# VANDERBILT STUDENT VOLUNTEERS FOR SCIENCE
**http://studentorgs.vanderbilt.edu/vsvs**

# SOUND AND RESONANCE

**Fall 2018**

**Goal:** To introduce students to sound waves, resonance, and the speed of sound.
Fits TN Standards: 8.PS4.1,, 8PS4.2

## LESSON OUTLINE

1. **Wave Demonstration**
   VSVS volunteers demonstrate compressional and transverse waves with a slinky, an air blaster and wave machine.
2. **Sound is produced by vibrations.**
   Students spin a hex nut inside an inflated balloon and observe that they can feel the balloon vibrating when there is a sound being produced.
3. **Natural Frequency**
   **A. Student Activity**
   Students are introduced to resonance by having them listen to the pitches created in tubes of different lengths.
4. **Introducing Tuning Forks**
   Students are introduced to tuning forks. They note the frequency and corresponding keynote on each fork.
5. **Finding the length of a tube at which resonance is heard**
   Students hit a tuning fork with a mallet and place it at the opening of the shortest of 4 tubes. They listen closely to hear if the volume of the sound has increased. They move the tuning fork to the openings of the other tubes and discover which tube produces resonance. VSVS members will collect the data and write it on the board. The class will learn that longer tubes are needed for the tuning fork with the lower frequency, shorter tubes are needed for the tuning fork with higher frequency and that the same length tube is needed for tuning forks with the same frequency.
   **Optional**
   Students can exchange tuning forks so that they have one that has a different frequency, and repeat the above activity.
6. **Play "Twinkle Twinkle Little Star" with tubes.** Students take one numbered sound tube (Not #0 or # 1) and play a tune by hitting the tubes on their thighs or hands .
7. **Optional: Calculation of the speed of sound**
   Students use the formula, $\mathbf{v = f \times \lambda}$, to calculate the speed of sound. The wavelength is calculated by measuring the length (x 2) of the tube that resonates with the tuning fork.

**1. In the car ride, read through this quiz together as a team. Make sure each team member has read the lesson and has a fundamental understanding of the material.**

Lesson Quiz
1) What are the two kinds of waves? Which category do sound waves fall under?
2) How does the frequency affect the pitch of the sound produced?
3) How does wavelength affect the pitch of the sound produced?
4) What happens when two waves of the same wavelength are in phase with each other? What is this called?

5) The vibration of what causes human eardrums to mimic the movements and allows us to perceive sound?

**2. Use these fun facts during the lesson:**

- The scientific study of sound waves is known as acoustics.
- Since sound is produced by the vibration of air molecules, sound cannot travel through a vacuum (an area empty of matter). Thus, there is no sound in space.
- A violinist produces different notes by pressing down on strings with his/her fingers, thus changing the frequency at which the strings vibrate. A flute player changes pitch by opening and closing holes along the flute, essentially changing the length of a tube.
- Resonance can produce vibrations powerful enough to destroy objects.
  - A singer can break glass by singing a note at the same frequency as the natural frequency at which the glass vibrates. Energy transfers from the sound to the glass until its vibrations become so strong it shatters.
  - Soldiers marching over a bridge can set up extreme vibrations at the bridge's natural frequency and shake it apart. This is why soldiers break step to cross a bridge.
  - In 1940, the Tacoma Narrows Suspension Bridge collapsed after strong wind gusts caused the bridge to vibrate at its natural frequency.
- Sound travels at different speeds through different media. Old western movies show characters putting their ear to steel tracks in order to hear for an oncoming train. This is because sound travels faster through solid objects than through air. Sound travels through water about four times faster than it does through air.
- The human range of hearing is on average from 20 to 20,000 Hertz. The ability to hear sounds at the highest frequencies decreases with age. The Mosquito alarm is a device used to deter loitering by emitting a sound at high enough frequency that only younger people can hear it.
- Some animals, like dogs, have eardrums that can vibrate at higher frequencies than human eardrums, allowing them to hear higher pitches that we can’t, such as training whistles.
- Any frequency that is below the human range is known as infrasound. Ultrasound is any frequency above the range of the human ear. Bats, whales, and dolphins use ultrasound for navigation by emitting sounds and listening for the echoes, a process known as echolocation.

**Materials (for 8 groups)**

| | |
|---|---|
| 16 | 9” balloons with hex nut inserted |
| 3 | garbage bags for inflated balloons with hex nuts inserted |
| 1 | slinky |
| 1 | Air Blaster |
| 1 | Wave machine |
| 6 | 10 oz cups |
| 8 | tuning forks (4 “A”s and 4 “G”s) |
| 8 | mallets |
| 8 | sets of plastic tubing (Each set has 4 different lengths, numbered 0-7. The sets are color coded.) |
| 2 | balloon inflators |
| 16 | Instruction sheets |
| 16 | Observation sheets |

**Warning:** This lesson can be **noisy**. Tell the students that they must stop this activity at a certain signal, e.g. when you turn the lights out, or some other strategy that the teacher uses.

Your Notes:

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

Pre-lesson set-up:

- Inflate enough balloons (use the balloon pumps) so that each **pair** of students can share a balloon. Use the balloon clips to tie-off the balloons (or hand tie). **Do this during Part I., preferably outside the classroom. It is too distracting for the students to see it being done in the room!**
- Put the following vocabulary words on the board: **vibration, pitch, frequency, natural frequency, resonance**
- Refer to these words as you introduce them during the lesson.

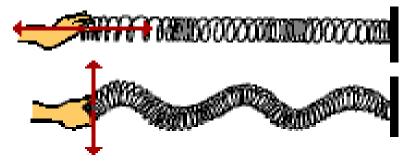
## I. Sound Waves: Demonstrations

### A. Comparing transverse and compressional waves

Materials: slinky

Two VSVS volunteers need to perform this demonstration.

- Hold the slinky so that there is no slack between the two ends.
- Have one volunteer slowly move the slinky up and down (the other volunteer should hold it steady).
    - This is an example of **a transverse wave**. Light waves are transverse waves.

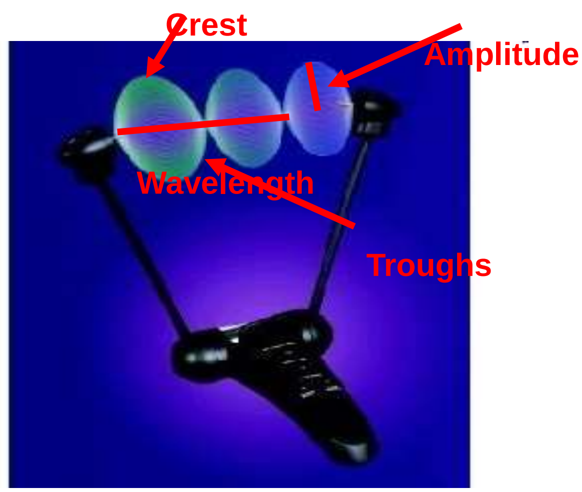


Slinky waves can be made by vibrating the first coil back and forth in either a horizontal or a vertical direction.

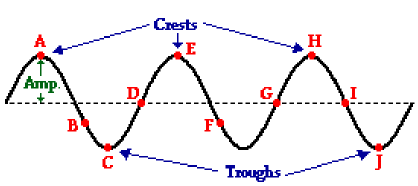
- For the **compressional wave**, have one volunteer pull back on the slinky (as if cocking a spring) and release it. This should result in a pulse traveling down the length of the slinky.
    - Tell students that this is an example of a compressional wave. Sound waves are compressional waves.

Tell students to look at the diagram on their observation sheet. Turn the wave machine on and adjust it so that it has 2 standing waves (see training presentation).

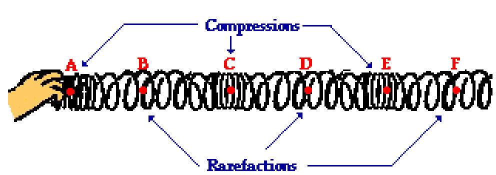
- Point out the crest, trough, amplitude and wavelength




A transverse wave has an alternating pattern of crests and troughs, For a **transverse wave**, the wavelength is determined by measuring from crest to crest..




Transverse wave




Compressional wave

http://www.physicsclassroom.com/class/waves/Lesson-2/The-Anatomy-of-a-Wave

Your Notes:

Tell students that because the coils of the slinky are vibrating longitudinally, there are regions that become pressed together and other regions where they are spread apart.

> A region where the coils are pressed together in a small amount of space is known as a compression. Points A, C and E on the diagram above represent compressions
>
> A region where the coils are spread apart, thus maximizing the distance between coils, is known as a rarefaction. Points B, D, and F represent rarefactions.

A compressional wave has an alternating pattern of compressions and rarefactions.

For a compressional **wave,** a wavelength measurement is made by measuring the distance from a compression to the next compression or from a rarefaction to the next rarefaction. On the diagram above, the distance from point A to point C or from point B to point D would be representative of the wavelength.

**B. Using an Air Blaster:**

**Materials:** Air Blaster and 3 10 oz cups.

- Use the air blaster to demonstrate how a compressional (sound) wave travels.
  - Stack the cups upside in a pyramid on a table. Aim the Air Blaster at them and knock the cups over.
  - The changing air pressure within the compressional wave knocks over the cups

## II. How is Sound Produced

**Materials**

16 balloons with hex nut inserted

- Give each pair an inflated balloon with a hex nut inside. Tell the pairs that each student will do this activity once, and then pass the balloon to the next student.
- Show the students how to make the hex nut start spinning (by making a circular motion with the balloon). Tell the students to start spinning slowly, then faster, and observe what happens. The student should:
  - be able to feel the vibrations
  - feel that the vibrations and sound stop at the same time
  - hear that a higher pitch is made when the hex nut is moving fast
  - hear that the pitch gets lower as the hex nut slows down

- Ask the students what this experiment tells them about sound. Some answers should be:
  - Sound is produced by vibrations.
  - The faster the vibrations occur, the higher the pitch.

**Collect all the balloons. The hex nuts are reused.** Remove the balloon clip, deflate balloons, and return them to the kit box.

## III. What is Natural Frequency?

**Materials**

8 sets of plastic tubing (each set has 4 different lengths, numbered 1, 3, 5, 7 or 0, 2, 4, 6).

**Student Activity**

Ask the students if they have ever held a seashell to their ear to “hear the ocean”? Tell them that they are not hearing the ocean, but are hearing the air vibrating inside the shell, at the **natural frequency** of the shell.

Your Notes:

____________________________________________________________________________

____________________________________________________________________________

____________________________________________________________________________

Tell the students they must be quiet so that they can hear the pitch of the sound in their tubes.

- Give each group one set of the plastic tubes.
- Tell each student to hold one of the tubes to an ear and listen.
- Then have pairs of students exchange tubes so that they can listen to a different length of tubing.
- Ask the students what they hear:
    - The pitch of the sound changes with the length of the tube.
    - The shorter tube produces a higher pitch.
    - The longer tube produces a lower pitch.
- Have the students look at the diagram on their Instruction Sheet, and explain to them that **lower** frequencies have **longer** wavelengths. Resonance occurs when the wavelength "fits" the tube's length.

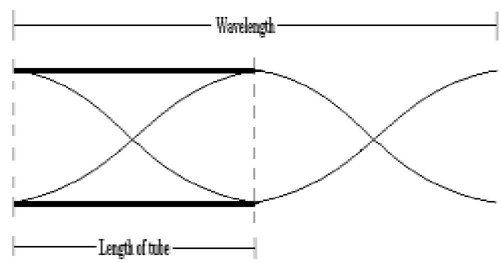
| |
|---|
| **For VSVS members only:** The length of the tube is actually half the wavelength. |

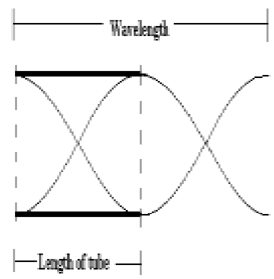
**Demonstration:**

Look to make sure you won't hit anything.

Slowly twirl the longer tube so that a *constant* low pitch is heard.

- Twirling the tube forces air up the tube.
- The ridges in the tube makes the tube and its air **<u>vibrate</u>**.
- Since the tube always produces the same **<u>pitch</u>**, the **<u>frequency</u>** of the wave produced by the tube is always the same.
- This frequency that the tube vibrates at is called its **<u>natural frequency</u>**.




Explain to the students that the sound is produced in the following manner:

- The tube always produces the same **pitch**, and the **frequency** of the wave produced by the tube is always the same.
- The frequency that the tube vibrates at is called its **natural frequency**.

- Explain that the tubes have different **natural frequencies.**
- Each tube vibrates at its **natural frequency**.
- This **natural frequency** is determined by the **length** of the tube.
- When the frequency of sound in the air matches the **natural frequency** of the tube, it gets reinforced many times so that the sound is magnified and can be heard above the rest of the sound mixture. This is called **resonance.**

Ask the students if they can tell you some other simple examples of **resonance**.
Some examples include:

- A window will vibrate and buzz when a particular note comes from a radio or stereo.

Your Notes:

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

- A swing will go much higher if the person on it pumps at just the right time. The timing is more important than the force of the pump. Small pumps or pushes, done in rhythm with the natural frequency of the swing, will make the swing go higher than strong pumps at the wrong time.
- Buildings can be severely damaged in an earthquake if their natural frequency matches the frequency of the waves created by the earthquake.

To reinforce the fact that each tube produces a different pitch, have all students holding tube #0 hit the tube on the palm of their hand. Then tell all students holding tube #1 to hit the tube on the palm of their hand. Continue with all tubes so that the students can hear a complete scale.

## IV. How Do Tuning Forks Work?

### Do not pass out the tuning forks and mallets until you have discussed the properties of tuning forks and how to use them.

**Materials**
8 mallets
8 sets of plastic tubing (each set has 4 different lengths, numbered 1, 3, 5, 7 or 0, 2, 4, 6).
8 tuning forks (4 of one frequency and 4 of another)

Ask the students what they know about tuning forks. Be sure to include the following information in the discussion.

- Tuning forks are usually made of metal.
- They have a handle and two tines that can vibrate when struck.
- These vibrations are so fast that they are impossible or very difficult to see.
- Each tuning fork is made to vibrate at **one frequency**, which is written on the fork. This frequency is its natural or resonant frequency.
- The number of times the tines vibrate in one second is called the **frequency**.
  **Frequency** is directly related to **pitch**.

**The faster the vibrations occur, the higher the frequency and the higher the pitch.**

Show the students how to hold the tuning fork at the **handle** and to hit the **tines** of the fork with the black rubber side of the mallet so that the fork produces a sound.

Show them that the sound is stopped as soon as the tines stop vibrating (do this by touching both tines).

**Caution the students NOT to hit the tuning forks on a hard surface.**

Give each group a mallet and the tuning fork that corresponds to the set of tubes that each group was given.

**Set 0,2,4,6, (orange numbers) needs the "A" tuning fork**
**Set 1,3,5,7 (green numbers) needs the "G" tuning fork**

**Note:** There are 4 different lengths of tubing in each set. Make sure the groups have kept the sets labeled 0,2,4,6 or 1,3,5,7 along with the correct tuning fork.
**Note:** The class will use 2 different tuning forks, so the students should be aware that different groups will get different results!

Your Notes:

___

___

___

- Tell the students to look for the **frequency** number on the fork. Tell them to look for a **letter** as well.
- Tell the students to record the letter and number on their observation sheets. The letter and number will correspond to one of the sets in the table below (and on their instruction sheets). Tell them that the **letters** correspond to only 1 note on the piano, the **pitch.**

**Table of tuning fork frequencies and corresponding notes**

| Frequency | Keynote |
| --- | --- |
| 440 | A |
| 392 | G |

- Have ONE student in the group strike the **tines** of the fork with the black rubber side of the mallet so that the fork produces a sound and have the rest of the group listen for the sound.

This may have to be done a few times for everyone to hear it. Caution the students to avoid touching the vibrating tines unless they want to deliberately stop the sound.

- Remind the students that a tuning fork vibrates at a frequency that produces a special pitch.
- Ask the students if they can anticipate what will happen to the sound from a tuning fork if we match the natural frequency of the tuning fork with the natural frequency of a tube?
  *The sound will become **louder** when the tuning fork and tube have matching frequencies because of resonance.*
- Tell the students that this is what they need to be listening for in the next experiment.

## V. Finding the Length of a Tube at Which Resonance is Heard

Tell the students that they are going to find the length of tubing that will resonate with their tuning fork, and that these lengths will depend on the fork they are using. Tell the students to be quiet during this demonstration or the resonance will not be heard.

Tell the students to do the following:

- Place the set of tubes on the table in their **numbered order.** Leave about 3" between each tube.
- Place the tines of the tuning fork at the opening of the shortest tube.
- Hit the tuning fork to start it vibrating and listen for the resonance.
- Move the tines to the opening of the next tube and repeat. Continue doing this until the resonant sound increases to its loudest level.
- Continue moving the fork to the openings of the remaining longer tubes to show that the volume of the sound is no longer loud.
- Record the number of the tube that gives the loudest resonance.

Have one VSVS member record the results on the board, including the number and corresponding length of tube.

Ask the students what observations they can make about these measurements. They should observe that:

- **Longer** tubes are needed for the tuning fork with the **lower** frequency.
- **Shorter** tubes are needed for the tuning fork with **higher** frequency.
- The **same** length tube is needed for tuning forks with the **same** frequency.

Your Notes:

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

**Optional (time permitting):** Have the students exchange tuning forks **and** tubes so that they now have a tuning fork with a different frequency. Repeat the experiment with the second tuning fork, and record the results.

## VI. Play "Twinkle Twinkle Little Star" with the Tubes

All students can do this, with one tube each. If the class is noisy have three VSVS volunteers do it.

- Have each person take one numbered sound tubes (2&3, 4&5, 6&7). Note that #'s 0 and 1 do not play
- To play a note, just whack the tube (that corresponds to the correct note) on your thigh or hand (NOT a table).

This tune is taped to the inside of the kit lid.

**Twinkle Twinkle, Little Star**

7 – 7 – 3 – 3 – 2 – 2 – 3

4 – 4 – 5 – 5 – 6 – 6 – 7

3 – 3 – 4 – 4 – 5 – 5 – 6

3 – 3 – 4 – 4 – 5 – 5 – 6

7 – 7 – 3 – 3 – 2 – 2 – 3

4 – 4 – 5 – 5 – 6 – 6 – 7

## VII. Calculating the Speed of Sound

Do this if you you have time. Otherwise, leave it for the teacher to do.

- The speed of sound in air at 68ºF is 344m/s (meters per second).
- The speed of sound can be calculated using the following formula:

$$\mathbf{v = f \times \lambda}$$

Speed (**v**) = frequency (**f**) x wavelength (**λ**)

- The speed can be calculated by using an **open-ended** tube.
- The frequency is obtained from the inscription on the tuning fork (or the Table).
- The wavelength is found by measuring the length of the tube that the tuning fork resonates in and multiplying this by **2.** This measurement must be converted to **meters.**

Tell the students to enter their measurements and observations on the observation sheet and to follow the steps to complete the calculation.

Lesson written by: Pat Tellinghuisen, VSVS Director
Walter Saba, Undergraduate Teaching Fellow, Vanderbilt University

Your Notes:

___

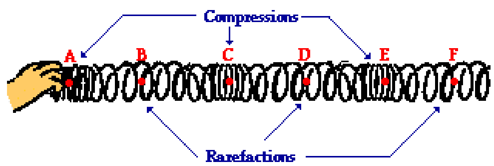
___

___

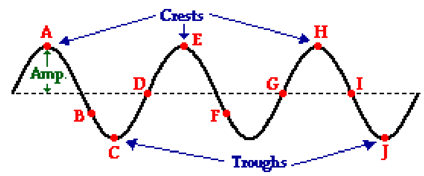
# SOUND AND RESONANCE

## Observation Sheet

**Names** ________________________________________________




Compressional wave




Transverse wave

http://www.physicsclassroom.com/class/waves/Lesson-2/The-Anatomy-of-a-Wave

| **Tuning fork frequency** | **Keynote** | **Which tube (#) produced the loudest resonance?** |
|---|---|---|
| | | |
| | | |

**Length of tube**

| Tube number | Length of tube |
|---|---|
| 0 | 30.6cm = .306m |
| 1 | 32.2cm = .322m |
| 2 | 36.5cm = .365m |
| 3 | 41.1cm = .411m |
| 4 | 465cm = .46m |
| 5 | 49.3cm = .493m |
| 6 | 55.1cm = .551m |
| 7 | 63.5cm = .635m |

## Calculation of Speed of Sound (Optional)

**v = f x λ**

Speed (**v**) = frequency (**f**) x wavelength (**λ**)

1. The **FREQUENCY (f)** of the tuning fork =________________Hz
   (Shown on the fork)

2. Number on tube that resonates with tuning fork =________________

3. Length of this tube =________________meters
   (Look at the "Length of Tube" **Table above.)**

**4. The WAVELENGTH (λ)** of sound = length of tube x 2 =________________meters

5. Speed of sound = wavelength x frequency
   = value in #4 x value in #1. =________________ m/se

# Observation Sheet - Answers

| **Tuning fork frequency** | **Keynote** | **Which tube (#) produced the loudest resonance?** |
|---|---|---|
| 440 | A | #2 |
| 392 | G | #3 |

**Length of tube**

| Tube number | Length of tube |
|---|---|
| 0 | 30.6cm = .306m |
| 1 | 32.2cm = .322m |
| 2 | 36.5cm = .365m |
| 3 | 41.1cm = .411m |
| 4 | 465cm = .46m |
| 5 | 49.3cm = .493m |
| 6 | 55.1cm = .551m |
| 7 | 63.5cm = .635m |

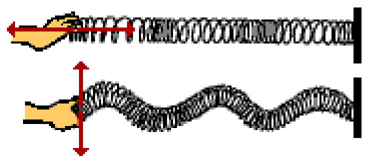
## Calculation of Speed of Sound (Optional)

| | | |
|---|---|---|
| 1. The **frequency** (**f**) of the tuning fork (shown on the fork) | = 440 Hz | = 392 Hz |
| 2. Number on tube that resonates with tuning fork | = #2 | = #3 |
| 3. Length of this tube (Look at the Length of Tube Table above.) | = .365 meters | = .411 meters |
| 4. The **wavelength** (**λ**) of sound = length of tube x 2 | = .73 meters | = .822 meters |
| 5. Speed of sound = wavelength x frequency<br>= value in #4 x value in #1. | = .73 x 440<br>=321.1 m/sec | =.822 x 392<br>=322.2 m/sec |

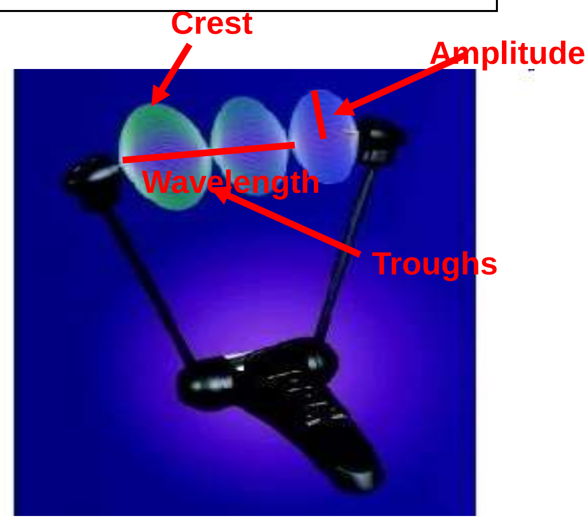
**Instruction Sheet**
**Sound and Resonance**

**Warning!** This lesson can be **noisy**. You must **stop** an activity when a VSVS member tells you.

## 1. Wave Demonstration by the VSVS Team




Slinky waves can be made by vibrating the first coil back and forth in either a horizontal or a vertical direction.

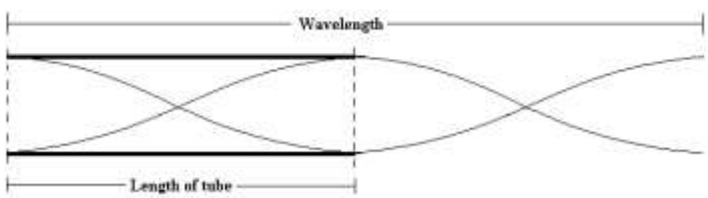


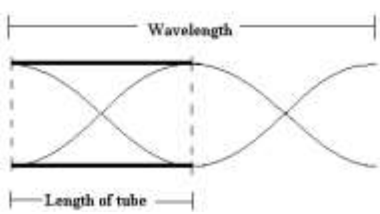

## 1. How is Sound Produced?

- Each pair has an inflated balloon inserted with a hex nut. Once you have done this activity, pass the balloon to the next student.
- Start spinning the hex nut by making a circular motion with the balloon. Start spinning it slowly and then faster. Observe what happens.
- What does this experiment tell you about sound?
- Return the balloons to a VSVS member.

## 3. What is Natural Frequency? Demonstration by the VSVS Team

- Listen to the different pitches produced by the twirling “whistling tubes”.
- Look at the diagram below and note that **lower** frequencies have **longer** wavelengths. **Resonance** occurs when the wavelength fits the tube.




Your Notes:

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

**3B. Student Activity**

- You must be quiet so that you can hear the pitch of the sound in the tubes.
- Hold one of the tubes to an ear and listen.
- Exchange tubes so that you can listen to a different length of tubing.
- What do you hear?
- Where does the sound come from?
- Think of some other simple examples of **resonance**

**4. How do Tuning Forks Work?**

- What do you know about tuning forks?
- Look for the frequency number on the fork. Look for a letter as well. Record the letter and number on your observation sheet.
- One student in your group should strike the <u>tines</u> of the fork with the black rubber side of the mallet. This will make a sound. ***Only hit the tuning fork with a mallet!***
- The rest of the group should listen to the sound.
- Avoid touching the vibrating tines unless you want to stop the sound.
- What do you think will happen to the sound of the tuning fork if we match the natural frequency of the tuning fork with the natural frequency of a tube?

**5. Finding the Length of a Tube at Which Resonance is Heard.**

- Place the set of tubes on the table in their numbered order.
- Place the tines of the tuning fork at the opening of the shortest tube.
- Hit the tuning fork with the black rubber side of the mallet to start it vibrating and listen for the resonance.
- Move the times to the opening of the next tube and repeat. Continue doing this until the resonant sound increases to its loudest level.
- Continue moving the fork to the openings of the remaining longer tubes to show that the volume of the sound is no longer as loud.
- Record the number of the tube that gives the loudest resonance.

A VSVS member will record the class results on the board

- What do you observe about the measurements?

Optional:

- Exchange the tuning forks and the tubes so that you have a tuning fork with a different frequency.
- Repeat the experiment and record your results.

**6. Play a tune with the tubes.**

**7. Calculating the Speed of Sound: Optional**

- Enter your measurements and observations on the Observation Sheet and follow the steps to complete the calculation.
- Enter your measurements and observations on the Observation Sheet and follow the steps to complete the calculation.

Your Notes:

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________