ELECTRICITY DEMONSTRATOR HANDBOOK

A project of the Virginia Coordinating Council of the Institute of Electrical and Electronic Engineers for introducing Girl Scouts to electricity

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Foreword

This manual describes a program provided by the Virginia Coordinating Council of the Institute of Electrical and Electronic Engineers (IEEE). This program was designed to introduce electricity to Girl Scouts. The program attempts to teach electricity in an intuitive manner; it was developed to remove the semi-magical notions that many people have about electricity.

Section 1 of the program introduces the notions of circuit, voltage and current, safe and dangerous current levels, conductors, semi-conductors, and insulators, and problems with electricity and water used together. A 9 volt battery, an ammeter, and a glass baking dish with some water in it are used for Section 1.

Section 2 of the program uses a bicycle-driven alternator to demonstrate the power required to generate electricity and to sustain light and heavy loads. A load assembly with several light bulbs and switches is used with the bicycle-alternator to provide a variable electrical load.

Section 3 is a demonstration of a teaching motor. The motor shows interacting magnetic fields and commutation. This section uses a device which can be an AC or DC motor and generator, along with a power supply and a permanent magnet.

Section 4 of the program shows the operation of transformers and explains why the utilities use them. An exhibit containing transformers and loads accompanies this section.

Section 5 involves the participants in making an alternator that is cheap enough for everyone to take one home. This part of the program requires about 3-4 hours to execute and should have the other parts of the program interspersed within it, especially during times when cement is setting.

1.0 Introduction to Electricity

This section of the demonstrator describes the nature of voltage and current. Safety is introduced in a description of how much current is hazardous and the ease with which electricity flows through water is demonstrated.

parts
1. 9v (transistor radio or smoke detector) battery
2. volt - ohm - meter (VOM)
3. glass dish containing ½ inch of water

About 3 - 20 girls should be formed into a ring facing each other and holding hands. They will form an electrical circuit. Two adjacent girls should stop holding hands and, instead, touch a finger to different terminals of the 9 volt battery. One of these girls should touch the positive terminal and the other should touch the negative terminal. These two girls should have no other contact. This will start a small current (~10 - 50 microamperes) flowing through the ring of girls.
Two other girls on the ring, well separated from the girls touching the battery should stop holding hands and, instead, touch the metal parts of the lead wires from the VOM. The other end of the lead wires should be plugged into the VOM; customarily, the red lead is plugged into the positive (+ V-Ω-A) jack of the VOM and the black lead is plugged into the negative (- COM) jack. The rotary switch of the VOM should be set to the 50 microampere range (μA) of the ammeter function. The ammeter function is labeled DC A.

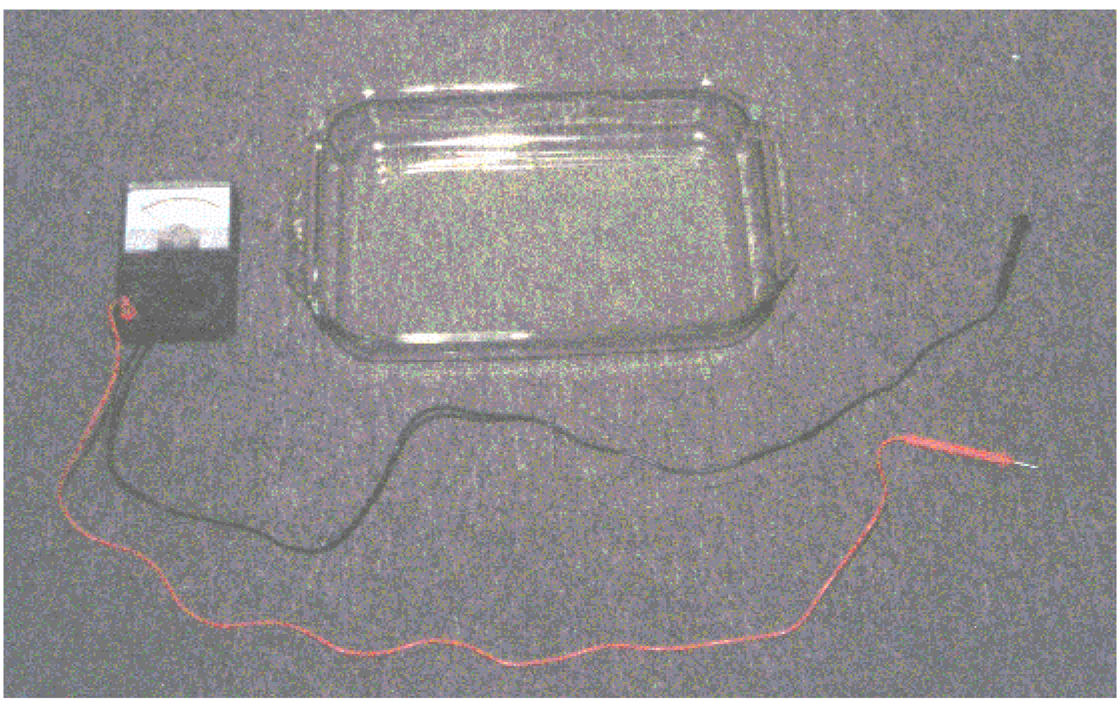

Figure 1. VOM and Glass Dish

The girls should be told:

1. The force pushing current through them is the voltage of the battery. Nine volts is considered a small voltage, so very little current is pushed through the girls. This is why 9v. batteries are not sold with terminal covers, not restricted to adults only sales, and have no warning labels.

2. The normal voltage in the outlets in houses is 120 volts, which is enough to push a much larger amount of current through a person; this voltage is hazardous and this is why the electrical system in the house is designed to prevent people from touching the terminals.

3. The amount of current that is hazardous varies with people and where it is applied. Generally 1 milliampere (1/1000 of an ampere) is at the low end of the hazardous range; 10 milli-amperes can kill people when applied to sensitive areas for a period of time. The amount of current flowing through the girls from the 9v. battery is about 20 to 50 times too small to be hazardous.

4. Have two girls in the ring stop holding hands. This will stop the current flow. The VOM reading will show that the current stopped. When they once again hold hands, the current will start up again.

5. Again, have two girls stop holding hands, but, instead, put their hands into the water in the glass dish. This will show that the water can complete the circuit even when their hands are not touching. If one of the girls takes her hand out of the water and puts her hand on a dry part of the glass disk, current will not flow, showing the insulating properties of glass. The resistance to the flow of electricity varies enormously from one material to another. Most metals have very low resistance to the flow of current. Glass has a high resistance. People have an intermediate value of resistance.

2.0 Bicycle Generator

The bicycle generator uses a 20 inch bicycle and an automotive alternator. Since the alternator has internal rectifiers, its output is direct current (DC) and it is called a generator. An alternator without rectifiers produces an alternating current (AC) output. The generator selected for this project is a re-built GM (automobile) unit with an internal voltage regulator. The generator is connected to the rear wheel of the bicycle with a fan belt; see the figure. The generator is mounted on a barn or fence hinge and tension is maintained on the belt with rubber bands attached to the hinge.

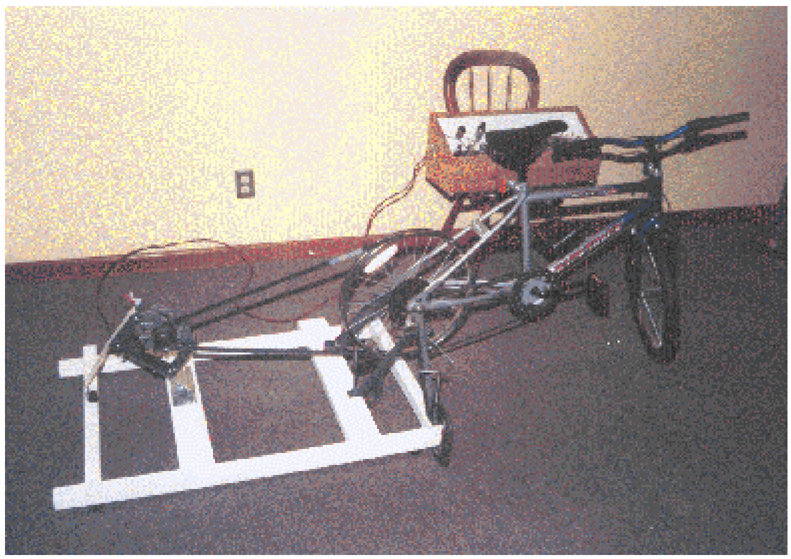

Figure 2. Bicycle Generator

The generator produces 12 volts, which is too low to be a hazard to the girls. The generator produces an output when a rotating magnetic field passes through the wire wound on the stator, which is the fixed (non-rotating) part of the generator. The rotor (the rotating part) of the generator must have a magnetic field before the generator can produce any electricity. The rotor is built as an electromagnet and therefore has no magnetic field until electricity is flowing through the rotor. This means that the generator is nothing more than two metal assemblies until something starts a current through the rotor. The something that starts the current flowing through the rotor is a battery composed of two D-cells that are mounted in the load box (light bulb assembly). See Figures 3 and 4. When the rotor is spinning, the operator pushes the red button on the load box for a second. This sends a weak current through the rotor and creates a weak magnetic field. Now the generator begins to produce current, some of which is used to maintain a strong current in the rotor.

The battery in the load box is needed to start production of electricity in the generator but, once the generator begins to produce electricity, the battery is no longer needed. If there were a permanent magnet in the generator, the battery would not be needed. The generator was built with an electromagnet, however, because electromagnets are adjustable and permanent magnets are not. This is done because the engine of a car rotates at many different speeds and an adjustable magnetic field makes it possible to generate a nearly constant voltage even when the car engine is rotating at varying speeds.

The load box contains 4 automotive lights, a cigarette lighter, and a spare cigarette lighter socket for use with 12 volt appliances, such as fans, radios, etc. Each of the four light bulbs (two turn signals and two headlights) contain 2 filaments and a separate switch for each; there are eight filaments. Any combination of these filaments, cigarette lighter, or spare cigarette lighter socket may be turned on or off. As the girl is riding, she may flip the switches on and off so she may feel the increased or decreased effort required to pump the pedals. The headlights require much more effort to keep lit than the turn signal lights.

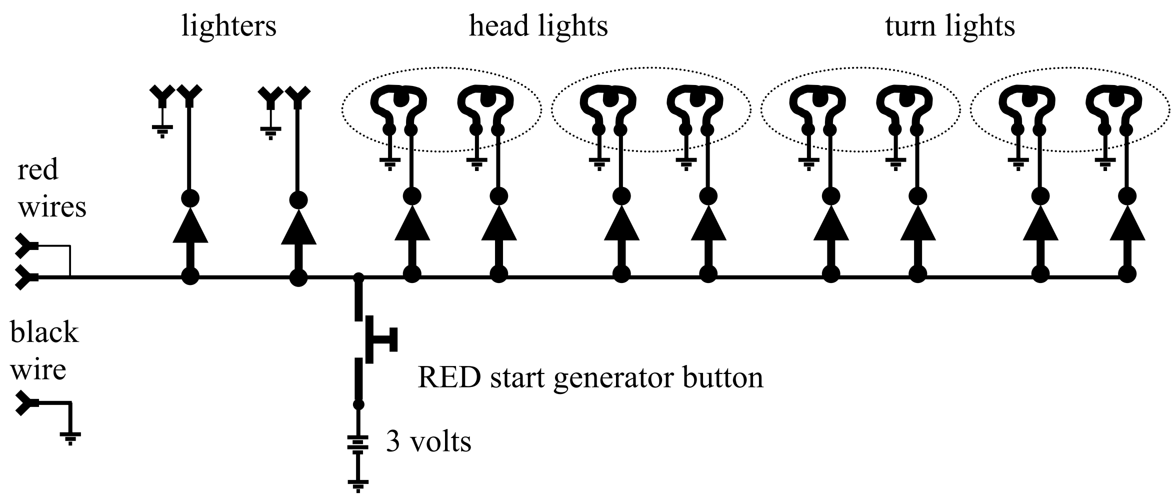

Figure 3. Load Box Schematic

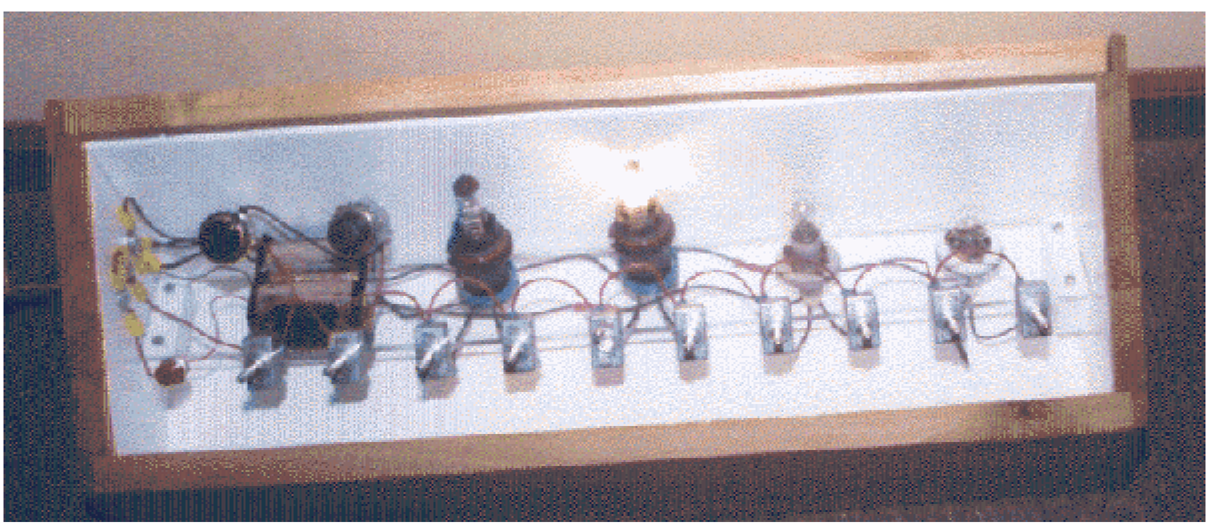

Figure 4. Load Box

One of the bicycle supports is permanently attached to the generator frame (left support) and the other support (right) is attached with two "C" clamps. To attach the bicycle to the generator frame, remove the support attached with "C" clamps. Loosen the nuts holding the rear wheel on the bicycle so there is room between the loose nut and the hub for the notch of the support to slip in between. Once the nuts are loosened, the rear wheel can fall off, so hold the rear wheel and bicycle together while putting the axle in the slot of the support. At this point, the left side of the rear wheel should be supported by the fixed support on the generator frame. The left support should be between the loose nut on the axle and the hub of the wheel. Ensure that the belt for driving the generator is looped around the rear wheel so it may be positioned as shown in Figure 5 later. Now, slip the right support into the gap between the loose nut and the hub on the right side of the rear wheel. Position the right support on the generator frame to look like a mirror image of the left support. Loosely clamp the right support in two places as shown in Figure 5.

Figure 5. Close-up of Bicycle Attachment

The bicycle frame and, especially, the rear wheel should be lined up with the pulley of the generator. That is, the rim of the rear wheel and the pulley of the generator should be in the same plane, and the bicycle body should be pretty close to that plane, too. When this is done, tighten the 2 "C" clamps to securely attach the right support to the generator frame.

Put the drive belt (fan belt) around the rim of the rear wheel and the pulley of the generator. This will require that the generator be lifted up on its hinge, which attaches it to the generator frame. The rubber bands should be attached to the hinge and hook to apply tension to the drive belt. This completes mechanical assembly of the bicycle generator.

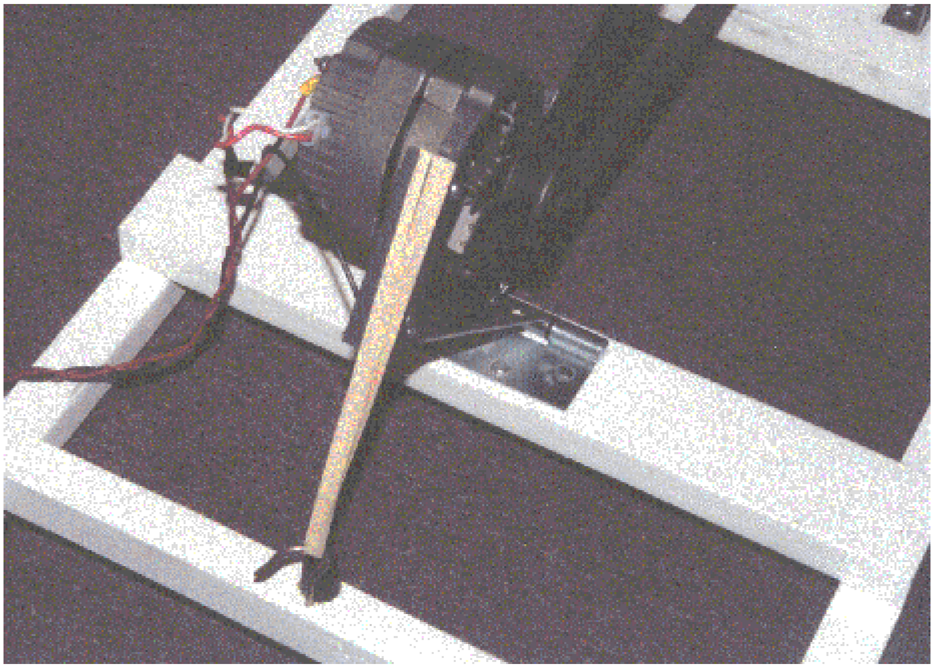

Figure 6. Close-up of The Generator

The wires with one end attached to the generator should have their other ends attached to the load box. The black wire from the generator goes to the rear-most terminal of the load box; the two red wires go to the other two terminals. Either red wire may go to either of the two terminals near the front of the load box. Note that the two red wires are redundant; only one would be needed if they were connected together at the generator.

To use the generator, turn off all of the loads (lights and cigarette lighter) on the load box. Peddle the bicycle at a moderate speed so the rear wheel rotates at least once per second. While peddling, depress the red push-button on the load box for one second. Release the red push button and turn on one of the light bulbs. If the bulb doesn't light, repeat the procedure with a little more speed.

3.0 Teaching Motor

The teaching motor is a commercial unit made for classroom instruction. At the time it was purchased (Sargent-Welch Scientific Products), it was being discontinued. It is model number is 10-100; it was manufactured by Science First in Buffalo, NY. Appendix C is a copy of the instructions that come with the motor.

This product is a motor and generator that uses DC or AC input as a motor and will generate DC or AC. The shaft has slip rings for AC at one end and a commutator at the other end for use with DC. See Figure 7. With AC input, it is a synchronous motor. The stationary field (stator) may be generated by a pair of permanent magnets or electromagnets. The unit had been configured as a DC motor for the Girl Scout events; use of other configurations seems to be overly involved for the presentation.

As a DC motor with a permanent magnet stator, a good operating voltage is 12 volts. The current drain comes in pulses depending on the angle of the brushes and the commutator; the current averages less than 1.5 amperes, but the pulses are higher, perhaps 3 amperes. The motor is excellent for demonstrating principles, but it is a poor motor as far as efficiency and reliability goes. The windage, electrical resistance, and friction losses are enough to stop it unless it is operated carefully. Windage is the loss due to pushing air around with the rotor. The resistance loss is largely tied up in the slipping contact of the brushes on the commutator, as is the friction loss. The commutator gets covered in oxide after a few minutes use; a pencil eraser will remove it. In addition, the contact pressure of the brushes is determined by bending them, which must be carefully done to achieve enough pressure for reliable contact, but not so much pressure as to stop the motor. When the brushes are clean and properly bent, the motor speed is limited by windage loss; it will not exceed a reasonable speed. Generally, the motor must be started by spinning the shaft with one’s fingers.

There is no DC source supplied with the electricity demonstrator. A pair of 6 volt lantern batteries has been used, as has a DC power supply. The DC power supply had a 1.5 ampere maximum current capability; a large valued capacitor was required on the output to supply the current pulses required by the motor, as they exceeded the 1.5 ampere capacity of the power supply.

The open structure of the motor shows the stator magnets and the current path to the rotor from the terminals. Before the motor is allowed to rotate, the girls may put iron or steel items near the stator magnets to satisfy themselves that a magnet is there. Without a current supply, the rotor magnet, an electromagnet, will not be magnetic.

One of the more interesting demonstrations of motor principles involves having one of the girls hold a permanent magnet near the rotating shaft. She will feel the rotating magnetic field of the rotor cause the magnet in her hand to vibrate. This clearly demonstrates the principle of interaction of two magnetic fields causing the shaft to rotate.

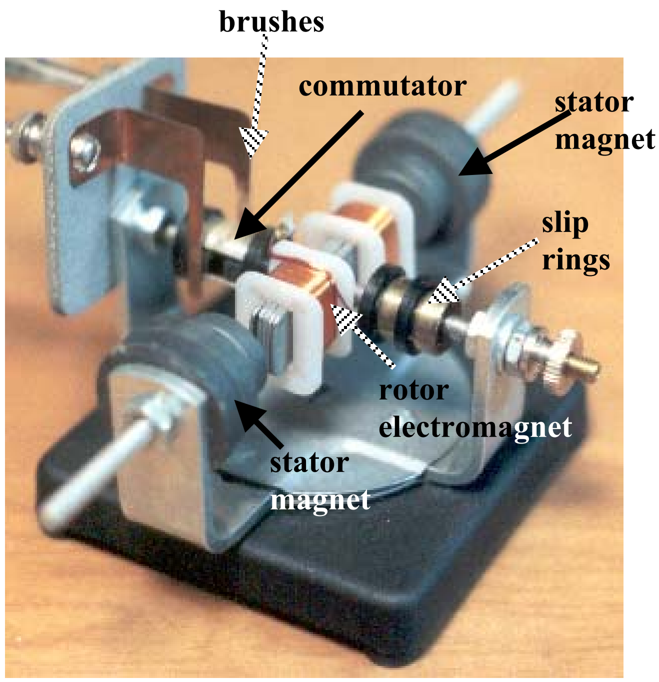

Figure 7. Teaching Motor

4.0 Transformers and Alternating Current

The transformer display shows why the utility companies use transformers. In the demonstrator, there is a 12 volt section and a 120 volt section. A 1 ohm resistor may be switched in or out of each of these sections. See Figures 8 and 9. The insertion has no discernable effect in the 120 volt section but has a very noticeable effect in the 12 volt section. The one ohm resistor in the 120 VAC section drops the voltage at the light bulb about 0.3 volts. The same value of resistance in the 12 volt section drops the voltage at the bulb by about 100 times as much.

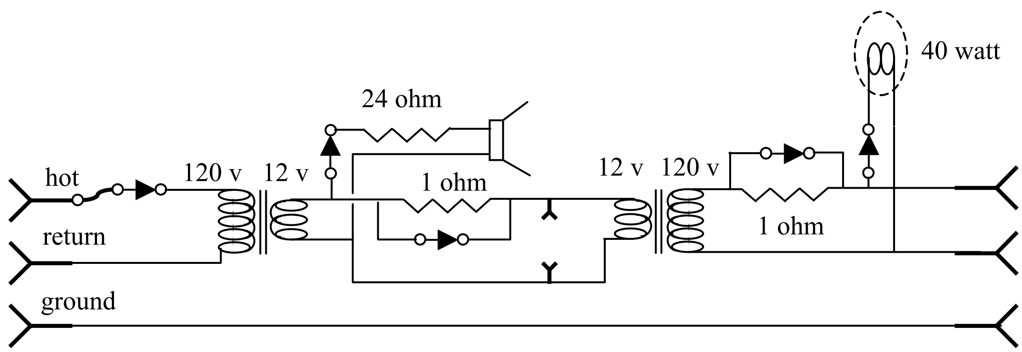

Figure 8. Schematic of the Transformer Demonstrator

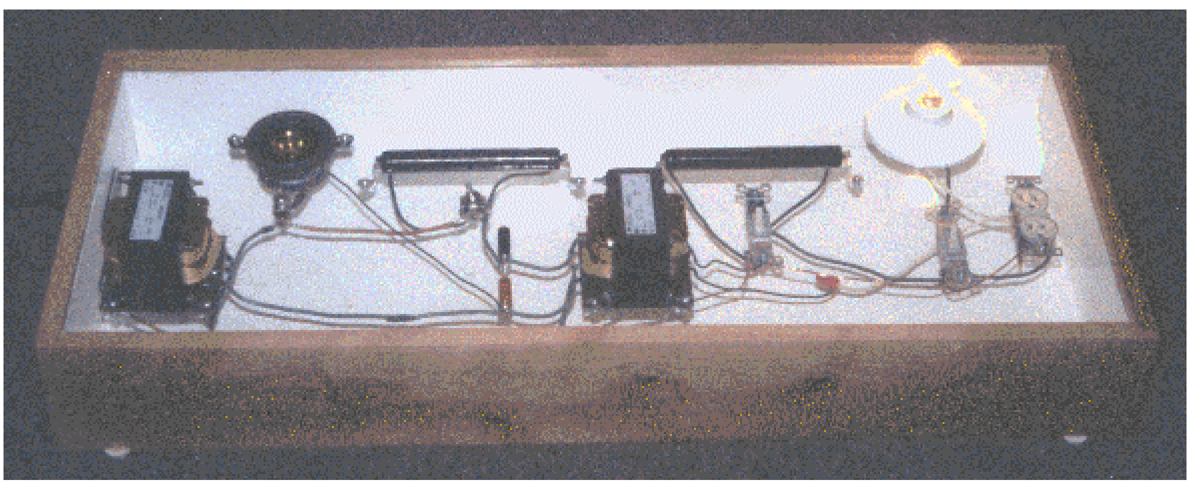

Figure 9. Transformer Demonstrator

Things the girls should be told and try themselves are:
1. Listen to 60 Hz AC from the speaker so they know what 60 Hz sounds like.

2. It is OK to touch 12 volts, but not 120 volts, so the 12 volt section has terminals that are not protected from touching. This voltage in the 12 volt section is the same as that used for

the teaching motor and the bicycle-driven generator. The transformer demonstrator uses alternating current (AC) vice direct current (DC) that the bicycle-driven generator and teaching motor use.

3. In addition to noting the reduced effect of the one ohm resistor on the brightness of the light depending on whether it is in the 12 volt section or the 120 volt section, note that the resistor in the 12 volt section gets warm and the same value resistor in the 120 volt section does not warm noticeably.

4. It is possible to operate the light bulbs of the load box used with the bicycle-driven generator from the 12 volt section of the transformer demonstrator. This would show the similar heating power of AC and DC, which is probably beyond the scope of most presentations.

5. Holding a small permanent magnet near the transformers will cause the magnet to vibrate, showing the girls how electricity gets from the primary to the secondary windings of the transformer.

5.0 Making an Alternator

The National Science Foundation has an internet web site that features, among other things, a project designed by William Beaty which is included in this manual as Appendix A. See http://www.eskimo.com/~billb/amateur/coilgen.html. This project is for building an alternator using permanent magnets and a coil of wire. The housing is made of cardboard.

This design was modified to reduce the cost to about $4. A limit of $5 was set as the maximum that each girl could easily afford for an alternator she could take home. The parts list is:

item	description	source
wire	30 AWG magnet wire	Marlin P. Jones item 8966WI
magnet	1.87 x 0.87 x 0.390 inches ferrite	Radio Shack part 64-1877
light emitting diode	T1 - ¾ red LED	Digi - Key part 67-1102-ND
cardboard housing	illustration board	Bienfang (Hunt 722-170)
roofing nails	1 inch	hardware store
cement	5 minute epoxy	hardware store
base	wooden block	lumber store

During trials with some Girl Scouts, it became apparent that 3 - 4 hours are needed. Since some setting of cement is required, it is recommended that parts be glued together and put aside after the cement is applied. Other parts of the electricity demonstrator be used (bicycle-driven generator, transformer demonstrator, etc.) while waiting for the cement to set. The completed alternator is shown in Figure 10.

Some of the girls took one look at the finished alternator and immediately knew what to do and were able to construct theirs with little help. Others couldn't follow simple instructions and/or duplicate what they saw the leader build moments earlier. There is an enormous variation is abilities among girls of similar age and background. One counselor or leader for each 4 - 6 girls is a good ratio; the counselor should construct an alternator while the girls construct theirs.

William Beaty used four magnets in his design; the design described here uses three, because they cost about $1 each. They are described in http://www.radioshack.com/SupportGate.asp?SupportPage=%2Fsupport%5Fsupplies%2Fdoc53%2F53236%2Ehtm, which is Appendix B. Three magnets are cemented together, as shown in Figure 11. The double ended arrow indicates that the direction of the north or south pole of the magnets is not important, but it is important that they all be oriented together. The roofing nails will be cemented (5 minute epoxy) to the middle magnet at the centers of the small ends. Some nails have a web connecting the head and shaft; this web interferes with rotation of the nail in the cardboard housing. Before cementing the nails, file away the web so the nail will turn freely in the cardboard housing. If the shafts of the nails are not perpendicular to the plane of each nail's head, bend it until it is.

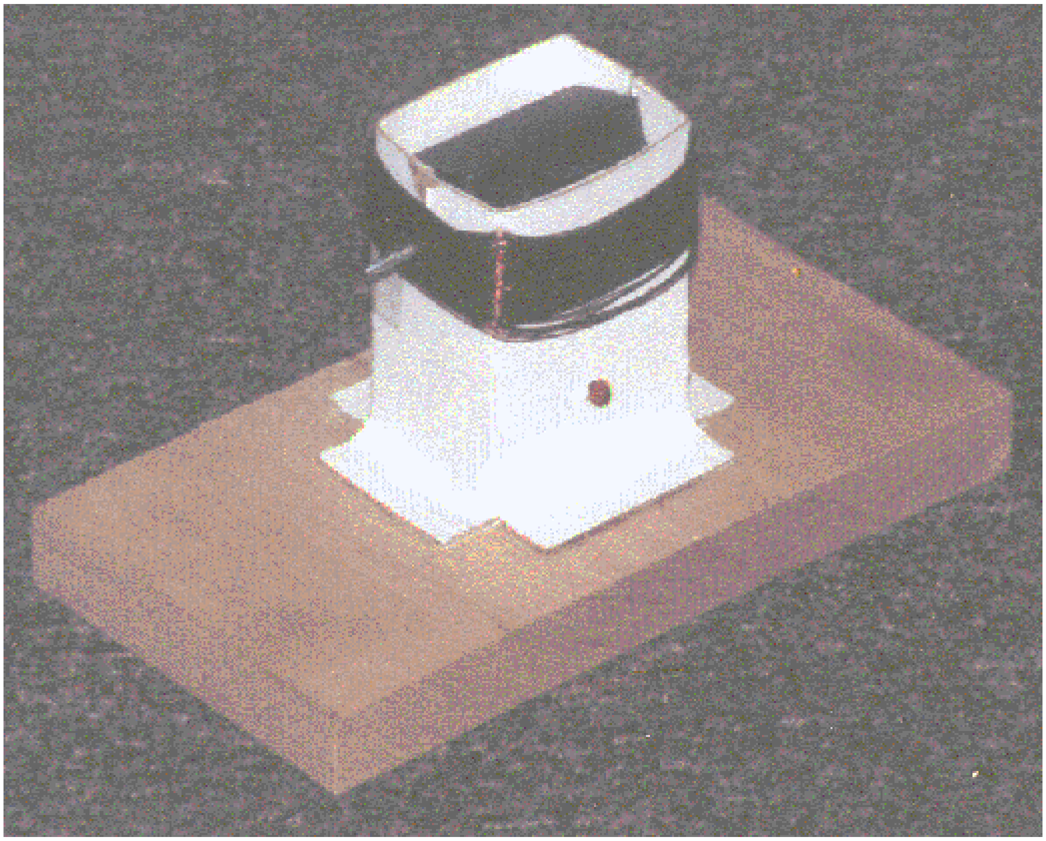

Figure 10. Close-up of the Alternator

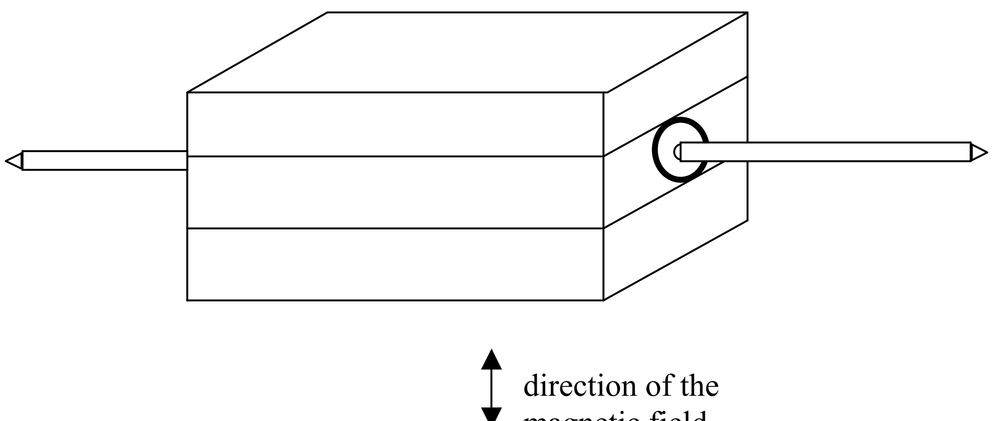

Figure 11. Cemented Assembly of Magnets

The housing is made by cutting some cardboard to size, bending it, and taping the joint.

A slot is cut into the housing to receive the nails that are glued to the magnets. The long sides of the cardboard housing should be made about 1/8 inch longer than the long side of the magnet assembly of Figure 11. The long side of these magnets is about 4.64 cm or 1.828 inches. Adding 1/8 inch or 0.125 to this makes the long side 1.95 inches long. See Figure 12.

The width of the housing must allow the diagonal of the side of the magnet assembly to pass through as the assembly is rotating. The magnet assembly is 1.125 inches (1 1/8) high and 0.875 inches (7/8) deep. the diagonal of the is sides is, from the Pythagorean Theorem, 1.425 inches (~1 7/16). Adding 1/8 inch to this yields 1.55 inches (~1 9/16) for the short side of the cardboard housing. The procedure for determining the dimensions of the cardboard housing is included here in the case that substitute magnets are used. The 1/8 inch addition to the magnet dimensions allows the magnet assembly to rotate freely inside the cardboard housing. The addition of 1/8 inch is a large allowance for construction errors in industry, but probably as much precision as some girls can muster.

The cardboard housing is made of a single piece of cardboard cut to a convenient height of 3 to 4 inches and a width of (1 9/16 + 1.95 + 1 9/16 + 1.95) = 7.025". Three 90 degree creases divide the cardboard housing into long and short sides, and the last corner (edge) is taped together. A slot is cut into the middle of the two short sides for the nails that are cemented to the

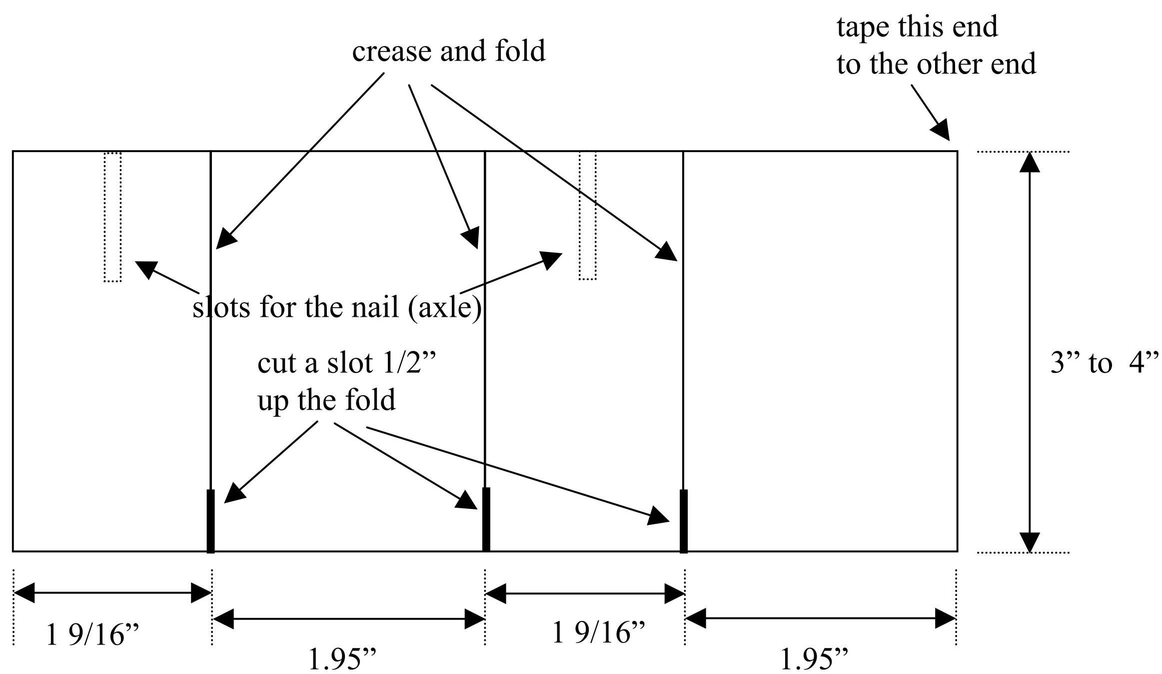

Figure 12. Folding Details For the Cardboard Housing

magnets. These cuts should be about ¾ inch long and just wide enough for the nails to fit. At the bottom of the housing, the corners should slit up about ½ inch and folded out to make a gluing surface to mount the cardboard housing to the wood block that serves as the base.

The tools for making the alternators and the magnet wire are shown in Figure 13. The other construction materials are shown in Figure 14.

Figure 13. Tools and Wire for the Alternator

After the housing is fabricated, place the magnet-and-nails assembly in the slot and test the assembly by rotating one or both nails with your fingers to ensure that the nails, and the magnets, spin freely. If they do not, the dimensions of the cardboard housing are incorrect, or the nails were not cemented to the center of the side of the magnet assembly. In come cases, the shaft of the nail in not perpendicular to the plane of the nail's head.

Once the magnet assembly spins freely in the slot of the cardboard housing, it is time to wind 200 turns of #30 magnet wire around the cardboard housing. When starting the winding, leave about 8 inches of wire at the beginning of the coil sticking out so a connection may be made to it later. Start the winding between the nails of the magnet assembly and the top end of the cardboard housing. This will prevent the magnet assembly from falling out of the housing. If the wire is wound too tightly, the cardboard housing will crush and prevent the magnet assembly from spinning freely. If the wire is wound too loosely, the wire will not stay on the cardboard housing. Wind about 50 turns between the nails and the top of the housing and then wind about 50 turns on the other side of the nails. Switch back and forth every 50 turns or so.

Figure 14. Construction Materials for the Alternator with a Finished Alternator

The closer the windings are to the spinning magnet assembly, the brighter the light will be. If the wire is wound so that it crisscrosses the layers below, the mass of wire will be thick and the outer layers will be too far from the magnets. This is why it is best to minimize crossovers and why it is recommended to put 50 turns on one side of the nails before winding on the other side.

After 200 turns are put on the cardboard housing, tape the coil to keep it together and cut the end wire of the coil to about 8 inches as was done with the beginning. The magnet wire is coated with varnish which is insulation. This varnish must be removed from the ends of the coil so a LED may be soldered to the coil. Fine sandpaper works well for this task. Remove the varnish from the last ½ inch of each end of the coil.

With pointed scissors, twist a hole in the cardboard housing just large enough for the LED to fit tightly when it is pushed into the hole. For a neat looking alternator, make another, smaller hole to thread the wires to the interior of the housing where the connection to the LED will be made. After soldering the LED to the coil, push the LED through its hole from the inside of the housing. This is a good time to test the alternator.

The last task is to bend the tabs or ears at the bottom of the cardboard housing outward so that glue may be applied to them. Glue the cardboard housing to the wooden block. Contact cement works well for this task.

APPENDIX A

ELECTRICITY | BOOKS | GOOD STUFF | NEW STUFF | HELP!

Ultra-simple Electric Generator

(c)1996 William Beaty

PARTS:
4 - 1cm x 2cm x 5cm ceramic magnet, Radio Shack #64-1877 $3.96 total
1 - #30 Magnet wire 200ft, Radio Shack # 278-1345 $3.99
1 - Miniature Lamp, 1.5Volt 25mA Radio Shack #272-1139 $1.29
1 - Cardboard strip, 8cm x 30cm
1 - Large nail, 8cm long or more
Misc. - Knife or sandpaper to strip the wires
Misc. - tape
Optional: hand drill or electric drill

This is an electric generator which is capable of lighting a tiny light bulb. The generator is made up of a hollow-ended cardboard box with a nail through the center, many turns of wire wound around the box, and four magnets clamped around the nail. When the nail and magnets are spun fast by hand, the little light bulb lights up dimly.

INDEX:

CONSTRUCTION

First make the hollow-ended box. Score the cardboard strip like so:

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         |  |        (hole)     |  three layers of cardboard.  Then pull
         |  |                   |  the nail out and use it to widen all
         |  |         O         |  the holes slightly, so when you put
         |  |                   |  the nail back through, it will be a
         |  |                   |  bit loose and able to spin.
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At this point you should clamp your four magnets around the nail and give it a spin. This makes sure the box is large enough. The nail and magnets should spin freely. The corners of the magnets should NOT bump the inside of the box as they spin. If the box is a bit too small, start over and make it a little bigger. Either that, or try a thinner nail.

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Pick the spool of number-30 magnet wire from the kit of spools. This is the thinnest. Tape one end of the number-30 magnet wire to the side of the box, then wind all of the wire onto the box as shown. It's OK to cover up the nail hole. Pull the taped end of the wire out, then tape down both of the wires so the coil doesn't unwind. You should have about 10cm of wire left sticking out.

Use sandpaper or the edge of a knife to scrape the thin plastic coating off 2cm of the wire ends. Remove every bit of red coating, so the wire ends are coppery.

(note: the five lines of wire shown above are not real, that's the 'equals signs' I used to draw with. The real wire can just be wound up in a big wad in the center of the cardboard box.)

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Spread the wire away from the nail hole and tape it in place. Stick the nail back through the holes and make sure it can spin. Take your four magnets, stick them face to face in two pairs, Then stick the two pairs inside the box and on either side of the nail so they grab the nail. Push them around until they are somewhat balanced and even, then spin the nail and see if they turn freely. If you wish, you can stick 2cm squares of cardboard between the magnets to straighten them, and tape the magnets so they don't move around on the nail.

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                                 |_____________|

    SIDE VIEW OF THE
    NAIL AND MAGNETS             VIEW FROM THE END
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TWIST THE WIRES TOGETHER

Make sure that each end of the generator's wires are totally cleared of red plastic coating. If there is a bit of plastic left, it can act as an insulator which turns off your light bulb circuit.

Twist the scraped end of each generator wire securely around the silver tip of each wire from the small light bulb. (If necessary, use a knife to strip more plastic from the ends of the light bulb wires.) One generator wire goes to one light bulb wire, the other generator wire goes to the other light bulb wire, and the two twisted wire connections should not touch together. In the twisted wires, metal must touch metal with no plastic in between.

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TEST IT

Spin the magnet REALLY fast and the bulb will light dimly. If it doesn't work, try spinning it in a dark room so you don't miss the dim glow. If needed, adjust the position of the magnets so they don't hit or scrape the cardboard. This thing has to spin *fast*, and if the magnets whack the cardboard and stop, you won't see any light. (IF IT DOESN'T WORK, SEE "DEBUGGING" BELOW)

Once you get it to work, try clamping the point of the nail into the chuck of a hand-crank drill. Spin the magnets fast with the drill and the bulb will light brightly. Don't go too fast or you'll burn out the bulb, or fling magnets all over the room. You can try this with an electric drill as well, although electric drills don't spin as fast.
Note: your generator produces Alternating Current, not Direct Current. The output voltage is about 2 volts max, so there is no shock hazard at all.

HOW IT WORKS

All metals contain a movable substance called "electric charge". Even uncharged wires are full of charge! After all, the atoms of the metal are made half of positive protons and half of negative electrons. Metals are special because their electrons don't stay connected to the metal atoms, instead they fly around inside the metal and form a type of electric "liquid" inside the wires. All wires are full of electric fluid. Modern scientists call this the "electron sea" or "electron gas." It is not invisible, it actually gives metals their silvery shine. The electron gas is like a silvery fluid. Sort of.

When a circle of wire surrounds a magnetic field, and the magnetic field then changes, a circular "pressure" called Voltage appears. This circular voltage tries to force the movable charges in the wire to rotate around the circle. In other words, moving magnets create electric currents in closed circles of wire. A moving magnet causes a pumping action. If the circuit is not complete, if there is a break, then the pumping force will cause no charge flow. But if the circuit is "complete" or "closed", then the magnet's pumping action can force the electrons of the coil to begin flowing. This is a basic law of physics, and it is used by all coil/magnet electric generators.

When the circuit is closed and the magnet is moving, charges in the metal are forced to flow. The charges of the light bulb's filament are pushed along. When the charges within the copper wire pass into the thin light bulb filament, their speed greatly increases. When the charges leave the filament and move back into the larger copper wire, they slow down again. Inside the narrow filament, the fast-moving charges heat the metal by a sort of electrical "friction". The metal filament gets so hot that it glows. The moving charges also heat the wires of the generator a bit, but since the generator wires are so much thicker, almost all of the heating takes place in the light bulb filament.

OTHER THINGS TO TRY

Disconnect one wire from the light bulb. Spin the magnet. While still spinning the magnet, have a friend touch the wires together so the bulb lights up again. Is the nail still as easy to spin? Keep spinning the magnet while your friend connects and disconnects the bulb. Feel any difference in how hard you must spin the nail?

SO WHAT?

When you crank the generator and make the light bulb turn on, you are working against electrical friction in order to create the heat and light. You can FEEL the work you do, because when you connect the bulb, it gets harder to crank the generator. When you disconnect the bulb, it gets easier.

Think of it like this. If you rub your hands together lightly, the skin stays cool, but if you rub your hands together hard, your skin gets hot. It's hard to heat skin, it takes work. And it's hard to heat the light bulb filament, it takes work. You twist the generator shaft, the generator pushes the wire's charge through the tiny filament, and if you don't keep spinning the magnet, the magnet will be slowed quickly.

FEEL THE ELECTRONS

When your hand spins the magnet, you can feel the extra work it takes to light the bulb. This happens because your hand is connected to the flowing charge in the bulb, and when you push on it, you can feel it push back on you! How is your hand connected to the flowing charges? Your hand twists the nail, the nail spins the magnet, the magnet pushes the invisible magnetic fields, the fields push the movable charges, the charges flow slowly through the light bulb filament, and the tiny filament causes friction against the flow of charge and heats up. But then the reverse happens! The charge can't move much because of the tiny filament, so it resists the pressure from the magnetic fields, which in turn resist the pressure from the magnet, which resists the twisting pressure from the nail, which resists the twisting pressure from your fingers. So, in a very real way, you can FEEL the electrons in the light bulb filament. When you push them, you can FEEL their reluctance to move through the narrow filament!

MOTOR CHALLENGE!

There is a simple way to convert your generator into a motor. It involves using paint or tape to insulate a spot on the nail, then using a 6V battery and using the generator's wires, touching the nail to form a switch. The rotating magnets turn the coil on and off. Can you discover the trick?

MAGNET WARNING

WARNING: Keep the magnets away from computers, disks, videotapes, color TV sets, and wallets and purses containing credit cards. Try this: Keep the generator far from your color TV, turn on the TV, start spinning the nail so the magnet is spinning fast, then bring the generator about 2ft away from the TV screen. DON'T BRING IT CLOSER!!! Keep spinning the magnets, and you'll see a cool wobbling effect in the TV picture, along with some color changes. The field from the magnet is bending the electron beam that paints the picture on the screen. Be careful, if you bring the magnet about 15cm away, the iron sheet inside the TV picture tube will become magnetized and the distorted colors will be permanent.

DEBUGGING

DON'T USE DIFFERENT PARTS. This generator cannot power a normal flashlight bulb, it needs the special 25-milliamp, 1.5-volt bulb sold by Radio Shack. Don't use a normal 250mA bulb, since that kind of bulb requires way more energy before it starts to glow. If you simply cannot find the 25mA bulb, you can use a 1.5V 40mA bulb, but add twice as much magnet wire to your coil (buy two of those kits of magnet wire.)

Don't use other magnets, use the large Radio Shack large rectangular magnets. They cost about $1 each, and have no holes through the center. Most other magnets are way too weak and will not work unless you spin the magnets incredibly fast, at thousands of RPM (revolutions per minute.)

If the generator refuses to work, inspect the spot where the wires twist together. The generator wire has a very thin red plastic coating, and you must clean ALL of it off the wire ends before twisting them to the light bulb wires. If there is plastic between the metal of the generator wire and the light bulb wire, the circuit will be "open" and no charge will flow.

Be sure to follow the instructions and diagrams. You MUST wind the coil so the coil goes across the side of the box which has the nail hole. If you wind it so the nail-hole side of the box has no coil crossing it, then the magnetic fields won't cut across the wires, and no electric voltage will be created.

Also, don't wind the coil over the open end of the box, otherwise you won't be able to get your fingers inside to make changes to the magnet.

If you cannot spin the magnets fast enough with your fingers, try a "twist drill" or hand-crank drill. Clamp the nail in the end of the drill and spin the magnets as fast as you can. An electric drill may work too, but most electric drills don't move as fast as the hand-cranked type.

DON'T SUBSTITUTE THE MAGNETS OR THE LIGHT BULB WITH A DIFFERENT TYPE. It needs strong magnets and a low-voltage, low-current bulb. If your generator doesn't work, check the parts again and make sure you have the right type of magnets and the right type of light bulb. Don't use fewer magnets. Weaker magnets may work, but you won't be able to spin them fast enough by hand, and a high speed motor will be required in order to spin them.

The generator can be improved by using more turns of wire. You used only the spool of #30 wire. With more wire, the magnets don't have to spin as fast to light the bulb. Connect the thinnest of the remaining spools of wire to the wire that's there, making sure to scrape the wire ends totally clean before twisting them together. Make sure to wind the extra wire in the same direction as the rest of the coil.

Or, if you want to light your light bulb REALLY bright, buy a second kit of wire, hook the second #30 spool to the coil you have already made, then wind all the wire onto the coil.

Created and maintained by Bill Beaty. Mail me at: billb@eskimo.com.
If you are using Lynx, type "c" to email.
Best if viewed with ANY Browser.

APPENDIX B

ALTERNATOR MAGNET SPECIFICATIONS

Ceramic Magnet
(640-1877) Specifications Faxback Doc. # 53236

Description: .... Ceramic Block 1.87 x 0.87 x 0.390 Inches

Material: .... Oriented Strontium Ferrite

Magnetic Properties:

Residual Flux Density (B sub r): .... 3,850 Gauss

Coercive Force (H sub c): .... 2,950 Oersteds

Max Energy Product (BH sub max): .... 3.5 MG * Oe

Average Recoil Permeability: 1.1

Field Strength needed to saturate: .... 10,000 Oe

Temperature needed to permanently ruin: .... 1,800 Degrees F

Physical Properties:

Density: .... 0.180 lbs/In^3

Coefficient of Thermal Expansion: .... 10.3 per degrees C x 10^-6

Resistivity at 25 degrees C: .... 10^10 micro-Ohms/cm/cm^2

Rockwell Hardness Scales: .... off C

Dimensions (HWD): .... 3/8 x 1-7/8 x 7/8 Inches

Specifications are typical; individual units might vary. Specifications are subject to change and improvement without notice.

(EB 6/21/99)

TEL 716-874-0133 **Science First** **FAX 716-874-9853**
Designers & Manufacturers of Hands-On Labs
95 Botsford Place, Buffalo, N. Y. 14216

10 - 100 Motor Generator

Parts List

24-1110 Instructions
51-5102 Clip (2)
57-1004 Brush holder (2)
80-0100 Replacement Brush Set (4 brushes)
53-1007 Bronze brush B
53-1009 Bronze brush D
80-0102 Field Coil Assembly (2)
80-0158 South pole piece
51-5100 Armature Brackets (2)
53-1005 Upper bearing
60-0160 Armature Assembly
53-1006 Bronze brush A
53-1008 Bronze brush C
80-0101 Base
80-0157 North pole piece

Additional Materials Needed: galvanometer, 3 - 6 volt power supply

Warranty and Replacement Parts:

We replace all defective parts free of charge. Additional replacement parts may be ordered toll-free at **1-800-875-3214.** We accept Master Card and Visa, School P.O. All products warranted to be free from defect for one year. Does not apply to accident, misuse or normal wear and tear. Made in U.S.A.

Description:

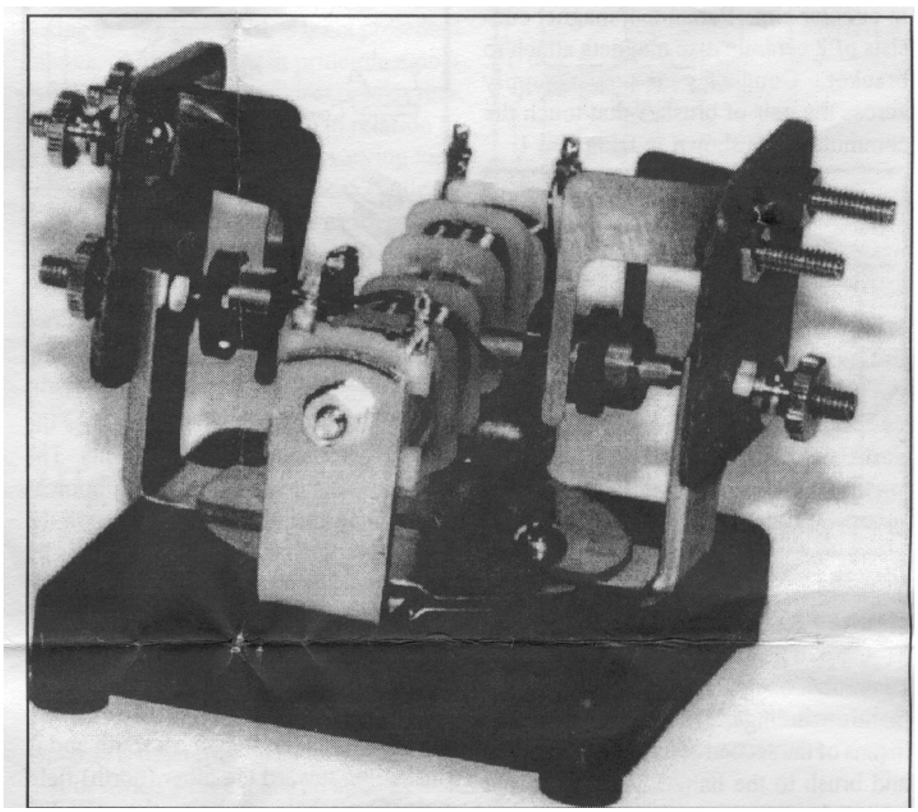
The Motor Generator can operate either as a motor, using electrical energy to perform mechanical work, or as a generator, converting mechanical work to electrical energy. Depending on which parts are used, the electrical energy may be in the form of alternating (AC) or direct (DC) current.

Now with modular design sharing common parts with our related product, 10-155 St. Louis Motor, the Motor Generator is completely and easily dissectible and is a fast and effective way for student and teacher to demonstrate:

nomenclature and function of parts of both motor and generator
field magnet
armature
commutator and slip rings
electromagnetic field

Accessories Recommended

The following accessories are useful in performing the experiments described in these instructions. They are
available from your distributor or manufacturer Science First.
10-171 Battery Kit -low voltage power supply with clip leads.
40-276 Table- Top Pulley - clamps to table, adjusts in height, rotates. Use with Motor Generator to lift weights, demonstrate how work is performed.
For best results:
Experiment with brush shape, pressure and angle to obtain best performance. Remove unused brushes to reduce fiction and wear. Lubricate bearings and sliding contact areas of brushes, commutator, and slip rings with light oil periodically.



How To Teach With The Motor Generator

Concepts Taught:

Electromagnetic induction, magneto, DC and AC currents, generator vs. motor, armature, field magnet, commutator, induced current, series and shunt motors, transformation of energy - electrical to mechanical and vice versa, and energy conservation.
Curriculum Fit: Physics Sequence / Electricity and Magnetism. *Unit: Moving charge and magnets.* Grade 9-10.
Physics Sequence: Energy. *Unit: Energy Transformations.* Grades 9-10.

Basic Motor

Permanent field magnet - DC only

Mount the north and south pole pieces to the base by simply sliding through slits in circular clip. Permanent magnet consists of 2 ceramic disc magnets attach to bracket. Connect your power supply across the pair of brushes that touch the commutator, as shown in Diagram 1.

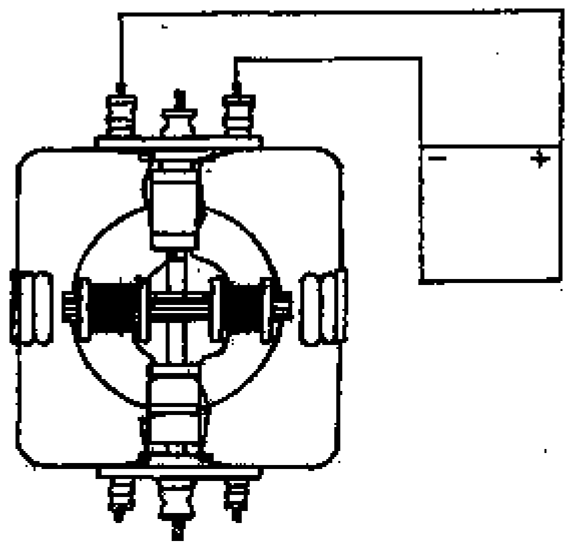


Diagram 1 - Basic DC Motor - Top View

How the Basic Motor Operates:

Current flows down one brush into the commutator segment and through the armature windings. It then flows back by means of the second commutator segment and brush to the battery. As the current passes through the windings of the wire coil of the armature, it magnetizes the soft iron in the armature. One end of the armature becomes a *north* pole, the other end *south.* Because like poles repel and unlike poses attract each other, the north pole of the armature will be pulled toward the south pole of the field magnet. The armature and commutator rotate. See Diagram 2.

Once the armature poles are close to the field pole, the brushes lie across the gaps between commutator segments. The armature is then short-circuited momentarily. The armature freewheels until the short circuit is broken. Each brush is by then touching the commutator segment opposite to the one on which it began. Current again flows through armature windings but in the opposite direction. The polarity of the armature is reversed; the north pole has become a south and is pushed on toward the other (north) field pole. Every half revolution the poles become aligned, the polarity is reversed and the armature moves. See Diagram 3.

If connections to battery are reversed, current direction and armature polarity are reversed. The motor then runs backward.

This motor will not run on alternating current. When AC is used, the armature merely vibrates backward and forward in sympathy with the current reversals. Compare the rotation direction of your motor. Take into account polarity of the battery, polarity of the magnet and winding direction on the armature.

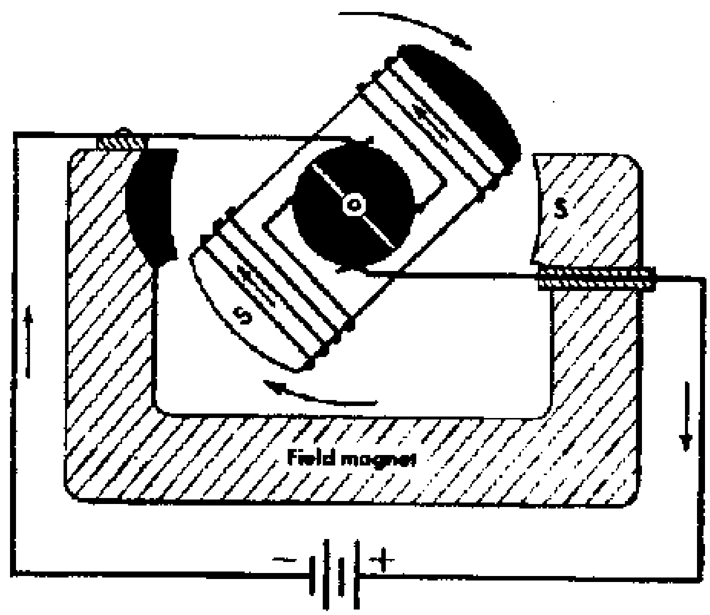


Diagram 2 - Two-pole motor - poles of field magnet attract opposite poles of armature. Upper armature is always a north pole

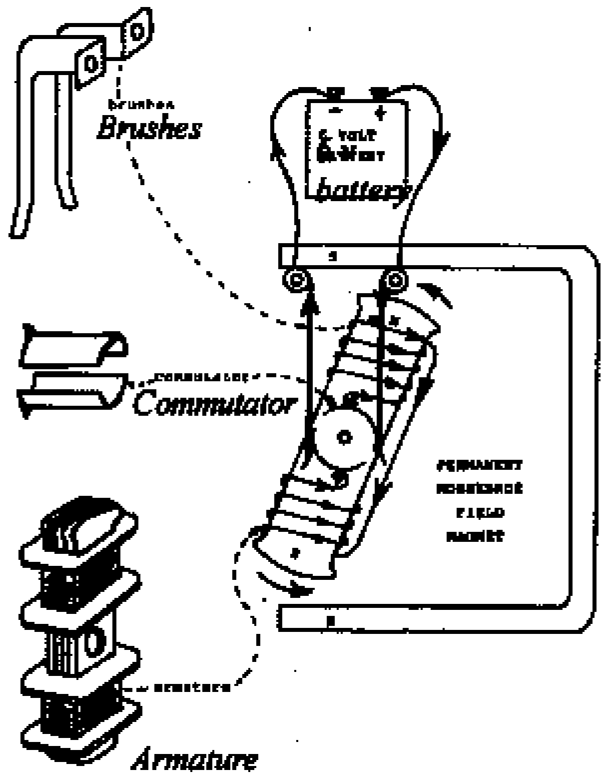


Diagram 3 - Basic DC Motor

Basic DC Generator

Permanent Field Magnet - DC
To run as a generator use the configuration in *Diagram 1,* but without the *battery*

Turn the armature by external means - spin by hand or devise a pull string of fine cord or fishing line onto unused slip rings. The iron core of the armature is magnetized by the field magnet. The closer each armature end is to a field pole, the more strongly it takes on the polarity opposite to that of the field pole. As the armature rotates, it is magnetized first in once sense, then, half a revolution later, in the opposite sense.

According to the *law of induction* formulated by Michael Faraday, this change in magnetization induces an electromotive force (EMF) in the windings around the armature. The faster and larger the change, the larger the induced EMF, which is experienced as a voltage between the ends of the windings. Connecting the brushes to an external circuit allows current to flow through both that circuit and the armature winding.

Lenz' Law states that the direction of the induced EMF is such that it tries to cause a current that would oppose the change causing it. As the iron is magnetized in one direction, the current generated is such that, as it flows in the armature windings, it tries to magnetize the iron in the opposite direction. Therefore the EMF must alternate in direction as the armature is magnetized in alternate senses.

However, because the commutator reverses connections to the brushes every half revolution, it is able to correct for the alternations of the EMF and therefore to produce a unidirectional voltage at the brush terminals. Connect a galvanometer to the brushes to observe a series of pulses in the same direction.

Basic AC Generator

Alternating current - AC

The motor generator has a second set of brushes sliding on two continuous rings known as slip rings. Each ring is connected to one end of the armature winding. By connecting to the slip ring brushes instead of the commutator brushes, the reversing action of the commutator is bypassed and the generator provides AC as can be verified by connecting the galvanometer.

Because the same machine acts as both motor and generator, it follows that the two functions are not completely separable. The generator will act partially as a motor and vice versa.

Take Lenz' Law as applied to the DC generator. The current generated tends to oppose that which caused it. When an armature end becomes a North pole as it approaches the field South pole, the induced current suppresses development of that North pole. If that current were driving the machine as a motor, it would produce a South pole to cause the motor to rotate in the opposite direction.

In the DC generator, the induced current will produce a torque that opposes whatever is driving the generator. The higher the current drawn from the generator, the more difficult it is to turn. This is to be expected from *conservation of energy principles* since the extra electrical energy must come from mechanical work done in the generator; otherwise, Lenz' Law would not be true. Verify this by connecting the brushes together. Note that the generator is harder to spin.

On the other hand, consider the *basic motor:* As it increases speed after being switched on, it behaves like a generator, inducing a "back EMF" - a voltage in opposition to the battery voltage. Once this voltage, plus the voltage dropped across the resistance in the wires, equals the applied battery voltage, the speed settles to a constant. If the mechanical load on the motor is increased, the motor slows and the induced voltage drops. The battery is then able to supply more current and the motor, more torque. This can be demonstrated by slowing the motor down with your fingers.

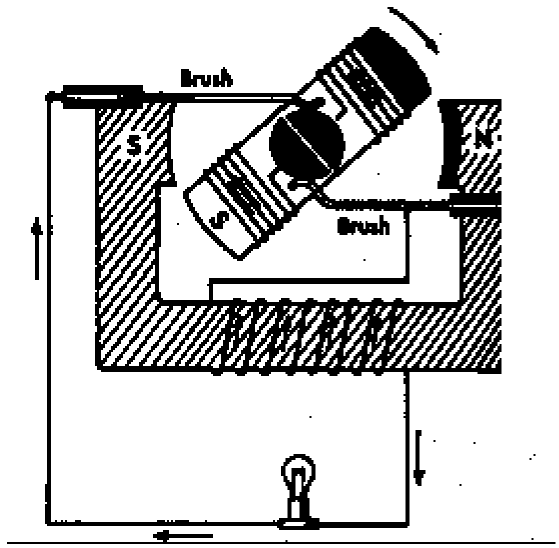


Diagram 4 - Simple DC generator - as the armature revolves, its wires cut magnetic lines and generate alternating voltage. The current in the coil alternates. The commutator reverses connections to outer circuit so the current through lamp is direct.

Because of the symmetry between motor and generator, you may wonder why a motor version of the AC generator using the slip ring brushes is not presented above. Although it is, in principle, a possibility, in practice it requires precise timing of the current reversals in relation to the armature position under varying load conditions. This type of motor - called a *synchronous* motor - requires that the speed of rotation by synchronized with the speed of reversal of the AC source in order to supply a continuous torque in the same direction as that of the rotation. For this reason, the motor generator is not a workable synchronous motor.

High Power Motors

Electromagnet Fields

The development of strong rare earth magnets (such as neodymium, iron, boron) greatly enhanced the power output and the usefulness of motors with permanent field magnets. Nonetheless, for high power application, the permanent field magnet is best replaced by an electromagnet in which a core material such as iron is magnetized by a current carrying coil.

Replace the 2 permanent (ceramic disc) magnets in the *basic motor* with the wound field *coil* electromagnet pair to demonstrate two such motors - the series and the shunt motor - which differ only in their electrical connections. It should be noted that a motor designed to operate in two modes is not as efficient or as powerful as one designed to operate in just one of these modes.

Slide the field electromagnet attachments as far into the slit (on the base) in the circular clip as possible without the armature hitting these field windings. In both series and shunt motors, the voltage drop across the windings times the coil current is approximately equal. Likewise, the coil current times the number of turns also remains the same in normal operations.

Series Motor

Connect the electromagnet field coil in *series* with the commutator brushes so the same current passes through the armature and then the field coil. Increasing the mechanical load slows the motor and lowers the back EMF resulting in a higher current. Although this occurred in the permanent field motor, now, in the series motor, the strength of the field magnet is also increased. The resultant torque is therefore automatically increased when needed. Series motors are for high torque, low speed applications such as the starter motor for a car. They are characterized by few turns, heavy wire, and low resistance.

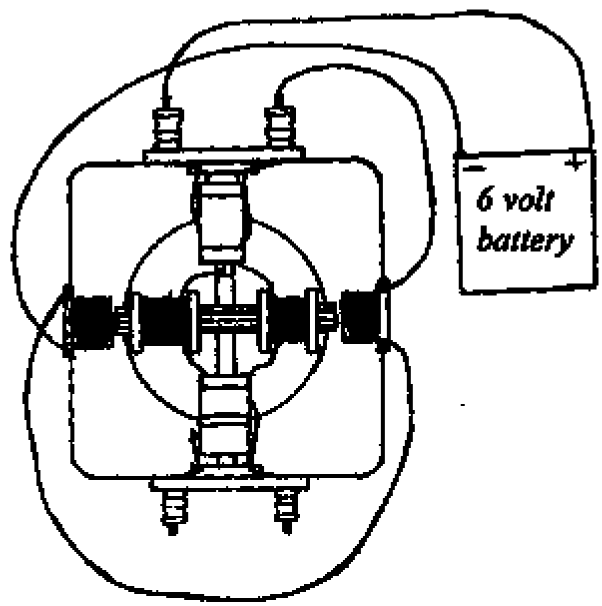


Diagram 5 - Series Motor - Top View

Shunt Motor

Connect the field magnet so that the field current is *independent* of the armature, having been diverted ("shunted") through its own separate circuit. See Diagram 6. A 10 ohm variable resistor may be included to facilitate adjustment of the field current. You may be surprised to find that in most shunt motors, increasing the field current causes the motor to slow down. Remember, the speed of a motor becomes steady when the induced back EMF reaches a certain level. That same level is reached at a lower speed if the field magnet has been strengthened by increasing its current. Although the speed is lower, the torque and power developed are higher, as your intuition may imply.

In this demonstration motor, you may find that the speed remains fairly constant as the field current is increased. This is because - with only two poles - the speed is determined by a number of factors, not just the back EMF. At any rate, the speed does not increase in proportion to the field current.

Shunt motors are characterized by many turns, small (fine) wire and high resistance. The speed of the shunt motor varies less than that of the series motor under varying load conditions.

Reversing the battery connections reverses both armature and field currents and therefore does not change the motor direction. Motor direction can only be achieved by reversing either the *brush* or *field connections.* Both shunt and series motor will therefore run on AC but not for long periods. The alternating magnetic fields induce currents ("eddy currents") within the iron cores which result in overheating. Ten or twenty seconds is safe for testing the use of AC with a source of about 10 volts.

Most motors and generators are constructed from "laminations". The field cores and armatures are made of thin layers of iron stacked together with insulation between layers. The laminations reduce the eddy currents and hence the overheating. They also reduce the power loss that core heating represents. Proper laminated construction is expensive and therefore has been omitted from this demonstration model.

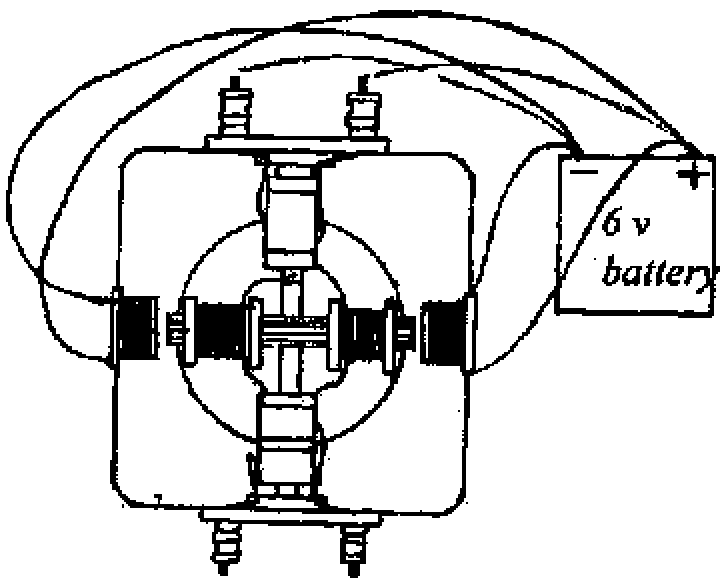


Diagram 6 - shunt motor - top view

High Power Generators

Most high power generators produce AC which, if desired, can be changed to DC through the use of external electronics. DC generators are out of favor because the high currents burn out the commutator and brushes quickly.

In AC generators (alternators), on the other hand, the roles of the armature and field coils can be interchanged. The armature becomes the *rotor* and is supplied with a small DC current ("exciter" current) via slip rings. The field coils become the *stators.* The rotating electromagnet (rotor) induces large alternating current in the stationary stator without the need for high-current sliding contacts.

Virtually all generators over 1000 watts are AC. The reasons for this are: no brushes to replace, high efficiency, smaller size and lower cost. For instance, low-cost AC generators superseded DC "dynamos" in automobiles when low-cost electronics for control of the exciter's current and rectification of the AC output became available. New permanent magnet materials replaced the windings on the rotor. This removed all need for any sliding contact.

Accessories

The following accessories and related products may be ordered from your distributor or, if unavailable, directly from manufacturer **Science First.**

10-171 Battery Kit - low-cost 1 1/2 to 6 volt DC power supply with clip leads. Use to run 10-100 Motor Generator.

40-276 Table Top Pulley - adjusts to 10 cm. Rotates 360". Use with 10-100 Motor Generator to lift weights.

Related Products

10-110 Electromagnet Kit -experiment with induced currents, reversed polarity and magnetic lines of force. Includes 2 copper coils with binding posts; round iron core; square iron core; U-shaped double core; plastic card; 4 clip leads; iron filings; instructions.

10-155 St. Louis Motor - converts energy from electrical to rotary. Similar to Motor Generator in design and component. Electromagnet attachment available separately.

10-140 Primary Secondary Coil - study electromagnetic induction and transformer effects. 2 coils, one heavy, one fine; soft iron core; instructions.

20-030 Electromagnet - powerful compact electromagnet weighs 2 pounds, lifts 200

10-135 Toy Motor Kit - all you need to build a working DC motor in single kits or economical class- packs. Sandpaper, pliers only tools needed. Ages 12 up. Learn how each part of motor works. With battery clips (not shown.) Good instructions. *You need one AA battery.*