Tool Kit I
Good Vibrations – The Science of Sound

Objective
Explore the physical properties of sound, including basic wave theory and the concepts of energy transfer.

Materials
- An oven rack, cooling rack, or other similar lightweight metal object
- String
- Slinkys
- Bungee cords

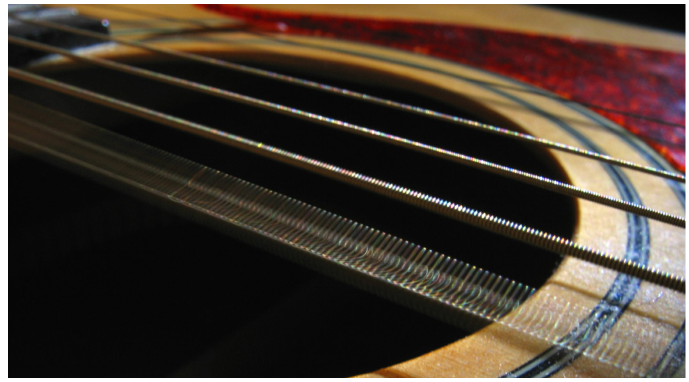
Arizona Science Standards Addressed
- Strand 1: Inquiry Process
  - Concept 1: Observations, Questions, and Hypotheses
  - Concept 2: Scientific Testing (Investigating and Modeling)
  - Concept 3: Analysis and Conclusions
  - Concept 4: Communication
- Strand 5: Physical Science
  - Concept 1: Properties of Objects and Materials
  - Concept 2: Position and Motion of Objects
  - Concept 3: Energy and Magnetism

Background Information for Educators

What is sound? How does it relate to music? Sound occurs when energy interacts with any object in such a way as to force it to vibrate (e.g., move back and forth rapidly). For sound to occur, we need three things:

1. **A source of energy**
2. **Vibrations**
3. **A medium for those vibrations to travel through**

A source of energy might come from finger plucking a guitar string, air blowing across a saxophone reed, or hitting a drumhead. That energy creates a disturbance

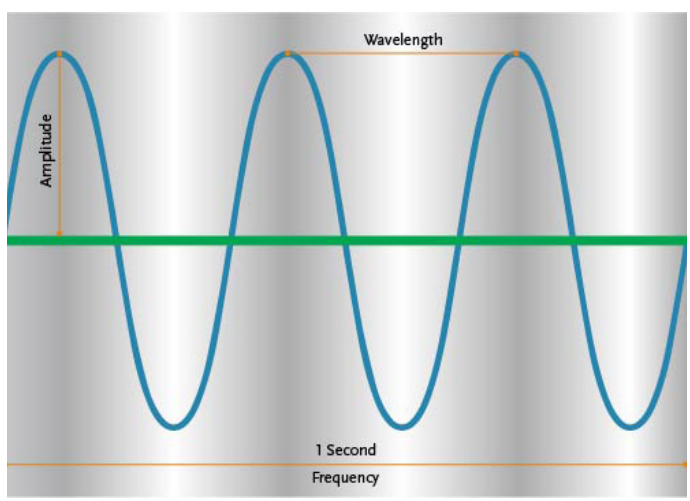


A guitar string models the up-and-down motion of a transverse wave.

that causes the string, reed, or drumhead to vibrate. These vibrations can be transferred from one medium to another. For example, a guitar string vibrates causing the wood in the guitar to also vibrate, which then causes the air surrounding the guitar to vibrate, thus creating sound waves. These sound waves then cause your eardrum to vibrate, which sends a signal to your brain that gets interpreted as sound. Sound waves, like waves at the beach or waves anywhere else, have the following key characteristics:

1. **Amplitude**
2. **Wavelength**
3. **Speed**
4. **Frequency**

The **amplitude** of the wave indicates the amount of energy the wave carries. For example, if you hit a

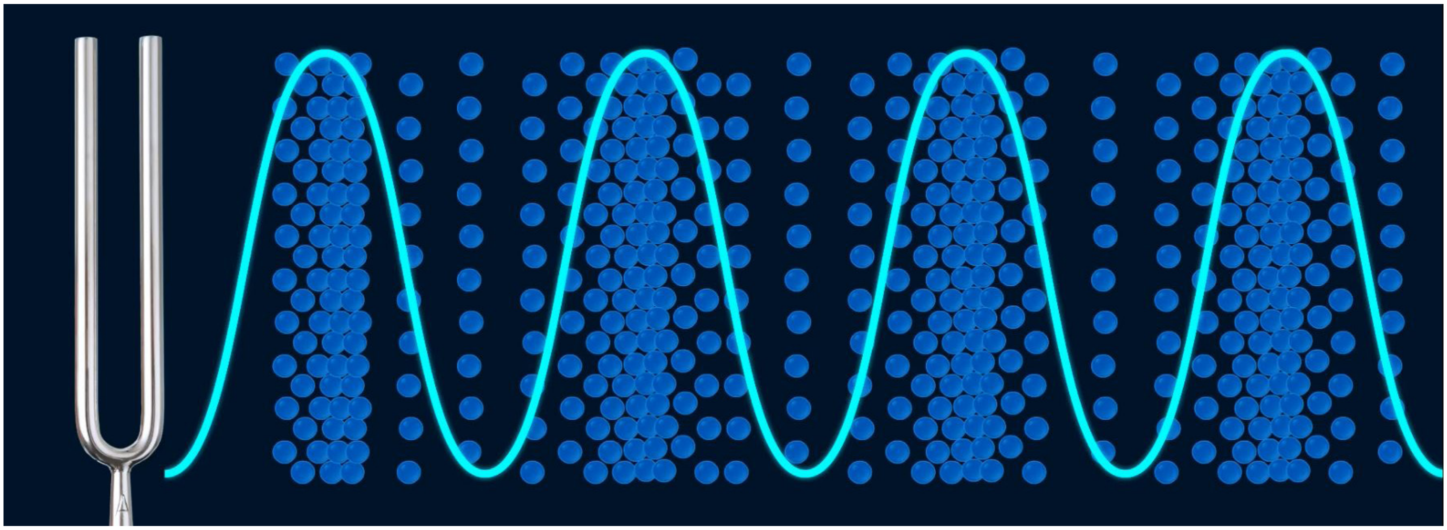


Waves can be described by their frequency, amplitude, wavelength, and speed.

drum with a lot of energy, the drumhead will move up and down a greater distance than if you gently tap the drum. The amplitude of the resulting sound wave will directly correlate to how hard, or soft, you've hit the drum. Amplitude can also be thought about as loudness: the greater the amplitude, the louder the sound. If we were to graph that sound wave, the wave with higher amplitude would have a taller crest (or "peak") than the wave with lower amplitude. You can also see amplitude while at the beach. A ten-foot ocean wave will carry significantly more energy than the little waves you might see in a lake.

waterfalls, roaring lions, subwoofers, big drums, or huge organ pipes. High frequencies correspond to the high, shrill sounds we hear—birds, squeaking mice, flutes, soprano singers, or tiny organ pipes.

There are many different types of waves. The manner in which a wave transports its energy, called **propagation**, is a distinguishing characteristic for each different type of wave and is directly related to the **medium** through which a wave can propagate. A sound wave propagating through a solid medium, such as a guitar string or drumhead, causes up-and-down motion, creating



The compression and rarefaction of a longitudinal wave traveling through air

Wavelength is a measure of the distance between each successive repetition of a wave. Again, if we were to graph a wave, the wavelength would be represented by measuring the distance between each crest (or "peak") of the wave. The **speed** of a wave is the measure of how fast the wave itself is traveling. Waves travel at different speeds if they are traveling through air, water, or a solid object such as wood. **Frequency** is the measure of how often a wave is observed repeating in a specific measure of time; it is directly related to wave speed and inversely related to wavelength. For example, as wave speed increases, frequency will also increase. Inversely, if the wavelength increases, the frequency will decrease.

Frequency is commonly measured in hertz (Hz), which is a measure of how often a wave pattern repeats in one second. Low frequencies correspond to the low, rumbling sounds we hear in music and nature—

crests and troughs, just like on our graphed wave above. This is called a **transverse wave**. Conversely, a sound wave propagating through the air causes air molecules to alternatively bunch up or separate in a process known as **compression** and **rarefaction**. This is called a **longitudinal wave**. A visual representation of the compression and rarefaction of a longitudinal sound wave, together with an overlay of how that wave would be graphically represented, can be seen below.

Both longitudinal and transverse waves are known as **mechanical waves** as they propagate through physical interactions with the mediums in which they travel. In other words, molecules are mechanically displaced as they propagate. **Electromagnetic waves** are another class of waves that enable the propagation of wave energy using charged particles called **electrons**. Personal electronic devices, such as cell phones, electronic recording devices, and electric or electrically amplified musical instruments, all transfer energy between electromagnetic and mechanical waves in order to create sound. For further details on electronics, electromagnetism, and sound, see MIM's advanced STEM curriculum.

Observe, Question, Hypothesize, Test, Model, Analyze, and Explain

Choose from the following activities to facilitate the process of scientific inquiry of the basic principles of waves, wave properties, and wave propagation through various mediums, such as liquids, solids, and air.

Activity 1:
ZOMBIE SOUNDS – The Basic Principles of Waves

Invite all students to stand in a circle holding hands and pretend to be zombies. Invite one or two students to be "zombie masters," which we'll call **energy**. Energy causes the zombies to start slowly to move in a circle, making low, zombie-type sounds. Energy also causes **vibrations** that students can feel in their throats as they make zombie sounds. Duck down and make soft zombie sounds or on tiptoes and make loud zombie sounds. Invite two students to exit the circle and become "zombie hunters" who will "scare" the zombies. When zombies are scared, they move quickly, still walking on their heels in a circle, making high-pitched squealing noises.

Invite two more students to be "zombie scientists." Using their two hands (or a paper roll) to form a "science tube," the scientists are tasked with observing, testing, and analyzing the following:

How "frequently" does a zombie's head pass in front of the science tube when the zombies are scared versus when they are not scared?

Do the zombies sound louder when they are crouched over or standing on their tippy-toes?

Holding hands, you represent a **wave** form with heads being the point of compression ("crest") and hands being the point of rarefaction ("trough"). When you move quickly, your "heads" pass in front of the "science tube" (or **oscilloscope**) with greater **frequency** than when you move slowly. Hunched over, you represent a wave of lower **amplitude**, which sounds "softer" than when you're on your tiptoes and represent a "loud" wave of greater amplitude.

Note: for the purposes of this basic activity, differentiating between wave types or nomenclature is not a curricular aim.

Extensions

Different groups of zombies can **transfer** their wave energy from one to another.

Different groups of zombies can represent different **mediums** through which wave energy might travel. Remember that sound travels faster through solid mediums (zombies can stand very close to one another and move very quickly) compared to liquids or gases (zombies can stand farther apart and move more slowly).

Different **wavelengths** can be modeled by how closely zombies stand while holding hands.

The interaction of **wavelength**, **frequency**, and **speed** can be modeled by having zombies stand close together and move slowly and by having zombies stand far apart but move quickly—with heads passing in front of an "oscilloscope" at about the same rate. While both waves will exhibit the same frequency ("heads passing in front of the oscilloscope"), the wavelength and speed are obviously very different.

Longitudinal waves can be mimicked by having zombies all stand shoulder to shoulder in a line. One zombie on the end pushes against the zombie

Students pretend to be zombies while learning about the basic physics of waves.

next to him/her, causing a chain reaction of the push to travel through the entire group of zombies. The energy of the wave moves "longitudinally" along the line of zombies.

Transverse waves can be mimicked by having zombies move their arms in an up-and-down, wave-like motion, just as one would see at a sporting event. The energy of the wave moves up and down, perpendicularly, or "transverse" to the line of zombies.

The differences between **mechanical waves** and **electromagnetic waves** can be illustrated by having the zombie masters or hunters use flashlight signals to start or alter a zombie wave. Light waves are a form of electromagnetic energy.

Activity 2:
EXTRA-LONG STRING – The Basic Principles of Waves (Transverse Waves)

Have two students hold each end of a long string or bungee cord and pull it tight, then have a third student, positioned in the middle, "pluck" the middle of the string. You can't hear a sound, but you can see the up-and-down motion of the **transverse wave** that is being created. Have students describe what they're seeing and initiate a discussion about sound wave characteristics.

How does the motion of the extra-long string compare to the graphic of the wave? Is it the same shape? How does it differ from the wave motion observed in the Slinky?

Both the graphic and the extra-long string are visual representations of a wave.

Rope can easily model the up-and-down motion of transverse waves.

Extensions

Have a fourth student hold a midpoint of the string while the outer two students maintain the same tension on the string, then have the third student pluck the string again.

How do the vibrations of the string change? Does the string vibrate faster or slower? Is the frequency higher or lower?

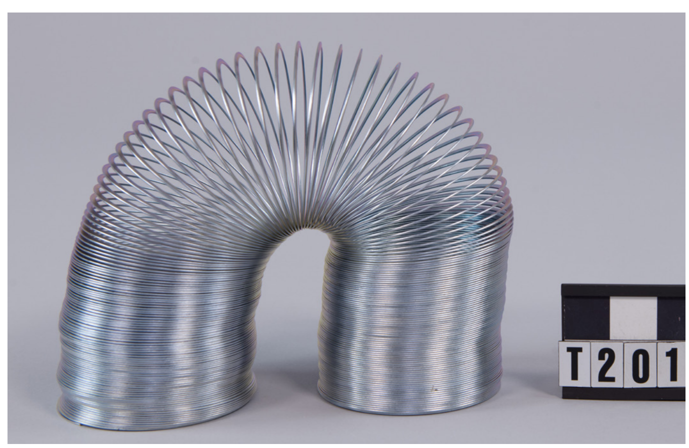
By holding a midpoint of the string, you effectively shorten it just as you do while playing many string instruments. A shorter string will vibrate at a higher frequency than a longer string, assuming both strings are held at the same tension.

Activity 3:
SLINKY WAVES – Longitudinal Waves

When a sound wave moves through air as a **longitudinal** wave, air molecules bunch up and spread apart in a process known as compression and rarefaction. Have two students stretch a Slinky across a smooth surface such as a table. Then, have a third student take a rung in the middle of the Slinky and, while keeping the Slinky on the table, pull it either to the left or the right, and then release it (like a slingshot). Ask the students to describe what they're seeing.

What happens if the rung is pulled farther to the right or left? What happens if a middle rung is grabbed versus a rung close to either end?

Energy causes air molecules to get pushed closer together, then spread farther apart, just like the Slinky



Slinkys can model the compression and rarefaction of a longitudinal wave.

rungs. This makes areas of high and low pressure. This process of compression and rarefaction is propagated back and forth along the Slinky until the energy dissipates. Sound will propagate through air in the same way until its energy dissipates. When the energy dissipates, you hear no more sound.

Activity 4:
COOLING-RACK GONG – Energy, Vibrations, Medium, Transfer

Tie string or yarn to a metal structure, such as a cooling rack (used for cakes or cookies) or even a wire coat hanger, leaving two pieces of string, each about two feet long, hanging loosely. Wrap one loose end of the string around each index finger, and then stick your fingers in your ears. Stand up so that the rack hangs in front of you, bend over slightly and knock the wire structure against a hard object such as a table or chair. A gong-like sound is heard, but only by the person holding the string in his or her ears.

Why does only the person with the string wrapped around his/her finger hear the sound?

The cooling rack is heard only by the person holding it.

The string (a solid) transmits vibrations much better than air does, so the person with the string hears sounds no one else can.

Activity 5:
TUNING FORKS – Energy, Vibrations, Medium, Transfer (Surface Waves)

Holding the tuning fork by the small end, strike the pronged end on the bottom of your shoe. Ask the students to observe what they hear.

What happens if you hold the tuning fork in the air near your ear?

What happens if you place the small end of the tuning fork on a hard surface such as your desk?

What happens if you place the small end of the tuning fork on your skull bones just on either side of your ear?

Can you describe the different mediums through which the energy of the sound waves is propagating?

A tuning fork transfers its vibrational energy to the water surrounding it causing small ripples.

Holding the tuning fork near your ear will enable your ear to hear only the sound waves propagating through the air. Holding the tuning fork against a hard surface such as a desk will transfer some of that energy to that hard surface and then to the air, possibly getting more air molecules to vibrate and increasing the loudness and amplitude of the sound. Holding the tuning fork against the bones on your skull will transfer some of that energy, via your bones and soft tissues, directly to your ear.

Extensions

> *What will happen if you place the pronged end of the tuning fork partway into a glass of water?*
>
> The vibrations from the tuning fork are transferred to the water, creating tiny waves across the top of the water. Waves that travel across the surface of a liquid are known as surface waves. Surface waves are characterized by the circular motion of the energy being propagated along the wave. You can see the circular motion of a surface wave in action at the beach when a wave crashes into a circular tube.

Activity 6:
"DO YOU HEAR WHAT I HEAR?" –
Energy, Vibrations, Medium, Transfer, and Alteration

What we hear is altered by the mediums through which sound waves propagate energy.

Students on a field trip discover how amplitude, or loudness, can damage their hearing.

Field trip participants discover the inner workings of the human ear in MIM's STEM Gallery.

Students record a short message on a tape or digital recorder. Play the message back.

> *Students rate how similar or different the recorded voice sounds from the voice heard in their head.*

The speaker will generally say that the recorded voice sounds very different from the "real" voice, while other students will say that the recorded voice sounds quite similar. This is because of the way sound waves travel differently through solids and liquids. When you hear someone else speak, you hear only the sound waves that travel through the air to your eardrums. When you hear yourself speak, you hear not only the sound waves that travel through the air but also the sound waves that travel through the liquids and solids of your own bones and tissues. As a result, you hear your own voice differently from anyone else.

At MIM, learn more about the perception of sound and the human ear in a exhibit called "How Science Brings Music to Life."

Assessment

Formative

Students explain or physically model their understanding of wave theory through responses to and interactions with one another and the teacher/ facilitator.

Summative

Students can explain the basic components of wave theory, including amplitude, wavelength, speed, and frequency. Students can also explain the differences between longitudinal and transverse waves. Students can explain further how different mediums, through which sound waves propagate energy, can alter the resulting sound we hear.