

Electromagnet Experiment Stand

A Variable Power Electromagnet



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Background

An electromagnet is formed when a current carrying wire is wrapped around an iron core. The strength of the electromagnet depends on, among other things, the number of times the wire is wrapped around the core and the amount of current that is flowing through the wire. The Electromagnet Experiment Stand is a device that demonstrates the relationship between the strength of an electromagnet and the number of coils wrapped around its core as well as the relationship between the strength of an electromagnet and the amount of current flowing through its coils.

Overview

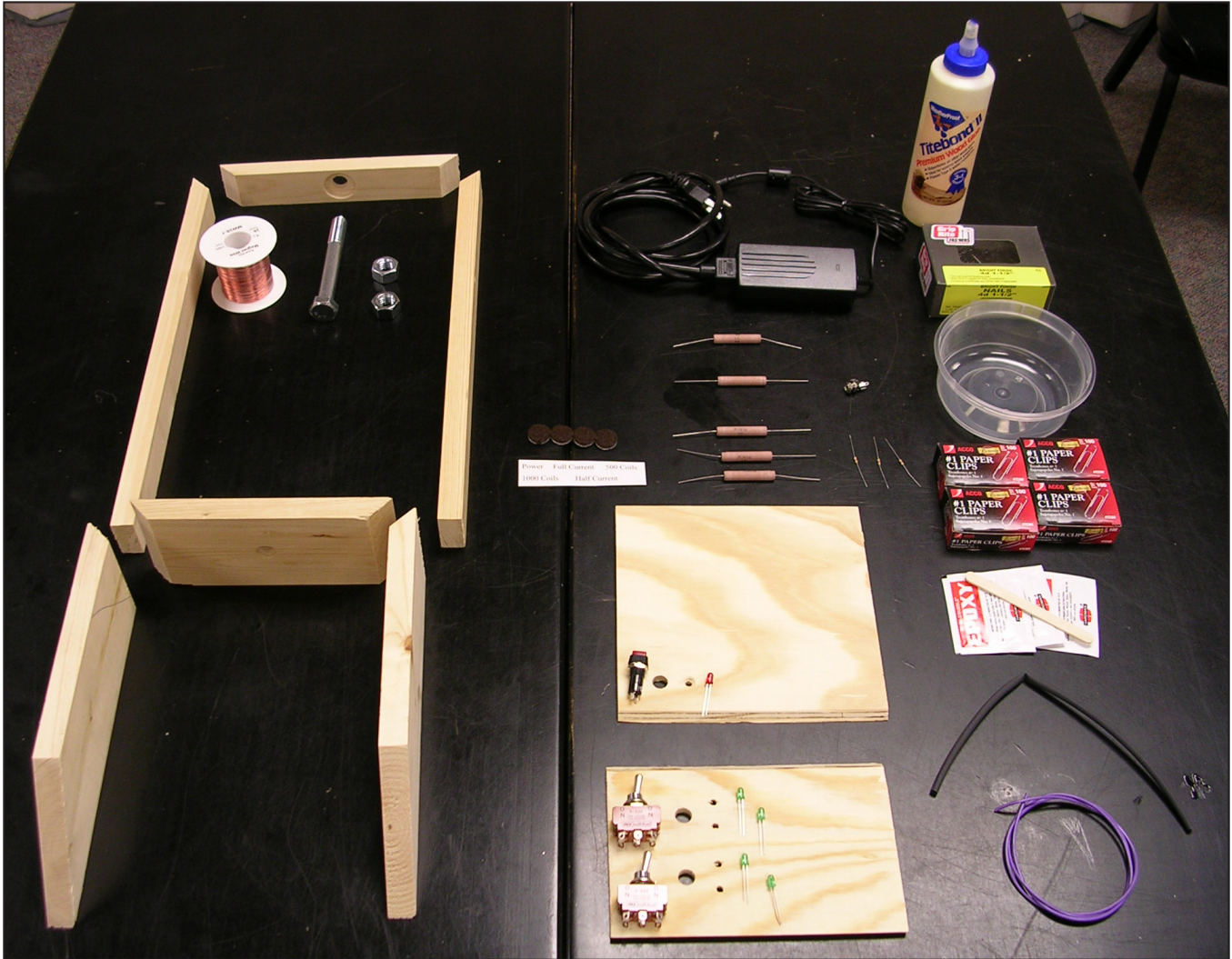
The Electromagnet Experiment Stand consists of a coil wound from approximately 49 meters (160 feet) of 22 gauge solid core, enamel insulated magnet wire. The electromagnet's core consists of a 5/8" diameter, 5 3/8" long hex bolt. The coil was wrapped around the core in six layers, each containing approximately 130 turns, for a total of roughly 780 turns. The coil is tapped between the 3rd and 4th layers so that the inner three layers of the coil can be powered independently from the outer three layers. The electromagnet is powered from a 5 volt, 2.2 amp power supply. As the full coil has a resistance of about 2.6 ohms, nominal current draw is about two amps. A 1.3 ohm load is added to the circuit when the inner three layers of the coil are not used in order to keep the current flowing through the coil constant. An additional 2.5 ohm load can be added to the circuit in order to reduce the current flowing through the coil by roughly half. The different settings are controlled by a pair of toggle switches mounted to the front of device, one to control the amount of current flowing through the coils and one to control the number of active coils.

The main base is constructed from sections of 1 × 4 white pine and 1/4" plywood. The electromagnet is suspended above the main base with a support frame made from sections of 1 × 2 white pine.

Component List

- 22 gauge solid core, enameled magnet wire (170 feet needed)
- toggle switch (DPDT, 15A, 2 needed)
- momentary contact switch or toggle switch (SPST, normally open, 3A)
- 5/8" diameter hex bolt (5 3/8" long)
- 5/8" hex nuts (2 needed)
- power supply (5 VDC, 2.2 A or greater output; 120 VAC input; 2.1 mm diameter output plug)
- 2.1 mm power jack (panel mount)
- 1 ohm, 10 Watt power resistors (3 needed)
- .5 ohm, 10 Watt power resistor (1 needed)
- .3 ohm, 10 Watt power resistor (1 needed)
- 130 ohm, 1/4 Watt resistors (3 needed)
- green LEDs (T-20 package, 4 needed)
- red LED (T-20 package, 1 needed)
- 1N4001 diodes (2 needed)
- 24 gauge stranded hook-up wire (roughly 10 feet needed)
- 1 × 4 plank of white pine (roughly 3 feet needed)
- 1 × 2 plank of white pine (roughly 3 feet needed)

- ¼" thick plywood (roughly 2 square feet needed)
- 3/16" diameter heat shrink (roughly 12 inches needed)
- 1½" long 4d finishing nails (roughly 20 needed)
- 400 paper clips
- 1 small container
- adhesive labels (Full Current, Half Current, All Coils, Half Coils and Power)
- adhesive felt feet (4 needed)
- 5 minute epoxy (3 packets needed)
- wood glue



All of the components have been gathered. The wood for the base sections has been cut and holes for the hardware have been drilled.

Base Construction

1. Cut an 8" long piece from the 1 × 4 white pine board. Miter cut both ends to a 45° angle. This piece will form the back of the base.
2. Drill a hole in the back board to accept the 2.1 mm power jack. Since our power jack was not designed to be used with a material as thick as the pine board, a Forstner bit was used to remove the excess wood.



The base's back board had been cut and a hole for the power jack has been drilled through it.

3. Cut two pieces from the 1 × 4 white pine board. Make each piece 11 7/16" long. These pieces will form the right and left sides of the base.
4. Make a 45° angle cut along the face of the right and left side boards. When completed, the 'top' of these pieces will be 8" long and the 'bottom' will be 11 7/16" long. The angled faces of these pieces will eventually support the device's control panel.



The right and left sections of the base.

5. Miter cut the rear, interior edges of the right and left side boards to a 45° angle. Remember, these two pieces are not interchangeable. The miter cuts must be made on the correct edges.
6. Join the right, left and back sections of the base to form a 3-sided, U-shaped box. Use wood glue and finishing nails to secure the joints.



The three sections of the base, prior to joining, showing the correct miter cuts.

7. Cut an 8" × 8" panel from the ¼" plywood. This panel will form the top of the base.
8. Choose one edge of the top panel as the front and bevel it to a 45° angle. The dimensions of the base of the top panel should still be 8" × 8" after the bevel cut is made. It may be easier to make the top panel slightly larger than necessary and then trim it to the correct size as the bevel cut is made.

9. Drill a hole in the top panel, near the front edge, to accept the momentary contact switch. Drill a second hole nearby to accept the red LED.



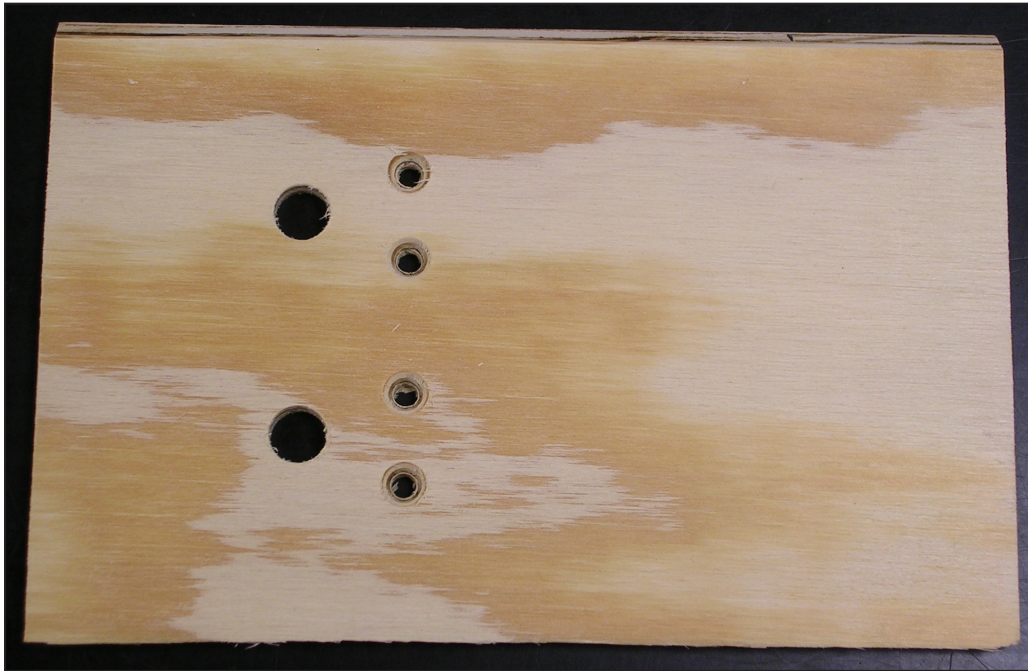
The top of the base has been cut and the front edge has been beveled to a 45° angel. Holes have been drilled for the momentary contact switch (large) and red LED (small).

10. Cut an 8" × 5 9/16" panel from the 1/4" plywood. This panel will form the front of the base.
11. Bevel the top and bottom edges of the front panel to a 45° angel. When complete, the front panel's profile will be a parallelogram. The top edge will be parallel to the top of the base and the bottom edge will be parallel with the bottom of the base. As with the top panel, it may be easier to cut this piece slightly larger than needed and then trim it to the correct size as the bevel cuts are made.



An edge-on view of the front panel showing the two 45° bevel cuts. The 'top' of the piece is to the left.

12. Drill holes in the front panel to accept the two DPDT toggle switches and the four green LED's. The LED's will be used to indicate the position of the switches, so they should be clustered together.



The front panel has been cut and the top and bottom edges have been given a 45° bevel. Holes have been drilled for the toggle switches (large) and green LEDs (small).

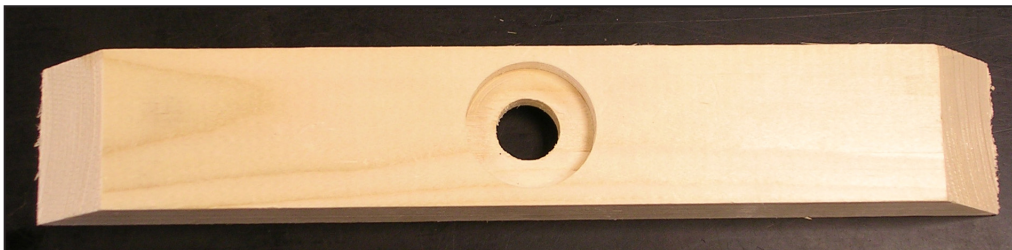
13. Attach the top panel and front panel to the base. The front panel should be positioned so that it covers the front edge of the top panel. Use wood glue and finishing nails to secure these pieces to the base.



The lower base is assembled.

Magnet Support Frame Construction

1. Cut a $9 \frac{13}{32}$ " long piece from the 1×2 white pine board. Miter cut both ends to a 45° angle. This piece will form the top rail of the magnet support frame.
2. Drill a hole through the center of the top support rail to accept the $\frac{5}{8}$ " diameter hex bolt. In order to provide enough room for two hex nuts, a Forstner bit was used to remove some excess wood.



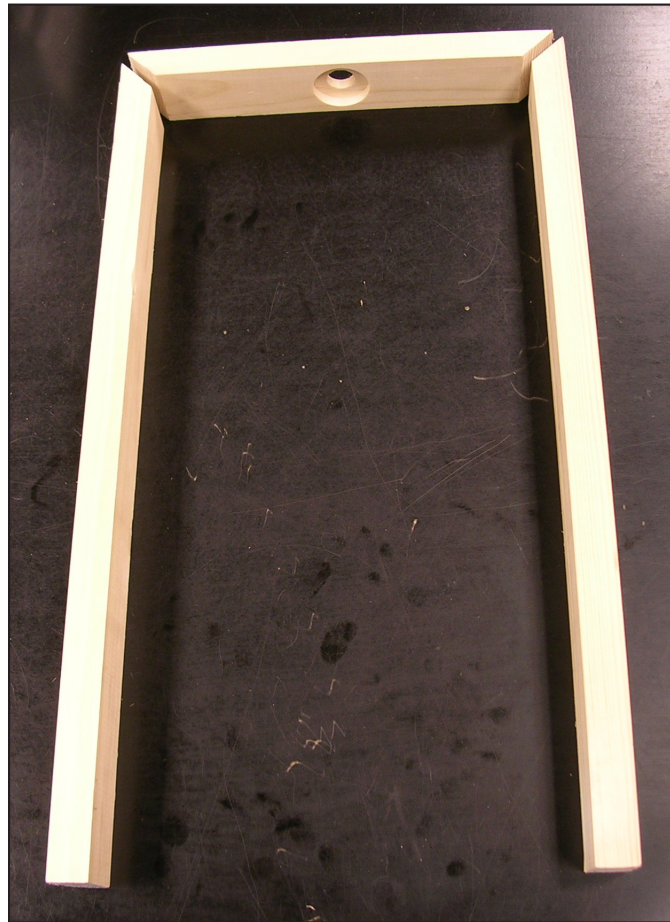
The edges of the top support rail have been miter cut and a hole has been drilled to accept a $\frac{5}{8}$ " hex bolt.

3. Cut two 17 ½" long sections from the 1 × 2 white pine board. Miter cut one edge of each piece to a 45° angle. These two pieces will form the side rails of the magnet support frame.



The two side rails, one seen edge-on.

4. Join the top and side rails together to form a U-shaped object. Use wood glue and finishing nails to secure the joints.



Seen prior to joining, the top and side rails form the magnet support frame.

5. Wow, that was easy. The magnet support frame is complete.

Final Base Assembly

1. Attach the magnet support frame to the base using finishing nails and wood glue, if desired. The magnet support frame should be placed so that it is positioned midway along the base's top panel.



The magnet support frame has been attached to the base. The hole through the center of the top support rail sits above the center of the base's top plate.

2. Use a drill to drill a $\frac{1}{4}$ " diameter hole through the side of the base. The positioning of this hole isn't critical. It will be used to allow the wires that power the electromagnet to pass out of the base. These instructions will be written under the assumption that this hole is located on the left side of the base, slightly behind the magnet support frame.



A $\frac{1}{4}$ " hole is drilled in the side of the base to allow for wires to run between the electromagnet and the interior of the base.

3. Sand and paint your base to your liking.
4. Congratulations! The base is now completely assembled!

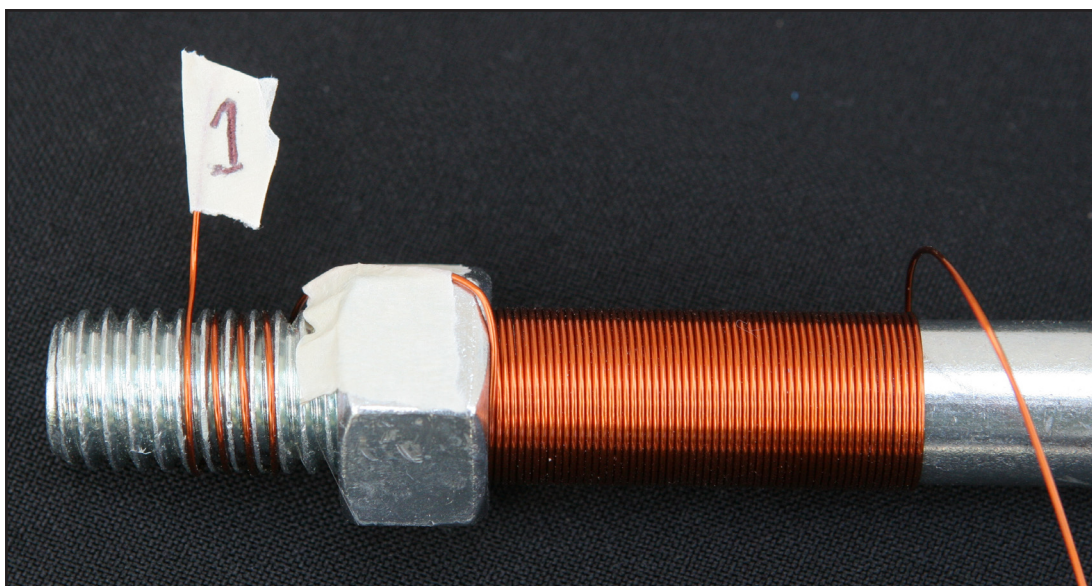
Coil Construction

1. Take a small piece of tape or paper and attach it to the end of the roll of 22 gauge magnet wire. Write the number '1' on the piece of tape or paper. This will be used later to help identify the electromagnet's leads.
2. Attach a nut to the threaded end of the 5/8" hex bolt. Tighten the nut until it jams against the unthreaded portion of the shaft. This will create an area roughly 3 and 3/8" across where you will wrap your electromagnet's coil.



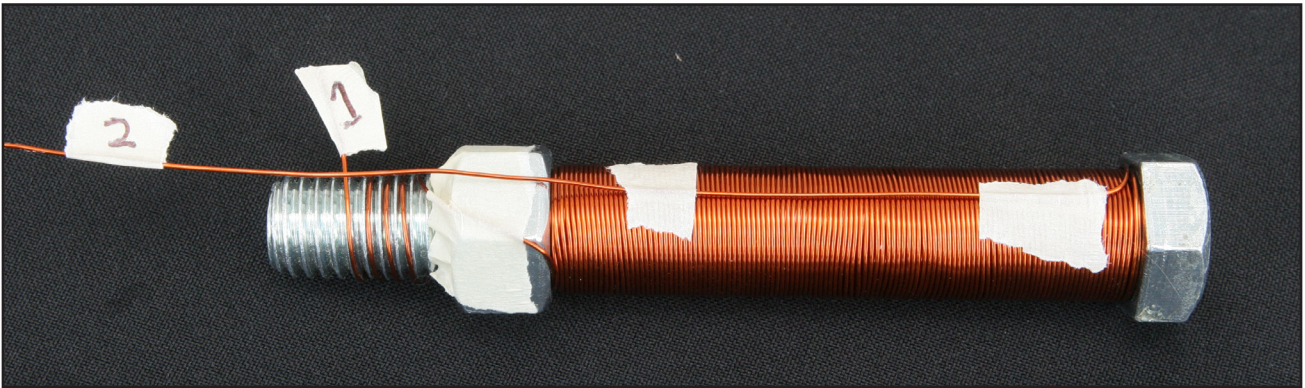
Use the area between the hex cap and the hex nut to wrap your coil.

3. Starting at the hex nut and working your way towards the hex cap of the bolt, begin wrapping the 22 gauge magnet wire around the shaft of the bolt. **Do not** start wrapping the coil from the very end of the wire. Give yourself a foot or so of 'extra' wire at the beginning of the coil. The label you created in Step 1 should be attached to this 'extra' portion of wire. The coils should be wound as neatly and as tightly as possible.



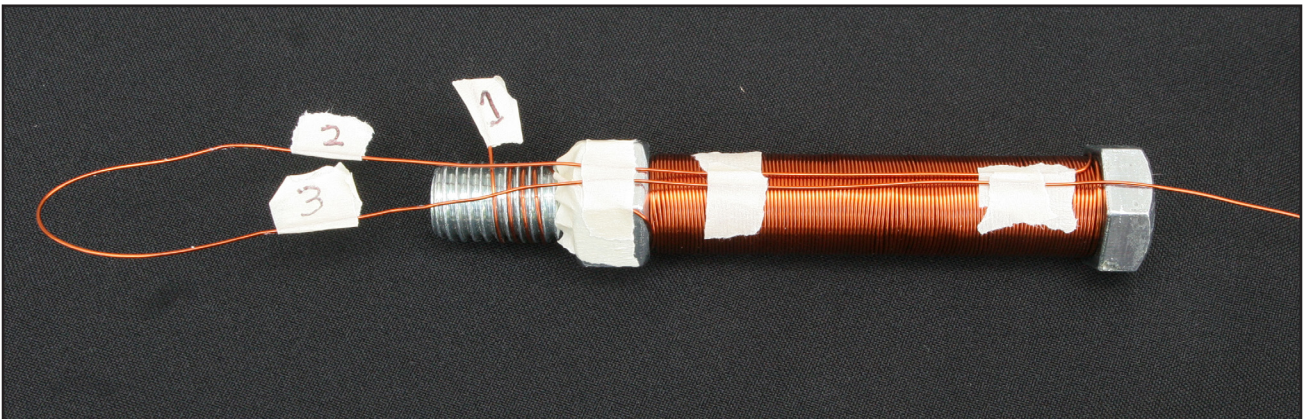
Begin wrapping the coil at the hex nut, leaving some extra wire at the beginning of the coil.

- When the windings reach the hex cap, begin a second layer atop the first layer. Work will now progress towards the hex nut but the direction of the windings will remain unchanged. For example, if the wire was being wound about the bolt in a clockwise fashion on the first layer, the clockwise motion would continue on the second layer, and all subsequent layers.
- When the windings reach the hex nut, begin wrapping the third layer, working towards the hex cap.
- When the third layer is complete, create a center tap by running the magnet wire directly up the shaft of the bolt. Extend the wire about a foot beyond the end of the bolt. Label this outgoing wire '2.'



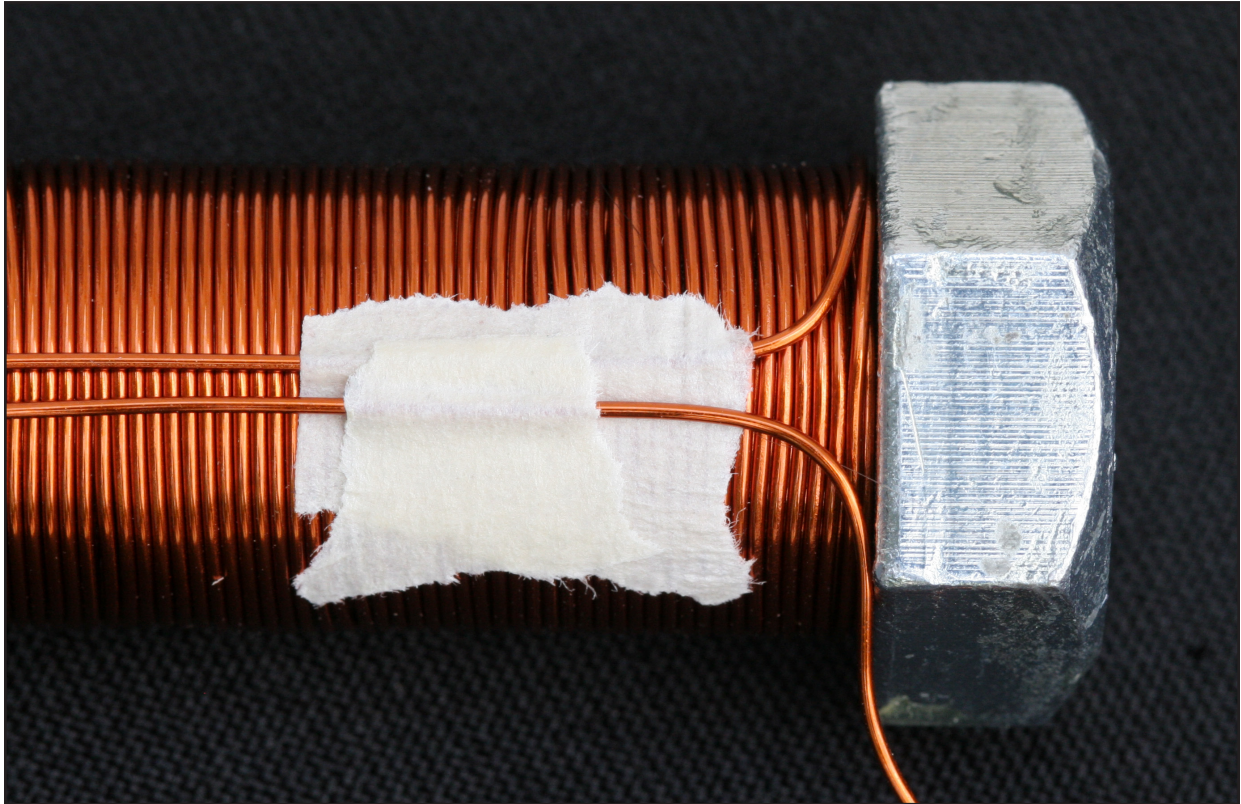
Three layers of wire have been wrapped around the core. Before continuing with the fourth layer, the wire was brought back up the length of the bolt's shaft in order to create a center tap.

- Bend the wire back upon itself and run it directly down the shaft of the bolt to the hex cap. Label this ingoing wire '3.'



Bend the wire back upon itself in order to complete the center tap.

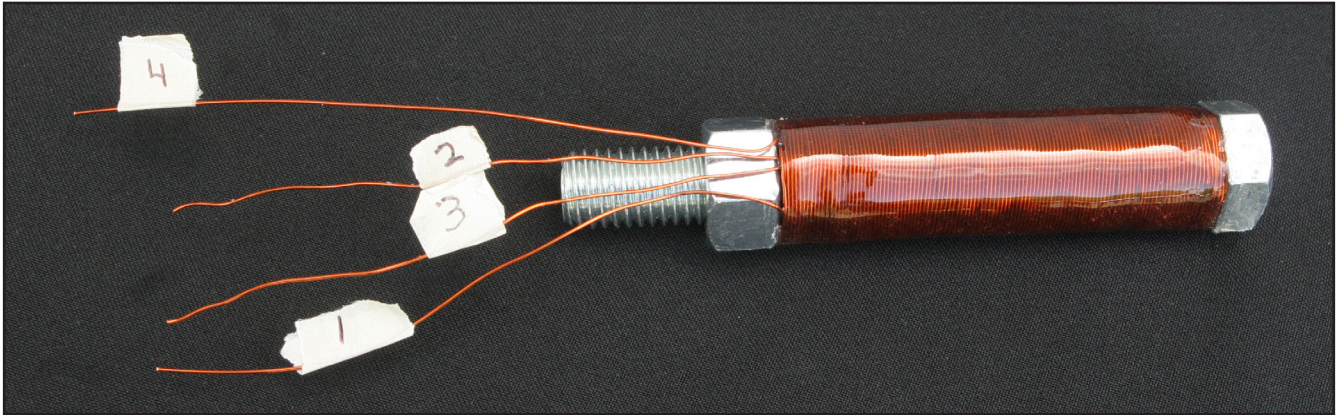
8. Wind the fourth layer of the coil. It will start at the hex cap and work its way up the shaft. Make certain that the fourth layer is wrapped in the same direction (clockwise or counter-clockwise) as the rest of the coil.



Continue wrapping the fourth layer as if the center tap never happened.
Use small bits of tape to hold the center tap wires in position.

9. When the fourth layer is complete, add a fifth layer.
10. When the fifth layer is complete, add a sixth layer. This is the coil's final layer of wire. When the sixth layer is complete, cut the wire from the spool, giving yourself about a foot or so of 'extra' wire. Label this final lead '4.'
11. Cover the coil with epoxy and let it set.

- Cut the loop of wire that was formed when you created the center tap in steps 6 and 7. Make the cut between the labels you placed on that section of wire. When complete, your coil will have four leads protruding from it, labeled 1, 2, 3 and 4. Each of these leads should be a foot or so long. Leads 1 and 2 control the inner three layers of the coil while leads 3 and 4 control the outer three layers. The full coil consists of about 780 turns of wire and has a total resistance of about 2.6 ohms.



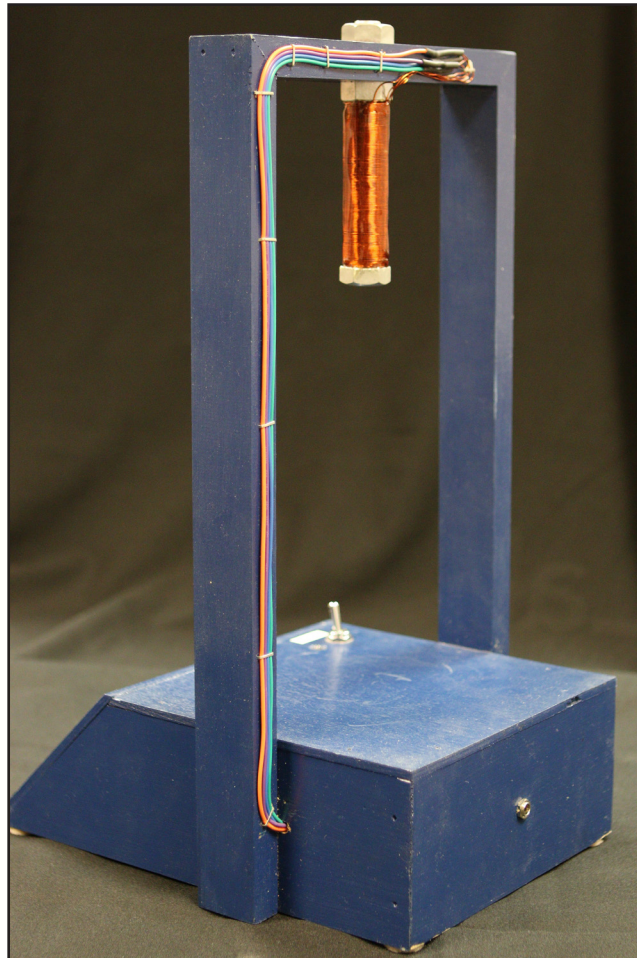
The completed coil.

- Use a medium grit sandpaper to scrape away the insulation from the last inch of each of the four lead wires. If the labels are in the way, move them but keep them on their respective leads. It is in your best interest not to lose track of which lead is which!
- That's a wrap!

Assembly

- Place the bolt through the hole in the top rail of the magnet support frame. The coil at the end of the bolt should be pointed towards the base.
- Secure the bolt to the magnet support frame using a hex nut.
- Cut four lengths of hook-up wire long enough to run from the bolt secured to the top of the magnet support frame, along the top rail, down a side rail and through the $\frac{1}{4}$ " hole drilled into the side of the base with about 6" or so to spare.
- Solder one hook-up wire to each of the magnet's four leads. Cover each of the joints with heat shrink. Move the labels that are attached to the magnet wire to the ends of the hook-up wire, being careful not to confuse them.
- Carefully wrap and secure any loose magnet wire to the magnet support frame with clear packing tape. The idea is to prevent the magnet wire from moving or flexing in order to prevent breakage.

6. Draw the four hook-up wires along the back of the magnet support frame from the electromagnet to the hole drilled in the side of the base. Secure the hook-up wires to the back of the magnet support frame with clear packing tape or staples. If a staple gun is used, make certain that the staples do not break through the hook-up wire's insulation.



The magnet's hook-up wires are secured to the back of the support frame.

7. Draw the four hook-up wires through the $\frac{1}{4}$ " hole drilled into the side of the base.
8. Place and secure the momentary contact switch, the two DPDT toggle switches and the 2.1 mm power jack in their respective holes. Depending on the exact hardware used, it may be easier to remove an item from its mounting hole for wiring.
9. Create a 2.5 ohm resistor by wiring two 1 ohm resistors and one .5 ohm resistor together in series.
10. Create a 1.3 ohm resistor by wiring a 1 ohm resistor and a .3 ohm resistor together in series.
11. Flip the base over so that you can access its interior.
12. Place the red LED and the green LEDs in their respective mounting holes. Consult the Point to Point Wiring Guide or the Circuit Diagram in order to orient them correctly for wiring.
13. Use epoxy to secure the LED's to the base by covering them with a small puddle. **Do not** cover the LED's leads with epoxy as you still need to solder wires to them. Once the LEDs are epoxied to the base, they will be nearly impossible to remove. If you are uncertain about your wiring skills, you may wish to epoxy these components after they are wired and are operating correctly.

14. Find a convenient place within the base to mount the 2.5 and 1.3 ohm resistors. Secure them to the base with epoxy.
15. Wire the components together. Use the Point to Point Wiring Guide or the Circuit Diagram, located at the end of this document, to guide you. Whenever possible, cover exposed joints with heat shrink.
16. Once you have double checked your connections and you have finished soldering the joints, attach the four adhesive felt feet to the bottom of the base.
17. Set the device upright and attach the adhesive labels to mark the switch settings. The momentary contact switch on the base's top platform is the magnet's ON-OFF switch and should be labeled 'POWER.' The top two green LEDs indicate the power settings. The top LED in this group should be labeled 'FULL CURRENT' and the one below it should be labeled 'HALF CURRENT.' The lower two green LEDs indicate the number of coils used. The top LED in this group should be labeled 'ALL COILS' and the one below it should be labeled 'HALF COILS.'
18. Give yourself a little pat on the back because you are done!

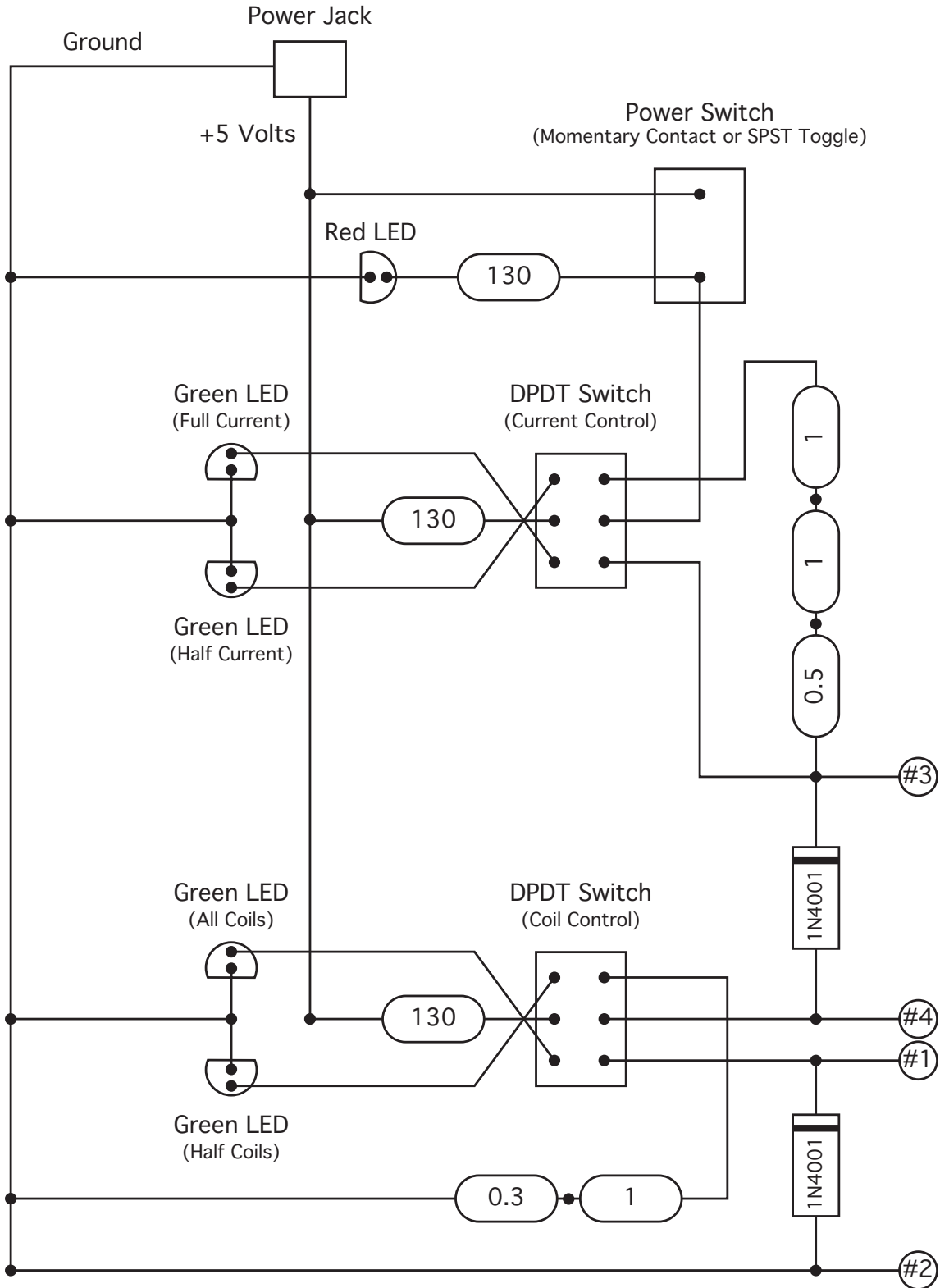
Operation

When power is supplied to the Electromagnet Experiment Stand, the green LEDs will light to indicate which settings are selected. Current will only flow through the electromagnet's coil while the momentary contact switch is pressed and the red power LED is on. As soon as this switch is released, no current flows through the coil and the red LED turns off. When 'FULL CURRENT' and 'ALL COILS' is selected, the complete electromagnet is connected directly to the 5 volt supply. As the coil has a resistance of about 2.6 ohms, it draws about 2 amps of current. Selecting 'HALF COILS' removes the inner three layers of coils from the circuit. In order to keep the current draw mostly constant, a 1.3 ohm dummy load is added in series with the remaining coils. Selecting 'HALF CURRENT' adds a 2.5 ohm dummy load in series with the magnet (either all six layers of coils or the outer three layers of coils and the 1.3 ohm dummy load, depending on which coil setting is selected), creating a total load of about 5 ohms and a total current draw of about 1 amp.

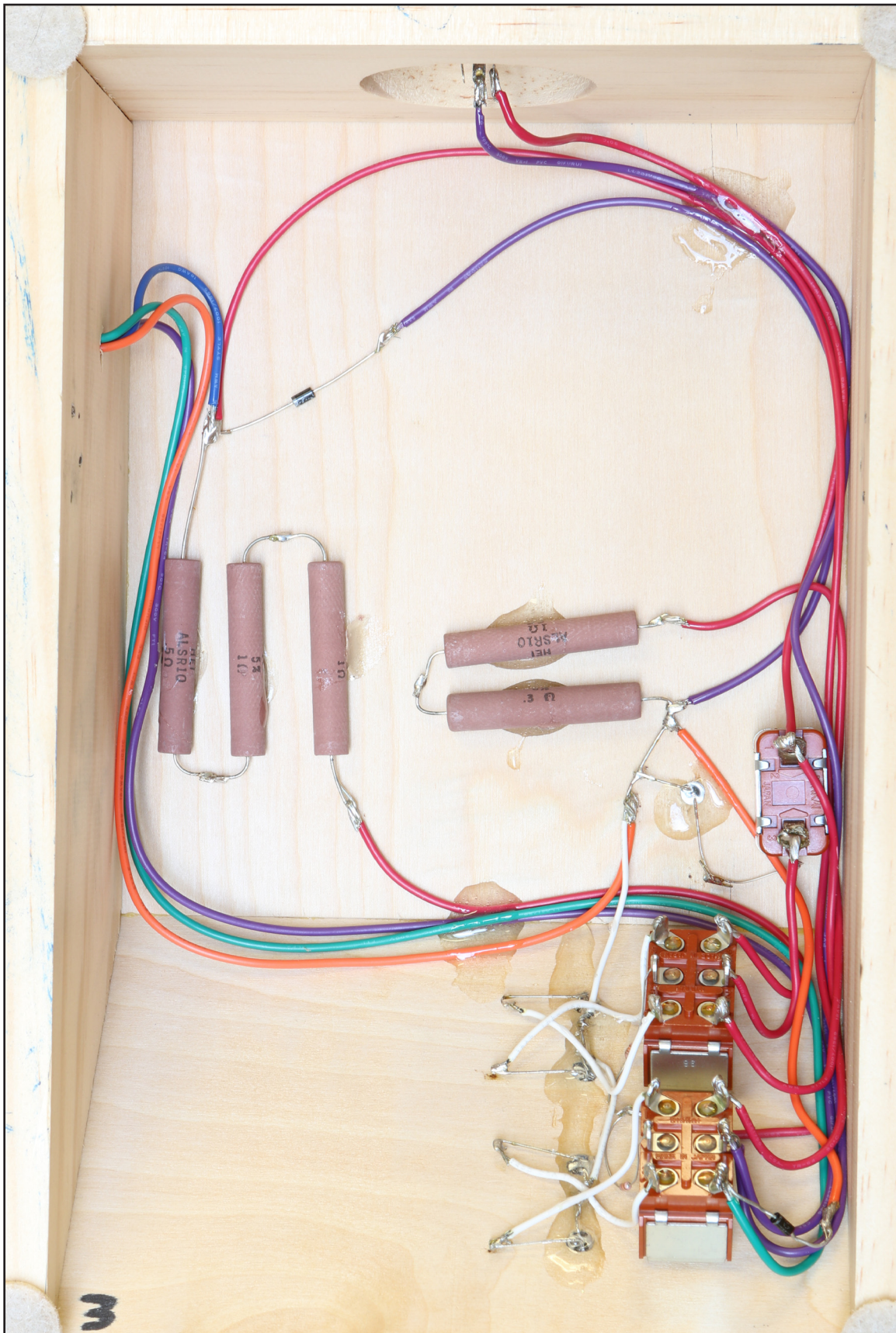
Typically, a number of paper clips are placed in a small container on the top of the base. The settings are selected and the power button is pressed. The magnet is not strong enough to pull the paper clips up from the base. The container of paper clips must be 'introduced' to the magnet by lifting it up with one hand while the other hand keeps the power button pressed. Different numbers of paper clips will be held by the electromagnet when different settings are selected.

Point to Point Wiring Guide

This diagram is a representation of the components as seen from inside the base. Resistors are represented by rounded rectangles. The flat end of the LED is the cathode. Note the orientation of the 1N4001 diodes. The numbered circles (#1, #2, #3 and #4) are the labeled leads from the electromagnet. Small, dark circles indicate a soldered connection.



Wiring Photo



Circuit Diagram

+5 Volts

