Tooth Tunes

In this activity, students will have a physical experience that solidifies their understanding of the electric and magnetic field behavior that is associated with amplified audio signals and loudspeakers. Ideally, students will have already had some exposure to speaker construction and the right hand rule for solenoids. The inner-workings of a guitar pickup, which depend on a fluctuating magnetic field to induce a current, will come into clearer focus as a result of completing this physically engaging activity.

Learning Objectives:

1. Describe the interaction between a conductive coil, a variable voltage (audio signal), and a nearby magnet in the context of a speaker design.
2. Describe the similarities between speaker construction and operation to that of an electric guitar pickup (solenoid vs. inductor)
3. Describe how an electric guitar pickup induces an electric current that is in keeping with the activity of a nearby, ferromagnetic guitar string.

Standards:

HS-PS2-5 Motion and Stability: Forces and Interactions

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-PS4-5 Waves and their Applications in Technologies for Information Transfer

Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

Materials Required:

1. 1” wooden dowels
2. ¼” wooden dowels
3. Magnet wire (varnished copper wire, 22 gauge)
4. Rare earth magnets
5. Amplifier with MP3 input and speaker output wires with alligator clip connections for signal (+) and ground (-) leads
6. Drill with ¼” bit
7. Masking tape
8. Guitar pickup for demonstration
9. An electric guitar and amplifier for demonstration

Safety:

Students should be cautioned about working with rare earth magnets prior to beginning the activity:

1. Rare earth magnets can pinch fingers
2. Rare earth magnets can break, resulting in sharp edges
3. Under no circumstances should a rare earth magnet be placed in a student’s mouth

References:

Video: How Guitar Pickups Work - https://www.youtube.com/watch?v=SfkX-fgmIbc

Activity:

Instructor Preparation:

Prepare one Tooth Tune mouth bit per student by cutting a 3/4" long slice from the 1" dowel. Drill a ¼" hole in the center of the slice, part way through. Cut a 4" length of the ¼" dowel and press it into the ¼" hole; glue should not be needed but can be used. Set up the audio amplifier to play music, with the alligator-clip speaker wire in place and ready to hook up to the assembled Tooth Tune mouth bits.

Experience:

Each students will be given a Tooth Tune mouth bit. Cut ~1 meter of magnet wire and wrap it around the 1" diameter end of the Tooth Tunes mouth bit, leaving ~2" of wire sticking out from each end of the wrap. Secure the wire wrapping with masking tape. It is not important if the wraps overlap. Use sandpaper to remove the varnish from the exposed ends of the magnet wire to allow an electrical connection with the alligator clips (the varnish is an electrical insulator).

At the amplifier, connect the two wire ends of the mouth bit to the two alligator clips on the speaker wire. Place the ¼" dowel part of the Tooth Tunes mouth bit into your mouth and bite down on it with your back molars. Take a magnet (2 or 3 stacked together works best) and slowly bring the magnet up close to the end of your mouth bit. Smile! Everyone is watching, but you are the only one experiencing the magic!

Comparison / Discussion:

Challenge students to explain/show how how the principles at work in an electric guitar pick-up are similar to those at work in the Tooth Tunes activity. Recall that a guitar pickup is constructed by combining a magnet and coil, just like the Tooth Tunes mouth bit. The strings on an electric guitar are made of a ferromagnetic metal, and when a string is plucked, its vibration above the magnet alters the magnetic field, and an electric current that alternates in keeping with the changing magnetic fields is induced in the coil. The interactions of the magnet and coil in a pick-up are the same as

the interactions of the Tooth Tunes mouth bit and the magnet. The difference is that the mouth bit uses a current (audio signal) to drive a magnetic field, while a guitar pickup relies on the altering of a magnetic field to drive a current.

Understanding:

When a current moves along a wire, it creates a magnetic field around the wire. If the wire is wound into a coil, the magnetic field is concentrated at the center of the coil and the direction of the field is shown by the "right hand rule of thumb". Take your right hand, curve your fingers like you are holding a glass and stick your thumb straight up. When the current goes around a coil in the direction of your bent fingers, the magnetic field points in the direction of your thumb, and is concentrated in the center of the coil.

The interaction of a coil of wire and a permanent magnet, when there is a current in the wire or a disturbance of the magnet's field, are basic concepts of Physics that are used in many everyday applications of "motor effect" and "generator effect." "Motor effect" manifests when a coil and a magnet are near each other and a current flowing in the wire results in a motive force between the coil and the magnet. "Generator effect" manifests when movement of the magnet's field, passing through the coil, results in a current and voltage being induced in the coil.

In an electric guitar's pickup, a coil and a magnet are fixed in place, and there is a ferromagnetic wire (the metal string) just above the coil and within the magnet's field. When the vibrating string moves in the magnet's field, it causes that magnetic field to distort, undulate, and move, in time with the vibrating string. This distortion of the field induces a current and voltage in the coil. As the string vibrates back and forth, the direction of the current and the sign of the voltage change, creating the variable, alternating voltage signal that is sent to the amplifier. The frequency of the variable voltage matches the frequency of the string's vibration.

An amplifier takes the variable voltage output from the guitar and increases the amplitude of the variation (why do you think they call it an amp?) without changing the frequency. This higher amplitude variable voltage is sent to the speaker to make sound; the larger the amplitude the louder the sound. In the speaker, a magnet is held in a fixed position, and a coil is attached to a cone. When the voltage is positive, the current flowing through the coil produces a magnetic field that is opposed to the magnetic field

of the magnet, and the cone is driven away from the magnet. When the voltage is negative, the opposite happens and the cone is pulled towards the magnet. When the cone moves, it pushes or pulls on the air surrounding it, and those variations in air pressure are what we call sound. The Tooth Tunes mouth bit experiences the same push/pull between the magnet and the coil, except that the coil is attached to the dowel that is clamped between teeth, and push/pull is transferred to the molars causing the inner ear to vibrate. The inner ear vibration is what the student "hears".

There are many examples of other devices that use this interaction of a coil and a magnet. Electric motors use the interaction to cause rotation. Solenoid switches use the interaction to close a switch, the Cern supercollider uses coils and magnets to direct beams of charged particles and older television sets used CRTs (cathode ray tubes) to create the picture.

Name _____

Assessment
Tooth Tunes

1. Which of the following components are found in an electric guitar pickup?

   A. Magnet
   B. Coil
   C. Cone
   D. All of the above
   E. A and B

2. When you hear sound coming from a speaker, what are you actually experiencing?

   A. The movement of the cone
   B. The variation of air pressure
   C. The vibration of the magnet
   D. The vibration of the coil

3. When you hear the music from your Tooth Tunes bit, what are you actually experiencing?

   A. The vibration of your inner ear
   B. The variation of air pressure
   C. The vibration of the magnet
   D. The vibration of the coil

4. Why did you only hear music when the magnet was very close to the coil?

   A. The inverse square law applies to magnetic fields
   B. The coil's field needs a constant field to interact with
   C. If the coil and magnet are too far away from each other, the vibrations are too small to hear
   D. All of the above

5. The job of an audio amplifier is to _____.

A. increase the impedance of the coil
B. increase the frequency of the sound
C. increase the amplitude of the variation
D. increase the tone of the sound

6. An electric guitar string must be made of a ferromagnetic material.

True -or- False

7. To make a sound louder, you need to increase the _____.

A. wavelength
B. frequency
C. pitch
D. amplitude

8. If you pluck an electric guitar string lightly, you make a soft sound. If you pluck the string with more force, you make a louder sound. Why?

A. The string vibrates faster, resulting in a louder sound.
B. The string moves more, creating a larger disturbance in the magnetic field.
C. The vibrating string causes more air to vibrate.
D. This is false, only the amp controls the volume.

9. What form of energy is being converted into electricity by an electric guitar pickup?

A. Kinetic
B. Potential
C. Magnetic
D. Electromagnetic

10. Which of the following would be the result of replacing the magnets in an electric guitar pickup with stronger, rare earth magnets?

A. Increase the amplitude of the voltage variations in the induced current
B. Fewer wraps in the coil would be required to get a similar voltage
C. Increase the pull on the string and distort the string's vibration
D. All of the above

Assessment Key:

1. E - A and B
2. B - The variation of air pressure
3. A - The vibration of your inner ear
4. D - All of the above
5. C - increase the amplitude of the variation
6. True
7. D - amplitude
8. B - The string moves more, creating a larger disturbance in the magnetic field.
9. A - Kinetic
10. D - All of the above

Reviewing Faculty Cohort Members:

Dave Parker, Noble High School, North Berwick, ME - daveonindigolady@gmail.com
Tim Wilhelm, Kankakee Community College, Kankakee, IL - tjwillyhelm@gmail.com
Chad McCormack, Wells High School, Wells, ME (4/18)