



## Department of Electrical and Computer Engineering

### BUILD A SPEAKER

#### ***Purpose***

Build a working speaker from paper, magnets, and wire, Figure 1. The speaker can be hooked up to an mp3 player or other music source. An amplifier can be used (either built by the student or provided by the leader) to make the sound louder.

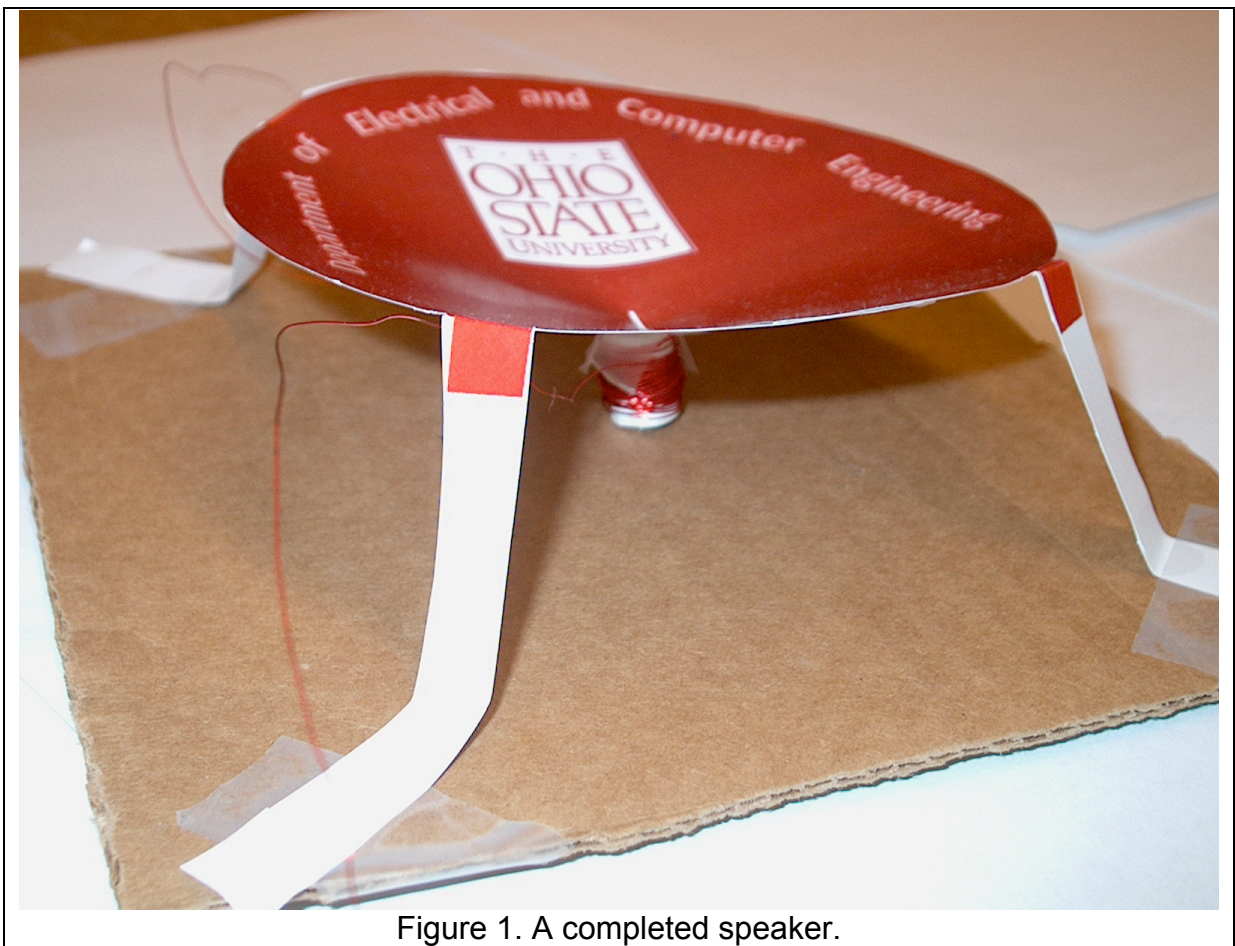


Figure 1. A completed speaker.

#### ***Principles of operation***

We will use two general principles, sound waves and electromagnetic fields, and put them to work to create a speaker.

## Sound waves

Sound waves are compressional waves. They propagate in materials or air, and are characterized by alternating regions of compressed material and rarified material. Figure 2 shows the compressed air in white and the rarified air in black. Sound cannot propagate in a vacuum because there is no material. Thus science fiction movies in which you can hear explosions or engines in space are not realistic.

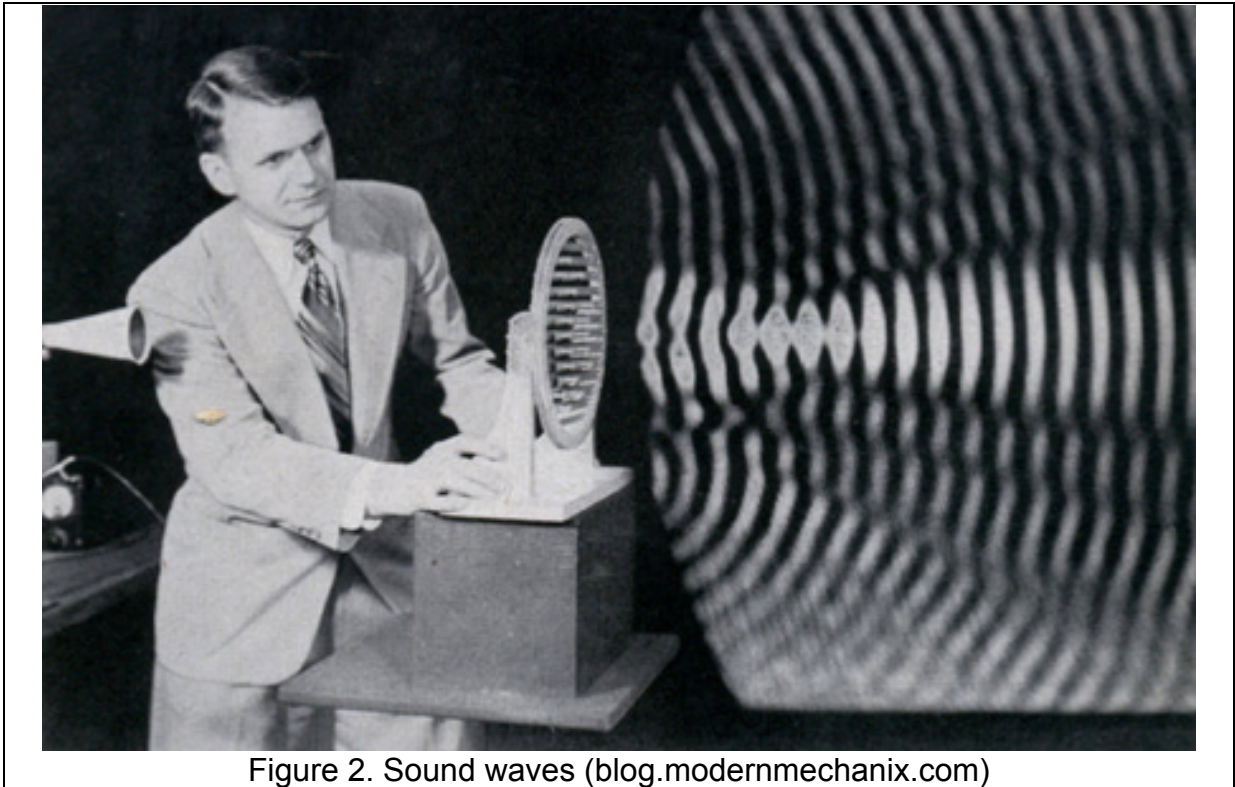


Figure 2. Sound waves (blog.modernmechanix.com)

Sound waves are created by something vibrating, such as vocal chords, strings, engines. In the case of a speaker, the speaker's diaphragm vibrates. Figure 3 shows the parts of a commercial speaker. The diaphragm is usually a stiff, light material in the shape of a shallow cone. There is also a permanent magnet and a coil of wire (voice coil). We will get to those in the next section.



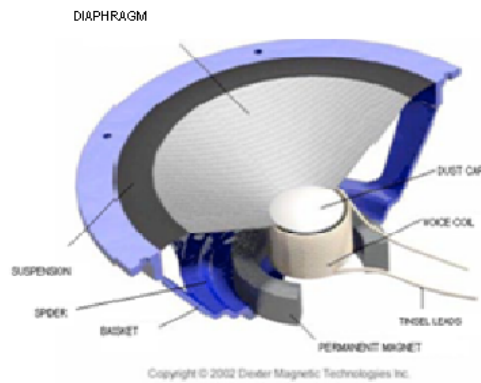


Figure 3. Parts of a speaker. <http://www.dextermag.com/Speakers-Microphones.aspx>

To create sound, we want to set the diaphragm vibrating. The moving diaphragm pushes the air above it, which launches the sound wave. The outer rim of the diaphragm is attached to and suspended from a support system (the basket) that is in turn attached to a flexible structure called the “spider,” often consisting of a set of pleats. The spider is attached to a permanent magnet, which in this figure is shaped in a ring (we will use a simple cylinder when we build our speaker). The center of the cone-shaped diaphragm is attached to a coil of wire. When the speaker is operating, the voice coil generates a magnetic field that “pushes” against the permanent magnet. The coil moves up and down, moving the diaphragm with it.

### ***Signal from a stereo or mp3 player***

We want the speaker to produce the sound our music. Let us suppose the music is recorded on an mp3 player. The mp3 player has stored the music in memory (in a digital format). The electronics of the mp3 player retrieve the data from memory, convert it to an analog signal, and puts out a current that is proportional to that signal.

We now have the music information in the form of an electrical current, and want to convert that signal to sound. That is what the speaker does.

### ***Operation of the speaker***

We will apply the principles of electromagnetism to convert the electrical (music) signal to displacement. The key principles we will apply are:

- A permanent magnet produces a magnetic field
- An electrical current also produces a magnetic field
- Magnets repel or attract other magnets and thus can cause motion

### ***Interaction of electricity and magnetism***

Consider a permanent magnet such as those shown in Figure 4. Each magnet has a south pole and a north pole. If the two south poles are pointed near each other, you can feel them trying to repel each other. That is, there is a force. We say that each magnet has a magnetic field, and that field produces the force.

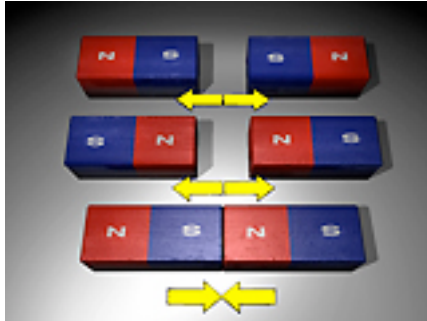


Figure 4. Permanent magnets. Like poles repel, opposite poles attract.

Figure 5 shows the magnetic field of a permanent magnet. The field is invisible, but we draw lines to indicate the direction the field points. The field lines leave the north pole and re-enter the magnet at the south pole. Field lines flow north to south.

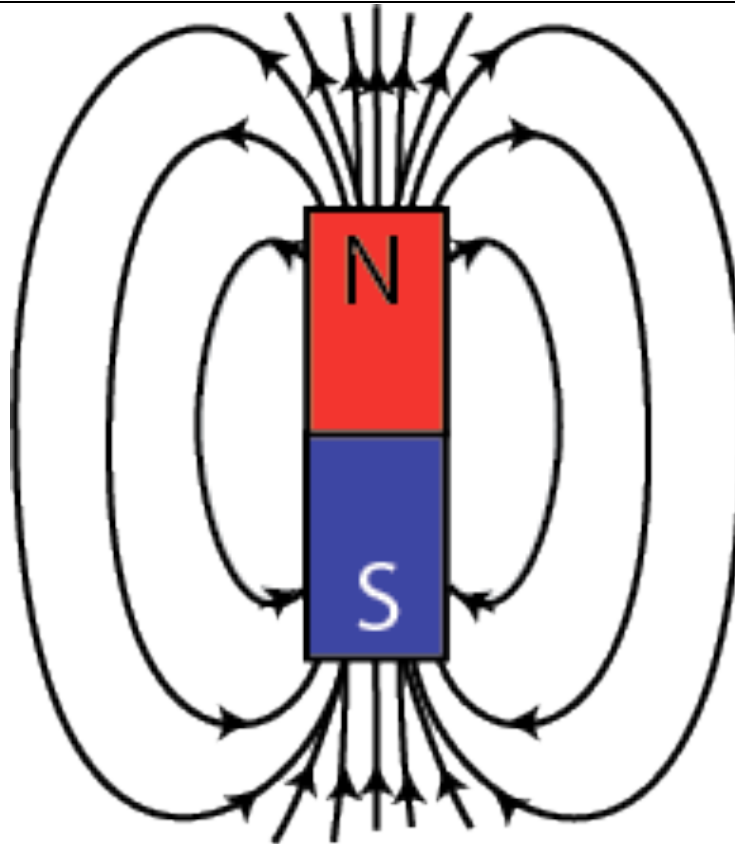


Figure 5. The field of a permanent magnet.

The magnetic field operates on other magnets. For example Figure 6 shows the needle of a compass. The needle is magnetic, and has a north and south pole. The north pole of the compass needles is attracted to the south end of the permanent magnet, and is repelled by the north end. Similarly, the south end of the needle wants to point to the north. We paint that end white and call it the indicator.

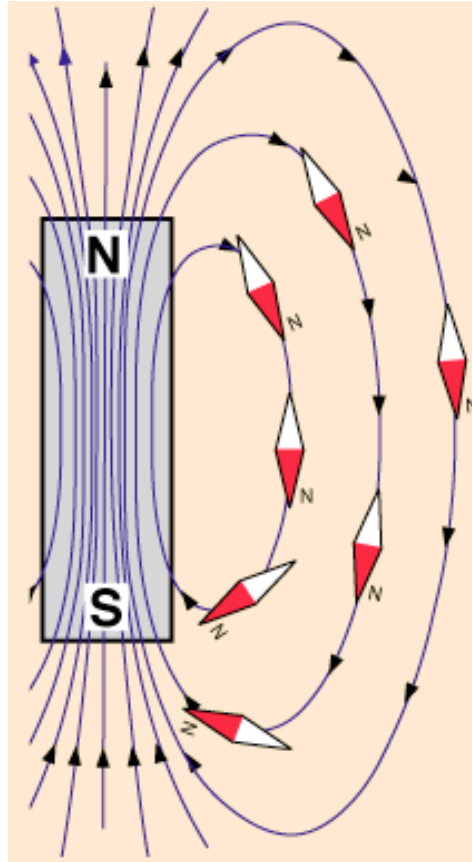


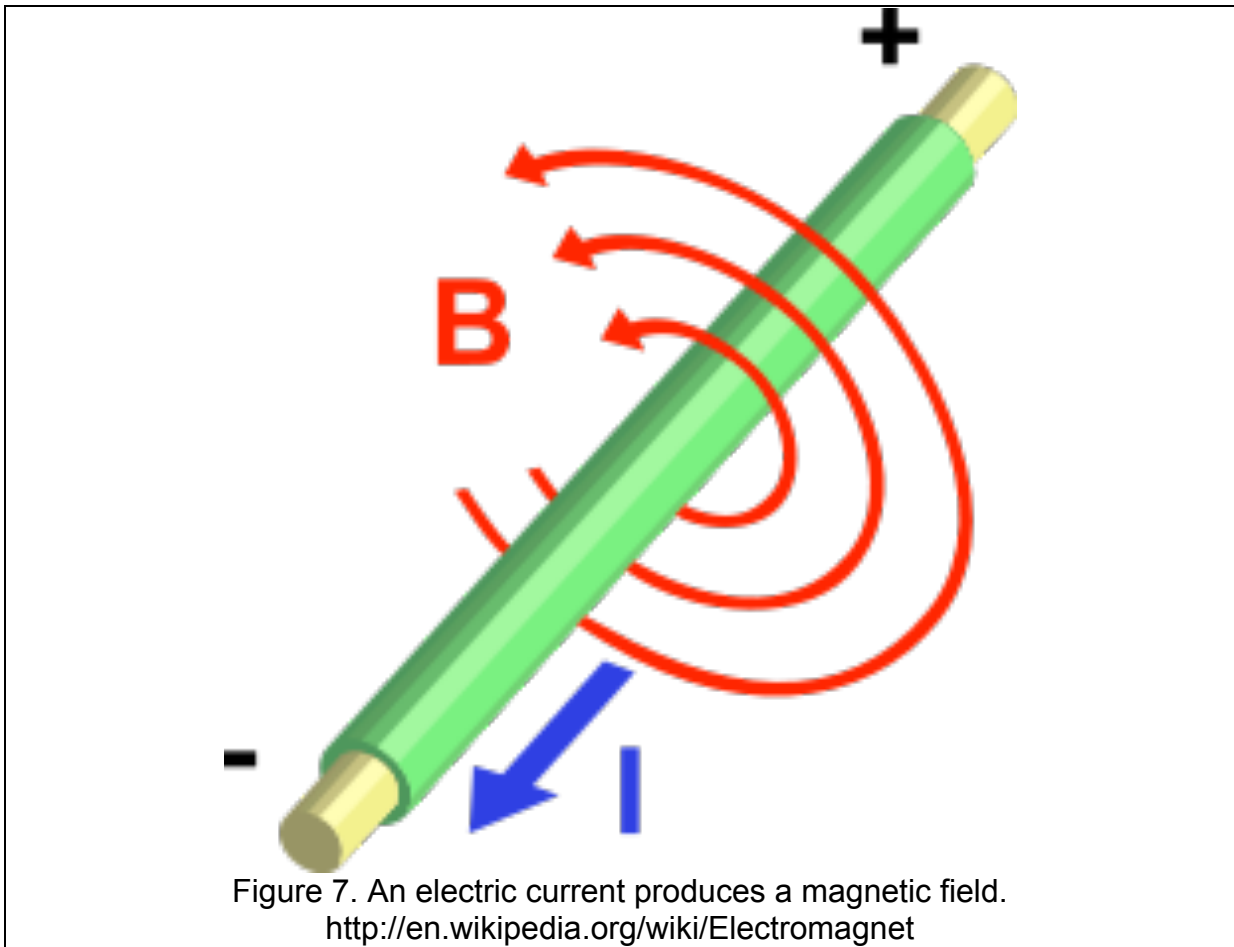
Figure 6. The needle of a compass (which is magnetic) tries to align with the magnetic field of the permanent magnet (for example, the earth's magnetic field).  
[hyperphysics.phy-astr.gsu.edu/.../elemag.html](http://hyperphysics.phy-astr.gsu.edu/.../elemag.html)

OK, we have established that permanent magnets can make other magnets move. For our speaker, however, we have only one permanent magnet. The other magnet will be an electromagnet.

Whenever a current flows through a wire, it produces a magnetic field. Electricity and magnetism always go together—a current produces a magnetic field, and magnetic field can induce a current.

Figure 7 shows a current ( $I$ ) flowing through a piece of wire. The magnetic field lines ( $B$ ) form circles around the wire. Current always flows from plus to minus. The direction of the magnetic field lines can be found from the right-hand-rule: If you point your thumb (it has to be your right thumb) in the direction the current is flowing, then your fingers curl in the direction of the magnetic field.





Remember, though, that the current coming out of your mp3 player is alternating. It reverses direction at the same frequency as the sound wave it's supposed to represent. When the current reverses, the magnetic field reverse too.

We could place a magnet near the wire in Figure 7, and there would be a force on it when the current flowed. As the current oscillates, the magnet would move—but the force is pretty weak.

We can strengthen the force by making the wire into a loop, Figure 8. The magnetic field lines go through the loop, but they are scrunched together. Since they are bunched up, the field is stronger inside the loop. That will tend to move the magnet more.

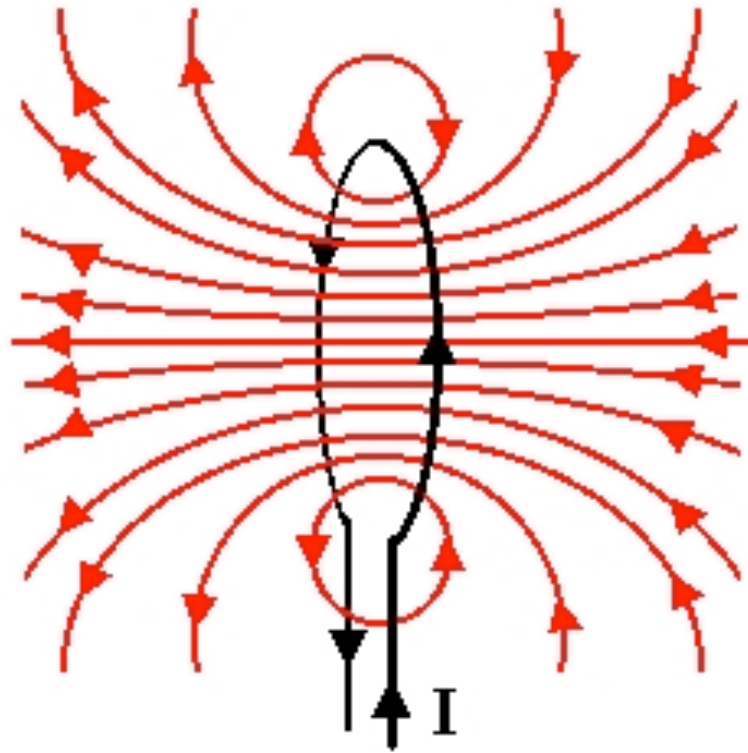


Figure 8. Bending the wire into a loop strengthens the magnetic field.  
[physicsed.buffalostate.edu/.../rhr/rhr.htm](http://physicsed.buffalostate.edu/.../rhr/rhr.htm)

Figure 9 shows the loop (and electromagnet) with a permanent magnet inside. Remember, the magnetic field lines come out of the north and go into the south. Now we have two magnetic fields, though, one for the electromagnet (drawn in red) and the other from the permanent magnet (not drawn). The magnet will get pushed. The north pole of the permanent magnet is repelled by the north pole of the electromagnet, but the south poles repel too. In this case, the permanent magnet's south pole is in a weaker region of the electromagnet's magnetic field, so the north-north repulsion will be stronger than the south-south repulsion, and the magnet will move to the right. If we reverse the current, the electromagnet's poles will reverse and the magnet will move to the left.

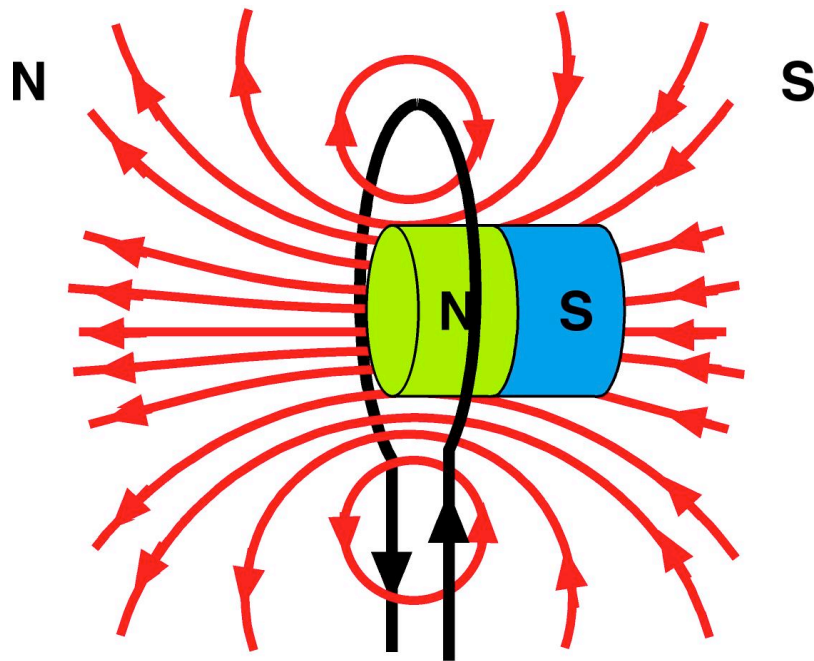
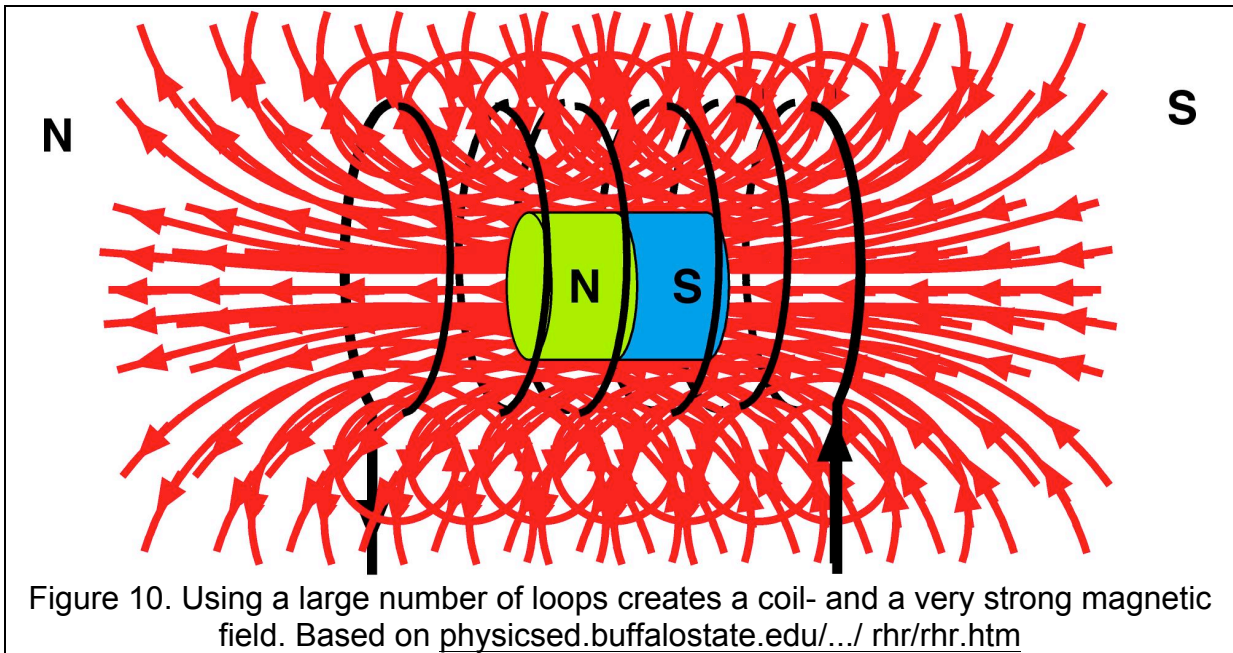


Figure 9. A permanent magnet inside an electromagnet. Based on [physicsed.buffalostate.edu/.../rhr/rhr.htm](http://physicsed.buffalostate.edu/.../rhr/rhr.htm)

So, we can push the magnet, but the field is still pretty weak. We can amplify the magnetic field by amplifying the number of loops, as shown in figure 10. Now instead of a loop, we have a coil. The magnetic field lines from all the loops add up, intensifying the magnetic field.





Putting it all together, the electrical current coming from the mp3 player oscillates at the same frequency as the sound wave we want to produce. The varying current generates a varying magnetic field. By placing a permanent magnet in the field, the permanent magnet will move back and forth at the desired frequency. Or, we can fix the permanent magnet, and let the coil move. This is how we will do it in our speaker. We will glue the magnet to a piece of cardboard, and glue the coil to the speaker diaphragm. When the signal from the mp3 player flows through the speaker's coil, the coil will move up and down, thus deflecting the diaphragm, pushing the air back and forth, and creating sound.

Personal music devices are design to operate very tiny speaker- the ear phones. So, if you connect your mp3 player directly to the speaker, you will hear something, but it won't be very loud. An amplifier will help.

In the next section, we describe how to build the speaker. In an appendix, we describe a simple amplifier circuit, which could be built by students using a breadboard if they are familiar with that, or could be built ahead of time.

## CONSTRUCTION OF THE SPEAKER

### **Materials:**

For each speaker you will need:

#	Unit	Description	Vendor	PN	Unit Cost
1	Sheet	Paper (or print out template)			
1	Piece	Cardboard, 6" square			
2	Each	1/4 in x 1/10 in Thick Disc, Grade N42, Rare Earth Neodymium Magnets	Applied Magnets	ND011-1	\$0.10
3	Meters	30 AWG magnet wire, enameled	Small parts	*	
1	Each	Mp3 player, computer, radio- anything that plays sound through a standard audio jack			
1	¾ " length	"Jumbo" drinking straw			
1	2" length	¼ " diameter dowel or something of similar diameter			
0.5**	Each	Audio cable	Mycablemart.com	<a href="#">FS-3MM-03MM</a>	\$1.17 (divided by 2)

\* example: MW-30-01, 1 lb spool (≈1000 meters), \$20

\*\* Each cable as purchased can be cut in half, creating two usable cables

Collectively you will need:

Scissors

Tape ("Scotch")

Hot glue gun and glue

Lighter, candle, matches OR fine sandpaper (to remove insulation)

Wire strippers

(Optional amplifies instructions in Appendix 1)

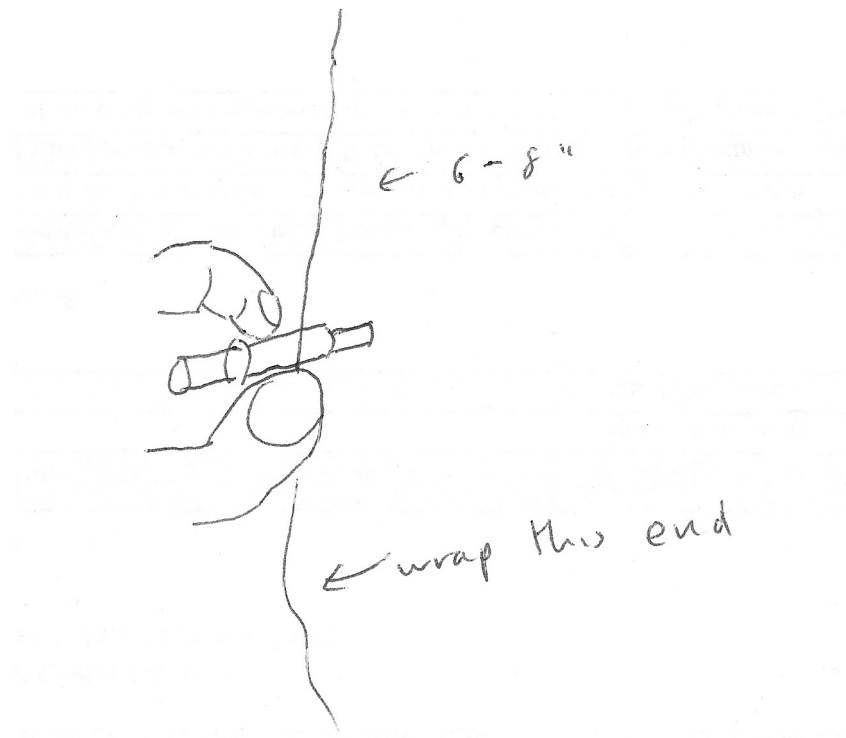
### **Components to build:**

For each speaker we must create (in any order):

- *Voice coil*
- *Diaphragm*
- *Base*
- 

#### *Voice Coil:*

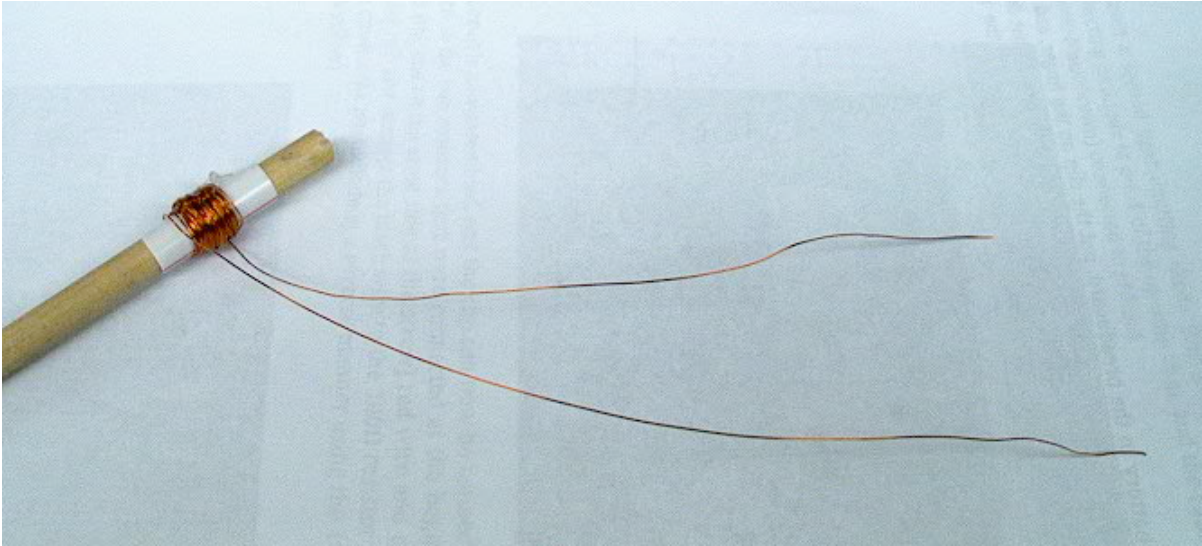
- Slip the dowel into the straw. The dowel is to prevent you from crushing the straw while you wrap the coil
- Next, take one end of the magnet wire and point it toward the ceiling.
- Pinch the wire between your thumb and the straw about 8" below the end of the wire (the point here is to leave an 8" lead at the beginning of the coil)



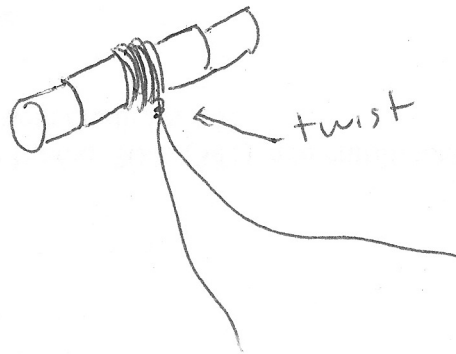
- Wrap the LONG (bottom) end of the wire onto the straw. Coil the remaining wire around the straw



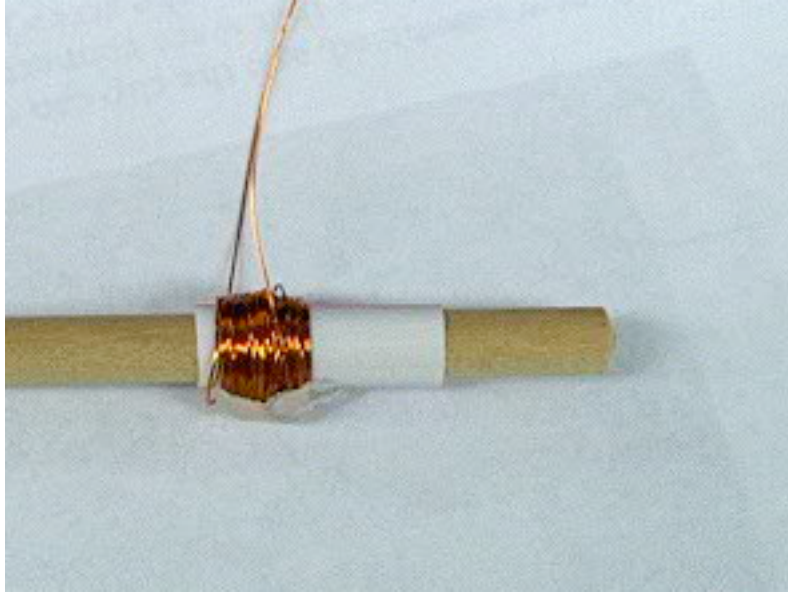
until there is only 8" remaining. OVERLAP the wire AS MUCH AS POSSIBLE.



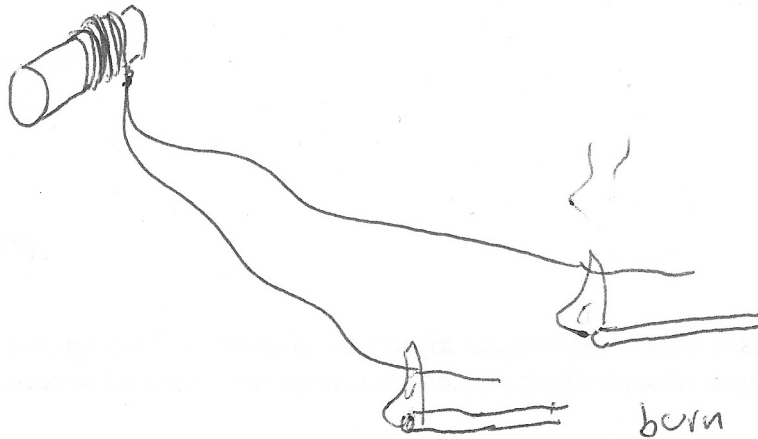
- Twist the two leads together near the straw a couple of twists, to keep it from unwinding



- Carefully slide the coil toward one of the straw. Don't let it come off the straw!



- Remove the dowel. It is not part of the speaker.
- Remove insulation from wire ends
  - Using a match or lighter, burn off and half inch of the insulation from the ends of the two wires.
  - OR use sandpaper to remove the insulation.



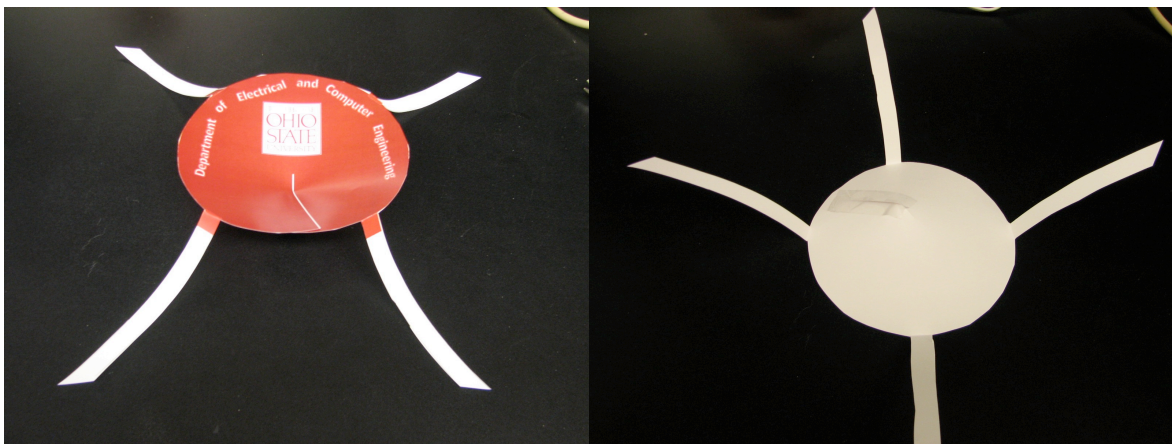
*Diaphragm:*

We need a diaphragm to create the sound waves. It must be cone shaped and, for our purposes, have “legs” that we can use to attach it to the base, and suspend the coil over the magnets.

- Draw “legs” on the paper template provided. That is, extend each square tab to the end of the paper.

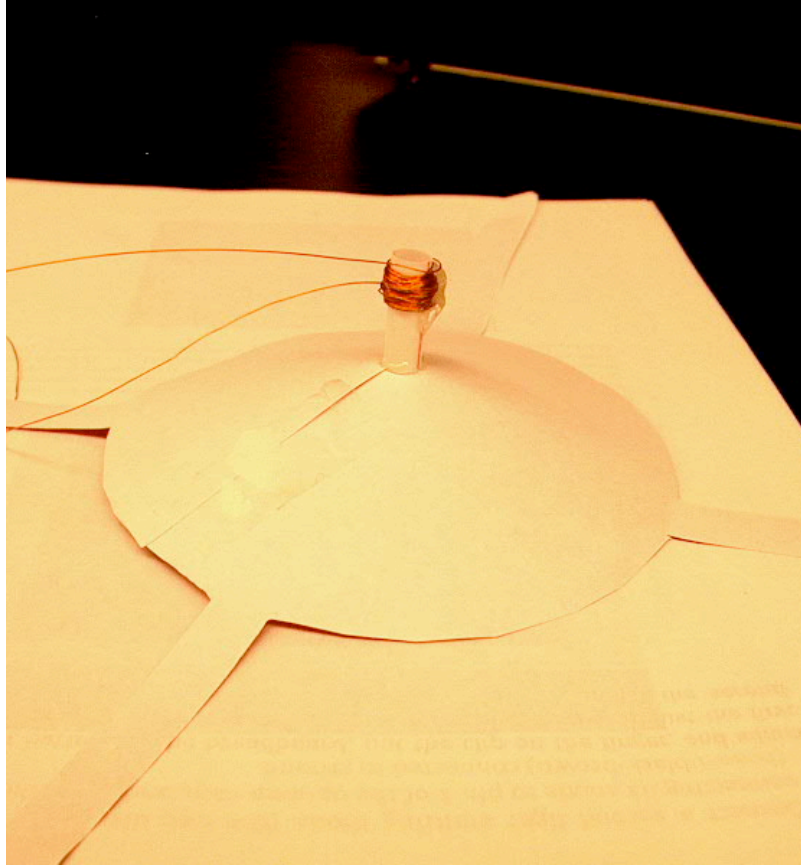


- Cut out the paper template WITH these legs.
- Cut the marked line (radius) in the template.
- SLIGHTLY overlap the circle to create a shallow cone and tape it in place



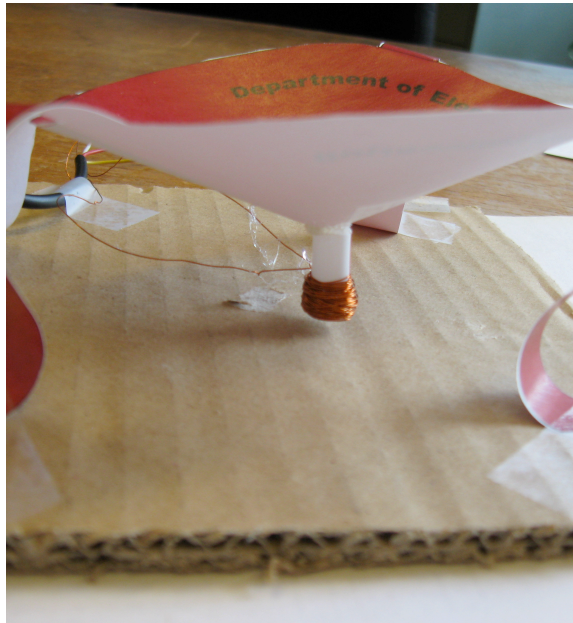


- Using a hot glue gun, glue the straw to the tip of the cone, making sure the coil is AWAY from the diaphragm.

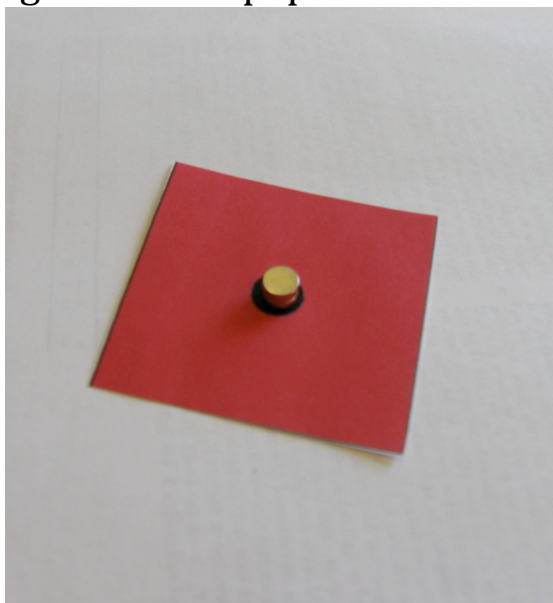


**For the Base:**

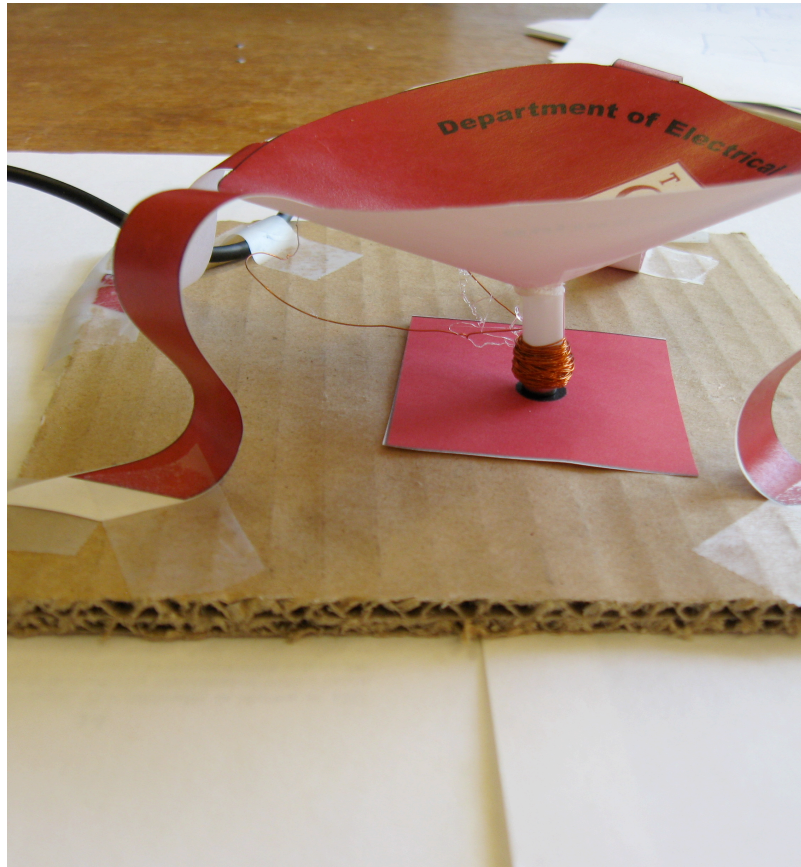
- Turn the diaphragm over and tape the legs to the cardboard square. You want the coil to be **ALMOST** touching the cardboard but not quite. The coil doesn't have to be in the middle of the cardboard, but it's important that it be just barely or not quite touching the cardboard.



- Cut a square of paper about 2" on a side
- Glue the magnets to the paper

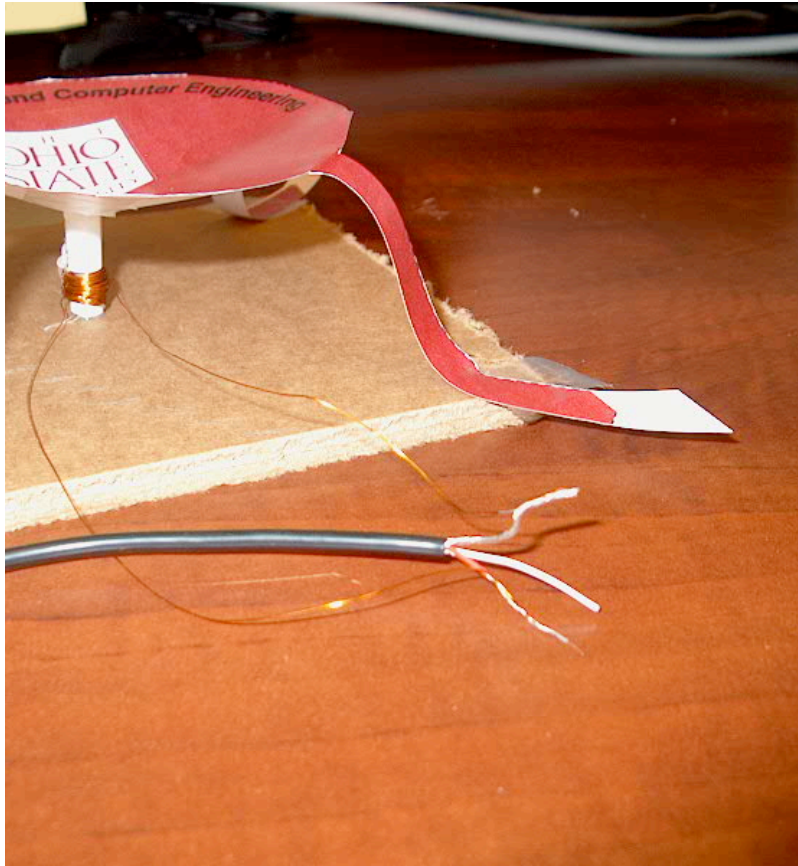


- Slide the paper with the magnet under the coil



### **Cable**

- Cut the audio cable in half
- Carefully strip the outer insulation (black) from the last 2 or 3 inches of the cable, being careful not to cut the wires inside
- There will be two or three wires inside
- Strip the insulation off the last inch or so of two of the three wires.
- Tightly twist the metal end of one of the cable wires to the burned end of one of the speaker wires. Repeat with the other cable wire and other speaker wire.



Plug it in and try it out!

**Debugging tips:**

It will not be very loud. We are using very cheap components here. Put your ear right up next to it.

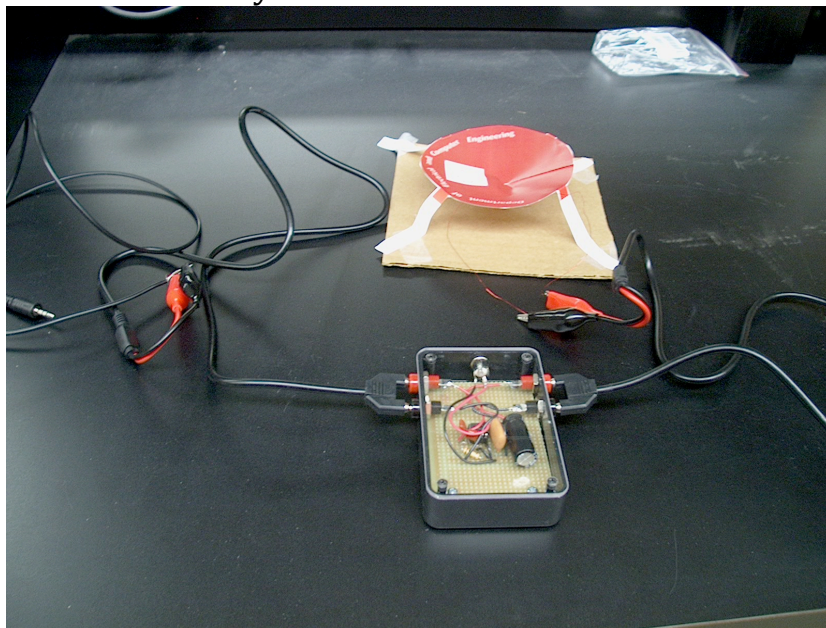
If you still don't hear anything, try the following:

- Make sure the magnets are inside the coil
- Make sure the coil is around the magnets and not above them
- Make sure the diaphragm can move up and down easily (very easily). If it doesn't, try adjusting the legs.
- Make sure the wires are twisted very tightly.



## Appendix 1: The Amplifier

- For louder sound, use the amplifier:
  - If you have a black box amplifier
    - connect the converter cables into the input and output ports on the box
    - Use Alligator clips to connect the speaker leads to the two wires from the amplifier output
    - Use alligator clips to connect the input wires to the MP3 player wires – connect the black wire on one to the uninsulated wire on the other. Connect the red wire on the input to either the red or white wire on the MP3 output cable.
    - Plug the power adaptor into the black box.
    - Play!



- If you have the homemade amplifier (directions follow)
  - Use alligator clips to connect the speaker leads to the wires coming out across the capacitor as shown below  
PICTURE
  - Use alligator clips to connect the MP3 output wires to the wires across the resistor. Be

sure to connect the uninsulated wire from the Mp3 Player to the ground wire coming out of the bus as shown below.

PICTURE

- Plug in the power and play!



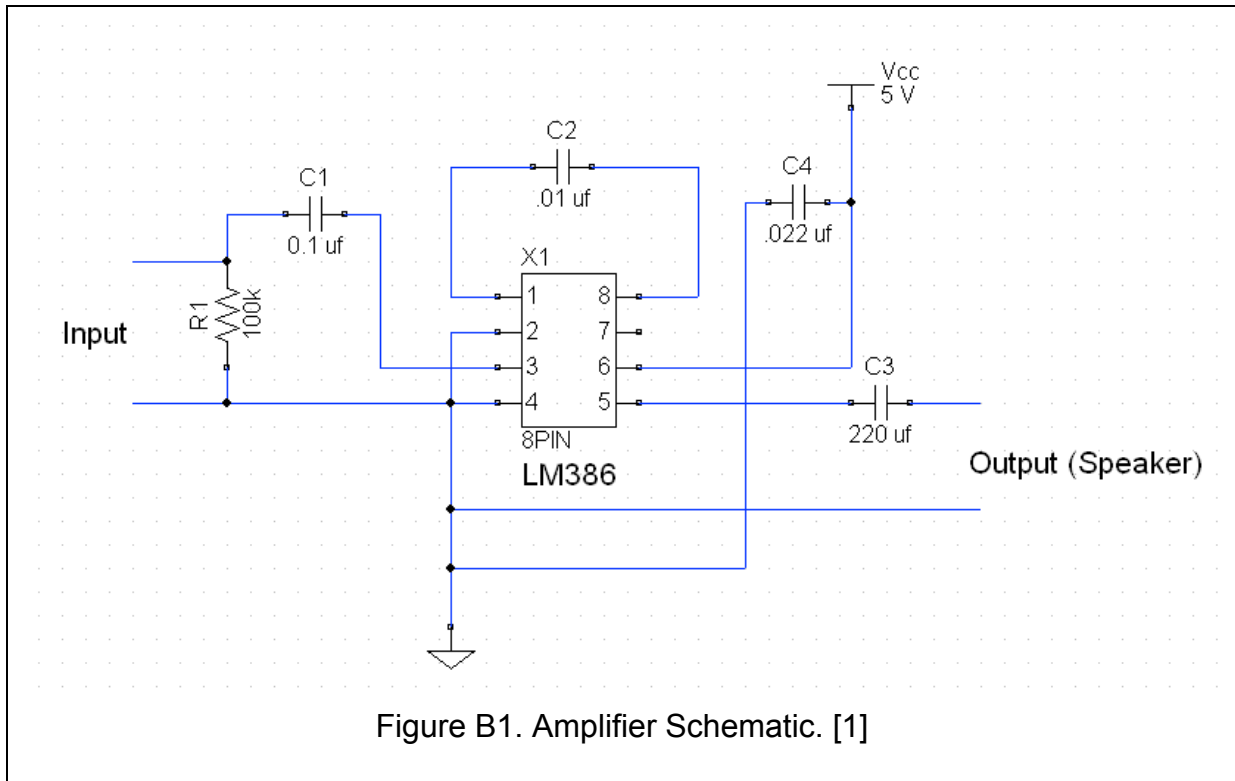
## Appendix A. Template for speaker

## Appendix B. Amplifier

The speaker will work without an amplifier but it will be louder with one. This appendix gives a simple amplifier circuit, parts list, and instructions for building one on breadboard.

This circuit uses a low-voltage audio power amplifier, National Semiconductor LM386N-1.

Figure B1 shows the circuit schematic:



The power source is a 5V wall-transformer. The parts list is given in Table B1. Prices circa Feb 2009.

Quant	Unit	Description	Vendor	P/N	Cost
1	Ea	5 V wall transformer	Jameco	RDU050050C5031	\$10
1	Ea	breadboard	Digikey	438-1045-ND	\$8.73
1	Ea	100KΩ resistor	Digikey	OD104JE-ND	\$0.42
1	Ea	Capacitor, Ceramic	Digikey	399-4331-ND	\$0.16
1	Ea	Capacitor, Ceramic	Digikey	490-3812-ND	\$0.17
1	Ea	Capacitor, Electrolytic	Digikey	P51530ND	\$0.31

1	Ea	Capacitor, Ceramic	Digikey	399-4169-ND	\$0.22
1	Ea	Audio Amp Chip	Digikey	LM386N-1 ND	\$1.09
1	Ea	Power jack	Digikey	SC11510ND	\$4.56
4	Each	Alligator-alligator clip leads	Digikey	GC396-ND (pkg of 10)	
		Jumper wire	Radio Shack	276-173*	\$6.49

This is a kit with assorted jumper wires. If you will be doing a lot of breadboard work, it's cheaper to buy spools of jumper wire, e.g. Digikey C2004B-100-ND, 100 foot spool, \$16.24.

Tools: Wire strippers, wire cutters, soldering iron

1. First we introduce the breadboard:
  - a. The breadboard, Figure B2, consists of 4 long columns of holes (two along each long edge) and many pairs of rows. The hole in each column are connected together, such that a wire inserted in any hole in a column will be electrically connected to any wire connected to any hole *in the same column*. Each column is called a "bus." Each row of five holes is also connected (blue line in the figure). The rows are *not* connected across the trough down the middle of the board.

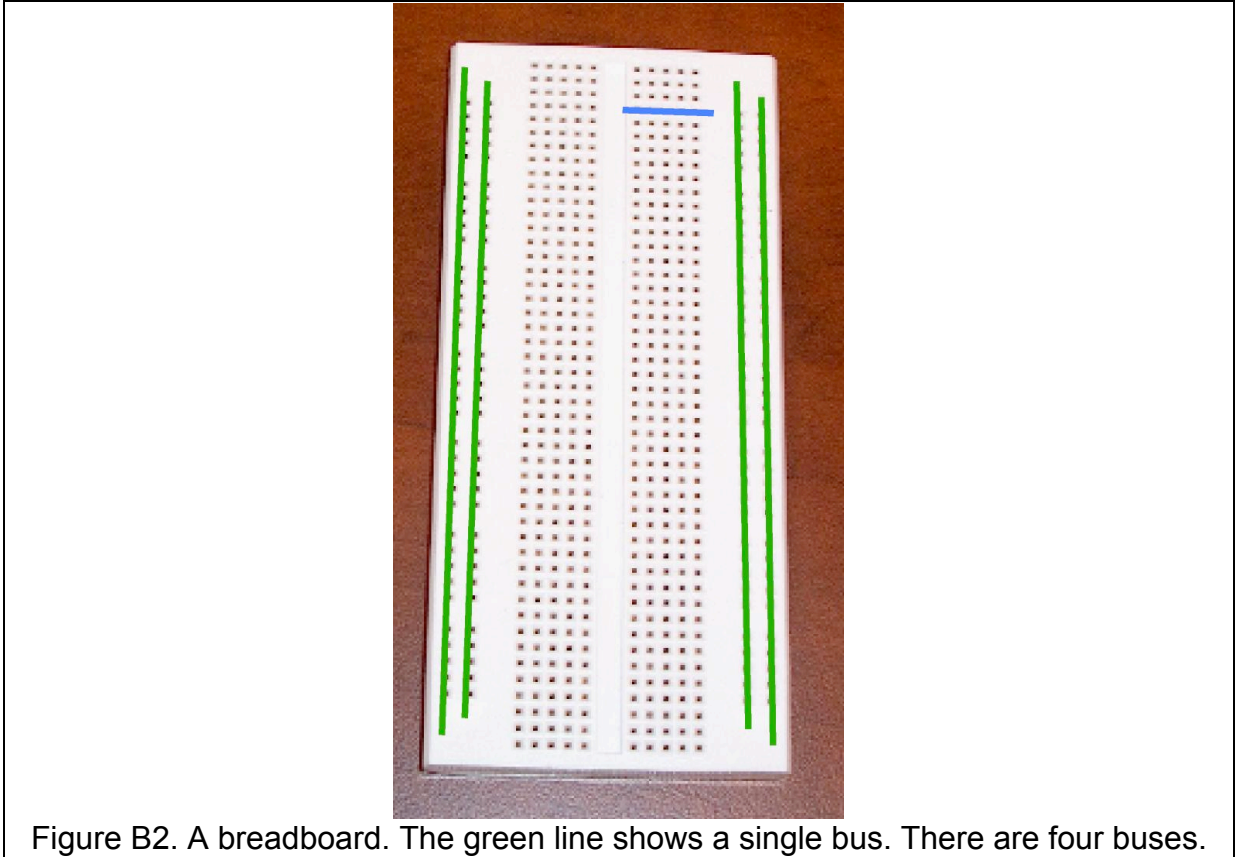


Figure B2. A breadboard. The green line shows a single bus. There are four buses.

2. Prepare the power jack by soldering two wires to it. Solder a black wire to the center lug, and a red wire to the lug on the right when viewing the jack from above (upper right hand corner of Figure B3).
3. Insert the amplifier integrated circuit (IC) into the breadboard such that it straddles the center trough, and each pin is in a separate row.
  - a. The small circle embossed on the chip in the upper right-hand corner indicates the location of pin 1. Figure B4 shows the pin numbering system.
  - b. Using short pieces of hook-up wire, connect pins 2 and 4 to one of the buses. We will call this the ground bus.

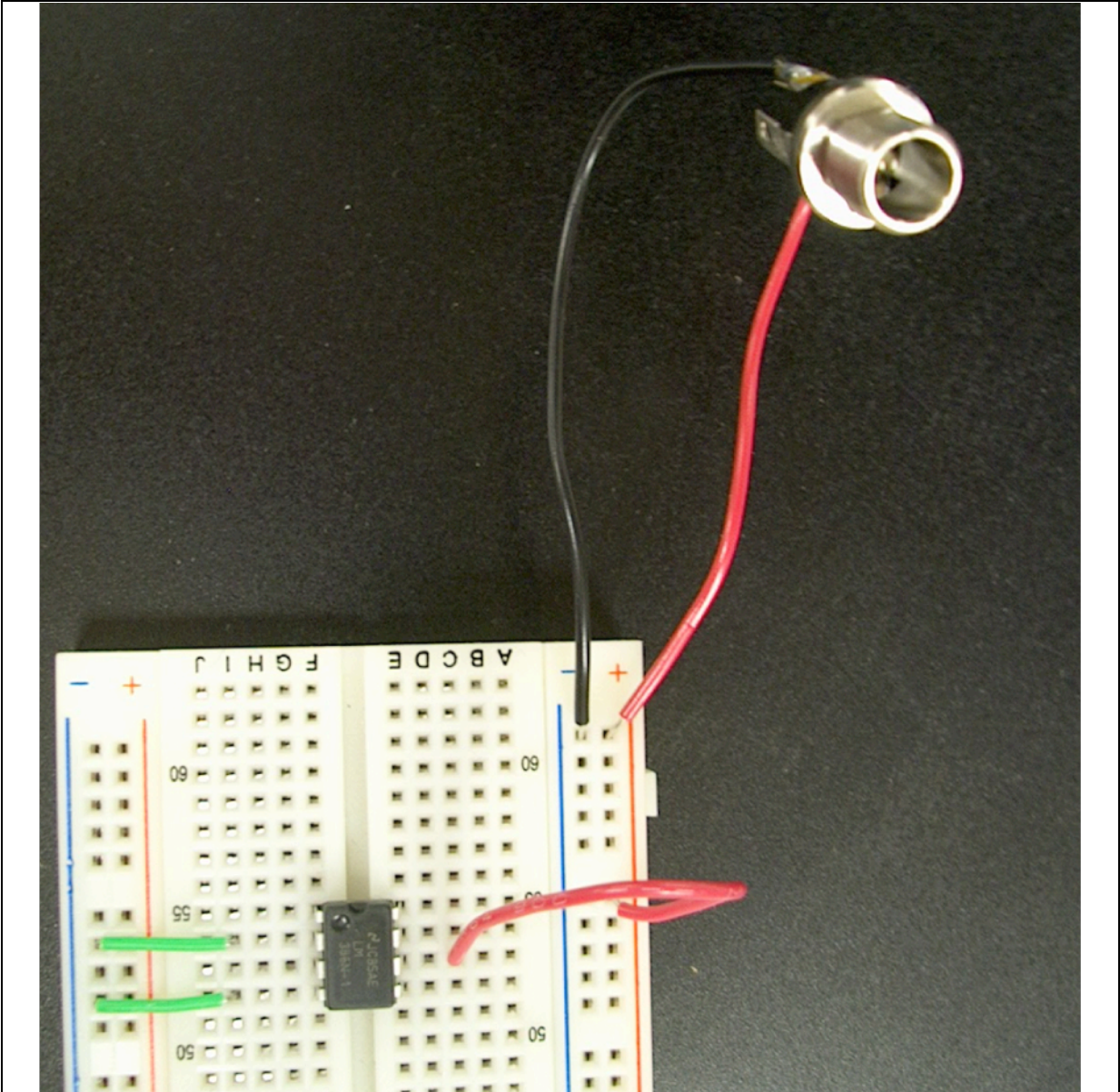


Figure B3. Step two of amplifier assembly

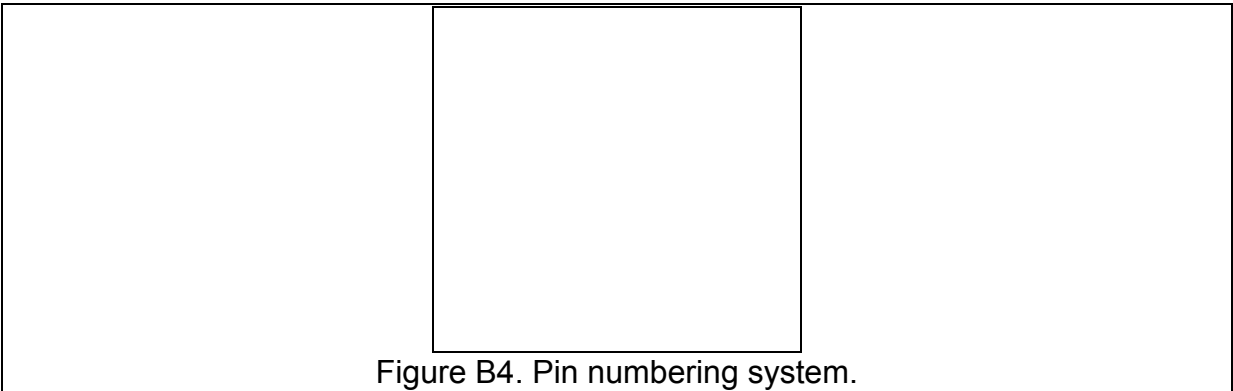


Figure B4. Pin numbering system.



- c. Connect the wires from the power jack to the two buses on the right. We will later connect the ground bus we started before to the bus with the black wire, making that bus ground also. The other bus, connected to the red wire, will be the positive bus.
- d. Connect a wire from Pin 6 to the positive bus.

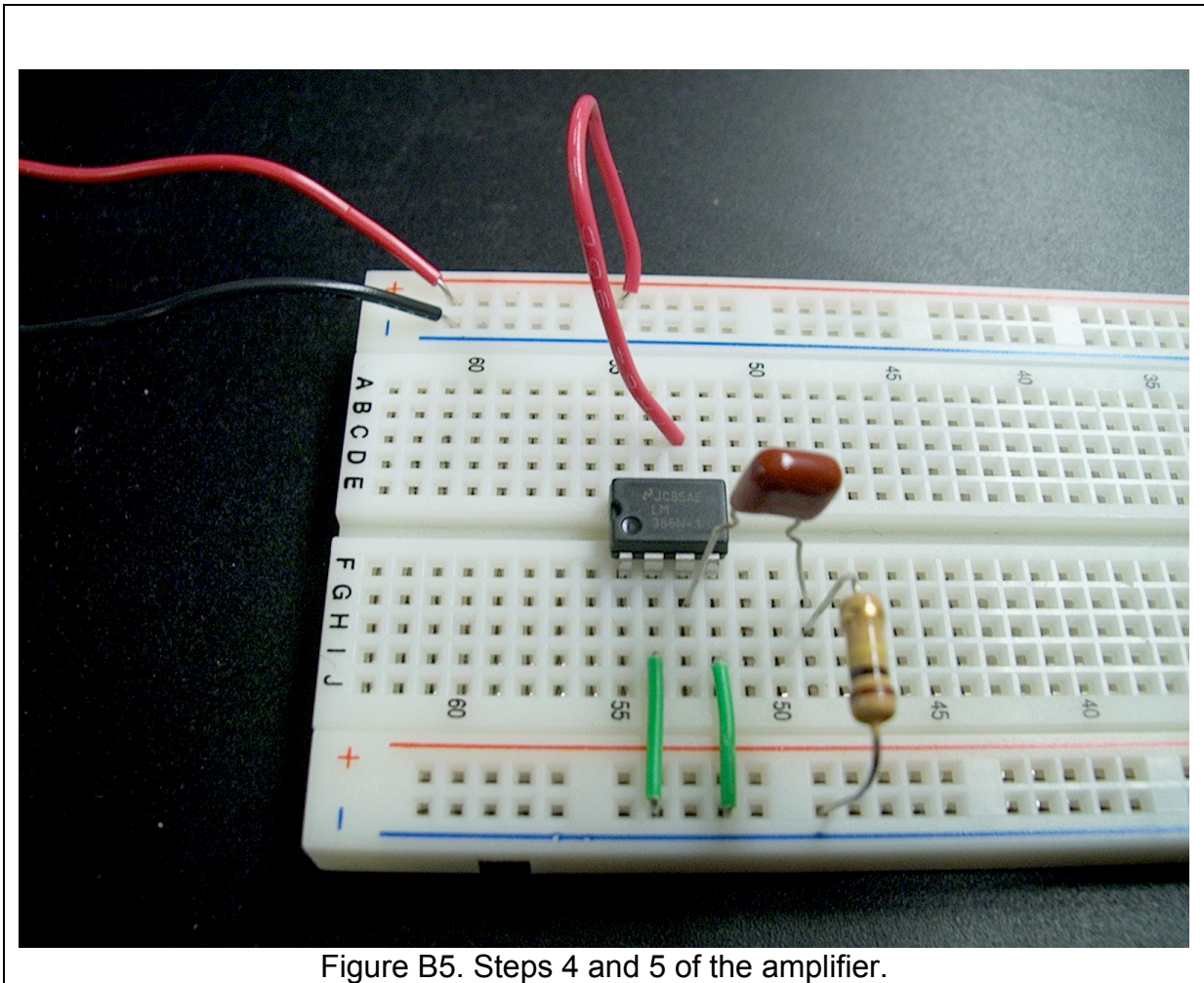


Figure B5. Steps 4 and 5 of the amplifier.

4. Connect the 0.1  $\mu\text{F}$  capacitor from pin 3 to a row that you are not using, Figure B5. This row should have no other components in it (yet) and should NOT be a bus.
5. Connect the 100  $\text{k}\Omega$  resistor from the row with only the capacitor in it to the ground bus.



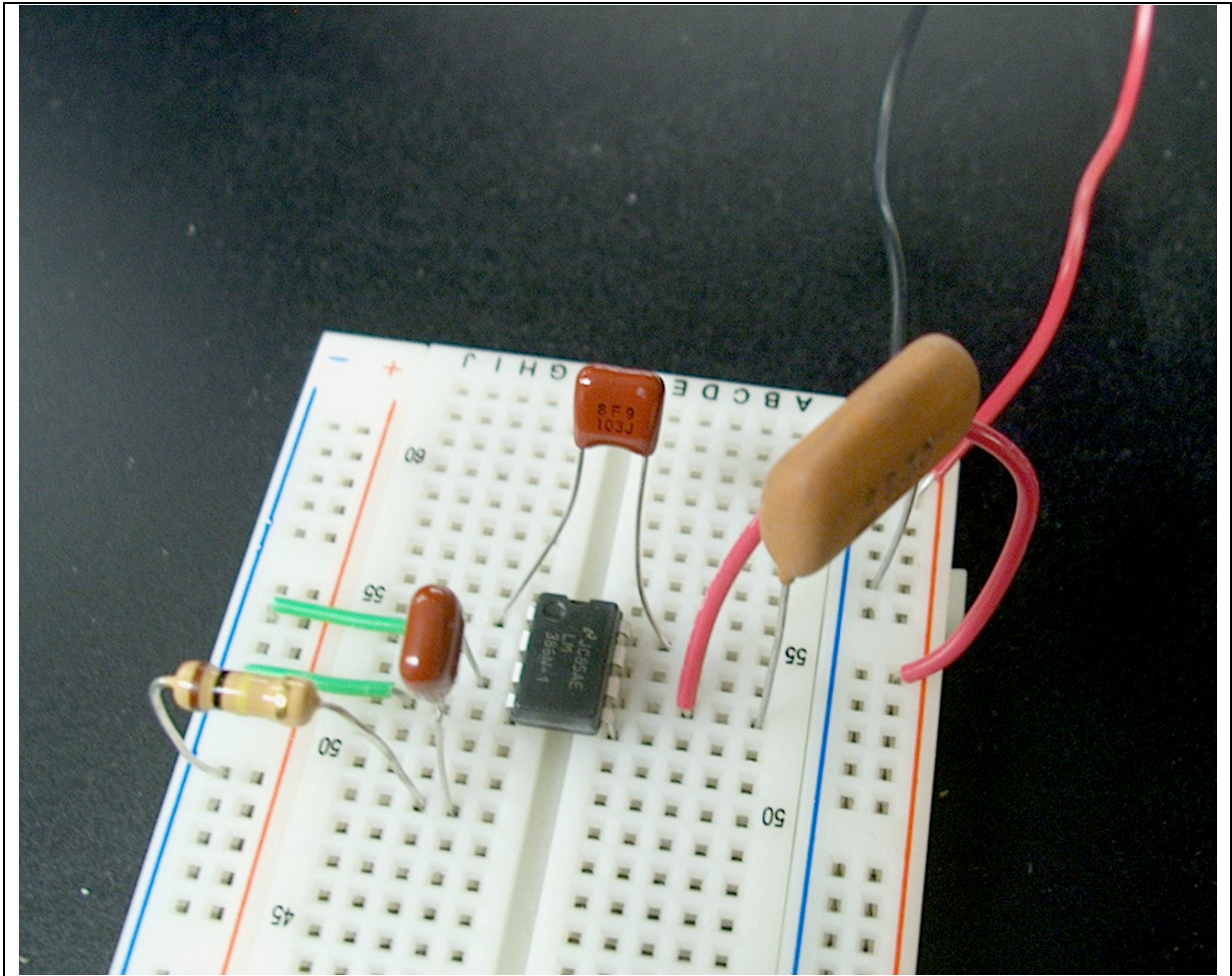


Figure B6.Steps 6 and 7 of the amplifier.

6. Connect the 0.01  $\mu\text{F}$  capacitor from Pin 1 to Pin 8 of the IC.
7. Connect the 0.022  $\mu\text{F}$  capacitor from Pin 6 to the right-hand ground bus. That is the bus with the black wire.

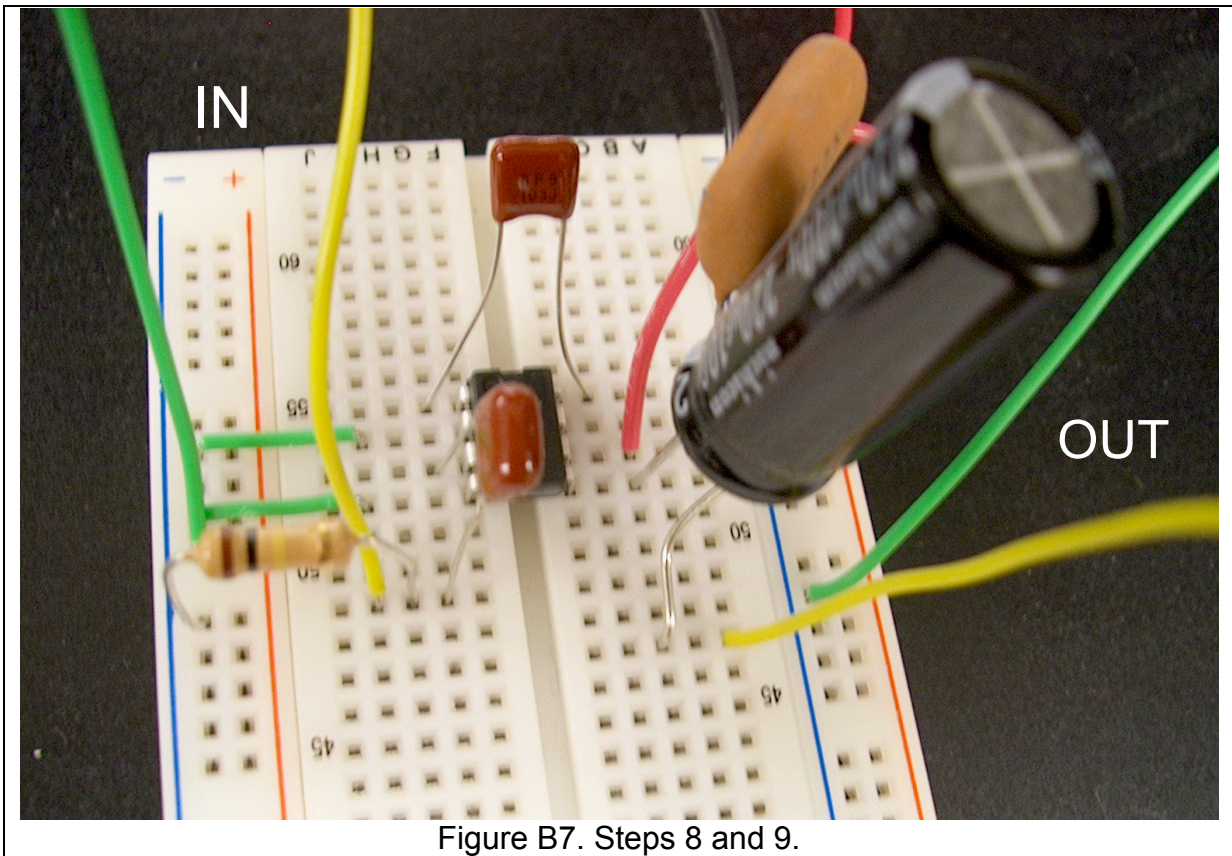


Figure B7. Steps 8 and 9.

8. Connect the 220  $\mu\text{F}$  capacitor from Pin 5 to some row that you are not using (yet).
9. Create the output leads by sticking one end of a wire into the row where the capacitor of Step 8 ended (yellow in the picture). Stick another piece of wire in the ground bus. These are the output leads that you will connect to the speaker using alligator leads. (One alligator lead connects the yellow wire to one wire of the speaker, and another alligator lead connects the green wire to the other wire of the speaker.)
10. Create the input leads by sticking one piece of wire into the *same row* that is shared by the resistor and the 0.1  $\mu\text{F}$  capacitor. There are now three connections in this row. Connect another wire to the left-hand ground bus. These two leads will connect to the output of your mp3 player.



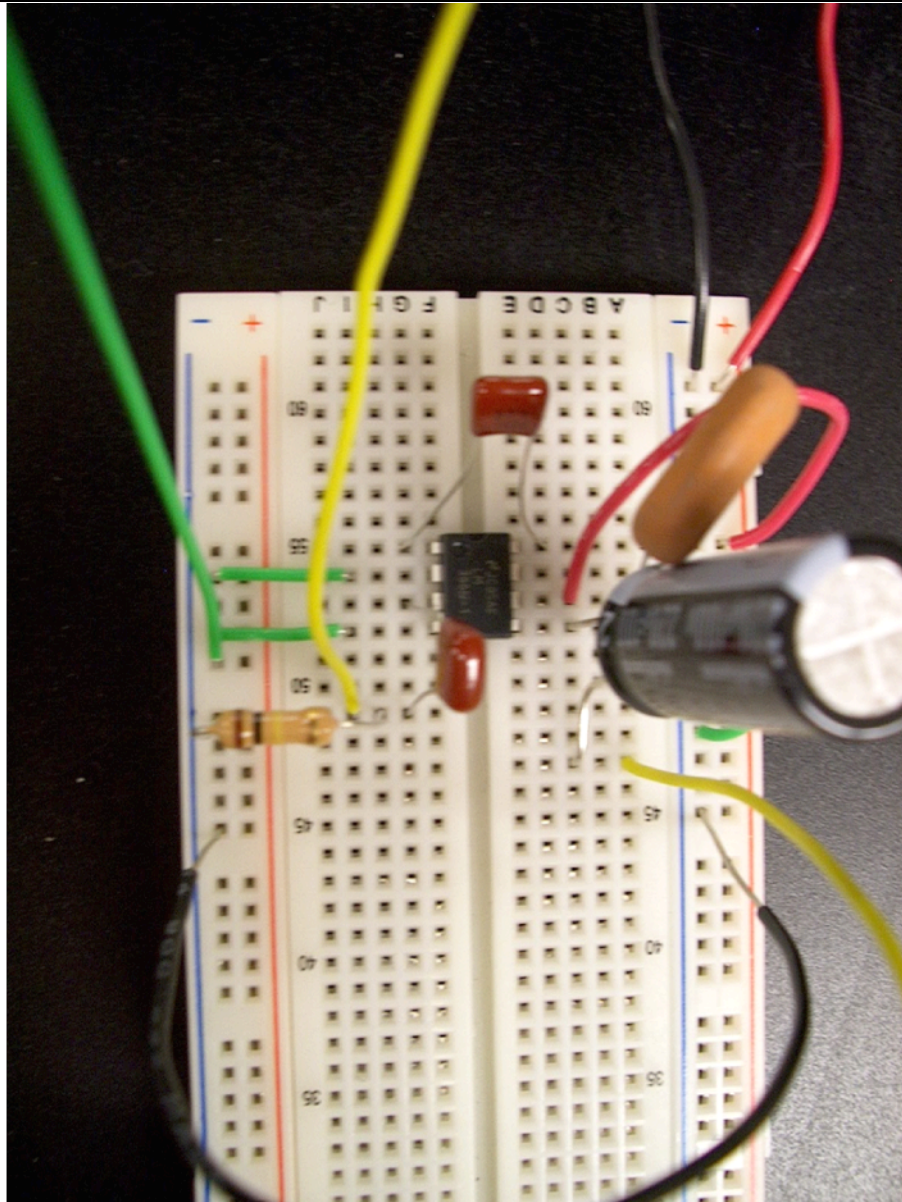


Figure B8. Step 11 of amplifier assembly.

11. Finally, connect the two ground buses together with a wire (black Figure B8.. Double check that you have not connected either ground bus to the positive (red) bus. The ground bus on the right is the one with the *black* wire.

### **References**

- [1] A. Sinha, A. Luzader, and M. Lee, "STEM Outreach-- building a speaker," The Ohio State University, Columbus, Senior Design Project Final Report 2008.