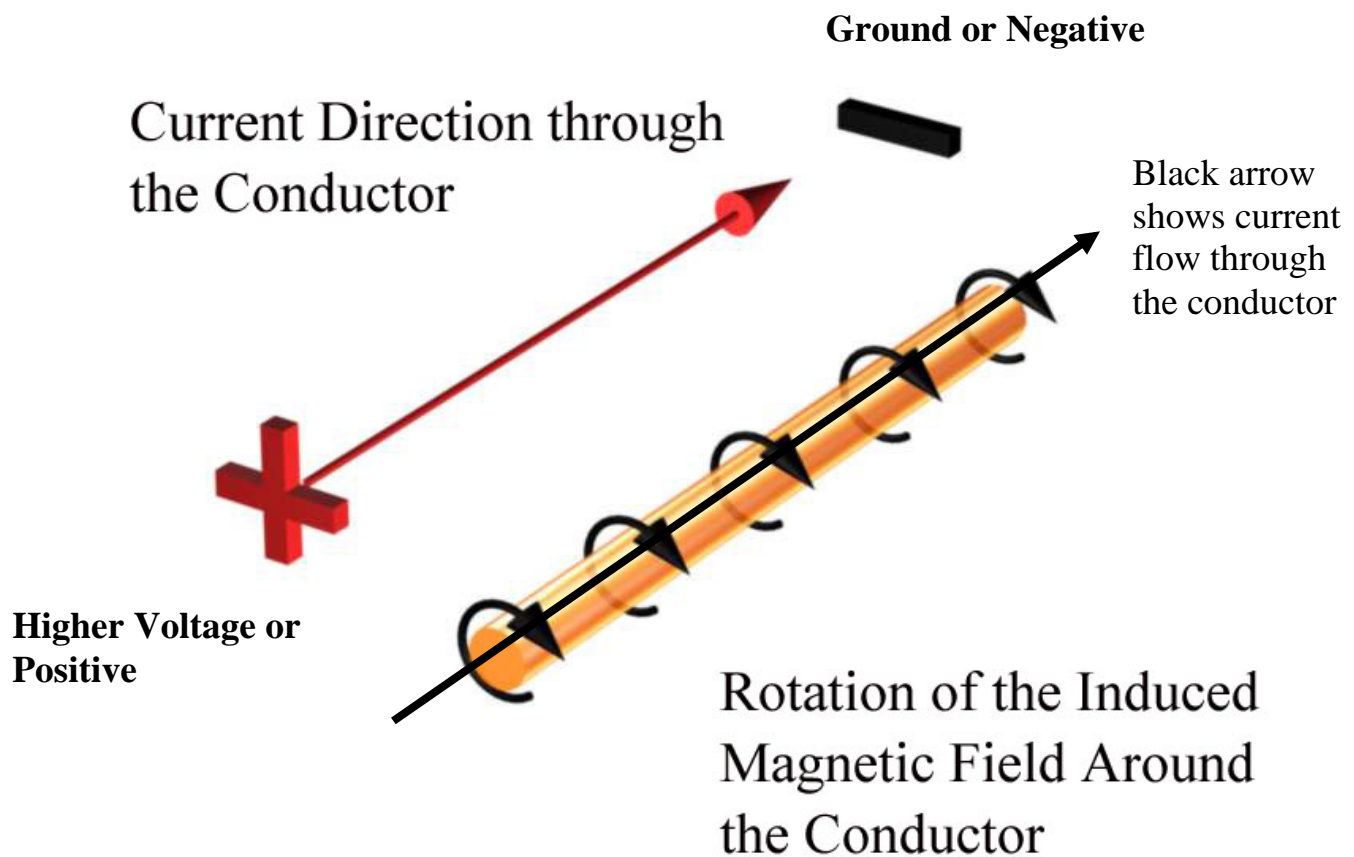


Current and Magnetism



Overview

This unit introduces electrodynamic theory and describes the relationship between current and magnetism.

Objectives

Students who participate in this unit and the related activities will:

- Define current and understand how it affects the strength of a magnetic field
- Recognize and use terms and concepts associated with fundamental electrodynamic principles.
- Explain the fundamental relationship between current and magnetism

Terms to Research

Electro Magnetism	Induced Current	Power Supply
Fixed Magnets	Voltage	Conductor
Electromotive Force	Current	Multimeter
Corollary	Magnetic Field	Empirical
Ammeter	Galvanometer	Coulomb
Resistance	Ampere	Counter Clockwisw CCW
Axially	Trebuchet	Induction (<i>Reference Faraday</i>)
Incontrovertible	Torque	Conventional current Flow

Materials

GEARS-IDS™ Kit	Magnets	Heavy Duty Test Leads
Triple Beam Balance or Electronic Scale	1.5 Volt D Cell Battery or DC Power Supply	6-10' of 18-22 Gauge Insulated Wire
Multimeter		Scale
Sensitive galvanometer		Tape

Introduction to Electro-Magnetic Principles

Electrodynamics is the study of moving electric charges and their interaction with electric and magnetic fields.

Within the first few decades of the 19th century, Danish Physicist, [Hans Oersted](#) noted that a compass needle would move (deflect) in response to a nearby current passing through a wire (conductor). Oersted's experiment demonstrated that when an electric charge moves through a conductor, a magnetic field is generated around the conductor. (*Moving charges are called current and are measured in units called Amperes.*) This experiment demonstrated the incontrovertible relationship between electricity and magnetism and established the direction for further research in electrodynamics.

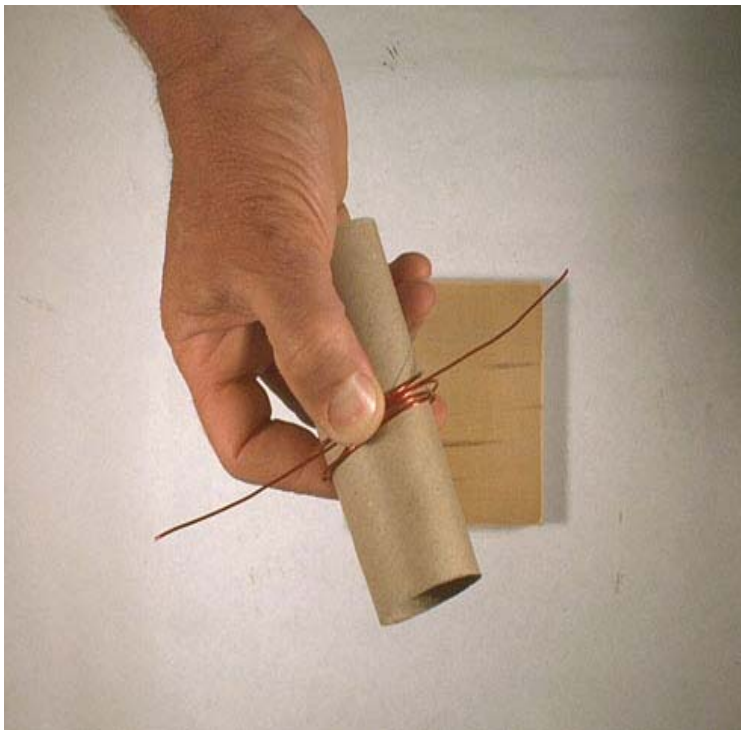
Within a decade, a self-trained English physicist, [Michael Faraday](#) discovered a fundamental electrodynamic principle. Faraday observed that current moving through a conductor produced a magnetic field around the conductor. He then proved it was possible to induce a current in a conductor by moving the conductor through a magnetic field. By 1831 Faraday was able to demonstrate electromagnetic induction. His experiments demonstrated that when a conductor and a magnetic field are moving relative to one another, a current is induced in the conductor.

Inducing a Current in a Conductor Using a Magnetic Field

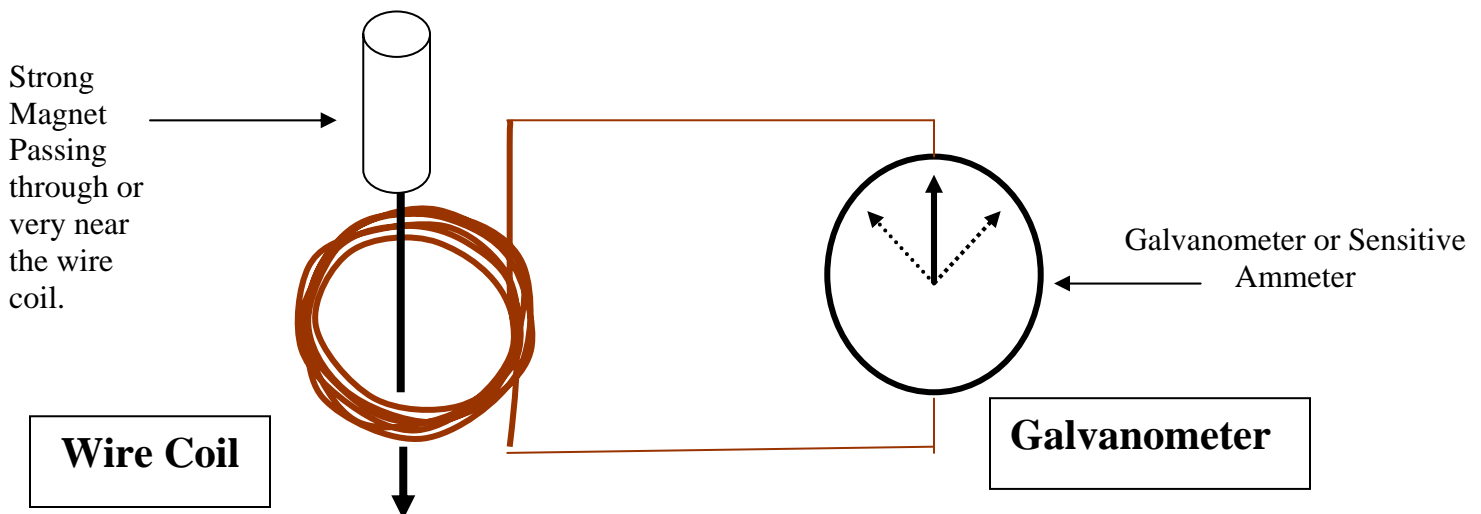
Recreating Faraday's Discovery in an Effort to Learn More about Current and Magnetism

Materials:

- 8 -10 ft. of 18 -22 gauge magnet wire
- Toilet paper roll or equivalent diameter PVC pipe.
- Sensitive analog voltmeter or galvanometer. (Check with the science department)
- A strong magnet. Neodymium magnets are very strong and can be harvested from old computer hard drives.
- Power supply or 1 or 2 AA or D cell batteries
- Compass
- A pair of test leads



1. Wind 8' of wire (*preferably (18-22) gauge magnet wire*) to form a loop around a cylinder or paper roll . Create 15 or more loops. Leave about 6" of wire leads.
2. Slide the wire loop off the cylinder and place a small piece of tape around the wires to hold the loop together.
3. Sand both ends of the wire to expose the bare conductor and connect the circuit to a sensitive milli-ammeter, micro-ammeter or galvanometer.
4. Pass a strong (*neodymium*) magnet through the wire loop and observe a deflection on the meter needle. Any deflection of the meter needle is an indication that current is being induced in the wire coil.



The previous demonstration illustrates that when a magnet passes through or near a conductor, a current is induced in that conductor. (*The coil of wire is made from copper, one of many materials that are capable of conducting electricity*)

The answer to the following question demonstrates one of the marvelous symmetries of science.

If a current can be induced in a conductor by a (moving) magnetic field, is it then possible to induce a magnetic field by passing current through a conductor?

The following demonstration answers the question.

A power supply is used in the demonstration below. This is a safe method for conducting this experiment. AA or D cell batteries can be used but caution must be taken to prevent overheating of the wire coil. 1-1/2 to 3 volts is all that is necessary for this demonstration.

Inducing a Magnetic Field in a Conductor Using Current

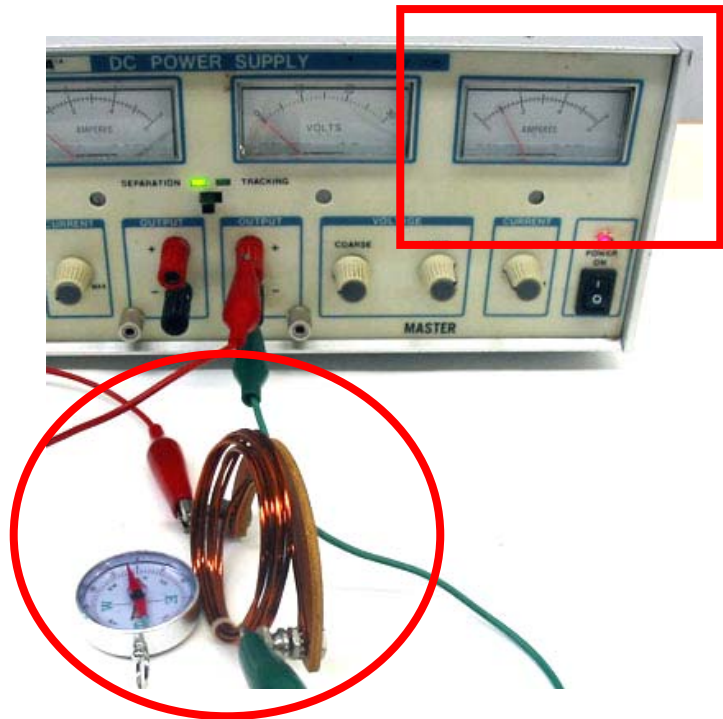
Recreating Faraday's Discovery in an Effort to Learn More about Current and Magnetism

Materials: The coil of wire from the previous demonstration can be used for this example.

- 8 -10 ft. of 18 -22 gauge magnet wire
- Toilet paper roll or equivalent diameter PVC pipe.
- Sensitive analog voltmeter or galvanometer. (Check with the science department)
- A strong magnet. Neodymium magnets are very strong and can be harvested from old computer hard drives.
- Power supply or 1 or 2 AA or D cell batteries
- Compass
- A pair of test leads
- Safety glasses for all the participants

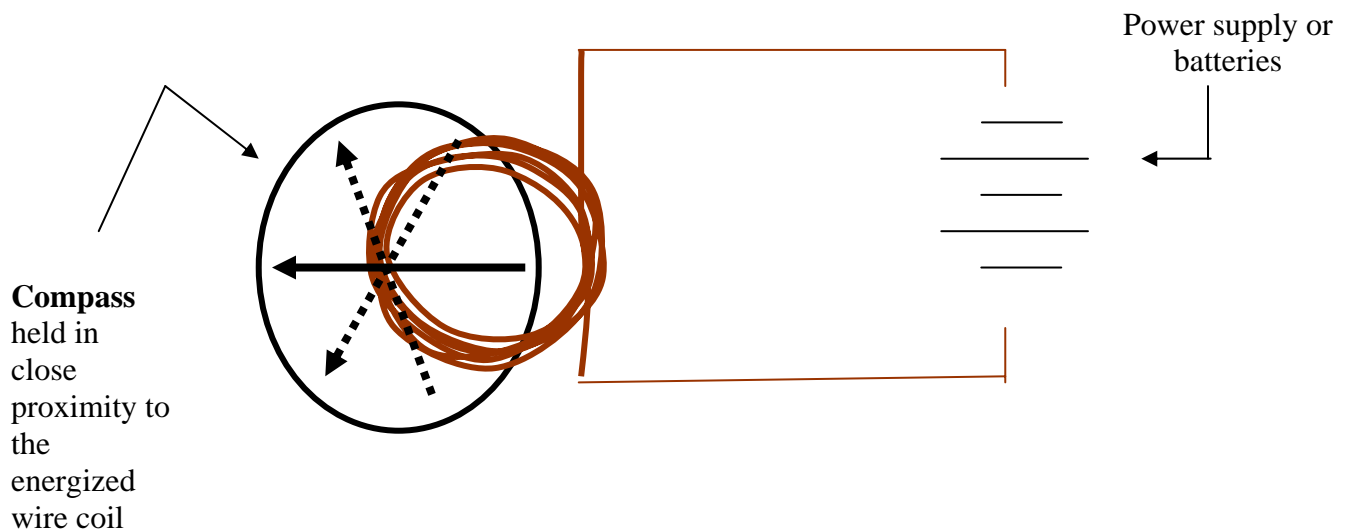
CAUTION: Excessive current can be dangerous and can make the wires hot enough to melt the insulation and cause severe burns! Some of the electrical energy (current) passing through the wire is converted into heat. Increasing the electrical energy (current) through a wire, increases the heat. If you double the current passing through a wire, the heat generated will be 4 times greater! Things can quickly become too hot to handle and burst into flames.

1. Have one student hold the coil of wire using a length of tape, string or other non conducting material.
2. A second student will make the electrical connections between the power supply or the batteries.
3. A third student will bring the compass in close proximity to the energized coil of wire.
4. After making certain all three students are ready, connect the coil to the power supply or batteries
5. The student holding the compass should not a deflection of the compass needle at the moment the coil of wire is energized. The compass should return to it's original position when the wire coil is disconnected from the power supply or batteries.



Note: It may be necessary to reorient the compass to the wire coil in order to maximize the compass deflection.

A compass is an instrument that reacts to very small magnetic fields. The deflection of the compass at the moment the wire coil is energized, indicates that a magnetic field is associated with the passing of current through the wire coil.

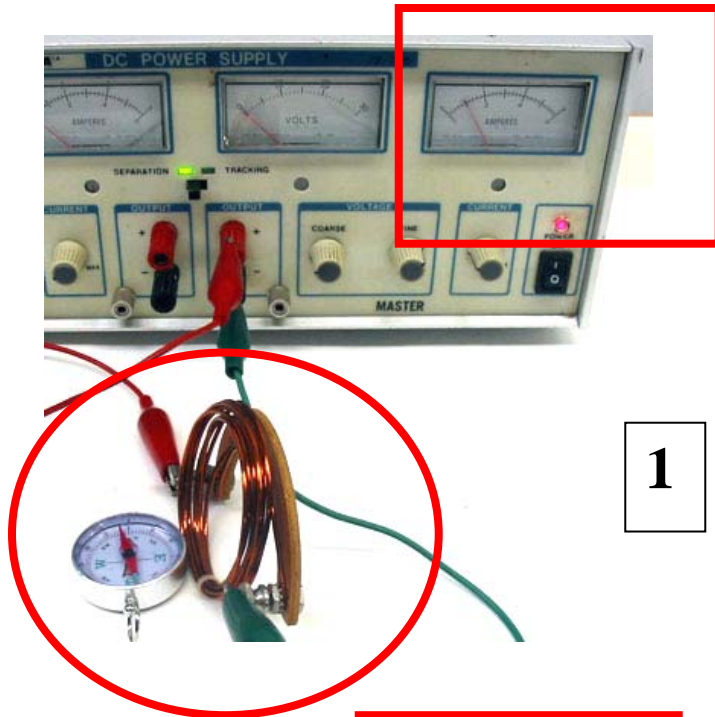


Note Book Assignment

Create a sketch of the two demonstrations. Use the drawings at the bottom of pages 3 and 5 as examples for your notebook sketch. Label all the items in the sketch. On the same page create a written description of the two (2) demonstrations and explain what they prove to you about the relationship between magnetism and electricity.

These are fundamental insights necessary for a more thorough understanding of how fixed magnet DC motors operate, how to evaluate their performance and how to “Engineer” them into a mechanism.

A Few More Insights into Magnetism and Electricity



1

The strength of the magnetic field is proportional to the amount of Current in the wire.

The two images on this page illustrate the relationship between (Increasing) current and the resultant increase in the strength of the magnetic field induced in the wire coil.

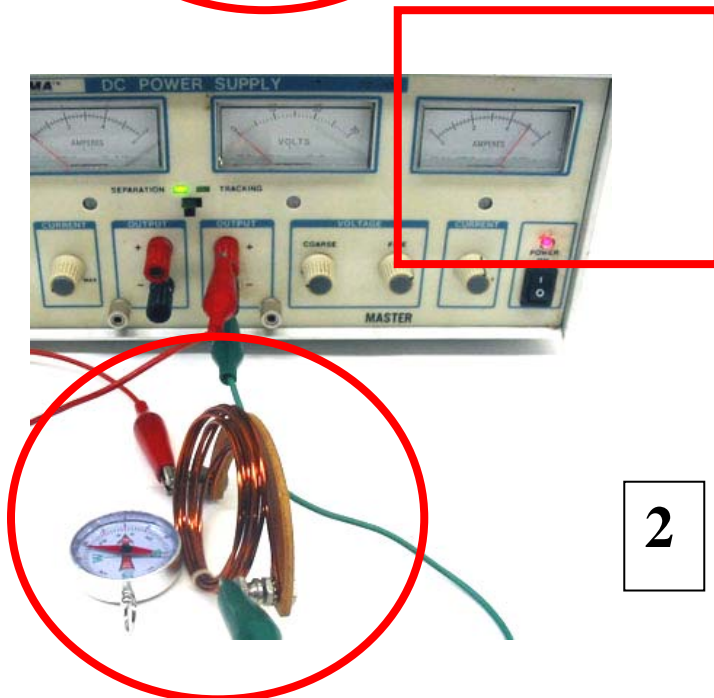
In this demonstration an increasing current is passed through a coil of copper wire. The coil is held in close proximity to a compass needle.

Increasing current is evidenced by the clockwise deflection of the ammeter needle on the power supply. *That is the meter in the rectangular red box.*

An increasing magnetic field is indicated by the counter clockwise deflection of the compass needle. *The compass is in the red oval.*

Note the current reading on the ammeter and the position of the compass needle in the no#1 image

Compare the ammeter reading and compass positions in both image #1 and image #2.



2

In your notebook create a written description of the relationship between increasing and decreasing current and the effect that has on the strength of the magnetic field induced in the wire coil.

A Final Insight into Magnetism and Electricity

Reversing the polarity of a circuit reverses both the direction of the current and the direction (polarity) of the magnetic field.

Here is a simple proof! Wrap several winds of wire around a compass. Attach the two wire ends to a battery and observe the effect on the compass needle. Now reverse the wire connections to the battery and again observe the effect on the compass needle. Why does this experiment prove that reversing the direction of current, reverses the magnetic field induced in a current carrying conductor?

Caution: By connecting a conductor across the battery terminals you are creating a low resistance path for the current. This can result in excessive current in the conductor causing the conductor to heat up rapidly. Pay attention to the fact that the wire can become very hot, very quickly.

Build a Simple Electro Magnet

Materials: The coil of wire from the previous demonstration can be used for this example.

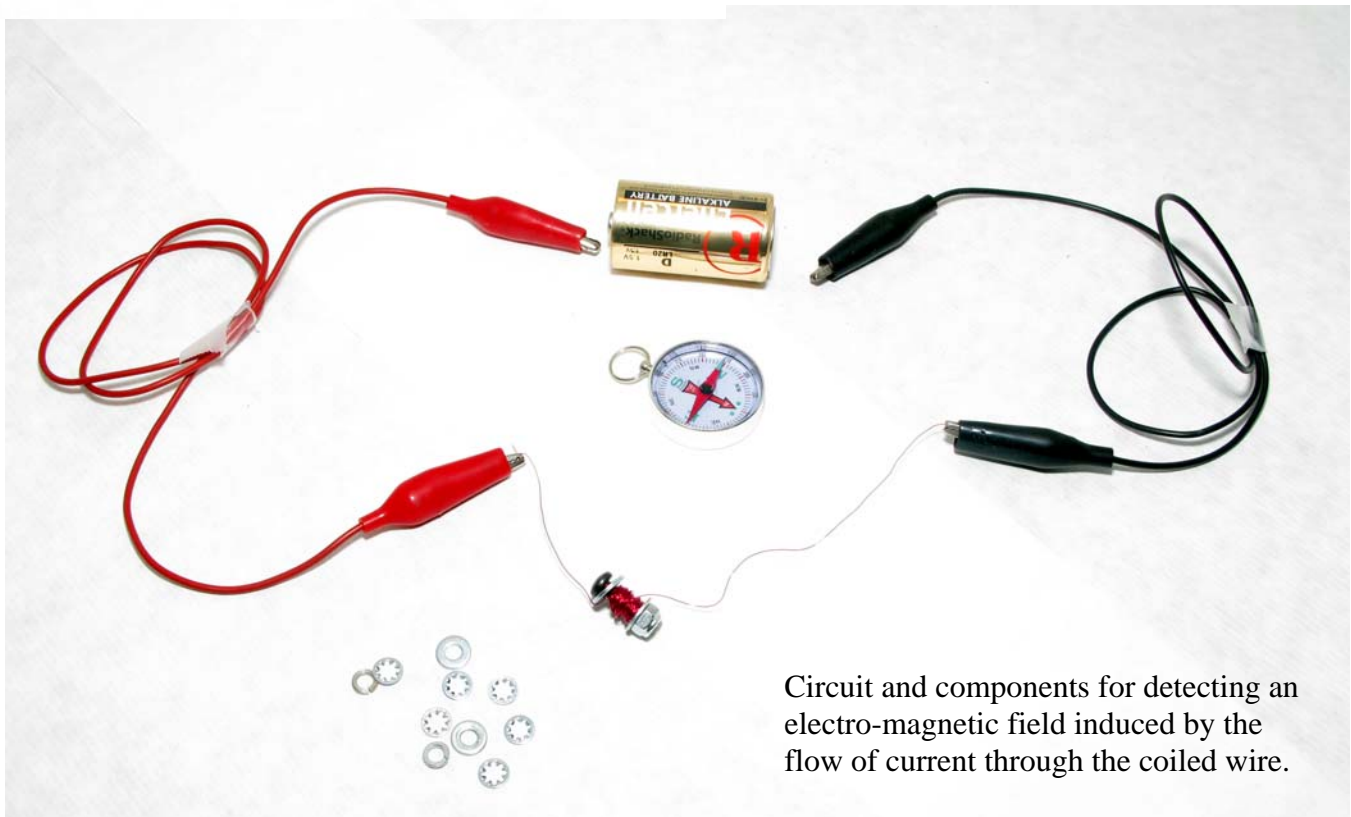
- 8 -10 ft. of 18 -22 gauge magnet wire
- #10-32 x 3/4" Machine Screw
- #10 nut
- 2- #10 washers
- Power supply or 1 or 2 AA or D cell batteries
- Compass
- A pair of test leads
- Safety glasses for all the participants

1. **Wrap the wire around the #10-32 x 3/4" machine screw** as many times as the length of wire will allow. Leave 6" for each end.
2. Scrape or sand the enamel off the ends of the wire so they can make a good electrical contact.
3. Energize the electro magnet using the power supply at 1-1/2 volts or connecting it to 1 AA or D cell battery
4. Demonstrate the magnetic force of the device by picking up as many of the nuts and washers in the GEARS kit as possible.
5. Using the compass, try and prove that the polarity (direction) of the current through the electro-magnet affects the direction of the magnetic field.
6. Increase the current by adding a second battery or raising the voltage on the power supply. Do not exceed 3 volts of electrical pressure!

CAUTION: Excessive current can be dangerous and can make the wires hot enough to cause severe burns! Some of the electrical energy (current) passing through the wire is converted into heat. If you double the current passing through a wire, the heat generated will be 4 times greater! Things can quickly become too hot to handle and burst into flames.

#10-32 x 3/4" Machine Screw, Washers and
Lock Nut

18 -22 gauge magnet wire

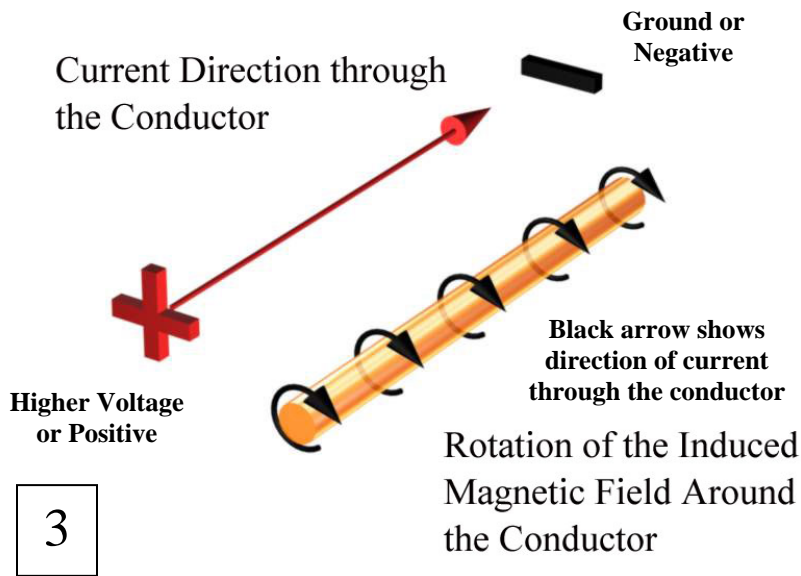


Circuit and components for detecting an
electro-magnetic field induced by the
flow of current through the coiled wire.

Note: The poles of the electro- magnetic field can be identified using the magnet. The needle of the compass is a magnet. The end of the needle that indicates the North direction (here on earth) is actually the north pole of the needle magnet. It will be attracted to a south magnetic pole, and repelled by a north magnetic pole. You might have concluded correctly, that the Earth's North pole is the actually the south pole of the earth's magnetic field!

How the Current in the Electro-Magnet Creates the Magnetic Poles

When the wire (conductor) is wrapped around the machine screw (iron core) and a current is passed through the conductor, a magnetic field is generated axially around the wire (conductor). Refer to image 3 below.



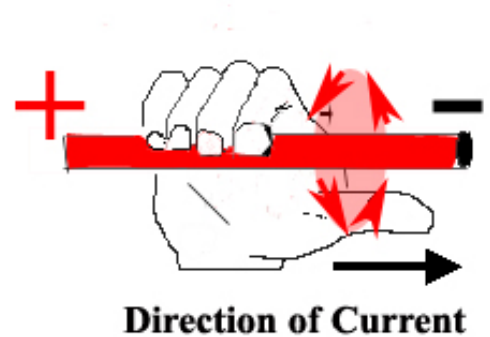
3

of your fingers will describe the direction of rotation of the magnetic field surrounding the conductor. The graphics below illustrates the relationship between the direction of current flow and the direction of the rotating magnetic field surrounding the conductor.

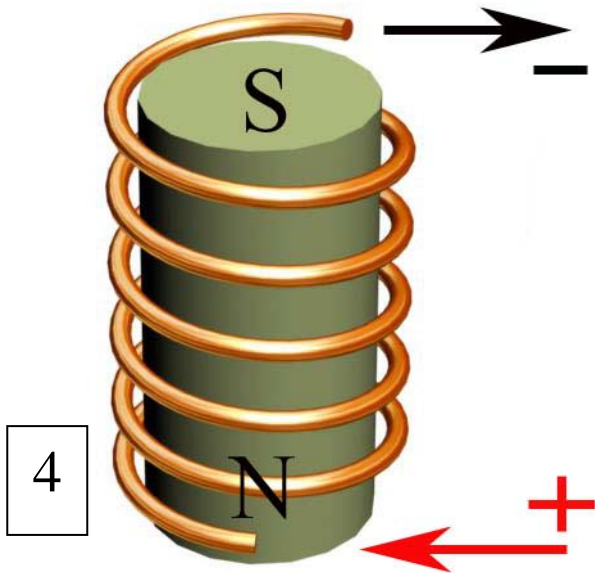
The direction of the magnetic field around the conductor be determined using the **Right Hand Rule**

The right hand rule allows us to determine the rotational direction of the magnetic field surrounding the current carrying conductor.

To apply the right hand rule: Grasp a conducting wire with your right hand. Point the thumb of your right hand in the direction of **conventional current flow** (positive to negative), the wrap



The next example illustrates how the North and South poles of the electromagnet are formed...and how they can be identified.

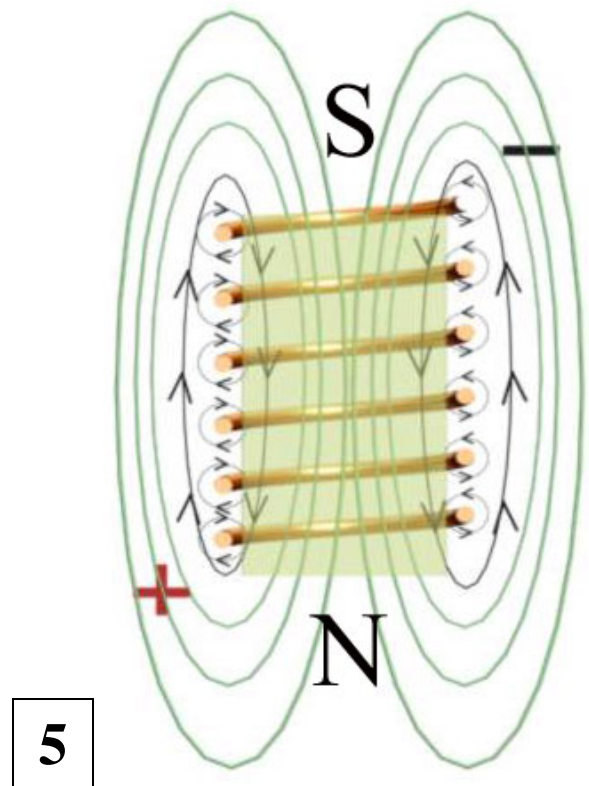
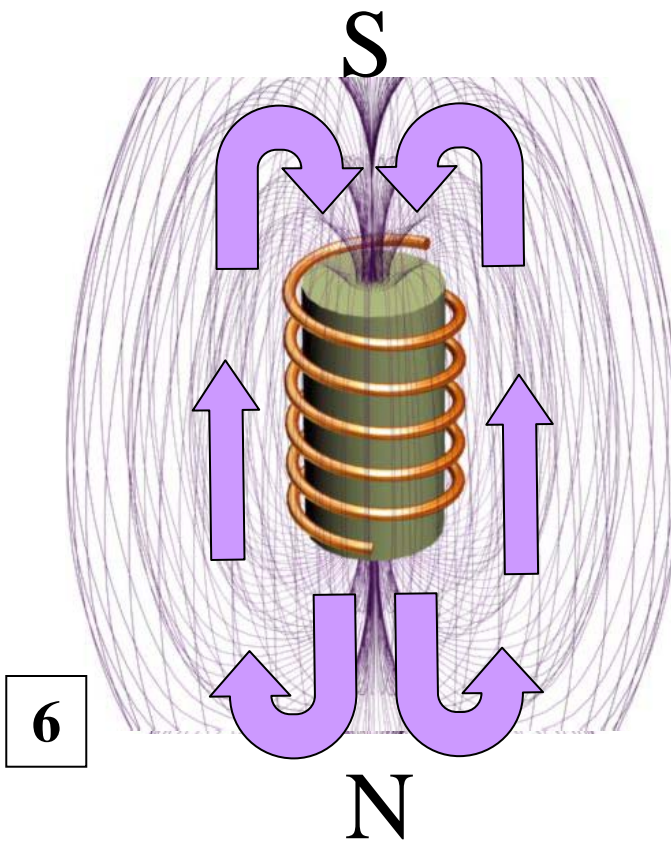


The graphic (# 4) illustrates the conductor wrapped around an iron core. The arrows indicate the direction of current flow through the conductor.

When we apply the right hand rule to the example in image #4, it is possible to visualize the direction of the induced magnetic field around the conductor.

Image # 5 illustrates how the magnetic fields surrounding each wrap of the conductor are additively resolved into a common magnetic field with the same direction.

Image #6 illustrates a 3D perspective view of the magnetic field of the electro magnet.



Note: The direction of a magnetic field has been established by convention as exiting from the north pole and entering the south pole. Use the compass to identify the poles. (See bottom page 8).

Activity #1

Build a Fixed Magnet DC Electric Motor

Participants in this activity will build a simple electric motor. The purpose of this activity is to understand the electro-magnetic principles that govern the operation of a FM DC motor.

Materials

Pencils and Paper Small Magnets (4-6 per motor) Enameled Magnet Wire 24-18 gage (<i>Approximately 2 ft per motor</i>) Alligator clip Test Leads (2 per motor) D Size Battery Holder (Optional) Try Square	Clear Tape Duct Tape Toilet Paper Rolls (4 per class) Exacto Knives Wire Cutters Stop Watch Needle Nose Pliers Wooden Block <i>approximately 3/4 x 4 x 4 inches</i>	D Sized Alkaline Dry Cell Large Paper Clips (<i>2 per motor</i>) Dark Marker 100-200 Grit Sand Paper Electric Drill 1/16 inch drill bit Drawing Compass 1 x 1/2 x 1 Styrofoam Block (<i>1 per motor</i>)
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Procedure

- 1.) [Click here to review the slide show that illustrates the motor building procedure](#)
- 2.) Carefully review and make a sketch of the motor construction diagrams.
- 3.) Obtain the materials listed above.
- 4.) Create the motor armature: Wrap approximately 10-15 turns of wire around the toilet paper roll. Be careful to leave approximately 1-2" at the beginning and end of the wrap. Use small pieces of clear tape to hold the wire wraps in place. After sliding them off the roll.
- 5.) Using a razor knife and sandpaper, carefully remove ALL the enamel insulation

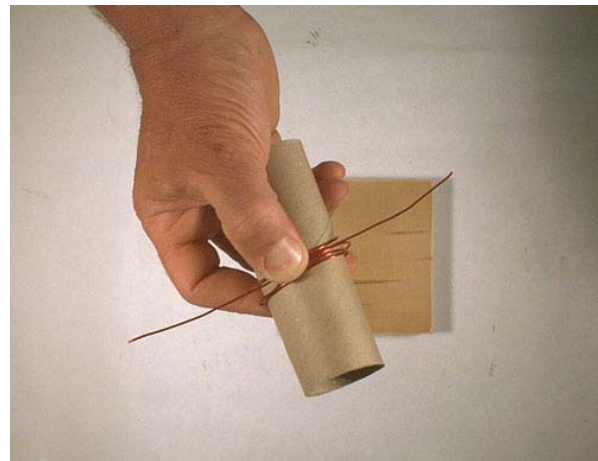


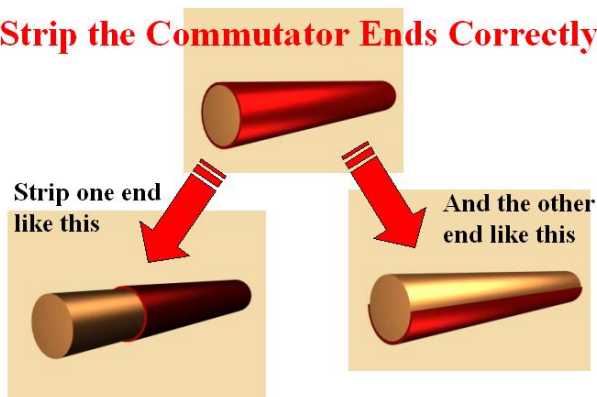
Fig. 1a Wrapping the Armature

from one end of the armature lead. Refer to the construction diagrams and remove only HALF the enamel insulation from the other end of the armature lead.

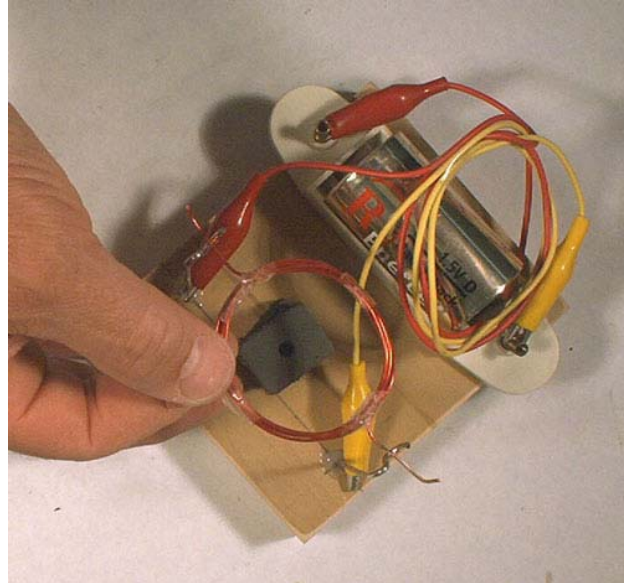
Note: Removing only half the material is an important step. The motor will not operate properly if more or less than 1/2 the insulation is removed.

- 6.) Draw a line on the wooden block Drill two 1/16" holes, 3" apart in the wood block. Use a 6" try square to keep the holes parallel.
- 7.) Bend the two paper clips (as shown) to

Strip the Commutator Ends Correctly



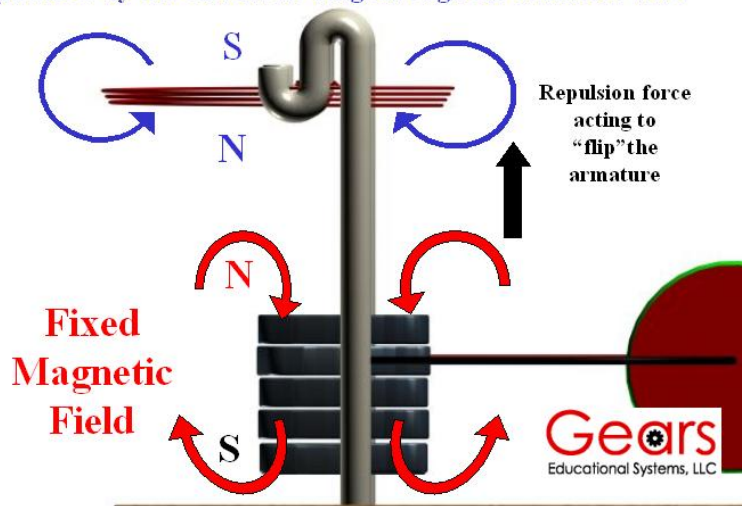
- accommodate the armature. Set the bent paper clips in the 1/16" holes.
- 8.) Balance the armature on the paper clips. Be certain that the armature leads are level and that the armature can spin freely above the magnets. Make any adjustments necessary in order to insure that the armature is balanced and spins smoothly. Make certain the contact surface between the commutator and paper clip brushes are clean and free of corrosion, dirt, oil or insulating material.
 - 9.) Place the battery and battery holder on the wooden block and attach the test leads to the battery terminals. Do not complete the circuit at this time.
 - 10.) Stack the magnets under the armature.
 - 11.) Connect the circuit. The armature should move slightly, in a rocking motion each time the circuit is completed. *(If the armature does not move, this indicates a poor electrical connection somewhere in the circuit or a dead battery. Check the battery voltage with a meter. Clean each connection and try again.)*
 - 12.) Spin the armature gently. The armature should continue to spin. If the armature does not continue to spin then: Be certain that the armature is as lightweight as possible. Increase the voltage (Add more batteries in series) Increase the magnetic field. (Obtain stronger magnets or add more magnets) Check for shorts and poor connections in the circuit. Twist the 1/2 insulated end of the wire. Reverse the test lead polarity



How this Motor Model Works

1. When the un-insulated ends of the armature are in contact with the paper clip, current flows through the armature.
2. Current flowing through the armature induces a magnetic field in the armature that is in opposition to the fixed magnetic field of the magnets.
3. The opposing fields create attractive and repulsive forces strong enough to create a torque on the armature causing it to rotate.
4. The armature begins to rotate towards an equilibrium position, with the attractive magnetic fields as close together as they can be, and the repulsed fields as far apart as possible.
5. The motor would come to a complete stop if it were not for the fact that one armature lead has 180 degrees of insulation left on it.
6. The insulated portion of the armature lead effectively **turns off the current** through the armature, allowing the momentum of the armature to carry itself through a turn of 360 degrees and the interaction of the induced and fixed magnetic fields begins again.
7. This motor is in fact operating on a magnetic "Push" and/or "Pull" that lasts through approximately half the time the armature is rotating.

Direction of Electromagnetic Field (Induced by the current flowing through the armature wire)



Activity #2 Intermediate

Teams of (2-3) students can research the operation of a fixed magnet DC motor. Make a set of sketches and drawings that help describe the operation of a fixed magnet DC motor. Combine the sketches and research into a slide show and present to the class, your explanation of how a fixed magnet DC motor works. The presentation can provide information about:

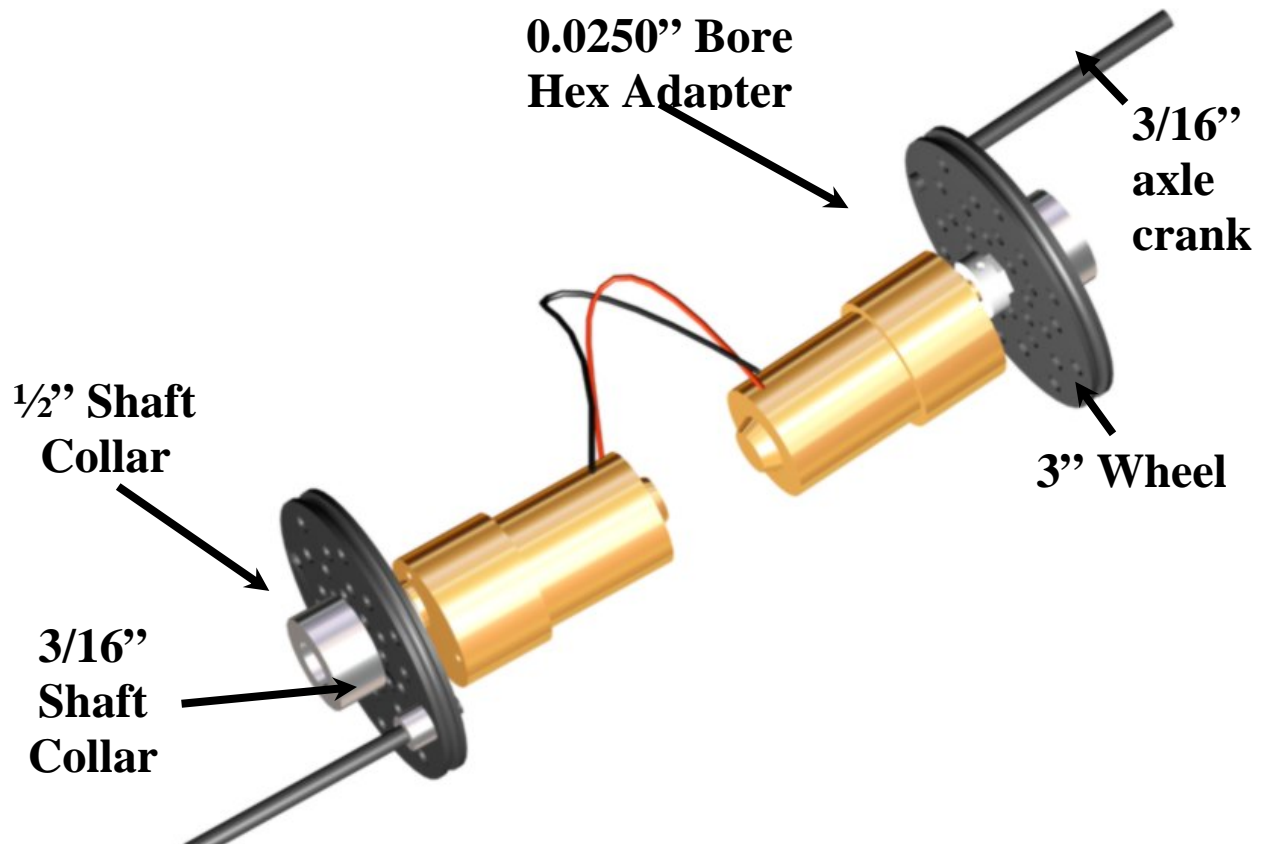
- Why motors have multiple poles on the armature
- Motor cogging and why it is not a desirable quality in motors
- What forces act to inhibit the overall efficiency of DC motor operation
- Strategies used to control DC motor speed and performance
- What factors affect DC motor rpm
- What factors affect DC motor torque
- Different types of DC motors such as fixed magnet, series wound, shunt wound and compound wound motors.

Activity #4

Use the brushed DC gear head motors supplied in the GEARS kit as generators. This activity is intended to raise questions and promote discussion about what is happening and why it happens.

Kit Materials: 2- Gear head motors, 2- Wire nuts , 1- 3" Wheel, 1- Hex Adapters (0.250" bore).
1- 1/2" Shaft Collar, 1- 4" axles, 2- 3/16" Shaft collars.

- 1.) Assemble the components as illustrated in the picture below. Note: It is only necessary to construct a cranking system for one motor (*not both as shown in the illustration*).
- 2.) Connect the wire leads as shown. (Note, it does not matter how the leads are connected with respect to polarity. Black to red or black to black will work)
- 3.) After the motors are connected, have two students each hold one motor.
- 4.) Have one student turn the motor crank in a clockwise direction. Observe the rotation of the second motor.
- 5.) **Note: Only One student at a time should crank a motor. Cranking both motors at the same time could cause injury and/or damage the motors.**
- 6.) Switch the leads and again crank the motor in a clockwise direction. Note the rotation of the second motor. Has it changed? How? Can you explain why.
- 7.) What effect does cranking faster have on the second motor?
- 8.) Try reading the voltage in the wires as you crank the motors at different speeds. What is the relationship between speed and voltage.
- 9.) If you crank one motor 10 full turns, how many times will the other motor turn? Why
- 10.) Try reading the current in the circuit as you crank the motor. What happens to the current if you try to slow the wheel on the turning motor while you crank the other motor?



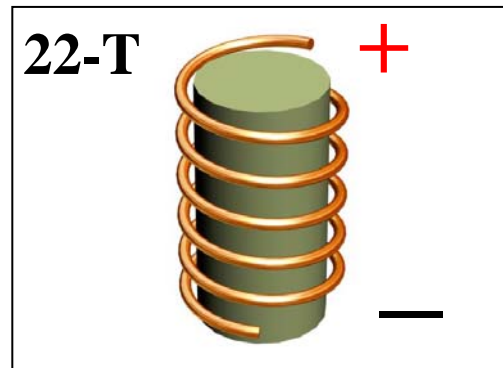
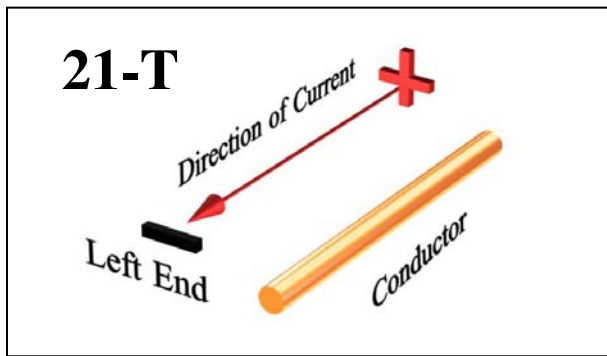
Current and Magnetism

Name _____ Date _____ Class _____

Directions: Answer the following questions using the information gained from researching the terms and information provided in this lesson

- 1.) Magnetic fields produced by currents moving through a conductor are called;
A.) Electro-magnetic fields B.) Fixed magnetic fields C.) Induced Current Fields D.) Both A and B.
- 2.) Voltage is the _____ that drives current through a circuit.
A.) Electro-magnetic fields B.) Charge C.) Force D.) Conductor
- 3.) Current is the movement of _____ through a circuit.
A.) Electro-magnetic fields B.) Charge(s) C.) Voltage D.) Conductors
- 4.) Fixed magnetic fields are associated with _____.
A.) Electro-magnetic fields B.) Permanent magnets C.) Electro magnets D.) Conductors
- 5.) A _____ can be used in place of a battery to provide DC current to a circuit.
A.) Voltmeter B.) Electromagnet C.) Power Supply D.) Multimeter
- 6.) Electrodynamics refers to the study of _____ in electrical circuits.
A.) Electro-magnetic fields B.) Current C.) Fixed magnetic fields D.) Both A and C.
- 7.) Danish Physicist, Hans Oersted discovered that current passing through a conductor created a _____ that surrounded the conductor.
A.) Conductor B.) Magnetic field C.) Current D.) Fixed magnetic field
- 8.) Moving charges or current are measured in which of the following units?
A.) Amperes B.) Volts C.) Watts D.) Both A and C
- 9.) Michael Faraday demonstrated that it was possible to induce a current in a conductor when either on or both the _____ or the _____ were moving relative to each other.
A.) Conductor, magnetic field B.) Magnetic field, conductor C.) Volts, Amperes D.) A and B
- 10.) The famous American inventor _____, who, like Faraday gained his knowledge and insight into the workings of the natural world through exhaustive empirical studies.
A.) Thomas Jefferson B.) Thomas Edison C.) Thomas Thompson D.) Thomas Dillon
- 11.) Molecules and atoms that have more or less electrons than protons are called _____.
A.) Isotopes B.) Electro chemicals C.) Ions D.) A or C
- 12.) Batteries convert _____ into _____.
A.) Chemical energy, electrical B.) Mechanical energy, electrical energy C.) A and B
- 13.) An atom or molecule with 8 protons and 6 neutrons has a net _____ charge.
A.) Negative B.) Positive C.) Neutral D.) A or B
- 14.) An important rule of battery safety is: Never connect a _____ across the battery terminals.
A.) Insulator B.) Motor C.) Conductor D.) Resistance

- 15.) A current flow of 1 Ampere is equal to the flow of one _____ per second.
 A.) Coulomb B.) Volt C.) Watt D.) Both A and C
- 16.) A Coulomb is equal to 6.24×10^{18} units of _____.
 A.) Volts B.) Charge C.) Amperes D.) Watts
- 17.) Ohm's law is an algebraic expression that describes the relationship between Current, Voltage and _____ in a circuit.
 A. Resistance B.) Impedance C.) Amperage D.) The magnetic field
- 18.) Ohm's law suggests that if (only) the voltage in a given circuit is increased, the _____ through the circuit will also increase.
 A.) Current B.) Resistance C.) Impedance D.) Insulation
- 19.) All magnetic fields are polarized in a North-South direction.
 A.) True B.) False
- 20.) When you wrap the fingers of your _____ hand around the coils of an electromagnet in the same direction as the flow of conventional current through the conductor, then your thumb will point towards the _____ pole of the electromagnet.
 A.) Left, South B.) Right, South C.) Left, North D.) Right, North
- 21.) In the diagram labeled **21-T** below, draw circular arrows around the conductor illustrating the direction of rotation of the magnetic field around the conductor. The direction of rotation is _____ when viewed from the left end of the conductor.
 A.) Counter Clock Wise (CCW) B.) Both A and C C.) Clockwise (CW)



- 22.) In the diagram labeled 22-T (Above, Right), use the right hand rule to determine the North and South Poles of the electromagnet. The North magnetic pole is on the _____ of the cylinder.
 A.) Top B.) Bottom C.) Right D.) Left
- 23.) Which of the following influences the relative strength of the magnetic field surrounding the electromagnet?
 A.) Number of wire turns B.) Amount of Current C.) The direction of the Poles D.) Both A and B
- 24.) Current in a wire always produces heat.
 A.) True B.) False
- 25.) Connecting a coil of wire across battery terminals can melt the wire and cause severe burns.
 A.) True B.) False

Assessment Rubric for Current and Magnetism

This rubric is offered as an example only. Each instructor is encouraged to create their own assessment tools with respect to the needs and expectations of their individual students/classes.

Proficiency	Meets/Exceeds Requirement	Meets Some of the Requirement	Meets little or None of the Requirement
Creates and uses a wire coil and a magnet to induce a current in a conductor			
Researches and defines the terms listed in the beginning of this lesson			
Connects a wire coil to a DC power supply and induces a magnetic field around the coil.			
Presents clear sketches that detail and describe the relationship between current and magnetism			
Builds and Determines the polarity of an electro magnet			
Completes a working model of a DC motor			
Presents additional information to the class on the topic of current and magnetism			

Additional Assessment Tools Can Include:

Performance assessment.

- Portfolio (An organized chronology of individual achievement. This could be a notebook or a web page or a multimedia presentation about the topic)
- Work Sheets, Labs and design challenges.
- Examples of Spread Sheets used to determine voltage, current and resistance
- Tests and Quizzes

Student Response/Journal Entry/Assignments

This is a listing of required documents or deliverables to be produced and present in each student's notebook.

1. Photographs of working DC motor model
2. Research Presentation
3. Model Motor Project
4. Tests or Quizzes.

Links and Resources.

<http://www.reliance.com/mtr/mtrthr.htm> An lengthy explanation of AC and DC motor theory.

<http://electronics.howstuffworks.com/motor.htm> As always a light and informative look at the topic