

Measuring Electricity

Electricity makes our lives easier, but it can seem like a mysterious force. Measuring electricity is confusing because we cannot see it. We are familiar with terms such as watt, volt, and amp, but we do not have a clear understanding of these terms. We buy a 60-watt light bulb, a tool that requires 120 volts, or an appliance that uses 8.8 amps, but we do not think about what those units mean.

Using the flow of water as an analogy can make electricity easier to understand. The flow of electrons in a circuit is similar to water flowing through a hose. If you could look into a hose at a given point, you would see a certain amount of water passing that point each second. The amount of water depends on how much pressure is being applied—how hard the water is being pushed. It also depends on the diameter of the hose. The harder the pressure and the larger the diameter of the hose, the more water passes each second. The flow of electrons through a wire depends on the electrical pressure pushing the electrons and on the cross-sectional area of the wire.

Voltage

The pressure that pushes electrons in a circuit is called voltage. Using the water analogy, if a tank of water were suspended one meter above the ground with a one-centimeter pipe coming out of the bottom, the water pressure would be similar to the force of a shower. If the same water tank were suspended 10 meters above the ground, the force of the water would be much greater, possibly enough to hurt you.

Voltage (V) is a measure of the pressure applied to electrons to make them move. It is a measure of the strength of the current in a circuit and is measured in **volts (V)**. Just as the 10-meter tank applies greater pressure than the 1-meter tank, a 10-volt power supply (such as a battery) would apply greater pressure than a 1-volt power supply.

AA batteries are 1.5-volt; they apply a small amount of voltage for lighting small flashlight bulbs. A car usually has a 12-volt battery—it applies more voltage to push current through circuits to operate the radio or defroster. The standard voltage of wall outlets is 120 volts—a dangerous voltage. An electric clothes dryer is usually wired at 240 volts—a very dangerous voltage.

Current

The flow of electrons can be compared to the flow of water. The water current is the number of molecules of water flowing past a fixed point; electrical current is the number of electrons flowing past a fixed point.

Electrical current (I) is defined as electrons flowing between two points having a difference in voltage. Current is measured in **amperes** or **amps (A)**. One ampere is 6.25×10^{18} electrons per second passing through a circuit.

With water, as the diameter of the pipe increases, so does the amount of water that can flow through it. With electricity, conducting wires

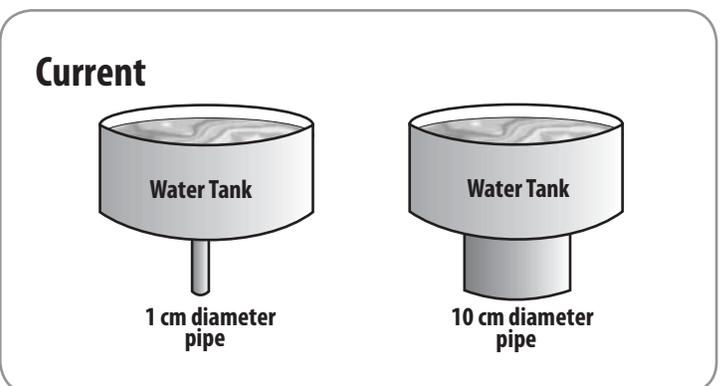
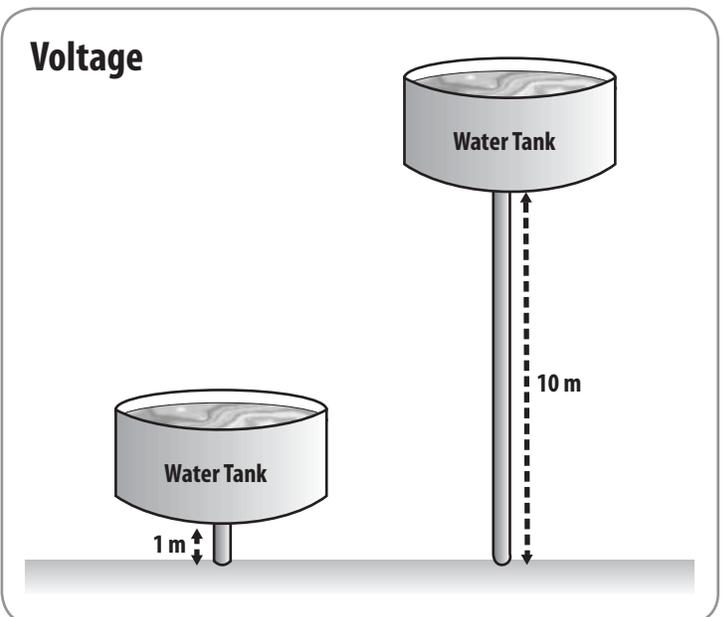
take the place of the pipe. As the cross-sectional area of the wire increases, so does the amount of electrical current (number of electrons) that can flow through it.

Resistance

Resistance (R) is a property that slows the flow of electrons. Using the water analogy, resistance is anything that slows water flow, such as a smaller pipe or fins on the inside of a pipe.

In electrical terms, the resistance of a conducting wire depends on the properties of the metal used to make the wire and the wire's diameter. Copper, aluminum, and silver—metals used in conducting wires—have different resistance.

Resistance is measured in units called **ohms (Ω)**. There are devices called resistors, with set resistances, that can be placed in circuits to reduce or control the current flow. Any device placed in a circuit to do work is called a load. The light bulb in a flashlight is a load. A television plugged into a wall outlet is also a load. Every load has resistance.



Ohm's Law

George Ohm, a German physicist, discovered that in many materials, especially metals, the current that flows through a material is proportional to the voltage. He found that if he doubled the voltage, the current also doubled. If he reduced the voltage by half, the current dropped by half. The resistance of the material remained the same.

This relationship is called **Ohm's Law** and can be described using a simple formula. If you know any two of the measurements, you can calculate the third using the following formula:

$$\text{voltage} = \text{current} \times \text{resistance}$$
$$V = I \times R \quad \text{or} \quad V = A \times \Omega$$

Electrical Power

Power (P) is a measure of the rate of doing work or the rate at which energy is converted. Electrical power is the rate at which electricity is produced or consumed. Using 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.

A large pipe carries more water (current) than a small pipe. Water at a height of 10 meters has much greater force (voltage) than at a height of one meter. The power of water flowing through a 1-centimeter pipe from a height of one meter is much less than water through a 10-centimeter pipe from 10 meters.

Electrical power is defined as the amount of electric current flowing due to an applied voltage. It is the amount of electricity required to start or operate a load for one second. Electrical power is measured in **watts (W)**. The formula is:

$$\text{power} = \text{voltage} \times \text{current}$$
$$P = V \times I \quad \text{or} \quad W = V \times A$$

Electrical Energy

Electrical energy introduces the concept of time to electrical power. In the water analogy, it would be the amount of water falling through the pipe over a period of time, such as an hour. When we talk about using power over time, we are talking about using energy. Using our water example, we could look at how much work could be done by the water in the time that it takes for the tank to empty.

The electrical energy that an appliance or device consumes can be determined only if you know how long (time) it consumes electrical power at a specific rate (power). To find the amount of energy consumed, you multiply the rate of energy consumption (measured in watts) by the amount of time (measured in hours) that it is being consumed. Electrical energy is measured in watt-hours (Wh).

$$\text{energy} = \text{power} \times \text{time}$$
$$E = P \times t \quad \text{or} \quad E = W \times h = Wh$$

Another way to think about power and energy is with an analogy to traveling. If a person travels in a car at a rate of 40 miles per hour (mph), to find the total distance traveled, you would multiply the rate of travel by the amount of time you traveled at that rate.

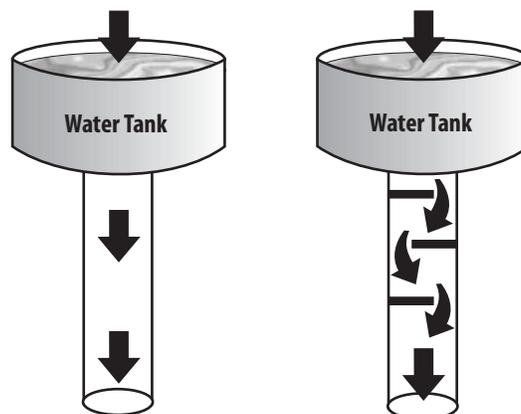
If a car travels at 40 miles per hour for 1 hour, it would travel 40 miles.

$$\text{distance} = 40 \text{ mph} \times 1 \text{ hour} = 40 \text{ miles}$$

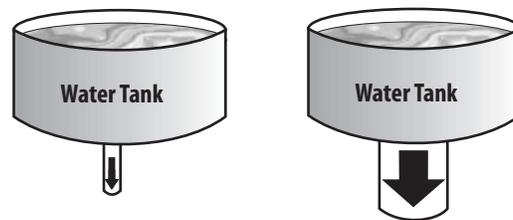
If a car travels at 40 miles per hour for 3 hours, it would travel 120 miles.

$$\text{distance} = 40 \text{ mph} \times 3 \text{ hours} = 120 \text{ miles}$$

Resistance



Electrical Power



The distance traveled represents the work done by the car. When we look at power, we are talking about the rate that electrical energy is being produced or consumed. Energy is analogous to the distance traveled or the work done by the car.

A person would not say he took a 40-mile per hour trip because that is the rate. The person would say he took a 40-mile trip or a 120-mile trip. We would describe the trip in terms of distance traveled, not rate traveled. The distance represents the amount of work done.

The same applies with electrical power. You would not say you used 100 watts of light energy to read your book, because a watt represents the rate you use energy, not the total energy used. The amount of energy used would be calculated by multiplying the rate by the amount of time you read.

If you read for five hours with a 100-W light bulb, for example, you would use the formula as follows:

$$\text{energy} = \text{power} \times \text{time} (E = P \times t)$$
$$\text{energy} = 100 \text{ W} \times 5 \text{ hours} = 500 \text{ Wh}$$

One watt-hour is a very small amount of electrical energy. Usually, we measure electrical power in larger units called **kilowatt-hours (kWh)** or 1,000 watt-hours (kilo = thousand). A kilowatt-hour is the unit that utilities use when billing most customers. The average cost of a kilowatt-hour of electricity for residential customers is about \$0.12.

To calculate the cost of reading with a 100-W light bulb for five hours, you would change the watt-hours into kilowatt-hours, then multiply the kilowatt-hours used by the cost per kilowatt-hour, as shown below:

$$500 \text{ Wh} / 1,000 = 0.5 \text{ kWh}$$
$$0.5 \text{ kWh} \times \$0.12/\text{kWh} = \$0.06$$

Therefore, it would cost about six cents to read for five hours with a 100-W light bulb.



Calculation of Power

Power (P) is a measure of the rate of doing work or the rate at which energy is converted. **Electrical power** is defined as the amount of electric current flowing due to an applied voltage. Electrical power is measured in **watts (W)**. The formula is:

$$\text{power} = \text{voltage} \times \text{current}$$

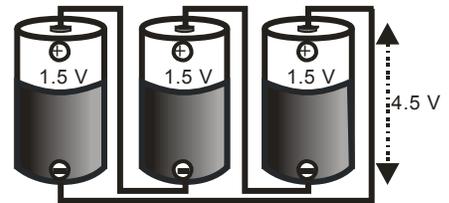
$$P = V \times I \quad \text{or} \quad W = V \times A$$



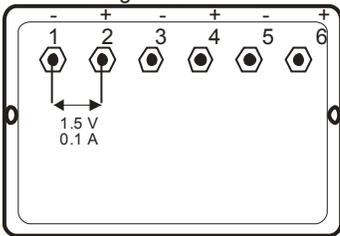
Series Circuits

In series circuits, the current remains constant while the voltage changes. To calculate total voltage, add the individual voltages together:

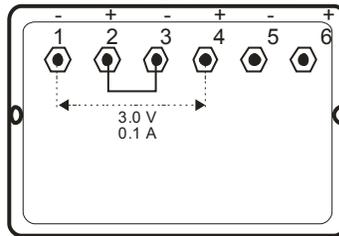
$$I_{\text{total}} = I_1 = I_2 = I_3$$
$$V_{\text{total}} = V_1 + V_2 + V_3$$



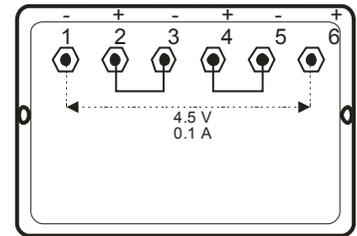
Single PV Module



Series - 2 PV Modules



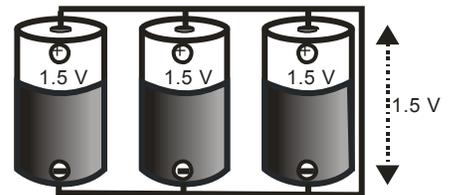
Series - 3 PV Modules



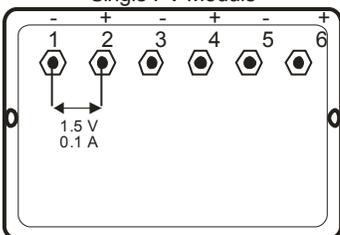
Parallel Circuits

In parallel circuits, the voltage remains constant while the current changes. To calculate total current, add the individual currents together:

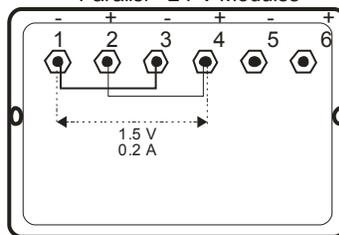
$$I_{\text{total}} = I_1 + I_2 + I_3$$
$$V_{\text{total}} = V_1 = V_2 = V_3$$



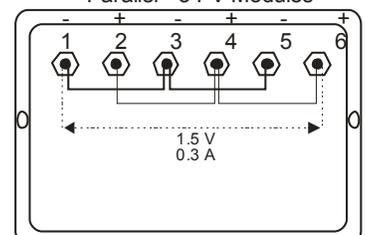
Single PV Module



Parallel - 2 PV Modules



Parallel - 3 PV Modules





Basic Measurement Values in Electronics

SYMBOL	VALUE	METER	UNIT
E	Voltage (the force)	Voltmeter	Volts (V)
I	Current (the flow)	Ammeter	Amps/Amperes (A)
R	Resistance (the anti-flow)	Ohmmeter	Ohms (Ω)

1 Ampere = 1 coulomb/second

1 Coulomb = 6.24×10^{18} electrons (about a triple axle dump truck full of sand where one grain of sand is one electron)

Prefixes for Units

▪ Smaller

(m)illi x 1/1000 or .001

(μ) micro x 1/1000000 or .000001

(n)ano x1/100000000 or .000000001

(p)ico x 1/1000000000000 or .000000000001

▪ Bigger

(K)ilo x 1,000

(M)ega x 1,000,000

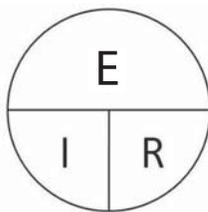
(G)iga x 1,000,000,000

Formulas for Measuring Electricity

$$E = I \times R$$

$$I = E/R$$

$$R = E/I$$



The formula pie works for any three variable equation. Put your finger on the variable you want to solve for and the operation you need is revealed.

▪ Series Resistance (Resistance is additive)

$$R_T = R_1 + R_2 + R_3 \dots + R_n$$

▪ Parallel Resistance (Resistance is reciprocal)

$$1/R_T = 1/R_1 + 1/R_2 + 1/R_3 \dots + 1/R_n$$

Note: ALWAYS convert the values you are working with to the "BASE unit." For example—don't plug kilo-ohms (K Ω) into the equation—convert the value to Ω first.