Physics of the Electric Guitar

Connections in Electricity and Magnetism

First discovered by Michael Faraday, electromagnetic induction is the process of using magnetic fields to produce voltage, and in a complete circuit, a current. He started, at first using different combinations of wires and magnetic, but it wasn't until he tried moving the wires that he created a current. It turns out that electromagnetic induction is created by just that – moving of a conducting material through a magnetic field (or the moving of a magnetic field past a conductor).

Electric guitars make use of Faraday's discovery. Pick-up coils, consisting of a small magnet wound with wire, created an interaction with a magnetic string or wire, which in turn creates a current in the coil. This current can be transmitted to a speaker and converted to sound by a reciprocal process.

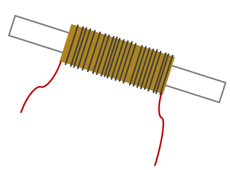
While Faraday discovered the science, most historians give credit to Leo Fender, who in the 1940s created the electric guitar. In this lab you will learn how a pick-up coil works and use a home-made pick-up to play the "physics guitar."

Activity 1 - What does electricity have to do with magnetism?

One of the basic pieces of an electric guitar pick-up is a simple coil of copper wire. In this activity you will see the simple connection between electric current in the copper coil and creating a magnetic field.

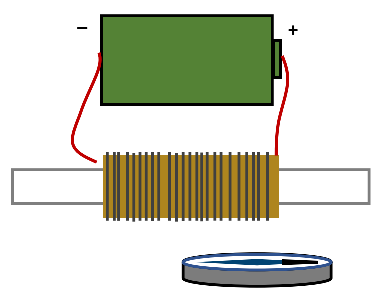
Materials

- Copper coil assembly
- Magnetic compass
- C-cell battery



Procedure

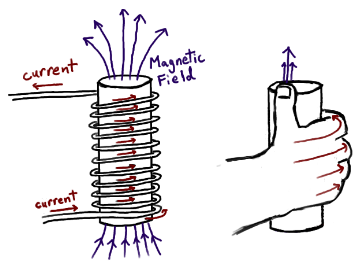
1. Hold the two bare wires of the coil to the + and – terminals of the battery and observe what happens to the compass needle when the coil is placed close to the compass.
2. Explore moving the coil over and beside the compass and observe the position of the pointer relative to the coil.



3. What is the relationship between the “poles” of the wire coil and the **+** and **–** ends end of the battery?

4. Reverse the battery and see what happens. Describe the orientation (direction) of the magnetic force relative to the coil of wire when the current is created?

The “Right Hand Rule”



Activity 2 – Inserting a nail into the coil.

A current carrying coil, wound around a magnetic material, like a steel nail, constitutes what is called an electromagnet . You goal is to compare the behavior of the electromagnet with a metal core, compared to the coil and battery alone.

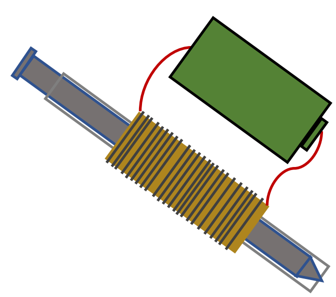
Materials

- Copper coil and battery
- Iron nail
- Aluminum rod
- Paper clips

Procedure

1. Connect the battery and place an iron nail inside of the coil. How many paperclips you can pick up?

   Number of paper clips ___________



2. Now connect the a battery to the coil assemble **without the nail** and record how many paperclips you can pick up.

   Number of paper clips ___________

3. How would you explain the difference in the results between the two experiments?

4. Repeat step 1, this time using an aluminum nail. What could you conclude?

5. Explain the ways in which you think an electromagnet is similar to an ordinary “permanent” magnet.

6. In what ways do you think an electromagnet is different from an permanent magnet?

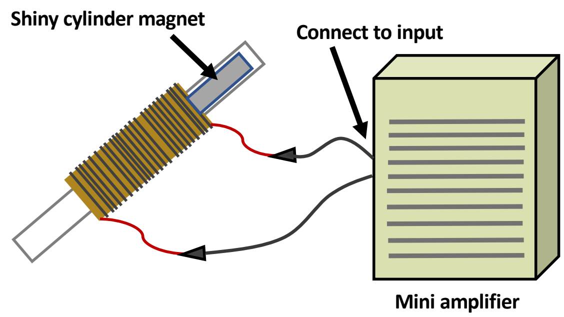
Activity 3 – What does Faraday’s Law tell us?

In this activity, you will begin to explore the relationship between current in a wire and magnetic fields, the foundation of Faraday's Law of Induction.

Materials

- Copper coil
- 2 inch long neodymium rod magnet
- Mini amplifier
- Alligator to “mono” connector
- Galvanometer (optional)

Procedure



1. Connect the copper coil to the mini amplifier using the mono to alligator connector and turn on the mini amp.
2. Place a neodymium rod magnet inside the coil cylinder.
3. Cover both ends of the cylinder with your fingers and make the magnet slide back and forth inside.
4. Explain how you think the sound in the amplifier is created.

5. (Optional) If you have a galvanometer, try holding the coil cylinder steady and slide the magnet in from one end or the other and observe the effect. Try reversing the magnet. What do you find?

6. Why you think a magnet that is not moving does not create a sound.

7. Faraday's Law summarizes the relationship between current in a wire and magnetic force (field). Summarize this relationship in your own words.

Activity 4 – Getting a picture of magnetic force.

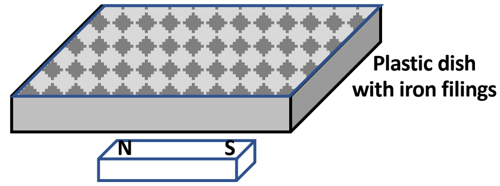
Magnets are able to interact with certain other materials, exerting a force in what we refer to as the magnetic field, the "area of influence" surrounding a magnet. In this activity, you will be able to learn more about the nature of magnets and magnetic fields.

Materials

- Disk magnet
- Small bar magnet (labeled N and S)
- Dish of iron shavings
- Magnetic compass

Procedure

1. Slide the bar magnet under the dish of iron filings and tap the dish lightly. Draw a picture below of the pattern you observe in the iron shavings.



2. Based on the geometry of your drawing, where do you think the magnetic field is the strongest?

3. Using a compass to determine where the poles are of a disk magnet. Draw a picture of a disk magnet and pattern you think you would see in iron shavings. You can check your prediction.

4. Rub one pole of the bar magnet 10 times, <u>in one direction only</u>, along the length of the piece of guitar string in your box of supplies. Hold the string near the compass and note as many observations as you can make.

5. What conclusion can you make?

Activity 5 – The electric guitar pick-up.

Electric guitar pick-ups take advantage of the principles you have been investigating. In this activity, you will be able to see how the pick-up works.

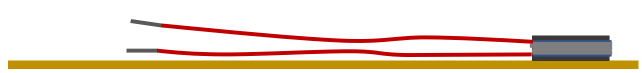
Materials

- Guitar "pick-up" stick
- Alligator to (mono) audio connector
- Mini amplifier
- Guitar string board

A word of caution: **the guitar string board is not a guitar**. The board is just a way to mount strings of different modes of vibration. It cannot be tuned like a guitar. If you try, you will break the strings. Please do not!

Procedure

1. Attach two wires on the electric "pick-up stick" to the speaker-amplifier using the alligator to mono audio connector.
2. Tum the amplifier to the on position and turn the volume knob to near maximum.
3. Slide the "pick-up stick" magnet under one of the strings and pluck the string (making sure the magnet does not touch the string).
4. Move the magnet in and out from under the string while it is vibrating and note what happens.
5. Draw the magnetic field lines of the magnet on the pick-up stick.



6. What is the purpose of the magnet inside the coil on the pick-up stick (i.e. what function does it serve?

7. The magnet in the center of the coil is not *moving* through the coil. Explain how the wire coil is able to generate a current.

8. Why won't nylon strings work on an electric guitar?

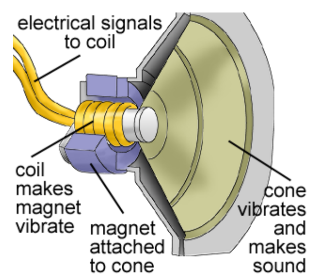
Activity 5 – Talking back to the speaker.

In this activity you will identify the parts of a common loud speaker and consider how it works relative to the force created by the interactions between magnets and coils of current-carrying wire.

Materials

- Mini amplifier
- Alligator to mono connector
- Small loud speaker

Procedure



1. Study Illustration C to the right and find the components we have discussed to this point: the coil and the magnet.
2. Connect the mini-amplifier to the small speaker using the mono-to-alligator adapter. **Very gently** tap the loud speaker and observe the effect.
3. Using the same set-up, talk into the loud speaker.
4. Make a list of the sequence of events that results in a current when talk into or tap on the speaker.

Activity 6 – Making your own speaker and microphone.

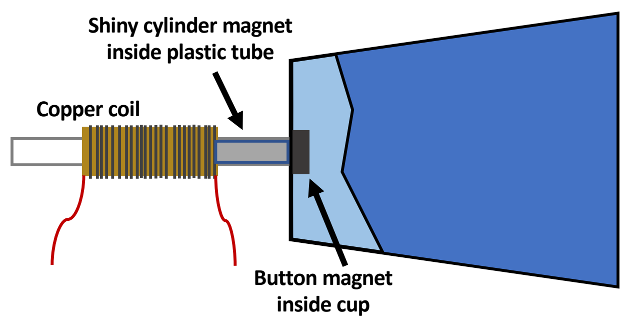
You will now be able to identify the parts of a common loud speaker and consider how it works relative to the forces created by the interactions between magnets and coils of current-carrying wire.

Materials

- Copper coil assembly
- Mini amplifier
- Stereo to mono connector
- Alligator to mono connector
- Disk magnet
- Cylinder neodymium magnet
- 12 oz plastic cup
- Smart phone or other music source with earphone jack

Procedure

1. Place the disk magnet inside a plastic cup to hold the shiny cylinder magnet to the outside of the bottom of the cup.
2. Slide the cup and magnet assembly into the cupper coil tube.
3. Connect the wires of the coil to the **output jack** of the mini amp.
4. Use the mono to stereo connector to connect your phone (stereo end to the earplug jack) to the **input jack** of the mini amp.



   (Make sure the stereo jack is fully inserted in your phone. You may need to remove the protective case if you have one.)
5. Find a song and enjoy your new loud speaker! You'll probably get the best results laying the speaker on the table.
6. Beginning with the current coming from your phone, list the sequence of steps involved in your hearing the sound.

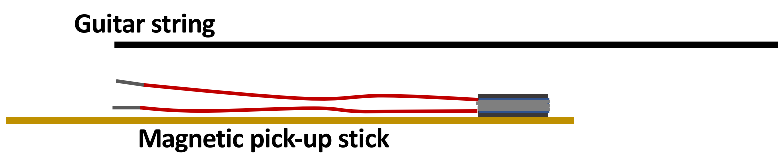
7. Try to see if you can use the plastic cup as a microphone, connecting it to the input jack

of the mini amp.

Making sense of it all

Study the illustration below of the magnetic pick-up with a guitar string positioned above it.

- Draw the magnetic field lines for both the string and the pick-up
- Draw the location of the N-S poles in the string



Using this illustration, describe how a vibrating guitar string creates current in the pick-up coil, which can be turned into sound at a speaker. As part of your explanation, do the following:

Consider the terms: magnetic field, vibration, magnetize, current, and any others you feel are important.

Teacher Notes

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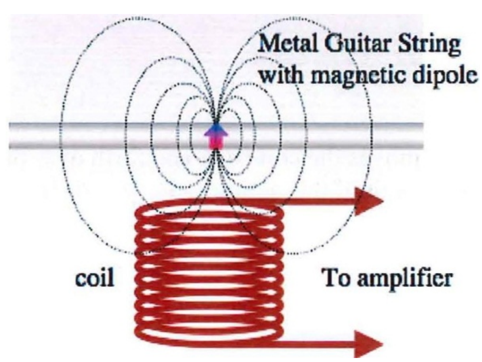
1. Go through the kit boxes with your students at each class period to identify the items and to insure that all parts are present and nothing is missing. The piece of guitar string is one item that can easily be overlooked and/or lost.
2. Explain to students the difference between the "mono to alligator" connector and the "mono to stereo connector" so they know the purpose of each.
3. Activity 3 suggests using a galvanometer to show the reversibility of the current as the magnet passes through the coil in opposite directions. Galvanometers are not supplied. If you have them available, you will also need two double ended alligator leads to connect the coil leads to the galvanometer terminals.
4. Please warn your students, do not to try to tune the guitar strings. The board is not a guitar and trying to tune them will likely break the strings.
5. Mini amplifiers:
   a. The volume controls can be a little "scratchy" since the contacts oxidize over time and lack of use. Running the volume up and down several times will usually correct the problem.
   b. Please make sure the mini amps get turned off after every class period. In the kit box, they are placed with the switches up and the black index line visible; the "off" position.
6. Students will usually incorrectly draw the poles at the ends of the guitar string. However, when the domains in the string align in the presence of a magnet (when it becomes magnetized), they will do so in concert with the field of the nearby magnet. Thus the field is perpendicular to the string, with the poles on either side of the string, not at the ends. Depending on the level of your students, it is acceptable to talk in terms of atoms aligning, rather than domains, even though this is in reality a domain phenomenon.



Schematic of electric guitar with magnetic dipole and pickup coil.

7. Please feel free to make any suggestions. Email Dave Sederberg. dsederbe@purdue.edu