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Electrifying!

Ken McAuliffe

Photo taken by Rebecca Pierik

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My name is Ken McAuliffe, and I'm the Electrical Systems Coordinator at the Museum of Science in Boston. The museum is a big and complex building that uses a lot of electricity to power everything from lights and machinery to exhibits and computers. Part of my job is to make sure all of the exhibits, offices, and even the Omni movie theater are wired to receive electrical power.

It's an important job. The electricians have to make sure all the exhibits and offices have the right type of power. We also have to plan for electrical problems inside and outside the building. It would be incredibly disruptive if the building lost electrical power and the museum became dark during peak visiting hours. And if there is a power outage in the museum's main server room, which houses the museum's website and thousands of electronic files and archives, a lot of important information could be lost. So a big part of my job is to prevent a power outage and, when there's no way to stop it, to make sure any power disruption is as short and painless as possible.

My career as an electrician really started my senior year in high school, when I started thinking seriously about choosing a career. I learned from a family friend that electricians make good wages and are always in demand. I liked working with my hands—and the good pay was appealing. After I graduated, I enrolled in an electrical certification program. I was a full-time student for one year, then an apprentice electrician for four more years, before I got my license.

That was fifteen years ago. I've had steady work ever since—sometimes more than enough work. And, of course, my friends and family are very happy to have an electrician around.

Power Coming In

From an electrician's standpoint, the museum is a complicated collection of circuits. Power comes into the building through the electrical distribution grid. The voltage difference coming into the museum off the grid is about 13,800 volts.

While power plants can generate a pressure difference as high as 765,000 volts, the high-voltage transmission lines carrying the power from the plant lead to power substations, where the voltage is decreased by devices called transformers. For homes and other small businesses, other transformers on the grid reduce voltages to around 240/120 volts.

Transformers at the museum reduce the 13,800 volts to about 480 volts—the voltage required by industrial machines such as our climate control system and the Omni theater. The voltage is reduced further to 240 and 120 volts for other machines and lighting.

When the Grid Goes Down

So, what happens when the grid goes down? Well, that's when all my work pays off. Whether it's a broken power line or power on the grid fails, causing a blackout, we're prepared. That's the other big part of my job.

In order to replace the museum's electric power during a blackout, we've installed a back-up generator. Our generator is like a mini–power plant. It burns diesel fuel to turn a turbine that spins wires in a magnetic field to produce electricity, just as in a power plant. The generator can produce enough power to keep essential systems such as necessary lighting, our server room, and our phone system functioning.

But it takes the generator about fifteen minutes to fire up and start generating electricity. That's far too long for people to be standing around in the dark exhibit halls. And it's far too long for our servers—the brains of our entire computer network—to be down.

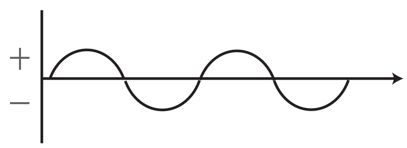
To solve these problems, we've installed an Uninterrupted Power Source (UPS) system. The UPS system has a large battery that stores energy. When the museum loses power, the UPS system detects the power loss and automatically switches the museum's power to battery power. The UPS can hold the various loads of the museum for fifteen minutes or so—just enough time for the generator to get up and running.

Photo taken by Rebecca Pierik

The Uninterrupted Power Source system at the Museum

AC/DC

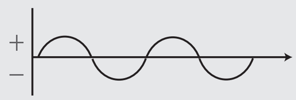
The battery in the UPS system provides a current that's different than one produced by an electrical generator at a power plant or our backup generator. Electrical generators produce ***alternating current,*** or AC power. The spinning magnets of the power plant generator create a voltage difference that continuously switches directions. A graph of alternating current looks like this:



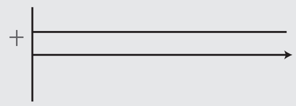
Alternating Current (AC)

AC vs. DC

Alternating current
is the current available from the power distribution grid. It continuously switches directions.



Direct current
is the current in a battery-powered circuit. It only flows in one direction.



AC adapters
convert AC current to DC.

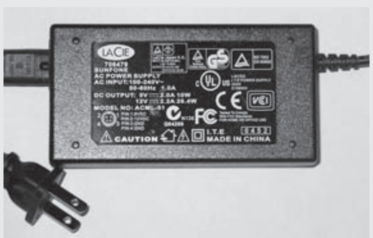
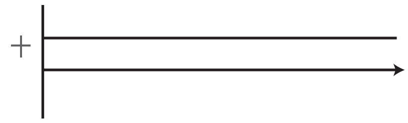


Photo taken by Rebecca Pierik

The current that flows from an outlet in your wall to a plug is AC.

Batteries don't produce alternating currents. In a battery the current flows in only one direction. That's why it is called direct current, or DC. A graph of direct current looks like this:



Direct Current (DC)

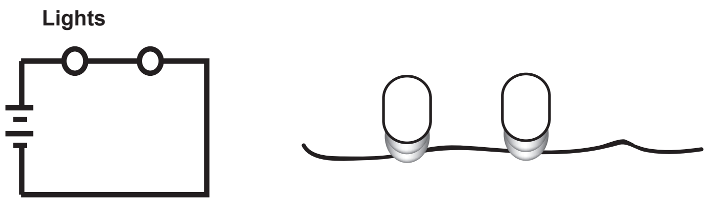
Most of the equipment as well as the lighting in the museum require AC power. So the UPS system must convert the DC power from the battery into AC power that mimics the power available on the grid. And all of this must happen seamlessly in the event of a blackout. Our current system has never been tested in a real blackout. But once a month I simulate a "blackout" by switching off grid power to the UPS system, which causes it to connect to the museum's electrical system and start providing battery power. So far, the system has worked perfectly in every test run. I'm confident that it will work well during a real blackout.

Some devices are designed to use AC, while others need DC power. While most electrical appliances such as dishwashers, lamps, or electric heaters run on AC power, many electronic devices require DC power. Many electronic devices that plug in to wall sockets are equipped with an adapter that converts the AC current to DC. Adapters can also reduce or step down voltages for devices that require a lower voltage difference.

Wiring the Butterfly Exhibit

As the Electrical Systems Coordinator, I also oversee the installation of electrical power to the equipment for our new exhibits. In 2005, the museum introduced our butterfly observatory—a plant- and sun-filled room where visitors can watch free-flying butterflies and learn about their behavior and biology. It's a beautiful place—and very popular with visitors.

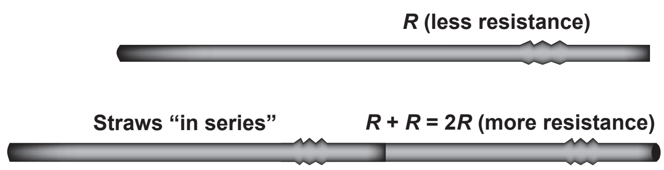
The lights in the observatory had to be mounted on the ceilings along tracks. We had a choice of how to connect these lights to the electrical system. We could arrange them in series or parallel. A ***series circuit*** is a circuit in which resistors (the lights) are arranged one right after the other in a chain, as shown below:



In a series circuit, the wires are connected so that the current takes one path straight through multiple resistors. The current in a series circuit is the same. In order to find the total resistance in a series circuit (R_{total}), the values of the individual resistors (R_1, R_2, R_3) are added:

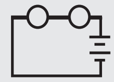
$$R_{total} = R_1 + R_2 + R_3$$

Imagine blowing through a single straw versus blowing through several straws connected end to end. Together, the straws have more total resistance. The same is true for resistors connected in series in an electrical circuit.

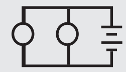


We also had the choice of connecting the lights in parallel. A ***parallel circuit*** is a circuit in which the current branches before each resistor.

Series vs. Parallel

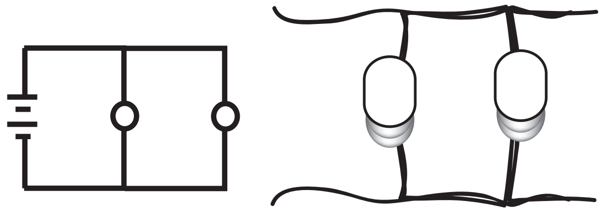
A ***series circuit*** 

is a circuit in which resistors (the lights) are arranged one right after the other in a chain.

A ***parallel circuit*** 

is a circuit in which the current branches on the way to each resistor then comes back together after it has passed through the resistors.

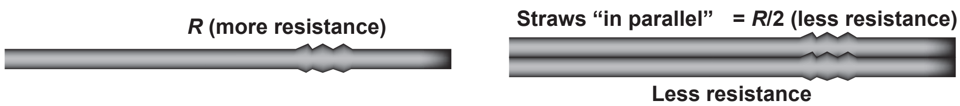
In a parallel circuit, one wire connects one side of all the resistors, while the return wire connects the other ends. The current in a parallel circuit splits up, with some current flowing along each parallel branch and re-combining when the branches meet again. In a parallel circuit, the voltage difference across each resistor is the same.



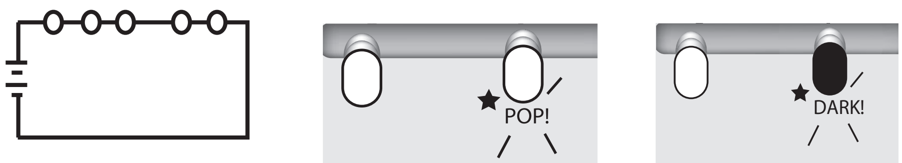
Unlike a series circuit, we have to add the reciprocal value of each resistor to find the total resistance, using the following equation:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

While at first this may be confusing, it helps to imagine blowing through a single straw, then blowing through several straws in parallel. It's much easier to blow through several straws than to blow through one. Blowing through an additional straw in parallel, no matter how narrow, reduces the total resistance.

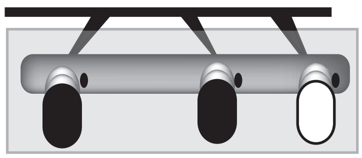


Electricians tend to wire loads in parallel for several practical reasons. For instance, if you have light bulbs strung in series and one bulb burns out, the other bulbs will go out too. That's because the current cannot flow through the burned-out bulb after the current path has been interrupted.

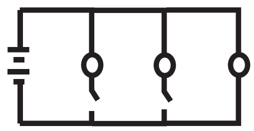


That's why strings of holiday lights can be so maddening. If a string won't light, it's usually because one bulb has burned out. To repair the string, you have to search for the one broken bulb and replace it. When lights are wired in parallel, the circuit remains intact, even if a bulbs burns out. This is a big advantage in lighting systems. Even if a few bulbs burn out, the rest will stay lit.

Another advantage is that a parallel circuit gives you a little more flexibility. When connected in parallel, a light or a set of lights can be switched on or off independently. In the following diagram, three lights are arranged in parallel. Each light has its own switch, connected in series. Even if the switches for two lights are open, the remaining light remains lit. That's because the current can still flow through the conducting loop of the last branch in the circuit.

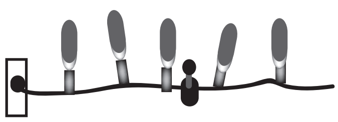


Dark bulb

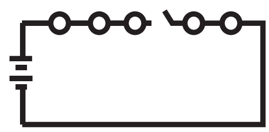


Open switches

Of course, with lights arranged in series, you only have two options: lights on or lights off. This is true regardless of where you put the switch.



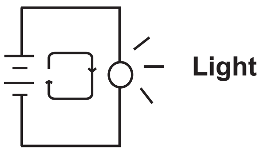
Switch open = lights off



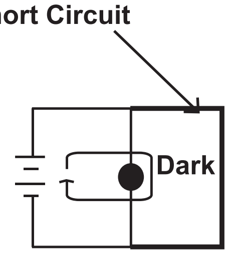
If you use two switches, both have to be closed for current to flow around a circuit. This can be useful for safety purposes. Some industrial equipment is wired with two switches in series. Both switches have to be switched on in order for the equipment to receive power. This reduces the chance that the equipment will be turned on accidentally.

As you have probably guessed, we arranged the lights in the Butterfly Observatory in parallel. This way, we can turn the lights on or off individually, and we don't have to worry that one burned-out bulb will leave everyone in the dark.

Circuit



Short Circuit



Playing It Safe

Over the years, I've learned a lot about being careful with electricity. My first lesson actually came when I was only seven years old. I had an electric football board game that plugged into the wall socket. It had lights and sounds. One day in the summer, I was playing it just after running through a sprinkler. I was soaked. My hands and clothes dripped water all over the board. When I switched the board on and touched it with my wet hands, I got a terrible shock—strong enough to leave burns on my arms.

You'd think I never would have wanted to become an electrician after that experience. But I've learned that working with electricity—and electrical equipment—can be quite safe if you take the necessary precautions and follow the rules.

Rule #1: Don't become a part of the circuit!

This is the most important rule. A ***short circuit*** is an accidental lower-resistance connection that bypasses the load or the resistance in a circuit. In a short circuit the current follows the path of least resistance: a metal bar, your body, or another conductor. If a wire were accidentally connected to both the positive and negative sides of a battery, as in the example to the left, almost all the current would flow through the wire instead of the light bulb.

What happens then? Because the resistance drops and the voltage remains constant, the current would get very strong. (Remember Ohm's Law?) At the museum or in a typical household electric system, that high current can be dangerous!

This explains the shock I received when I was a young boy. Water is a good conductor, and so are our bodies. I touched the water on the board and caused a short circuit between the electric wires of the game and the ground. The current followed the path of least resistance—through me and into the ground.

Fortunately, many residences and businesses have circuit breakers. A ***circuit breaker*** detects when current is increasing quickly due to a short, and it opens the circuit. But you should never count on a circuit breaker to keep you safe. It's better not to work with electrical appliances or electronics when you are anywhere near water.

Rule #2: Use a ground!

As we were installing one of the lights in the Butterfly Observatory, a wire came loose and got in contact with the metallic light casing of a bulb, making the metal casing "hot," because there was a large surge of current running through it. When my colleague moved his ladder close to the hot casing, a charge actually arced through the air to close the circuit between the casing and the ladder. The charged moved through air because the ladder was connected to the ground—a good return path. The arc gave us a good scare and melted the lighting track, but fortunately, that's all it did.

This experience highlights the importance of using a ground wire. A ***ground wire*** connects any metal in an electrical appliance to the Earth. That way, if a wire comes in contact with the metal, the current will flow through the ground wire, instead of through another grounded object, which might be you.

Rule #3: Turn off the power!

Whenever possible, I disconnect the circuit I'm working on from the power source. That way I'm not dealing with "hot" wires at all. Of course, this is not always possible. Sometimes we need to keep a circuit connected to the power source while we work on it. During museum hours, it's not always easy to disconnect parts of the electrical system from the power source in order to do maintenance. In that instance, we use grounds and we use our heads to make sure we do not become part of a circuit.

Working with electricity is not always easy, but it's a fun challenge. Besides, everyone needs electric power. And that means everyone needs an electrician!

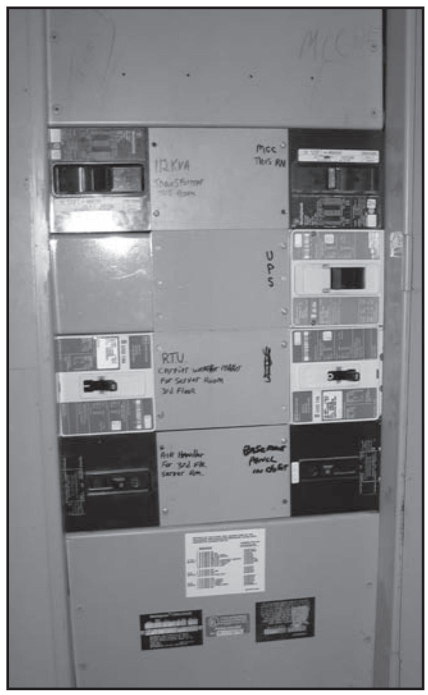


Photo taken by Rebecca Pierik

A circuit breaker box

What's the Story?

1. In your own words, write a paragraph explaining how the museum's electrical system would work if an electrical blackout happened.

2. What is a short circuit? Why can short circuits be dangerous?

3. What is alternating current (AC)? What is direct current (DC)? What kinds of devices require AC? What kinds of devices require DC?

Designing with Math and Science

4. Draw a diagram of a circuit with three resistors connected in parallel. Calculate the total resistance in the parallel circuit you drew if each resistor has a resistance of 3 Ohms.

5. Draw a diagram of a circuit with three loads connected in series. Calculate the total resistance in the series circuit you drew if each load has a resistance of 3 Ohms.

Connecting the Dots

6. Use Ohm's law to calculate the current in the series circuit above if the voltage difference is 15 volts.

What Do You Think?

7. Name an electrical device you use often that plugs into a wall. Do some research to determine the following about the device (you may be able to determine some of the answers simply by looking at the device or its box):
   - A. Does the device require AC or DC? Does it have an adapter?
   - B. Does the device use a ground wire? Why?
   - C. What is the voltage difference required by the device?
   - D. How many watts of power does the device consume?
   - E. How much energy does the device use every hour?