

Electromagnetism Workshop for PAC07

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SUPPLY LIST

Nd Magnets:	1	$\frac{3}{8}$ in. dia. x $\frac{3}{8}$ in. long
	1	$\frac{1}{2}$ in. dia. x $\frac{1}{2}$ in. long
	1	disc
Lag Screw	1	$\frac{1}{4}$ in. x 1 in.
Wires:	2	Bare copper with ring ends
	1	3 in long with stripped ends
Rolls of Wire:	1	red: 30-gauge (.010", .255 mm dia), 200 ft. (with custom connections)
	1	green: 26-gauge (.016", .405 mm dia.), 75 ft.) (with custom connections)
	1	copper: 22-gauge (.025", .644mm dia), 40 ft.)
Batteries	2	AA
Generator:	1	wooden base
	2	eye bolts with nuts
	1	handle
Clip Leads		as needed
Iron Filings		as needed
Compass	1	
Transformer	1	7.2 volt wall plug plus cord
Bolts	2	$\frac{1}{2}$ x $2\frac{1}{2}$
Nut	1	$\frac{1}{2}$
Washer	1	$\frac{1}{2}$
Hose	1	$\frac{1}{4}$ x $\frac{3}{8}$ approx. 1 in. long
	1	$\frac{1}{4}$ x $\frac{1}{2}$ approx. 1 in. long

POTENTIAL SUPPLIERS

sciplus.com
wondermagnet.com
rare-earth-magnets.com
magnetsource.com
sargentwelch.com
alliedelec.com
mscdirect.com

scientificsonline.com
gaussboys.com
herbach.com
freyscientific.com
digikey.com
mcmaster.com
radioshack.com

1 Magnetic Field

The electric field at a point in space is defined as the direction a positive charge will move. The magnetic field is similar but there are important differences. Unlike electric charges, there are no free magnetic charges (magnetic monopoles). This means that magnets exist only as dipoles; any time a north magnetic pole exists it is coupled to a south magnetic pole. With this in mind, when a magnetic dipole that is free to move (such as a compass needle) is placed in an external magnetic field it will rotate to align itself with the external field, but its center of mass will not move.

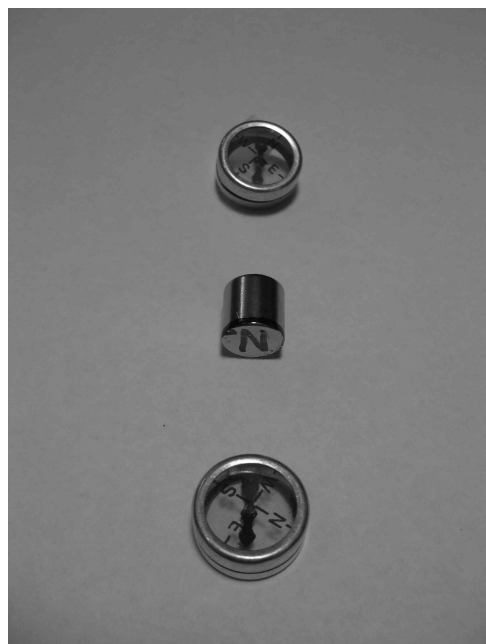
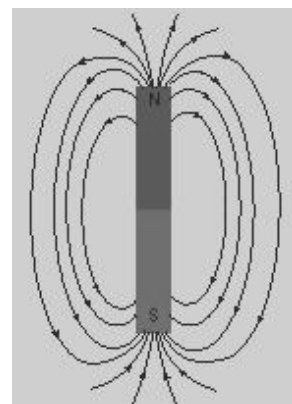
References: <http://www-spf.gsfc.nasa.gov/Education/Imagnet.html>
<http://science.howstuffworks.com/compass.htm>
<http://education.nasa.gov>

1.1 Direction of Magnetic Fields

By definition, magnetic field lines are directed outward at the north pole of a magnet and inward at the south pole. The arrow of the compass that points toward the Earth's geographic North is a north magnetic pole. It is sometimes more instructive to think of the north pole of a magnet as a "north seeking pole", since the geographic North pole of the Earth is actually a magnetic south pole.

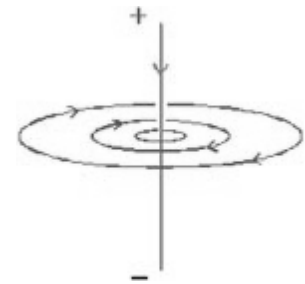
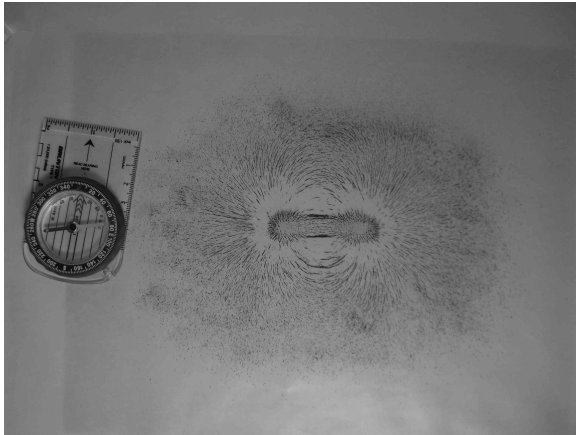
References: http://gsc.nrcan.gc.ca/geomag/field/index_e.php

With this in mind, a compass can be used to determine which is the north or south pole of an unknown magnet as shown. Note that a line is drawn around the magnet's north pole for reference.



1.2 Visualizing Magnetic Field Lines

A bar magnet is placed under the sheet of paper. Iron filings sprinkled on the paper show the basic geometry of the magnetic field lines. The compass indicates that the magnetic field lines are pointing toward the left hand edge of the page; the left end of the magnet is a north pole.

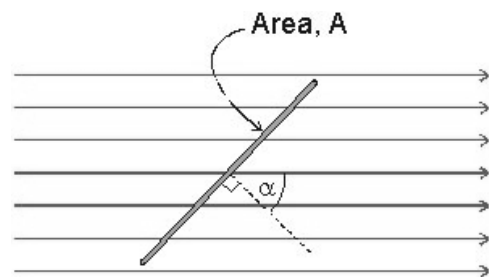


A current carrying wire also produces a magnetic field: $B = \mu_0 I / 2\pi r$. In this equation I is the current, r is the distance from the wire, and μ_0 is the permeability of free space ($= 4\pi \times 10^{-7} \text{ N/A}^2$). The direction of the magnetic field created by a current is given by the right hand rule (RHR).

References: *Physics for Scientists and Engineers*, Tipler & Mosca, 5th Edn.

2 Electromagnetic Induction

As discussed above, electrical currents give rise to magnetic fields. Magnetic fields can also be used to induce electric fields (and therefore electrical currents) with one key difference. The electric current that creates a magnetic field can be a constant current or a current that changes with time. However, in order for a magnetic field to induce an electric current there must be a change in the magnetic flux. Magnetic flux through any area is defined as (the area) \times (the component of the magnetic field perpendicular to the area): $\Phi = AB \cos(\alpha)$. The induced voltage (or EMF as it is often referred to) is the time rate of change of the magnetic flux: $V = \frac{\Delta \Phi}{\Delta t}$. A voltage can be induced by changing: 1) the strength of the magnetic field, 2) the orientation of the field to the area, or 3) the area.



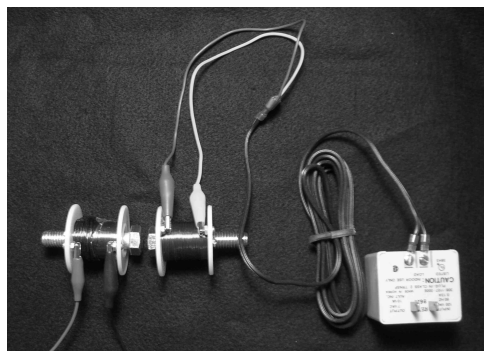
References: <http://www.saburchill.com/physics/chapters/0056.html>

2.1 Transformers

A transformer makes use of the changing magnetic field to induce currents. One coil (the primary coil) creates the magnetic field, the other responds to it (the secondary coil). The magnetic field is essentially the same for every loop. So the total flux for a coil is the flux of each coil times the number of coils: $\Phi_{total} = NAB$. Here N is the number of turns (or number of loops of wire), A is the area of each loop (assumed to all be equal) and B is the field which is perpendicular to the plane of the coils ($\alpha = 0$). With a different N for the primary and secondary coils a different voltage will be seen across each when they are subject to changing magnetic fields. The change in magnetic field is created by varying the current in the coil creating the field, typically by applying AC power to the coil. If the number of turns of the primary (N_p) is less than the number of turns of the secondary (N_s), this will be a step up transformer; the secondary voltage will be greater than the primary. Reversing the situation gives a step down transformer.

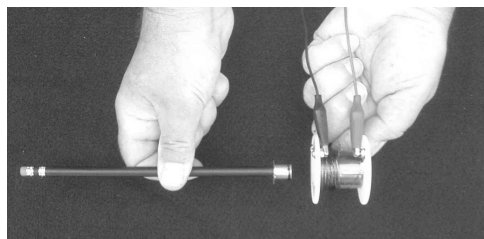
The magnetic field created by the primary coil is: $B_0 = \mu_0 nI$. Here n = the number of turns per meter of length, I = the current, and μ_0 = the permeability of free space. This formula applies when the core of the solenoid is air. The strength of the magnetic field can be substantially increased by using an iron (ferromagnetic) core as the magnetic domains of the iron line up with the external field. The final field is now: $B = \mu nI$, where $\mu = K_m \mu_0$, and K_m is the relative permeability of iron (≈ 5500). Keep in mind that for any region of magnetic field, iron will increase the field.

The number of turns in each coil can be calculated using the diameter of the wire from the supply list, and the dimensions of the spool. The region where the wire is wrapped has a diameter of 24 mm (.94") and a length of 32 mm (1.26").

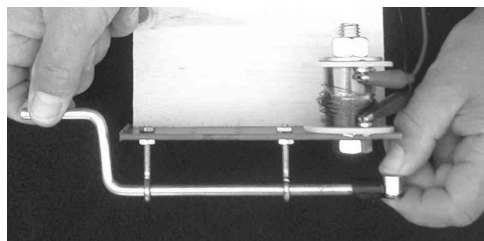


2.2 Generators

A generator converts mechanical energy into electrical energy. A mechanical force moves a magnet in the vicinity of a coil of wire. The magnetic flux changes because the orientation of the field is changing with time due to the magnet's motion. The induced current will always create a magnetic field to counteract the change in flux (Lenz's Law). The right hand rule (RHR) can be used to determine the direction of current flow. As the north pole of the magnet moves in to the coil, a counterclockwise current (as viewed facing the eraser of the pencil) will be induced creating an induced magnetic field that will tend to cancel the imposed change in the flux.



It is much more useful to generate continuous currents instead of a single pulse, which can be done by rotating the magnet near the coil. Note that if the magnet is oriented so its magnetic field is parallel to the shaft, the field in the region of the coil stays constant (no induced voltage) no matter how fast the crank is turned.



3 Forces Due to Magnetic Fields

A static magnetic field will exert zero force on a stationary charge but will exert a force on a moving charge, such as the charges moving in a wire carrying an electric current. The force is proportional to the charge (q), the speed (v) and the magnetic field (B) and the direction is given by the right hand rule (RHR): $\vec{F} = q\vec{v} \times \vec{B}$. Similarly for a current carrying wire (current = I and length = l) the force is: $\vec{F} = I\vec{l} \times \vec{B}$.

3.1 Force on a Current Carrying Wire

When a magnet is brought close to a wire with a current flowing through it, there will be a magnetic force exerted on the wire. The force is proportional to the magnetic field and the current, with the direction given by the RHR: $\vec{F} = I\vec{l} \times \vec{B}$.

3.2 Electric Motors

As a magnet is brought near a current carrying loop, the loop rotates to align its magnetic field with that of the magnet. The RHR can be used to determine the rotation direction.

References: <http://www.linux-host.org/energy/tmotor.htm>

A freely rotating coil can be modified slightly to make a simple electric motor. The insulating enamel is removed around the entire circumference of the wire on one side but only on one-half of the circumference on the other side. The simple commutator made by leaving half of one wire insulated turns off the flow of current for 180° of rotation.



In addition the motor above, a very simple electric motor can be made using a powerful Nd magnet, a battery, a lag screw, and one piece of wire. This motor is a valuable tool for learning the RHR, once the direction of current flow and the geometry of the magnetic field lines are visualized. Notice that when using the ring magnet, making electrical contact near the ID of the ring reverses direction. Consider the shape to the magnetic field lines when describing this phenomenon.

