COLLABORATIVE FOR STEM EDUCATION AND OUTREACH

SOUND AND RESONANCE

Fall 2022

Goal: To introduce students to tuning forks, resonance, and the speed of sound.

Associated TN State Standards:

8.PS4.1 Develop and use models to represent the basic properties of waves including frequency, amplitude, wavelength, and speed.

8.PS4.2 Compare and contrast mechanical waves and electromagnetic waves based on refraction, reflection, transmission, absorption, and their behavior through a vacuum and/or various media.

LESSON OUTLINE

I. How is Sound Produced?

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.

II. Sound Waves: Demonstration

Instructors demonstrate longitudinal and transverse waves with a slinky.

III. What is Natural Frequency?

A. Demonstration

Instructors twirl "whistling tubes" of two different lengths to show that two different pitches are created. The pitch and frequency created depends on the length of the tube and is called the natural frequency of the tube.

B. Student Activity

Students are introduced to resonance by having them listen to the pitches created in tubes of different lengths.

IV. How Do Tuning Forks Work?

Students are introduced to tuning forks. They note the frequency and corresponding keynote on each fork.

V. 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. Instructors 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.

VI. 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 .

VII. Optional: Calculating The Speed of Sound

Students use the formula, **$v = f \times \lambda$,** 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.

Materials (for 8 groups)

16	9" balloons with hex nut inserted
16	balloon clips
3	garbage bags for inflated balloons with hex nuts inserted
1	slinky
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	"whistling" tubes of different lengths
2	balloon inflators
8	calculators
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.

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 in the car on the way to the school (and put into a garbage bag), or outside the classroom. It is too "exciting" 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. 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.

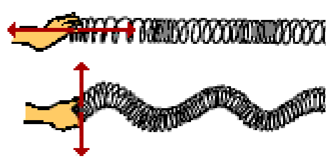
II. Sound Waves: Demonstration

Materials:
Slinky

Two instructors need to perform this demonstration.

- Hold the slinky so that there is no slack between the two ends.
- For the longitudinal 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 longitudinal wave. Sound waves are longitudinal waves.
- 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.

- Today we will be talking about sound waves.


Longitudinal wave
Transverse wave

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

www.physicsclassroom.com/Class/waves/U10L1a.html

III. What is Natural Frequency?

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

A. Demonstration

Show the students the whistling tubes. Before you do the following demonstration, **look to make sure that you will not hit anything!**

Slowly twirl the longer tube so that a **constant** low pitch is heard. At this point, do not increase the spinning speed.

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

- Twirling the tube forces air up the tube.
- The ridges in the tube make the tube and the air **vibrate**.
- 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**.

Background: the lowest pitch heard is called the fundamental frequency. Other pitches (higher) can also be heard if the tube is swung faster. These pitches occur at fractions of the fundamental frequency and are called overtones.

Show the students the second **shorter** tube, and repeat the demonstration. You will have to twirl this shorter tube a little faster to hear the pitch.
Ask the students how the pitch is different than the pitch of the first tube.

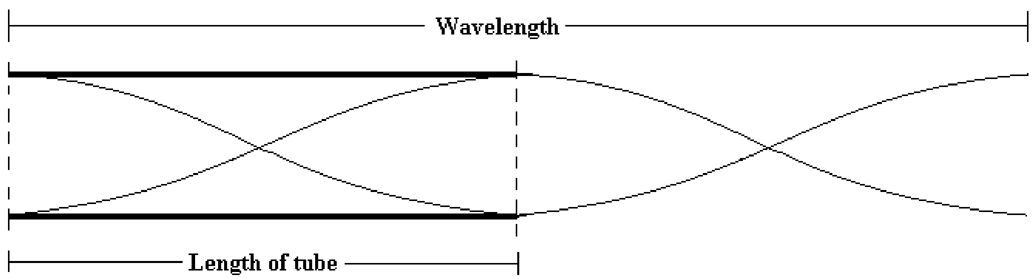
The pitch from the shorter tube is higher.

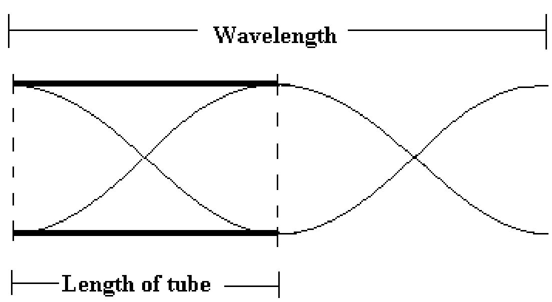
Note: if the pitch of the second shorter tube is lower than the first, repeat the demonstration. The longer tube was twirled too fast to get its lowest frequency.

- Explain that the two 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.**

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.

Background: The length of the tube is actually half the wavelength.





B. 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.

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.

Ask students: where does the sound come from?
The noise in a room is a mixture of different frequencies. These frequencies are heard as a low hum.

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.
- 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 with the palm of their hand. Then tell all students holding tube #1 to hit the tube with 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!

- 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.*
- 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 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 instructor 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.

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 Tubes

All students can do this, with one tube each. If the class is noisy have the instructors 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).
- To add harmony, play the notes in parentheses at the same time as the note above it.

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

Twinkle Twinkle, Little Star

7 – 7 – 3 – 3 – 2 – 2 – 3
(5)
4 – 4 – 5 – 5 – 6 – 6 – 7
(5)
3 – 3 – 4 – 4 – 5 – 5 – 6
(4)
3 – 3 – 4 – 4 – 5 – 5 – 6
(4)
7 – 7 – 3 – 3 – 2 – 2 – 3
(5)
4 – 4 – 5 – 5 – 6 – 6 – 7
(5)

VII. Optional: Calculating the Speed of Sound

Do this if you feel the class can do the math and you have time. Otherwise, leave it for the teacher to do.

- The speed of sound in air at 68°F 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 originally written by the Vanderbilt Students Volunteers for Science. For more information on this lesson, visit https://studentorg.vanderbilt.edu/vsvs/

Lesson credit to: Pat Tellinghuisen, Former VSVS Director
Paige Ellenberger, VSVS Coordinator
Walter Saba, Undergraduate Teaching Fellow, Vanderbilt University

SOUND AND RESONANCE
Observation Sheet

Names ____

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/sec

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 = value in #4 x value in #1.	= .73 x 440 =321.1 m/sec	=.822 x 392 =322.2 m/sec

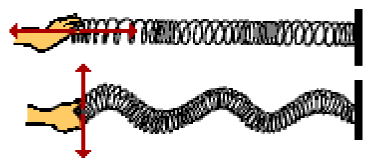
Instruction Sheet
Sound and Resonance

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

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 an instructor.

2. Sound Waves: Demonstration



Longitudinal wave

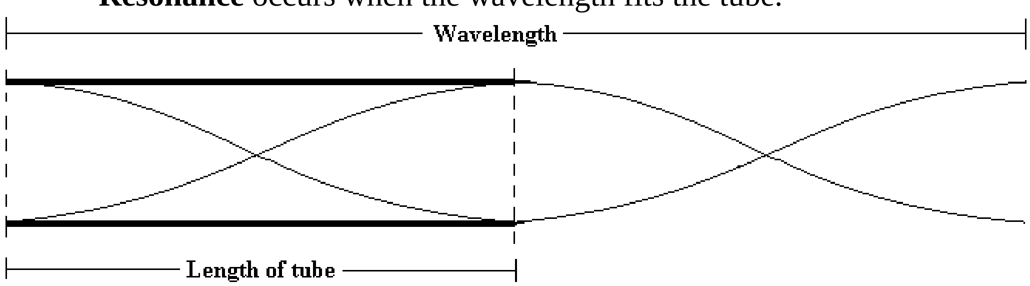
Transverse wave

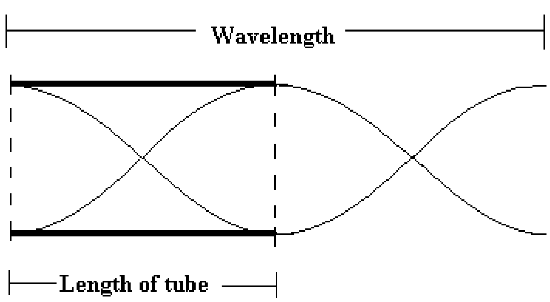
Slinky waves can be made by vibrating the first coil back and forth in either a horizontal or a vertical direction.

3. What is Natural Frequency?

3A. Demonstration

- 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.





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.

An instructor will record the class results on the board

- What do you observe about the measurements?

If the teaching team decides there is enough time:

- 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 "Twinkle Twinkle Little Star" with Tubes

7. Optional: Calculating the Speed of Sound

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

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