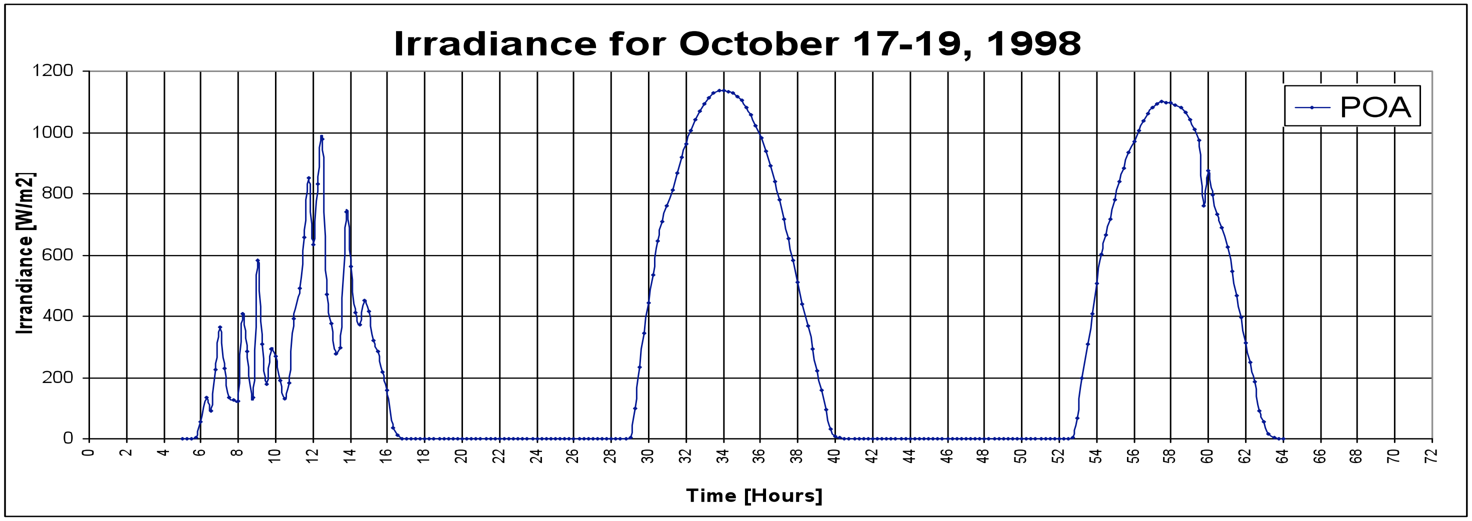
For each day, for how many hours was the sunlight intensity over 500 W/m^2 ? Answers will vary depending on your chart.

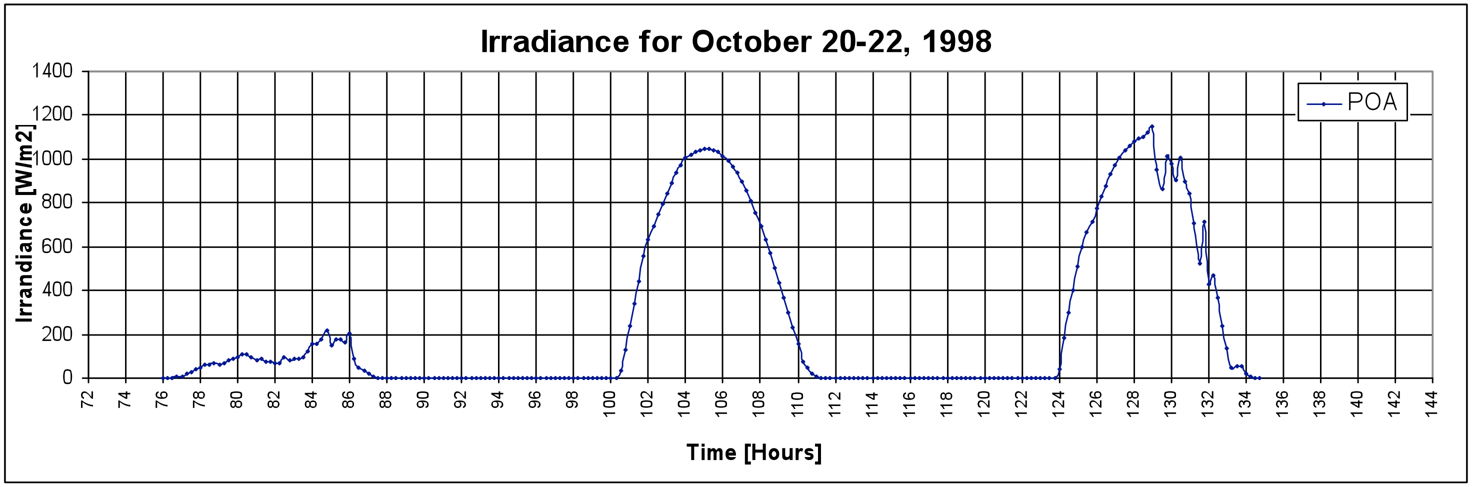
For each day, for how many hours was the sunlight intensity over 1000 W/m^2 ? Over 1200 W/m^2? Answers will vary depending on your chart.

Student Activities for Grades 6-8th

Tabulating Data to be Presented in Another Format – Irradiance Strip Chart

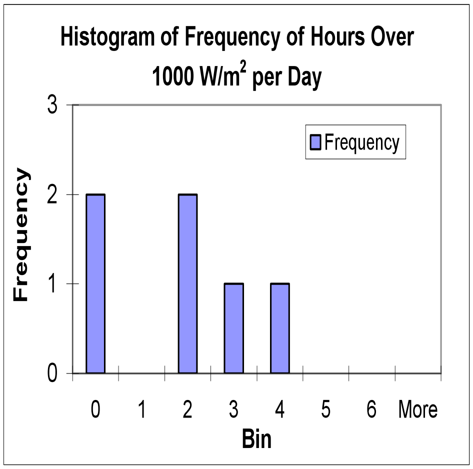
Have students make a chart through observation over time from the strip chart that will show how many hours per day the sunlight intensity was greater than 1000 W/m^2 (any other arbitrary value can be used as well) over a six day period. The graphs below represent an approximation of what the strip chart may look like.





This data can then be put into bins for constructing a histogram showing how many hours of the day the sunlight intensity exceeded a certain amount. In this case, the criteria being evaluated was how many hours per day did the sunlight intensity exceed 1000 W/m^2.

Bin [Hours per day over 1000 W/m2]	*Frequency [Days with x hours over 1000 W/m2]*
0	2
1	0
2	2
3	1
4	1
5	0
6	0
More	0



Analyzing the histogram made from the strip chart, we see that during a 6-day period there were 2 days that had 2$^+$ hours with sunlight intensity over 1000 W/m^2. Likewise, there was 1 day that had 3$^+$ hours with sunlight intensity over 1000 W/m^2. Similarly, there was 1 day with 4$^+$ hours with sunlight intensity over 1000 W/m^2 and 2 days with 0$^+$ hours with sunlight intensity over 1000 W/m^2. (Note: there may not be ***exactly*** 2 hours with the sunlight over 1000 W/m^2, so **2$^+$** is used to indicate it is **more than 2 hours**, **but still less than 3 hours**.)

Overall, these numbers of hours during the week with such high sunlight intensity translate into this school site being a good site to make and use solar electric energy with photovoltaics! Of course, you may find that your school is even a better site after you have done some data analysis!

Learning How to Read and Use the Irradiance Strip Chart

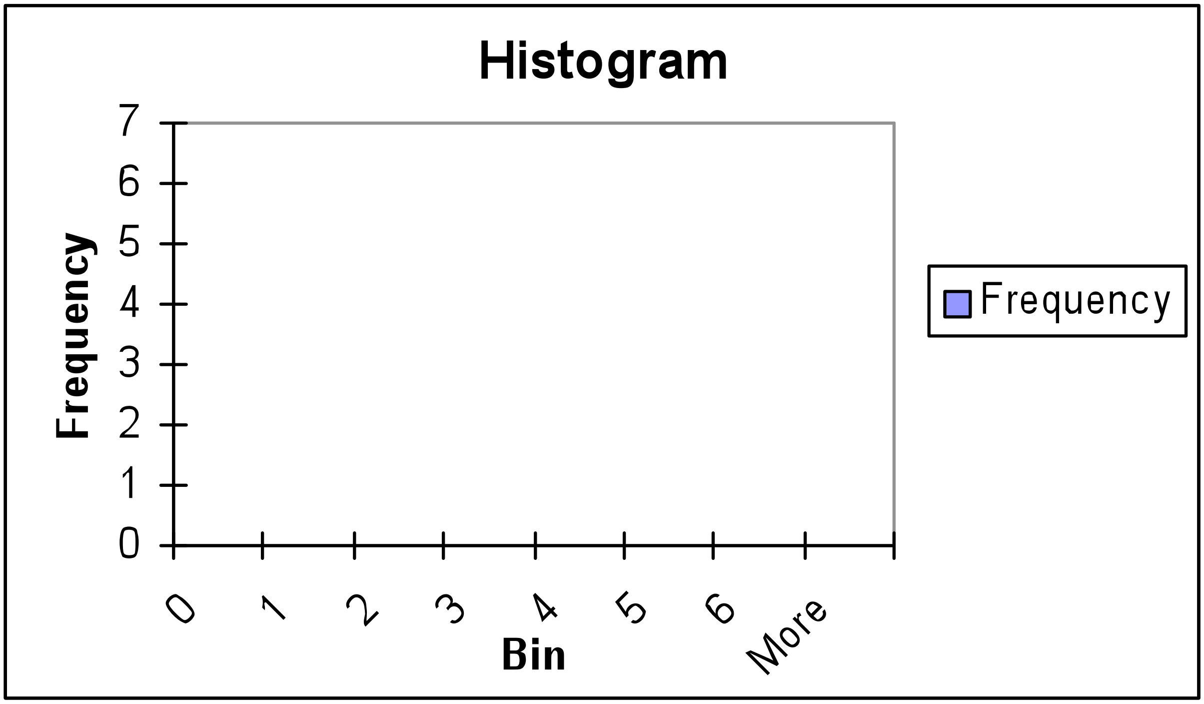
Student Worksheets

Directions:

Record the number of hours that the sunlight intensity is greater than 1000 W/m^2 during each of the 7 days that are displayed on the strip chart. Note that in a climate where the pyranometer rarely goes over 1000 W/m^2, a lower threshold of 900 W/m^2 or 800 W/m^2 could be used.

Day	Number of Hours over 1000 W/m^2
1	
2	
3	
4	
5	
6	
7	

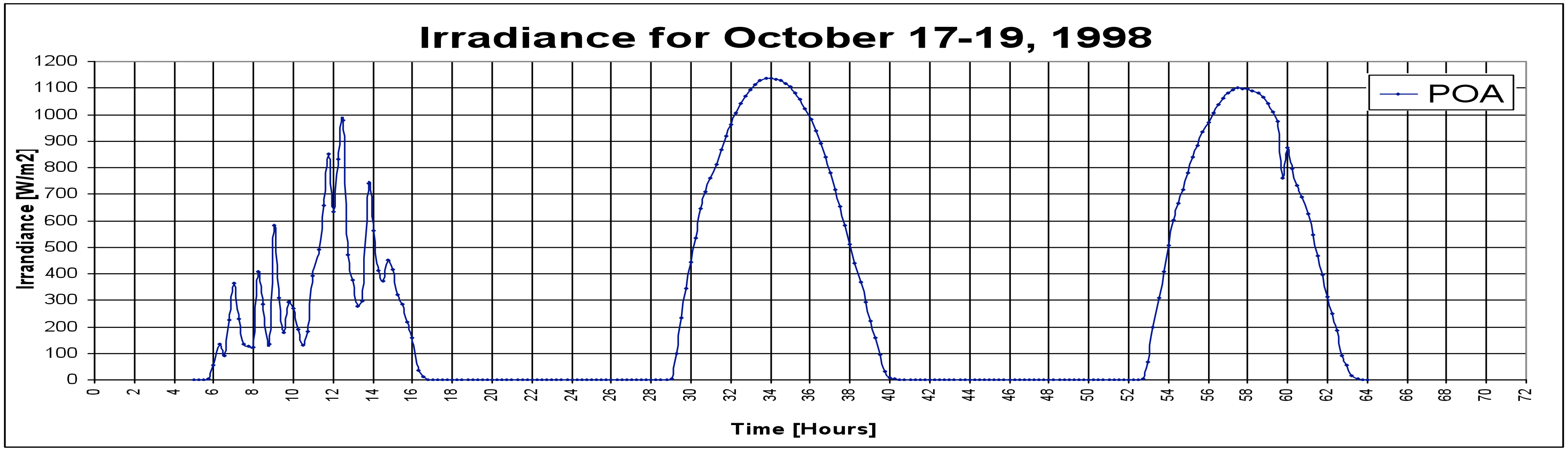
With the help of your teacher, you will now use this data to construct a histogram.



Averaging Data for Comparison

Students can find the average irradiance during the daylight period for every day of a week, then compare which day had the highest average vs. highest peak. It is best to do this for ONLY THE DAYLIGHT HOURS as the average will lose a lot of meaning if including the nighttime hours (the same quantity of Watts/m^2 will be divided by 24 hours instead of 8-16).

1. Have students do a “visual estimate” for each hour-long period during the day for an entire week. Have students begin counting in the next whole hour AFTER the sun rises and stopping in the whole hour BEFORE the sun sets. They will have 8 – 16 hourly estimates (depending on the season and length of day) for each day (roughly 8 during the winter and about 16 during the summer).
2. Students find the average sunlight intensity for each day by totaling all of the hourly estimates and dividing by the number of hours of daylight they have.
3. Compare the daily averages of each day.
4. Compare the daily averages to the days that have the highest peak.



Doing a visual estimate from this graph, estimating from hour 6 to 7, it appears that the Irradiance averages 190 Watts/m2 (Note: your visual estimate in this region may vary markedly due to the erratic nature of the sunlight on this particular day. *Why do you think the sunlight intensity is so erratic?* It is likely due to clouds passing overhead, but that is merely a guess without more information.)

Hour	Estimated Irradiance	Hour	Estimated Irradiance	**Hour**	Estimated Irradiance	**Hour**	Estimated Irradiance		Total Hours of Sunlight	**Average Irradiance**
6-7	190	9-10	320	12-13	700	15-16	260		11	**332.7**
7-8	230	10-11	210	13-14	480	16-17	50		Sum of Est. Irrad.	
8-9	250	11-12	500	14-15	470				3660	

Doing the same kind of estimation on the next day is easier.

Hour	Estimated Irradiance	Hour	Estimated Irradiance	**Hour**	Estimated Irradiance	**Hour**	Estimated Irradiance		Total Hours of Sunlight	**Average Irradiance**
29-30	210	32-33	1020	35-36	1050	38-39	380		11	**731.8**
30-31	590	33-34	1110	36-37	900	39-40	120		Sum of Est. Irrad.	
31-32	850	34-35	1120	37-38	700				8050	

There is quite a bit of variation between these two days. *Which one do you think is the more “typical day” for this time of year?*

Comparing Seasonal Values of Sunlight Intensity

Have students keep track of the data for particular days during the year – like the Equinox (fall [September 22] and spring [March 20]) and the Solstice (winter [December 21]and summer [June 21]). Compare the maximum irradiance (sun intensity) values for each of the days. *What do you notice? Why does it occur? [There may not be a "right" answer here – it will depend on your local weather conditions on those days - irradiance could appear highest on a cold winter day with fresh fallen snow in front of the PV array reflecting additional light onto the array and, as PV cells lose efficiency (hot summer day) when they overheat, they tend to perform better on cold, clear days].*

Compare the number of hours for each day when sunlight intensity is over 1000 W/m^2. *What do you notice? Why does it occur?*

Have students keep track of a week around the Equinox and Solstices (3 days before and 3 days after) so that a better data set will be accumulated (i.e., in case it is stormy on the Winter Solstice). Have students calculate the average maximum irradiance (sun intensity) for all 7 days for summer, fall, winter, and spring and compare the maximum irradiance (sun intensity) on these days. *Again ask, what do you notice? Why do you think it occurs?*

Have students calculate the length of day (hours and minutes) and length of night (hours and minutes) from the information on the strip chart. Compare time of day for sunrise and sunset on these days. *What do you notice? Why does it occur? (This may require students doing a library or Internet search on Equinox and Solstice, what they are, when they occur, why they occur, etc..)*

Again, using the daily averages calculated from the week-long data around these four days in summer, fall, winter, and spring, have students calculate the average length of day (hours and minutes) and length of night (hours and minutes) during these periods and compare. *How do the average lengths of day compare in fall and spring? How does the length of day in summer compare to length of day in winter?*

Using Strip Chart Data to Create Your Own Graph

This activity can be done either with (a) the teacher calling out data points he/she reads off of the strip chart or (b) the teacher could have written data points down previously and simply provides students with tabulated data to use to create a graph. When first introduced, it may be helpful if the students have a blank sample graph to use to fill in data with axes and scales in place. Over time, provide students with less pre-formatted information on the graph so they decide how best to construct it to represent the data.
Assuming (a), teacher (or student) reads data points out loud from the strip chart. Teacher calls out time interval being represented (i.e., every 15 minutes) and the irradiance recorded on the strip chart. Students use the values read aloud to create their own graph. Ultimately, the student-created graphs should look very much like the strip chart graphs for the same time interval.

Using Strip Chart Data to Help Understand the Effect of Scale

Have students make two graphs side-by-side on a piece of graph paper. On one, have the Y-axis scale go from 0-1500 Watts/m^2 with increments of 100 Watts/m^2 – call it Graph A. Have the 2nd graph Y-axis scale go from 0-15,000 Watts/m^2 with increments of 1000 Watts/m^2 – call it Graph B.

Have students graph the same irradiance data on the two graphs and then compare.

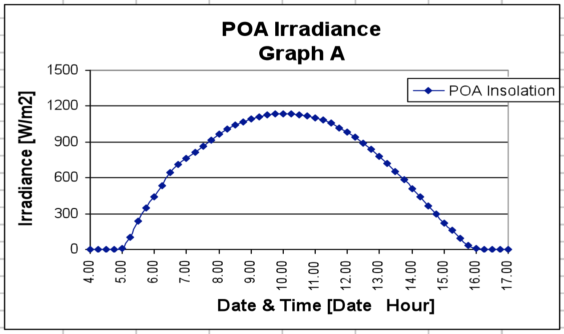
See samples on next page to see effect of scale on graph.

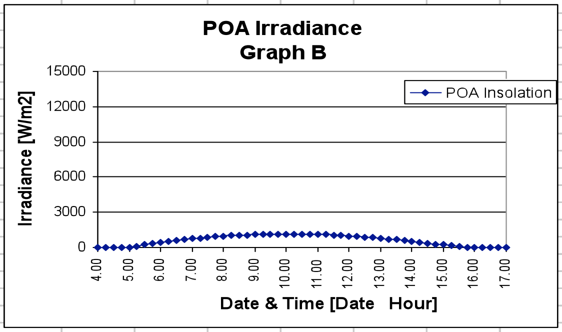
On Graph B, does the daily fluctuations in irradiance seem big or important? No, even the highest value is very low on the graph and it might lead one to think that all the values are low, there is not much of a variation from the maximum to minimum irradiance values, it is difficult to pinpoint exactly what the maximum value is for a particular day, or if there was a slight dip due to clouds passing by.

On Graph A, does the daily fluctuations in irradiance seem big or important? Yes, the daily fluctuations go from the bottom to near the top of the scale, changes are easy to see, maximum points are easy to pinpoint, etc..

Newton Middle School Data

Date & Time	Time	POA Insolation
[Date Time]	[Hour] (in decimal form)	[W/m2]
10/18/98 4:00	4.00	0
10/18/98 4:15	4.25	0
10/18/98 4:30	4.50	0
10/18/98 4:45	4.75	0
10/18/98 5:00	5.00	5
10/18/98 5:15	5.25	98
10/18/98 5:30	5.50	234
10/18/98 5:45	5.75	345
10/18/98 6:00	6.00	445
10/18/98 6:15	6.25	537
10/18/98 6:30	6.50	645
10/18/98 6:45	6.75	710
10/18/98 7:00	7.00	759
10/18/98 7:15	7.25	811
10/18/98 7:30	7.50	866
10/18/98 7:45	7.75	918
10/18/98 8:00	8.00	964
10/18/98 8:15	8.25	1006
10/18/98 8:30	8.50	1041
10/18/98 8:45	8.75	1071
10/18/98 9:00	9.00	1094
10/18/98 9:15	9.25	1113
10/18/98 9:30	9.50	1127
10/18/98 9:45	9.75	1136
10/18/98 10:00	10.00	1136
10/18/98 10:15	10.25	1133
10/18/98 10:30	10.50	1128
10/18/98 10:45	10.75	1118
10/18/98 11:00	11.00	1105
10/18/98 11:15	11.25	1082
10/18/98 11:30	11.50	1056
10/18/98 11:45	11.75	1021
10/18/98 12:00	12.00	982
10/18/98 12:15	12.25	940
10/18/98 12:30	12.50	891
10/18/98 12:45	12.75	839
10/18/98 13:00	13.00	779
10/18/98 13:15	13.25	717
10/18/98 13:30	13.50	653
10/18/98 13:45	13.75	584
10/18/98 14:00	14.00	513
10/18/98 14:15	14.25	440
10/18/98 14:30	14.50	367
10/18/98 14:45	14.75	294
10/18/98 15:00	15.00	224
10/18/98 15:15	15.25	158
10/18/98 15:30	15.50	94
10/18/98 15:45	15.75	33
10/18/98 16:00	16.00	9
10/18/98 16:15	16.25	2
10/18/98 16:30	16.50	0
10/18/98 16:45	16.75	0
10/18/98 17:00	17.00	0





Comparing Strip Chart Data to the Archived Data

You will need to ZOOM IN to a particular day (let's say 2 days ago) on the "Irradiance" strip chart. Do it so that only the 24 hours of that day are showing and no other days are showing. If possible, use the PRINT SCREEN command to get a printed version of the one day that you have zoomed in to. Copy that sheet for later distribution to the class.

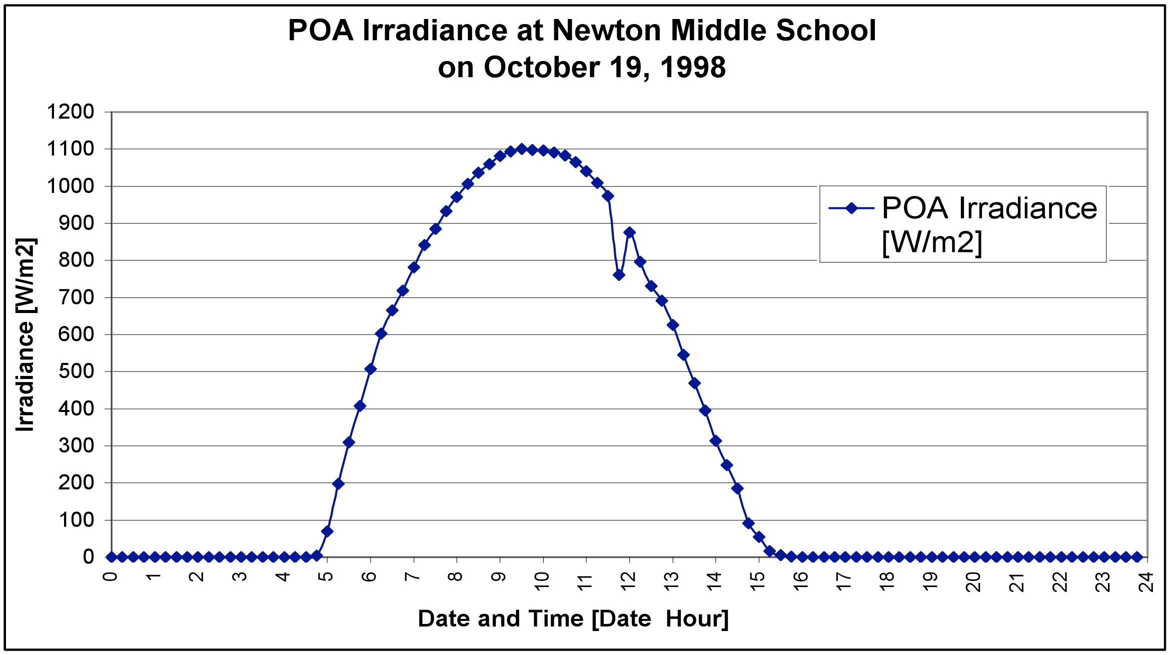
From the archived data in the "Altair Energy folder" on your computer, copy the Irradiance and Time data for a convenient day to compare to the strip chart data. Use the same day that you have just PRINTED from the strip chart.

Give the students the raw data for a particular day (same day as above). [Note: depending on your students' ability to sort and filter raw data, you may want to only select 2 columns of data to give you students – the "Date Time" column and the "POA Irradiance" column. You may find that including all of the other data from the file will make this assignment too confusing or overwhelming for your students.

Have your students make a graph with the following features:

- X-axis scaled to 24 hours with intervals of 1 hour
- Y-axis scaled to 1500 Watts/meter^2 with intervals of 100 Watts/meter^2
- Graph the **Irradiance** data from the archived data that you have given them

After the students have completed the graph, pass out the strip chart graph to compare to their own.



Using Archived Data

The same kinds of activities can be done from the archived data and it may help make some interesting seasonal comparisons to do this (that you cannot do easily from the strip chart). Have students graph the data for particular days during the year – the Equinox (fall [September 22] and spring [March 20]) and the Solstice (winter [December 21]and summer [June 21]). Have students compare the maximum irradiance (sun intensity) values or the average daily values for each of the days.

The table of the next page shows how to calculate the hourly averages of sunlight intensity in the column on the right. Since the data are recorded every 15 minutes (or ¼ of an hour, 0.25 of an hour as a decimal), to find the average hourly irradiance, one should add together the 4 measurements for a particular hour (use 5; 5.25; 5.50; and 5.75 as an example). Adding the irradiance corresponding to those hours, one finds that: 4.8 + 97.8 + 233.8 + 345.4 = 681.8. Then divide by 4 to find the hourly average irradiance to be 170.5 W/m^2.

At the bottom of the next page, the daily average of sunlight intensity is calculated. This value can be compared to the estimated hourly averages and daily averages students calculated directly from the strip chart. This may help students understand how error can be introduced through simple estimation. (Estimation is not always easy).

Sample Data to Calculate Hourly Averages for Irradiance

Time [Date / Time]	Irradiance on PV array [Watts/m^2]	Hourly average [Watts/m^2]	
10/18/98 4:00	0		
10/18/98 4:15	0		
10/18/98 4:30	0		
10/18/98 4:45	0.4		
10/18/98 5:00	4.8	170.5	= (4.8+97.9+233.8+345.4) / 4
10/18/98 5:15	97.9		
10/18/98 5:30	233.8		
10/18/98 5:45	345.4		
10/18/98 6:00	444.8	584.1	= (444.8+536.6+644.8+710) / 4
10/18/98 6:15	536.6		
10/18/98 6:30	644.8		
10/18/98 6:45	710		
10/18/98 7:00	759	838.5	
10/18/98 7:15	811		
10/18/98 7:30	866		
10/18/98 7:45	918		
10/18/98 8:00	964	1020.5	
10/18/98 8:15	1006		
10/18/98 8:30	1041		
10/18/98 8:45	1071		
10/18/98 9:00	1094	1117.5	
10/18/98 9:15	1113		
10/18/98 9:30	1127		
10/18/98 9:45	1136		
10/18/98 10:00	1136	1128.8	
10/18/98 10:15	1133		
10/18/98 10:30	1128		
10/18/98 10:45	1118		
10/18/98 11:00	1105	1066.0	
10/18/98 11:15	1082		
10/18/98 11:30	1056		
10/18/98 11:45	1021		
10/18/98 12:00	982	913.0	
10/18/98 12:15	940		
10/18/98 12:30	891		
10/18/98 12:45	839		
10/18/98 13:00	779	683.2	
10/18/98 13:15	717		
10/18/98 13:30	652.7		
10/18/98 13:45	584		
10/18/98 14:00	512.5	403.3	
10/18/98 14:15	440		
10/18/98 14:30	366.7		
10/18/98 14:45	293.9		
10/18/98 15:00	223.6	127.3	
10/18/98 15:15	158.2		
10/18/98 15:30	93.9		
10/18/98 15:45	33.4		
10/18/98 16:00	8.9		
10/18/98 16:15	2.3		
10/18/98 16:30	0		
10/18/98 16:45	0		
10/18/98 17:00	0		

Total of Hourly Averages =	**8052.5**	[Watthours/m^2]
Hourly Averages Used =	**11**	[hours]
Hourly Average for Daylight Hours (8052.5 / 11) =	**732.0**	[Watts/m^2]

Learning How to Read and Use the Strip Chart – AC Power

Grade Level - Subject

6-12th Grade – Math, Science, and Technology Education (see specific activities for appropriateness for 6-8th or 9-12th grade).

Overview

In this lesson students will explore and learn:

- how to read and interpret the strip chart feature of the software that interacts with the rooftop photovoltaic (PV) system and displays the AC power produced from sunlight
- how to re-group the data to highlight different kinds of information
- how to compare data for correlation

Purpose

The purpose of this lesson is to introduce students to the concept of obtaining useful information from a graphical representation of data. Students will extract a variety of data from the real-time strip chart and categorize it into useful forms. Students will also compare archived data for a specific time period to the graphical representation of the data in the strip chart to verify the accuracy of the strip chart and its sensors.
Do note that most of the activities used in the previous section on Irradiance can be used for AC Power with very slight modifications.

Learning Objectives

After completing this lesson, students will be able to:

- Identify maximum and minimum data points and supply plausible reasons for this behavior.
- Identify trends and disturbances to trends and supply plausible reasons for this behavior.
- Understand how the scale of a graph or chart can influence interpretation of that data.
- Realize that a set of data can have more than one explanation
- Realize that measurement is not precise. Measurement can be a source of error.
- Understand the concept of correlation.

Vocabulary

maximum
y-interceptquantitative data
time scale
source of error
minimum
x-intercept
error
AC power
trend
qualitative data
correlation
photovoltaic system

Resources & Materials

rooftop pv system
archived data
graph paper
pencils/markers
real-time computer monitor output
handouts on PV system, strip charts, archived data
rulers
calculators

Preparatory Activities & Prerequisite Knowledge

Students should already know or be familiar with the following:

independent variable (x)
dependent variable (y)
how to read a graph (x and y axes)
how to plot/construct a graph (x and y axes)

Before the first day of this lesson, students should have some familiarity with photovoltaic modules and systems, how they work, and why we use them. They should also have completed the unit on Appliance Power and Energy so they will be able to attach meaning to the AC electrical power output of the PV system.

watts
direct current (DC)
power
alternating current (AC)

Discussion and Analysis of AC Power Strip Chart

Teacher leads students through introduction and discussion of data collection devices and strip chart information.

Introduction

Provide background information on (review from Power and Energy Unit lessons):

- DC Power
- AC Power

The PV system on your roof produces **DC (Direct Current)** electric power. However, most, if not all, of the electrical devices in your school building require **AC (Alternating Current)** electric power. A device, called an **inverter**, is able to **take DC electricity and convert it into AC electricity with reasonably high efficiencies (90-96%).** Just 10-20 years ago, inverters operated at much lower efficiencies, in the range of 50-65%, and they would reduce the amount of AC electricity produced by a significant amount. Recent technological advances with inverters have really helped the PV industry as much more of the DC electricity generated by a PV system can be used as AC electricity.

DC electricity is what is produced by car batteries, radio/CD batteries, wristwatch batteries, etc.. It takes a **generator** to produce **AC electricity**. Our power plants that supply electricity to homes and businesses produce AC electricity. Generators produce AC electricity.

Teacher-led Questions, Answers, and Discussion

Turn on the classroom computer and bring up the real-time strip chart for the rooftop PV system. Have students examine the charts and discuss what the graph is showing/telling them.

Use the following questions to spark a discussion of the strip charts and the information they provide.
Look at the **"AC Power" strip chart.**

What is AC Power? AC Power is Alternating Current electricity – it is the type of electricity we use in our household appliances.

What units are used to measure AC Power? AC Power is measured in terms of **kilowatts**.

On the Y-axis, what is the scale used to measure AC Power? The scale goes from 0 kW to 2.5 kW.

On the X-axis, what is the variable being used? What units are being used? Time is being measured in units of hours.

Looking at the strip chart as it first comes on the screen, how many hours or days does it *represent?* It represents 168 hours or 7 full days (7 days x 24 hours/day = 168 hours).

What do you notice during those seven days? Are there any patterns? There appears to be seven "humps" across the screen. They seem to coincide with 7 days as there is roughly 1 hump per day.

There seems to be time during the day when the system is making lots of AC Power and times during the night when it is not making any – when the graph reads 0 kW. *Can you think of reasons why this might be true?* The PV system makes power or electricity (DC which is converted to AC by the inverter) by converting sunlight to electricity so there must be sunlight for the system to work and there is no sunlight at night.

Looking at a particular day, what time of day was the system making the most AC power? The most intense sunlight is usually around 12 noon, so the most AC power being made will usually be around 12 noon as well.

If there is no sunlight shining on the PV system, can it make electricity? No, the PV system needs sunlight to make electricity (or a lot of another kind of light – but it will take a lot of power to make light intense enough for the PV system to make electricity).

On most days, the AC power graph will have a nice smooth, curved "*bell-shape*" to it. *Do you see any sudden dips in your daily **bell curves**?*

What do you think causes the sudden dips in the bell curves? Changes in the weather, like clouds moving in and shadowing the PV system. Snow falling on the PV system could also make the curve dip. Someone covering part of the PV system could also cause the curve to dip. Some dips will be more extreme, depending on what has caused it (gradual weather change vs. big, dark cloud suddenly blocking the sun).

ZOOM IN ON THE STRIP CHART SO YOU ARE ONLY LOOKING AT 2 DAYS WORTH OF DATA.

By looking at a smaller time frame (1 or 2 days instead of 7 days), we can obtain more detailed information from the strip chart.

Can you tell what time the PV system started making electricity on the first day? Can you tell what time the PV system stopped making electricity? Answers will vary depending on your chart.

Do you notice anything about when the PV system is making electricity and what the Irradiance strip chart is doing at the same time? When the sunlight is most intense, the PV system is making the most electricity. When there is no sunlight, the PV system is not making any electricity. And, in between these extremes they appear to follow each other's behavior similarly (i.e., both rising or falling at the same time).

Which day had the most electricity produced at one time? Answers will vary depending on your chart and recent weather.

For each day, for how many hours was the AC power produced over 2 kW? Answers will vary depending on your chart.

Comparing Irradiance to AC Power

Usually, the AC Power will follow the Irradiance in terms of being a high value, a low value, or zero. *Can you think of some instances when this might not be true?* If there has been a snowstorm at night and the next day it is bright and sunny. The PV array and the pyranometer may be covered in snow and though the sunlight may be striking the snow on the array and pyranometer, it may not actually be striking the PV array or the pyranometer. As the snow melts, it may melt (or get blown off by the wind) **first from the pyranometer**, but not the PV array. With no snow left of it, the pyranometer (measuring sunlight intensity for Irradiance) may indicate that the sunlight is very intense (and it may be), but if most of the PV panels are covered in snow, they will not be able to produce much or any electricity. You may see the Irradiance graph being very high while the AC Power graph is very low. Gradually, as the snow melts during the day, the two graphs will return to their usual patterns of looking quite similar.

On a particular day, at what time does the sun start striking the PV system? What time does the PV system start producing AC Power? **Answer will vary depending on your strip chart data.**

What time does the sunlight intensity reach its maximum? What time does the AC Power produced reach its maximum? Answer will vary depending on your strip chart data.

Tabulating Data to be Presented in Another Format – AC Power Strip Chart

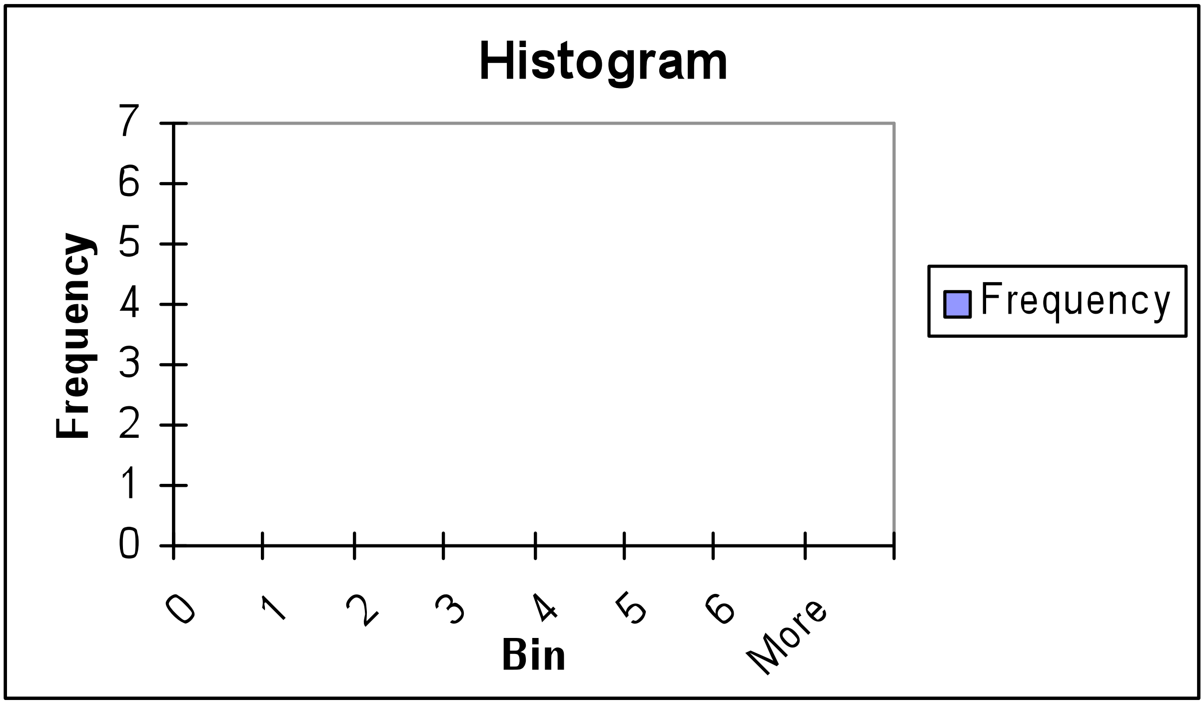
Student Activities for Grades 6-8th

Have students make a chart through observation over time from the strip chart that will show how many hours per day the sunlight intensity was greater than 1.8 kW (any other arbitrary value can be used as well) over a seven day period. This data can then be put into bins for constructing a histogram showing how many hours of the day the AC Power exceeded a certain amount.

See previous section with **“Tabulating Data to be Presented in Another Format”** for Irradiance for method and details of creating a histogram from the strip chart.

Day	Number of Hours over 1.8 kiloWatts
1	
2	
3	
4	
5	
6	
7	

With the help of your teacher, you will now use this data to construct a histogram.



Averaging Data for Comparison

Students can find the average AC Power during the daylight period for every day of a week, then compare which day had the highest average vs. highest peak. It is best to do this for ONLY THE DAYLIGHT HOURS as the average will lose a lot of meaning if including the nighttime hours (the same quantity of kilowatts will be divided by 24 hours instead of 8-16).

1. Have students do a "visual estimate" for each hour-long period during the day for an entire week Have students begin counting in the next whole hour AFTER the sun rises and stopping in the whole hour BEFORE the sun sets. They will have 8 – 16 hourly estimates (depending on the season and length of day) for each day (roughly 8 during the winter and about 16 during the summer).
2. Students find the average AC Power for each day by totaling all of the hourly estimates and dividing by the number of hours of daylight they have.
3. Compare the daily averages of each day.
4. Compare the daily averages to the days that have the highest peak.

See previous section with **"Averaging Data for Comparison"** for Irradiance for method and details of creating a histogram from the strip chart.

Comparison of Two Sets of Data Using the Strip Chart

Have students compare the strip charts for Irradiance to AC Power over a range of days. *What do you notice about when Irradiance peak vs. when AC Power peaks?* They both tend to peak at the same time. *Why?* When the sunlight is most intense, the PV panels will be able to make the most electricity (except in very hot conditions).

What do you notice about when the sunlight is steadily increasing in intensity over the course of a few hours (often happen between 9 and 12 a.m.) compared to AC Power during the same time? Most of the time, if sunlight intensity is increasing, AC Power will be increasing as well. *How about when Irradiance is decreasing (after noon-time), what is happening to AC Power? Why?*

On a day when the Irradiance is very erratic, how is the AC Power affected? Why? To make electricity effectively, the PV panels need consistent sunlight. If the sunlight is intermittent, so will the AC Power produced.

Comparing Seasonal Values of AC Power Produced

Have students keep track of the data for particular days during the year – like the Equinox (fall [September 22] and spring [March 20]) and the Solstice (winter [December 21]and summer [June 21]). Compare the maximum AC Power values for each of the days. *What do you notice? Why does it occur? [There may not be a "right" answer here – it will depend on your local weather conditions on those days - AC Power could appear highest on a cold winter day with fresh fallen snow in front of the PV array reflecting additional light onto the array and, as PV cells lose efficiency when they overheat (hot summer day), they tend to perform better on cold, clear days].*

Compare the number of hours for each day when AC Power is over 1.8 kW. *What do you notice? Why does it occur?*

Have students keep track of a week around the Equinox and Solstices (3 days before and 3 days after) so that a better data set will be accumulated (i.e., in case it is stormy on the Winter Solstice). Have students calculate the average maximum AC Power for all 7 days for summer, fall, winter, and spring and compare the maximum AC Power on these days. *Again ask, what do you notice? Why do you think it occurs?*

Using AC Power Strip Chart Data to Create Your Own Graph

This activity can be done either with (a) the teacher calling out data points he/she reads off of the strip chart or (b) the teacher could have written data points down previously and simply provides students with tabulated data to use to create a graph. When first introduced, it may be helpful if the students have a blank sample graph to use to fill in data with axes and scales in place. Over time, provide students with less pre-formatted information on the graph so they decide how best to construct it to represent the data.

Assuming (a), teacher (or student) reads data points out loud from the strip chart. Teacher calls out time interval being represented (i.e., every 15 minutes) and the AC Power recorded on the strip chart. Students use the values read aloud to create their own graph. Ultimately, the student-created graphs should look very much like the strip chart graphs for the same time interval.

Using Strip Chart Data to Help Understand the Effect of Scale

Have students make two graphs side-by-side on a piece of graph paper. On one, have the Y-axis scale go from 2.5 kiloWatts with increments of 0.1 kiloWatts – call it Graph A. Have the 2nd graph Y-axis scale go from 25 kiloWatts with increments of 1 kiloWatt – call it Graph B.

Have students graph the same AC Power data on the two graphs and then compare.

See previous section with **"Using Strip Chart Data to Help Understand the Effect of Scale"** for Irradiance for method and details of creating Graphs A and B to illustrate how scale affects impressions of what a particular graph may be indicating.

Comparing Strip Chart Data to the Archived Data

You will need to ZOOM IN to a particular day (let's say 2 days ago) on the "AC Power" strip chart. Do it so that only the 24 hours of that day are showing and no other days are showing. If possible, use the PRINT SCREEN command to get a printed version of the one day that you have zoomed in to. Copy that sheet for later distribution to the class.

From the archived data in the "Altair Energy folder" on your computer, copy the AC Power and Time data for a convenient day to compare to the strip chart data. Use the same day that you have just PRINTED from the strip chart.

Give the students the raw data for a particular day (same day as above). [Note: depending on your students ability to sort ad filter raw data, you may want to only select 2 columns of data to give you students – the "Date Time" column and the "AC Power" column. You may find that including all of the other data from the file will make this assignment too confusing or overwhelming for your students.

Have you students make a graph with the following features:

- X-axis scaled to 24 hours with intervals of 1 hour
- Y-axis scaled to 2.5 kiloWatts with intervals of 0.1 kiloWatts or 2500 Watts with intervals of 100 Watts
- Graph the **AC Power** data from the archived data that you have given them

After the students have completed the graph, pass out the strip chart graph to compare to their own.

See previous section with **"Comparing Strip Chart Data to the Archived Data"** for Irradiance for example of creating a graph from archived data.

Calculating efficiency using your schools PV system

The PV system on your school has a pyranometer attached to it. It gives us readings of the sunlight intensity or irradiance. We can see these readings on both the strip chart and in the archived data. We can calculate the efficiency of the entire PV array using the method above.

First calculate the area of the entire array. For sake of having a number, let's say that your students calculate the area to be 30.2 m^2. Pick a certain time of day and read the AC Power output from the strip chart. Let's say it is 2350 Watts. At the exact same time on the strip chart, find the corresponding solar input. Let's say that value is 980 Watt/m^2. Then plug these values into the Efficiency Equation.

Efficiency of PV Array = (Watts Output ÷ Area of Array) ÷ (Watts Input ÷ Unit area)

Efficiency of PV Array = (2350 Watts Output ÷ 30.2 m^2) ÷ (980 Watts ÷ m^2)

Efficiency of PV Array ≈ 0.079 ≈ 7.9%

Standards addressed in these lessons (PV Unit – Strip Chart – Irradiance and AC Power)

Math Curriculum Standard (from *National Council for Teachers of Mathematics*):

ALGEBRA

- Understand patterns – represent, analyze, and generalize a variety of pattern with tables, graphs, words, and, when possible, symbolic rules.
- Use mathematical models to model and solve contextualized problems using various representations, such as graphs, table, and equations.

DATA ANALYSIS AND PROBABILITY STANDARD

- Formulate questions, design studies, and collect data about a characteristic shared by two populations or different characteristics within one population
- Use observations about differences between two or more samples to make conjectures about the populations from which the samples were taken

Science Curriculum Standard (from *National Academy of Science and National Research Council*):

TRANSFER OF ENERGY

- Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.
- Electrical circuits provide a means of transferring electrical energy when heat, light, sound, and chemical changes are produced.

EARTH IN THE SOLAR SYSTEM

- The sun is the major source of energy for phenomena on the earth's surface, such as growth of plants, winds, ocean currents, and the water cycle. Seasons result from variations in the amount of the sun's energy hitting the surface, due to the tilt of the earth's rotation on its axis and the length of the day.

Technology Curriculum Standard (from *International Society for Technology in Education*):

TECHNOLOGY PRODUCTIVITY TOOLS

- Students use technology tools to enhance learning, increase productivity, and promote creativity.

TECHNOLOGY RESEARCH TOOLS

- Students use technology to locate, evaluate, and collect information from a variety of sources.
- Students use technology tools to process data and report results.

DATA ANALYSIS AND PROBABILITY STANDARD

- Formulate questions, design studies, and collect data about a characteristic shared by two populations or different characteristics within one population

Supplies and Materials Ordering Information

Cost Sheet
Supplies for PV Workshop

Supplies	**Item #**	**Price**	**Supplier**
Digital Multimeter 9V 10 amps	25-000	12.95	Real Goods
Digital Multimeter	990087	$19.95	Kelvin
Digital Multimeter	990123	$39.95	Kelvin
Genecon Generator	P6-2631	$44.00	Arbor Scientific
Solar Cell (1000 mA, 2V DC)	260099	$3.85	Kelvin
Solar Cell (100 mA, 3V DC)	220103	$14.95	Kelvin
Solar Cell (3-6-9 Volt)	280202	$22.00	Kelvin
Solar Mini Panel (200 mA, 1V DC)	W56870	$4.95	Pitsco
K'NEX Solar Set	280486	$52.95	Kelvin
AC Watts Up Meter	P6-8000	$100.00	Arbor Scientific
Motor - 1.5 - 7V DC	850646	$0.59	Kelvin (minimum order of 10)
Solar Racer Kit	841236	$8.45	Kelvin
Solar Car Kit	JSS-Kit	$29.95	Solar World
Photon Solar Racer	Photon	$24.95	Solar World
Solar Meters	Hand-held	$124.50	SolAqua
75dB Piezo Electric Buzzer	Cat. # 273-054	$2.79	Radio Shack
Solar Module (4 1/4" x 1 3/4")	PSR	$15.95	Solar World
Windshield Washer Pump		$12.99	Autozone

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280 Adams Blvd.
Farmingdale, NY 11735
1-800-535-8469
www.kelvin.com

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Pittsburg, KS 66762
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El Paso, Texas 79914-4976
(915)726-2893; 1-877-483-2980
http://www.solaqua.com/daysolmet.html

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www.arborsci.com

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800-762-7325
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