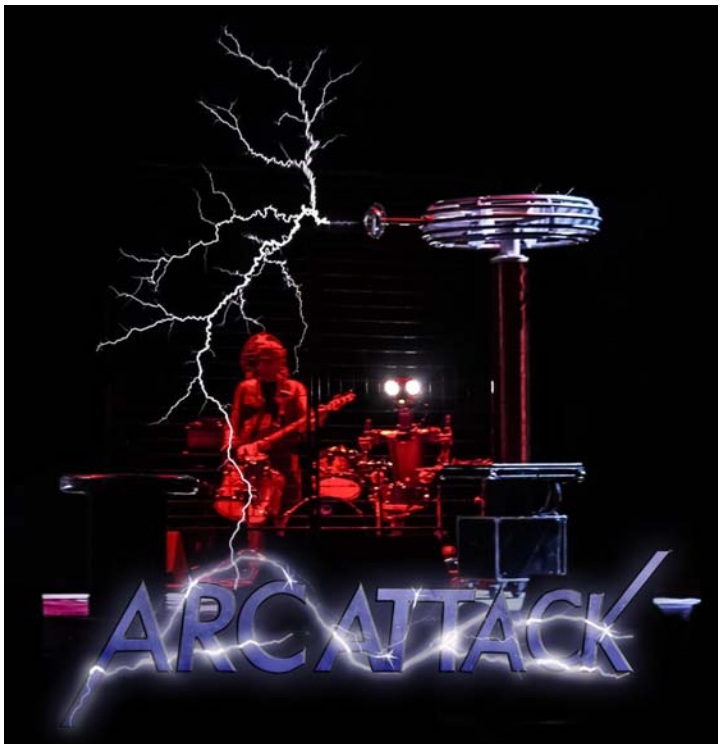
Alberta Bair Theater
for the performing arts

EDUCATION GUIDE



Thursday, October 4, 2018
9:30am and 12:30pm

Tickets: $6.00 per person

Recommended for Grades 6 through 8

ABT Student Matinee series sponsored by

Valley
CREDIT UNION

Alberta Bair Theater for the Performing Arts
2801 Third Avenue North ▪ Billings, Montana 59101
406-256-8915
www.albertabairtheater.org

Mission

ArcAttack is a performing arts group that originated in Austin, Texas in late 2005. Our goal is to explore new possibilities between the union of scientific and musical concepts and to share this knowledge with the world. After years of performing, we realized that we were doing much more than simply entertaining crowds through musical performance. We discovered that our performance has a natural tendency to stimulate our spectators' curiosity about science and technology. Using music as a medium of propagating these concepts and ideas, we hope to help others understand the relationship between science, art and music. "Engineering!" is a new addition to our educational series, as part of a continuing effort to expand our capabilities as educators while reflecting the latest standards in science education through our performance.

Introduction to the Teachers' Resource Manual

The ArcAttack workbook is a comprehensive guide to understanding not only the science behind our musical performance, but also lays the foundation for the understanding of the basic scientific principles that compose modern day technology and promote it's advancement. It is geared towards use for multiple grade levels including the high school physics classroom; however, most of the concepts and activities can be studied with students between 4th-8th grades.

We will explore scientific facts and theories through simple explanation and hands on experimentation. We will also learn about key historical people who have changed the way we understand both science and music, and discover the many ways in which they intersect.

The world of science and technology is vast, and can provide an individual with endless avenues to explore and challenges to overcome. We only hope that you enjoy the subject matter in this guide as much as we do, and join us in our lifetime learning process.

The ArcAttack study guide introduces key scientific principles and historical figures in an interactive format as a foundation to understanding concepts students will experience during the live performance. The experiments that follow illustrate principles tied to the core components of the technology we feature in order to provide a framework for the student to experience in a hands-on fashion how these principles have allowed for the creation of that technology. It also introduces key people throughout history who have had a major impact on the development of current technology in order to illustrate science as a human endeavor. Finally, it explores natural phenomenon associated with the key components of the ArcAttack presentation and provides resources for further exploration by student and teacher alike.

ArcAttack - Education

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Properties & changes of properties in matter
- Motions & Forces
- Transfer of energy

SCIENCE AND TECHNOLOGY

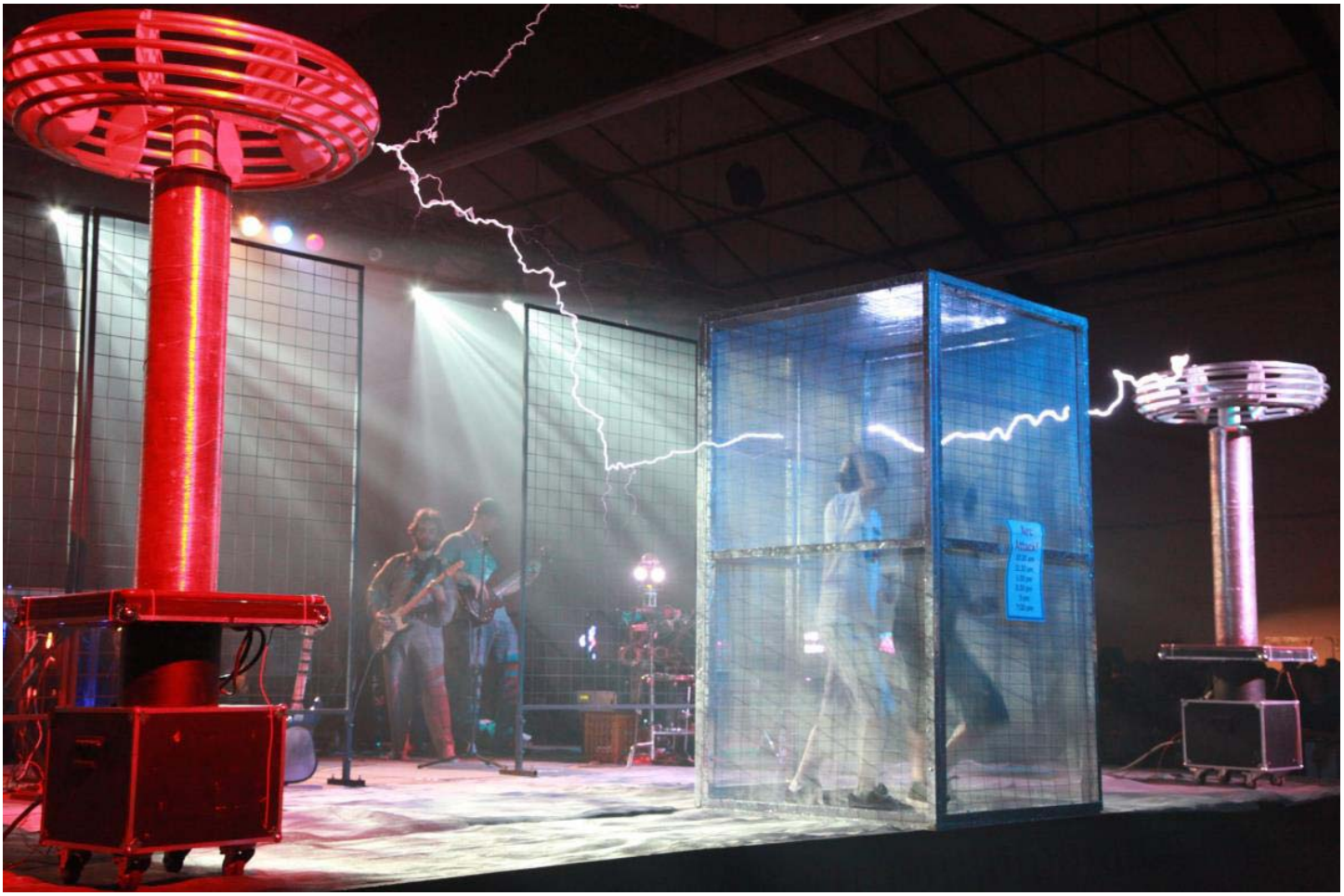
- Abilities to distinguish between natural objects and man-made objects
- Abilities of technological design
- Understanding about science and technology

SCIENCE AS INQUIRY

- Personal Health
- Populations, resources, and environments
- Natural Hazards
- Science and technology in society

SCIENCE AS INQUIRY

- History of Science
- Science as a human endeavor



The Science of ArcAttack!

Tesla Coils

The Singing Tesla coils are perhaps the most exciting component of the Arcattack performance. Although you may have seen images of Tesla Coils producing lightning, like in the image below, the Tesla Coils used by ArcAttack are of a different variety, called solid state Tesla Coils. Unlike traditional Tesla Coils, solid-state Tesla Coils contain transistors that make them capable of producing musical notes. The music that the audience hears is generated by the method in which these coils produce lightning.

The music is created by turning the Tesla Coils on-and-off very quickly. When this is done fast enough, the brain interprets the sound as a continuous note. For example, turning the coils on and off 440 times per second is heard as the musical note "A."

King Beat and his robotic drums

King beat is a robotic band mate that specializes in playing the drums. His movements are a combination of pre sequenced actions and live control from an operator by means of a wireless signal. When King Beat docks in front of the drum set, his hands move into position to play the snare drum. The rest of the drums are played with a separate automated machine, comprised of a controller and individual mallets that are mounted to each drum. The robot and the accompanying automated drum set are activated by a MIDI signal that is sent from a master sequencer.

Can Crusher

The can-crusher is a giant electromagnet that is named after its most impressive feature. It is comprised of a high voltage power supply, a very large capacitor to store electrical energy, and electromagnetic coils. The machine has two main purposes, or "modes." In the first mode, the machine can be used to magnetize and launch an aluminum ring up to 20' in the air. The second mode is it's "can crushing" mode, in which an aluminum soda can is sheared in half and launched in 2 directions like a cannon. Both of these demonstrate "Lorentz" force, and other properties of electricity and inductance as well. The complexity of the explanation is tailored to the level of the audience. The machine is used both as a standalone demo, as well as a percussive "instrument" in ArcAttack compositions.

Bell Machine

The Bell Machine is a set of 7 aluminum chimes, which are played by "Air rockets". These rockets are blasted from the bottom of the machine by means of a quick high pressure burst of air. The rockets travel up a 5' clear tube to eventually hit the chime at the top. This machine demonstrates basic pneumatic systems and the resonant properties of aluminum cylinders.

The String Instrument

This machine is the most basic stringed instrument, consisting of a single string and electromagnetic pickup. It is built with parts available from any hardware and music store, and is played using drum sticks that are used to strike the string, slide on the string, and shorten the string in order to create different percussive effects, pitches and sound effects. It is a demonstration of how sound is created from a vibrating string, and also an example of how extremely functional a simple device can be.

Lightning Guitar

The lightning guitar is a basic MIDI control that was designed specifically to be immune to Tesla coil arcs and interference. The performer wears a faraday suit, and plays the Tesla coil with this controller while being struck by lightning.

Key Scientific Principles

Static Electricity

Have you ever been shocked by the doorknob after you crossed the living room carpet in your socks? Have you ever taken off your sweater and noticed your hair was standing up? You weren't the only one. During the 5th century BCE, Greek philosophers were making observations about the world around them. One observation was how, when rubbed with fur, amber would attract feathers or small pieces of straw. "*ηλεκτρον*" (*elektron*) was the Greek word for amber. In 1600 CE, William Gilbert explored the properties of amber and realized that the attraction of certain materials was actually a force (force – a push or pull). He called this force *electron* (Greek for amber) and came up with a new Latin phrase, *vis electrica,* or "the amber force."

In order to understand this "amber force" we need to understand the structure of matter.

According to quantum mechanics, atoms are composed of three main subatomic particles: the proton, neutron, and electron.

The protons (positively charged) and neutrons (no charge) are located in the nucleus of the atom, acting as the core. Protons and neutrons are strongly bound together. The electrons have a negative charge and can be found in electron shells – concentric spherical regions of space around the nucleus – where each shell is characterized by a discrete energy level. Outer shells have higher energy levels than inner shells. It takes a certain discrete amount of energy to cause an electron to change to a higher-level shell and releases that same discrete amount of energy when the electron returns to its original lower-level shell. Electrons are weakly bound to the nucleus and can be removed or added to an atom by everyday occurrences, like rubbing a balloon on your hair. When an atom has the same number of protons and electrons, it is electrically neutral. When an atom has more electrons than protons, then it has an overall negative charge. Similarly, if an atom has more protons than electrons, it has an overall positive charge. Material objects are made up of different types and combination of atoms. For example, table salt (NaCl) is made up of a sodium atom (11 protons and 11 electrons) and a chlorine atom (17 protons and 17 electrons). The sodium atom is *ionically bonded* with the chlorine atom.

So how does an object, like a balloon, become charged? There are several different ways that an object can become charged: by friction, induction, or by conduction. We will be discussing charging by friction and induction.

Charging by Friction

There are many different types of atoms and these atoms can be combined in a variety of ways to form the material objects we encounter every day. Depending on the type of atoms an object is made of, an object can be more or less attracted to an electron. This electrical property is known as *electron affinity*. If an object has a high electron affinity, then it is more attractive to electrons. Different materials have different affinities for electrons. The *triboelectric series* is an ordering of materials by their electron affinity. This property is very important to consider when discussing the method of charging by contact or friction. When you rub the balloon on your hair, or your socked feet across the carpet, you are experiencing friction. During the process, atoms in the balloon are forced to be close to the atoms in your hair. The protons in the atoms of one object start to interact with the electrons on the other object. The rubber of the balloon has a higher electron affinity and will take electrons from the atoms of your hair. When you pull the balloon away from your hair, the balloon will have more electrons and has a negative charge while your hair has lost electrons, and now has a positive charge. You might notice that your hair is attracted to the balloon. This is evidence that *opposite charges attract*. If you rub two balloons on your hair and place the balloons near each other you will notice that *like charges repel.*

Since charging by friction requires the transfer of electrons, charge is not created from nothing. The charge of an object is created either by losing electrons (positive charge) or gaining electrons (negative charge). The net charge for the system of objects that are being rubbed together is 0 since the same number of electrons that left the now positively charged object have been transferred to the now negatively charged object. Charge cannot be created nor destroyed, it is always conserved; this is known as the *law of conservation of charge*.

Charging by Induction

Charging by induction is another way an object can become charged. However, unlike charging by friction, no contact is necessary when charging an object. In order to understand induction, you must first study conductors, insulators, and polarization. Conductors allow the free movement of electrons within the object, while insulators do not. An object can become polarized when the electrons rearrange such that one side of an object is more negative than the other.

An example of charging by induction can be seen in the figure below. We have two conductive metal spheres supported by an insulating stand. This ensures that no electrons will leave the metal sphere through the stand. When the conducting spheres are placed next to each other, the electrons are free to move about the two spheres. Let's say we bring a negatively charged balloon (you just rubbed it on your hair) towards one of the spheres. Since *like charges repel*, the electrons on the sphere will be repelled by the negative charge of the balloon. Note that the protons do not move toward the negative balloon, but that the side of the metal sphere closest to the balloon has a positive charge due to a lack of electrons. So there is a stronger negative charge in the sphere furthest from the negative balloon. When the spheres are separated, we have two charged objects: one positive and one negative. Again, the net charge in the system is zero – charge is conserved.

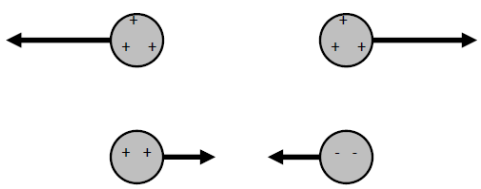
Electric Forces and Fields

Electric Forces

As you have observed, like charges repel and opposite charges attract. But what is causing these charged objects to move towards or away from each other? A force is defined as a push or a pull. The charged objects are experiencing a pull when attracted and a push when repelled from each other. French physicist Charles Coulomb discovered that the force between two charged object depends on the amount of excess charge two objects have and the distance between the two objects. One electron has the charge of -1.602×10-19 coulombs. So if an object has an excess of 1014 electrons, its overall charge is q = (-1.602×10-19 C/electron)(1014 electrons) = - 1.602×10-5 C.

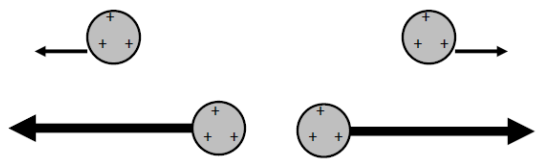
The electric force between two charged objects is proportional to the product of the excess charge on each:

$$F \propto q_1 q_2$$



The electric force between two charged objects is proportional to the inverse of the square of the distance between the objects:

$$F \propto \frac{1}{R^2}$$



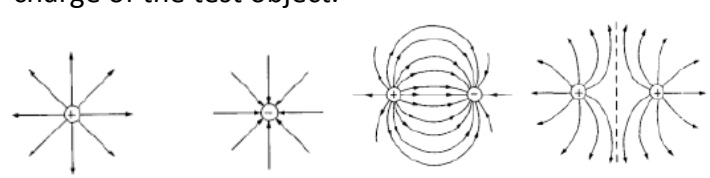
When we put the two observations together, we get that $F = k\frac{q_1 q_2}{R^2}$ where k is the electric force constant, $k = 9 \times 10^9 \, {}^{N \cdot m^2}/_{C^2}$

What similarities can be drawn between the equation for electric force and Newton's law for gravitational force?

Electric Fields

Have you ever walked by a trashcan and been repulsed by the smell? The dirty trash has a *field* around it that your nose can detect. A field is a three-dimensional description of a region of space. In this case, the field your nose detects is that created by the odorous molecules from the trash. If there are more odorous molecules, the field is stronger, and you can tell! If there aren't very many odorous molecules around the trash, you might not notice the smell.

Electric fields work in a similar way. As we just discussed, an electric force exists between any two charged objects. If a test charge (your nose) is placed within a certain radius of the large charge that's creating the field (trashcan), there will be a force acting on the test charge. The larger the charge of the test or the field-creating charge, the larger the force is between the two. The larger the charge on the field-creating charge, the stronger the electric field. The direction of the electric field is defined as the direction that a positive charge would move in a certain field. If the electric field and the test charge are positive, the electric field is drawn from the field-creating charge. If the direction of the electric field is negative, then the positive test charge is attracted to the field-creating charge and the electric fields lines are drawn into the field-creating charge. Electric field can be quantitatively defined as the amount of force per charge, or $E = {}^{F}/_{q} = \frac{{}^{kQq}/_{R^2}}{q} = \frac{kQ}{R^2}$ where Q is the charge of the field-creating object and q is the charge of the test object.



(a) Positive charge (b) Negative charge (c) Positive and negative charge (d) Positive and positive charge

How Lightning Works

Lightning starts with the water cycle:

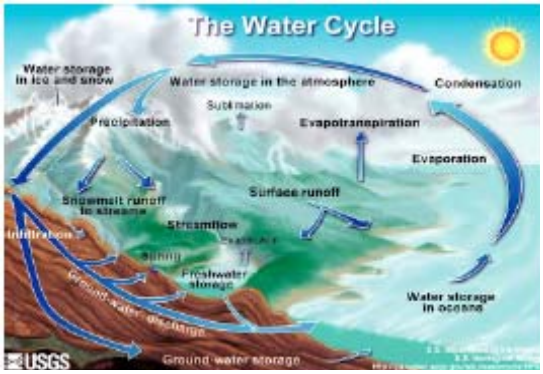
Evaporation – the process by which a liquid absorbs heat and changes to a vapor.

- Think about a puddle on a hot day: the water is heated by the sun, causing the water molecules to increase in energy. They start moving faster and faster. Eventually they escape the puddle as vapor or gas and rise into the atmosphere.

Condensation – the process by which a vapor or gas loses heat and turns into a liquid

- Think about a cold soda can: There are water molecules (among other things) in the air around the can. When these molecules come into contact with the COLD can, the molecules lose energy and collect as water droplets on the outside of the can. It looks like the can is sweating. The same thing is happening in the atmosphere. As the vapor form the puddles and other bodies of water rise higher into the atmosphere, the temperature surrounding the molecules lowers (the higher up, the colder). These cooled water molecules collect and form clouds.

Looking at the water cycle, once the clouds form, the water molecules collect around impurities (like dirt particles) and gravitation causes these to fall as rain.



In an electrical storm, clouds gain a charge, and act like a capacitor

Capacitor – an electric circuit element used to store charge temporarily, consisting in general of two metallic plates separated and insulated from each other by a dielectric. Also called condenser.

The upper part of the cloud gains a positive charge and the lower part of the cloud gains a negative charge. Why this is so and how it happens hasn't been agreed upon in the scientific community.

- One explanation: when moisture accumulates in the atmosphere (clouds), there are millions of water droplets and pieces of ice. During the process of evaporation and condensation, the water molecules/droplets collide. During these collisions, electrons are knocked away from their atoms, creating a charge separation. These electrons gather at the bottom of the cloud, causing the lower portion of the cloud to accumulate a negative charge. The molecules that have lost electrons (so are no positively charged) collect in the top portion of the cloud. Also, as the rising water molecules experience colder and colder temperatures and begin to freeze, the frozen portion becomes negatively charged, and the unfrozen droplets become positively charged. Frozen droplets begin to collect at the bottom of the cloud, too. There is an electric field associated with this charge separation.

◊ Electric field – the effect produced by the existence of an electric charge, such as an electron, ion, or proton, in the volume of space or medium that surrounds it; the distribution in space of the strength and direction of forces that would be exerted on an electric charge at any point in that space. Electric fields themselves result directly from other electric charges or from changing magnetic fields. The strength of and electric field at a given point in magnetic fields. The strength of an electric field at a given point in space near an electrically charged object is proportional to the amount of charge on the object, and inversely proportional to the distance squared between the point and the object.

- As more and more collisions occur and frozen droplets collect, the strength of electric field increases. The electric field in the cloud (particularly the strong negative charge at the bottom) becomes so strong that it causes the electrons on the earth's surface to be pushed down further into the curst (repulsion). This causes the earth's surface under/near the cloud to become positively charged.

So now the bottom of the cloud has a negative charge and the surface of the earth has a positive charge. Electrons need to flow from the negatively charged surface (the cloud has MORE electrons → has a negative charge) to the positively charged surface of the earth (the earth's surface has LESS electrons → has a positive charge). How do the electrons get from the cloud to the ground? They follow a **conductive path**.

Air Ionization

The strong electric field between the earth and the cloud causes the surrounding air to separate into electrons and positive ions, too (ionization). In this ionized air, or plasma, the electrons are allowed to move much more freely than before. This makes the ionized air a great conductor of electricity. Now that there is a way for the electrons to flow, a conductive path begins to form.

Once the ionization process begins and plasma forms, a path is not created instantaneously. In fact, there are usually many separate paths of ionized air stemming form the cloud. These paths are typically referred to as step leaders. These step leaders grow towards the earth in stages. This means that it may not be a straight line towards the earth. Also, the air may not ionize equally in all directions, ex: impurities might cause the air to ionize more easily in one direction. The shape of the electric field also affects the step leaders. The shape of the electric fields depends on where the charged particles are (in this case, they are at the bottom of the cloud and at the earth's surface).

The step leader that reaches the earth first provides the conductive path between the cloud and the earth. But this is NOT the lightning strike, just the path that the strike will take. The lightning strike is the sudden flow of current moving from the cloud to the ground.

As the step leaders get closer to the earth, object on the earth's surface begin to feel the strong electric field. The objects essentially "reach" for the cloud by creating positive streamers. These are purplish and are more common on sharp edges. Once they have been created, it's the step leader's job to bridge the gap.

When the streamer and the step leader meet, the ionized air (plasma) has made its way to the earth, leaving that conductive path. Now, the electric current flows (very quickly!) from the cloud, down the conductive path, to the earth. Remember: this path does not have to be a straight line!

The flash of light we see is the effect of the strike. Heat is associated with electrical current. Since there is SO MUCH current flowing from the cloud to the earth, there is a huge amount of heat being released. Did you know a bolt of lightning is hotter than the surface of the sun? The heat is actually the cause of the flash we see.

Thunder – when the streamer and the step leader meet and the current flows, the air around the strike becomes very hot, too. The heat causes the air to expand very rapidly – like an explosion. This explosion is followed by thunder. Thunder is a shockwave radiating from the strike. As the air heats up, a compression wave is created that moves through the air. This wave takes the form of a sound wave - thunder!

Voltage and Current

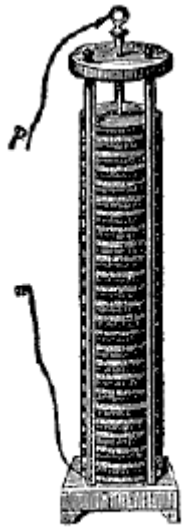
The Scientific Revolution

After the Catholic Church arrested Galileo for his theories on the solar system, science was finding more hospitable environments in places like England and France. Sir Isaac Newton was developing his understanding on forces and gravity and Benjamin Franklin was developing his understanding of static electricity.

Science Returns to Italy: Luigi Galvani and Alessandro Volta

About 150 years after Galileo's death, Luigi Galvani was performing experiments involving electrical charges and frogs. It was known that when a charge was applied to the spinal cord of a frog, the frog's muscles would twitch. These charges could make the frog's legs jump – even if the legs weren't attached to the frog's body! While Galvani was cutting into a frog's leg, his steel scalpel (steel is a metal, so it is a good conductor) touched a brass hook that was holding the leg in place and the leg twitched! Galvani continued this experiment and was getting the same results. He was convinced he was seeing animal electricity, the life force within the muscles of all animals.

Luigi Galvani began work with Alessandro Volta. They were able to reproduce the original results, but Volta did not agree with Galvani's explanation. Volta found that two dissimilar metals were essential to the effects they were observing. In 1900, Volta developed the *voltaic pile*. His apparatus consisted of a pile of zinc and silver discs. Between the metal discs there was a cardboard disc that had been soaked in saltwater. (What is special about salt water?) A wire connected the bottom zinc disc to a wire on the top silver disc and when connected, a spark was produced.



A sketch of the original voltaic pile invented by Alessandro Volta

As you've seen with the Van de Graaff generator, before the voltaic pile was invented, sparks could only be generated by friction, which involved mechanical work. The voltaic pile provided a continuous source of charge and was widely regarded as the first battery.

You may have heard of the terms *galvanic*, *galvanize*, and *galvanometer*, referring to the work of Luigi Galvani. The unit of electric potential is the *volt*, named after Alessandro Volta. Electric potential is often referred to as *voltage*.

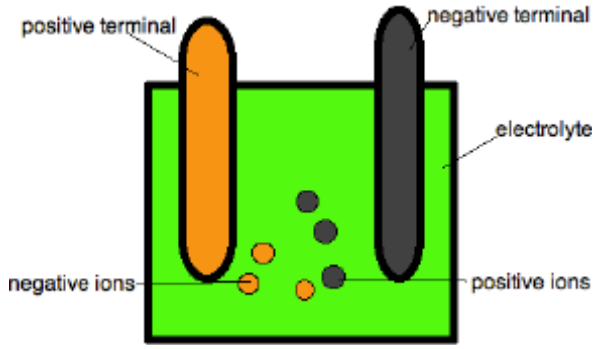
How Batteries Work

In the simplest form, a battery has three main components:

1. electrolyte (like the saltwater in the voltaic pile)
2. a metal (zinc) that will lose positive ions
3. a metal (carbon manganese dioxide composite) that will lose negative ions.

When the zinc is in the electrolytic solution, the solution pulls positively charged ions off of the post. The zinc post now has more negative ions and has a negative charge. When the second metal is put into the same solution, the solution pulls negatively charged ions, leaving the carbon post positively charged. When a conductive wire is placed between the positively charged carbon terminal and the negatively charged zinc terminal, electrons flow from the zinc to the carbon and the chemical reaction continues. When all of the reactants are used up, the battery dies.

When the terminals of a battery are connected with a direct path, the battery will die very quickly (short circuit). However, something that will slow down the flow of electrons, like a light bulb, can be placed between the terminals, connected by a wire.



Current

We mentioned that electrons were flowing from one terminal to the other. Current is defined as the rate of flow of electric charge (how many units of charge are flowing per second). The symbol for current is I and the unit for current is an Ampere.

When Benjamin Franklin chose positive and negative charges, he determined the direction of current. Current flows from positive to negative, however, as we have noticed from our battery, electrons flow from negative to positive! Don't get discouraged; current being in the opposite direction of electron flow is just a convention.

Simple Circuits

In the previous reading, we discussed that connecting a bulb to the terminals of the battery would result in the bulb lighting up. This is known as a simple circuit. Individual parts of a circuit, such as a battery, bulb, and switches are called **circuit elements**. A simple circuit consists of two of these devices, a source of electric potential (battery) and an energy-consuming device (light bulb). A bulb will light only if it is part of a complete circuit: a closed loop from one terminal of the battery, through the bulb, and to the other terminal. The wires from the battery are known as positive and negative leads. As electrons travel from the negative terminal to the positive terminal of the battery, they travel through the bulb. When the filament in the bulb gets really hot, it glows (remember: current and electrons flow in opposite directions).

The Slide Analogy

One ladder, one slide

The elevation (E) is "provided" by the ladder.

The run length (R) is the slide's horizontal distance.

Incline (flow rate) of the slide panel is determined by the relation I = E/R, incline = elevation/run length.

The bun-burning power is determined by BB = IE, bun burning = flow rate x elevation.

One battery, one bulb

The electrical potential (E) is provided by the battery.

The resistance (R) is due to the device in the circuit, like a bulb.

The current (I) is determined by I = E/R, current = electrical potential/resistance.

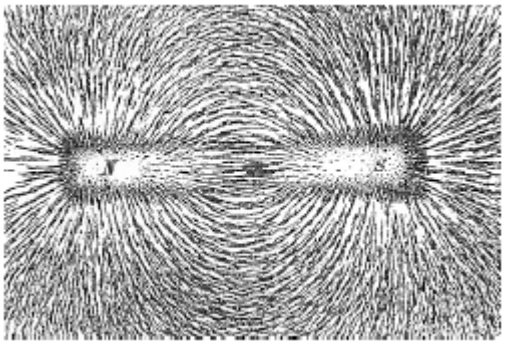
Power in the circuit is determined by P = IE, power = current times electrical potential.

Magnetism

What is a magnet?

A magnet, in its most basic definition, is an object that produces a magnetic field. While the magnetic field is invisible, it is responsible for the magnet's ability to attract magnetic metals, such as iron or nickel, and also gives it the ability to attract or repels other magnets. Magnets have two poles, north and south. They are named this, because when allowed to orient themselves, they naturally will align themselves with the earth's magnetic field. The north pole will point towards the earth's north pole, and the south pole will point towards the Earth's south pole. This is the underlying property that makes a compass work. Through simple observations, some of the fundamental, yet most exciting properties of magnets can be established:

- Magnets have 2 opposite poles, north and south pole
- Like poles repel
- Similar poles attract
- Magnets are strongest at their poles
- The ability to attract or repel varies greatly with distance



Magnetic Domains

All magnetic materials are made up of thousands of smaller "permanent magnets" called domains. A permanent magnet is essentially a magnetic material that produces a persistent magnetic field. A domain consists of approximately 1 quadrillion individual atoms. When a piece of magnetic metal is introduced to a magnetic field, its domains will align themselves to the direction of the externally applied field. This will cause the metal to produce its own magnetic field. After the external field is removed, some of the domains will stay in alignment, and the metal will now produce its own magnetic field. The number of domains that stay in alignment after the external field is removed, is greatly dependent on the type of magnetic material.

Magnetic material types

Hard magnetic material

Most common household magnets will fall under this category. Refrigerator magnets are a good example. Basically, a hard magnet is categorized by its ability to retain its magnetic alignment after it has been removed from an external magnetic field. This characteristic is what allows us to build "permanent magnets", or magnets that produce a persistent magnetic field.

Soft magnetic material

Magnetic material of this type is used in transformer and electromagnetic cores, when it is not desirable for the material to maintain its magnetic field after the external field has been removed. In a transformer core, the magnetic field of the material must be easily reversed, without wasting much energy. This property is what allows us to build high frequency transformers that are also very efficient.

Activities and Demonstrations

Static Repulsion and Attraction with Balloon and Acrylic Rod

Grade level recommendation: All grades

Time allotment: 30 min

Safety Precautions: none

Materials:

- Rubber balloon
- Piece of wool
- Acrylic rod
- Glass rod
- Electroscope
- Sink with running water

Procedure:

Step One: The balloon and your hair.

Blow up the balloon and observe what happens when you rub the balloon against your hair. This works best on a cold and dry day. Hold the balloon just above your head and observe how your hair reacts. Then place the balloon on a wall with butcher paper over it. Observe.

Step Two: The balloon and water.

Rub the balloon against your hair again (or with the wool cloth) and then turn on the sink so that a small steady stream of water is coming from the faucet. Hold the balloon close to the stream, but don't get it wet. Observe that the water bends!

Step Three: Bulbs in Parallel.

Take the glass rod and rub the rod with the piece of wool. Bring the glass rod close to the top of the electroscope and observe any motion in the leaves. Repeat with the acrylic rod.

Explanation:

When you rub the balloon, you remove some of the electrons from it. The electrons are transferred from the balloon to your hair. The balloon now has a positive charge and your hair a negative charge. This causes the attraction between the two. The same thing happens with the water. Given the geometry of the water molecule, the water bends towards the balloon. The acrylic rod is an example of a material that will give up electrons easily, while the glass rod is not (electron affinity). When you bring the charged acrylic rod near the top of the electroscope, you observe that the leaves deflect due to the same inducted charge in each.

The Transfer of Charge and the Van de Graaff Generator

Grade level recommendation: All grades Time allotment: 30 min

Safety Precautions: This demonstration should be led or supervised closely by the teacher.

Students should not operate the generator without proper instruction and supervision.

Materials:

- Van de Graaff Generator
- Metal rod
- Styrofoam bowls (3-5)
- Paper clip

Procedure:

Step One: Demonstrating an Arc.
Turn on the generator and allow time for charge to gather in the dome. Bring the metal rod close to the dome. Observe arcing between the two metal surfaces. Turn off the generator.

Step Two: Demonstrating Repulsion.
Take a stack of 3-5 Styrofoam bowls and place them upside-down on the top of the dome. Turn the generator on and observe what happens to the bowls. Turn off the generator.

Step Three: The Human Chain.
Have a student volunteer come up to the generator and place both hands on the dome. Turn on the generator and instruct the student to keep his/her hands on the dome. Ask the student to describe what he/she feels and observe any changes in their hair. Then ask for a second volunteer. Have the first student take one hand off the dome and reach for the second student's hand. Students will feel a little shock! See how long of a chain can be made. Turn off the generator.

Step Four: Electric Wind.
Partly unfold a paper clip and tape it to the dome so that the clip is pointing off of the dome. Turn on the dome and allow the dome to gather charge. Then have students come up and place their hand in front of the point of the paper clip and observe that there is a "wind."

Explanation:
As the rubber belt in the generator rubs against the first comb, it becomes positively charged. Then the belt is in contact with a second comb connected to the dome. Electrons from the metal dome are attracted to the positive belt. The belt runs through the combs very quickly, causing a positive charge to build up in the dome.

The Lemon Battery

Grade level recommendation: 4-12 Time allotment: 30 min

Safety Precautions: Food is for demonstration purposes only and should not be consumed.

Materials:

- Lemon half or wedge
- 2 galvanized (zinc-coated) nails
- plate or bowl
- other fruits or vegetables to test (potatoes work best)
- The Lemon Battery worksheet
- Voltmeter or multimeter
- Other common metal objects (paper clips, keys, etc.)

Procedure:

Step One: Making a the Battery.
Stick the two nails into the lemon making sure they are not touching.

Step Two: Measure the Voltage.
Using the multimeter or voltmeter, measure the potential difference between the two nails.

Step Three: Make a Better Battery.
Allow students to explore the "potential" of their food by trying various other vegetables and fruits as well as other combinations of metallic materials.

Explanation:
The acid in the fruit/vegetable acts as a corrosive agent to one of the nails. This causes one nail to reduce and the other to oxidize, creating a potential difference between them. The nails then act like terminals in a battery. You might even be able to light up a small bulb!

Building a Simple Circuit

Grade level recommendation: 4-12

Time allotment: 30 min

Safety Precautions: Do not leave the bulbs connected for long. Since the resistance of the small bulbs is low, the battery will get warm. Never short a battery by connecting its terminals directly.

Materials:

- insulated copper wire
- electrical tape
- 1.5 V D-cell battery (one per group)
- small bulb (3 per group)

Procedure:

Step One: Making a Circuit.
Using the battery, 4 inches of wire, and one bulb, connect the three components such that the bulb lights up. There are 4 ways to do this.

Step Two: Bulbs in Series.
Take a second and third piece of wire. Use the tape to connect two bulbs in series with the battery. Observe the change in brightness of the first bulb when a second is added. Repeat with more wire and a third bulb.

Step Three: Bulbs in Parallel.
Rearrange the circuit components so that the two bulbs are in parallel. Observe the change in the brightness of the first bulb when a second is added in parallel. Repeat with more wire and a third bulb.

Explanation:
When bulbs (a resistive component) are added in series, the total resistance in the circuit increases. Current has to push through two bulbs in a row. When in series, the total resistance is equal to the sum of each resistive component. The bulbs are equally as bright since the bulbs have the same resistance, but are not as bright as a single bulb circuit. When bulbs are added in parallel, the current divides between each path to the bulbs. Since the resistance is the same in each bulb and fewer electrons are traveling through each, the bulbs in parallel will be equally as bright as a single bulb in a circuit. Total resistance of bulbs in parallel is equal to the product of all resistive elements divided by the sum.

Building a Simple Electromagnet

Grade level recommendation: 4-12 Time allotment: 30 min

Safety Precautions: none

Materials:

- spool of wire
- 12 volt lamp battery
- a long nail at least 3”
- DC Switch (optional)
- Wire cutters
- Paper Clips

Procedure:

Step One: Wrapping the wire.
Take the long nail and wire, and tightly coil the wire around the nail at least 50 times. Make sure to leave 3 to 5 inches on either side of the wire.

Step Two: Hooking up the battery.
Take the exposed wire from the top part of the nail and electrical tape it to the negative pole of the battery. Take another small piece of wire and electrical tape it to the positive pole of the battery.

Step Three: Hooking up the switch.
Take the wire that is connected to the positive pole of the battery and attach it to one of the terminals of the DC switch. Make sure the switch is in the off position. Attach the loose end of the wire wrapped around the nail to the other terminal on the DC switch.

Step Four: Turning the switch on.
Flip the switch to the on position and hold the nail up to a pile of paper clips.

Explanation:
The material of the core of the magnet (usually iron) is composed of small regions called magnetic domains that act like tiny magnets (see ferromagnetism). Before the current in the electromagnet is turned on, the domains in the iron core point in random directions, so their tiny magnetic fields cancel each other out, and the iron has no large scale magnetic field. When a current is passed through the wire wrapped around the iron, its magnetic field penetrates the iron, and causes the domains to turn, aligning parallel to the magnetic field, so their tiny magnetic fields add to the wire's field, creating a large magnetic field that extends into the space around the magnet. The larger the current passed through the wire coil, the more the domains align, and the stronger the magnetic field is. Finally all the domains are lined up, and further increases in current only cause slight increases in the magnetic field: this phenomenon is called saturation.

When the current in the coil is turned off, most of the domains lose alignment and return to a random state and the field disappears. However some of the alignment persists, because the domains have difficulty turning their direction of magnetization, leaving the core a weak permanent magnet. This phenomenon is called hysteresis and the remaining magnetic field is called remnant magnetism. The residual magnetization of the core can be removed by degaussing.