Laser Interferometer Gravitational-Wave Observatory
Supported by the National Science Foundation
Operated by Caltech and MIT

Speaker Inquiry

Grade(s): MS HS
Topic: Physical Science

Standards:
Performance Expectations
MS-PS2-3 Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.
HS-PS2-5 Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
HS-PS3-3 Design, build and refine a device that works within given constraints to convert one form of energy into another form of energy.

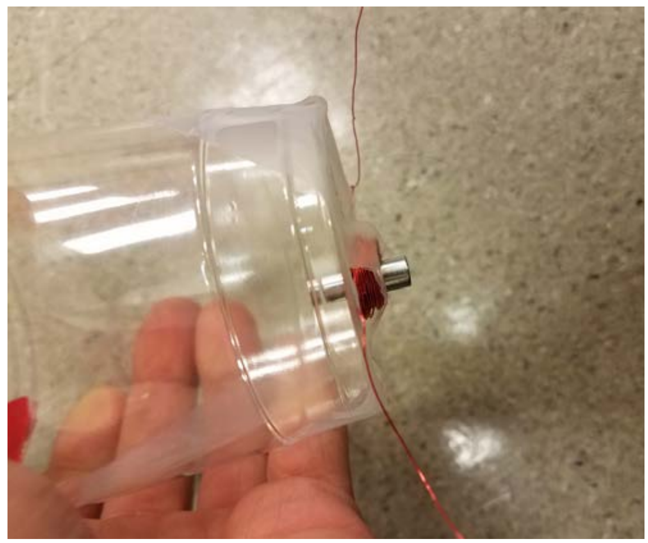
Disciplinary Core Ideas
MS-PS2.B Electric and magnetic (electromagnetic) forces can be attractive or repulsive and their sizes depend on the magnitudes of the charges, currents or magnetic strengths involved and on the distances between the interacting objects.
HS-PS2.B Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.
HS-PS3.A "Electrical energy" may mean energy stored in a battery or energy transmitted byu electric currents.
HS-PS3.A Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.

Science and Engineering Practices:
Asking questions and defining problems
Planning and carrying out investigation
Constructing explanations and designing solutions.

Objectives:
To demonstrate energy can be transferred from object to object.
To determine what elements are critical to the speaker to cause it to transfer electrical energy into sound.

Materials:
Magnet wire (gauge 22 – 32)
sandpaper
Wire cutter (or precut the magnet wire)
Neodymium magnet (other magnets work as well)
Wired Headphone jack (stereo or mono can work, or headphone jack, solder and wire)
Sound source (radio, cell-phone, etc.)
Tape
Cups, bowls, other miscellaneous items.
Optional: alligator clips

Advanced Preparation:
Create a speaker using a cup, magnet wire, headphone jack:

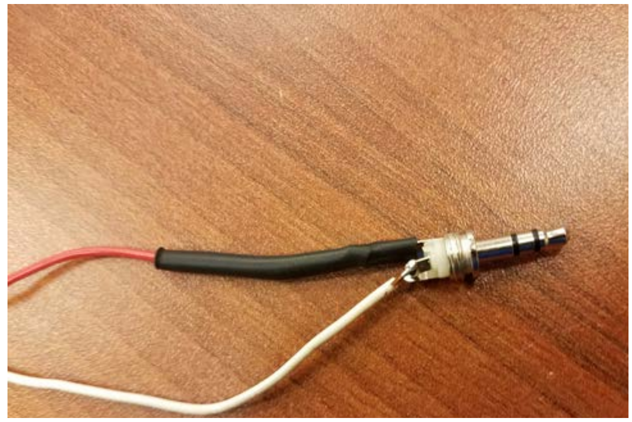


Leaving 5-10 cm of wire at the end, wrap the remaining wire in a tight coil about the size of a C battery (you can wrap it around a C battery if you like). Always wrap the wire in the same direction (don't switch directions half way through). Wrap the wire so that you have 100 coils. Leave another 5-10 cm of wire coming off of the other side of the coil of wire and cut off the remaining magnet wire. Firmly tape the coil of wire to the outside bottom a plastic or Styrofoam cup. Sand the ends (about 2 cm) of each end of the magnet wire, so that you have bare copper.

Take two neodymium magnets – place one inside the cup and the other outside the cup – directly on top of the copper wire (or just inside the wire loops).

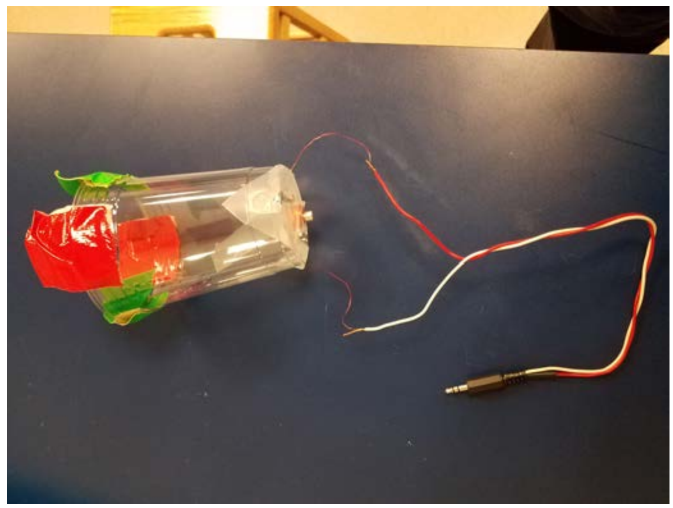
Either: Take a pair of headphones and cut the wire that leads to one of the headphones, OR take a headphone jack and solder the end of an insulated wire to the long metal jacket, and solder the other wire to one (or both) of the other two small leads. Make sure the electrical contacts/bare wires don't touch (you can use electrical tape or heat shrink tubing to help).

Attach each end of the wire coil to a wire coming from the headphones - either by twisting them together or using alligator clips to attach the wires. Do not let the two wires from the coils come in contact with each other.



Test out your cup speaker by putting the headphone jack into a sound source and seeing if you can hear the sound coming from the cup.

Now add one embellishment, that won't affect the sound much – this could be poking a hole in the Styrofoam cup, adding a piece of tape to the end of the cup, coloring the whole thing pink, sticking wires through the cup. At the end of the lesson, the students should have determined that this element was un-necessary.



We recommend providing multiple sound source stations with headphone jacks for students to test out their speakers. This will require your creating multiple headphone jacks.
Depending on your students and class size you may want to pre-cut the magnet wire for each group, pre-sand the magnet wire ends, and/or provide the students with small pieces of sandpaper.

Activity

Part 1
Show the students your speaker. Plug it in to your sound source and let them listen to it. Ask them what parts they see, and tell them to be very exact, recording every little part. Tell the students that they must first create a speaker just like yours, and get it to work. Prior to letting them do this, we recommend having the students practice sanding the enamel off of the end of the magnet wire first – and letting you inspect the ends quickly.

Trouble-shooting failed speakers: Often when speakers don't work it's because the end wire isn't sanded well, and therefore it's not electrically connected to the headphones. Sometimes students will make really large coils of wire, and twist them like the number 8 and then fold one half them in half to create a smaller 0. This will almost be like having no coils of wire, because half of the coils go in one direction and half go in the opposite direction – canceling each other out.
Let them know that you used 100 coils of wire.

After the students succeed in making a speaker work, ask them what parts of the speaker do they think are necessary? Gather as much feedback as you can. If necessary you can seed them with questions such as: The cup can be called the speaker cone – is it necessary? Does it need to be that shape? What about the magnets – are two magnets – one on each side of the cup necessary? Do you need 100 coils? Tell them they are to create an investigation to determine: 1) What parts are necessary to have a successful speaker. 2) What elements can be changed to make the speaker louder. Prior to allow them the time to investigate, ask them how many variables should they try to change at once? Depending on your group, you may want to require that they students write down the particular variables they are changing, and how they will quantify their data. Ideally you will give the students enough materials where they can test their new speaker against their old speaker.

Science backdrop: When electrical current flows, you create magnetic fields. When you coil the wire, this effectively creates a more powerful magnetic field. If you hold a magnet near the wire, it will attract or repel the wire (depending on the direction of current). A sound source produces electric currents that change, creating magnetic fields that change. If you bring a magnet near a coil of wire that's connected to a sound source, you can often feel the vibration in the coil and in the magnet – that vibration is producing the sound! The cup, or any object connected to a coil acts as a sound source – moving more air, in order to make the sound louder. Most speakers use lightweight but stiff speaker cones (like the cup). The cones are lightweight but stiff so that they can easily move more air – producing a louder sound. The cones aren't necessary to produce sound, but they make it louder, since they allow the speaker coil to move more air.

Investigable questions

Do you need two magnets? No – one magnet interacting with a wire is good enough.
Do you need 100 coils? No. Technically you don't even need a coil of wire, but a single wire is really weak and hard to hear. More coils generally produce louder sounds.
Do you need a cup? No, but any large light surface (like a cup) can help you hear the sound. Students have attached the coils to balloons, English muffins, papers, the desk, and even the whiteboard – all of which produce sound.

LIGO Connection:

Every electric current creates a magnetic field. LIGO uses this to their advantage and LIGO is also hurt by this. On the positive side LIGO uses coils of wire to move magnets connected to our mirror pendulum systems. These coils of wire can push and pull on the mirror in order to get the laser correctly lined up. When the laser is correctly bouncing off of the mirrors, these coils of wire are used to keep the mirrors still when other noise (such as ground motion) tries to move the mirrors. On the negative side, LIGO can also be affected by other currents and magnetic fields LIGO science specialists have looked at the magnetic fields around the chambers and have even tried hooking up huge coils on the walls around parts of the interferometer in order to determine how additional electromagnetic fields might affect the interferometer. One issue that we know occurs, is that the electric current in the wall is alternating current, vibrating around 60 Hz (60 times per second). This causes noise (motion) in our detector (due to the magnetic fields produced) that we can't fully eliminate.

Resources:

https://www.exploratorium.edu/snacks/cup-speaker

Safety Considerations:
Wires can poke you and cause small cuts. Magnets can pinch your skin. If the speaker wires are allowed to touch and "short circuit" they can heat up, causing a burn (unlikely) and burning out the sound source (unlikely – since generally there is protection against this sort of breakdown).