Curiosity Guide #908
Guitar Science

Accompanies Curious Crew, Season 9, Episode 8 (#908)

Playing Unplugged

Investigation #1

Description

Try out two different types of guitars to hear how they sound.

Materials

- Acoustic guitar
- Electric guitar, unplugged
- A friend

Procedure

1) Strum the acoustic guitar to get a sense of the sound.
2) Then ask your friend to strum the unplugged electric guitar.
3) How do the sounds differ?

My Results

Explanation

The unplugged electric guitar is generally quieter than an acoustic guitar, especially if the electric guitar has a solid body. Although the sound in both instruments originates from the strings, the body of the acoustic guitar transmits the vibration through the soundboard and into the air inside the guitar's body, making the sound resonate more loudly. The vibrating strings of the electric guitar also move the air around the string and can even vibrate the body and neck. However, because the acoustic guitar can disturb more air, the acoustic guitar produces a fuller sound.

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Resonant Air

Investigation #2

Description

Why do many types of guitars have a sound hole? Find out!

Materials

- Guitar
- Cardboard
- Pitchpipe
- A friend

Procedure

1) Play the open A string or use a pitchpipe to get the pitch.
2) Lean toward the top of the guitar and sing the pitch while a friend listens over the sound hole.
3) What do you notice?
4) Try plucking the open A, then slide a piece of cardboard back and forth over the hole
5) What do you notice?

My Results

Explanation

In the first example, you can hear the pitch resonating out of the sound hole. In the second example, the resonance gets stifled. These are examples of Helmholtz resonance. Just like when blowing across an empty bottle, the air inside the guitar produces a pitch. Singing the open A matches the resonance of the air in the guitar's body. Closing the opening inhibits the rich bass sound. The air inside a guitar oscillates in and out as though the volume of air behaves like a giant spring.

Some interesting guitar facts for you! As far back as 5,000 years ago, people were playing guitar-like instruments like the Sitara from ancient India. Those early stringed instruments influenced the design of the first guitars in the 1500s. Modern guitars still have some of the same general parts. There is a body, a fretboard, a headstock, tuning pegs, and strings. Whether you are playing an electric or acoustic guitar, the strings get plucked, picked, or strummed to produce a vibration. Still today, guitars are played throughout the world and are used in many different styles of music.

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String Theory

Investigation #3

Description

Find out how guitar strings work!

Materials

- Guitar strings
- Acoustic guitar
- Shoe box
- Rubber band
- 2 pencils

Procedure

1) Stretch a rubber band lengthwise on the box.
2) Slide a pencil under the rubber band near one end.
3) Slide the second pencil under the rubber band about 4 inches away.
4) Pluck the rubber band.
5) Now slide the second pencil further away and pluck the band again.
6) How do the sounds compare?
7) Pluck one of the strings of the guitar.
8) Press that string against one of the frets and pluck the string again.
9) How does fretting the string affect the sound?
10) Pluck one of the strings and tighten or loosen the tuning peg.
11) What do you notice?
12) Visually compare the strings.
13) How are the strings different? How are the strings the same?

My Results

Explanation

Several factors affect the pitch of a guitar string. These include mass, density, length, tension, and mode of vibration. Whenever a string is plucked, that string begins to vibrate at a certain frequency. More vibrations produce a higher pitch, and fewer vibrations produce a lower pitch. Although the guitar strings are all the same length, close examination reveals that some are thicker than others. In steel-string guitars, each string from high to low has more mass. Objects with greater mass vibrate more slowly, so these thicker strings would produce a lower pitch. We can see and hear that by comparing the high and low E strings. One is thicker than the other.

Classical guitars use nylon and wire-wound nylon strings that get increasingly denser. A denser string vibrates more slowly, so a denser string can produce a lower pitch. Turning the tuning pegs affected the pitch of the strings. As the pegs tightened or loosened the strings, the sounds went higher or lower. A tighter string allows faster vibrations and a higher pitch. Also, did you notice that the length of the string changes the pitch? When playing the rubber band or using the fretboard on the guitar, a longer string has a lower pitch. Finally, the mode of vibration refers to the different patterns of vibration that can occur.

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Capo Quality

Investigation #4

Description

Capo what?? A capo is a mighty useful gadget!

Materials

- Acoustic guitar
- Capo

Procedure

1) Strum the guitar.
2) Attach the capo and strum the guitar again.
3) What do you notice?

My Results

Explanation

Attaching a capo to a guitar shortens the playing area of all the strings. The capo presses the strings against the fretboard to shorten them. Shortening the strings raises the pitch of the guitar. A partial capo can shorten some of the strings while leaving others full length, like the low E. In either case, the capo serves as a movable nut that compresses the string through some kind of clamp mechanism. A capo allows the guitar to play in a different key without the guitarist having to retune the guitar. Try moving the capo to the 12th fret. The strings are now half the length and will jump an octave in pitch.

More string facts! We discovered a couple of different ways to change the pitch of a guitar's six strings, but not all guitars have six strings! In fact, there are guitars with 4, 7, 8, 10, or 12 strings. Guitars with additional strings have a fuller sound. When tuned, the six-string guitar notes are E, A, D, G, B, and E. Guitar strings can be quite different depending on the type of guitar and the sound that the guitarist wants to produce. Guitar strings are made of different materials and have different gauges and winding patterns. Electric and acoustic guitars use steel strings, while the wide-neck classical or Spanish guitars use nylon strings. Looks like you're tuned up and ready to play!

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Silent String

Investigation #5

Description

How do guitars produce sounds? Try this investigation!

Materials

- Guitar string
- Wooden board, 2 by 4 by 18 inches long
- 2 three-inch screws
- Drill
- Screwdriver
- A friend
- Guitar

Procedure

1) Drive one of the screws into the center of the flat face of the board, 1 ½ inches from the end.
2) Wrap the end of the guitar string under the head of the screw.
3) Repeat on the other side of the board.
4) Hand-tighten one of the screws with the screwdriver, so the guitar string is taut and produces a clear pitch when plucked.
5) Pluck the string for a friend. Have the friend compare this sound to the sound from the guitar.

My Results

Explanation
Plucking a guitar string by itself vibrates the air around it. However, the vibrations are difficult to hear. Guitars can amplify their sound by integrating a soundboard and body to increase the amount of air around the instrument that gets disturbed.

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Guitar Anatomy

Investigation #6

Description

Can you take the pressure? Take a look at some guitar parts that can!

Materials

- Guitar soundboards
- Neck
- Headstock
- Guitar for comparison purposes
- Graphics of soundboard designs

Procedure

1) Examine the parts of guitars that interact with the strings.
2) Play some strings on the guitar. Notice the tension on the guitar strings. Also, watch the vibrations.
3) What do you think would be the stress points on a guitar?
4) How much pressure or force would each of these pieces have to withstand?
5) Look at the graphics of soundboard designs to find out the kind of engineering that goes into designing and making a guitar.

My Results

Explanation

When a guitar is tuned, there can be as much as 80 pounds on a classical guitar and nearly 200 pounds of tension on the neck and soundboard of a steel string guitar. The neck of the guitar is fairly substantial, and an acoustic guitar even has a truss rod to counteract the string tension and the bowing of the neck. However, the soundboard is made of thin wood, 2.5 mm for spruce, or 2.8 mm for cedar. So, how can a soundboard withstand that much force? The secret is all in the bracing that helps keep the soundboard flat, but not so stiff that the bracing inhibits vibration. A top that can vibrate will also vibrate the air around the instrument and improve its resonance. Nylon string classic guitars have many different bracing patterns that allow the soundboard to vibrate and allow the bridge to rock back and forth and side to side to achieve different modes of vibration. Steel string guitars have a more identifiable X bracing pattern to withstand the higher tension, which structurally ties the pieces all together. Manufacturers repeatedly tap the board to monitor the target tap tone and shave bracing material accordingly to achieve that tone. It's ideal to have a slim taper on the braces before the body is assembled so you don't have to work through the sound hole to plane the braces down afterwards. Although the back and sides of the guitar don't contribute much to the radiant sound, the back and sides are integral in creating a body of air that can pulsate through the sound hole.

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Pickup Power

Investigation #7

Description

Find out what a pickup does in an electric guitar.

Materials

- Electric guitar single coil pickup
- Humbucking Pickup
- Amplifier
- Cable
- Multimeter
- Ferrous pliers
- Tuning fork

Procedure

1) Examine the parts of the pickup by first pulling the cover off.
2) Notice the six metal buttons, the enamel coated copper wire windings, the black bobbin.
3) Connect the two leads to leads of a multimeter. Set the multimeter to millivolts.
4) Move the ferrous pair of pliers over the pickup.
5) What do you notice?
6) Connect the two leads to an amplifier cable so one lead connects at the tip of the cable while the second connects on the shaft.
7) Strike a tuning fork and pass the fork over the pickup.

8) What happens when you place the tuning fork to the side of the pickup?

My Results

Explanation

A pickup for an electric guitar converts mechanical energy from the moving strings into electrical energy. The moving string passes through the magnetic field, induces voltage to the amplifier, and converts the energy back into mechanical energy and sound waves through the speaker. The pickup itself is made from magnets placed in the bobbin housing and wrapped thousands of times with enamel-coated copper wire. Sometimes the pegs are magnets themselves, while on other guitars, a less expensive permanent magnet runs beneath the ferrous pegs and magnetizes them. As the metal strings move above the pegs, the voltage is induced. This was evident when the ferrous pair of pliers registered a change in voltage on the multimeter. Another sign of voltage was when the tuning fork's sound was magnified through the pickup and amplifier. When the disturbance was directly above the pickup, the sound was louder. Guitars with a single pickup system have a bright tone, but they can also have a hum from interference. One solution is the Humbucker pickup that uses a second coil that is inverted from the first. The Humbucker pickup has a stronger magnetic field, which makes this pickup more sensitive and reduces noise interference.

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Magnetic Music

Investigation #8

Description

Find out more about how sound is produced in an electric guitar!

Materials

- Amplifier
- Cable
- Multimeter
- Magnet
- Copper wire
- Tuning fork

Procedure

1) Wrap the copper wire many times around the magnet, leaving two exposed leads.
2) Connect the two leads to an amplifier cable so one lead attaches at the tip of the cable while the second attaches on the shaft.
3) Strike a tuning fork and pass it over the pickup.
4) Could you hear the tuning fork through the amplifier?

My Results

Explanation

The moving tines of the tuning fork pass through the magnetic field and induce voltage to the amplifier. Then the energy is converted back into mechanical energy and sound waves through the speaker. To increase the volume, try adding more windings. Pickup magnets are usually aluminum, nickel, and cobalt, often called alnico. Pickup magnets can also be ceramic and occasionally neodymium.

Let's think about this! There are many similarities between acoustic and electric guitars. The guitar body, strings, fretboard, and tuning pegs are easily recognized on both types of guitars. However, there are differences, too. The acoustic guitar is hollow and bulkier, while the electric is thinner and smaller. The sound of the acoustic guitar is magnified by the large soundboard top and through the sound hole, while the electric guitar relies on pickups to convert the vibrations into electrical energy. The electric guitar also has other controls to change the tone, the volume, and even the pitch. And the thick string bass guitar adds a lot to any rhythm section. Encore!

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Make a Homemade Guitar

STEM Challenge

Description

Become a guitar engineer! Design, build, and redesign your own guitar!

Materials:

- Choose from the following.
  - Kleenex boxes
  - Shoe boxes
  - Cardboard tubes
  - Popsicle sticks
  - Rubber bands of different thickness
  - Cereal boxes
  - Wood box
  - String
  - Pencils
  - Toothpicks
  - Paint can
  - Wood boards
  - Fishing line
  - Wire
  - Scissors
  - Glue
  - Tape
  - Hot glue
- Graphics of acoustic guitars, with parts labelled

Procedure

1) Review the materials to design, build, and redesign a homemade guitar.
2) What will you use for the guitar body? Will your guitar have a sound hole and if so, how big?
3) What will you use for strings?
4) How will the strings attach?
5) What will you use for the nut and for the bridge?
6) Are you able to tune your guitar?
7) Record your design notes in My Results. Don't forget to show any redesigning you do!

My Results

Materials I used for which guitar parts (example: shoe box/guitar body)
Some of my steps/My favorite discoveries
What I changed & Why & RESULTS!

Explanation
Building a guitar requires a skilled craftsman, often called a guitar luthier. A luthier can repair or make a guitar. Making a homemade toy guitar offers a unique challenge to build something that is durable, can transmit sound, and has a way to tune the strings, which is probably the most challenging part.

More to think about: We've seen how guitar strings transmit vibrations through the saddle, bridge, and reinforced soundboard, and how sound resonates through the sound hole. We've experimented with how the strings' mass, density, tension, and length determine pitch. How is pitch calculated? The Western music scale has 12 half steps in a single octave, so guitar luthiers divide the playable string so that each fret increases the frequency by 2 to the one-twelfth power. This makes the frequencies go up by one half step in each fret. Pressing the 12^{th} fret shortens the string to half of its original length, so the string will produce a pitch one octave higher. Amazing design!

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