SOUND

IDEA TO REMEMBER!

Sound is a pressure wave derived from vibration!

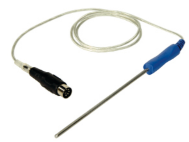
OBJECTIVE:

Understand the wave nature of sound and how it relates to the various properties of sound.

MATERIALS:

PASCO Interface

Wireless sound sensor



Temperature sensor

Keyboard

PVC pipe

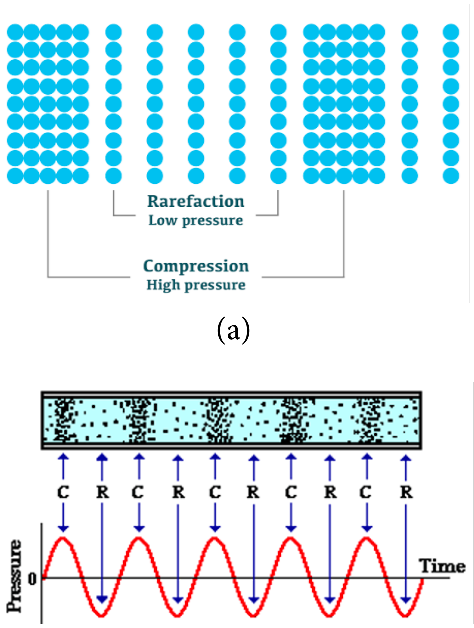
Meter stick

CONCEPT:

Sound is produced when an object vibrates, creating a pressure wave. Think of this "wave" as an expanding bubble centered on the sound source, and is often a rhythmic pattern of high and low-pressure regions. These are referred to as **compressions** and **rarefactions**, respectively. <u>The medium (air, liquid or solid) actually changes **density** as the particles compress and decompress from the back and forth oscillation of the source!</u> As the particles vibrate, they transfer energy to other nearby particles, thus, sound is transmitted through the medium. This is illustrated in Figure (1a), and Figure (1b) illustrates how the varying pressure regions translate into a sinusoidal, longitudinal wave pattern that is periodic in nature.

THINK: What kind of wave was produced from the string vibrator in the standing wave on a string lab demonstration? Longitudinal or transverse?

In this lab we will cover three different sound topics: *sound detection*, *the speed of sound*, and *the mathematics of music!*



(a)

(b)

Figure 1

Sound Detection

Humans and many animals detect sound when vibrating air particles hit and vibrate the eardrum. Much like the eardrum, a microphone, or sound sensor, contains a diaphragm that vibrates in response to vibrations in the air pressure, which is converted to an electrical signal (voltage) to serve as an input to a sound processing system (brain or computer). In this lab use will use a sound sensor to detect and explore the wave nature of sound and how the features of the wave relate to some properties of sound, namely, *loudness* and *pitch*.

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THINK: What is the loudness and pitch of sound in relation to wave properties?

Speed of Sound

Think of your favorite instrument producing a single, constant sound at a concert hall or theater. Now imagine jumping into a pool directly in front of the stage, or imagine surrounding the musician with glass. The sound you hear would be different for each case because the sound would travel through different media (gas, liquid, or solid), where the speed of sound varies through each medium. This depends on the type of interaction between the atoms that make up the medium. The *stronger* the attraction between the particles, the *faster* the sound wave travels through it. Likewise, the speed of sound also depends on the density of the medium: the *lower* the density of the material, the *faster* the speed of sound.

THINK: Can you predict the order of speed a sound wave through water, air, plywood, concrete, steel, glass, and sound-dampening foam?

As you saw in the Resonance Tube lab, the speed of sound in air v travels 331.3 m/s @ 0°C and increases with the square root of absolute temperature T_C:

$$v = (331.3 + 0.606T_C)\frac{m}{s} \tag{1}$$

We will ignore that sound is affected by humidity for the sake of simplicity. This lab uses an active sonar/radar technique of sending a sound wave and waiting for the return echo. This allows us to calculate the speed of sound with a known distance. See Figure (2).

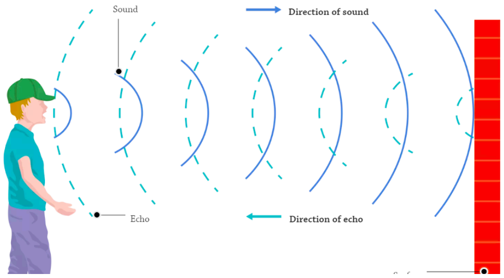

Figure 2

Mathematics of Music

The musical scale used in western music originated with the ancient Greeks. This is called a *diatonic scale* and even non-musicians are familiar with it as *do-re-me-fa-sol-la-ti-do*. This scale can be played with the white keys on a piano keyboard, starting with C. There are eight notes from *do* to *do*. This range of notes is called an **octave**. Over time, five more notes were added to the western musical scale. This 12-note scale is called a *chromatic scale*. For a scale starting with C, the five extra notes are played on a piano keyboard by pressing the black keys.

Musical scales are tied closely to mathematics. You will use your sound sensor to record the waveform of the sound that is produced. Your challenge is to measure the frequencies of all the notes of a chromatic scale and then to determine mathematical patterns.

Figure (3) shows a sample wave of C4 on the same electronic keyboard you will use. The complexity of the wave is due to *overtones*, which are other resonant frequencies. Overtones are what make every musical instrument unique; many instruments are designed to play the standard harmonic frequencies of the scales but the overtones come from the vibration of the instrument body and components, and these vibrations add other frequencies to the primary wave to create the unique sound.

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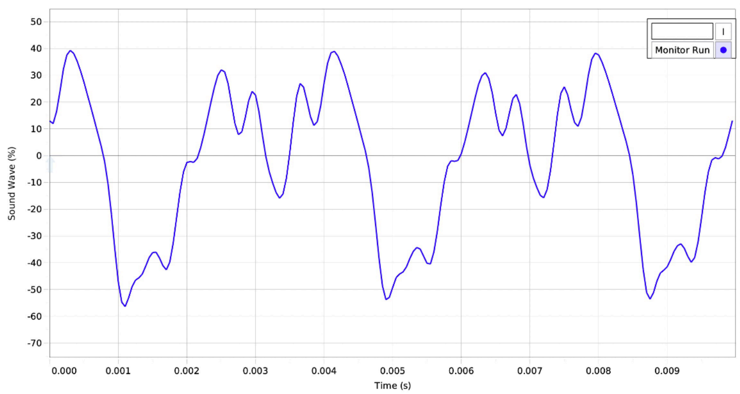

Figure 3

Real World Applications

- Humans can normally hear sound frequencies 20–20,000Hz, but anything higher is called an *ultrasonic* sound. While we cannot hear ultrasonic waves, some animals do hear ultrasonic waves, such as cats and dogs, and some animals produce and hear ultrasonic waves in a specialized technique called **echolocation** that allows them to pinpoint objects and other animals, even in the dark.
- We can apply sound to create technologies such as **radar** and **sonar** systems, sonograms, surgical tools, and cleaning systems.
- The **Mach number** represents the ratio of flow velocity past a point on an object's surface (or boundary) to the local speed of sound. It is named after the Moravian physicist and philosopher Ernst Mach.
- A blind or vision-impaired person develops a heightened perception or more refined processing of sound waves.

1) Sonar on a nuclear submarine!

2) Shooting a baseball faster than the speed of sound!

PRECAUTIONS:

Not much for worry! Have fun and learn!

PROCEDURE:

Part 1

1. ☐ Fill out the top information on the worksheet **and** complete the memory exercise—Questions M1–M3.

2. ☐ REQUIRED: Read the *Concept* section.

3. ☐ Setup Capstone as shown in Figure (4).

   3.1. Connect the sound sensor to the PASCO Interface.

   3.2. Open the PASCO Capstone software on your computer and click on *Hardware Setup* on the left sidebar.

   3.3. Under *Available Wireless Devices*, select the wireless sound sensor with the **matching six-digit code** on your device.

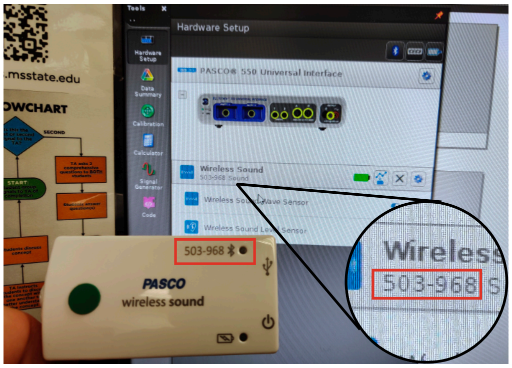

Figure 4

4. ☐ Connect the keyboard to power, turn it on, and place the sound sensor on one of the keyboard speakers.

5. ☐ Double-click on *Scope* on the right sidebar, and change the vertical axis to *Sound Wave (%)*. Change the data collection mode to *Fast monitor* and then change the sampling rate to 20kHz.

6. ☐ Click on *Monitor* and hit the C4 key on the keyboard. **Click *Stop* while the sound is still playing to capture the sound wave.**

7. ☐ Click on *Scale axes* to zoom in on the wave generated.

8. ☐ Select the *Add Coordinate tool* and position the tool at two consecutive peaks to measure the time

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CONCEPT & PROCEDURE VIDEOS:

difference. You may need to increase the decimal places of the tool: right-click > *Tool Properties* > *Numerical Format* > *Horizontal Coordinate* > increase the value of *Number of decimal places* to 4.

9. ☐ Record the time data for the note in Table 1 on the worksheet and calculate the values for the rest of the fields in Table 1.

10. ☐ Repeat steps 7–10 to complete Table 1. Figure (6) labels the keyboard notes and octaves.

11. ☐ Answer Question 1 on the worksheet.

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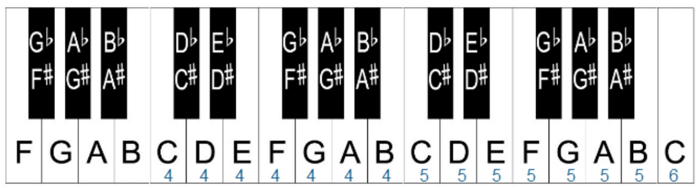

Figure 6

Part 2

Now, it's time to turn the microphone on to you!

1. ☐ Click *Monitor* and hum into the microphone. Try to produce a smooth wave (it's not easy).

2. ☐ Take a look at vowel sounds one at a time—"aaaaa", "eeeee", iiiii"… Click *Monitor* and *Stop* while you are still making the sound to analyze the waves. Look at the difference between you and your partner's "aaaaa" sound. Try with your mouth closed and then open.

3. ☐ Answer Question 2 on the worksheet.

4. ☐ Play a C4 on the keyboard and try to mimic the sound. Find the primary wave period for your attempt and answer Question 3 on the worksheet.

5. ☐ Click *FFT* on the right sidebar. Set the vertical axis to *Sound Wave (%)*. Notice the frequency range for your voice.

6. ☐ Look at a variety of human sounds—cough, hiss, snap your fingers, etc.

7. ☐ Sometimes you can whistle a smooth wave. Try this and answer Question 4–5 on the worksheet.

Part 3

1. ☐ Measure the inner length of the PVC pipe using the meter stick and record it in Table 2 on the worksheet.

2. ☐ Click *Scope* on the right sidebar, set the vertical axis to *Sound Wave (%)*, set the data collection mode to *Fast Monitor Mode* and the sample rate to 20 kHz.

3. ☐ Place the wireless sound sensor at the open end of the PVC pipe.

4. ☐ Activate the scope trigger ( ) -- a green arrow should appear on the y-axis of your graph. Drag the arrow up to 10 on the y-axis.

5. ☐ Click *Monitor*, grab two pens and sharply hit them together (be careful not to double-hit or hit the equipment) close to the wireless sound sensor. Click *Stop* and then click the auto-scale ("Adjust y-axis scale to fit data") button ( ).

6. ☐ A good trial will show the sound of the original diminishing significantly followed by a sudden increase in Sound Wave (%). If you don't see a convincing echo return, click *Monitor* and continue to tap your pens until you get a good trial.

7. ☐ Click the first peak of your echo and then click the "crosshairs" icon. Again, increase the decimal places of the tool: right-click > *Tool Properties* > *Numerical Format* > *Horizontal Coordinate* > increase the value of *Number of decimal places* to 4.

8. ☐ Record this time value in Table 2 and complete calculations in table.

9. ☐ Repeat procedure with longer PVC tube and follow the **Let's THINK!** instructions below.

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How to move around in a Capstone graph:

Let's THINK!

- **Ask questions**: What are you learning here?... Why is this Physics concept important and how can it be used?... What do you not understand?... (For more information on this Physics topic, scan the QR codes in the *Real World Applications* and at the start of the *Procedure* section.)
- **Discuss** the concept and demonstration with your partner to help each other understand better. Discussion makes learning active instead of passive!
- For **FULL PARTICIPATION [15 points]** you must call on the TA when you have finished your group discussion to answer some comprehensive questions. If you do not fully understand and the TA asks you to discuss more, you must call on them one more time to be dismissed with full marks.
- **CONCLUSION [10 points]**: In the Conclusion section at the end of the worksheet, write 3 or more sentences summarizing this concept, how this lab helped you understand the concept better, and the real world implications you see. Do you still have questions? If so, write those as well.

Updated Date	Personnel	Notes
2022.09	Chase Boone, Bernard Osei, Ahmad Sohani	2022 Summer Improvement: Created new format.
2023.09	Bob Swanson	Improved part 3 of procedure.

Name: ______________________________ *PH2233* Section #: __________

Name: ______________________________ TA Name: ____________________

SOUND
WORKSHEET [70 points]

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Memory exercise [each 2 extra credit points]**:**

M1) Harmonics are ______________________________

M2) Every object resonates at a ______________________________

M3) Oscillations are driven by ______________________________

Part 1

Table 1: Keyboard data [16 points; ~0.3 point per cell]

Note	Time 1 (s)	Time 2 (s)	Frequency f (Hz)	Difference from previous note Δf (Hz)	Ratio to previous note	Ratio to C4
C4						1.0
D4						
E4						
F4						
G4						
A4						
B4						
C5						
C6						

1) Do you notice any patterns? [5 points] ______________________________

Part 2

2) Was open or closed mouth a cleaner wave? Why? [5 points]

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3) What is the calculated frequency you produced when mimicking the piano? What is the frequency difference between you and the piano? How many overtones do you see in your voice? [10 points]

4) Were you able to make a "pure" wave when making human sounds? How? Who made the better sound? [2 points]

5) What physics term is related to what musicians refer to as *pitch*? What about *loudness*? [2 points]

Part 3

Table 2: PVC tube data [12 points; 1.5 points per cell]

Length of tube L (m)	Time for echo (s)	Measured speed of sound v (m/s)	Room temp. T_C (°C)	Theoretical speed v (m/s)

Show your work for Table 2. [8 points]

Conclusion

Write 3 or more sentences summarizing this concept, how this lab helped you understand the concept better, and the real world implications you see. Do you still have questions? If so, write those here as well. [10 points]

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