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A Simple Loudspeaker Which Students Can Build and Take Home

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Abstract
We have developed an inexpensive electrodynamic speaker which students can build and take home. The design uses a plastic drinking cup as a base, the tight-fitting lid as the cone, and a drinking straw as a support for the voice coil. The permanent magnet fits inside the cup. Steel washers and a bolt are used to produce a field configuration similar to a commercial speaker. The speaker produces a loud and clear sound when connected to a home audio system. It has been used with students at the middle, high-school, and college level.

Introduction

This simple speaker was developed initially as a laboratory project for use in a science course for non-science majors (Krupczak, 1996). The construction of a loudspeaker is used to demonstrate an application of electromagnetism in a familiar technological device. Our goal was to create a working speaker that each student could build in the laboratory and then take home. We have since found that students in middle and high-school ages can also enjoy this project.

Several simple speakers for use as lecture demonstrations have been developed. Keeney and Hershey (Keeney, 1997) built a working electrodynamic loudspeaker demonstration using a paper cone and surround supported by a ring stand. Heller (Heller, 1997) created a lecture demonstration of a loudspeaker by attaching a coil to the bottom of a waxed paper drinking cup. When a cylindrical rare-earth magnet is brought up along the coil axis the device acts as an electrodynamic loudspeaker. A primitive speaker lecture demonstration similar to Heller's, developed by Richard Noll at Ohio State is described in an overview of simple experiments in electricity and magnetism by Van Heuvelen, Allen, and Mihas (Van Heuvelen, 1999). Senior (Senior, 2000) describes the use of a plastic cup as the vibrating diaphragm for a musical toy used as a lecture demonstration of sound vibration.

Our project is unique in being an electrodynamic loudspeaker constructed from simple materials, which all types of students can build in less than one hour and then keep and take home. The cost of materials is low, so that each student in a laboratory can keep the completed project. The final product is compatible with typical home audio equipment and produces a clear and audible sound. The design is simple enough that the explanation of the underlying physical principles at work is readily apparent. Lastly, the final product is durable enough to withstand some degree of careless handling and still remain operational.

Project Description

The speaker developed is based on a plastic drinking cup and straw, along with the associated tight-fitting lid. Ceramic disk magnets sit at the bottom of the cup. Steel washers and a hex bolt are used to help produce a field configuration similar that in the magnet of a commercial speaker. The coil is wound around the end of a plastic straw. The straw fits over the hex bolt. A photograph of a completed speaker is shown in Figure 1. Figure 2 is a schematic drawing of the speaker components.

The basic operating principles are those found in any electrodynamic loudspeaker. When an audio signal is sent to the coil, a time-dependent magnetic field is produced in the coil resulting in a time-dependent force on the coil from the permanent magnet. The movement is transferred by the straw to the cup lid which acts the vibrating diaphragm or cone of the speaker.

The cup used for the speaker shown in Figure 1 is a 473 ml (16 fluid ounce) clear plastic cup and matching lid[1]. The clear cup was chosen to allow the internal components to be visible after the speaker is constructed. Good results were also obtained using the common 946 ml (32 fluid ounce) polystyrene cups[2]. Typically these larger cups are opaque. A hole approximately 25 mm (1 inch) square is cut in the side of the cup. This allows access to the coil leads and also serves as the port employed in bass-reflex speaker enclosures.

While most cups and lids were found to produce a reasonable speaker, the straws used require some care in obtaining. The straws must have a large inner diameter to fit over the cap screw without rubbing. An appropriate size is the industry standard “giant” size straw[3] which has an outer diameter of 7.47 mm (0.294 inches).

The coil is made from 5.5 m (18 feet) of 0.13 mm diameter (36 AWG) magnet wire[4]. The small gauge wire is used to keep the total mass of the coil as low as possible. The coil is wrapped around the lower 20 mm (0.75 inches) of the straw. A detailed view of the coil is shown in Figure 3. The coil need not be wrapped in parallel rows, overlapping turns are acceptable so long as the maximum diameter of the coil does not exceed the inner diameter of the upper steel washer. Following the procedure specified, the resulting coil will have an impedance of 8 ohms at 1 kHz. This insures compatibility with consumer audio equipment. Some students have difficulty working with this fine wire. Acceptable results can be obtained by using the same length of 0.16 mm diameter (34 AWG) magnet wire, leading to a coil impedance of 5 ohms.

The permanent magnet for the speaker is based on two ceramic ring magnets[5] with an outer diameter of 60 mm (2.375 inches), an inner diameter of 29.4 mm (1.157 inches) and 7 mm (0.287 inches) thickness. Two magnets are used to increase the net field strength. A number of other types of magnets configurations will also result in a functioning speaker. We have used a 6 mm diameter rare-earth magnets inserted inside the straw, as well as rectangular ceramic magnets with success. The configuration shown here resulted in the loudest sounding speaker using low-cost and readily available magnets.

Commercial speakers which use ceramic magnets utilize ferromagnetic pieces to create a radial magnetic field in the region of the coil. A similar strategy was employed using a combination of standard hardware to create a magnet configuration like that in a commercial speaker. A US standard ¼ x 2 inch steel fender washer is located at the bottom of the assembly. A US standard 10 - 32 x 1.00 inch cap screw is pushed through the washer and secured with a nut. This bolt becomes one pole of the magnet. On the top a US standard ½ x 2 inch fender washer is used. This upper washer has a sufficiently large inner diameter to accommodate the coil wrapped around the straw. The surface along the inner diameter of the upper washer becomes the other pole of the magnet. A significant fraction of the magnetic field is radial in the region where the coil is located. During assembly, the washers are secured in place on the magnets using electrical tape.

The cup assembly is glued to a 150 mm (6 inches) square base made of foamboard. Cardboard can also be used. Hot glue has been found to be a convenient method of securing the cup to the base. However, double-sided carpet tape is a satisfactory alternative. The coil leads are soldered to a compression terminal block[6] which provides a means of connection to a signal source. Soldering is not essential, but it does result in a more secure result. The wire leads can just be wrapped several times around the terminal block leads.

When materials are purchased in bulk from the specified sources[7], the cost for all of the materials is under five dollars per speaker. This low cost makes it possible for each student to take the completed speaker home. If this is not possible, then the speakers are readily disassembled and the major components reused.

A straight-forward fabrication procedure has been developed. The essential tools needed are: scissors, utility knife, hot glue gun, soldering iron, and screwdriver. It is possible to avoid using the knife, hot glue gun, and soldering iron if desired. Besides the speaker components, necessary supplies include cellophane tape and electrical tape.

A recommended assembly procedure is as follows. First the coil is wound around the straw. The cup is prepared by cutting the hole in the side. The ceramic magnet assembly is taped together and installed inside the cup. The free end of the straw is installed in the lid. It was found that it is not necessary to glue the straw in place. As the lid with the straw and coil is installed on the cup, the coil leads are put through the hole in the cup. The coil leads are soldered to the terminal block which is then secured to the base. The straw fits over the cap screw in the magnet assembly. The cup is glued to the base. It is recommended that the coil wires be secured to the base using cellophane tape. However, some slack should remain in these wires to allow unimpeded movement of the coil. The speaker is connected to an audio signal. The straw is then adjusted up or down to obtain that position of the coil resulting in maximum loudness from the speaker. Once the optimum coil position has been found, the excess straw above the top of the lid can be trimmed off. Alternatively, the excess straw can be left in place which seems to add to the aesthetic appeal and novelty of the device. Students can complete the assembly in 30 to 50 minutes.

Results

The drinking-cup speaker is capable of producing a sound level of 80 dB when connected to an inexpensive home audio amplifier. This is significantly louder than the sound level of normal conversation which is approximately 60 dB. The speaker can even produce faint but audible sound when connected to the low-power headphone output of small personal audio devices such as compact disc players. The quality of the sound is good. Resonances in the cup and lid can lead to buzzing when reproducing signals with significant low-frequency components. Use of cellophane tape helps secure the lid and improves sound quality.

A pre and post test was conducted with 70 students in 9th through 12th grade. The students were give a pre-test in which there was no prior discussion about the loudspeaker or any related topics. The questionnaire consistent of the question: "In your own words, explain how a loudspeaker works." After building and testing their loudspeaker, students were given a post-test with the same question. Pre and post test responses were evaluated using the rubric shown in Table 1.

Table 1: Scoring Rubric for Loudspeaker Pre- and Post Test Questionnaires.

Score	Response Description
0	No attempt
1	Answer includes an accurate description of what a loudspeaker does (reproduces sound) rather than how it works
2	Answer includes at least one accurate, but incomplete idea of how the sound waves are produced by the loudspeaker
3	Answer includes accurate explanation of how 2 or more of the following are used in a loudspeaker: magnet, electromagnet, coil, vibration, sound waves, energy, current.
4	Answer includes accurate explanation of how 3 or more of the following are used in a loudspeaker: magnet, electromagnet, coil, vibration, sound waves, energy, current.
5	Accurate complete explanation: the current running through the coil produces an electromagnet which interacts with the permanent magnet in the speaker vibrating it at the same frequency that the sound was produced.

The students' post test scores yielded an average of 2.6 out of a maximum of 5 points. Post test scores improved by an average of 26% from the pre-test. Thus the average increase in understanding was about one full point on the rubric. On the pre-test only 13% of the 70 students evaluated mentioned anything about electricity and magnetism having anything to do with how a speaker works. This increased to 89% on the post-test. These results help to establish that this is not just a fun activity for the students but they are also learning something.

Conclusion

A working electrodynamic speaker has been developed which students can build and then take home. The speaker is inexpensive, easy to build, robust in design, compatible with home audio systems, and readily understood using the principles of electricity and magnetism. The project is a novel demonstration of electromagnetism.

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Senior, Tom, "Head Noises," *Phys. Teach.*, **38**, 30 (2000).

Van Heuvelen, Allen, Leith Allen, and Pavlos Mihas, "Experiment Problems for Electricity and Magnetism, *Phys. Teach.*, **37**, 482 (1999).

Footnotes:

1.) Clear Plastic Big Drink Cup, Stock No. TP16, and Plastic Snap On Lid, Stock No. 626, Solo Cup Company, Urbana, Illinois, USA 61801-2895.

2.) Straw, Stock No. 724R, Sweetheart Cup Company, 10100 Reisterstown Rd., Owings Mills, MD, 21117 USA. www.sweetheart.com.

3.) Go Cups, Stock No. GC32, Sweetheart Cup Company, 10100 Reisterstown Rd., Owings Mills, MD, 21117 USA. www.sweetheart.com.

4.) Single Beldsol® Solderable Magnet Wire, Part No. 8058, Belden Inc., 2200 U.S. 27 South, Richmond, IN 47374 USA. www.belden.com.

5.) Ring Magnet, Ceramic Grade 5, Part No. 30A0010, Adams Magnetics Inc., 2801 N. 15th Ave., Melrose Park, IL 60160 USA. www.adams-magnetic.com.

6.) Terminal block, Part No. 15CT200, Mouser Electronics, 958 N. Main St., Mansfield, TX 76063-4827 USA. www.mouser.com.

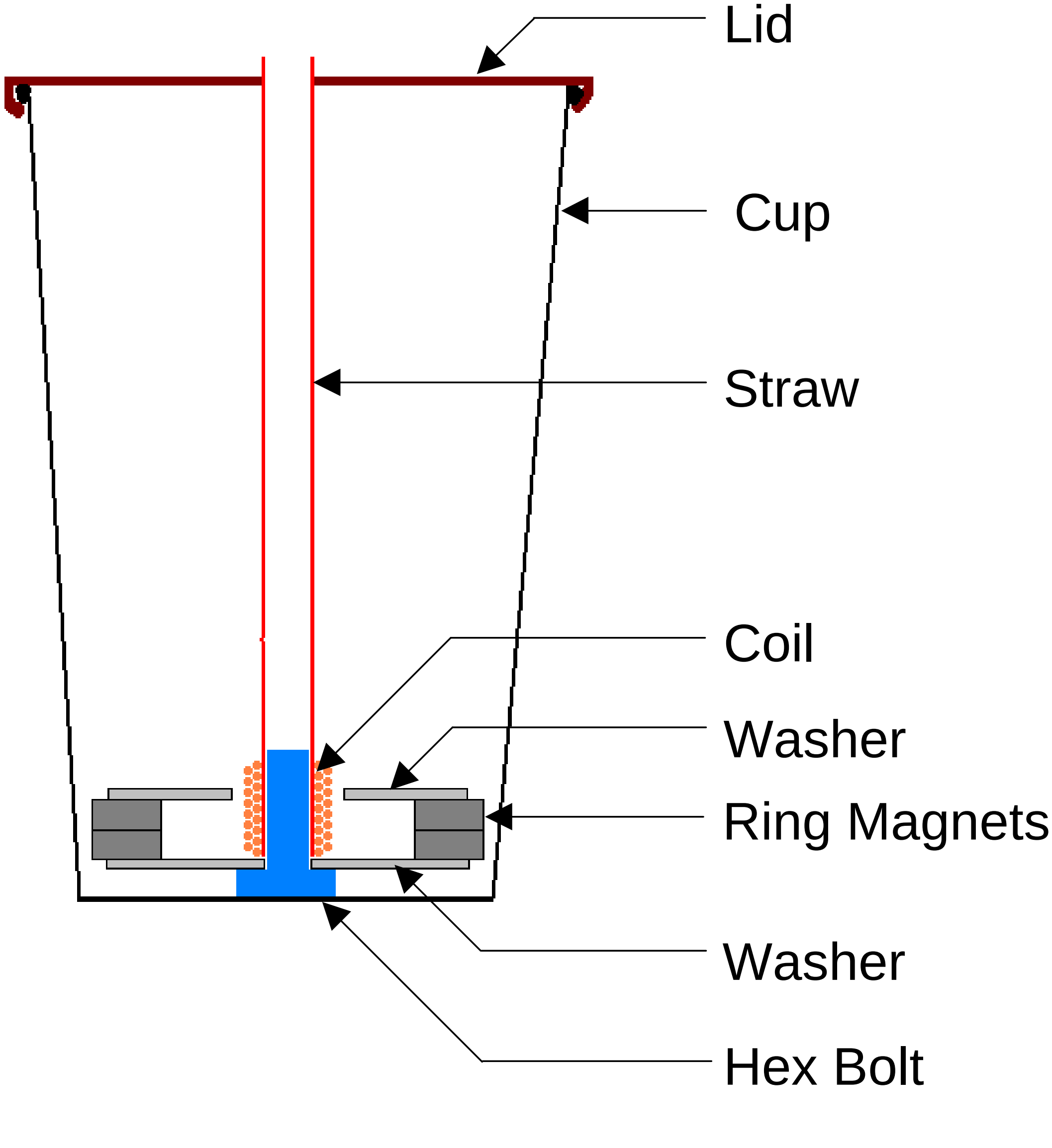
7.) The author may be able to help provide materials at cost in exchange for feedback on results from using the project. Instructions suitable for classroom use can also be obtained from the author.

Figure Captions

Figure 1: Photograph of a Drinking-Cup Loudspeaker.

Figure 2: Schematic Drawing of Loudspeaker.

Figure 3: Detail of Coil Wound Around the End of a Drinking Straw.



Lid
Cup
Straw
Coil
Washer
Ring Magnets
Washer
Hex Bolt