# ArcAttack!

Creators of the Original
Singing Tesla Coils

Teacher Resource Guide

# ARCATTACK!

*Live*

Teachers' Resource Manual

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# History and Mission

ArcAttack was founded in 2005 by Joe DiPrima. Arcattack is a multimedia performance art group specializing in the production of music through homemade instruments. It is ArcAttack's mission to inspire interest in research and educate audiences about the technology featured in live performances.

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.

Through our lessons and musical performance, we will explore the same basic scientific principles and inspirations that have led us to the creation of the ArcAttack project.

# 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 $4^{th}$-$8^{th}$ 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 & Foces
- 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 IN PERSONAL & SOCIAL PERSPECTIVIES

- Personal Health
- Populations, resources, and enviroments
- Natural Hazzards
- Science and technology in society

## HISTORY AND NATURE OF SCIENCE

- History of Science
- Science as a human endeavor


| | SINGING TESLA COIL | ROBOTIC DRUM SET | CHAINMAIL FARADAY SUIT | LIGHTNING POWERED GUITAR |
|---|---|---|---|---|
| **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 objects made by humans | ✓ | ✓ | ✓ | ✓ |
| Abilities of technological design | ✓ | ✓ | ✓ | ✓ |
| Understanding about science and technology | ✓ | ✓ | ✓ | ✓ |
| **SCIENCE IN PERSONAL & SOCIAL PERSPECTIVES** | | | | |
| Personal health | ✓ | | ✓ | |
| Populations, resources, and environments | | | | |
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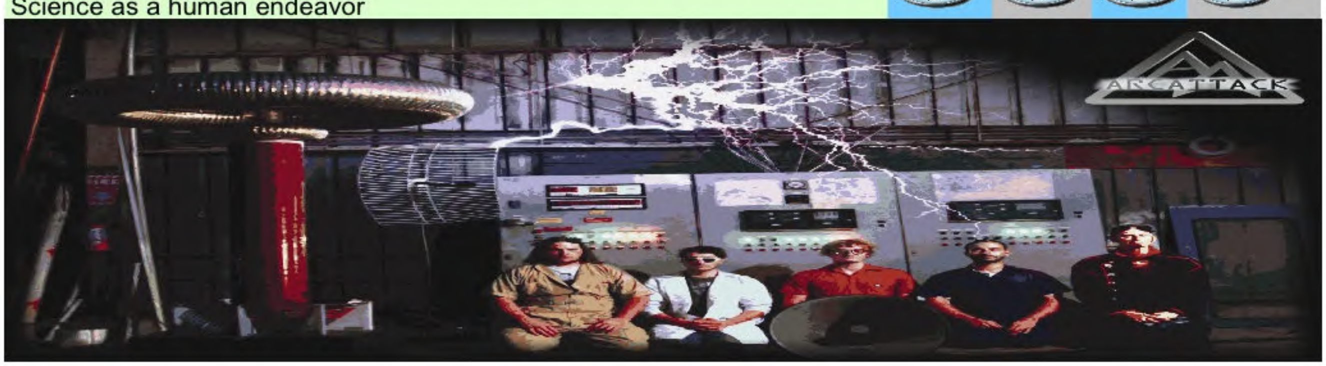


# The Science of ArcAttack!

## Tesla Coils

A Singing Tesla coil is perhaps the most exciting component of the Arcattack performance. It is a variety of solid state Tesla coil (meaning it has transistors) that is capable of modulating musical notes. What this means is that we turn on and off the Tesla coil very rapidly—440 times per second to produce the musical note “A”. Each time the Tesla coil is turned on, an electric arc occurs. The ear interprets each series of popping arcs as sound.

## Robotic Drum Set

Our robotic drum set was constructed by Craig Newswanger of Resonance Studios in Austin, Texas. The robot is activated by a midi signal that is sent from a computer to the robot’s brain. The brain then interprets this data and tells the robotic arm to strike the drum with a mallet. The arm is driven by a solenoid actuator, which strikes as firmly or as softly as the computer tells it to.

## Computer Control/MIDI and the Lightning-Proof Guitar

Musical Instrument Digital Interface, or MIDI, is a “digital message” that travels between the electronic instruments, like the synthesizer and the lightning-proof guitar.  This communication between instruments ensures that they are synchronized.  The signal is sent through fiber optic cables to the Tesla coils, telling the coil at which frequency it is to be turned on and off.

# Key Scientific Principles

# Static Electricity

Figure 1: http://upload.wikimedia.org/wikipedia/commons/thumb/a/a7/Gouttes-drops-resine-2.jpg/220px-Gouttes-drops-resine-2.jpg

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 (Figure 1) would attract feathers or small pieces of straw. "$\eta\lambda\epsilon\kappa\tau\rho o\nu$" (*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 (Figure 2). 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* (Figure 3).

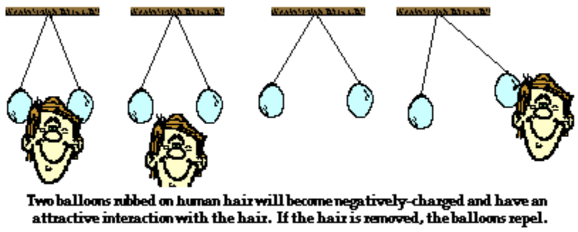



**Figure 2: http://www.physicsclassroom.com/class/estatics/U8l2a.cfm**


**Figure 3: http://www.ecd.com/blog/wp-content/uploads/2009/04/triboelectricseries.jpgcontent/uploads/2009/04/triboelectricseries.jpg**

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.

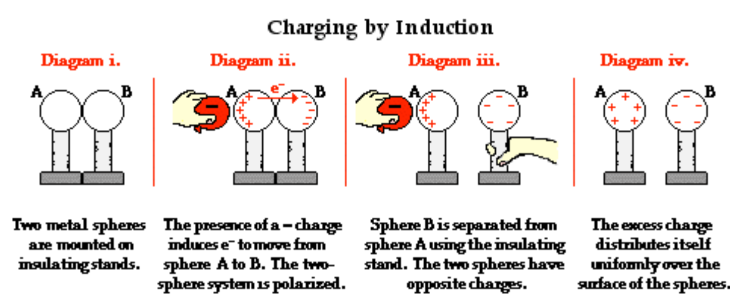



**Figure 4: http://www.physicsclassroom.com/class/estatics/U8l2b.cfm**

# 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 $-1.602\times10^{-19}$ coulombs. So if an object has an excess of $10^{14}$ electrons, it's overall charge is q = ($-1.602\times10^{-19}$ C/electron)($10^{14}$ electrons) = $-1.602\times10^{-5}$ C.

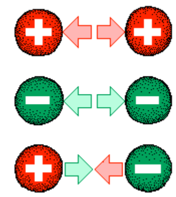
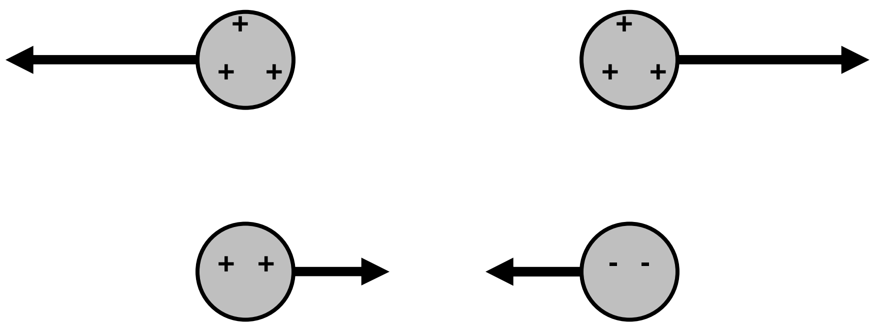
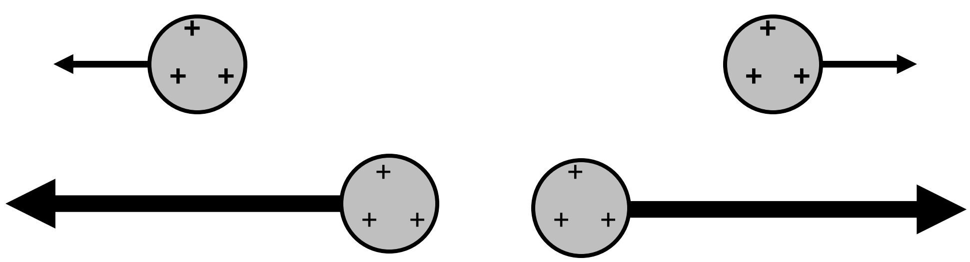


**Figure 5: http://www.datasync.com/~rsf1/eas.htm**

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.

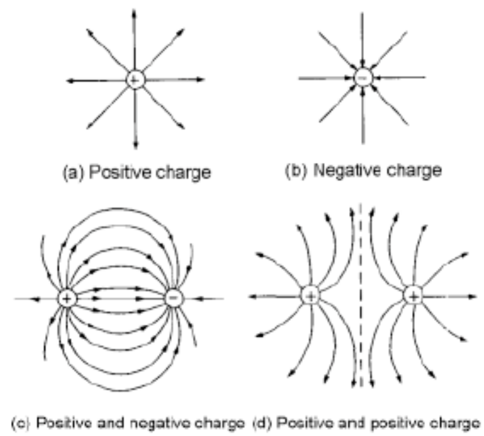



**Figure 6: http://www.mea.or.th/internet/understanding_emf_web/emf_eng/webpage_eng/page01_eng.htm**

# How Lightning Works

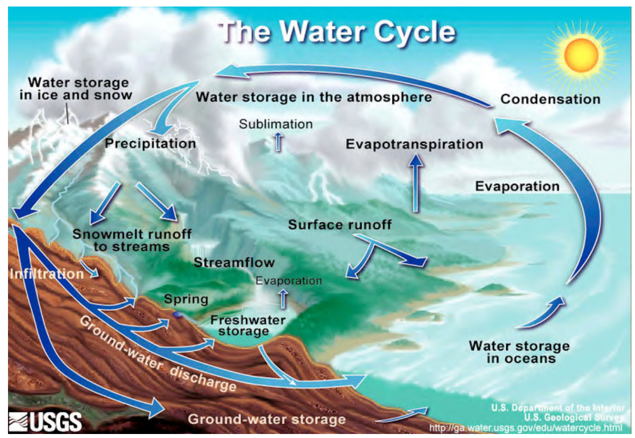
## Lightning starts with the water cycle:

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 could 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 co=loud 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!

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Zavisa, John. "How Lightning Works." 01 April 2000. HowStuffWorks.com. <http://science.howstuffworks.com/lightning.htm> 02 September 2009

# 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 Glavani 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*.

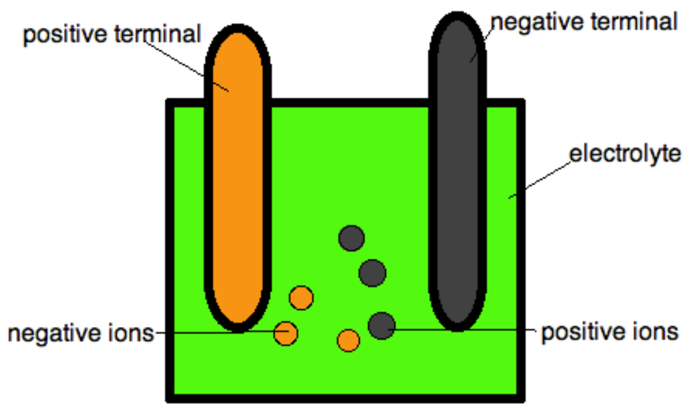
# How Batteries Work

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

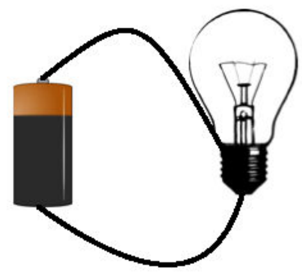
We mentioned that electrons were flowing from one terminal to the other. **Current** is defined as the rate of flow of electric charge (how many units of charge are flowing per second). The symbol for current is *I* and the unit for current is an *Ampere*.

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

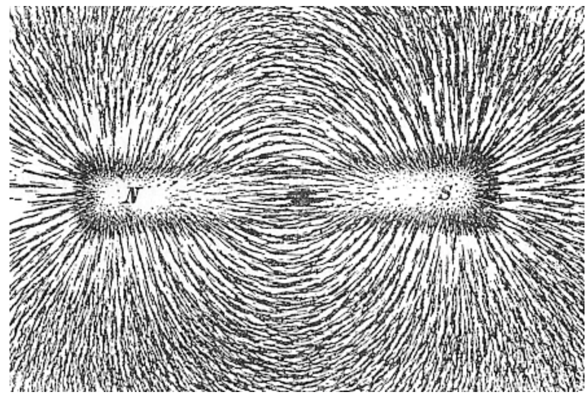


| | |
|---|---|
| One ladder, one slide | One battery, one bulb |
| The elevation (E) is "provided" by the ladder. | The electrical potential (E) is provided by the battery. |
| The run length (R) is the slide's horizontal distance. | The resistance (R) is due to the device in the circuit, like a bulb. |
| Incline (flow rate) of the slide panel is determined by the relation I = E/R, incline = elevation/run length. | The current (I) is determined by I = E/R, current = electrical potential/resistance. |
| The bun-burning power is determined by BB = IE, bun burning = flow rate x elevation. | 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 2 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.

# Supplemental Worksheets And Keys

# The Transfer of Charge and the Van de Graaff Generator

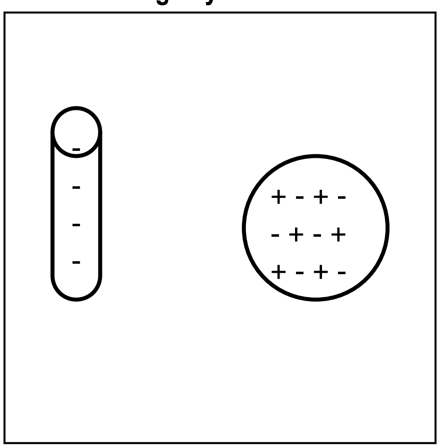
**Conductors** are materials that allow the flow of charge to move freely. **Insulators** are materials in which the flow of charge is restricted and stored.

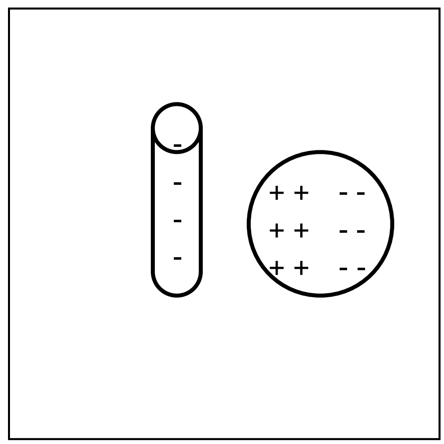
As you've seen with the balloon experiment, objects can become charged by several methods.

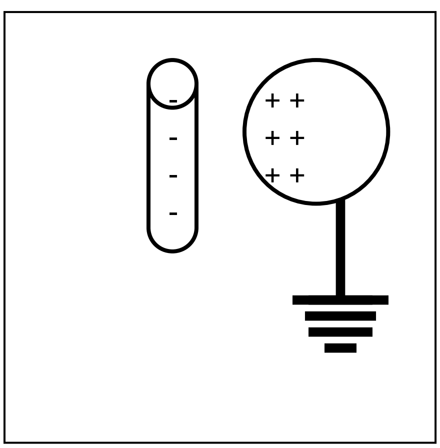
**Charge by contact**:
Touching or rubbing of two materials, which cause on material to lose electrons and the other to gain those electrons
What is an example of this that you have observed?

Can a **conductor** become charged by contact? How?

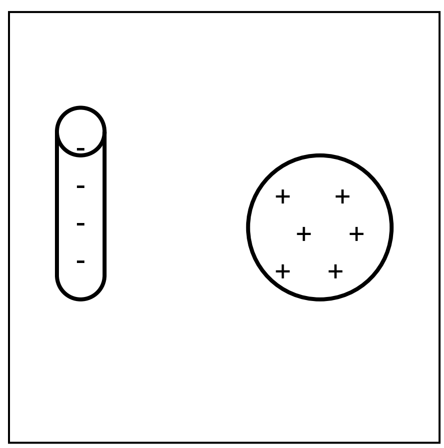
**Charge by induction**:

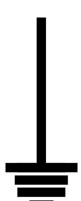






When the ball is **grounded**,





**Grounded** – when a conductor is connected to the earth by means of a conducting wire or copper pipe, the conductor is said to be grounded. The earth can be considered an infinite reservoir for electrons ( - charged particles) because it can accept or supply an unlimited number of electrons.

# The Transfer of Charge and the Van de Graaff Generator

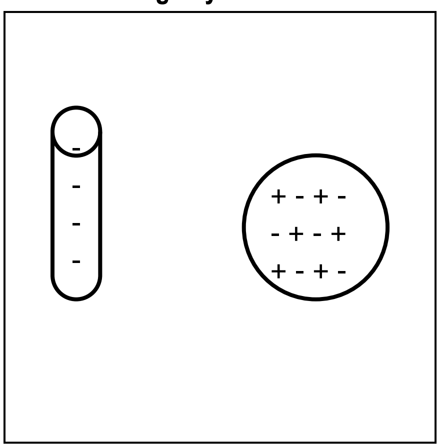
**Conductors** are materials that allow the flow of charge to move freely. **Insulators** are materials in which the flow of charge is restricted and stored.

As you've seen with the balloon experiment, objects can become charged by several methods.

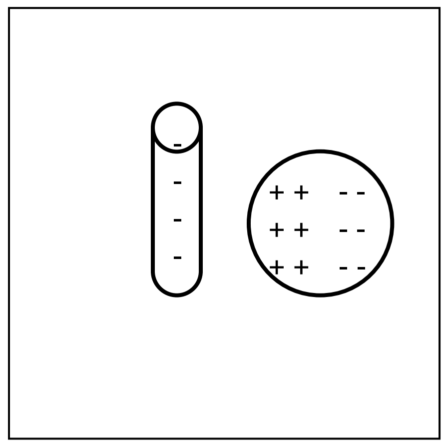
**Charge by contact**:
Touching or rubbing of two materials, which cause on material to lose electrons and the other to gain those electrons
What is an example of this that you have observed?
Balloon experiment with static electricity.

Can a **conductor** become charged by contact? How?
When we rubbed the balloons on our hair, the balloons and hair exchanged charged particles. One became negative and one became positive. Then they attracted each other.

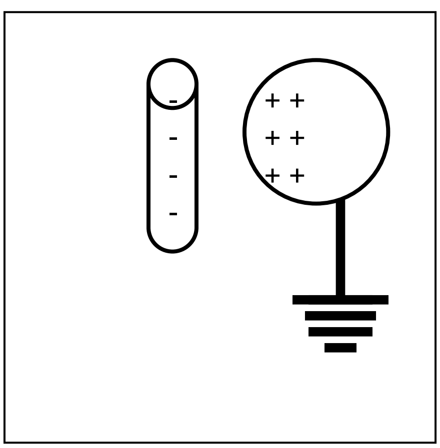
**Charge by induction**:



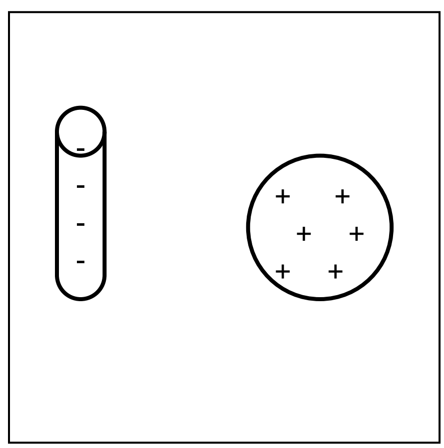
First, bring a charged object towards a neutral object, like this rod and a metal ball.



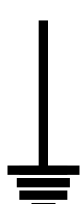
The charges in the ball rearrange themselves since the + in the ball are attracted to the – in the rod.



When the ball is **grounded**, the – leave the ball.



The ball has been charged by **induction**.



**Grounded** – when a conductor is connected to the earth by means of a conducting wire or copper pipe, the conductor is said to be grounded. The earth can be considered an infinite reservoir for electrons ( - charged particles) because it can accept or supply an unlimited number of electrons.

# May The Force Be With You

In the box on the left, draw a simple diagram of the Earth orbiting the Sun.

The _______ has more mass than the _________.

______________________ force attracts the ______ to the __________

This force depends on the __________ of the Earth, the _________ of the Sun, and the ____________ between them.

Please circle the true statements for (a) and (b)

(a) $F \propto \dfrac{1}{m_{Earth} \times m_{Sun}}$ $\qquad F \propto m_{Earth} + m_{Sun}$

$F \propto m_{Earth} \times m_{Sun}$ $\qquad F \propto \dfrac{1}{m_{Earth} + m_{Sun}}$

(b) $F \propto \sqrt{R}$ $\qquad F \propto \dfrac{1}{R^2}$

$F \propto R$ $\qquad F \propto R^2$

In the box on the left, draw a simple diagram a hydrogen atom.

A hydrogen atom has ____ proton(s), ____ neutron(s), and _____electron(s).

The proton has a _______ charge and the electron has a _________ charge. The _______ has more mass than the _________.

The proton and the electron are ______________ to each other.

Since the proton and electron are ____________________ to one another, there must be some force causing this.

What is the definition of a force?

Look at your diagrams. What do you notice? What comparisons can you make?

From your diagrams and your previous knowledge of gravitational force, what can you conclude about the force between the electron and proton?

Do you think that the force between the charged particles depend on the mass? Why or why not? If not, what would it depend on?

How do you think the force between the charged particles depends on the distance? Directly? Inversely?

**Coulomb's Law**

# May The Force Be With You

In the box on the left, draw a simple diagram of the Earth orbiting the Sun.

The Sun has more mass than the Earth.

Gravitational force attracts the Earth to the Sun (and the Sun to the Earth).

This force depends on the mass of the Earth, the mass of the Sun, and the distance between them.

Please circle the true statements for (a) and (b)

(a) $F \propto \frac{1}{m_{Earth} \times m_{Sun}}$ $\quad F \propto m_{Earth} + m_{Sun}$

$F \propto m_{Earth} \times m_{Sun}$ $\quad F \propto \frac{1}{m_{Earth} + m_{Sun}}$

(b) $F \propto \sqrt{R}$ $\quad F \propto \frac{1}{R^2}$

$F \propto R$ $\quad F \propto R^2$

In the box on the left, draw a simple diagram a hydrogen atom.

A hydrogen atom has 1 proton(s), 0 neutron(s), and 1 electron(s).

The proton has a positive charge and the electron has a negative charge. The proton has more mass than the electron.

The proton and the electron are attracted to each other.

Since the proton and electron are attracted to one another, there must be some force causing this.

What is the definition of a force?

A push or a pull

Look at your diagrams. What do you notice? What comparisons can you make?

Similar pictures. Electron "orbits" proton as Earth orbits Sun.
Earth is drawn to Sun as electron is drawn to proton
Force acts on both the electron and proton as it does on both the Earth and the Sun

From your diagrams and your previous knowledge of gravitational force, what can you conclude about the force between the electron and proton?

Force is proportional to the inverse of the distance squared.
Forces act on both elements of system.

Do you think that the force between the charged particles depend on the mass? Why or why not? If not, what would it depend on?

Protons and electrons are virtually massless, so force depends on charge. Protons and electrons have the same magnitude of charge, but opposite signs.

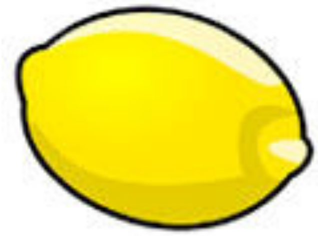
How do you think the force between the charged particles depends on the distance? Directly? Inversely?

Like gravitational force, the electric force is inversely proportional to the square of the distance between the particles.

## Coulomb's Law

$$F = k\frac{q_1 q_2}{R^2}$$

# The Lemon Battery



**Materials**

- Lemon half or wedge
- 2 galvanized (zinc-coated) nails
- plate or bowl
- other fruits or vegetables to test

**Pre-lab**

What were the critical ingredients of Galvani's and Volta's batteries?

**Procedure**

1. Using the picture of the voltaic pile in your reading as a guide, design a battery that will register 0.5V or more. When you think you have a design that will work, ask the teacher to use a *voltmeter* to measure the voltage that your lemon battery produces. Record your voltage below:

   V = _______________

2. Sketch your working lemon battery before. Identify and label the parts.

3. Try to make a different battery that will register more voltage with a different vegetable or fruit. You may also try to make a battery with different metal objects (try a penny, a key, or a paperclip). Compare your observations with your classmates. Which vegetable or fruit works best?

# Ohm's Law

Go to http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc and open the simulation by PhET, University of Colorado at Boulder. Take note of the various tools offered to you. Be sure to select "show values".

1. Build a simple circuit with one bulb and one batter. Use the non-contact ammeter to measure the current in the circuit.
2. Add a second bulb in series and measure the current in the circuit.
3. Add a third bulb in series and measure the current in the circuit.
4. Build a new circuit with two bulbs in parallel and measure the current through each bulb.
5. Add a third bulb in parallel and measure the current through each bulb.
6. Try various circuit designs and see what the "grab bag" will give you. Record the current through each circuit element.

| Schematic Diagram | Resistance of Bulb 1 | Resistance of Bulb 2 | Resistance of Bulb 3 | Total Resistance | Voltage of Battery | Total Current |
|---|---|---|---|---|---|---|
| | | | | | | |
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# Glossary

| | |
|---|---|
| Alternating Current | Electrons flow in both directions in a cyclic manner |
| Amp | The unit of measure of current |
| Battery | A power source that uses electrochemical reactions to produce a positive and a negative terminal |
| Capacitor | Electrical component that can store electrons in a circuit |
| Circuit | A series of components connected by wires so that current can flow in a complete cycle |
| Conductor | A substance through which electrons can move freely |
| Current | The rate of flow of charge |
| Direct Current | Electrons flow in one direction only, from negative to positive, although it is conventional to symbolize current traveling from positive to negative terminals |
| Electron | Negatively charged subatomic particle |
| Ground | A connection in a circuit to the earth |
| Hertz | The unit of measure for frequency |
| Inductors | Components that can store energy in a magnetic field |
| Insulator | A substance through which electrons cannot move freely |
| Joule | The unit of measure of energy |
| Microcontroller | A circuit that can be programmed |
| Multimeter | A tool that can be used to measure voltage, current and resistance |
| Neutron | Subatomic particle with no charge |
| Ohm | The unit of measure of resistance |
| Ohm's Law | Defines the relationship between current, voltage, and resistance: $V = IR$ |
| Parallel circuit | Circuit in which current is divided among different paths through various components |
| Power | The amount of work that is done by the electric current |
| Proton | Positively charged subatomic particle |
| Resistance | The measurement of the ability of current to move through a material |
| Resistor | A component used in a circuit to reduce the current |
| Schematic | A drawing showing how components in a circuit are arranged and connected |
| Series circuit | Circuit in which current runs through each component |
| Short circuit | A component is shorted when two wires are connected together in parallel with the component, resulting in a path of negligible resistance |
| Static electricity | Form of current that is trapped in an insulating body |
| Volt | The unit of measure of voltage or potential difference |

| | |
|---|---|
| Voltage | The attractive force between positive and negative charges |
| Watt | The unit of measure of power |

# Bibliography and Recommended Readings

McComb, Gordon, and Earl Boysen. *Electronics for Dummies*. Hoboken, NJ: Wiley Publishing, Inc., 2005. Print. ISBN: 0-7645-7660-7

McDermott, Lillian C. *Physics By Inquiry*. II. John Wiley & Sons, Inc., 1996. Print. ISBN: 0-471-14441-X

University of Colorado Boulder. "PhET." *Circuit Construction Kit (DC Only)*. N.p., n.d. Web. <http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc>.

# ArcAttack

Creators of the Original Singing Tesla Coil

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