

Electricity

Abracadabra! Levitating with Eddy Currents!

(from <http://www.sciencebuddies.com>)

Objective

The objective of this science fair project is to demonstrate eddy currents and induced magnetic fields.

Introduction

What is a magnet? A magnet is a material that produces a **magnetic field**, which can **exert a force** on other materials without actually touching them. A magnetic force can attract or repel, and some materials can exert a larger force than others. Every magnet has at least one north pole and one south pole. Did you know the Earth is a magnet? A magnet produces a field at all points around it in space. The Earth has a magnetic field that repels space radiation and solar wind. The magnet's poles (such as Earth's north and south poles) are where the magnetic field begins and ends. If you look at the magnetic field of Earth, you will notice that the magnetic field is not straight. The field starts at the north pole and bends as it meets the south pole. Since the magnetic field bends, it has a direction.

Russian physicist Heinrich Lenz started studying electricity and magnetism in 1831. In 1834, while investigating magnetic induction, he noticed and described an interesting phenomenon. This phenomenon is now called **Lenz's law** and it occurs when a magnet interacts with a conductor. A **conductor** is a material that permits electrons (and therefore electricity) to flow through it easily. This means that a conductor has a low **resistance** and **resistivity** to the motion of electrons. When a magnetic field varies along the length of the conductor, like when you let go of a magnet down a metal tube, the magnetic field induces a **current** within the conductor. This current is called an **eddy current**. Once the eddy current is established, it then produces a magnetic field. This **induced** magnetic field opposes the magnetic field of the magnet that is moving along the conductor. As a result of two opposing magnetic fields, the magnet will stop moving and float, or levitate. This is the principle behind the world's fastest trains, called *magnetic levitation* (maglev) trains. There is no physical contact between the train carriages and the tracks.

Factors that increase the effect of eddy currents include stronger magnetic fields, faster-moving magnetic fields, and thicker conductors. Factors that reduce the effect

of eddy currents include weaker magnets, slower-moving magnetic fields, and non-conductive materials.

In this electricity and electronics science fair project, you will investigate magnets and eddy currents. You will accomplish this by sending a **neodymium** magnet down a conductive tube and then down a non-conductive tube. Is there a difference between the ways the magnet falls down the two tubes? Do this science fair project and find out!

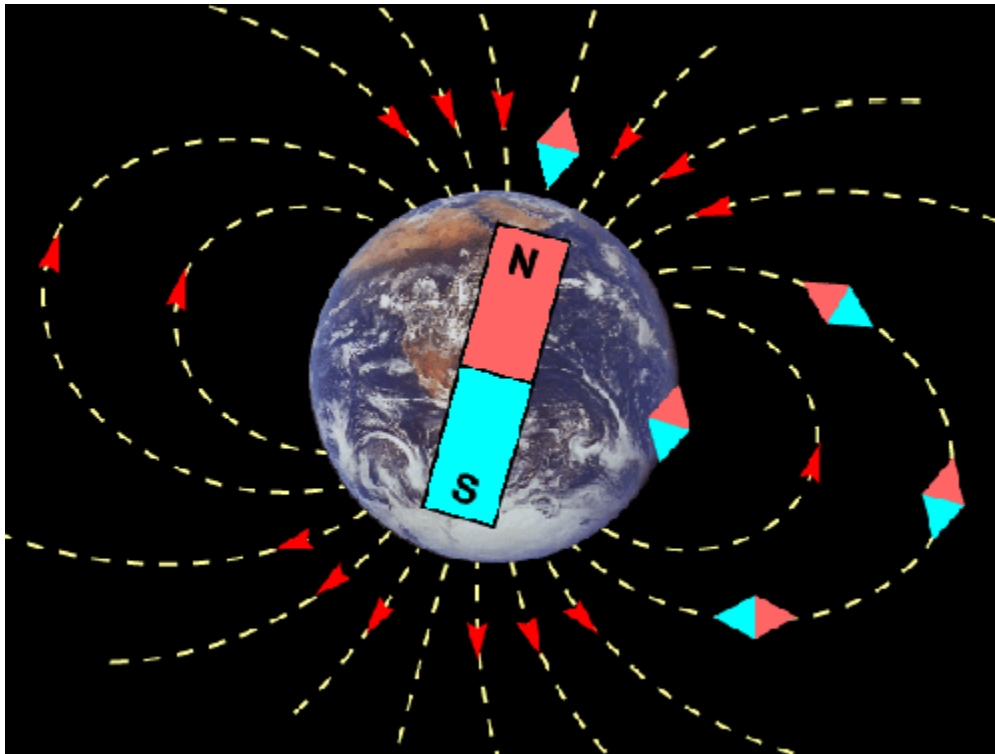


Figure 1. This image depicts Earth's magnetic field. (NASA, 2006.)

Terms, Concepts and Questions to Start Background Research

- Magnetic field
- Exert
- Force
- Lenz's law
- Conductor
- Resistance
- Resistivity
- Current
- Eddy current
- Induce

- Neodymium

Questions

- What is a conductor?
- What is the difference between a conductor and a non-conductor?
- What is the resistivity of copper?
- What is a magnetic field?

Bibliography

- Davidson, M. (2006, June 15). Molecular Expressions: Electricity & Magnetism Introduction—Lenz's Law. Retrieved December 12, 2008 from, <http://micro.magnet.fsu.edu/electromag/java/lenzlaw/index.html>

This science fair project is based on the Eddy Currents project on the Exploratorium's website:

- Exploratorium. (n.d.). *Eddy Currents*. Retrieved December 12, 2008, from http://www.exploratorium.edu/snacks/eddy_currents/index.html

This HowStuffWorks video is a thorough discussion of Lenz's law and eddy currents:

- HowStuffWorks.com. *Physics: Lenz's Law and Eddy Currents*. Retrieved December 12, 2008, from <http://videos.howstuffworks.com/hsw/17415-physics-lenzs-law-and-eddy-currents-video.htm>

There are several sources online that list resistivity values for different materials. The following are two examples.

- Wikipedia Contributors. (2009, February 2). Resistivity. *Wikipedia The Free Encyclopedia*. Retrieved February 2, 2009 from <http://en.wikipedia.org/w/index.php?title=Resistivity&oldid=268052857>
- European Council of Vinyl Manufacturers. (n.d.). *PVC: Electrical insulation characteristics*. Retrieved February 2, 2009, from <http://www.pvc.org/PVC.org/What-is-PVC/PVC-s-physical-properties/Electrical-insulation-characteristics>

Materials and Equipment

- Neodymium magnet (1); available online at www.dowlingmagnets.com. We suggest the 21-piece nickel-copper set, part # 731007. The magnet diameter should be a few millimeters (mm) less than the diameter of the pipes you are using. If you use a 1/2-inch-diameter pipe (which is about 12.7 mm) then your magnet should be about 5 mm in diameter.
- Copper pipe, 1/2-inch inner diameter (4 feet)
- PVC pipe, 1/2-inch inner diameter (4 feet)

- Volunteer
- Stopwatch
- Lab notebook

Experimental Procedure

1. Open the package of magnets. Play with one of the magnets to get a feel for its force around the other magnets and the pipes. Make sure you know how to use the stopwatch.
2. Hold the copper pipe vertically. Hold the pipe near the top and have the volunteer hold the pipe near the bottom so that the pipe doesn't shake.
3. Hold a magnet at the top of the pipe. Position it at the center of the pipe's opening. Let go of the magnet and immediately start the stopwatch. Time how long it takes for the magnet to fall out of the tube. Record this time in your lab notebook.
4. Repeat step 3 nine additional times and record the data in your lab notebook.
5. Repeat steps 2-4 with the PVC pipe. Do you see a difference in the times? Were you able to *see* the magnet floating down the tube?
6. Plot the data that you collected on a scatter plot. Label the x-axis *Tube* and the y-axis *Falling Time*. List the resistivity values of each material on the scatter plot. You can find resistivity values in the two sources listed in the Bibliography.

Variations

- Repeat this experiment using tubes of different conductors. For example, try using a brass tube and an aluminum tube.
- What happens as you increase the diameter of the tube? Does the time it takes for the magnet to fall down the tube decrease, increase, or remain the same?

Conductance as a Water Quality Measurement

(from <http://www.sciencebuddies.com>)

Objective

The goal of this experiment is to assess the purity of water samples by measuring their conductance (the inverse of electrical resistance) using a low-cost data acquisition device that you control using your personal computer.

Introduction

Electrical conductance, which is the inverse of electrical resistance, is a measure of how easily current can flow. The higher the conductance, the more easily current can flow. Conductance is very useful when testing **water purity**. You can use conductance to estimate the amount of **total dissolved solids** (salts) or **ions** in water. The more dissolved solids that are present in the water, the higher the conductance of the water. This is because the solids dissolve into positively and negatively charged ions that can conduct an electrical current proportional to their concentration. Water that has no dissolved solids or ions (i.e., "pure" water), conducts electricity several orders of magnitude less readily than regular tap water.

Measuring the conductance of water is only one of many tests that exist to determine water purity. Performing this test would tell you that there are solids present, but not what the solids are. With a home water test kit (about \$15) you can also measure the levels of bacteria, lead, pesticides, nitrates, nitrites, chlorine, and **pH**.

As mentioned above, conductance, G , is the inverse of resistance, R . So $G = 1/R$. You can measure resistance using a data acquisition device. Connecting the leads from CH1 and Gnd (see the diagram below) will give you a reading of 0 volts, V , which is equal to no resistance. Placing material between the leads will lead to a voltage reading, which will determine resistance (and thus, conductance). Measuring the voltage of a battery is an example of a simple reading to get because it doesn't require any instruments.

In this project, you will be measuring conductance using a data acquisition device that you connect to your computer. The data acquisition device (see the Materials and Equipment section below) measures analog signals, which are continuously variable, and converts them into digital signals, which are the sequences of 0's and 1's used in computer circuits. Conductance is just one example of an analog signal. Analog signals may come from instruments, sensors, or transducers that convert a huge variety of measurements into a change in voltage. Examples include: load, pressure, torque, frequency, strain, temperature, linear speed, rotational speed, flow, relative humidity, resistance, and current.

Terms, Concepts and Questions to Start Background Research

To do this project, you should do research that enables you to understand the following terms and concepts:

- Electrical conductance
- Water purity
- Total dissolved solid (TDS)

- Ion
- pH
- MicroSiemens (μS)
- MicroSiemens/cm

Questions

- What materials will raise TDS?
- Can we reasonably assume what solids are in the water we are testing?

Bibliography

- This website is an excellent source of information regarding water purity: Lake Access. (n.d.). Electrical Conductivity: Measuring Salts in Water. Retrieved August 16, 2005 from <http://lakeaccess.org/russ/conductivity.htm>.
- These sites explain the pH scale:
 - Environment Canada. (2002). Kids' Corner pH Scale. *The Green Lane: Acid Rain, Environment Canada website* Retrieved March 14, 2006 from <http://www.ec.gc.ca/acidrain/kids.html>.
 - Decelles, P. (2002). The pH Scale. *Virtually Biology Course, Basic Chemistry Concepts, Johnson County Community College* Retrieved March 14, 2006 from <http://staff.jccc.net/pdecell/chemistry/phscale.html>.
- TransEra Corp. (2007). Data Acquisition Tutorial. Retrieved March 27, 2008 from <http://www.htbasic.com/support/tutorials/hardware/data-aquisition.html>.
- DATAQ Instruments. (2005). DATAQ Instruments Application Notes and Article Reprints. *DATAQ Instruments* Retrieved August 16, 2005 from <http://www.dataq.com/applicat/index.htm>.

Materials and Equipment

To do this project, you will need the following materials and equipment:

- A Windows-compatible personal computer and one of the following:
 - If your computer has a serial port (RS-232), you will need the [Data Acquisition Starter Kit \(DI-194RS\)](#)
 - If you have a computer with a USB port, you will need the [Data Acquisition Starter Kit \(DI-148U\)](#)
- WinDaq Acquisition and Playback Software (free) must be installed on the computer (administrator privileges are required)
- Two insulated 16-gauge solid copper wires of equal length and type (at least 18 inches each)
- A straw

- Electrical tape
- Styrofoam™ cups (12; 3 cups for each liquid sample)
- Pen or marker
- Four different types of water or liquids

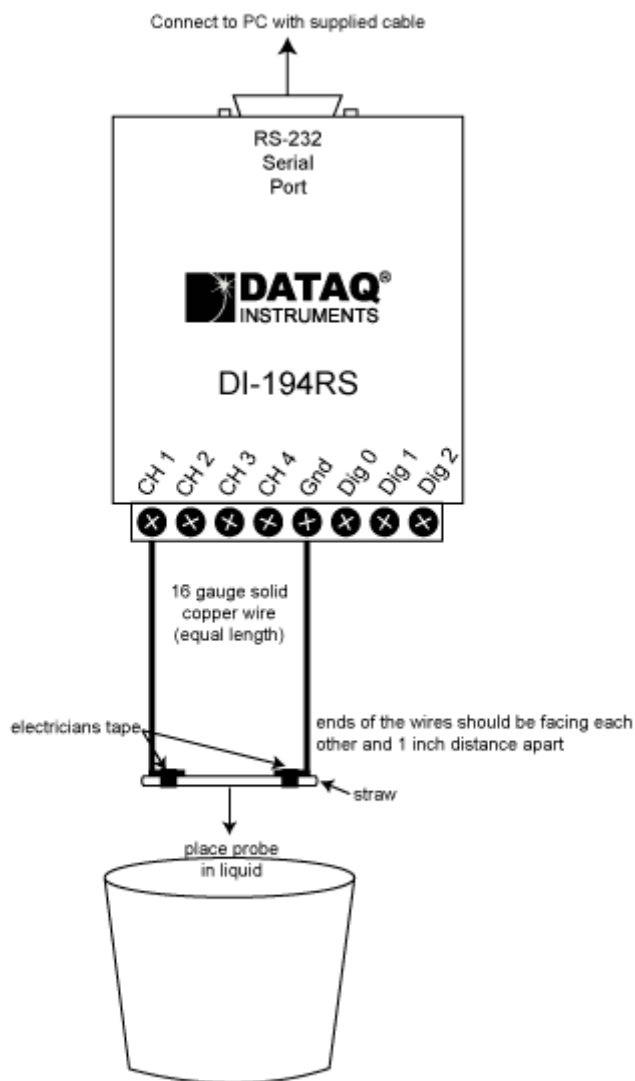
Experimental Procedure

Note Before Beginning: This science fair project requires you to hook up one or more devices in an electrical circuit. If you don't have experience in putting together electrical circuits you may find it helpful to have someone who can answer questions and help you troubleshoot if your project isn't working. A science teacher or parent may be a good resource. If you need to find another mentor, try asking a local electrician, electrical engineer, or person whose hobbies involve building things like model airplanes, trains, or cars. You may also need to work your way up to this project by starting with an electronics project that has a lower level of difficulty.

1. Cut two pieces of insulated 16-gauge copper wire that are each at least 18 inches long. Strip 1 inch off an end of both wires; do not strip the ends that will go on the probe (there should be no bare wire in the liquid, other than the very ends).
2. Now you will build your probe. Cut the straw so that it fits into the cups, as shown in the diagram below.
 - a. Position each wire on the straw, so the ends are facing each other and so the ends are 1 inch apart.
 - b. Then securely tape the two unstripped signal leads (wires) to the straw. The tape must securely fasten the wires so that they do not move around

when you handle the probe. If the wires move, it could change the distance between the two ends, which could unexpectedly alter your measurements in the middle of your experiment and lead to bad results.

- c. Bend the wires 90°, as shown in the diagram.
- d. Now connect the other, stripped end of the signal leads to the data acquisition device. Connect one wire to Gnd and the other to CH1.
- e. Use the following diagram for connections:



3. Label all of your cups with the name of the liquid and a letter, such as *Tap Water A*, *Tap Water B*, etc. Take your first liquid and pour an equal amount into three Styrofoam cups.
4. Set up parameters (sample rate, number of channels, etc.) in the WinDaq Acquisition Software. Then place the probe in the liquid, and record the data in a data table. Use the User Annotation function in WinDaq to label the data (i.e., "Sample 1 - Tap Water_A", "Sample 1 - Tap Water_B") to easily identify the

samples. Voltage readings should be between about 0.125 and 2.5 V (in our tests, tap water readings were around 0.6 to 0.7 V). Record the data repeatedly until you get consistent results to ensure accuracy. WinDaq Data Acquisition Software Manual and Multimedia demonstrations are available with the included CD or via the Internet at <http://www.dataq.com/products/software/acquisition.htm>.

5. Wipe the signal leads dry and repeat step 4 for each of the two remaining cups of the first liquid sample.
6. Disconnect your probe, rinse out the straw, and dry the leads. This is an important step because it ensures there is no residue left from the previous liquid, which could alter the results. Repeat steps 3-5 for each different liquid.
7. Analyze the recorded data using WinDaq Playback Software and/or Excel. Average the values for the three replicates for each liquid to get a single data point for each type of liquid. A special formula is required to convert voltage readings to microSiemens (μS) with the data acquisition device. Use the calculator at <http://www.dataq.com/science-fair/calc-siemens.php> to convert volts to microSiemens.

- **If you are using the DI-194RS, the formulas are as follows.** Keep in mind that V = voltage in volts, Ω = ohms, and σ = mhos.

Resistance, R , (Ω) = $137,000 \times V / (2.5 - V)$

Conductance, G , (σ) = $7.3 \times (2.5 - V) / V$

Special notes for advanced students:

- The voltage output will read zero for the DI-194RS, with a short or 0Ω applied to the inputs.
- 2.5 is the voltage output reading for the DI-194RS in free air or infinite resistance.
- 137,000 is a constant for the DI-194RS, used to convert the formula's output to resistance in ohms. This number is the effective input impedance of the units.
- The conductance formula is the reciprocal of the resistance formula, with an output in Siemens—or mhos—(σ), and is multiplied by 1,000,000 to give an output in microSiemens (μS).

- **If you are using the DI-148U, the formulas are as follows.** Keep in mind that V = voltage in volts, Ω = ohms, and σ = mhos.

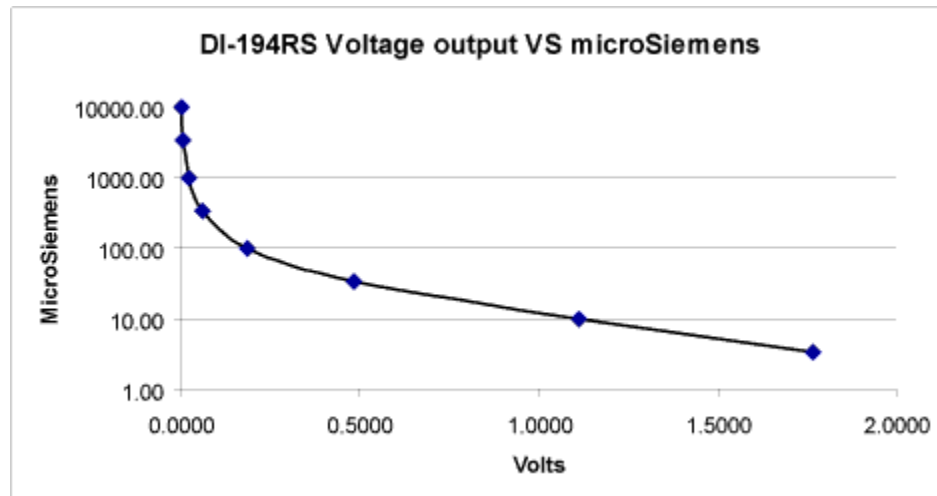
Resistance, R , (Ω) = $225,000 \times V / (1.39 - V)$

Conductance, G , (σ) = $4.44 \times (1.39 - V) / V$

Special notes for advanced students:

- The voltage output will read zero for the DI-148U, with a short or 0Ω applied to the inputs.
- 1.39 is the voltage output reading for the DI-148U in free air or infinite resistance

- 225,000 is a constant for the DI-148U, used to convert the formula's output to resistance in ohms. This number is the effective input impedance of the units.
 - The conductance formula is the reciprocal of the resistance formula, with an output in Siemens—or mhos—(σ), and is multiplied by 1,000,000 to give an output in microSiemens (μS).
8. Use the following chart to view the relationship between voltage and microSiemens:



9. Note that for voltages less than about 0.125 V, the relationship between conductance and voltage changes very rapidly. Conductance values in this range are likely to be unreliable.
10. WinDaq Playback Software Manual and Multimedia demonstrations are available with included CD or via the Internet at <http://www.dataq.com/products/software/playback.htm>.
11. Note: Measurements should be taken at the same temperature.

Variations

This base experiment can lead to many variations and more-advanced experiments.

- Use pH and other water-quality measurements to determine total pollution in rainwater or lake water.
- Electrical conductivity as a general water test is just for taste and is not necessarily a health hazard. Measure the total dissolved salts in multiple liquids (e.g., coffee, tea, cola, etc.).
- How does temperature affect the conductivity of water?

- Since "lite" soy sauce contains less salt than ordinary soy sauce, if you add equal amounts of lite and regular soy sauce to equal amounts of distilled water, will you get different conductance values for the two samples?
- Add known amounts of different materials (e.g., table salt (NaCl), Epsom salts, potassium chloride) to dissolve them in equal amounts of distilled or deionized water. Is the measured conductance the same for each material? Does the molecular weight of the added material matter? (Do background research on *molarity*, which is how chemical concentrations are measured in the lab.)
- Measure the same samples over a period of time (days or weeks)—how is TDS affected and what could be the possible reasons for this?
- Does "pure" water exist? Try to create water with no solids or ions.

Conductance as a Water Quality Measurement

(from <http://www.sciencebuddies.com>)

Objective

The goal of this experiment is to assess the purity of water samples by measuring their conductance (the inverse of electrical resistance) using a low-cost data acquisition device that you control using your personal computer.

Introduction

Electrical conductance, which is the inverse of electrical resistance, is a measure of how easily current can flow. The higher the conductance, the more easily current can flow. Conductance is very useful when testing **water purity**. You can use conductance to estimate the amount of **total dissolved solids** (salts) or **ions** in water. The more dissolved solids that are present in the water, the higher the conductance of the water. This is because the solids dissolve into positively and negatively charged ions that can conduct an electrical current proportional to their concentration. Water that has no dissolved solids or ions (i.e., "pure" water), conducts electricity several orders of magnitude less readily than regular tap water.

Measuring the conductance of water is only one of many tests that exist to determine water purity. Performing this test would tell you that there are solids present, but not what the solids are. With a home water test kit (about \$15) you can also measure the levels of bacteria, lead, pesticides, nitrates, nitrites, chlorine, and **pH**.

As mentioned above, conductance, G , is the inverse of resistance, R . So $G = 1/R$. You can measure resistance using a data acquisition device. Connecting the leads from CH1 and Gnd (see the diagram below) will give you a reading of 0 volts, V , which is equal to no resistance. Placing material between the leads will lead to a voltage reading, which will determine resistance (and thus, conductance). Measuring the voltage of a battery is an example of a simple reading to get because it doesn't require any instruments.

In this project, you will be measuring conductance using a data acquisition device that you connect to your computer. The data acquisition device (see the Materials and Equipment section below) measures analog signals, which are continuously variable, and converts them into digital signals, which are the sequences of 0's and 1's used in computer circuits. Conductance is just one example of an analog signal. Analog signals may come from instruments, sensors, or transducers that convert a huge variety of measurements into a change in voltage. Examples include: load, pressure, torque,

frequency, strain, temperature, linear speed, rotational speed, flow, relative humidity, resistance, and current.

Terms, Concepts and Questions to Start Background Research

To do this project, you should do research that enables you to understand the following terms and concepts:

- Electrical conductance
- Water purity
- Total dissolved solid (TDS)
- Ion
- pH
- MicroSiemens (μS)
- MicroSiemens/cm

Questions

- What materials will raise TDS?
- Can we reasonably assume what solids are in the water we are testing?

Bibliography

- This website is an excellent source of information regarding water purity: Lake Access. (n.d.). Electrical Conductivity: Measuring Salts in Water. Retrieved August 16, 2005 from <http://lakeaccess.org/russ/conductivity.htm>.
- These sites explain the pH scale:
 - Environment Canada. (2002). Kids' Corner pH Scale. *The Green Lane: Acid Rain, Environment Canada website* Retrieved March 14, 2006 from <http://www.ec.gc.ca/acidrain/kids.html>.
 - Decelles, P. (2002). The pH Scale. *Virtually Biology Course, Basic Chemistry Concepts, Johnson County Community College* Retrieved March 14, 2006 from <http://staff.jccc.net/pdecell/chemistry/phscale.html>.
- TransEra Corp. (2007). Data Acquisition Tutorial. Retrieved March 27, 2008 from <http://www.htbasic.com/support/tutorials/hardware/data-aquisition.html>.
- DATAQ Instruments. (2005). DATAQ Instruments Application Notes and Article Reprints. *DATAQ Instruments* Retrieved August 16, 2005 from <http://www.dataq.com/applicat/index.htm>.

Materials and Equipment

To do this project, you will need the following materials and equipment:

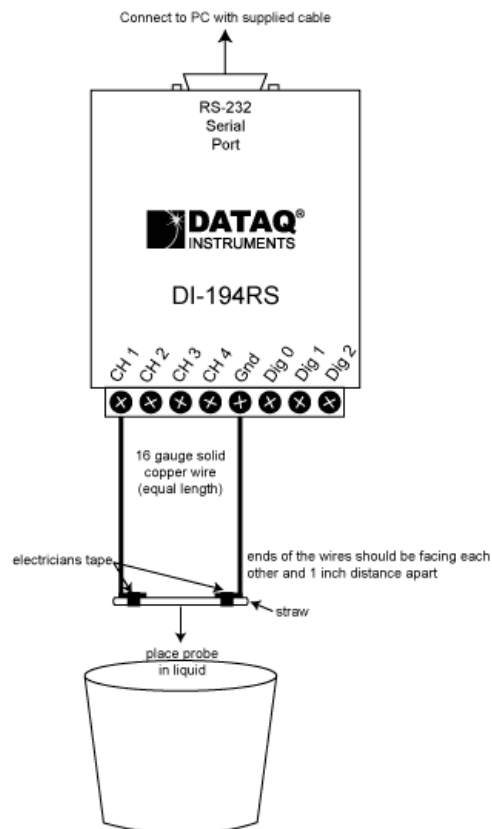
- A Windows-compatible personal computer and one of the following:
 - If your computer has a serial port (RS-232), you will need the [Data Acquisition Starter Kit \(DI-194RS\)](#)
 - If you have a computer with a USB port, you will need the [Data Acquisition Starter Kit \(DI-148U\)](#)
- WinDaq Acquisition and Playback Software (free) must be installed on the computer (administrator privileges are required)
- Two insulated 16-gauge solid copper wires of equal length and type (at least 18 inches each)
- A straw
- Electrical tape
- Styrofoam™ cups (12; 3 cups for each liquid sample)
- Pen or marker
- Four different types of water or liquids

Experimental Procedure

Note Before Beginning: This science fair project requires you to hook up one or more devices in an electrical circuit. If you don't have experience in putting together electrical circuits you may find it helpful to have someone who can answer questions and help you troubleshoot if your project isn't working. A science teacher or parent may be a good resource. If you need to find another mentor, try asking a local electrician, electrical engineer, or person whose hobbies involve building things like model airplanes, trains, or cars. You may also need to work your way up to this project by starting with an electronics project that has a

lower level of difficulty.

12. Cut two pieces of insulated 16-gauge copper wire that are each at least 18 inches long. Strip 1 inch off an end of both wires; do not strip the ends that will go on the probe (there should be no bare wire in the liquid, other than the very ends).
13. Now you will build your probe. Cut the straw so that it fits into the cups, as shown in the diagram below.
 - a. Position each wire on the straw, so the ends are facing each other and so the ends are 1 inch apart.
 - b. Then securely tape the two unstripped signal leads (wires) to the straw. The tape must securely fasten the wires so that they do not move around when you handle the probe. If the wires move, it could change the distance between the two ends, which could unexpectedly alter your measurements in the middle of your experiment and lead to bad results.
 - c. Bend the wires 90°, as shown in the diagram.
 - d. Now connect the other, stripped end of the signal leads to the data acquisition device. Connect one wire to Gnd and the other to CH1.
 - e. Use the following diagram for connections:



14. Label all of your cups with the name of the liquid and a letter, such as *Tap Water A*, *Tap Water B*, etc. Take your first liquid and pour an equal amount into three Styrofoam cups.
15. Set up parameters (sample rate, number of channels, etc.) in the WinDaq Acquisition Software. Then place the probe in the liquid, and record the data in a data table. Use the User Annotation function in WinDaq to label the data (i.e., "Sample 1 - Tap Water_A", "Sample 1 - Tap Water_B") to easily identify the samples. Voltage readings should be between about 0.125 and 2.5 V (in our tests, tap water readings were around 0.6 to 0.7 V). Record the data repeatedly until you get consistent results to ensure accuracy. WinDaq Data Acquisition Software Manual and Multimedia demonstrations are available with the included CD or via the Internet at <http://www.dataq.com/products/software/acquisition.htm>.
16. Wipe the signal leads dry and repeat step 4 for each of the two remaining cups of the first liquid sample.
17. Disconnect your probe, rinse out the straw, and dry the leads. This is an important step because it ensures there is no residue left from the previous liquid, which could alter the results. Repeat steps 3-5 for each different liquid.
18. Analyze the recorded data using WinDaq Playback Software and/or Excel. Average the values for the three replicates for each liquid to get a single data point for each type of liquid. A special formula is required to convert voltage readings to microSiemens (μS) with the data acquisition device. Use the calculator at <http://www.dataq.com/science-fair/calc-siemens.php> to convert volts to microSiemens.

- **If you are using the DI-194RS, the formulas are as follows.** Keep in mind that V = voltage in volts, Ω = ohms, and ϑ = mhos.

Resistance, R , (Ω) = $137,000 \times V / (2.5 - V)$

Conductance, G , (ϑ) = $7.3 \times (2.5 - V) / V$

Special notes for advanced students:

- The voltage output will read zero for the DI-194RS, with a short or 0Ω applied to the inputs.
- 2.5 is the voltage output reading for the DI-194RS in free air or infinite resistance.
- 137,000 is a constant for the DI-194RS, used to convert the formula's output to resistance in ohms. This number is the effective input impedance of the units.
- The conductance formula is the reciprocal of the resistance formula, with an output in Siemens—or mhos—(ϑ), and is multiplied by 1,000,000 to give an output in microSiemens (μS).
- **If you are using the DI-148U, the formulas are as follows.** Keep in mind that V = voltage in volts, Ω = ohms, and ϑ = mhos.

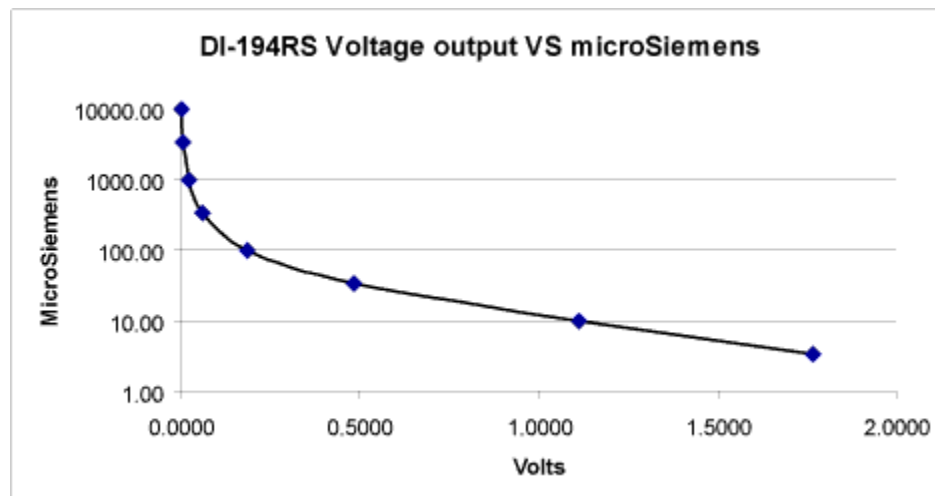
Resistance, R , (Ω) = $225,000 \times V / (1.39 - V)$

$$\text{Conductance, } \mathcal{G}, (\text{v}) = 4.44 \times (1.39 - V) / V$$

Special notes for advanced students:

- The voltage output will read zero for the DI-148U, with a short or 0 Ω applied to the inputs.
- 1.39 is the voltage output reading for the DI-148U in free air or infinite resistance
- 225,000 is a constant for the DI-148U, used to convert the formula's output to resistance in ohms. This number is the effective input impedance of the units.
- The conductance formula is the reciprocal of the resistance formula, with an output in Siemens—or mhos—(v), and is multiplied by 1,000,000 to give an output in microSiemens (μS).

19. Use the following chart to view the relationship between voltage and microSiemens:



20. Note that for voltages less than about 0.125 V, the relationship between conductance and voltage changes very rapidly. Conductance values in this range are likely to be unreliable.

21. WinDaq Playback Software Manual and Multimedia demonstrations are available with included CD or via the Internet at

<http://www.dataq.com/products/software/playback.htm>.

22. Note: Measurements should be taken at the same temperature.

Variations

This base experiment can lead to many variations and more-advanced experiments.

- Use pH and other water-quality measurements to determine total pollution in rainwater or lake water.

- Electrical conductivity as a general water test is just for taste and is not necessarily a health hazard. Measure the total dissolved salts in multiple liquids (e.g., coffee, tea, cola, etc.).
- How does temperature affect the conductivity of water?
- Since "lite" soy sauce contains less salt than ordinary soy sauce, if you add equal amounts of lite and regular soy sauce to equal amounts of distilled water, will you get different conductance values for the two samples?
- Add known amounts of different materials (e.g., table salt (NaCl), Epsom salts, potassium chloride) to dissolve them in equal amounts of distilled or deionized water. Is the measured conductance the same for each material? Does the molecular weight of the added material matter? (Do background research on *molarity*, which is how chemical concentrations are measured in the lab.)
- Measure the same samples over a period of time (days or weeks)—how is TDS affected and what could be the possible reasons for this?
- Does "pure" water exist? Try to create water with no solids or ions.

Rock On! Recording Digital Data with Magnets

(from <http://www.sciencebuddies.com>)

Objective

The goal of this project is to determine the maximum "recording density" for storing digitized information using a grid of bar magnets. You'll learn about how information is digitized, and how the digitized information is stored magnetically. The project helps you to understand the limitations on information density recorded on magnetic materials.

Introduction

Today, magnetic disk drives are used to store and retrieve information for many different applications. Digital video recorders (DVRs), MP3 players, and gaming systems are all examples of popular products that use a disk drive to store and retrieve information. Some other applications that you may not be familiar with are global positioning systems (GPS), banking systems, and automobiles.

How are all these different kinds of information stored on magnetic disk drives? How much data can fit in a given amount of space on a disk? How is data erased from a disk? This project will help you answer these questions as you learn how magnetic materials are used to store information.

Information like words, music, or movies is translated into a format that can be saved onto various permanent storage devices, like a magnetic disk drive. This translation is called *digitization*, which means that the information is converted into a stream of numbers. The smallest unit for digital information is called a *bit*. A bit can be either 0 or 1, that's it. By stringing together a series of bits, larger numbers can be represented. For example, a *byte* is a sequence of 8 bits. A byte can encode 2^8 (= 256) unique values. If you want to learn more about encoding information in bits and bytes, see the Science Buddies project Bits, Bytes, and Bases: Write a JavaScript Binary/Decimal/Hexadecimal Converter

http://sciencebuddies.com/mentoring/project_ideas/CompSci_p005.shtml.

Letters, numbers, and other symbols for printed text are digitized using a standard code, called *ASCII* (ASCII is an acronym for American Standard Code for Information Interchange). Each character is assigned a unique code. Click here for a Table of 7-bit ASCII Character Codes

http://sciencebuddies.com/mentoring/project_ideas/CompSci_ASCII_Table.shtml.

Using the ASCII table, what sequence of bits would correspond to the word "digitize?"

In this project, you will digitize a short piece of text (e.g., the name of your favorite band) using the ASCII representation of the text. Next, you will use bar magnets to represent the individual bits of the digitized text. The orientation of the magnet will determine whether it represents a 0 or a 1. You'll see how close together your magnets can be packed while still preserving your stored information. Finally, you'll see how easily you can erase your stored information with a permanent magnet.

Terms, Concepts and Questions to Start Background Research

To do this project, you should do research that enables you to understand the following terms and concepts:

- bit,
- byte,
- ASCII,
- magnet,
- bar magnet.

Questions

- Before MP3 players and DVRs, what was used to store and retrieve music and video?
- What are other examples of storage and retrieval methods or systems?
- Why do you think disk drives devices like iPODs and DVRs are now replacing tape-based devices like Walkmans and VCRs?

Materials and Equipment

To do this experiment you will need the following materials and equipment:

- a print-out of the ASCII code and binary code for 26 letters,
- plastic/glass tray with square/rectangular compartments,
- a few dozen 1 inch bar magnets,
- paper and pencil,
- ruler,
- one big horseshoe magnet.

Experimental Procedure

In this experiment, you will digitize a short piece of text (e.g., the name of your favorite band) using the ASCII representation of the text. Next, you will use bar magnets to represent the individual bits of the digitized text. The orientation of the magnet will determine whether it represents a 0 or a 1. You'll see how close together your magnets can be packed while still preserving your stored information. Finally, you'll see how easily you can erase your stored information with a permanent magnet.

1. You'll need a word or phrase to digitize. Pick the name of your favorite musician or band, your favorite song, or some other word or phrase.
2. Make a table to translate your chosen word or phrase into the binary ASCII code. For example, if we chose "Jem" as our favorite musician, here is how we would digitize her name:

J	e	m
0100 1010	0110 0101	0110 1101

3. Now use individual bar magnets to represent each bit of the coded word or phrase. We'll say that a magnet with its N pole facing right is a 1, and a magnet with its N pole facing left is a 0. (To make your code easier to see, you may want to color the N half of each magnet.) Place one magnet in each compartment of your plastic tray, arranging them according to the binary code for your word or phrase.
4. What is the information density of your recording? How many bits per square inch? Just for comparison, a 1990 hard disk could store 1 billion (1,000,000,000) bits per square inch, and a 2006 hard disk can store 100 billion (100,000,000,000) bits per square inch.
5. Gently tap your tray of magnets. What happens to the arrangement? Are some of the magnets attracted (or repelled) by their neighbors? Did something like this happen to your tray (see Figure 1):

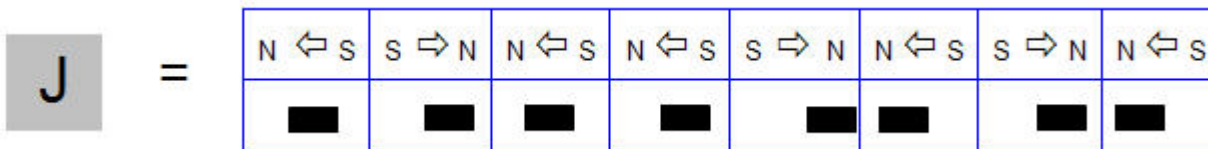


Figure 1. Neighboring bar magnets with opposite polarity are attracted to one another when tray is tapped.

6. If the magnetic material on a recording surface could move around like your bar magnets, how do you think this would affect the durability of the recording?
7. For the next part, you'll be working with the binary code for a single letter. Choose one letter from your word or phrase to use for this.

8. On a piece of paper, draw 8 squares, about the same size as the compartments in your tray. Arrange the magnets on the paper squares to represent the code for your chosen letter.
9. Do the magnets interact with each other now that there is no longer a wall separating them?
 - a. If the magnets do not interact, try again with smaller squares. How small can your squares be without the magnets interacting with their neighbors?
 - b. If the magnets do interact, try again with larger squares. How large do the squares need to be so that the magnets are not disturbed by their neighbors?
10. What is the highest recording density you can achieve when you place the magnets on a piece of paper (in number of bits per square inch)?
11. Again arrange your bar magnets on the paper to encode your chosen letter. Take the horseshoe magnet and, holding it a foot above the paper (measure with the ruler), pass it over the bar magnets. Did any of the bar magnets move?
 - a. If the bar magnets did not move, lower the horseshoe magnet slightly and try again. At what height does the horseshoe magnet move the bar magnets?
 - b. If the bar magnets did move, raise the horseshoe magnet slightly and try again. At what height does the horseshoe magnet first stop moving the bar magnets?
 - c. What does this tell you about erasing data stored on magnetic recording media?

The Strength of an Electromagnet

(from <http://www.sciencebuddies.com>)

Objective

The goal of this project is to investigate the strength of an electromagnet made from a coil of wire. How does the strength of the magnetic field change as the number of turns in the coil is increased?

Introduction

An electric current flowing in a wire creates a magnetic field. You can prove this to yourself with a magnetic compass. The magnetic field around a straight wire is not very strong. However, if the wire is wrapped in a coil, the fields produced in each turn of the coil add up to create a stronger magnetic field (see Figure 1).

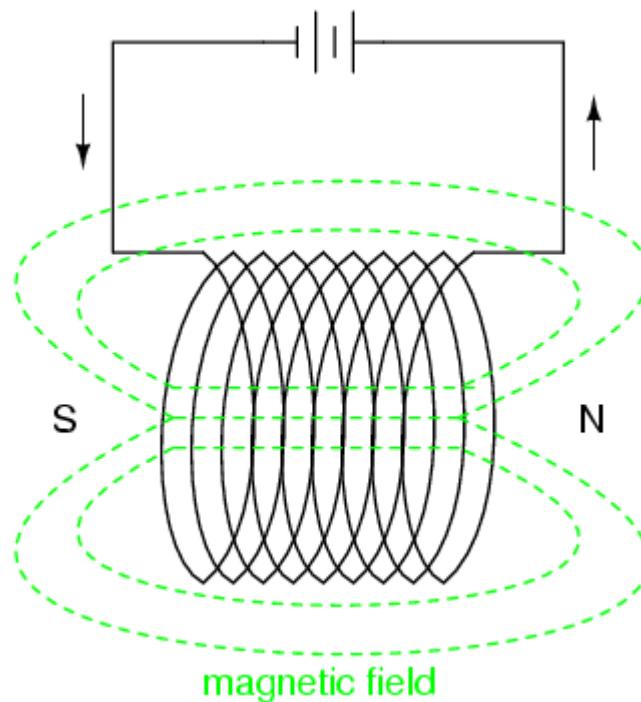


Figure 1. The green lines show the magnetic field surrounding a coil through which electric current is flowing.

The right-hand rule tells you the direction of the magnetic field produced by electric current. In the case of a single wire, when you hold your right hand so that the thumb points in the direction of the current flow, your fingers curl in the direction of the magnetic field (see Figure 2).

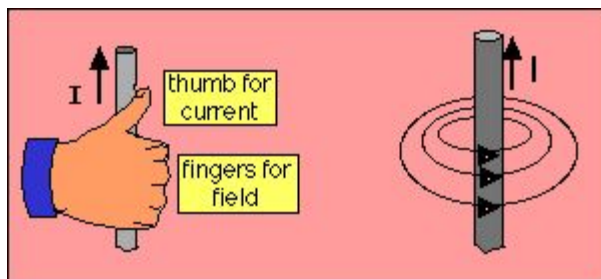


Figure 2. Illustration of the right-hand rule for a single wire.

For a coil of wire, when the fingers of your right hand curl in the direction of the current flow, your thumb points toward the north pole of the magnetic field created by the coil (see Figure 3).

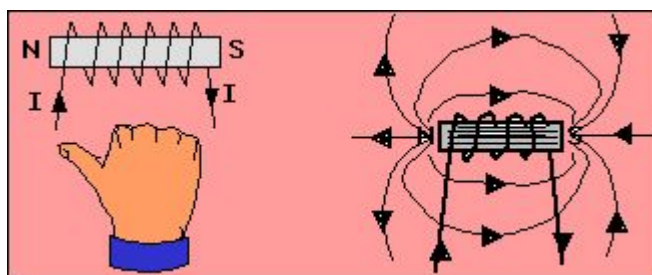


Figure 3. Illustration of the right-hand rule for a coil of wire through which an electric current is flowing.

In this project, you will investigate how the strength of the magnetic field produced by a coil of wire changes when the number of turns in the coil are changed. You will also investigate which orientation of the coil is more effective: holding the coil parallel to the material to be picked up, or holding the coil perpendicular to the material.

Terms, Concepts and Questions to Start Background Research

To do this project, you should do research that enables you to understand the following terms and concepts:

- electromagnet,
- right hand rule.

Questions

- Can you think of a way to demonstrate which end of your coil is N and which is S?
- What happens to N and S if you reverse the connections to the battery?

Bibliography

- Brain, M., 2006. "How Electromagnets Work," HowStuffWorks.com [accessed July 18, 2006] <http://www.howstuffworks.com/electromagnet.htm>.
- Thomas Jefferson National Accelerator Facility - Office of Science Education, date unknown. "What Is an Electromagnet?" [accessed July 18, 2006] http://education.jlab.org/qa/electromagnet_is.html.
- Nave, C.R., 2006. "Magnets and Electromagnets," HyperPhysics, Department of Physics and Astronomy, Georgia State University [accessed July 18, 2006] <http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/elemag.html>.

Materials and Equipment

To do this experiment you will need the following materials and equipment:

- 6 V lantern battery (e.g., Radio Shack 23-016 or 23-560),
- magnet wire (e.g., Radio Shack #278-1345),
- alligator clip leads (e.g., Radio Shack #278-1156),
- sharp knife for stripping magnet wire,
- masking tape,
- box of steel paper clips,
- 100-200 steel washers (approx. 1 cm diameter),
- three identical pieces of iron for the core material, for example:
 - iron nails,
 - iron bolts, or
 - short lengths of iron pipe.
 - Whatever you choose for the core material, all three pieces should be the same size.
- optional (for Variations 1 and 2, below): paper for making coil forms.

Experimental Procedure

Note Before Beginning: This science fair project requires you to hook up one or more devices in an electrical circuit. If you don't have experience in putting together electrical circuits you may find it helpful to have someone who can answer questions and help you troubleshoot if your project isn't working. A science teacher or parent may be a good resource. If you need to find another mentor, try asking a local electrician, electrical engineer, or person whose hobbies involve building things like model airplanes, trains, or cars. You may also need to work your way up to this project by starting with an electronics project that has a lower level of difficulty.

1. You will make three different electromagnets, using three identical pieces of core material. Each coil will have a different number of turns. For example, you could try 100, 200, and 500 turns. Wrap the magnet wire neatly around the core material. Here are some tips to make wrapping easier.
 - a. Leave 5-6 cm of wire free at each end of the coil for making the connection to the battery.
 - b. Make a holder for the spool of magnet wire, so that you can roll the wire right off of the spool. For example, you can stick a pen or pencil through the spool, and tape it down to a couple of small boxes.
 - c. Use a small piece of tape to attach the wire to the core material, about 0.5-1 cm in from the end.
 - d. Turn the core to unwind the magnet wire from the suspended spool. Use your fingers to keep the wire tight against the core material. Wrap each successive turn so that the wire lines up neatly.

- e. Keep track of the turns (each time the tape that holds the wire in place comes around). This is easier if you can recruit a helper to make tally marks for you.
 - f. When you reach the desired number of turns, again tape the wire to the coil form, and cut it off. Leave 5-6 cm of free wire for making the connection to the battery.
 - g. Particularly for the larger coils, you will need to wrap multiple layers of wire to get the desired number of turns.
2. Use the utility knife to carefully scrape off the enamel insulation from the magnet wire over a 1 cm length at each end. You'll see the shiny copper wire underneath. Be careful not to cut the wire.
3. Place the paper clips (or washers) in a shallow container (slightly longer than the coil). You will probably find that paper clips work well for coils with an air core, and washers work well for coils with an iron or steel core.
4. Pick up paper clips with the coil held parallel to the container.
 - a. Use the clip leads to connect the coil to the battery.
 - b. Touch the coil (lengthwise) to the paper clips (or washers), then pull the coil away from the tray.
 - c. Disconnect the coil from the battery, and count how many paper clips (washers) were picked up. Record the number in your lab notebook. Organize your data in a table like the one below.
 - d. Repeat at least five times for each coil.
5. Pick up paper clips with the coil held perpendicular to the battery.
 - a. Use the clip leads to connect the coil to the battery.
 - b. This time touch the core material to the paper clips (or washers), then pull the coil away from the tray. (In other words, this time the coil will be perpendicular to the tray of paper clips.)
 - c. Disconnect the coil from the battery, and count how many paper clips (washers) were picked up. Record the number in your lab notebook. Organize your data in a table like the one below.
 - d. Repeat at least five times for each coil.
6. Calculate the average number of paper clips (washers) lifted by each coil for each method (see the table below).

Number of Turns	Number of Paper Clips Picked Up											
	Coil Parallel to Paper Clips						Coil Perpendicular to Paper Clips					
	Trial					Average	Trial					Average
	1	2	3	4	5		1	2	3	4	5	
100												
200												
500												

7. Make a graph of the results. Plot the number of paper clips picked up for each coil orientation (y-axis) vs. number of turns in the coil (x-axis).

Variations

1. Try using different metals as core materials inside the coil. For example, steel, copper, aluminum, etc. You can use nails, bolts, pipe, tubing, etc. For making comparisons, it would be ideal to have core materials that are the same diameter and weight. You can wrap the coils directly around the core materials as described above, or you can make a single coil (for each number of turns that you want to test) and test it with different core materials inside. Here is a procedure for making coils so that you can swap the core material:
 - a. Make a coil form by wrapping several layers of paper around a sample of your core material.
 - b. Use enough layers of paper or cardboard so that the coil form will hold its shape.
 - c. Tape the paper, then slide it off the cylinder form.
 - d. Test the coil form with each of the core materials to make sure that they all fit.
 - e. Wrap your coil around the coil form, as described above.
 - f. Now you will be able to slide different core materials in and out of the coil. You can leave the paper material in place.
 - g. You could also try another experiment to see if removing the paper makes any difference in the strength of the electromagnet. Test the coils both with and without the paper material inside. As in the procedure above, you can compare the amount of weight that electromagnets with different core materials can lift.

2. What happens when you change the distance between the coil of wire and a metal core material? For example, increase the diameter of your core forms (described in Variation #1, above) by 2, 5, 10, and 20 mm.
3. What happens when you change the voltage applied across the coil? You can connect 2 or 3 lantern batteries in series, or use increasing numbers of D-cell batteries in series. As above, measure how many paper clips (or washers) you can lift with a coil at each voltage.

Where There Is Charge, There Can Be Sparks!

(from <http://www.sciencebuddies.com>)

Objective

Learn about one of the building blocks for all types of circuits—the capacitor. In this science project you will build a Leyden jar capacitor out of common household materials and determine how much charge is stored as you test different charge cycles.

Introduction

Static charge is the buildup of charge on an object. In 1745, Ewald Georg von Kleist invented a tool to capture and store static charge. At approximately the same time, Pieter van Musschenbroek from Leiden, the Netherlands, invented a similar tool. This tool is called the Leyden jar. The **Leyden jar** provided early electrical experimenters with a way to store electrical charge and then move it to another place to use. Leyden jars come in all shapes and sizes, but they all have the same design. The jar, which serves as the insulator, separates an inner conductive layer (or electrode) and an outer conductive layer (also an electrode). Examples of a conductive layer are aluminum foil and gold leaf. There is usually a metal rod with a ball on top placed in the mouth of the jar. The rod, or a chain connected to the rod, touches the inner conductor and is the conduit for electrical charge to the jar.

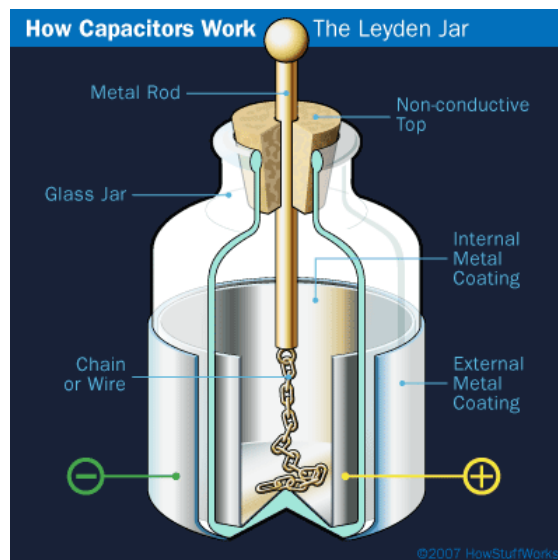


Figure 1. Inner workings of the Leyden jar.
(HowStuffWorks.com, 2007.)

Benjamin Franklin was an early electricity experimenter. He built and experimented with the Leyden jar. One of Franklin's favorite experiments was the "circle shock." In the circle shock, a group of people hold hands and one person at the end of the human chain holds the outside of the Leyden jar, while the person on the other end of the human chain touches the inner conductor. If there is enough charge in the jar, every person in the circle will feel a shock. Don't try this experiment, because you can get a nasty shock!

The original Leyden jar held water as the inner conductor. Early electrical experimenters thought that the charge was held in the water. However, Benjamin Franklin was the first person to figure out that the charge in the Leyden jar is located where the insulator meets the electrode (in this case, the water). Thus, water is not required and can be replaced by attaching an electrode, such as aluminum foil, to the inside of the jar. Franklin also connected several Leyden jars together and created what he called a **battery**. This is not a battery like we know today, but it was a way to store lots of charge for Franklin's electrical experiments.

The Leyden jar is an interesting device because it is the precursor to the modern capacitor. A **capacitor** is an electrical component that is used to store charge, and along with the resistor and batteries (or voltage supply), forms the basis of all circuits. Both capacitors and batteries are similar in that they are components that store charge. The major difference between a battery and a capacitor is that a battery produces charge through a chemical reaction. A capacitor is much simpler as it can't produce charge, it can only store charge. Capacitors are used in timer circuits and logic circuits and a variety of applications. For example, the screen on the Apple® iPhone™ is a capacitive touch screen.

In this project, become Ben Franklin and build your own Leyden jar. You will also build an electrophorus. An **electrophorus** is a tool that is used for transferring charge to the Leyden jar. Try using small jars that you can find around the house. Experiment with how much charge your Leyden jar can hold. Remember that even a small jar can store a lot of charge, so be very careful or you can get a painful shock.

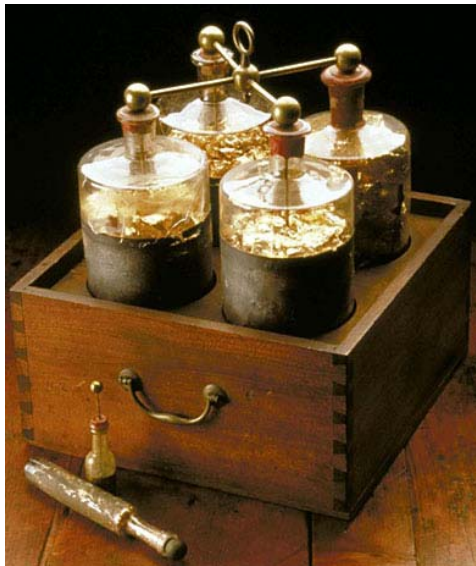


Figure 2. Leyden jar battery. (Bakken Library and Museum, n.d.)

Terms, Concepts and Questions to Start Background Research

- Static charge
- Leyden jar
- Benjamin Franklin
- Battery
- Capacitor
- Electrophorus
- Ground
- Static electricity generator
- Charge dissipation

Questions

- What kinds of materials can you use to create static charge?
- What kinds of jars can you use to store charge?
- Does changing the size of the electrodes affect the amount of stored charge?
- Is there a limit to the amount of charge the Leyden jar can hold?
- How long will the Leyden jar hold the charge? An hour? A day? This is called charge dissipation and this is a key factor that circuit designers evaluate.

Bibliography

- Check out the "Charge and Carry" project on the Exploratorium website:
Exploratorium. (n.d.). *Charge and Carry: Store up an electric charge, then make*

sparks. Retrieved March 25, 2008 from

http://www.exploratorium.edu/snacks/charge_carry/index.html

- The following website shows different homemade Leyden jars and has some additional sources:
Leyden Jars. (n.d.). Retrieved March 25, 2008 from
<http://www.alaska.net/~natnkell/leyden.htm>
- This website has a good general page on capacitors:
Brain, M. and Bryant, C. (2008). *History of the Capacitor*. Retrieved March 25, 2008 from the howstuffworks website:
<http://electronics.howstuffworks.com/capacitor3.htm>

Materials and Equipment

- Electrophorous Assembly
 - Disposable aluminum pie pan
 - Styrofoam™ cup
 - Tape (regular Scotch® tape will work fine)
- Leyden Jar Assembly
 - Small plastic jar with lid; a film canister, which is generally made with HDPE (high-density polyethylene) plastic, works very well
 - Hammer
 - Nail (a plain metallic nail that is slightly longer than the jar you are using)
 - Small piece of aluminum foil
 - Spoon
 - Tap water
 - Paper towel
- Charging the Electrophorous
 - Acrylic sheet, 11"x14" (available at hardware stores and should be larger than the pie pan)
 - Wool cloth (sweater, socks, or wool felt)
 - Assembled electrophorous
 - A stable table
- Measuring the Charge
 - Small piece of an aluminum sheet (an aluminum cover for an electrical box works well, as in Figure 6 below); available at hardware stores
 - Large, flat piece of Styrofoam
 - Plastic travel soap dish (clamshell variety); the soap dish should be rectangular
 - Scissors
 - A piece of insulated wire, 6" long
 - Wire strippers

- Tape (regular Scotch tape will work fine)
- Metric ruler
- General
 - Fine-tip pen
 - Insulated tongs
 - Lab notebook
 - Graph paper

Experimental Procedure

Safety Note: Adult supervision is recommended for this project. While the amount of current that can flow from this device is low, the amount of charge held in the device can cause a mild to moderate shock. To safely discharge the Leyden jar, take insulated tongs and touch the outside foil electrode to the nail, while holding onto the insulated handles. Always exercise caution when dealing with electricity and electrical parts.

The first step in this experiment is to make the Leyden jar and the electrophorus that is used to charge the Leyden jar.

Electrophorus Assembly

1. Take the Styrofoam cup and place the wide end of the cup in the middle of the inside of the aluminum pie pan. Tape the cup to the pie pan. Just tape the edge of the cup. You don't need too much tape. See Figure 3.



Figure 3. Simple electrophorus.

Leyden Jar Assembly

1. Gently hammer the nail through the top and middle of the plastic jar's lid. Make sure that the nail almost hits the bottom of the jar when the lid is back on and that it is straight and not tilted in one direction or another. Ask an adult for help. Then take the lid off and set it aside.
2. Take the piece of aluminum foil and wrap it tightly around the outside of the jar. Tape the edge of the foil to the jar. Rub the aluminum foil with the back of a spoon to make sure that there are no gaps between the foil and the jar. Make sure that the edge of the foil is not too close to the top of the Leyden jar. If it is too close, there could be a spark-over and no charge would be held in the Leyden jar.
3. Fill the jar with tap water, about 80% full. Make sure that the outside remains dry. Dry off any moisture with a paper towel.
4. Snap the lid back onto the jar. Wipe any excess moisture off the outside of the jar. See Figure 4 for a completed Leyden jar. Note that the nail is insulated from the outer electrode.



Figure 4. Leyden jar made from a film canister.

Charging the Electrophorus

1. Place the acrylic sheet on a table. If the piece of acrylic is new, rub it with the wool for about 1 minute until you create a static charge. Pick up the acrylic sheet to discharge it. Now you are ready to start the experiment. For the experiment, place the acrylic sheet on the table and rub the acrylic for 15-30 seconds to create a static charge. You might even hear the static charge popping and crackling while you are rubbing, signaling that it's ready to use. By rubbing the acrylic with the wool you are creating an excess of electrons on the acrylic.

Note: Be consistent in rubbing the acrylic sheet. Be sure to rub for the same amount of time for each trial. For example, if you rub the acrylic sheet for 30 seconds and then transfer the charge, you should keep rubbing the acrylic sheet for 30 seconds on each successive charge cycle. Charge cycles are explained below.



Figure 5. Rubbing the acrylic sheet with a piece of wool.

2. Place the electrophorus on top of the acrylic sheet, touching only the Styrofoam cup. You may hear a little bit of crackling and popping. The electrons on the acrylic sheet repel the electrons in the electrophorus. Touch the edge of the pie plate for just a second. You may get a little zap. When you touch the electrophorus, you create a path for the repelled electrons to go. Now the electrophorus is positively charged.

Charging the Leyden Jar

1. Now it is time to transfer the positive charge to the Leyden jar. Pick the Leyden jar up, only touching the outside foil. You will be acting as a ground.
2. Pick the electrophorus up by the Styrofoam cup. Don't touch any other part of the electrophorus.
3. Touch the head of the nail to the positively charged electrophorus (just the pie plate part). You may hear a zap when the electrophorus gets close to the head of the nail. You may also see a small spark. For the purpose of this project, *Charging the Electrophorus* through step 3 of *Charging the Leyden Jar* is called a *charge cycle*.
4. Once you've started the experiment and you proceed with your trials, be sure to note in your lab notebook how many times you charged the Leyden jar and the duration of the time that you rubbed the acrylic sheet.

Measuring the Charge

The next step is to determine how much charge is stored in the Leyden jar. Assemble your measurement setup.

1. Wedge the piece of aluminum sheet upright into the Styrofoam sheet. The aluminum piece should be perpendicular to the Styrofoam sheet. See Figure 6.
2. Snip off the lid of the clamshell soap dish with scissors. If necessary, use the scissors to carve a little notch in the short end of the soap dish in order to accommodate the nail. Ask an adult for assistance.
3. Strip a little bit of the insulator off both ends of the insulated wire, using wire strippers. Tape one end of the wire to the aluminum sheet. Tape the other end of the wire to the outside of the Leyden jar, on the foil. Make sure that the wire is in good contact with both the aluminum sheet and the foil of the Leyden jar. However, you don't want to over-tape the end of the wire to the foil because you will be taking the end off and putting it back on several times. Be careful not to rip the foil.
4. Place the Leyden jar on its side and place it into the soap dish. The Leyden jar should lie along the longer side and the nail should sit in the notch. The top of the nail head should be flush with the edge of the soap dish. Tape the Leyden jar to the edges of the soap dish so that it doesn't move around. As mentioned above, do not over-tape the Leyden jar because you need to keep the foil in one piece. Put the soap dish/Leyden jar about 3 inches in front of the aluminum plate. Place a ruler alongside the soap dish, with one end as close as possible to the aluminum sheet. Now there is a frame of reference for measurement.

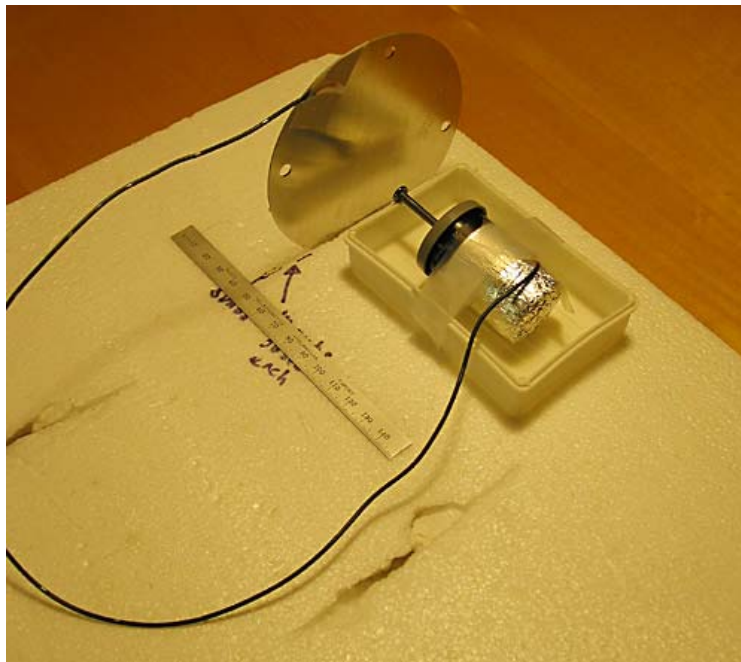


Figure 6. Testing assembly.

5. Before you begin your experiment, create a data table in your lab notebook, like the one below:

Leyden Jar #1 (HDPE film canister)	Rubbing Duration	Spark Length After 1 Charge Cycle	Voltage After 1 Charge Cycle	Spark Length After 5 Charge Cycles	Voltage After 5 Charge Cycles	Spark Length After 10 Charge Cycles	Voltage After 10 Charge Cycles
Trial #1							
Trial #2							
Trial #3							
Average							

6. Now you're ready to start your experiment. Remember, you have already completed one charge cycle for Trial #1. Start to move the soap dish slowly toward the aluminum sheet, making sure that you don't touch the aluminum sheet or the Leyden jar. Just touch the soap dish. At some point, you will get close enough that the Leyden jar will discharge and a spark will be created. When the Leyden jar discharges, you will see and hear the spark. Stop moving the soap dish when you see and hear the spark.
7. With the fine-tip pen and the ruler, mark the Styrofoam with where you stopped the soap dish, using the edge of the soap dish closest to the aluminum sheet as your point of reference. Measure the distance between the aluminum sheet and the leading edge of the soap dish. This distance is the length of the spark. Note this data in your data table.
8. Repeat *Charging the Electrophorus* through step 3 of *Charging the Leyden Jar* and the *Measuring the Charge* process two more times for Trial numbers 2 and 3. Measure the length of the spark each time and note it down in your lab notebook.
9. Then repeat the experiment three times for 5 charge cycles, and three times for 10 charge cycles. Remember, a charge cycle is *Charging the Electrophorus* through step 3 of *Charging the Leyden Jar*.
- After three trials with one charge cycle, charge the electrophorus 5 times in a row, transferring the charge to the Leyden jar each time.
 - Proceed with *Measuring the Charge*.
 - Repeat this for three trials.

- After three trials with 5 charge cycles, charge the electrophorus 10 times in a row, transferring the charge to the Leyden jar each time.
 - Proceed with *Measuring the Charge*.
 - Repeat this for three trials as well.
10. Remember to note down the length of the spark each time.

Determining Voltage

1. When you have the distance marked down, you can determine the voltage of the discharge or spark that you saw. It takes voltages of 30,000 volts (V) to make a spark 1 centimeter (cm) long in air with a pressure of 1 atmosphere (atm), or 30,000 V/cm @ 1 atm. This means that if you see or hear a spark at 1 millimeter (mm), which is 0.1 cm, then that spark had a voltage of 3000 V.
2. Air is an insulator. However, when the nail gets sufficiently close to the aluminum sheet, the voltage between the two is high enough to strip electrons from the air molecules. The air is then ionized. Ionized air allows current to flow between the nail and the aluminum plate. Knowing the voltage produced in the spark, can determine the amount of charge that the Leyden jar can hold.
3. Plot the data in a graph where the number of charge cycles is on the x-axis and the voltage in the corresponding spark is on the y-axis. Does the voltage increase with the number of charge cycles or does it stop changing after a certain number of charge cycles?

Variations

- Try using jars made of different materials. For example, try using a small plastic food container or a small wide-mouthed glass jar. Capacitance depends upon the material that the jar is made of and the size of the electrodes, so try finding jars of similar volume. Follow the design shown in Figure 1 and make sure that the inner electrode is isolated from the outer electrode.
- Try omitting water as the inner electrode and try using foil as the inner electrode. Is there a difference in charge storage?
- How long will the Leyden jar hold the charge? An hour? A day? This is called *charge dissipation* and this is a key factor that circuit designers evaluate. Charge dissipation occurs when charge leaks out of the Leyden jar into the air. Charge the Leyden jar and then let it sit for 1 hour. Test the voltage in the spark using the test assembly above. Try charging the Leyden jar with the same number of charge cycles and then letting it sit for 5 hours. Test the voltage in the spark using the test assembly. Is there a difference? How long will the Leyden jar hold the charge?