SOCIETY OF PHYSICS STUDENTS

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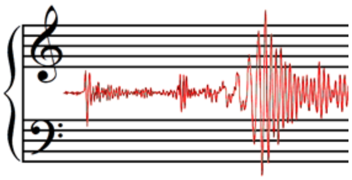

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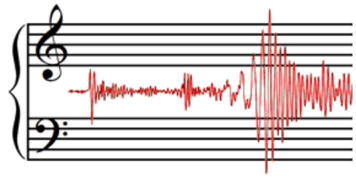


Proudly presents…♫♬♪♩♩

ARE YOU READY TO

SOCK?!!?!

Science Outreach Catalyst Kit

Exploring concepts in the Physics of ***Sound Waves***

Coming to a science outreach event near you!

2015 – 2016

This manual was produced as part of the Society of Physics Students internships program. For more information regarding the experience of being an SPS Summer intern, please visit:

http://www.spsnational.org/programs/internships/

For more information about the SPS **SOCK** program, as well as electronic copies of the manuals from previous **SOCK**s:

http://www.spsnational.org/programs/socks/

For more information about the Society of Physics Students, see

http://www.spsnational.org/

or email us at sps@aip.org or sps-programs@aip.org

2015 SPS SOCK Interns
Hannah Pell, Lebanon Valley College
Shauna LeFebvre, Union College

“If you want to find the secrets of the universe, think in terms of energy, frequency and vibration.”

Nikola Tesla

Table of Contents

*Dear **SOCK** Recipient,*

Congratulations on receiving the **SOCK** for your pursuit of science outreach! Science outreach events are important ways to promote the fun and necessity of science in your community, as well as to strengthen your understanding of and ability to effectively communicate the ideas and physical concepts that are explored. We decided to focus this year's **SOCK** specifically on sound waves and acoustics in an effort to take the **SOCK** in a whole new direction, as well as intertwine our mutual musical experience into the science. The **SOCK** is arranged like a "band in a bag"; there are four main sections: *strings*, *winds*, *percussion*, and *vocals,* with each individual section exploring introductory properties of sound related to the physics behind it, as well as additional demonstrations. In it we address physical properties of waves and important vocabulary for discussing acoustics, and include ***Did You Know?*** blurbs with further applications to the physics concepts.

The **SOCK** is an excellent tool for starting or expanding your chapter's outreach program. Be sure to read the manual thoroughly and *practice* the demonstrations and activities beforehand. Preparation is the key to a fun and informative outreach event, and we hope to have provided as much information as possible to allow you to do so! The **SOCK** is just the beginning though; if your chapter finds additional resources or new activities and lessons which would be beneficial to the **SOCK**, let us know! Send us reports, videos, or pictures from your outreach events. We would love to hear from you!

We hope that your chapter enjoys exploring the physics of sound, and finds success in all of your science outreach endeavors. Always remember, physics is fun! Thank you and congratulations on receiving a **SOCK** and for promoting physics within your community. If you have any questions, suggestions, or feedback of any kind, please be sure to contact us at sps@aip.org.

Now, go get ready to ***SOCK ON***!

Hannah Pell, Lebanon Valley College

Shauna LeFebvre, Union College

2015 Society of Physics Students SOCK Interns

Guidelines for the SOCK Manual

Planning an Effective Outreach Event: This section includes our suggestions for how the participants can get the most out of your outreach events using the **SOCK** as well as our reflections from outreach events this summer to provide additional insight from our experiences.

Items in the SOCK: A list of the items included in the **SOCK**, along with how much they cost and where to get them if you need more.

Contents Summary: Use this to quickly determine which activities to use in your outreach event. Each activity is listed with what outreach events the activity is ideal for (science fair, classroom, etc.), what type of activity it is (lab activity, hands-on, lesson, etc.), our motivation for including each activity, and a short summary.

Demonstrations and Activities: These are the actual instructions for the activities included. They have been organized into different sections:

- Motivation: Our primary reason and goal for including the activity in the **SOCK**.
- Objectives: The main points that students should take away from the activities.
- Materials: The things you will need for the activity. It will be noted if the item isn't included in the **SOCK**.
- Vocabulary: These are the key words that you should explain throughout the outreach event. There is a Vocabulary Index at the back of the manual as a resource.
- Introduction: The introduction has some background information as well as motivations for the activity. Use these to get ideas of how to introduce the activity to the students.
- Lesson: Some activities have a lesson included with them for classroom based outreach. This is the material you can present to the class before you lead them through the activity
- Procedure: The directions outlining how to do the activity with the audience.
- Discussion: These are prompts to lead a discussion after you have completed the activity. This should really center on the objectives stated earlier to make sure the students understand the scientific concepts.
- Did You Know?: These are little blurbs about practical uses or fun facts about the concepts discussed in the activity. We suggest these be used as a way to catch the audience's attention right from the beginning.

Other Fun Things to Explore: This includes other really cool applications of sound and acoustics in many other areas of science.

Font Formatting: **questions for the group** | **notes/warnings** | *important concept* |

Planning an Effective Outreach Event for Your Chapter

The SPS **SOCK** is designed to serve as a tool to aid your chapter in organizing science outreach events. We have included some tips for planning an informative, organized, and fun outreach event in your community.

Before the Event

1. **Determine the interest level**
   - First discuss the possibility of organizing an outreach event as a chapter. Be sure to have enough reliable volunteers. Outreach events are not only a reflection of you and your skills, but also your school and Society of Physics Students chapter. It is important to be both professional and engaging.
2. **Talk to your chapter advisor**
   - Once a group of volunteers has been established, talk to your chapter advisor. He or she may already have connections to schools in the area and can provide additional assistance and supervision in the preparation stages for the event.
3. "**Things to Consider"**:
   - Age and education level of the participants
   - Size of audience to ensure you have enough supplies
   - Presentation environment
     - Availability of power outlets, projectors, power strips, etc. (if needed)
     - Availability of water (if needed)
     - Table space
     - Availability of Wi-Fi (to show videos)
   - Time allotted - Ensure that the presentation time is used efficiently but does not appear rushed
     - Always allow time at the end for questions and a meaningful summary
4. **Communicate**
   - Be sure to set up your outreach event with the appropriate person with plenty of time beforehand and get his or her email address, phone number, and the location address for the event. Contact them as the event approaches to confirm your event. Be flexible, cooperative, and professional right from the get-go!
   - Ensure adequate transportation TO and FROM the event.
5. **Practice!!!**
   - In order to ensure a fun and educational experience for your audience, be sure to *practice*. Keep all of the considerations in mind as you do so. Each outreach event is different and your presentation must be catered to the specific audience and conditions of the event. Being

prepared will allow for a professional and fun experience for all involved.

- Always have back up plans, and make sure all of your volunteers know what they are. Things can often go wrong, so make sure you are prepared. It's a good idea to bring supplies for demos you are not planning on doing in case you have trouble with a planned activity

During the Event

1. **Be present and engaged!**
   - You can be more engaging by having students do the activities instead of just watching you demonstrate something. You might have the students do the activity as you provide direction, or maybe bring in a pre-made example to use as you give the lesson to get the students excited about making their own at the end. Avoid lecturing for long periods of time. You don't want the students to be bored during the outreach event.
2. **Answer questions to the best of your ability**
   - Don't ever be afraid to admit you don't know something! Outreach events are a learning experience for both you and the audience. You are all exploring physics together, and a question you don't know the answer to is an exciting opportunity to learn something new!
3. **Be time effective, but not rushed**
   - It can be easy to fall into the trap of trying to do too much. The best way to judge how much time you need is to *practice!*
4. Be sure to leave time at the end for a summary, questions, and feedback.
   Smile, be confident, and always remember… *Physics is FUN!*

After the Event

1. **Follow up!**
   - *Always always always!* Thank the contact and the group for the opportunity to explore physics with you. Ask him or her for feedback and a reflection as well. This will hopefully secure the connection and open doors for more outreach in the future!
2. **Reflect**
   - Make notes of things you learned to reference in preparation for your next outreach activity
   - Have a discussion with the SPS volunteers who participated. Ask questions and get feedback!
     - **What went well? What didn't?**
     - **How did your audience respond?**
     - **What could have been improved?**

Outreach Reflections: *High School*

Hannah: "The students were a wonderful group to work with, very thoughtful and inquisitive. The first class had a bit of a slow start (most likely due to a caffeine shortage on both sides), so we had some trouble engaging the students. After the first class, we tried **creating small groups**, and this was especially helpful for doing the worksheet. We found the wave demonstration to be more beneficial for the students when we **asked for volunteers.** We have found that the nature of the demonstrations and activities in this SOCK tend to be more **interactive**; people love making noise. My advice for working with high-schoolers in your outreach endeavors is this: keep it upbeat, avoid creating a lecture environment, and allow them plenty of opportunities to interact with one another. And keep the physics FUN!"

Shauna: "You can present the material perfectly and still not get reactions from the class. And that's okay! Not every student will be receptive to every activity. You do have to be ready to **adapt** though. If most of the kids in the class are not responding or participating in the program, you might have to shake things up. If you are using worksheets, try letting the students work on them in groups. The students may not readily give answers to you, but they will talk with their friends. Try to **avoid asking open-ended questions**. If you are more direct, it will be easier to get some responses from them. If you call on a group instead of an individual, they may be more comfortable because they have other people to collaborate with. Lastly, **watch your own body language**. Crossing your arms or keeping your hands in your pockets closes you off and makes you look uninterested. How are the students supposed to be excited to learn physics when you seem like you don't want to be there? So remember: **adapt, interact,** and **have fun**!"

Thank you to Yorktown High School and Aaron Schuetz!

Outreach Reflections: *Elementary School*

Hannah: "Kids love science; even saying the word physics grabs their attention. But more importantly, kids love **interactive** science. Given the task of teaching physics to nearly 120 third-graders (a group of 48 and group of 66), we decided to divide and conquer. Shauna and I planned three stations exploring different concepts in our musical **SOCK**: sound at a distance, percussion and wind instruments, and tuning forks. It was a win-win situation: the students were allowed the opportunity for more interaction while we could test more of our **SOCK** ideas. Thanks to the help of our fellow ACP interns, we introduced basic acoustics to nearly 120 third-graders, and it was exactly as awesome as it sounds. When working with younger students, I would suggest that your presentation alludes to **more questions and conversation** than anything. Avoid the quantitative stuff; kids are intuitive and visual learners. They like hands-on science. I would also advise having **extra staff and support available** to help manage the kids. Keep things light, and be sure to get the kids talking. Allow the outreach event to serve as an opportunity for the kids to **discuss their observations** and **ask questions**. Any of the demos in the **SOCK** can be used for elementary school when approached in this way."




Shauna: "If you can get enough volunteers, stations are great if you are presenting to a large group of students. Stations allow you to present more **hands-on activities** to smaller sub-groups and make it easier to have more activities in a short amount of time. Presenting material in this way does prevent you from going as in-depth as you would like for older students, though, so I find that this presentation works best with elementary-aged students. The most effective way to present in stations is to make sure that the **activity at each station reinforces the concepts of the one before**. It's easier for students to understand what you're teaching them if they can apply what they are learning at one station to the next station. There will be multiple volunteers from your chapter presenting, the students will be asking questions and interacting, and their teachers will be talking to their students. On top of that, most of the activities from this year's **SOCK** make their own noise. Make sure everyone is paying attention as you explain everything so you don't have go through an activity multiple times."




Thank you to Tuckahoe Elementary School, Theresa Coffman, and all of the third-grade staff!

Outreach Reflections: *Middle School Science Teachers*

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

The **National Institute of Standards and Technology (NIST)** Summer Institute for Middle School Science Teachers is a two-week workshop for middle school science teachers featuring hands-on activities, lectures, tours, and visits with NIST scientists and engineers in their laboratories. Each year, the SOCK interns have an opportunity to present some of the activities from the project and receive valuable feedback from the participating teachers. ➡ http://www.nist.gov/iaao/teachlearn/

Hannah: "Having the opportunity to work directly with middle school science teachers was very rewarding. We got great feedback and suggestions to add to the effectiveness of the lessons in the **SOCK**. It was a great chance to show them ways to boost their confidence in teaching physics. Unfortunately we didn't have a chance to work with middle-schoolers directly this summer, but a few things I learned from the teachers are to include more **visualizations and qualitative explanations** – like graphical examples versus working with equations. Additionally, it is important to keep that hands-on aspect of the science. Middle school science lessons have a significant amount of flexibility, so remember any of the demonstrations and activities provided here can be adapted for any kind of outreach!"



Shauna: "NIST was a really unique experience primarily because we were presenting to middle school teachers instead of middle school students. We took this opportunity to get the teachers' insight on creating demos for middle-schoolers. Middle school is a tough age group to prepare for because the level of middle school students varies greatly from school to school. The level of understanding of each student varies greatly, too, because he or she is making the transition from elementary science to high school science. That is why working with the teachers, who deal with this every day during the school year, was so helpful. They can give a better sense of their particular class. My best advice from this outreach is to **take advantage of the teacher's experience**. He or she knows what works and what doesn't for the class, and is excited that you are there trying to help the students. You can **contact them before an outreach event** and ask them what will fit best into their lessons and how advanced to make your lessons. **Outreach events become a lot easier if you use the all of the resources that are available to you.**"

Items in the SOCK

Item	Quantity	Total Cost*
Spring	1	$0.69
13 tuning forks with mallet	1	$44.90
Thermometer	1	N/A
Rulers	2	N/A
Rubber bands	1	$1.00
Tape	3	$2.91
SPS Pencils	60	$N/A
Plastic cups (pack of 50)	1	$3.48
Glitter	2	$2.00
Balloons	1	$1.00
Straws (100 per pkg)	5	$7.50
Sticky tack	3	$3.00
Boomwhackers©	1	$23.46
End caps	1	$10.42
Yarn	1	$3.77
Alarm	2	$2.00
Ball	1	$0.23
Scissors	1	$2.91
Sharpies (4 per pkg)	1	$3.97

*Costs are included to help you budget in case you need to buy more supplies for an outreach event

Recommended Items:

Oscilloscope
8-ohm mini speaker
Calculators
Meter sticks
Water
Large containers for water
Tissue boxes or any boxes with openings on the top
Paper plates

Some of the supplies in this year's SOCK

Contents Summary

Title: "Visualizing Waves"

- **Suggested Outreach:** Any
- **Type:** Demonstration
- **Motivation:** To serve as an introductory visualization of the properties of waves and their behavior
- **Summary:** "Visualizing Waves" provides a visual exploration of different types of waves, their properties, and general characteristics using a Slinky. Best if used for introducing or reviewing a lesson on waves in any kind of outreach setting.

Title: "Fun with Tuning Forks"

- **Suggested Outreach:** Science fair, festival, or middle school classroom
- **Type:** Demonstration
- **Motivation:** To reinforce the idea that music and physics are related through sound
- **Summary:** "Fun with Tuning Forks" is a collection of five mini-demonstrations of how we can use tuning forks to explore the physics of sound. Demonstrations reinforce the fact that vibrations cause waves and highlight the relationship of frequency and pitch.

Title: "Speed of Sound Lab"

- **Suggested Outreach:** Middle/High School Classroom
- **Type:** Laboratory
- **Motivation:** To utilize the scientific method to determine physical properties of sound waves as well as gain laboratory experience
- **Summary:** "Speed of Sound Lab" is a laboratory exercise best used in a classroom setting. The lab involves utilizing the resonance of a standing wave within a tube to experimentally determine the speed of sound. An accompanied worksheet is formatted to review the scientific method.

Title: "The Physics of the Acoustic Guitar"

- **Suggested Outreach:** Middle/High School classroom (Lesson), All Ages (Activities)
- **Type:** Lesson, Hands-On Activity
- **Motivation:** To provide a basic understanding of the acoustical mechanics of the guitar and emphasize the interconnectivity of physics and music
- **Summary:** "The Physics of the Acoustic Guitar" contains a physics lesson on the inner-workings of the guitar suitable for middle/high school, which is combined with supplemental activities that reinforce the concepts discussed in the lesson.

Title: "Straw Pan Pipes"

- **Suggested Outreach:** Classroom or Small Group, Middle/High school
- **Type:** Hands-On Activity, Laboratory
- **Motivation:** To explore relationships between pitch, frequency, and wavelength by examining mathematical methods to find patterns in a given set of data
- **Summary:** "Straw Pan Pipes" allow the students to create their own wind instrument while learning about its acoustical properties in the process. The supplemental activity worksheet guides the students to mathematically derive the equation relating frequency and wavelength by using ratios and unit analysis.

Title: "Boomwhackers!®"

- **Suggested Outreach:** Elementary/Middle School classroom
- **Concepts:** Hands-On Activity, Laboratory
- **Motivation:** To draw explicit conclusions from direct observation and use data to support them
- **Summary:** "Boomwhackers®" explores the acoustical properties of percussion instruments through activities and a supplemental worksheet. The theme of the activity is the relationship between tube length and pitch, and provides a quantitative way to find the fundamental frequency of such tubes.

Title: "Sound at a Distance"

- **Suggested Outreach:** Elementary classroom, science festival
- **Type:** Demonstration
- **Motivation:** To reinforce the idea that sound is caused by and travels through vibrations and can be amplified to allow us to communicate over long distances
- **Summary:** "Sound at a Distance" contains two activities which emphasize the importance of vibrations and waves in sound and communication. Students experiment with cups, straws, and strings to understand amplification, how we produce sound, and how sound travels.

Title: "Doppler Effect"

- **Suggested Outreach:** Any
- **Type:** Demonstration
- **Motivation:** To provide an understanding that the pitch of a sound is affected by the relative motion between the observer and source of the sound
- **Summary:** "Doppler Effect" is a short demonstration to show frequency shifts due to relative motion between a sound source and the listener spinning a speaker within a ball.

Demonstration: *Visualizing Waves*

Separate outlines included for elementary school and middle/high school

Motivation:

- To serve as an introductory visualization of the properties of waves and their behavior

Objectives:

- Students will be able to visualize different types of waves and understand their properties
- Students will be able to discuss waves using specific vocabulary words

Materials:

- Slinky

Vocabulary:

- Wave, longitudinal, compression, rarefaction, amplitude, wavelength, frequency, crest, trough, node

Introduction: What is a wave?

Waves are all around us in a variety of forms. We've seen waves at the beach, a wave from a friendly neighbor, and we also experience waves in the form of light and sound every day. Through this demonstration, we can visualize different types of waves and understand their characteristics. We have provided two outlines of the same discussion targeted at different age groups to ensure the most appropriate explanations.

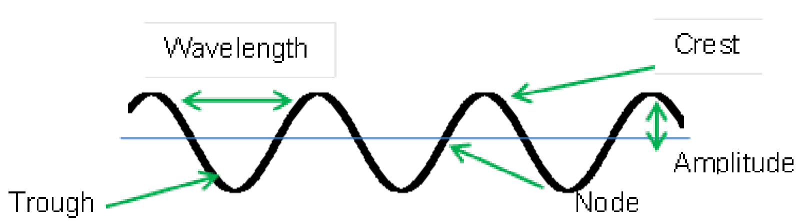
Demonstration:

Elementary School

Estimated Time: 15 minutes

Begin by asking the group about waves. **What do they already know and recognize?** A **wave** can describe something that is happening repeatedly, *over and over again*.

1. Transverse Wave
    a. **Transverse waves**, like light, do not need a medium to travel through. Light, and other transverse waves, can travel through empty space.



b. Transverse waves have many properties. The **amplitude** is measured by the highest or lowest point on the wave. **Can anybody point to the amplitude?** The **node** is the point on a wave that doesn't move up or down. **Can anybody point to a node?** Remember: a wave is something that is **periodic** - it happens over and over again. **What are some examples of waves that you know of?**

c. **Make a Wave!**

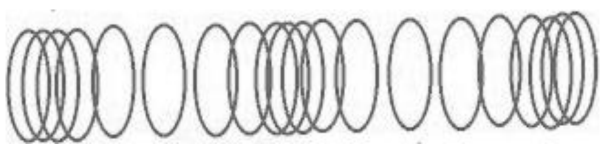
   i. Have the students form a line standing next to one another.

   ii. Create a **transverse wave** by having them move their arms up and down in succession as seen in the picture to the left.

Tuckahoe students do the wave

2. Longitudinal Wave

   a. **Longitudinal waves** travel through particles. Sound is an example of a longitudinal wave. Longitudinal waves travel as particles bump into other nearby particles, which bump into other particles, and so on.



Longitudinal wave

   b. In this spring example, at some points in the wave, the rings get really close together, or **compressed.** But then they quickly spread back out again.

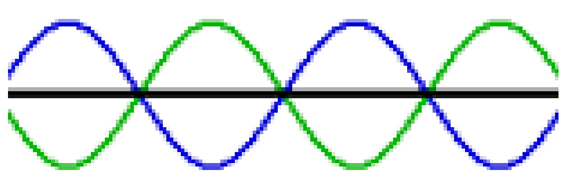
   c. **Make a Wave!**

      i. Have the students form a line standing next to one another.

      ii. Create a **longitudinal wave** by having them bump shoulders. The students are acting as the particles being pushed out of their resting place (compressed), and then returning back to it.

3. Standing Waves

   a. **Standing waves**, or stationary waves, are waves that have points that appear to stay in place. This happens because two waves that are travelling in opposite directions interfere with each other. You can see this in the picture below.

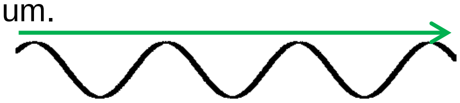


Standing wave

Middle/High School
Estimated Time: 10 minutes

Begin by asking the class about waves in general. **What do they already know and recognize?** **Waves** are a periodic or repeated disturbance traveling through a particular medium or material.

1. Transverse Waves
    a. A **transverse wave** occurs when the direction of propagation, shown by the green arrow, is **perpendicular** to the direction in which the particles move through the medium.

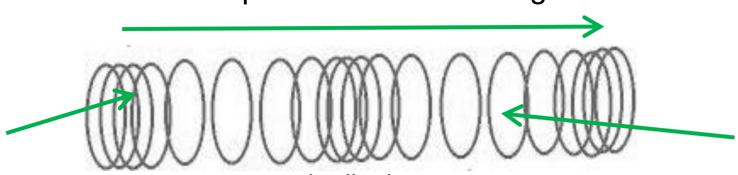


Transverse wave

    b. Transverse waves have many properties. The highest or lowest point on the wave is known as the **amplitude**, the point of maximum displacement. This is also given by the maximum amount of energy (highest and lowest points themselves are known as the **crest** and **trough**, respectively). We can measure the particular **wavelength** as the distance (typically in meters) between two crests or two troughs. The **node** of the wave is the point of no vertical displacement away from the equilibrium position.
    c. Have a student volunteer to hold the other end of the stretched spring still, while another volunteer creates the waves. A transverse wave is created by moving one end up and down. A standing wave will emerge at the right frequency. Ask the class to point out the *nodes, crests,* and *trough.*

2. Longitudinal Waves
    a. A **longitudinal wave** occurs when the direction or propagation is **parallel** to the direction in which the particles move through the medium.

Compression



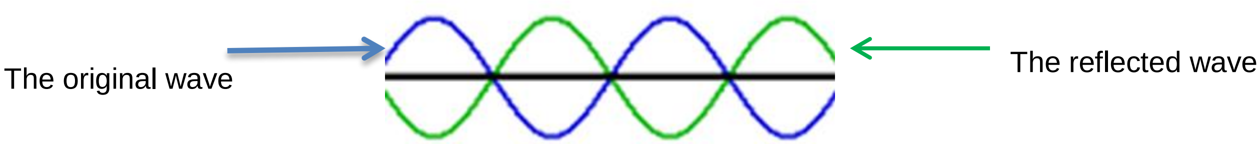
Rarefaction

Longitudinal wave

    b. In order for the wave to move through the spring, it must become denser at some points and then consequently spread out at others to account for the compression. The areas at which the spring is denser are known as **compressions**, and the areas where the spring is spread out or less dense are known as **rarefactions.**
    c. Have a student volunteer to hold the other end of the stretched spring still. Send one pulse through the wave and you will notice it moves along the

spring. **What do they notice?** Note that **sound waves** are a common example of longitudinal waves. Picture the rings on the spring as particles in the air. As you are speaking to them, the air molecules are temporarily displaced and then quickly return to their original location.

3. <u>Standing Waves</u>
   a. **Standing waves** are produced when two identical waves are travelling in opposite directions interfere with each other. This is most easily displayed when a wave is reflected off of a fixed surface. When the reflected wave runs into the original wave, the two waves constructively and destructively interfere with each other to make areas that appear to be stationary.



Standing wave

Did You Know? Discovering Pulsars

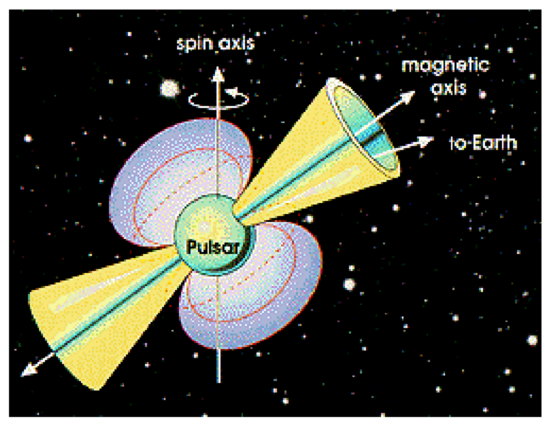


Image from NASA's *Imagine the Universe!*

Scientists can recognize waves because waves are patterns that repeat over and over again. Scientists are always looking for patterns in the data they collect. This is actually how pulsars were discovered. Jocelyn Bell Burnell and Anthony Hewish came across pulsars by chance in 1967. Bell noticed that they were picking up small pulses of radiation when the telescope they were using was pointed at a specific part of the sky. They ruled out all possible sources of known radiation, and Bell and Hewish were eventually able to attribute these pulses of radiation to spinning neutron stars. Neutron stars are stars that collapsed under their own gravity during a supernova explosion. They are very dense, rotate very quickly, have small radii on the order of 10 km, and have large magnetic fields. Neutron stars are difficult to detect unless they have charged particles moving along their magnetic fields, causing beams of radiation to be emitted from their magnetic poles. As the neutron star rotates, the radiation sweeps across space, like the light from a lighthouse. The pulses of radiation that Bell and Hewish detected came whenever the beam of radiation was pointing at Earth. For more information about the pulsars, visit http://www.atnf.csiro.au/outreach/education/everyone/pulsars/index.html.

Demonstrations: *Fun with Tuning Forks*

All ages

Estimated Time: 10 minutes (per demo)

Motivation:

- To reinforce the idea that music and physics are related through sound

Objectives:

- Students will explore the concepts of resonance and interference using tuning forks
- Students will understand that oscillations and vibrations are the source of sound waves

Materials:

- Set of 13 Tuning Forks
- Rubber Mallet
- Smallest Boomwhacker
- Cup of Water (for Demo 1, not included)
- 8-Ohm Mini Speaker (for Demo 2, not included)
- Oscilloscope (for Demo 2, not included)

Vocabulary:

- Tuning fork, oscillations, vibrations, resonance, interference, sinusoidal motion, harmonic, fundamental, overtones

Introduction: Physics with Tuning Forks!

Tuning forks are most commonly known for their musical use: tuning an instrument. But what can their behavior teach us about the physics of sound? In this series of demonstrations, students will understand that the nature of a sound wave is due to vibrations and oscillations, the concepts of resonance and interference, and visually see the sinusoidal motion of a tuning fork when struck.

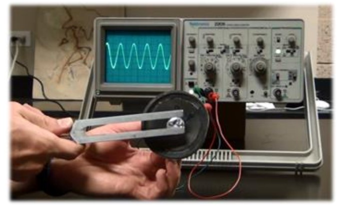
Demonstration One: ***Is it really doing anything?***

Note – **Use the provided mallet when striking a tuning fork. Do not strike the tuning fork on a hard surface. Tuning forks are a laboratory instrument and this demonstration will allow the students to get used to handling them properly.**

- When a tuning fork is struck, it begins to oscillate back and forth. These oscillations serve as the source of the sound wave that is produced.
- These oscillations are happening very quickly (usually on the order of several hundred times a second!), so they can be hard to see.

- Choose a tuning fork and fill a small cup of water. Strike the tuning fork and slowly lower the forked end into the cup until it touches the water.
- The water splashes out because of the vibrating tuning fork.
- If possible, show the following video: https://www.youtube.com/watch?v=B0AKuxTEDQg

<u>Demonstration Two:</u> ***Sinusoidal Motion***



- Connect the 8-ohm mini speaker to the oscilloscope.
- Strike the tuning fork and hold close to the speaker.
- The oscilloscope should show the sinusoidal curve representing the sound wave produced. Moving the fork closer to and further away from the speaker will result in a change in amplitude. **Why?**
- If you do not have access to an oscilloscope, try these online resources
    - Online oscilloscope: http://academo.org/demos/virtual-oscilloscope/
    - Free download: http://www.zeitnitz.eu/scope_en

<u>Demonstration Three:</u> ***Interference and Beats*** 

- Striking two tuning forks at near frequencies will produce a phenomenon known as **beats.** The beats are a product of the constructive and destructive interference of the sound waves. The beat frequency is the difference between the interfering frequencies; the note that you hear is the average of the two original.
- Choose two tuning forks of near frequency and strike one after another. Ask the students for observations. **What do they hear? Why?**

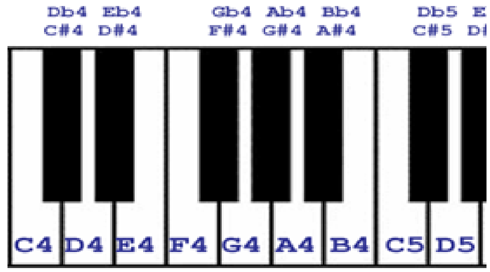
<u>Demonstration Four:</u> ***Strike a Chord!***

- Music can be explained by physics. Tuning forks can be used to explore multiple pitches (or *harmonies*) that tend to "sound good" together.
- Each tuning fork vibrates at a different frequency. There are specific frequencies that resonate within harmonies in music related by particular ratios. With C $f_C = 256\ Hz$ as our starting point, we have:

Note that C' is an octave higher than C

Note	Frequency Ratio
C'	2:1
G	3:2
F	4:3
E	5:4

- Using the C tuning fork and the ratios provided, have the students find the frequency of E (major third), F (perfect fourth), G (perfect fifth), C (octave)



Solution:

1. **E:** $\frac{\lambda_E}{\lambda_C} = \frac{5}{4} \rightarrow \lambda_E = \left(\frac{5}{4}\right)(\lambda_C) \rightarrow \lambda_E = \left(\frac{5}{4}\right)(256) = 320\ Hz$
2. **F:** $\frac{\lambda_F}{\lambda_C} = \frac{4}{3} \rightarrow \lambda_E = \left(\frac{4}{3}\right)(\lambda_C) \rightarrow \lambda_E = \left(\frac{4}{3}\right)(256) = 341.3\ Hz$
3. **G:** $\frac{\lambda_G}{\lambda_C} = \frac{3}{2} \rightarrow \lambda_G = \left(\frac{3}{2}\right)(\lambda_C) \rightarrow \lambda_G = \left(\frac{3}{2}\right)(256) = 384\ Hz$
4. **C':** $\frac{\lambda_{C'}}{\lambda_C} = \frac{2}{1} \rightarrow \lambda_{G5} = \left(\frac{2}{1}\right)(\lambda_C) \rightarrow \lambda_G = \left(\frac{2}{1}\right)(256) = 512\ Hz$

- Demonstrate the *harmonies* (simultaneous pitches with frequency ratios that are simple fractions) by allowing students to strike several tuning forks and place them on a window or other resonating surface and hear the chord!

Demonstration Five: ***Find the Fundamental***

- We can use tuning forks and a resonating air column to find the speed of sound. (See "Finding the Speed of Sound" for additional laboratory on page 22)
- Fill a cup or container with water and place the Boomwhacker® in the middle.
- Strike a tuning fork and hold above the Boomwhacker®.
  - **Note:** Avoid the lowest and highest tuning forks because they're harder to hear.
- Move the pipe up slowly until you find the **fundamental***:* this will be at the point where the sound amplifies from the constructive interference.
- Use this demo as a *qualitative* exploration of resonance and sound waves. **How does this work? What are the vibrations doing? Why did the sound get louder?**
- You can see this at https://www.youtube.com/watch?v=bHdHaYNX4Tk

Did You Know? Music and Tuning Systems

Tuning systems exist to outline the spacing of the frequencies, or the pitches, used in music. One such system is **just intonation**, where the pitches are related to one another by simple numerical ratios such as 3:2, 9:8, and 5:4 among others. **Pythagorean tuning** is a type of just intonation in which the ratios between the pitches are all derived from the number ratio 3:2. This system was primarily used during the Medieval and Renaissance periods. **Equal temperament** is the standard system used for piano tuning and most commonly used in Western music. The pitches in a given octave are separated by equal-ratio steps instead of the different ratios used in just intonation. For more information go to *https://en.wikipedia.org/wiki/Musical_tuning*

Laboratory: *Finding the Speed of Sound*

High School (classroom setting)
Estimated Time: 30-40 minutes

Motivation:

- To utilize the scientific method to determine physical properties of sound waves as well as gain laboratory experience

Objectives:

- Determine experimentally the speed of sound in air by exploiting a standing wave and the resonance effects of longitudinal waves
- Explore the concept of harmonics
- Understand how to use the scientific method and the wave equation to determine the wavelength given a known frequency

Materials:

- 13 Tuning Fork Set
- Rubber Mallet
- Smallest Boomwhacker® or PVC pipe (if Boomwhacker® is unavailable, not included)
- Thermometer
- Calculator (not included)
- Meter stick (not included)
- Container large enough to fit the Boomwhacker® (not included)
- Water (not included)
- Activity Worksheet

Vocabulary:

- Frequency, wavelength, standing wave, longitudinal wave, node, antinode, resonance, fundamental, harmonics

Introduction:

- The goal of this laboratory exercise is to calculate the speed of sound. We can do this by creating a standing wave in a tube that is closed at one end. When the frequency of the standing wave matches the natural frequency of the tube you will hear a loud tone of that frequency. If you know the frequency of the standing wave and measure the wavelength, you can calculate the speed of sound.

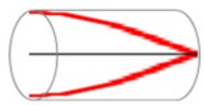
Laboratory:

Part One: Theory

- If you've ever blown across a bottle, you've heard the hollow, fog-horn like sound that is produced (also referred to as *Helmholtz Resonance*, see pg. 33). The resonance tone was made by creating a *standing wave* in the bottle, which acts like a tube that is closed at one end and open at the other.

- The tube will have its own particular resonance frequency. A loud tone is produced by introducing sound at the open end at the resonance frequency. A standing wave of one wavelength behaves as follows:

- A *node* forms at the closed end of the tube where the air doesn't vibrate. This node will be located at the air-water boundary of the laboratory setup. Additionally, an *antinode* forms at the open end where the air is free to vibrate. The first allowable standing wave will occur when the length of the tube is one-fourth of the wavelength of the sound wave with the resonance frequency as follows:



- The wavelength of the standing wave will be the *resonance wavelength*. Given that the resonance wavelength is one-fourth the length of the standing wave, we can deduce the following:

$$v_{sound} = f\lambda, \quad \lambda = 4L \quad \rightarrow \quad v_{sound} = 4fL$$

- The predicted speed of sound in air is given by: $\boldsymbol{v_{sound} = 332\,\frac{m}{s} + .6\,\frac{m}{s\cdot C}T}$ where **T** is the **temperature of air in Celsius**. This equation was determined experimentally and is accurate for temperatures between 0°C and 100°C. Since most classrooms are within this range, we can compare this prediction to our experimental values. We can then calculate the percent error and deduce qualitative reasons why the error may be so.
- **Questions to consider:**
  - **What is a standing wave?**
  - **What is resonance?**
  - **How can you use unit analysis to check the mathematical result?**

Part Two: Laboratory Exercise

- Gather all materials. We suggest dividing the class into small groups (pairs or groups of three).
  - *If class is large* (5-8 groups): Give each group a different tuning fork and ask them to record its given frequency on the data table. Then, collect and compare the results as a class.

- *If class is small* (2-4 groups): Give each group 2-3 different tuning forks so that they can compare different values within their own data set.

- Fill the graduated cylinder about ¾ full with water and place the Boomwhacker® in the center.
- Measure the temperature of the air in Celsius. Record on worksheet.
- **Prediction:** *Using the given equation for the speed of sound, make a prediction as to what value for the speed of sound we should find experimentally.*

$$v_{sound} = 332\,\frac{m}{s} + .6T$$

- Strike the tuning fork and hold horizontally directly above the pipe. Move the pipe and tuning fork up and down slowly until you find the point of resonance (point at which the loudest sound is produced).
- Have another student measure in **meters** the distance from surface of the water to the end of the pipe. Record in data table.

- Calculate the speed of sound for each tuning fork frequency. Compare with predicted value by calculating the percent error.

$$Percent\ Error = \frac{\text{Observed} - \text{Predicted}}{\text{Predicted}} \cdot 100$$

Part 3: Discussion

- ✓ Ask the students what they learned from the lab. Reinforce the ideas of a standing wave, resonance, and vibrations as the cause of waves.
- ✓ Discuss the fact that the speed of sound is not constant like the speed of light. It depends on how close the particles of the medium are to each other. Talk about how different factors like temperature, humidity, and air pressure affect particles in the air and how that changes the speed of sound.
- ✓ Ask students if sound travels fast enough to be considered instantaneous. How far away from the sound source would you have to be to notice the time difference? This is why we see lightening before we hear thunder.
- ✓ Discuss possible reasons for the experimental error. This could include:
  - Approximate measurements, rounding off decimals, etc.
- ✓ If time allows, briefly discuss the work of German physicist Hermann von Helmholtz, particularly his concept of "Helmholtz Resonance." (see page 33)

Lesson: *The Physics of the Acoustic Guitar*

Activities: **Rubber Band Guitar** (elementary) *and* **Chladni's Plates** *(middle/high school)*
Estimated Time: 15-30 minutes depending on activity/lesson choices

Motivation:

- To provide a basic understanding of the acoustical mechanics of the guitar and emphasize the interconnectivity of physics and music

Objectives:

- Provide a physical explanation for the acoustical mechanics of the guitar
- Explore the historical significance of the work of Ernest Chlandni
- Students will be able to visualize what sound waves look like when travelling through matter

Materials:

Rubber Band Guitar	*Chladni's Plates*
• Box (not included)	• Plastic Cup
• Scissors	• Glitter
• Rubber Bands (various sizes)	• Rubber Band
• Tape	• Balloon
• Official SPS Pencils (2)	• Scissors
	• Two Straws
	• Small Plate (not included)
	• Tuning Fork (optional)

Key Vocabulary:

- Chladni plates, resonance, Cymatics, acoustic guitar, oscillations, harmonics

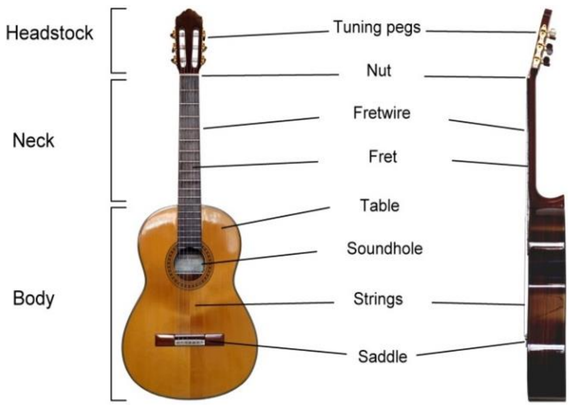
Introduction:

There are many reasons why the guitar is considered the world's most popular instrument: it's musically versatile, relatively low-priced, and frankly, it just sounds really good to us. But can we justify this claim with physics? Of course! This lesson is intended to be used in a physics classroom setting and includes two accompanied activities which demonstrate the ideas presented in the lesson. The students will get a sense of how the guitar works physically, have a chance to make their own, and experiment with Chladni's plates. *(**Note:** You may choose a combination of the lesson and activities to present depending on age group and time allotted.)*

Part One: Lesson – *The "Acoustic" Guitar: the Physics Behind the Music (high school)*

- **The guitar is designed to convert mechanical energy of string vibration into pressure waves** perceived by the ear. The plucked string oscillates in a complex pattern of vibration consisting of the fundamental and many partials.

- The 'pluck' in the string travels to the saddle which acts like a selective filter for certain frequencies; the energy is then transferred to the neck, which sends the energy to the flexible sound hole.



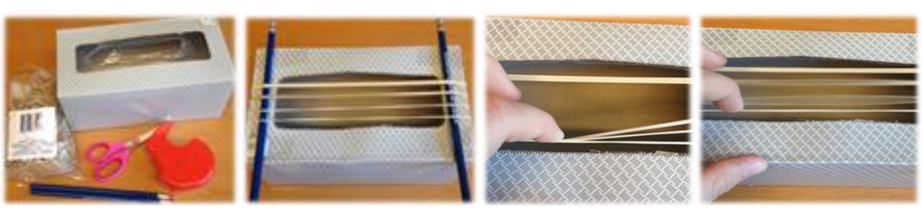
- **The speed the pluck travels through the string depends on the tension and mass per unit length of the string.** On each round-trip, some energy is transferred through the saddle; the string will come to rest after all energy is transmitted to the sound hole.
- The number of round trips per second corresponds to the *frequency.* For example, travelling at 440 round trips per second produces a 440 Hz tone (A).
- **The string would like to oscillate as closely as possible to harmonic partials – whole number multiples of the fundamental frequency.** While oscillating at 440 Hz, the string is also vibrating in halves (880 Hz), thirds (1320 Hz), and fourths (1760 Hz), producing *overtones*.
- **The sound hole acts like an amplifier**; sections of the soundboard that vibrate with the greatest amplitude are usually located away from the area beneath the vibrating saddle.
- When the body moves, the air mass also vibrates. The strings do not directly communicate with the air. **Together, the moving air and soundboard interact to suppress some frequencies and enhance others.**

Brian May, the lead guitarist of rock band Queen, is also an astrophysicist!

Part Two: Rubber Band Guitar *(elementary level advised)*

<u>Procedure:</u>

- Gather all materials.
- Cut an opening on the top of your box.
- Align pencils along the edges as shown in the second image. Tape to secure.
- Wrap rubber bands of various thicknesses around the box and pencils to create the strings.
- Play your instrument! **Experiment** by plucking various strings and changing the tension of each by how forcefully you pluck it, or by using different sized rubber bands. **What do you notice?**

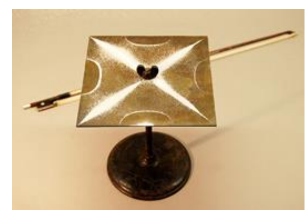


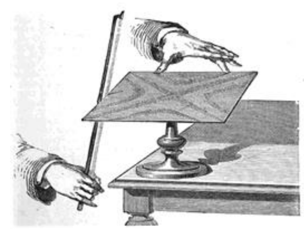
Discussion Questions:

- **What does understanding the guitar have to do with physics?**
- **What are a few similarities between physics and music? Differences?**
- **How can we use physics to explain sounds and music?**
- **What is one important thing that you learned?**

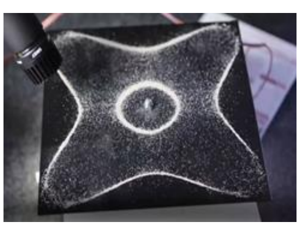
Part Three: Chladni's Plates *(middle/high school level advised)*

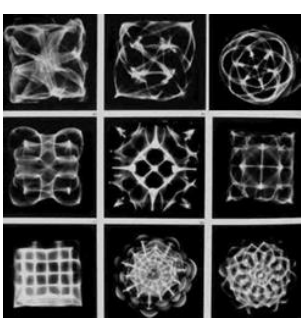
- **Ernst F.F. Chladni** (1756 – 1827) was a German physicist and musician, commonly referred to as the "father of acoustics." His vast contribution to the field of acoustics includes measurement of the speed of sound in different gases, extensive research on vibrating plates, and the development of a variety of instruments.
- One of Chladni's best-known achievements was inventing a technique to show the various vibrations of a rigid surface at different frequencies.
- Chladni repeated the experiments of Robert Hooke who had observed the nodal patterns associated with the vibrations of glass plates as seen right.





- His technique consisted of drawing a bow over a piece of thin metal sheet lightly covered in sand. The plate was bowed until it reached resonance, when the vibration causes the sand to move and concentrate along these lines where the surface is still.
- Variations of this technique are still commonly used in the design and construction of acoustic instruments such as violins, guitars, and cellos.





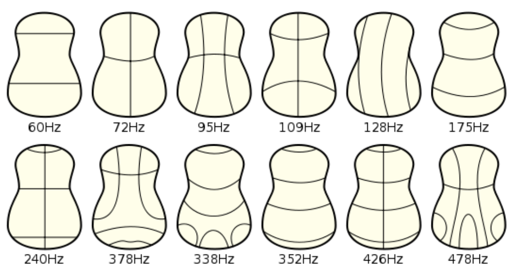
Procedure:

Introduction

- **Cymatics**: Cymatics is the study of visible sound. The surface of a plate is vibrated, and modal regions are made visible in a thin coating of particles, like sand. Different modal patterns emerge in the sand depending on the geometry of the plate and the driving frequency. This field of study was pioneered by the work of Robert Hooke and Ernst Chladni, and has since had profound influence on innovations in art, music, and engineering, and more.
- *If able:* Show the following video clip. "CYMATICS: Science Vs. Music – Nigel Stanford" at https://www.youtube.com/watch?v=Q3oItpVa9fs

- Gather materials.
- Cut the balloon and stretch very tightly over the plastic cup. Secure the balloon with a rubber band.
- Clip one end of a straw into a V-shape. Insert into another straw to double the length. Tape the straws together.
- Poke a hole in the side of the cup, close to the bottom, and insert the straw.
- Place something underneath the cup, like a plate or a piece of paper, to catch the glitter. Sprinkle a light layer of glitter across the balloon surface.
- 'Sing' various pitches into the straw and observe what happens to the glitter. The glitter will vibrate and move to create different formations. **Why?**
    - **Note:** Tuning fork is optional here. Strike the tuning fork and lightly touch the forked end on balloon surface. Notice how the glitter repositions itself.

- **Connect:** Chladni plates are used to design the back-plate of guitars and other acoustic instruments. The images below show the nodal lines that form on the back-plate of a well-designed guitar.



When constructing a guitar or any other acoustic stringed instrument (such as a violin), the adjustment of the top plate is important to the properties of the final instrument. Guitar makers know which Chladni patterns to look for at certain frequencies. They will apply those frequencies to the top plate of the guitar. The Chladni patterns made on the top plate provide some feedback to the maker during the process of adjusting the plate to its final shape. The guitar maker will change the shape of the top plate until they get the desired Chladni pattern.

- **Discussion Questions:**
    - **What is the significance of Chladni plates? How can we use them?**
    - **Can you think of any applications where visualizing waves would be useful?**
    - **What is Cymatics?**
    - **What is one important thing that you learned?**

Activity: *Straw Pan Pipes*

Middle/High School
Estimated time: 45 minutes

Motivation:

- To explore relationships between pitch, frequency, and wavelength by examining mathematical methods to find patterns in a given data set

Objectives:

- Students will understand the relation between pitch and pipe length
- Students will be able to quantify the mathematical relationship between frequency and wavelength
- Students will understand how to find patterns in data through various algebraic techniques and consequently draw conclusions from their analysis

Materials:

- 6 straws per student
- Tape
- Scissors
- Ruler
- Sticky Tack
- Calculator (not included)
- Activity Worksheet (we have included two different worksheets to choose from)

Vocabulary:

- Pitch, frequency, woodwind, resonator, velocity

Introduction:

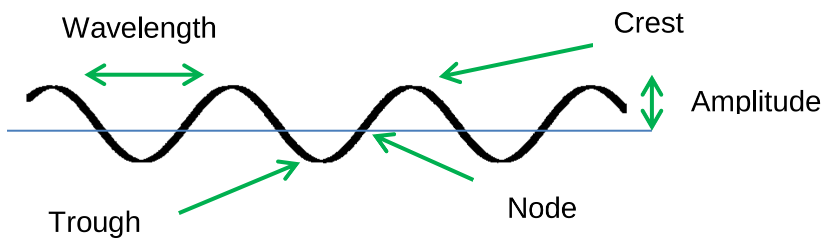
In wind instruments a column of air is set into vibration by a player blowing into or across a resonator. The particular pitch that arises from the vibration depends on the length of the resonator (usually a tube) and any manual modifications to that resonator, like pressing down different keys on a flute or saxophone. Using straws as our resonators, students will create their own wind instruments: a set of pan pipes. Additionally, they will be able to quantify the relationship between the frequency and wavelength of the pitch produced to find the velocity of the sound in air for particular pitches.

Activity: High School

Part 1: ***Introduction to Frequency, Wavelength, and Pitch***

- Begin the discussion by asking the group what they already know about properties of waves. Write down key vocabulary that the students mention.

- Draw a simple transverse wave on the board and ask the students to help you label all the parts that they can as follows:



- Ask the students to comment on the terms **frequency** and **pitch.** **What do they know?**
- Pitch and frequency are very similar, but not exactly equivalent. Reinforce the idea that **frequency** is a *physica*l term for how often a pattern reoccurs, whereas **pitch** is the *subjective* perception of the frequency of the sound wave. Pitch is not a physical property of a sound wave.

Part 2: ***Making Straw Pan Pipes***

- Each student will need 6 straws, a pair of scissors, ruler, and a little sticky tack.
- Instruct the students to cut the straws into lengths and label them according to the following table:

Straw	Length (cm)
1 or "C"	15.8
2 or "D"	14.5
3 or "E"	12.5
4 or "F"	12.0
5 or "G"	10.5
6 or "A"	9.4

Note: Lengths were determined experimentally to take into account the end-cap correction.

- Each straw must be covered at one end. To do this, roll a small ball of sticky tack, flatten it out on the table, and then apply it as a cover to the bottom of a straw. Repeat for all straws. Be sure that there are no holes for the air to escape.
- Have the students experiment with the straws for a few minutes. Allow them to practice making sounds. **What are some things that they notice?**

Warning – Warn kids not to blow too hard or too quickly so that they don't become light-headed. Explain that the best way to produce a sound will be to blow *across* the straw, controlling and directing your air. Tell the students to say the word "too" as they blow across.

- Ask the students to place the straws in order from longest to shortest. Align the open ends of the straws and tape the bodies of the straws together using the scotch tape to finish assembling the pan pipes.

- **Questions to consider:**
  - **What do you notice about the length of each straw and the sound it produces?**
  - **What is happening to the air that you are blowing?**
  - **Explain how the sound waves are behaving inside the pan pipes.**

- **<u>Optional:</u>** *Play a song!*
  - Here is some ‘sheet music’ for a few simple and recognizable tunes to teach the class to play, or you can encourage them to write their own!

Mary Had A Little Lamb

3212	**333**	**222**	**355**	**3212**	**3332**	**2232**	**1**
EDCD	EEE	DDD	EGG	EDCD	EEED	DDED	C

Twinkle Twinkle Little Star

1155	**665**	**4433**	**221**	**5544**	**332**
CCGG	AAG	FFEE	DDC	GGFF	EED
5544	**332**	**1155**	**665**	**4433**	**221**
GGFF	EED	CCGG	AAG	FFEE	DDC

Ode to Joy

3345	**5432**	**1123**	**322**	**3345**	**5432**	**1123**	**211**
EEFG	GFED	CCDE	EDD	EEFG	GFED	CCDE	DCC

Part 3: **Data Analysis**

- The following table provides data for the wavelength and frequency of pitches the pan pipe produces:

Note	Frequency (Hz)	Wavelength (cm)
C’	523.25	65.93
D	587.33	58.74
E	659.25	52.33
F	698.46	49.39
G	783.99	44.01
A	880.00	39.20

- The students will use two methods of analysis to find the mathematical relationship between frequency and wavelength to address the question: *How can we find patterns in a given set of data?*

- **Method 1: Ratios**
  - Ratios are an excellent mathematical tool for understanding how numbers compare to one another. The students are instructed to determine the proportionality between the two variables for several given data sets. They should find that $\frac{f_1}{f_2} = \frac{\lambda_2}{\lambda_1}$, suggesting that frequency and wavelength are inversely proportional.

- **Method 2*:* Unit Analysis**
  - Once the students have determined the inverse proportionality of *f* and λ, then we can use unit analysis to find the constant from the product of the variables. The students are instructed to go through the process of unit analysis step-by-step, and then answer qualitative questions reinforcing their analysis.

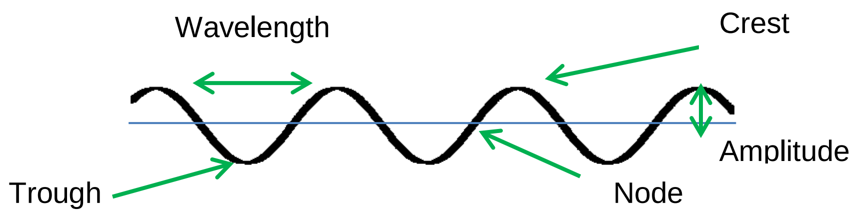
Part 4: Possible Discussion Topics

- The basic acoustical properties of wind instruments
- Labelling and discussing the parts of a wave with the correct vocabulary
- Understanding the similarities and differences between pitch and frequency
- Observation that longer tubes produce lower pitches and shorter tubes produce higher pitches
- Ability to search for patterns in a given data set using mathematical methods

<u>Activity: Middle School</u>

Part 1: *Introduction to Frequency, Wavelength, and Pitch*

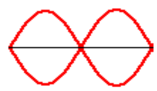
- Begin the discussion by asking the group what they already know about properties of waves. Write down key vocabulary that the students mention.
- Draw a simple transverse wave on the board and ask the students to help you label all the parts that they can as follows:



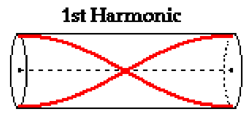
- Ask the students to comment on the terms **frequency** and **pitch. What do they know?**
- Pitch and frequency are very similar, but not exactly equivalent. Reinforce the idea that **frequency** is a *physica*l term for how often a pattern reoccurs, whereas **pitch** is the *subjective* perception of the frequency of the sound wave. Pitch is not a physical property of a sound wave.

Part 2: ***The Scientific Method***

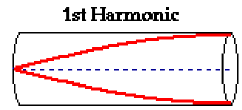
- The supplemental worksheet is formatted to mimic the scientific method and explores how we can use it to solve problems. In this case, our question is: *How can we use physics to make our own pan pipes?*
- **Do Research.** Explain the how the sound wave will behave in a pipe with one closed end.



Standing Wave



Open Air Column



Closed End Air Column

Musical instruments have a natural set of frequencies at which they vibrate called **harmonics**. The first harmonic (or **fundamental frequency**) is the lowest frequency at which the instrument will resonate and produce sound. The wave inside an open air column is one-half the length of a full standing wave, whereas the wave inside a closed air column is one-fourth the length of the sound wave.

- The students will then proceed to **construct a hypothesis** and **gather data**. The empirically gathered data will be used to **experiment** and construct the pan pipes.
- **Analyze and Draw Conclusions.** After the pan pipes construction (see High School lesson for assembly details), the students will be able to see the inverse relationship between wavelength / frequency and frequency / length of pipe. The worksheet includes questions for qualitative reasoning and observation descriptions to allow them practice in communicating science.

Did You Know? Helmholtz Resonance

Hermann von Helmholtz (1821 – 1894) was a famous German physicist and physician. One of his interests included fusing together the boundary between acoustical science and musical perception and aesthetics, as evidence by his famous text *On the Sensations of Tone as a Physiological Basis for the Theory of Music.* He coined the term “Helmholtz Resonance” to explain the phenomenon of air resonance in a cavity, such as when one blows across a tube. He used the term to identify various frequencies or musical pitches present in music. The pressure inside the bottle increases as more air is forced inside. When the external force pushing the air into the cavity is removed, the higher-pressure air inside will flow out. The cavity will be left at a pressure slightly lower than the outside, causing air to be drawn back in.

Activity: *Boomwhackers®!*

Elementary/Middle School
Estimated Time: 15 minutes

Motivation:

- To draw explicit conclusions from direct observation and use data to support them

Objectives:

- Students will understand how the length of a Boomwhacker® is related to the wavelength
- Students will quantitatively find the fundamental frequency of the Boomwhackers® and understand its relation to the length of the tube
- Students will understand basic acoustical properties of percussion instruments

Materials:

- Set of Boomwhackers®
- End caps
- Meter stick (not provided)
- Activity worksheet

Vocabulary:

- Fundamental, wavelength, frequency, node, antinode, eardrum

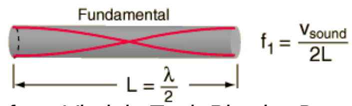
Introduction:

Percussion instruments are sounded by means of being struck or scraped. Boomwhackers® are an example of an idiophone, a classification of percussion instruments that produce sound through the vibration of their entire body. In this activity, students will be lead through a qualitative exploration of the acoustical properties of the Boomwhackers® as well as a quantitative means for finding the fundamental frequency of each Boomwhacker®.

Activity:

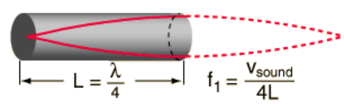
- Nodes are the points on a wave with zero amplitude, whereas antinodes are the points on the wave at the highest amplitude. If a sound wave is produced in a Boomwhacker®, the sound wave will have a node at the closed end and an antinode at an open end.
- Allow the students to play with the Boomwhackers®.
    - **Note:** Be sure to remind them to be careful and not to hit each other. The Boomwhackers© can be bent out of shape so don't hit them too hard either.
- Ask for observations. **How is the sound the long Boomwhackers® make different from the sound made by the short ones?**

- The Boomwhackers® physical length is half of the wavelength of the sound wave produced: $\boldsymbol{L = \frac{1}{2}\lambda}$ or $\boldsymbol{\lambda = 2L}$. Because both ends of the tube are open, there are two antinodes.



Picture from Virginia Tech Physics Department

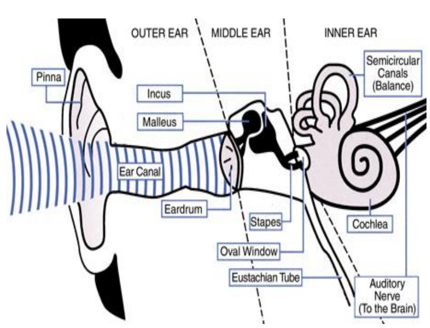
- Put the end caps on the Boomwhackers® so that each one has one closed end and one open end. Allow the students to experiment. **How has the sound changed?**
- The end cap creates a node at the closed end, but there is still an antinode at the open end. This makes the length of the Boomwhacker® one fourth of the wavelength: $\boldsymbol{L = \frac{1}{4}\lambda}$ or $\boldsymbol{\lambda = 4L}$.



Picture from Virginia Tech Physics Department

- Have the students measure the length of each Boomwhacker® and record the values onto the data sheet.
- Using the following equations and measured lengths, we can find the frequency of the sound produced.
  - Wavelength without endcap: $L = \frac{1}{2}\lambda \rightarrow \lambda = 2L$
  - Wavelength with endcap: $L = \frac{1}{4}\lambda \rightarrow \lambda = 4L$
  - Wave Equation: $v = f\lambda$ where $v_{sound} = 343\ m/s$

Did You Know? Mechanics of the Eardrum



Sound waves enter the ear canal and vibrate the ear drum. Our hearing range is limited by the length of the ear canal, which is roughly 2.5 cm. The frequencies allowed in a tube with one closed end are $f_n = n \cdot \frac{v}{4 \cdot L}$. This is why human ears are most sensitive to sound frequencies around 2000-8000 Hz when the hearing range is usually 20-20,000 Hz. Only 0.12% of the sound wave is transmitted by the ear drum because it transitions from travelling through air to travelling through muscle. The bones amplify the sound that does get through and then vibrate a membrane called the oval window, which then vibrates the liquid-filled cochlea tube. Since muscle and water are similar, 99% of the sound wave is transmitted from the oval window to the cochlea. The basilar membrane is vibrated, which excites fine hair sensors in our ears. Depending on the location of the sensors that get excited, a signal is sent to the brain which identifies the sound.

Activity: *Sound at a Distance*

Elementary/Middle School
Estimated Time: 10 minutes (per activity)

Motivation:

- To reinforce the idea that sound is caused by and travels through vibrations and can be amplified to allow us to communicate over long distances

Objectives:

- Reinforce the idea that sound is a longitudinal wave travelling by means of vibrations
- Demonstrate amplification of sound
- Combine these concepts to demonstrate how we can communicate over a long distance
- Provide introduction to engineering applications such cell phones

Materials:

- Plastic Cups
- Yarn
- Straws

Vocabulary:

- Amplification, vibrations

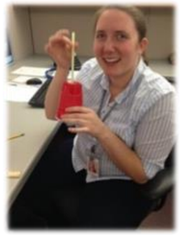
Introduction: Communication!

- We use sounds to communicate. Sound waves are created by the repetitive disturbance of particles in a medium, creating areas of high pressure (compressions) and areas of low pressure (rarefactions). We can amplify those waves to communicate over long distances. These demos will reinforce the importance of vibrations and explore this process.

Activity One: *Vocal Cords*

- Begin by asking the students: **How do we speak? How do we make noise?**
- Have the students place their hands on their throats and say their names. They will feel the vibrations in their vocal cords; this is what causes compressions and rarefactions of the pressure sound wave in the air.
- **Demonstration: Straw and Cup**
  - Poke a hole in the bottom of a plastic cup big enough to fit the straw inside. (We have found it easiest to use a pen).
  - Place the straw in the hole and drag your fingers along it. You should hear something that isn't quite so pleasant. **What's happening?**

- The friction between your fingers causes the vibrations in the straw, which in turn vibrates the cup, etc. The cup then amplifies the vibrations.

<u>Activity Two:</u> String-and-Cup Telephone

- Have the students drag their fingers over a piece of yarn. **Do the students hear anything?**
- Poke a small hole in another plastic cup. Thread a piece of yarn, about 2 meters long, through the plastic cup. Tie a knot so that it will not pull back through.
- Now have the students drag their fingers over the piece of yarn again. **What do the students notice?** The noise is louder now because the cup at the end has a large surface area, which amplifies the sound. **How can we use this to communicate over long distances?**
- Poke a small hole in another cup and string the free end of the yarn through the hole and tie it in a knot so it can't pull through.
- Have the students talk to each other using the string telephones.
  - Make sure that the students are far enough apart that the string is taut, but it doesn't pull the string through the hole in the cup.

SPS Interns on a very important conference call

- While two students are using the string telephone, pinch the middle of the string. They shouldn't be able to hear each other anymore. **Why is this?**
  - Explain that holding the string prevents the vibrations from one end from reaching the other.
- It might come up that cordless telephones and cell phones don't have a string connecting them. **How does sound travel in these devices?** The sound is transformed into an electromagnetic signal that is sent over satellites to another cell phone, and then is transformed back into a sound wave.

Demonstration: *Doppler Effect*

All Ages
Estimated Time: 10 minutes

Motivation:

- To provide an understanding that the pitch of a sound is affected by the relative motion between the observer and source of the sound

Objectives:

- Students will understand that motion of the sound source can affect their perception of the sound.
- Students will understand that the sound's pitch is higher when the source is moving toward the observer because the frequency increases; the opposite is true for a source moving away from the observer

Sheldon (Jim Parsons) of "The Big Bang Theory" on CBS wearing a Doppler effect costume.

Vocabulary:

- Doppler Effect, frequency, pitch

Materials:

- Buzzer
- String
- Ball
- Scissors

Introduction:

- If you stand by the road as a car drives past honking its horn, you can hear the pitch change as the car moves closer and farther from you. However, if you were in the car, the horn sounds the same the whole time. This is because of the *Doppler Effect*. If the source of the sound is getting closer to or farther away from the observer, the frequency you experience will shift. This demo explores these frequency shifts and what type of motions cause them.

Demonstration:

Part One: Building the Doppler Ball

- Cut a cross-shaped slit into the ball as shown in the picture.
- Cut a hole across from the slit for the string. Pull the string through the hole and out of the slit.
- Put the batteries into the buzzer. **Note:** Check that the buzzer's switch is in the "Off" position before you put the batteries in.

- Tie the string coming out of the slit securely to the buzzer. You may have to use tape to secure it.
- Push the buzzer and battery into the ball. Make sure it is easy to access the battery switch so you can turn the buzzer on and off.

NIST Summer Institute Teachers Testing the Doppler Balls

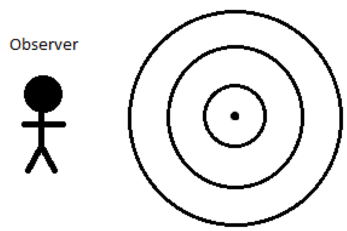
Part Two: Demonstration

Warnings:

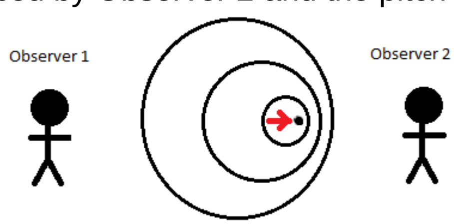
✓ Make sure you have enough room to swing the Doppler ball over your head. Be sure there isn't anything (or anyone!) breakable in your way.

✓ The buzzer makes a sound similar to a fire alarm. Check to see if this will be a disruption **BEFORE** you get to your outreach site.

- Turn on the Doppler ball. Keep the ball stationary so students can listen to the sound the buzzer makes. Explain that there is no relative motion between the source of the sound and the observer, similar to the figure below.

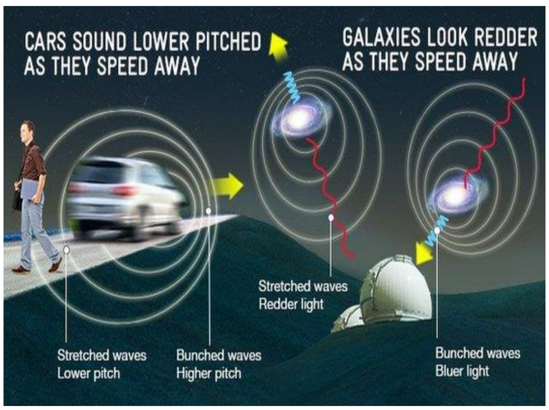


- Swing the Doppler ball over your head. **What do they notice about the pitch of the sound?**
- Explain that if the source of the sound is moving away from the observer the pulses get spread out like Observer 1 below is experiencing and the pitch would be lower. If the sound is moving towards the observer the pulses are pushed together as experienced by Observer 2 and the pitch will sound higher.



* *Additional videos to include in demonstration:*
    * "The Doppler Effect" https://www.youtube.com/watch?v=VYVWhBCwipE
    * "Example of Doppler Shift using car horn" https://www.youtube.com/watch?v=a3RfULw7aAY
    * "The Doppler Effect: what does motion do to waves?" https://www.youtube.com/watch?v=h4OnBYrbCjY
    * "Doppler Effect, Big Bang Theory Style" https://www.youtube.com/watch?v=z0EaoilzgGE

Did You Know? Doppler Shift and the Expanding Universe



We are living in an expanding universe. How do scientists know this? From the *Doppler Shift,* or more specifically, the observable redshift. From this demonstration, we learned that the apparent change in the pitch (or frequency) of sound is called Doppler shift. Light from distant stars and galaxies can be shifted in much the same way.

Light is also a wave which can be described by its frequency. Now, a star zooming towards you will have its light emission squeezed closer together. In this case, we would observe a blue shift, because blue is at the high-frequency end of the visible spectrum. The opposite is true if the star is speeding away from you; we notice a redshift because red is on the lower end of the frequency spectrum.

Hubble Space Telescope image from NASA's HubbleSite

Astronomers have noticed that almost all light from galaxies in our universe is redshifted. In fact, galaxies that are farther away are more redshifted than closer ones. It seems that not only are all the galaxies in the universe moving away from us, the farther ones are moving away from us the fastest.

Interestingly enough, not only is the universe expanding, but at an increasing rate. Astronomers are using data from the Hubble Telescope to try to figure out the fate of our universe: will it expand forever or will the expansion reverse and cause the universe to collapse back into another Big Bang?

Other Fun Things to Explore!

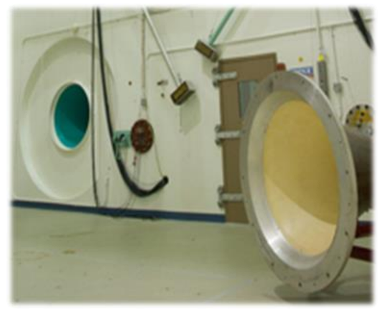
- *Ultrasound and Sonography*
    - **Ultrasound** is an oscillating pressure wave with a frequency greater than the upper limit of the human hearing range; this is usually around 20 kHz, but can vary from person to person.
    - Ultrasonic devices are used in many different fields to detect objects and measure distances. Ultrasonic imaging (or sonography) is used in both veterinary medicine and human medicine. It is low-risk and painless procedure, and produces pictures of the inside of the body using sound waves.
    - *For more info:*
        - http://www.radiologyinfo.org/en/info.cfm?pg=genus
        - http://www.livescience.com/38426-ultrasound.html
- *Acoustic Levitation*
    - **Acoustic Levitation** is a method for suspending matter by sending intense sound waves through a medium, sometimes on the order of ultrasonic frequencies. Acoustic levitation has progressed from motionless levitation to controllably moving hovering objects, which has many uses in the pharmaceutical and electronics industries.

    - *For more info:*
        - https://www.youtube.com/watch?v=669AcEBpdsY
        - http://www.aip.org/publishing/journal-highlights/acoustic-levitation-made-simple
- *Sonic Boom*
    - A **sonic boom** is attained when an object travels through air faster than the speed of sound. As an aircraft passes through air, it creates pressure waves surrounding it. As the aircraft speeds up, the pressure waves become more closely compacted, eventually merging into one: the sonic boom. Sonic booms generate enormous amounts of sound energy, sounding much like an explosion. The ratio between the velocities of the sound wave to the object travelling is given by the *Mach number.*
    - *For more info:*
        - http://science.howstuffworks.com/question73.htm
- *Useful Phone Apps (free unless noted otherwise)*

Apple	Both	Android
Sonar Ruler® ($.99) Science Learning Hub®	NoiseTube® iSeismometer®	Acoustic Frequencies®

Acoustical Research and Engineering: NASA Goddard

The National Aeronautics and Space Administration (NASA) provides an incredible variety of services to further the organization's vision: "To reach for new heights and reveal the unknown so that what we do and learn will benefit all humankind." You may be wondering: what does acoustics have to do with space exploration? At the NASA Goddard Space Flight Center, researchers and Hubble engineers utilize their Acoustic Testing Chamber to simulate launch conditions. Technicians expose payloads to the noise of a launch by using six foot tall speakers as pictured right. The speakers or horns use an alternating flow of gaseous nitrogen to produce a sound level as high as 150 decibels for two-minute tests; this is 25 dB over where the typical pain threshold begins and is comparable to standing near a jet engine. This uses the specific branch of acoustics called *aeroacoustics* that studies noise generation via aerodynamic forces interacting with surfaces.



Acoustical Testing Chamber at NASA Goddard Space Flight Center

Learn more about NASA at http://www.nasa.gov/

Architectural Acoustics: Whisper Galleries

Statuary Hall in the U.S. Capitol Building is a Whisper Gallery

Whispering Galleries are large rooms of circular, hemispherical, or elliptical shape typically covered by a dome-like enclosure. The acoustical properties of the architecture transmit all whispered communication from one part of the room to another part (which is determined by the shape of the room) within the circumference. The sound waves utilize the reflective property of an ellipse to produce this effect. When a sound wave leaves one of the foci and meets a point on the ellipse, it is reflected off and passes through the other focal point. When sound waves do not originate from the focal point, an echo is created. The term "whispering-gallery wave" has been adopted in physical science to describe a wave that can travel around a concave surface. Statuary Hall of the U.S. Capitol building used to be the home of the House of Representatives; imagine all the noise created from the echoes bouncing back across the chamber! However, there are two spots on the floor marking the focal points. You can hear very clearly someone talking to you from the other point as if they were right next to you through all the commotion!

To see a demonstration in Statuary Hall, see "Whispering Gallery – National Statuary Hall – US Capitol" https://www.youtube.com/watch?v=FX6rUU_74kk

A Little Note…

*Thank you from the 2015 **SOCK** Interns!*

We had an incredible time developing this **SOCK**, and we hope that you enjoy using it in all of your outreach endeavors! Acoustics is a wonderfully versatile field of study and has a wide variety of applications. Not just sound waves, but waves in general are *everywhere*. But if after all this you still doubt their importance, take it up with Nikola Tesla. (See pg. 3)

For us, music and physics are not exclusive. Physics is an exploration and understanding of our universe, whereas music is a demonstration of how we perceive it. Both are ways of figuring out who we really are, individually and on a global scale. Through both disciplines we seek ultimate understanding, search for patterns and symmetries, and look to nature for the answers to the questions we will never stop asking.

Physics teaches a particularly valuable skill. It teaches us how to think. Physicists perceive the world around them as much more than it appears to be. They make connections where there may not appear to be any, like with physics and music. Science is a way of thinking and a way of life, and our primary goal was to weave that perspective throughout the demonstrations and activities presented here. Physics is not all about the mathematics, the equations, the data… it is far more.

Outreach is not only about promoting the sciences, but promoting learning. So at the end of the day, if your student or audience member or general science enthusiast learns just one thing, you've been successful. Because again, that's what physics is all about.

Please contact us with any questions, thoughts, or suggestions. Thank you!!!

Hannah Pell, Lebanon Valley College
Shauna LeFebvre, Union College

SPS SOCIETY OF PHYSICS STUDENTS
An organization of the American Institute of Physics

Vocabulary Index

It is very important in science to be able to effectively communicate concepts and ideas to people who may not be familiar with them. Particularly in physics, certain vocabulary has very specific meanings, and it is important to use them accurately. Throughout the **SOCK** we hoped to emphasize this and encourage you to do so in all of your outreach events as well!

Vocabulary	Definition
Amplitude	Maximum displacement of the object from its resting position
Compressions	High density pressure region of a longitudinal wave
Crest	The point on the medium that exhibits the maximum amount of positive displacement from the rest position
Doppler Effect	A phenomenon characterized by a change in the perceived frequency of a wave as a result of relative motion between an observer and the source
Frequency	Number of complete cycles occurring per unit time, how often a repeated event occurs, reciprocal of the period
Fundamental	The component of lowest frequency in an oscillation or vibration, also referred to as the first harmonic
Harmonic	Single oscillation whose frequency is an integral multiple of the fundamental frequency
Hertz	Unit of measurement for frequency equivalent to 1 cycle/second
Interference	Process in which two or more coherent waves combine to form a resultant wave
Longitudinal Waves	Wave in which particles of the medium move in a direction parallel to the direction that the wave moves
Medium	Material through which disturbance is moving (air, water…), collection of interacting particles
Meters	Unit of length measurement, specifically for wavelength in this context
Nodes	Point of zero vertical displacement
Oscillation	Regular fluctuation in value, position, or state about a mean value, such as the regular swinging of a pendulum
Overtones	Any tones, with the exception of the fundamental, that constitute a musical sound and contribute to its quality, each having a frequency that is a multiple of the fundamental frequency

Partial	Produced when fundamental and overtones occur simultaneously
Period	Time it takes for a wave to repeat one full cycle
Periodic Motion	Motion that is regular and repeating
Pitch	Sensation of frequency, the perception of frequency
Pulse	A transient sharp change in voltage, current, or some other quantity normally constant in a system
Rarefaction	Area of lowest pressure density in a longitudinal wave
Resonance	Oscillation induced in a physical system when it is affected by another system that is itself oscillating at the fundamental frequency of the physical system
Standing Wave	A wave that oscillates in place and creates nodes of zero oscillation; a stationary wave
Transverse Wave	Wave in which particles of the medium move in a direction perpendicular to the direction that the wave moves
Trough	The point on the medium that exhibits the maximum amount of negative displacement from the rest position
Vibration	A periodic motion about an equilibrium position, such as the regular displacement of air in the propagation of sound
Wave	Any regularly recurring event that can be thought of as a disturbance moving through a medium
Wave Equation	$v_{sound} = f \cdot \lambda$
Wavelength	Disturbance that travels through a medium from one location to another

References and Additional Resources

- **Books**
  - *An Introduction to Acoustics.* Robert H. Randall.
  - *Physics of Waves.* William C. Elmore, Mark A. Heald.
  - *Physics and Music: the Science of Musical Sound.* Harvey E. White and Donald H. White

- **Videos**
  - “Top Ten Demonstrations with Tuning Forks.” https://www.youtube.com/watch?v=vNuDxc9tZMk
  - “The Doppler Effect: what does motion do to waves?” https://www.youtube.com/watch?v=h4OnBYrbCjY
  - “Music, physics, shapes in nature and why we like music: Yuri Landman at TEDxUtrecht.” https://www.youtube.com/watch?v=zheBPBfvEFQ

- **Websites and Webpages**
  - “Acoustics.” Science Clarified. http://www.scienceclarified.com/A-Al/Acoustics.html
  - “The Acoustics of the Guitar: The science behind acoustic guitar tone.” http://www.graphtech.com/docs/default-document-library/saddlescience.pdf?sfvrsn=2
  - The Physics Classroom. Lessons on “Waves” and “Sound and Music.” http://www.physicsclassroom.com/
  - *The Physics of Music and Musical Instruments.* David R. Lapp. http://kellerphysics.com/acoustics/Lapp.pdf
  - “Doppler Effect” http://www.exploratorium.edu/hubble/tools/doppler.html
  - “The Human Ear – Hearing, Sound Intensity and Loudness Levels” https://courses.physics.illinois.edu/phys406/lecture_notes/p406pom_lecture_notes/p406pom_lect5.pdf

Notes