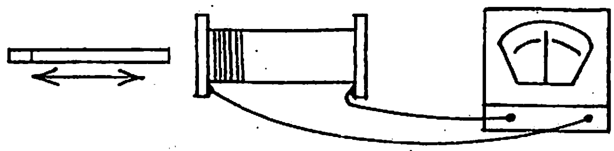
John B. Johnston, The Faraday Center, 103 Creamery Rd., Livingston Manor, NY 12758
(845) 439 - 4706

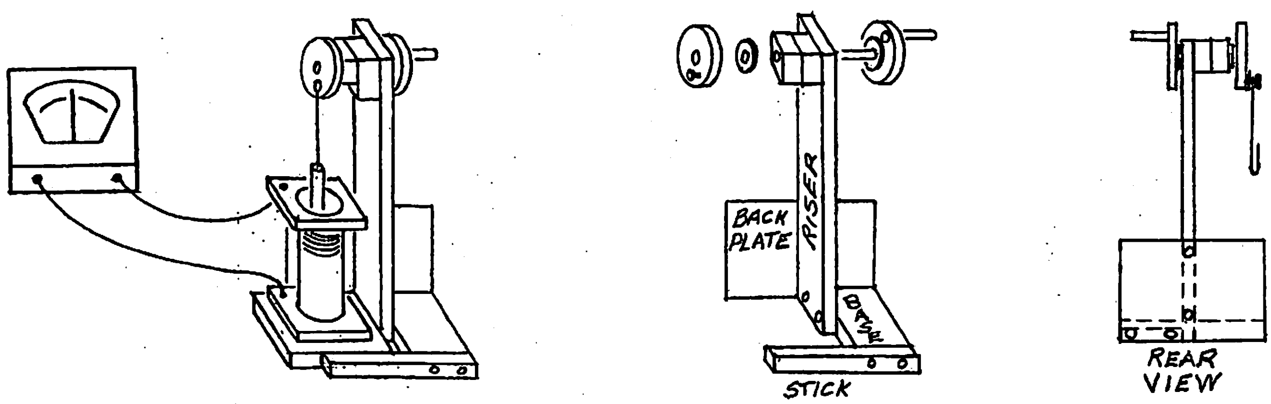
Electromagnetic induction - is right up there with fire and the wheel as one of the most important discoveries in human history. It made possible the massive production of electricity and electricity's use as a dominant factor in the 20th century's lifestyle. And there is no end in sight. Strangely, two brilliant men on opposite sides of the Atlantic discovered it simultaneously, Joseph Henry of Albany, NY and Michael Faraday of London, England. Soon after, technology took over, and generators and motors appeared. Ultimately, large companies evolved to produce and distribute electricity everywhere.

(a) You can replicate Faraday's discovery with an air core solenoid*, a permanent bar magnet, and an analog galvanometer just as he did. Simply move the bar magnet in and out of the solenoid and watch the deflections of the needle. The galvanometer is receiving an alternating current (AC) from the "generator". (Turns out that all generators naturally produce AC. If you want direct current (DC), you must add a rectifier "system" to the AC generator circuit.)



(b) The first "generators" were simple, handcranked devices made of brass that reciprocated. Here is a simple model you can make mostly out of wood.

Diagrams:



Construction: Cut out two ½" plywood discs 3" in dia.; drill 3/8" holes in their centers. Cut out two 3/4" boards, one 15" x 3 3/4" (riser), the other 5 3/4" x 3 3/4" (base). Cut out a 3/4" stick 8 3/4" x 1". Cut out a piece of 1/8" masonite 8 3/4" x 6" (back plate). Cut out two 5/4" spacer blocks 1 3/4" x 2¼". Cut two pieces of 3/8" dowel, one 1 3/4" long (handle), another 4¼" long (axle).

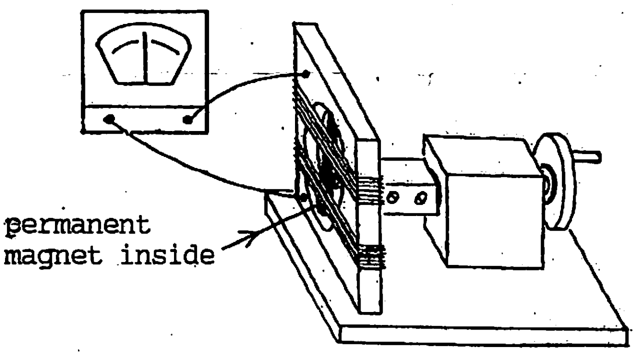
Assemble the pieces as per the diagrams. Glue the spacer blocks together (face to face) and then to the top front corner of the riser board; drill a 3/8" hole all the way through with its center 1" from the top for the axle. The axle should rotate easily in the hole. On a perfectly flat surface (your table saw top?), assemble the rest of the stand using only 4 long and 4 short screws. Drill a 3/8" hole near the rim of one disc for the handle and glue it in. Drill a screwhole for a #10 x ½" panhead screw near the rim of the other disc. Glue and insert the axle in the "handle" disc. Add a steel washer to the axle and poke it through the riser and spacers. Add another washer and glue, and press the second disc on the axle. Add a small washer to the panhead screw and drive it into the disc but not all the way. Cut a

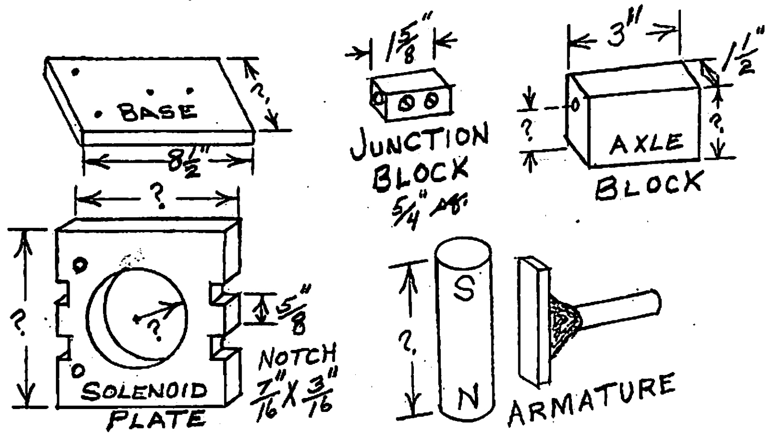
* air core solenoid #14825 - Science First (207) 701 - 8111 www.sciencefirst.com

6" piece of #16 copper or brass wire and bend the ends, one around the PH screw, the other as a "hook" for the magnet. The final attachment will depend on the bar magnet's size. Experiment. A mounted solenoid works best and should nest in the feet of the stand. To mount a solenoid (make a base), see "The Ring Flinger" where it is fully described. If the space for the mounted solenoid is not quite big enough, back out the two "stick" screws and add cardboard shims until the spacing is right; retighten the screws.

(c) Later, of course, generator technology took over and found that rotating systems were far superior to reciprocating. Here is a simple model you can make out of wood and some insulated copper wire. Its dimensions will depend on the size of the permanent magnet you have available. In this model, the loops of wire are a distorted solenoid with the poles of the spinning magnet going in and out of the loops (solenoid) generating an alternating current as in the reciprocating model. The parts are simple and few. A ½" dia. round bar magnet is recommended, but a flat bar magnet could work also if you change some dimensions. The magnet's length will determine the size of the "solenoid plate", its armature hole dia., and the height of the axle block and its axle hole (the "?" marks).

Diagrams:





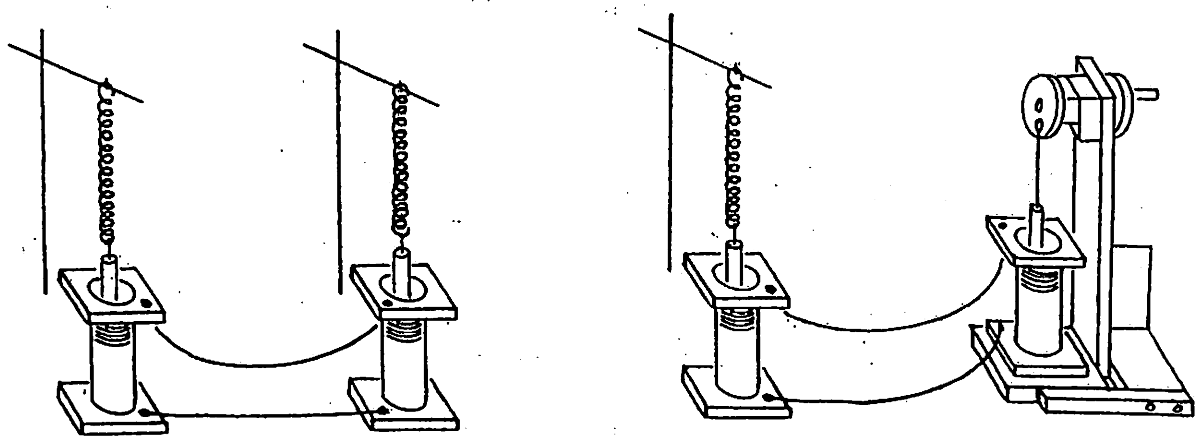
Construction: Cut the base and solenoid plate out of 3/4" plywood. Cut the armature hole on a scroll (jig) saw. Cut the notches for the wire. Drill two holes for the terminals, for #6 x 32, 1½" brass bolts. Two regular nuts, two thumb nuts, and four small washers, all brass, are required to fasten the ends of the copper wire. From one terminal, #16 or #18 insulated wire is wound on the solenoid plate until the notches are filled, ending at the other terminal. Cut out the junction and axle blocks; drill 3/8" holes in each block to accommodate the axle (3/8" dowel). The junction block also needs two #4 x ½" setscrew holes. Cut out one ½" plywood disc 3" in dia. and drill two 3/8" holes for the handle and axle like in (b). Cut two 3/8" dowels, one 1 3/4" long (handle), another 4 3/8" long (axle). Glue the ends of the dowels in the disc. Add a steel washer to the axle and insert the dowel through the axle block. Add another washer and slip the junction block over the end of the axle; it should only go halfway on. Tighten one setscrew.

Now the more difficult part, making the magnet armature. Cut a piece of sheet steel (from a tin can?) and attach a 1 3/8" length of straightened 3/8"O.D. copper tubing with plumber's epoxy putty. The magnet should "stick" to the sheet steel; add a little masking tape if in doubt. Pass the armature between the coils and insert it halfway into the junction block. The armature with magnet must be free to spin inside the coils; make any necessary adjustments. Tighten the second setscrew. With everything aligned and spaced, center the apparatus on the base and draw a light trace around the two objects in contact. Remove the apparatus and drill the four screwholes through the base. Reposition the apparatus and drive the four screws up through the bottom of the base. Connect to a galvanometer and crank slowly so its needle can deflect and show AC.

Now scale up your thinking. Imagine replacing the handcrank with a water or steam turbine (a special "wheel") connected to a huge generator. The spinning turbine furnishes the mechanical energy input needed to move the magnets and push the electrical energy (electrons loaded with energy) out onto the power lines and into the energy users (anything that plugs in). You've created a powerplant (and a power company)! Thomas Edison perfected the generator and set up the first distribution system in lower Manhattan that became ConEd. More than an inventor, Edison was a visionary.

(d) An old, but excellent, demo is "simple generator, simple motor" and "electromagnetic resonance". It requires two matched solenoids, matched bar magnets, and "tuned" springs on separate stands.

Diagrams:



For the springs, I found that a Slinky Jr. could be cut in half. Then cut one of the halves in half. Or each spring is a ¼ length of the original Slinky Jr. and makes an excellent, sensitive spring. Clamp the ends of the springs in a vise and bend them about 90° so they become "hooks".

First, suspend the magnets on the springs on the stands without the solenoids. Masking tape works well to fasten everything in place. Second, start them oscillating up and down together. If one oscillates faster than the other, add some mass (washers, paperclips, etc.) to the "fast" one to slow it down until it matches the other. (You are "tuning" the system.) Third, with the system "tuned", add the solenoids and connecting wires between them.

Presentation: Now the fun begins. Which ever magnet you decide to start oscillating becomes the generator. Immediately, the other magnet begins to oscillate as the motor. Note whether it's in phase with the "generator" magnet or a 180° out of phase. Now switch one end of the connecting wires or simply turn the solenoid upside down. The result is a 180° switch in phase. Now switch the polarity of the "generator" magnet by turning it upside down; as expected, the phase switches again. So polarity and wiring are very important in generator-motor design.

Next, start the "motor" magnet oscillating, now acting as the "generator" magnet. The original generator is now the motor. The entire process is reversed. In conclusion, generators and motors are the same device. It simply depends on which is pushing electrical energy out and which is taking it in. Most of the time when both magnets are oscillating, both are acting as "generators", feeding unseen electric currents back and forth to each other and keeping each other oscillating. Note the long time that the oscillations keep going. Electromagnetic resonance has been achieved, a sight to behold!

If you now experiment with different releases of the magnets and positions of the solenoids, you can come up with a combination where the currents will cancel each other out, causing the oscillations to dampen and cease very quickly, an excellent way to show the effects of back EMF.

Now it is easy to understand what happens when an electric motor, made largely of very low resistance copper wire, starts up. Its "generator" aspect kicks in, pushing back (back EMF), and a natural resistance develops, holding down the incoming current (amps). If the motor is suddenly stalled (slowed or stopped), its back EMF (resistance) disappears, and the motor's wiring is immediately overpowered with a high current. Overheating and fire will result. Thus, all good motors have circuit breakers that will pop to protect them in case they stall.

Just for fun, you might try, as in the diagram, connecting one of the model generators up to one of the "spring magnets" acting as a motor. Synchronizing the two will be a challenge. Phasing in electricity is very important. That's why we have 60 Hz as a standard in the USA for electric motors and generators.

This simple demo can teach a lot of fundamental principles about electricity and should be used in any introductory physics course taught in high school or college.