

The Ear, Music, and Math

HTHMA Class of 2010



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High Tech High Media Arts inspires its students to cultivate their inner strengths and strive for personal greatness as local and global citizens.

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Dear Darren Miller; Amy Hill; and Brandon Davidson,

Thank you so much for giving us the knowledge and tools necessary to create a book on Music, The Ear, and Mathematics. We had no idea what to expect when we filed into Darren's class that day and heard that we were starting a new project. Our moans and groans filled the classroom when we saw each group we were put into. It was difficult for us to really get into the project in the beginning because of the hard subject matter and stepping out of our normal social circles to be with people we wouldn't really have spent time with before. To us, this project was full of hardship and rocky times. With your strength and leadership, you teachers taught us how to hold the reins and ultimately let us take control of the entire project.

Amy, thanks for giving us time to critique other groups' pages so everyone's work could benefit. Thanks for reminding us how important a good, solid, yet nice critique is. We appreciated how you stressed the magnitude of grading hard on the paper, not your peer.

Brandon, thank you for teaching us about the mechanics of the ear. It was in your class that we learned about the inner ear, the cochlea, and how we hear sound. You made learning these boring terms interesting and applicable to us. In your class we learned how instrumental music made us feel. It was an interesting topic that made us think how people can feel something just from a tone in the music. It was up to our own interpretation on how we could feel a certain way from an instrumental song and not only that you played really great songs! We never realized that Black Sabbath could record an instrumental song that made you feel like you were listening to the ocean on a Mexican resort.

Darren, thank you for being the leader. You said that it was us, the students, who controlled everything but you were the one who students went to for help and ideas. It was your unique idea to create a book to teach us about sound and also teach music, the ear, and mathematics to others. Thank you for helping us along the way and being someone you could turn to for answers throughout this project.

We appreciate you! Thank you!

Sincerely,

*The Darren/Amy/Brandon Team
HTHMA Class of 2010*

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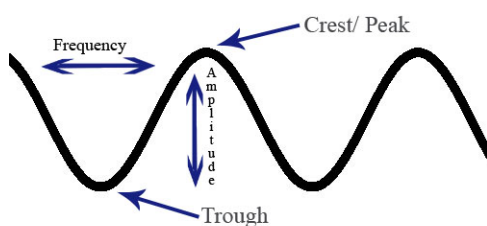
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Chapter 1

SOUND PRODUCTION

Margaux Gunning, Nic Nash, Trae Washburn

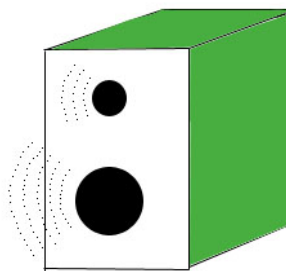
Sound is created by the vibrations caused by striking or rubbing two mediums (objects) together creating vibration inside of that medium. Sound in essence is vibration, and any vibration has a sound. Sound has the ability to vibrate in different surroundings such as water, air, or even objects. To go more in depth a medium vibrates sending its vibrations into the surrounding area causing the area's molecules (H_2O , O_2) to send vibrations off in all directions. These vibrations cause other molecules to vibrate, creating a chain until it reaches a receiver such as an eardrum. The eardrum then vibrates, the vibration is translated, sent to the brain, and is then processed as sound. These vibrations are sound waves.



A sound wave is not a *random* vibration. Sound waves have different amplitudes and pitches. These amplitudes cause vibrations that in essence resemble sine waves in the point that they have peaks and troughs. The degree of how far apart and how deep or high the troughs and peaks are determines the frequency of the

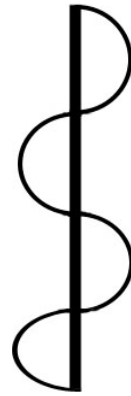
vibration and this is what allows for the determination of whether or not the sound will be registered as a high or low frequency. For instance, when you change the station your actually changing the frequency that your car picks up allowing you to hear the desired station.

Every sound wave creates a pressure wave. Pressure wave's travel through the air very similarly to the way a sound wave travels and they play a key role in helping us hear. An example of a pressure wave is the pulsing you feel when standing next to a loud bass speaker.. The base speaker is oscillates between positive and negative values very fast. This is what causes the pressure that we can feel. Lower frequencies vibrate between 60-200 times per second. When you start to get to really low frequencies you can even detect the osolating. It will start to sound like a wobble going slower and slower the lower the frequency.



Sound pressure waves also play a key role in helping us hear the amplitude of objects. When a pressure waves enters your ear it blows down certain hairs inside of your ear. The louder the noise the more hairs it will blow down. Without these pressure waves, we would never be able to tell the amplitude (how loud the sound appears) of certain

sounds. Sound pressure is the difference between the pressure of what is traveling through the air and the pressure found within that sound wave itself. Even very small changes in the difference of this pressure can cause a quite deafening a sound that can cause hearing loss. The human ear can detect sounds with a very wide range of amplitudes. This is often measured on a logarithmic decibel scale. (To the right is a picture of what a sound wave would look like when it oscillates between positive and negative values)



There are also objects that can measure sound pressure. Good examples of this would be a microphone in air and a hydrophone in water. The more sound pressure that enters into the microphone the more pressure it will receive. Microphones are also usually attached to another amplifier, which takes the sound pressure that enters it and then amplifies that through another speaker. This way whispers with little sound pressure can easily be turned into very loud noises.

P = The Root-Mean-Square of sound pressure

p_{ref} = a reference sound pressure

There are two kinds of waves when talking about sounds production; longitudinal and transverse waves. Longitudinal waves are waves that move parallel through the medium (object). They create sound waves that travel through air, and the vibrations of the particles create a wave. The energy is then transported through the particles to create the sound.

Transverse waves are waves that move perpendicular to the direction that the wave actually moves. If a slinky is stretched completely out, the pulse from the first vibration vibrates the entire slinky, because the energy sent out throughout the slinky as a whole. While there are many differences between these two types of waves there are yet several similarities. In both transverse and longitudinal waves, the particles vibrate through a medium in a direction.

The History of Sound Production and how it all started:

"In the 6th century BC Pythagoras of Samos observed someone playing a stringed instrument and as he observed the string being plucked, he related the amplitude of its vibration (which he saw as the width of the blurred area the motion of the string produced) with the perceived loudness of the sound. He also noted that when the vibration stopped altogether, the sound stopped as well. He even saw that the shorter strings vibrated more rapidly, and that this more rapid vibration seemed to produce a shriller, higher-pitched sound."

"By 400 BC, a member of the Pythagorean school, Archytus of Tarentum was hypothesizing that sound was produced by the striking together of objects. From this he also gathered that a fast motion resulted in a high pitch and slow motion resulted in

a low pitch. Though he was on the right track, today we know this to be true only under certain circumstances.”

“Around 350 BC, Aristotle observed that the vibrating string was actually striking the air. He also concluded that each bit of air struck a neighboring bit of air, which in turn struck another bit, and so on. From this Aristotle hypothesized that air was needed as a medium through which sound could be conducted. He further postulated that sound would not be conducted without a medium; that is, it would not be conducted in a vacuum.”

“Realizing that a vibrating string strikes the air many times in a series of blows, not just once, 1st century Roman engineer Marcus Vitruvius Pollio suggested that the air not only moved, but vibrated. He thought that it did so in response to the vibrations of the string. He maintained that it was actually these air vibrations that we heard and perceived as sound.”

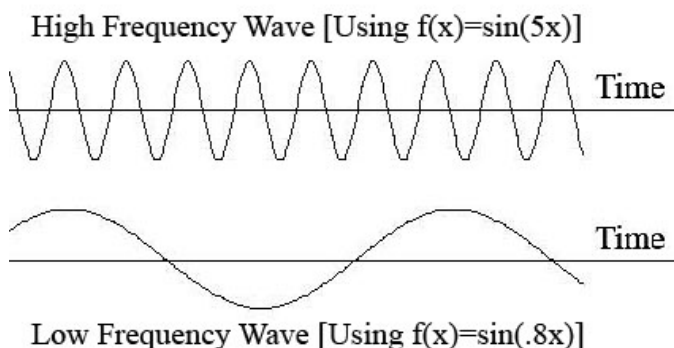
“It was not until about 500 A.D. that the connection between the motion of sound and the motion of waves was suggested. The Roman philosopher Anicius Manilius Severinus Boethius specifically compared the conduction of sound through the air to the waves produced by dropping a pebble into calm water. Though today we know that sound waves and water waves represent two distinct types of wave motion, longitudinal and transverse, the realization that sounds moved as a wave at all was an important step in the study of sound.”

Chapter 2.1

AMPLITUDE AND FREQUENCY

Scott Lindquist, Natalie Arenz

Every sound



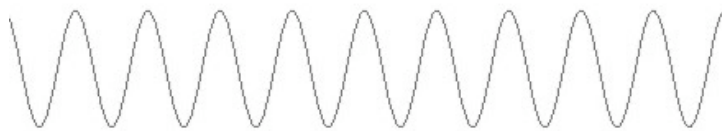
$$\sin(x) = \text{Frequency}$$

that our ears collect has a frequency. Frequency is the variance at which the wavelength of a sound changes. Wavelength has an inverse relationship with frequency. Sounds with wide spaces in between their waves have a low frequency. Sounds with thin spaces between their waves have a high frequency. Frequency is the amount of vibrations per second produced by a sound.

In music, frequency is often referred to as pitch. If a wave has a high frequency, it will also have a high pitch. For example, a whistle will make a sound with a higher frequency than a foghorn.

Objects vibrating in air create sound. Certain materials vibrate faster than others, or

Example of the type of wave a whistle would make



Example of the type of wave a foghorn would make

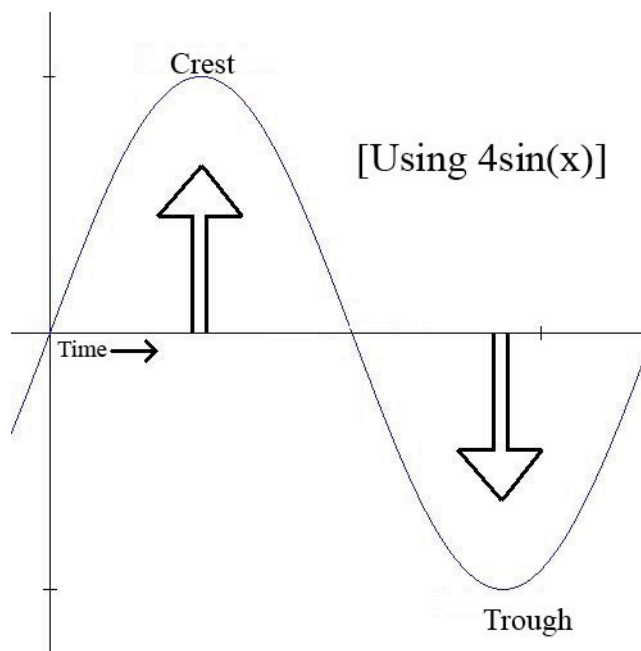
have more vibrations per second. This creates higher pitched sounds, thus having higher frequencies. An object that vibrates slowly has a low frequency and a low pitch.

Frequency is measured in Hertz. The unit Hertz was named after the German physicist, Heinrich Hertz. 1 Hz equals one vibration per second. Because of the structure of each different type of organism, different types of living things are able to hear different frequencies.

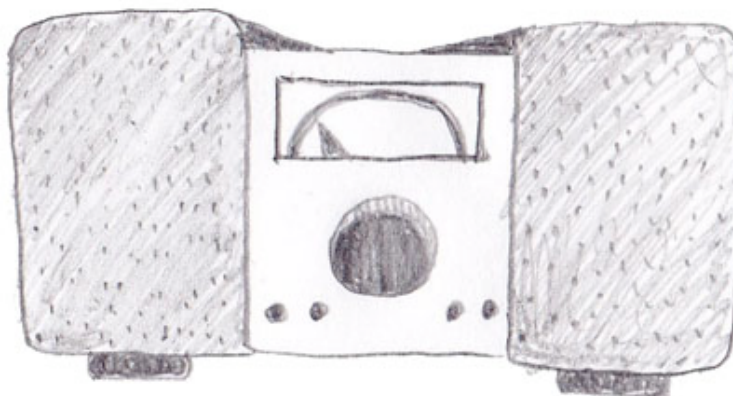
Amplitude is the intensity of a sound. Amplitude is very similar to volume. The only difference is amplitude is used to often describe wavelengths, while volume pertains just to how loud a sound is. Amplitude is half the distance from a sound wave trough to crest. The crest is the peak of a sound wave, and the trough is the lowest point of a sound wave.

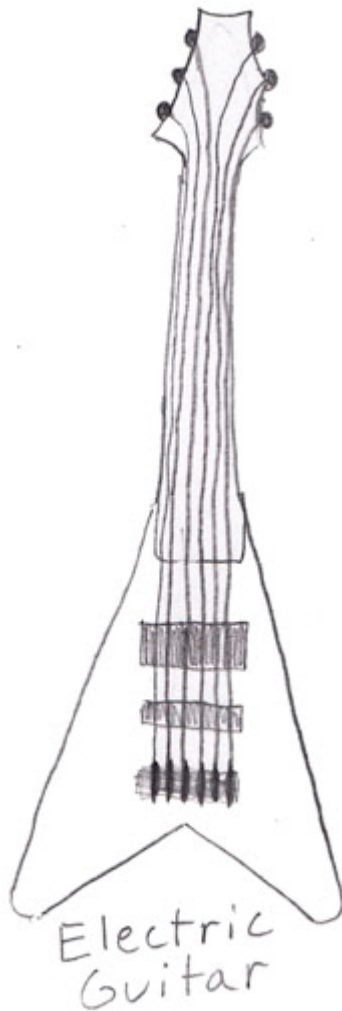
Amplitude is measured in Newton's. Newton's are how we measure work, or the amount of force it would take to move an object, without getting into the specifics. Amplitude is always measured in either Newton's, or, when using an amplifier, in watts.

An amplifier is a tool musicians often use to increase the intensity of the sound of their instruments. Amplifiers are measured in watts, and one watt equals 1 Newton per second. Electric guitars, basses and speakers all use amplifiers to increase their various intensities.



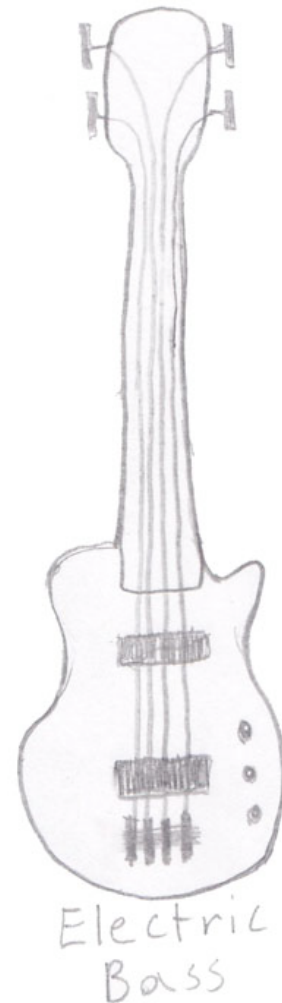
Amplifier





A lot of new terminology was just introduced. How about some review?

Frequency is the amount of vibrations per second at which objects vibrate. All sounds produce frequencies of varying wavelengths; with more compact waves creating higher pitched sounds and waves with more space create lower pitched sounds. If the wavelength of a sound is increased, that sound will have a lower frequency, thus having a lower pitch. Hertz are how we measure frequency. Amplitude is the intensity of a sound, and is similar to volume. Amplitude is measured in Newton's, or in Watts, when using amplifiers.



Chapter 2.2

INTERFERENCE

Eric Watts, Richard Ramirez

In chapter 2.1 you learned about the amplitude and frequencies of waves. Now we're going to apply this information to wave interference. Wave interference occurs when two waves are on the same linear path or emerge from the same source meaning the waves are "coherent" to one another.

The principle of superposition states that "The net response at a given place and time caused by two or more stimuli is the sum of the responses which would have been caused by each stimulus individually." The phenomenon that occurs during interference is able to exist because of this property. This means when two waves travel on the same medium they will interfere and their frequencies will be combined for a new outcome.

The two most basic and common forms of interference occur when two waves with the same amplitude and frequencies meet on the same linear path, the first is Constructive Interference (see A.1-A.3) which happens when the two waves crests and troughs align perfectly and increases the overall amplitude of the wave. For the purpose of the graphs below, we use the function for a sin wave. $A\sin(kx + \phi)$ is the equation for a sine wave on a 2D Cartesian graph. Variable A represents the amplitude, k represent the angular frequency, and ϕ represent the phase of the wave. In Image 1.1 A, k, and ϕ are all set to one. In 1.2 Variables A and k are effectively doubled to two, while phase remains the same because it only affects the waves position.

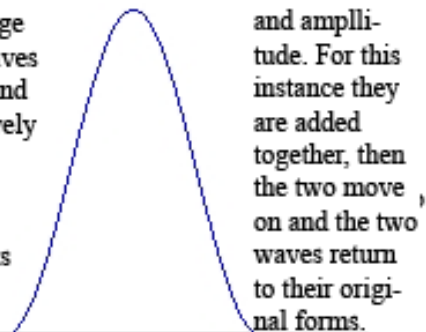
Once the instance of interference is passed, the wave returns to normal. The second is Destructive Interference (see B.1-B.3) that occurs when the crest of one wave meets the trough of the other, dampening the amplitude. Like constructive interference, it remains unchanged after the instance is passed. The equations are the same as the ones used in images 1.1 and 1.2. 2.1 show two opposite waves approaching one another, 2.2 shows what happens when they meet.



These two coherent waves are approaching one another. They are of equal value and are perfectly in sync which means they will interfere constructively effectively doubling the amplitude.

1.1

In this image the two waves have met and constructively interfered with one another, doubling its frequency

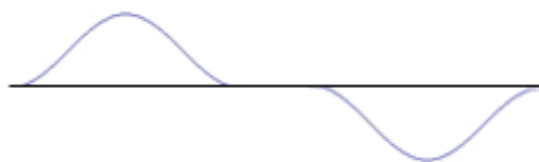


and amplitude. For this instance they are added together, then the two move on and the two waves return to their original forms.

1.2

Another product of interference is known as a Standing Wave, which occurs when two waves move in opposite directions on the same medium create a wave that seems to stand still. Which in turn means standing waves can be created by both constructive and destructive interference. Both image 1.2 and 2.2 are examples of standing waves. Whether it is constructive interference or destructive interference a standing wave will still appear. For an instance the outcome of the two waves is frozen. This can be applied in various manners but we will concentrate on holograms later in the chapter.

Now we'll move on to another important concept, *Beats*. Beats occur when two coherent waves with very similar frequencies interfere with one another, with instances of both constructive and destructive interference. Beats by definition are repeating fluctuations of high and low sound intensity, which can be applied in an array of different ways.



These two waves are equal and perfectly *out* of sync meaning they will destructively interfere. Because of this the wave will seem to cease existing till the instance of interference is passed

2.1

The two waves have met and cancelled one another out. Though for this moment there is no wave at all the instance will pass and the will return to their original forms

2.2

Now that you know a little bit more about beats let's take a quick look at music, something you encounter every day. Ask yourself; do you know what music is defined

as? Well, what defines music is a combination of wave frequencies that have a simple mathematical relation to one another, such as being fifths apart or octaves. When there is no easily discernible relativity between two frequencies then it is considered noise. The father of the concept of modern music was Pythagoras, ancient philosopher and mathematician.

One of the most recent uses of wave interference is the creation of holograms; holograms by definition are “photographs of three dimensional impressions on the surface of light waves.” If you have ever used a camera in your life its safe to assume that you’ve taken a blurry picture like photo 3.1. When you get a blurry picture, it means that someone or something was moving too quickly for the camera to photograph that instant in time. That object is probably only moving roughly twenty miles or so, while light moves at around 186,000 miles a second. Normally capturing light in the incredibly large timeframe of a cameras shutter is impossible, but this is where standing waves appear. As explained earlier in the chapter standing waves occur in all instances of interference, precisely when the two waves meet. The properties of both waves are added together and they seem to vibrate in place for long enough to be captured. The result is a hologram, a three-dimensional image in which depth can be seen. It is much more detailed than a simple image and can give you various perspectives.



3.1

Keep the basics in mind as you read ahead in the book, this is not the last time you will meet wave interference. As you explore on ahead in chapters you will learn that interference is applied in many situations, whether it be instruments or the Doppler effect. The most important things to remember are the basic forms and aspects of interference, concentrate on standing waves, super position, and constructive and destructive interference.

Chapter 3

HOW SOUND TRAVELS

Truman Dodd, Allie Olson

Have you ever wondered why your mom can hear you even when you yell at her from the opposite side of the room? Why are people able to eavesdrop through closed doors? Why can you hear people under water, but not if they're speaking above the surface? The reason for this is that sound can affect and is affected by many different variables. In this chapter we will be discussing how sound travels and how different materials affect sound waves referring to the sound of speed.

Sound travels as a series of compression waves that move through different materials. Everything is made up of atoms or particles, within the materials the sound waves vibrate off of the particles that make up the material the sound is moving through.

When a particle vibrates it hits another particle and that causes a chain reaction, which makes all neighboring atoms vibrate. How much of the sound you hear depends on how quickly the sound is moving the material. The three things that have the biggest affect on sound are: density, temperature, and altitude.

The first thing that we are going to discuss is density and with that we are going to discuss four different kinds of density: solids, liquids, air, and space. Since the denser the material the faster the sound will travel, making sound travel fastest through solids.

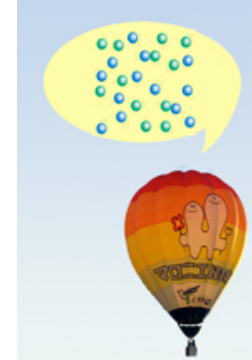


In a solid the particles are held together very closely and are in a fixed position so they won't move around unless they are in a whole, this allows the sound moving the through the particles to vibrate the whole object very quickly. For the equation of the speed of sound through solids, see the Speed of Sound section of this chapter.

When sound moves through liquid it isn't as fast as it would've been if it moves through solids. Liquids are made up of many particles but they are not held together in a fixed position so they can move freely, because of this it takes a little longer for the particles to hit each other and send the vibrations on. An example of this would be if you tried to yell something underwater to another submerged person you would see their mouths move before you hear them.

Temperature (Fahrenheit)	Speed of Sound (m/s)	Speed of Sound (Ft/S)
32	1403.35366	4,603
40	1424.39024	4,672
50	1447.56098	4,748
60	1467.68293	4,814
70	1485.06098	4,871
80	1499.69512	4,919
90	1512.19512	4,960
100	1522.86585	4,995
120	1539.32927	5,049
140	1552.13415	5,091
160	1555.18293	5,101
180	1553.35366	5,095
200	1551.52439	5,089
212	1543.29268	5,062

Air or gas is next, and because the particles are farther apart and are not in any fixed position sound will move slower than in a solid or liquid. However because gas is all around us we can hear sounds from any direction on earth. In space there is no oxygen or gases so there are very few particles and they will travel in any direction at any time. Because of this there is no sound in space because a vibrating particle will not be able to hit another particle to carry on the sound.

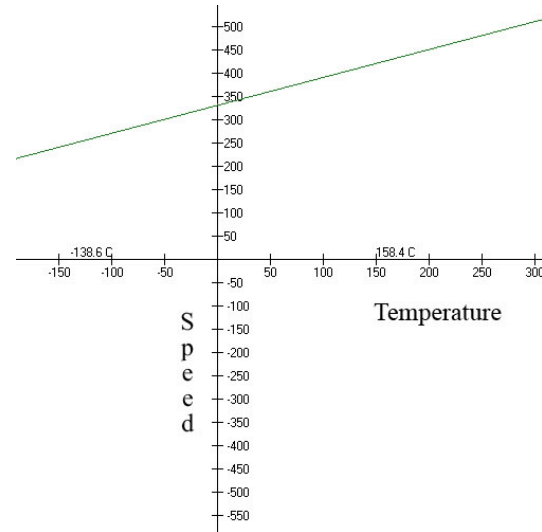


The equation to find the speed of sound in air is $v = 331 \text{ m/s} + 0.6 \text{ m/s} \cdot T$. Temperature and altitude also have an effect on the speed that sounds travel. Temperature like sound is a form of kinetic energy, which means that molecules at a higher temperature have more energy therefore they vibrate faster and in turn causes sound to travel faster.

Altitude affects the speed of sound as a function of temperature and humidity. In higher altitudes the density along with humidity decrease, which causes the speed of sound to decrease as well.

As previously stated, "a sound wave is a pressure disturbance which travels through a medium by means of particle-to-particle interaction." The speed of a sound wave just "refers to how fast the disturbance is passed from particle to particle," while frequency is "the number of vibrations which an individual particle makes per unit of time." (To learn more about frequency see chapter 2).

Two factors that affect the speed of sound all depend on the property of the medium that sound is traveling through. The first are the elastic properties and the second are the inertial properties. Elastic properties are the tendency for the material to not be deformed after force is applied. A material such as steel will have a stronger elasticity versus a material such as rubber. Generally, solids have the highest interaction between properties followed by liquids and then gasses.



Inertial properties have to do with how dense a material is. The greater the mass of the material the slower particles react with each other. "Even though the inertial factor may favor gasses, the elastic factor has a greater influence on the speed(v) of a wave, thus yielding this general pattern: 'solids > 'liquids > 'gasses." To find the density of an object you have to use this equation:

$$D = \frac{m}{v}, \text{ where } m = \text{mass and } v = \text{volume.}$$

To find the velocity of a sound wave, use this equation:

$V = \sqrt{\frac{C_{ij}}{P}}$, where C_{ij} = elastic properties of the object (must be a solid) the sound is going through and P = density.

Example:

The elasticity of steel is $17 \cdot 10^{10} \rho$ or $\left[\begin{array}{c} \text{ } \\ \text{ } \end{array} \right]$, and the density is 7700 kg/m^3 .

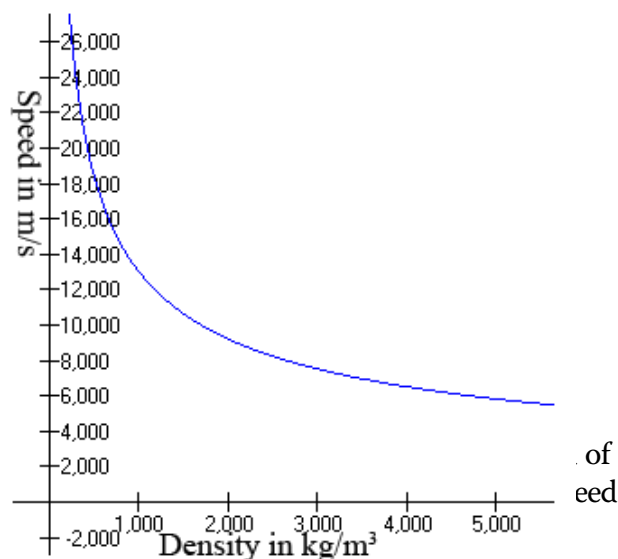
$$V = \sqrt{\frac{C_{ij}}{\rho}}$$

$$V = \sqrt{\frac{17(10^{10}) \text{ kg/m} \cdot \text{s}^2}{7700 \text{ kg/m}^3}}$$

$$V \approx \sqrt{2.2 \cdot 10^7 \text{ m}^2/\text{s}^2}$$

$$V \approx 4,698.7 \text{ m/s}$$

The speed of a sound wave is how fast sound is usually expressed in the unit of sound is:



$Speed = \frac{d}{t}$, where d = distance, and t = time

“The speed of a sound wave in air depends upon the properties of the air, namely the temperature and the pressure... At normal atmospheric pressure, the temperature dependence of the speed of a sound wave through air is approximated by the following equation:

$v = 331 \text{ m/s} + (0.6 \text{ m/s/C})T$, where T = temperature.

Now let's see an example of this problem:

The air temperature is 20 degrees Celsius

$$v = 331 \text{ m/s} + (0.6 \text{ m/s/C})T$$

$$v = 331 \text{ m/s} + (0.6 \text{ m/s/C})(20^\circ\text{C})$$

$$v = 331 \text{ m/s} + 12 \text{ m/s}$$

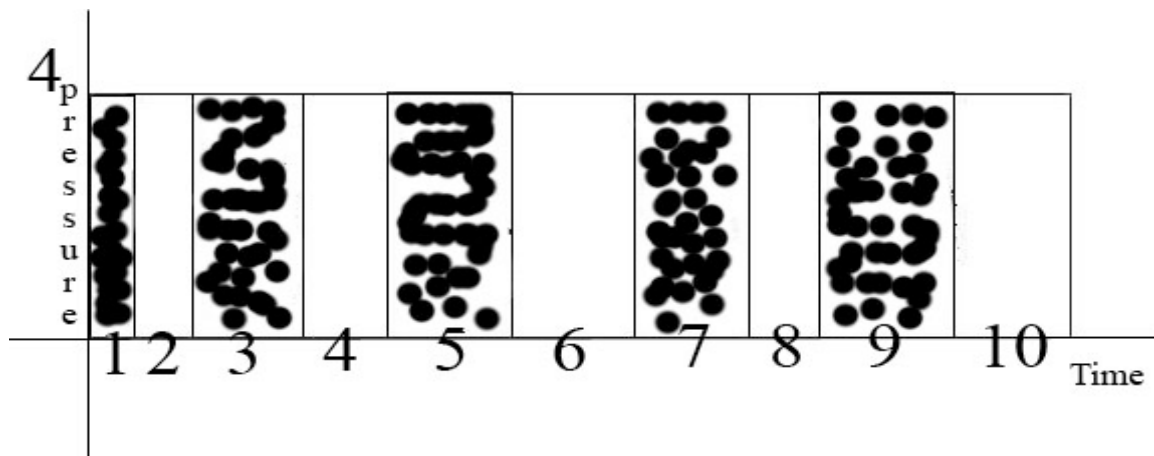
$$v = 343 \text{ m/s}$$

Chapter 4

TRIGONOMETRY AND MUSIC

Sarah Flores, Deyna Rrivera

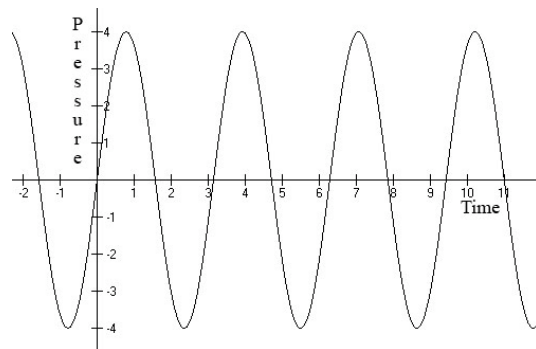
Music is everywhere. Music is a medicine for the soul. However, we cannot see is the way that music actually reaches our ears. Any kind of sound, be it a low or a high frequency, reaches our ears. Sound in simple terms, is a series of vibrations considered sound waves. Mathematicians have concluded that any sound wave at all is made up of sine and cosine waves. A thing that vibrates which if you really look, you can see that there is a wave produce. Pressure and time are large topics when discussing sound waves.



When things start to vibrate, air molecules are moved throughout the air and we can simply see this with a graph between pressures vs. time.

The diagram above shows some areas that are darker than others. The darker areas are molecules of air compressed together in a tight space, which makes the sine wave go up in that area. It makes sine wave go because there is more pressure being added into the specific area. The areas that are empty are lower points in the sine wave and that makes the sine wave go down because there is no pressure being added.

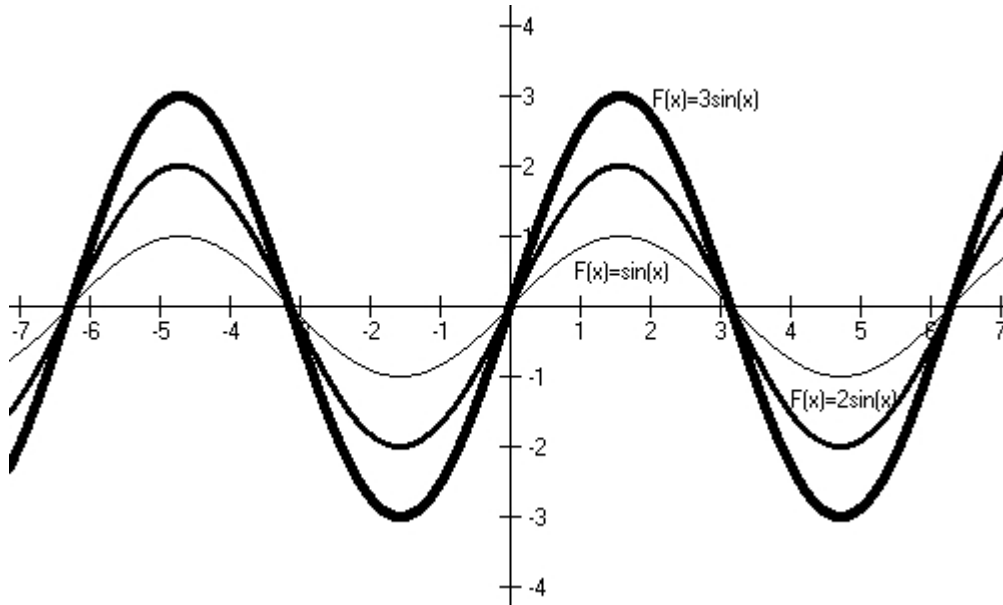
The air molecules are being pushed to the right and we see clumps of air molecules, the darker areas, in some areas. Those areas are called compressions and they are the highest point in the diagram. The empty spaces between them are called rarefactions and they are the lowest points of the graph. When transferred to an actual graph it looks like the image to the right.



This is now an example of a sine wave. The actual function a sine wave is $f(x) = A \times \sin(Bx + \theta)$. Where A is called Amplitude, B is frequency (radians per second) and θ is phase.

The function for cosine has just one difference, $f(x) = A \times \cos(Bx + \theta)$. Changing the amplitude of a function changes the graph too. The graph below can help you understand,

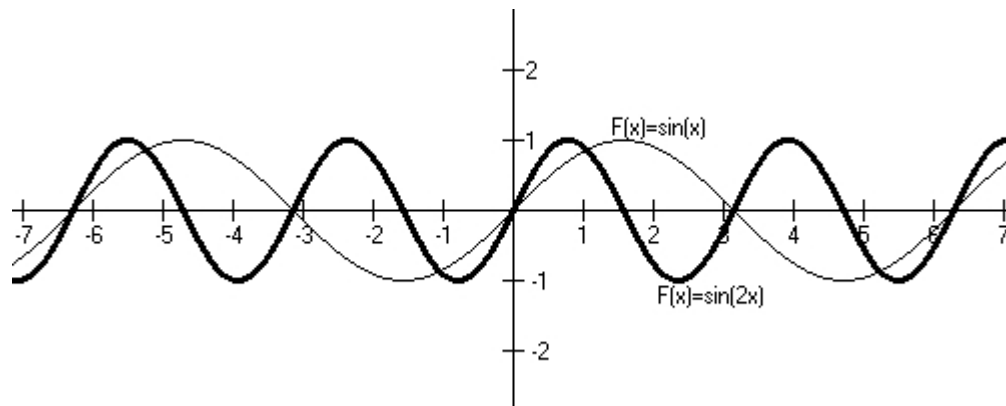
$$F(x) = \sin(x), f(x) = 2 \sin(x), f(x) = 3 \sin(x)$$



As you can see, changing the amplitude changes the wave of the function. We started with a simple one, $f(x) = \sin(x)$, the thinner line, and as you can see nothing really changed. However, in the next line we added a two in place of the amplitude, We added one more function so you can really see the difference between all the waves and added a third line and put a three in the amplitude which will be the thicker line. The higher the amplitude is, the louder the sound is. The lower the amplitude is, the softer the sound is.

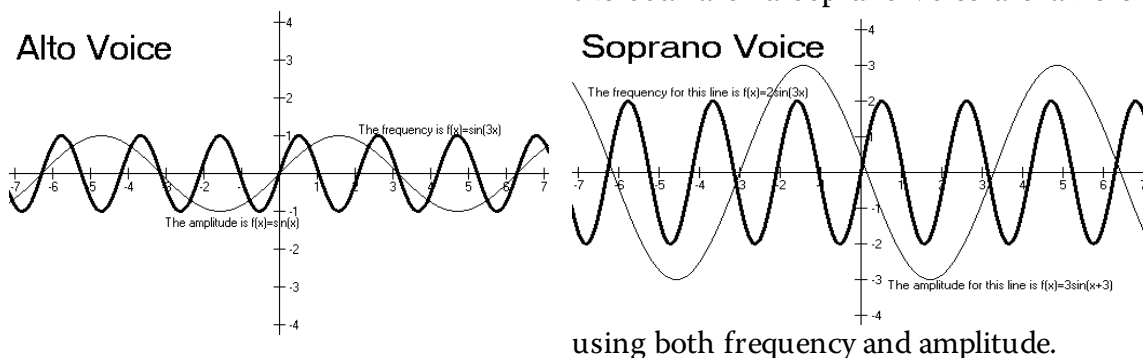
We get more complex sounds by adding waves of different frequencies and loudness together. Frequency is in the sine function is $f(x) = A \times \sin(Bx + \theta)$, is B . Frequency is the number of times the air molecules are vibrating back and forth. Like the changing the amplitude in a function changes the wave, same thing goes for frequency and it also changes the pitch of a sound. The diagram below can show you the difference between some functions.

$$F(x) = \sin(x), \text{ and } f(x) = \sin(2x)$$



As you can see, changing the frequency changes the wave of the function. We started with a simple one, $f(x) = \sin(x)$, the thin line, and as you can see nothing really changed. However, we just added a two in place of the frequency in the next function, the thicker line, and then the wave was stretched out just a bit more. The lower the frequency is, the lower the pitch is, and a good example is the voice of an alto. The higher the frequency is, the higher the pitch is like a soprano. You can refer back to chapter 6 for more information about Vocal Cords and Voice Changes

The graph below can show you a good example of how the sound of an alto voice and the sound of a soprano voice are different



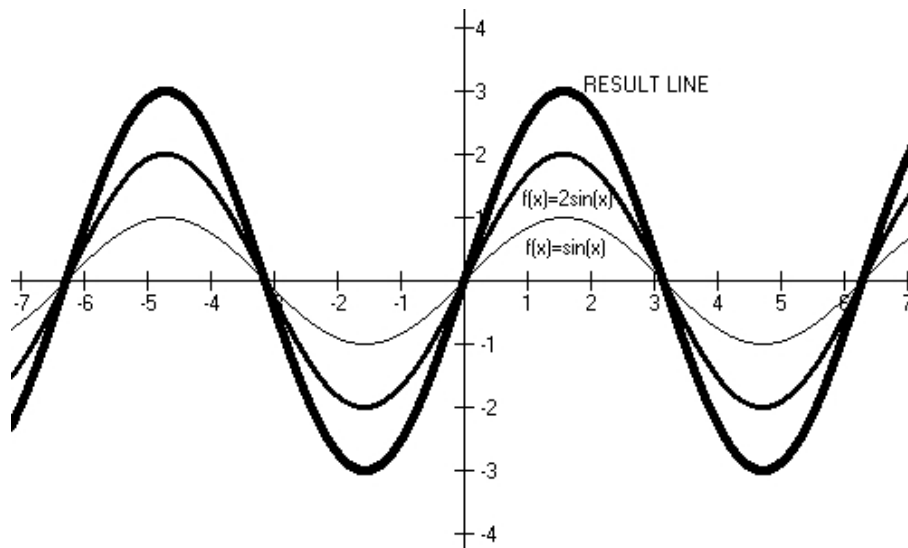
using both frequency and amplitude.

Interference is the sum of the amplitude of 2 waves. This means that the amplitude gets added together and the amplitude doubles but the frequency stays the same. Here is a graph that will show you.

Thin line: $f(x) = \sin(x)$

Thick line: $f(x) = 2\sin(x)$

Result of both lines: $\sin(x) + 2\sin(x) = 3\sin(x)$



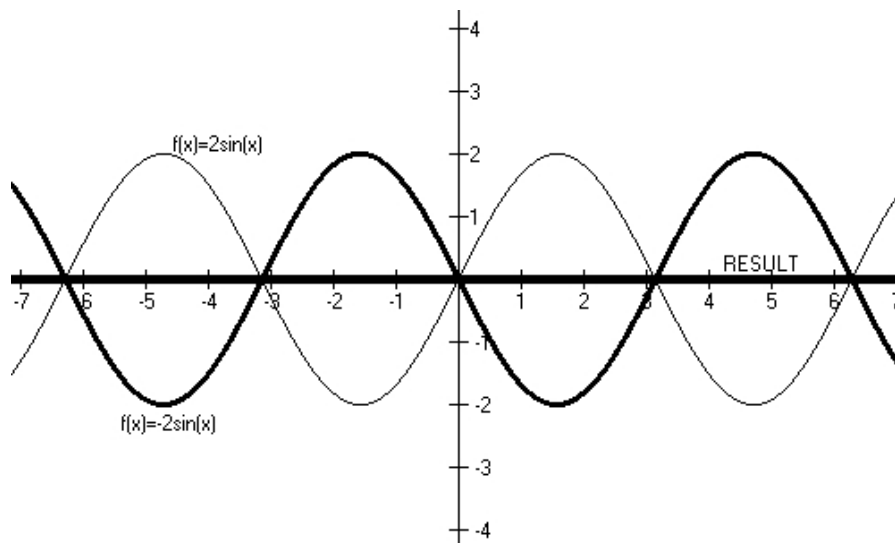
As evidenced by this graph, the thick line is the double of the dash line since the both line got added together the line is double the amplitude.

Destructive interference is when 2 waves of the same amplitude interfere, they are subtracted one from the other and the resultant is zero.

Thinner line: $y = 2\sin(x)$

Thin line: $y = -2\sin(x)$

Thick Line: $2\sin(x) - 2\sin(x) = 0$



As you can see, these have the same frequency but they don't have the same amplitude. The amplitude of the thicker line is negative. When the two lines interfere with each

other, shown above, the result line is 0. They cancel each other making it as there is no sine wave.

Now you know that music is a sound and that sound is represented in vibrations that actually are waves that go into your ear. But math is everywhere and waves are shown in sine and cosine functions and they are constructive or destructive waves. In general we can hear vibrations whose frequency is between 20 Hz and 20 kHz (cycles per second) and often mathematicians add another parameter to the pure tones. $Y(x) = A \sin(Bx + \phi)$, where A is amplitude, B is frequency (radians per second and ϕ is phase.

Chapter 5.1

HOW THE BRAIN AND EAR FUNCTION

Daylin Hartwell, Ruth McCowan

In this chapter, you will learn how the brain and ear function in relation to sound. The ear and brain function as sensory organs that enable us to hear. Hearing is a perception of sound energy translated by the brain and nervous system. Sound travels through the outer, middle and inner ear then finally sends this sound to the brain. The brain is a central nervous system, responsible for interpreting various waves such as sounds and making decisions.

“Siizzzle.” You hear your favorite breakfast, pancakes and bacon, being made in the kitchen. “Bzzzzzz.” As you leave your house, you know that a bee has just flown past you. “Screeeech.” Yikes! You know that that is the sound of a car coming to an abrupt halt or turning the corner. Every second of your normal day, these and many other sounds are caught by your ear and your brain interprets those sounds.

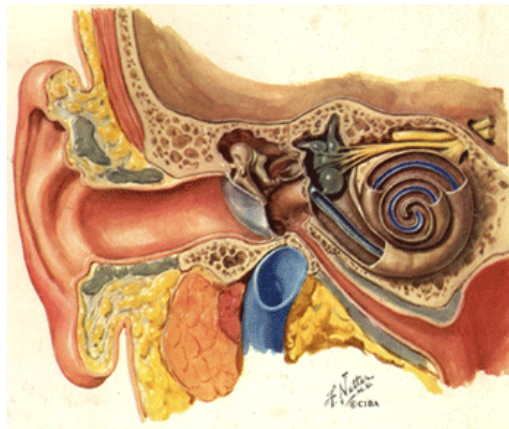


Figure 5.1.2

The ear is a sensory organ that enables one to hear sounds. This sound is a type of energy that flows through the air. Near the beginning of this chapter we discussed that hearing is the perception of sound energy translated by the brain and nervous system. In order for hearing to be accurate it needs to identify the sound, what makes the sound, and find the location of the sound as well as which direction it comes from. Along with those two components, hearing let's one know how loud or soft that sound is, which is called amplitude. Amplitude is defined as “the maximum displacement from the zero or mean position of a wave or oscillation [Latin *amplus* spacious].”

At the beginning of the process, sound waves go through the Outer Ear. The skin-covered flap is called the Pinna. It is uniquely designed to protect the inside of your ear from too much of our outside environment, and its most important role, to collect

sound. The second step is the Auditory Canal, or ear canal, which is normally about 2-3 cm long. This tunnel channels the sound waves to the middle and inner ear.

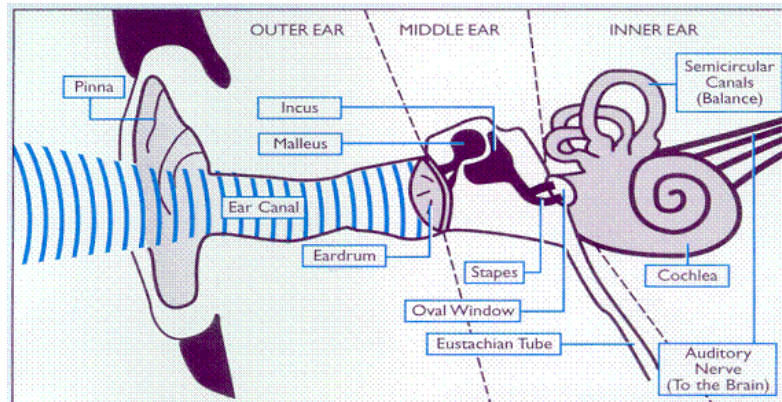


Figure 5.1.3

Next comes the middle ear transforms the energy of the sound wave into internal vibrations and then changes those vibrations into a compressed wave in the inner ear. The inner ear is the deepest part of your ear and in this section is a structure that puts everything together. Also known as the “Organ of Hearing,” the Cochlea is a snail shaped organ that converts sound vibrations to our perception of hearing. This also corresponds with audible range, which you will learn more about later in this chapter.

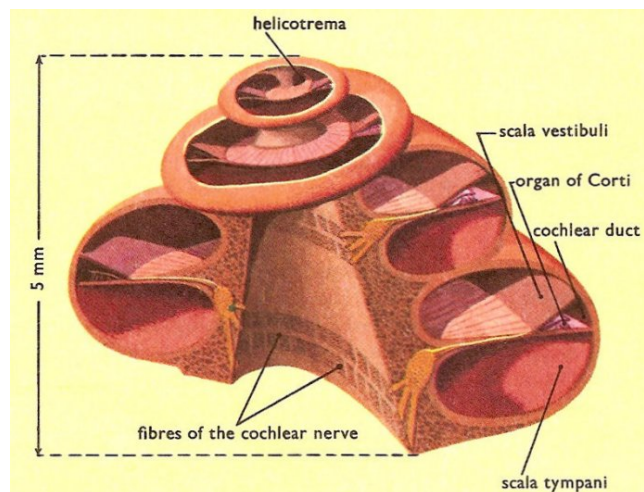


Figure 5.1.4

Inside the Cochlea are 3 canals: Vestibular canal, Tympanic canal and the Cochlear Duct. Each of these canals are filled with a liquid called Endolymph, which is really important to this whole system. The Cochlear Duct holds a very important part of the inside, because at the bottom of this duct you would find the Organ of Corti. Shaped like a cliff over water, the Organ of Corti has a base, called the basilar membrane and a jelly-like roof, called the Tectorial (Basilar) Membrane.

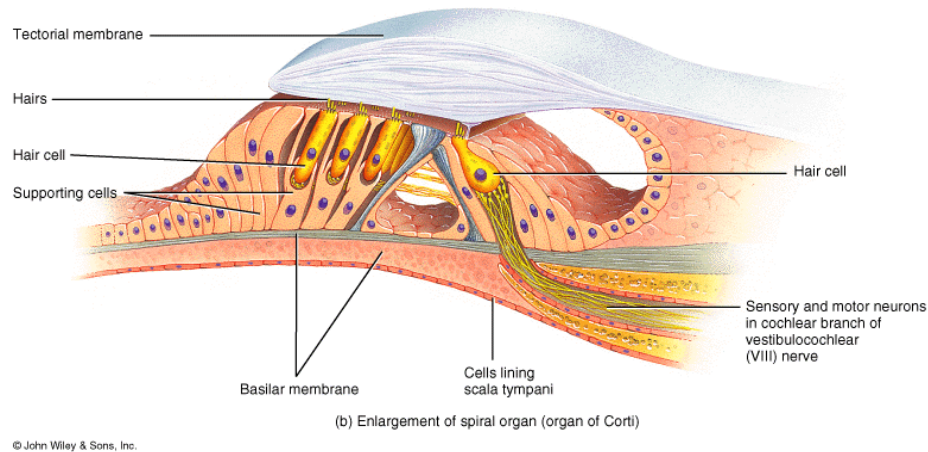


Figure 5.1.5

The peculiar thing is, that growing out of the basilar membrane are thousands of receptor cells that grow hairs out of them. The hairs grow up towards the tectorial membrane until they reach it, and then attach themselves to it! In order for the hairs to send those electrical signals, they must be doused in endolymph. Endolymph is really high in potassium ion (K^+), which creates a strong electromagnet gradient (large difference in voltage) from the base to the tip of the hairs. Being knowledgeable of this, when the sound comes in each hair vibrates in response to it and then sends those electrical signals to the cochlea nerve. The Cochlea Nerve is what then receives the impulses from the hairs and sends those signals to the brain.

Information is transmitted along a very diffuse and intricate pathway. Each center than analyzes the information for particular feature of sound. Auditory cortex integrates all of this information to create a coherent sound experience. This is experienced through sound waves, vibration through the ear drums, and is then transferred and amplified through ossicles, and the oval window vibrates. Waves are propagated through the fluid in cochlea. Then it passes down to the vestibular canal and back around the tympanic canal. Pressure is then released through the round window and Eustachian tube. Fluids travel in opposite directions and cause shearing action that excites the hair cells. These outer hair cells shorten and lengthen (2 microns) up to 30k times per second. Mechanical energy is then converted to electrochemical energy. Lastly, the auditory nerves send information to the brain.

The Brain consists of many different parts. The Cerebral Cortex aka Cerebrum makes up 85% of the brain. It is divided into two halves, the left and right hemisphere. It is the “thinking part of the brain”, and controls voluntary muscles, the muscles you can control known as skeletal muscles such as your arms and legs. The Cerebrum controls thought, reason, and action. It is located in the anterior portion of the forebrain. The Motor Brain also controls your voluntary muscles. It is located across the right and left hemispheres in the cerebrum. The Cerebellum is 1/8 the size of the cerebrum, and controls balance, movement, and coordination. It is located in the back of the brain below the cerebrum.

The Brain stem is very small, and connects the brain to the spinal cord. It controls your involuntary muscles, the muscles you cannot control such as your heart, breathing, lungs, sleeping, waking, digestion, body temperature, elimination of wastes and stomach. It is located beneath the cerebrum and is in front of the cerebellum. The Hippocampus controls your memory including “short term and long term”, and is part of the cerebrum. Nerves carry messages throughout your body, and are located in the spinal cord that is a long bundles of nerves inside your spinal column, which is the vertebrae that protects it.

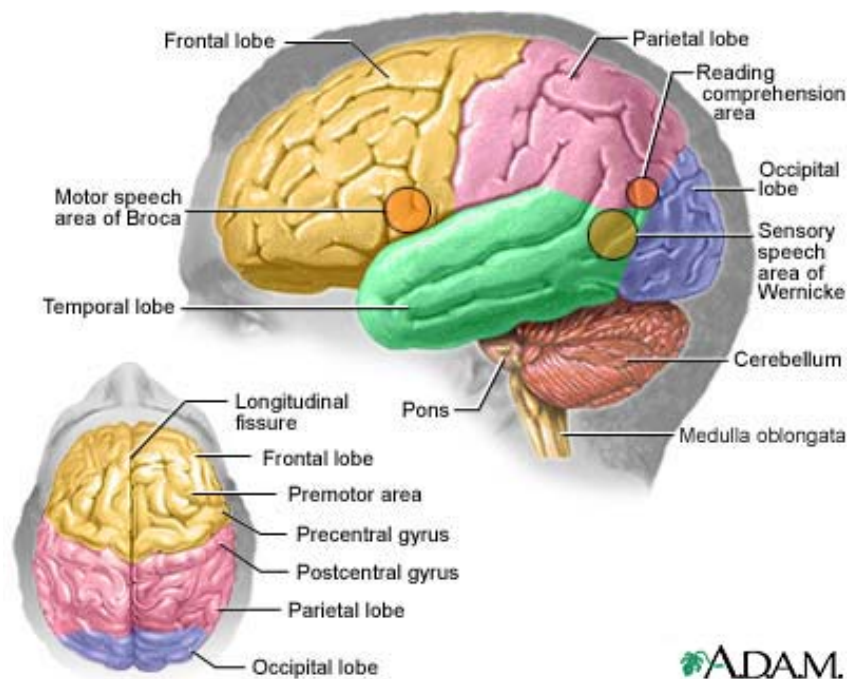


Figure 5.1.6

Information comes in and out of the brain through the spinal cord which causes information to the brain such as feelings of hot, cold, pain, joint sensation etc. Your vision and hearing do not go through the spinal cord but both go directly into the brain.

The frontal lobe is responsible for reasoning, planning, parts of speech, movement, and emotions. It is located behind the forehead. The parental lobe is responsible for movement, orientation, recognition, perception of stimuli. It is located at the top of the head. The occipital lobe is responsible for visual processing, and interprets information for the eyes. It is located at the back of the head. The temporal lobe is the perception and recognition of auditory stimuli, memory, and speech. It is located on the sides above the ears.

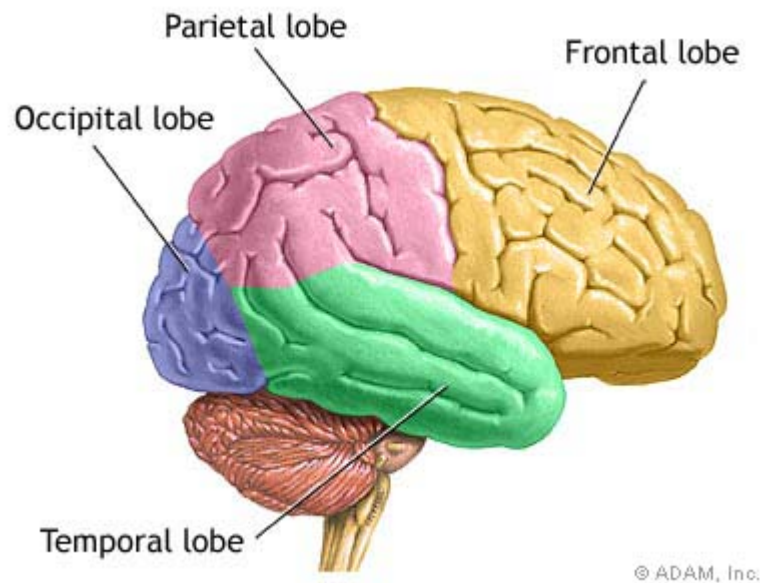


Figure 5.1.7

Temporal lobes deal with basic sounds, as well as complex hearing information. The right temporal lobe processes musical information, as well as help in the identification of noise. The left temporal lobe is critical for day-to-day functioning. Everyday our bodies work through many different obstacles in order to keep us alive. Of the many functions that our bodies carry out, the way that the ear and brain work together is amazing. Sound waves enter through the Pinna and are carried through the oval window in your ear and are transmitted through the cochlea nerves where mechanical energy is converted to electrochemical energy. Finally, the cochlea nerves send information to the brain and are interpreted by the brain. From the moment sounds go through your ear, the brain is ready to transmit those sounds to help us, and will be there for as long as we live.

Chapter 5.2

AUDIBLE RANGES

Ariel Swingley, Nicole Shaw

Sound is something that is uniquely perceived by each species. Every animal hears a different range of sound before it becomes too low or high to hear. That is exactly what an audible range is; the range of hearing, from the highest note to the lowest note, that a species can hear. In this chapter you can expect to learn about audible ranges and all its affiliates.

To move on with this chapter you will need to be able to know what the following terms mean.

Amplitude- The instantaneous amplitude of an oscillating quantity is its value at any instant, while the peak amplitude is the maximum value that the quantity contains

Concord vs. Discord- harmonize: go together vs. lack of agreement or harmony

Decibel- a unit used to measure the intensity of sound

Direction- setting and holding a course

Distance- (pertaining to a wave) interval between two points

Fourier analysis- mathematical technique for turning a time series into a set of coefficients which are the amplitudes of a set of sine waves of various frequencies so that those sine waves add up to the original data.

Harmonic- A component of a complex tone whose frequency is an integral multiple of the fundamental frequency of the complex

Loudness- the magnitude of sound

Phase- particular point in the time of a cycle; measured from some arbitrary zero and expressed as an angle

Pitch- the property of sound that varies with variation in the frequency of vibration

Precedence- the order in which something occurs

Reverberation- echo: the repetition of a sound resulting from reflection of the sound waves

Timbre- the attribute of auditory sensation in terms of which a listener can judge that two sounds similarly presented and have the same loudness and pitch are dissimilar

Human ears, just like all other species, have a specific range of hearing. The amount of waves per second, intensity and pressure of a sound wave all determine whether the sound is within the audible range, too high or low to be heard or even if it is at the very upper or lower end of the audible range causing the listener great pain. The literal definition of the human audible range is 0 to 130 decibels or from 20Hz to 20000Hz. Another way of defining the human audible range is by the Dynamic Range of hearing, which is the threshold of hearing to the threshold of pain (i.e. from the smallest noise you can hear to what will cause you to go deaf and literally be in pain.) Which is from the smallest noise (I_0) to such intense noise it causes pain ($10^{13}I_0$ or $10,000,000,000,000 \times I_0$); another way of expressing this exact formula would be 0 to 130 decibels. Decibels refers to the amplification of the noise what effects the ear is the pressure, frequency and intensity of the sound wave it's self.

Frequency:	20 Hz-20,000 Hz	Pitch
Intensity:	$10^{-12} - 10 \text{ watts/m}^2$	0 to 130 decibels
Pressure:	$2 \times 10^{-5} - 60 \text{ Newtons/m}^2$	$2 \times 10^{-10} - 0.0006$ atmospheres

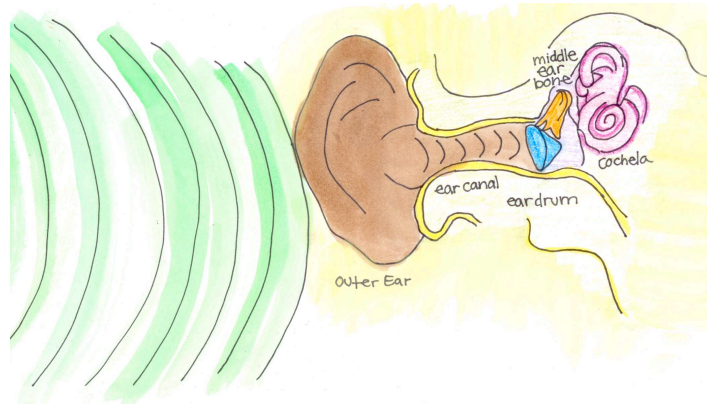
The chart above explains the three factors that make up a sound wave: frequency, intensity and pressure. The sound wave it's self is very important because it defines the sound and where it will land in the human audible range. Sound waves with higher frequency for example, have a much higher pitch and intensity which means it will be a higher decibel.

In physics there is a concept call the Elastic Limit. An elastic limit is how far something can be bent or changed before it will never be able to return to its former shape again. This concept works the same with ears and hearing. Ears can only hear a certain pitch for so long before the hairs in the cochlea die and you are in great pain and lose your ability to hear that tone. The chart below shows the decibel range of hearing.

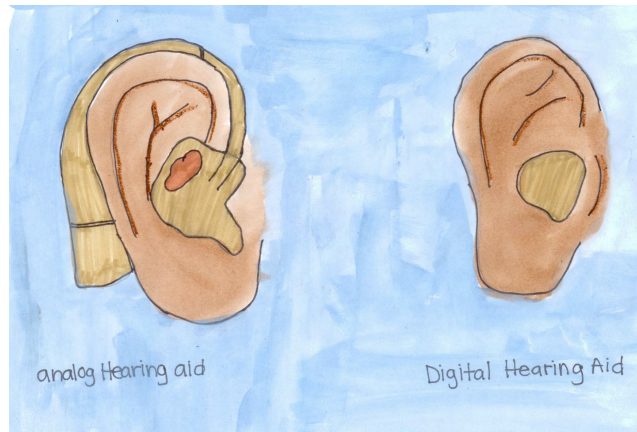
0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-120	120-130	130+
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10 decibels is a whisper. Wind blowing leaves is roughly 19 decibels. Traffic is around 82 decibels. 129 decibels is the threshold of pain so any noises 129 decibels or above puts the listener in grave pain. When a sound goes up from say 30 decibels to say 50 decibels the noise is not necessarily getting louder. When a noise goes up and down in decibels there Children can hear noises 20 decibels and lower well because the hairs in their cochlea have had no sound trauma yet. Older people usually cannot hear these noises because of all the loud sounds they have been exposed to throughout their lives. In the cochlea there are small hairs that are designated for certain pitches. If a certain pitch becomes too intense that hair then dies. Each hair has a certain intensity it can withstand and when it'

Let's discuss low and high sounds. For example, while something is vibrating slowly, it makes a low sound or another word for that would be a pitch. Likewise with high sounds, when something is vibrating quickly it has a high sound or pitch. When the sensation of frequencies is low, it is painless- unlike when the sensation of frequency is high, it is painful. An example of a low frequency would be when you're listening to the ocean's waves- it is low and adds no pain to the ear. An example of a high frequency that is painful would be when you're listening to music very loud, or standing by a construction site. The sound is high and is uneasy to the ears causing you pain. There is a lot of talk about sound waves. But what is a sound wave consisted of? Sound is a pressure wave, which consists of compressions and rarefactions. Sound is also called to be a "mechanical wave", and this forms the back and forth vibration of the bits of sound through the wave that is moving. To explain this better, when a sound wave is moving (left to right through the air), then the particles of air will be moving rightward and leftward. This is the natural way hearing process occurs.

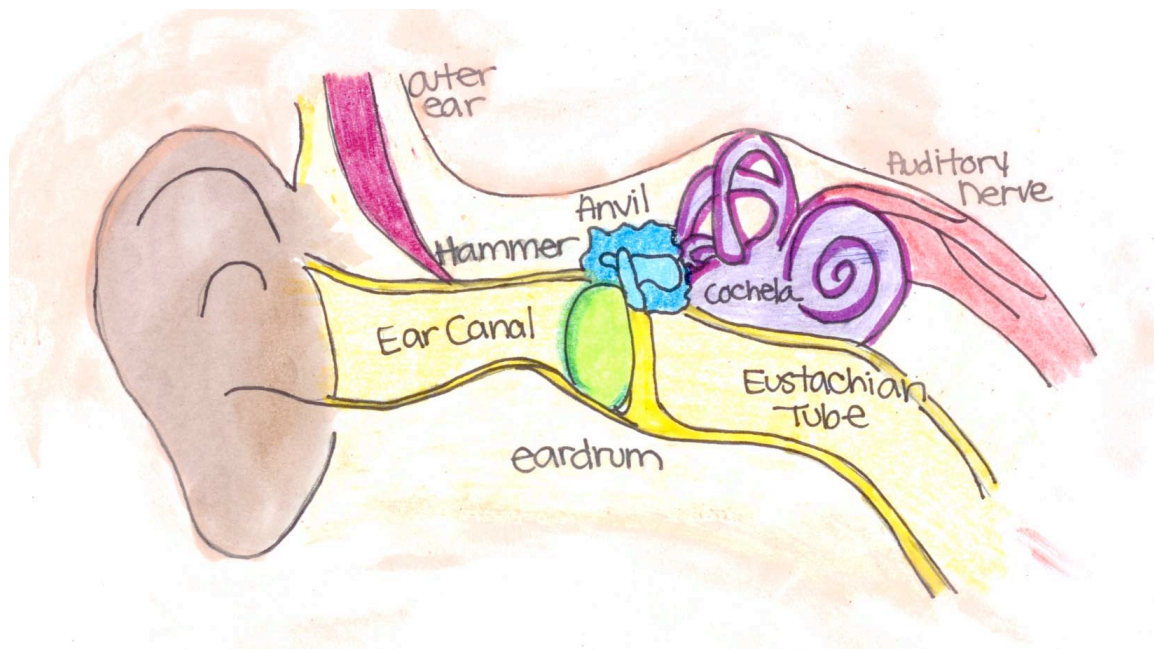


But people with hearing disabilities have been provided with different kinds of hearing devices. For instance, Analog hearing aids use a continuing electrical signal to make sound similar to a microphone. This converts the sound into small electrical signals. But not all of the signals are the same, but depend on the pattern of the sound, then they are made louder and then lastly go into the hearing aid so you can hear them. This modern tool is so you're protected against uncomfortably loud sound levels. There is also the Digital hearing aids that take the signal from the microphone and convert it into "bits" of data - numbers that can be manipulated by a tiny computer chip in the hearing aid. Analog and digital hearing aids don't have the same features, but the Analog hearing aid is less expensive. These are two quick examples of the kinds of machines we use to benefit poor hearing. The reason for having trouble hearing would be due to a worn sound medium.



A worn sound medium is when the vibrations of the surrounding medium are blocked or don't work as well as it used to due to age, abusing high sounds or damage from injuries. For example, when people grow older, they aren't able to hear as well as they used to. Or when someone is in an accident they could possibly lose their hearing.

What's your threshold of hearing? In humans the audible range of frequencies is *usually* said to be 20Hz to 20,000Hz (Hz is the standardized term for 'cycles per second'). The human inner ear plays a huge role in the transformation of sound vibrations that come through the air into our ear where it is recognized then processed to the brain. To explain a little further on how the ear works let's talk about the cochlea located in the ear. The cochlea has a liquid, and when the vibrations reach the cochlea the liquid moves along with it causing the hair cells to move back and forth. An example of this would be when you fill up a bottle with a liquid, and when you tilt it, it is indicating the position of the bottle. From the information from the ear, it lets the brain know how steady you are. (Like when you are on a boat, you don't know if you're leaning left from right, but due to the liquid in your ear it sends the message to the brain indicating how steady you are.) This function helps the brain receive the impulses and interprets them as a type of sound. But not all people or animals can hear the same, this goes into the range of frequencies. Each animal can hear an upper and lower frequency limit. For example a frog and a mouse hear almost a completely different range of sound – but what exactly is the reason for that?



When comparing a dog's ear to a human's ear we come to know that a dog's ear has two compartments. First, at the beginning of the opening of their ear canal, their ear canals travel up and down to the jaw. After that it then makes a 45 degree turn and travels horizontally towards their ear drum. In addition, most dog breeds have a much longer ear canal than humans. Dogs threshold of hearing at its low at 16 to 20 Hz and can go as high as 70,000 to 100,000. According to "Dog Facts" by Chuck Ayoub, "Eighteen or more muscles can tilt, rotate and raise or lower a dog's ear. With this advantage, dogs can identify and locate the sound much faster compared to a human, along with knowing that they hear sounds up to four times the distance that humans are able to." That was one reason why animals hear differently. Another reason is their ear shapes. By having a different ear shape, it gives it more of an advantage or disadvantage to the range of hearing for them.

Some may ask: What do we have that prevents worn sound mediums and helps us to be safe? The USA has the OSHA (occupational safety & health administrations) act. These are set rules for safe working conditions. Their goal is to assure safe and healthful working conditions through mainly providing research, information, education, and training in the field of occupational safety and health to all men and woman that are in a working environment under US property. Their goal is to have a safe working area for employees that are free from recognized hazards that are likely to cause death or serious harm to employees. Many workplaces aren't as safe as they should be, that's why this act has taken place and controls all work places. This is something very important to have, because if we recall to back in the industrial revolution, working conditions were horrible and caused many deaths and physical harm. This is not how a work place should be, and with their rules we can preserve our hearing, health, our well being, and safety.

The OSHA act was created back in 1970. This Act was a federal program that was to protect the entire work force from job-related death, injury and illness. The secretary of labor, James Hodgson, helped create the law, and called it "the most significant legislative achievement."



Their mission statement is to “promote safety and the health of America's working men and women by setting and enforcing standards, providing training, outreach and education, establishing partnerships, and encouraging continual process improvement in workplace safety and health. OSHA is determined to use its limited resources effectively to stimulate management commitment and employee participation in comprehensive workplace safety and health programs. They are dedicated to improving the quality of the efforts and know that to be successful they must become an agency that is driven by commitment to public service.

To be able to have such an act to be followed throughout the US there are many rules that must be followed. Here is a bit of what the OSHA website stated on their rules:

“To help ensure that employees are, in fact, free to participate in safety and health activities, Section 11(c) of the Act prohibits any person from discharging or in any manner retaliating against any employee because the employee has exercised rights under the Act. These rights include complaining to OSHA and seeking an OSHA inspection, participating in an OSHA inspection, and participating or testifying in any proceeding related to an OSHA inspection. OSHA also administers the whistle blowing provisions of sixteen other statutes, protecting employees who report violations of various trucking, airline, nuclear power, pipeline, environmental, rail, consumer product and securities laws.”

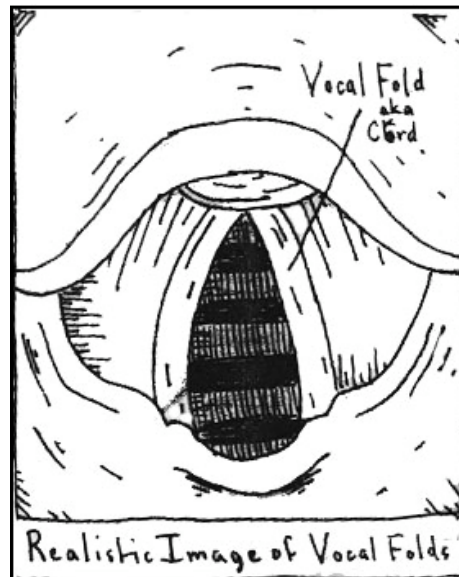
Chapter 6.1

VOCAL CORDS

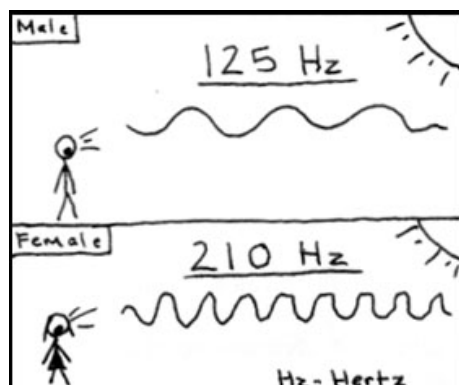
Adam Southgate, Colbie Hartwell, Roberto Sotelo

In this chapter, you will learn about vocal cords, what they do and how they function. You will learn about the way certain things effect your vocal cords, and what you can do to use them to the best of there ability.

Vocal cords consist of two flaps, each with their own muscle, and the separate muscle that controls the movement of the folds is called the larynx. Vocal cords are different sizes depending on your gender. Vocal cords are small, but larger in males and smaller in females. To give an exact number, males generally have folds that are 18 mm long, and females have a average size of 11 mm. Because male vocal folds are usually larger than females, this means more air is released when the vocal folds vibrate. This leads to the pitch being lower. Another notable difference of the vocal cords in males and females would be color. Vocal cords in females are generally whiter than in males.



In order for vocal folds to produce sound, they must vibrate against each other at varying speeds depending on the pitch of the noise you're trying to make. The movement, or vibrations, of vocal folds is measured in Hz (hertz- flaps per second). For



different genders, there are different pitches in your voice. Men's voices are usually lower pitched, inversely women's are higher. The frequency for males averages at 125 Hz, and in females the frequency averages at 210 Hz. Young children always have a high pitched voice, and it gets lower as you get older. The average of the children's frequency is usually around 300 Hz. Just as it was noted before, in order for vocal cords to work they need to snap open and closed while talking, singing, or making any type of noise. Air pressure builds up against them, and the folds snap

together and a sound is produced. The harder the snap of the vocal cords, the louder the noise. Also, the faster the flaps move, the higher the pitch of the voice. You can test this out yourself by feeling your throat while you make high notes/sounds and low notes/sounds. With a lower note, you can feel that your vocal cords flap slower.

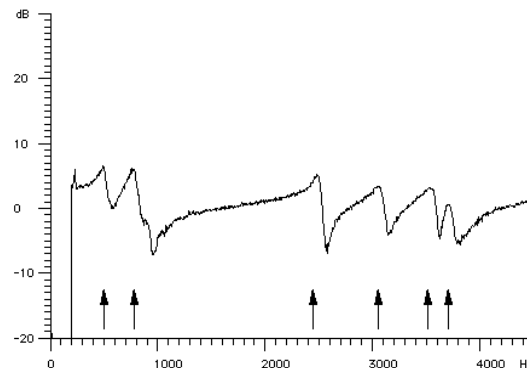
A function to show the relation of the length of your vocal chords to the frequency, or pitch, of your voice is $f = \frac{S.S.}{2\pi} \sqrt{\frac{A}{V \cdot L}}$, in which f is frequency, S.S. is Speed of Sound,

A is Amplitude, V is Volume, and L is Length of vocal cord. Just looking at this equation you can see that if the length of your vocal cords is greater then someone else's, the frequency will be lower, in turn making the pitch lower, leading to a lower voice. Also, most males have a higher volume than females do, which also leads to having a lower pitched voice. The higher the denominator in the equation, the smaller

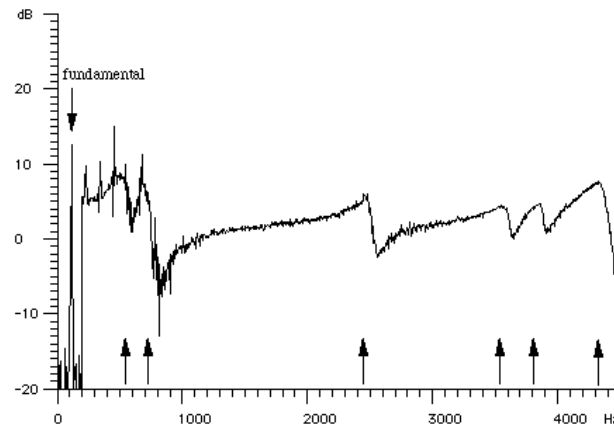
the number will be. $\sim \frac{342.9m/s}{2\pi} \sqrt{\frac{A}{V \cdot 18mm}}$ if you look at the equation, since the males vocal chords are longer, the rest of the equation doesn't even matter. The frequency will always be the lower if the denominator is bigger.

To be a good singer, you must know how to use and control your vocal cords effectively. You need to know the difference of projecting, and pushing your voice too far. You need to know how to use the appropriate muscles in your vocal cords. Some people make the mistake of using the pharynx, the muscle that controls swallowing, but you need to use the larynx, the real muscles that control your vocal cords. One instant effect that you can feel, when using the wrong muscles while singing, is pain in the throat. This happens because the larynx uses more precise movements and the pharynx is not meant to make precise movements so the muscle gets tired and you experience pain. Therefore, good singers have to control their larynx more efficiently, to be able to sing for long periods of time and to have a variety of pitches.

In the image below, a subject whispers the vowel in 'hoard'. We show the frequency response of the vocal tract. The sound of the whisper itself is masked by the injected signal used to measure the vocal tract resonances. The figure shows several peaks, indicated by the arrows. At these frequencies, the sound produced at the vocal folds is most effectively transmitted as sound produced in the external air.



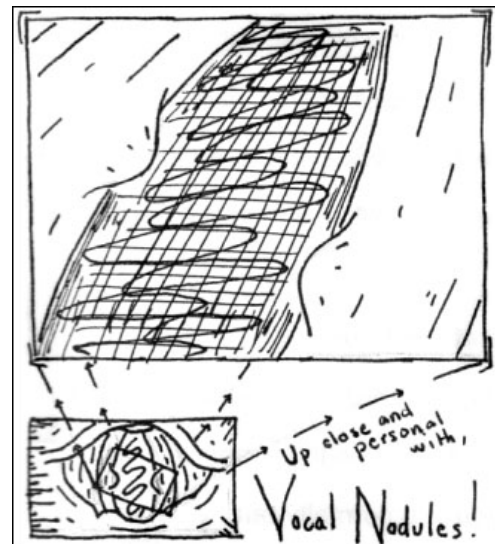
In the figure below, the subject sings the same vowel at the pitch Bb3 (117 Hz). In this graph, you can see the harmonics of the voice, and you can see that the fourth and sixth harmonics appear stronger in the sound spectrum because they are near resonances of the tract. (Wolfe, Joe. 2009)



Over the range shown and for this vowel, this subject's vocal tract has six resonances, which are indicated by the arrows. Note that the subject changes the first two resonances a little between whispering and singing. The frequencies of these two resonances determine the vowel in a particular accent. It is not unusual for people to have different accents when whispering, speaking and singing. The higher resonances are also substantially changed, probably because rather different vocal mechanisms are used in whispering and singing. (Wolfe, Joe. 2009)

Vocal cords can get infected or have diseases, just like anything else. One of the major things that happen to vocal cords is vocal cord paralysis. Vocal folds are moved by a muscle called the laryngeal nerve, otherwise known as the larynx. If this nerve doesn't function properly, the vocal cord cannot move. This is what vocal cord paralysis is. Another problem comes in the form of a disease called Laryngitis; it is an inflammation of the larynx. It causes a hoarse voice, and can also lead to complete loss of voice of the voice due to prolonged irritation to the vocal cords because of swelling within the larynx.

Vocal nodules are callous-like bumps that can form on one or both of your vocal cords. The size of vocal nodules ranges from a pinhead to a pea split in half. When you normally talk, your vocal cords press firmly together, but when you have vocal cord nodules it makes it so you cannot close them completely, which intern causes your voice to sound hoarse and raspy. Vocal cord nodules are caused by misuse of your voice, this includes talking excessively without your comfortable pitch, raised volume, amount of speech, as well as when you are not breathing enough. Another cause is continued abuse of your voice, which consists of shouting, screaming or crying excessively. Also, by coughing or clearing your throat too often, or impersonating inhuman things. Other factors include infections or allergies, smoking or second hand smoke, and throwing up frequently.



When doing things such as shouting and yelling with a force, it causes your vocal cords to bang together. This then causes vocal nodules to start forming at the point of impact. They do not completely envelop, and are unnoticed, until a while later as they slowly swell up and thicken.

There is no pain in having vocal nodules except the noticeable hoarse voice. Vocal cord nodules can be treated by a number of different treatments. The most effective treatment used against vocal nodules is voice therapy, which is best performed for at least 6 months, twice weekly in 30 minute sessions. Voice therapy is used in order to teach yourself how to keep your vocal cords healthy and how to prevent abusing your vocal cords. With the knowledge gained, your the chance of getting vocal nodules is greatly reduced.

In the next section of this chapter, you will be learning about how your voice changes. This will include things such as puberty, sickness, and will entail some things that you learned about within this chapter.

Chapter 6.2

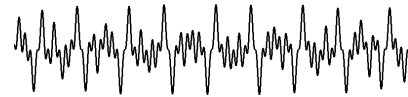
VOICE CHANGES

Charae Pimentel, Jing Calpito, Will VanRoan

The voice has an intricate role in any person's life. It helps you communicate whether it's over the phone or face to face. In this section, you will learn about all of the wonderful math that's involved in voice changes. As well as different stimulants that can change the human voice.

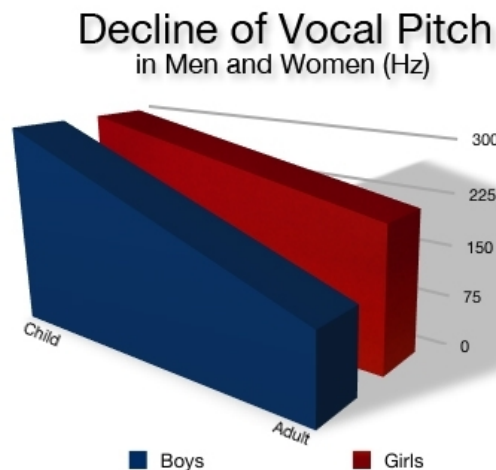
Puberty is an annoying and awkward part of every child's life, but the changes that occur during this time are very important. For girls this change is between the ages 8-13 and for boys between the ages 10-14. During puberty the child's body goes through many hormonal changes as well as physical changes including the development of breasts for girls and testicles for boys. *Need I say more?* Besides all those embarrassing changes one of the many parts of your body that is affected during this time of growth is your voice.

"Sound is made by the mouth as air is pushed out of the lungs, through the voice box. The voice box is a structure at the top of the windpipe that is made of cartilage. Stretched across it are two vocal cords, which are a bit like elastic bands. As air is expelled from the lungs it passes between the vocal cords, making them vibrate. This produces the sound of the voice."



The average child's voice is around 300Hz, meaning that their voice is very high-pitched tone. After puberty takes effect, females will have a vocal pitch of 210Hz whereas males will have a vocal pitch of around 125Hz.

Have you ever noticed that when a female's voice is developing it's not very noticeable? Well let's think about, the females' voice goes from 300Hz (frequency as a child) to 210Hz (after puberty). This means that the females voice on average only changes 90Hz, being a few tones lower than originally, still leaving the female relatively high. This supports the claim that girls' voice changes are barely noticeable.



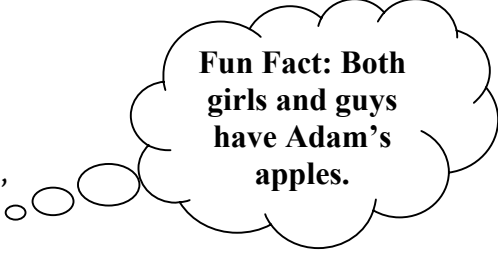
Males on the other hand have a very dramatic voice change. The males' voice goes from 300Hz (frequency as a child) to 125Hz (after puberty). This deepens the male's voice, more than double what it was originally, dropping an octave-see chapter 7. This is why the males' voice is exceedingly deep after puberty.

For this subject we are going to focus more on the male voice changes because the change is more dramatic. These changes occur when cartilage in the voice box receives thickening hormones (testosterone) making the Larynx (vocal cords) thicker and heavier. For example a boy's vocal cords might grow 60% longer during puberty. Therefore the vocal cords might go from vibrating 200 times per second to just 130 times a second (BBC). This can be explained using the frequency equation below.

$$F = \frac{\text{speed of sound}}{2L} \sqrt{\frac{\text{Area}}{V * L}}$$

frequency As the length (L) is increase we know that the will decrease and vice versa.

Males typically develop *laryngeal prominence*, also known as an Adam's apple, during puberty. The Adam's apple itself may have no effect on your voice, but the face changes that occur do. The shifting facial structure create, "larger cavities in the sinuses, nose and back of the throat give the voice more room to resonate in, and this deepens it further".



Fun Fact: Both girls and guys have Adam's apples.

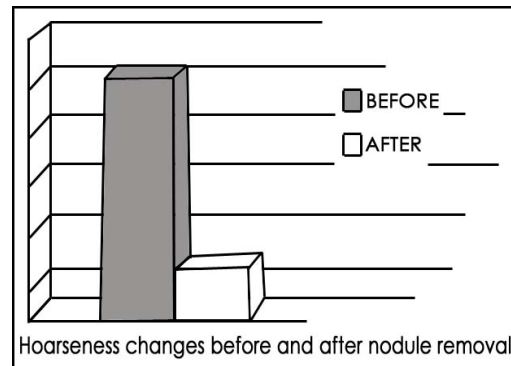
All of these changes are bound to cause some trouble, which is where "voice cracking" comes into play. This is especially common in boys, and occurs when the larynx is growing. During this process, your throat may have an inconsistent flow of input and output, and your body may produce unpredictable sounds. These croaks usually go away after a few months, but have been known to linger on into early teenage years.

Voice changing occurs throughout age, from a baby to a grown adult. During voice changing, there are several main symptoms such as, high-pitches, rough raspy and hoarse voice, loss of projection, resonance, and amplifying.

There are two main conditions of voice changes throughout age, Atrophy and Superficial Lamina Propria. Atrophy occurs mainly around the age of 40 to 50. Atrophy is when the vocal fold's muscle begins to thin out, lose tension, and the voice becomes weaker causing the voice to have less projection. Superficial Lamina Propria is when the tissues of the vocal fold (vocal cords), that are responsible for vibrations, begin to thin, stiffen, and stretch out, and treatment is sometimes necessary. Superficial Lamina Propria is common in elderly people, and causes the voice to take on a raspy or tinny sound. In both of these changes, the throat beings to shape into a scallop figure.



Starting from a baby the voice begins developing. A baby's voice begins changing a month after it's born. A child's voice in particular stays at a high pitch voice. Although, a child has small vocal cords the child is able to project their voice this may cause damage to the throat. There are two major changes for children's voice, Behavioral and Medical. A child can abuse their voices by screaming, cheering, shouting, or loud talking. This is when the child needs to behave and learn how to take control of their voices. A child is very sensitive to their surroundings, the child may damage their voice by inhaling toxic chemicals and getting infections that can damage the vocal cords.



At a young age, a child can get Papilloma, poly/cyst, or nodules. Papilloma is when the vocal cords catch a virus that affects the voice. Papilloma can block the airway causing noisy breathing affecting the voice. Poly/cyst when a tumor begins to grow in the throat, it will need to be surgically removed. Nodules are when swelling grows into a lump under the skin. Adults and teenagers can also get nodules and or cyst.

Once a person has nodules or cyst, their voice starts to become raspy. Their voice will all of a sudden sound hoarseness.

The graph shown displays the change in your voice after getting the nodules surgically removed. As seen in the graph the surgery did successful lowering the rate of hoarseness in the voice.

Our voices are constantly changing and it is up to us to stay away from deterrents that can affect our voices and keep a healthy body throughout our lives so our voice will be healthy as well.

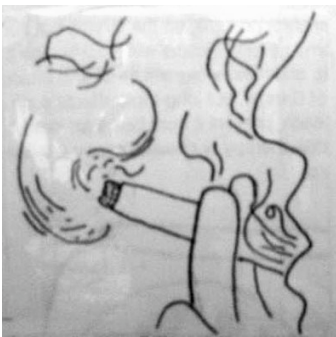
The planet's air supply is no stranger to airborne bacteria, and especially in large, urban cities such as San Diego, every breath can deal a harsh blow to your throat and lungs. Of course, the air is not the only potentially harmful substance that makes contact with our windpipes on a day-to-day basis; the food we eat and everything we touch prior to

eating it, also aids in the process of spreading bacteria. Once these particles find a host, they will begin their task of making you feel miserable, by causing your throat to become swollen and sensitive. All of this goes into nothing more than the common cold, and as far as throat and vocal cord threatening problems go, it's the least of your worries. Every ailment that can target your throat will have a direct affect on your voice, and the results are never pleasant.

As the name suggests, the Common Cold is about as unexceptional as sicknesses go, but its effects are always unpleasant and can occasionally lead to more serious issues. Popping up wherever, one of the 210+ contagious viruses exist, the bacteria preys on weakened immune systems and exposed orifices. The Cold is notorious for shutting down components throughout your entire body, making you feel exhausted and lifeless. However, some of the most apparent changes come from fluctuations within the throat. Swallowing may become difficult, your neck will become stiff, and hot or cold foods may become unbearable. The same infections that cause these symptoms are almost always accompanied by a hoarse or scratchy voice. While there is no official cure for these issues, over-the-counter medications and lozenges are always helpful, as well as herbal teas and avoidance of smoking and speaking. The frequency and level of contagiousness that the Cold possesses, makes it a continuously looming threat that should not be taken lightly.

Similarly, Laryngitis is infection that applies to the larynx (or vocal cords). The results can be crippling to public speakers or singers, but most victims will only be burdened by chest pains and dry, raspy voices. Laryngitis is typically caused by an Upper Respiratory Infection or a damaged larynx (as a result of excessive vocal strain or overuse). The similarities between it and the Cold continue with its treatments. Extended bed rest, proper hydration, and basic medication are all easy ways to reverse the effects of the illness.

Of course, when an interior section of your body (your throat) has such easy access (your mouth and nose) to the outside world, big problems are sure to arise. As far as vocal issues are concerned, it does not get much bigger or more serious than Throat Cancer and Vocal Cord Paralysis. The latter is a fairly rare disorder that causes the vocal cords to either swell significantly or become thin and tight.



Both conditions are equally dangerous and painful and will make breathing, eating, and speaking near impossible. The only treatments come in the form of soothing liquid medications or risky collagen injections to fill up thin vocal cords. Extraction from thick vocal cords has been lightly tested, but has showed very little prospect in lab tests. Throat Cancer, may not have as much of a debilitating effect on your voice, but it still involves the same primary factors (namely the larynx).

Every year, 24,000 Americans are diagnosed with throat cancer, and out of those, about 5,000 - 6,000 will lose their lives. The tumors accumulate primarily on the larynx, but

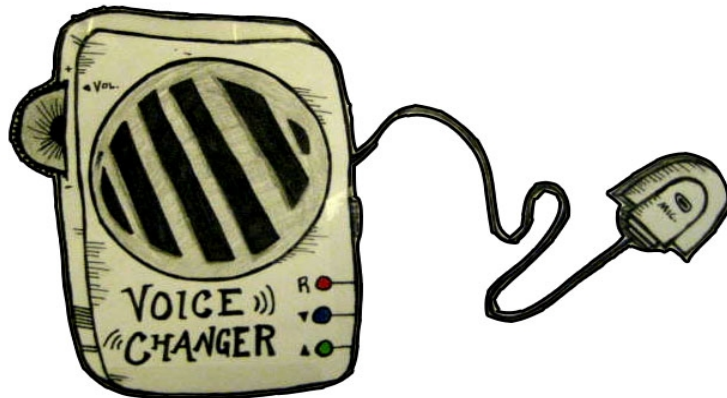
some cases have been reported in the pharynx as well. Victims will usually lose a lot of weight as a result of an inability to eat, and their necks will swell and bruise. Surgery is occasionally used to treat throat cancer, but long-term effects such as scarring or partial to complete loss of speech, prevent it from being an ideal candidate for treatment. Instead, radiation therapy or chemotherapy is used in an attempt to rid the patient of the tumors.

Breathing and lifestyle habits may also affect your voice. Different breathing rates such as high shallow breathing or lower abdominal breathing can cause the voice to change its pitch. High shallow breathing causes you're breathing to be at a fast rate causing the voice to be at a high tone. The voice is at high tone because you are constantly trying to catch your breath. The lower abdominal breathing is at slower rate causing the voice to be in a deeper tone, which is normally your normal voice. Lower abdominal breathing shows that you are relaxed; being relaxed will help you save and take care of your voice.

Emotions may also affect your breathing and with it affecting your breathing, your voice is affected. For example if you were depressed you would be breathing at a slower rate or if you were nervous you would be breathing at a faster rate causing your voice to have trouble projecting. In addition, lifestyle choice can change your voice. Obviously, smoking or excessive drinking will contribute to the deterioration of the lining of you lungs and esophagus. This may leave you with a dry, scaly throat and undesirable gruff voice. In order to keep a healthy and strong voice we need to avoid bad habits and breathe in a relaxed way.

"Voice Changers" are one of the many artificial ways to alter the sound of one's voice. These products can be used for maintaining anonymity over the phone or for jokes and gags. They work by shifting the pitch-sensitive fundamental waves of the user's voice via a microprocessor and produce an output that is dependent

on the pitch setting of the user's choice. High quality machines have a wider range of natural sounding tone options, and are used primarily by police forces and government agencies. These machines can cost several thousand dollars and can easily be mistaken for an actual human voice. The toys used by kids typically cost around \$10 and disguise their poor feedback options by calling the settings things like "Robot Voice" or "Baby".



One of the most popular ways to change one's voice is by the use of helium. This gas can be inhaled to increase the pitch of the user's voice over an octave from normal tone. This works because helium is lighter than the normal air that engulfs us, and

allows sound waves to move through it very quickly. This can be dangerous if done for an extended period of time.

“The speed (and pitch for that matter) of the sound varies with the molecular weight of the gas that we breathe in. The molecular weight of dry air at 0°C is about 28.964, while that of helium is about 4.003 at the same temperature. The speed of the sound in dry air (at 0°C again) is about 331.3 m/s, while in helium the speed of sound is 891.2 m/s. Therefore the frequency of the sound in helium is almost 2.7 times higher than the sound in dry air. This causes the octave change in our voice”.

Chapter 7

PYTHAGOREAN TUNING

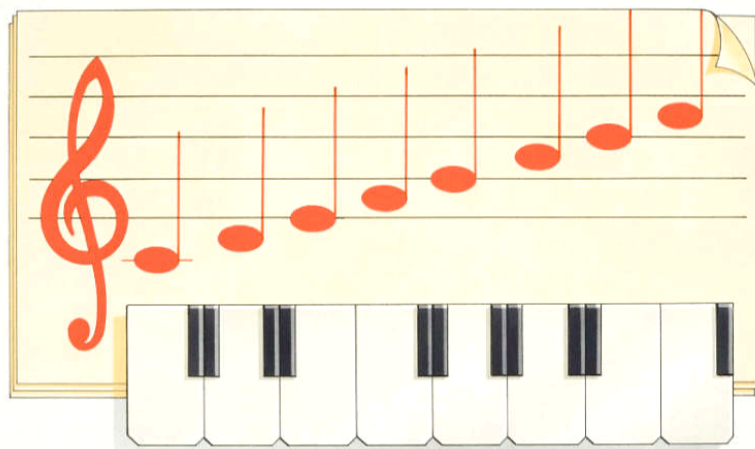
Caesar Michel, Lauren Bielma

The basic concept of the Pythagorean tuning system is: If a string is plucked it will play a note of a certain pitch, if the string is divided in half it will play the exact same note an octave* higher (*See paragraph 3 for more information). The Pythagorean tuning system is based on a stack of perfect fifths, each tuned in the ratio 3:2. A fifth is the interval, difference in pitch, between two tones. Pythagorean tuning was a very important part of music, and was widely used in medieval and renaissance times. Medieval music at that time was composed for this tuning system. The Major seconds and thirds are larger in Pythagorean intonation, and the minor seconds and thirds are smaller. Using these intervals in medieval music makes it more authentic and sounds better as well.

The Pythagorean tuning system was discovered by Pythagoras of Samos, a famous Greek math philosopher. Pythagoras was born in the island of Samos, around 580 and 572 BC, and died between 500 and 490 BC. Pythagoras had a group of followers known as the Pythagoreans. Pythagoreans were interested in philosophy, but especially in music and mathematics. Pythagoras discovered that musical notes could be translated into mathematical equations. One day he was passing by a Blacksmith's when he heard the sound of hammers ringing down on anvils. He thought the sound was beautiful. Pythagoras determined whatever scientific law caused the sound to be produced must have to be mathematical. He then discovered that musical notes could be translated into mathematical equations.

In order to understand the Pythagorean tuning system you need to know what the word octave means. The word octave comes from the prefix oct-, which means eight. An octave is the interval between one musical pitch and another with half or double its frequency. An interval is the amount of difference in pitch between two musical notes. The ratio of frequencies of two notes an octave apart is therefore 2:1. For example if one note has a frequency of 200 Hz, the note an octave higher will be at 400 Hz, and the note an octave below

would be at 100 Hz.



This image shows the musical notes of a full octave and the corresponding keys on an organ.

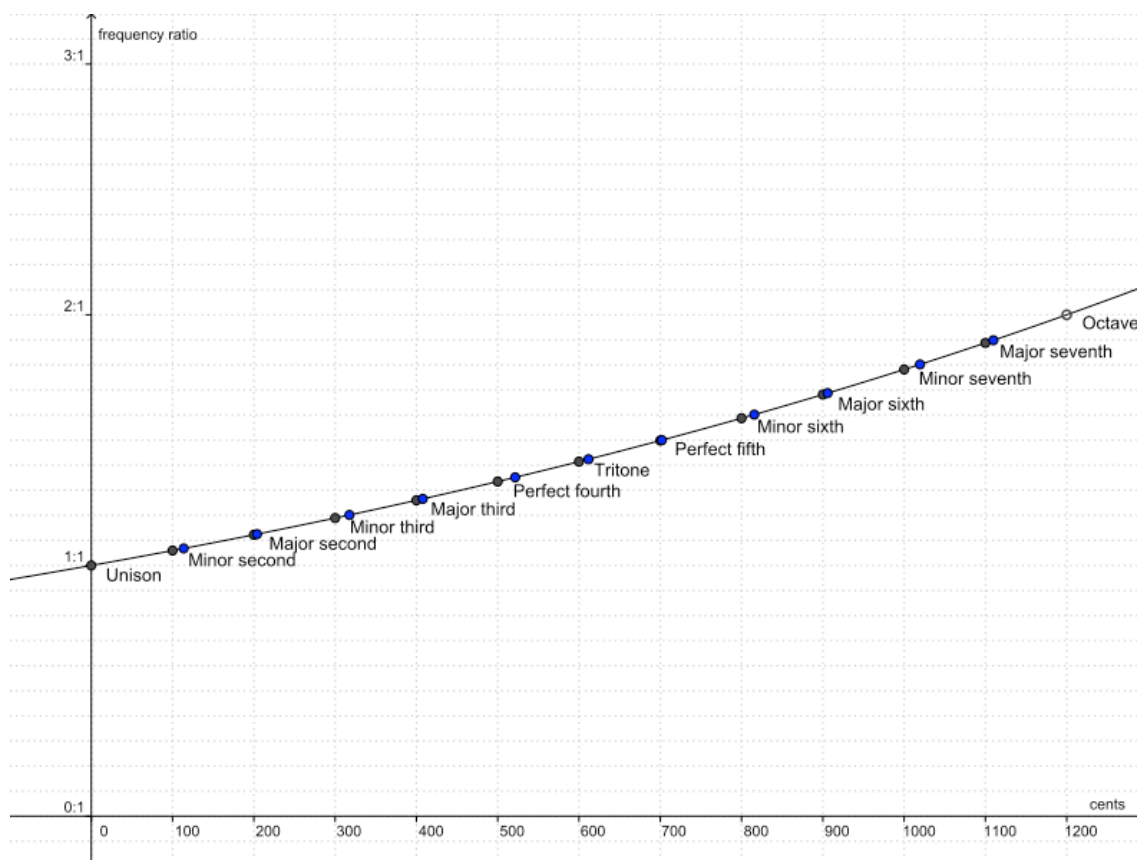
Pythagoras worked out a whole series of such mathematical ratio between notes, creating a scale with 8 notes A-G and 12 different pitches.

Pythagorean Scale			
Scale tone	Interval from Root	Log Cents	Freq. HZ
A	Unison	0	220.000
A#/Bb	Min. 2	90	231.7695
B	Maj. 2	204	247.500
C	Min. 3	294	260.7407
C#/Db	Maj. 3	408	278.4375
D	Perf. 4	498	293.333
D#/Eb	Aug 4/ Dim. 5	612/588	313.242/309.026
E	Perf. 5	702	330.000
F	Min. 6	792	347.6543
F#/Gb	Maj. 6	906	371.250
G	Min. 7	996	391.111
G#/Ab	Maj. 7	1110	417.6562
A	octave	1200	440.000

Starting from D for example, the A is tuned such that the frequency ratio of A and D is 3:2 if D is tuned to 288 Hz, then A is tuned to 432 Hz. The E above A is also tuned in the ratio 3:2 with A at 432 Hz, this puts E at 648 Hz, 9:4 above the original D.

The main weakness of the Pythagorean system is that a series of pure fifths will never take you to a note that is a pure octave above the note you started on. To be able to keep pure octaves, “instruments that use Pythagorean tuning have to use eleven pure fifths and one smaller fifth.” The graph bellows shows the error of the Pythagorean system (blue) compared to the Equal tempered tuning system (black). As you can see the notes of the Equal tempered system always land in a semitone, as

compared to the Pythagorean tuning notes(blue), who don't exactly land on the semitone.



Pythagorean Tuning, as said above, was the primary tuning system during medieval and renaissance times. The system is no longer used because there were many flaws found in calculation its ratio. There were other tuning styles that were to come along such as Equal Temperament.

Chapter 8

EQUAL TEMPERAMENT

Sophie Barnhorst, Ariana Galvan, Leland Clemmons

Picture the scene: it is 1672, and the evening has just begun. Men and women of all social rankings stream into the concert hall; eager to hear Arcangelo Corelli’s newest piece; the conductor takes his stage and quiets the eager audience. The baton raises... and then, with a firm down stroke, they begin. The music is complex; it modulates to different keys as quickly as the musicians can play. However, the audience begins to stir – the music wafting across the hall no longer sounds appealing, in fact, it almost appears as if the musicians have begun to play out of tune!

In this fictitious concert, it probably was not the musicians’ fault for the out of tune music – their instruments were unable to play those distant keys! Meantone tuning was the real culprit here. Used across the 17th and 18th centuries, meantone tuning allowed musicians to perform in only 15 keys out of 30. Half of the world of musical keys were so out of tune

that they were unavailable to musicians. The resolution to this massive problem had been suggested by a number of music theorists in both Europe and Asia as early as the 16th century. This solution was a new tuning system called Equal Temperament.

Equal temperament is a system of tuning, or perhaps better said, “de-tuning,” that evenly spaces the inequalities of tuning throughout the octave, thereby producing “acceptable,” although slightly out of tune, intervals throughout the octave. This tuning system makes all keys available in all flats and sharps, both major and minor keys, and allows all instruments, in all families, to perform together in tune. As the brilliant Chinese prince Zhu Zaiyu wrote in his 1584

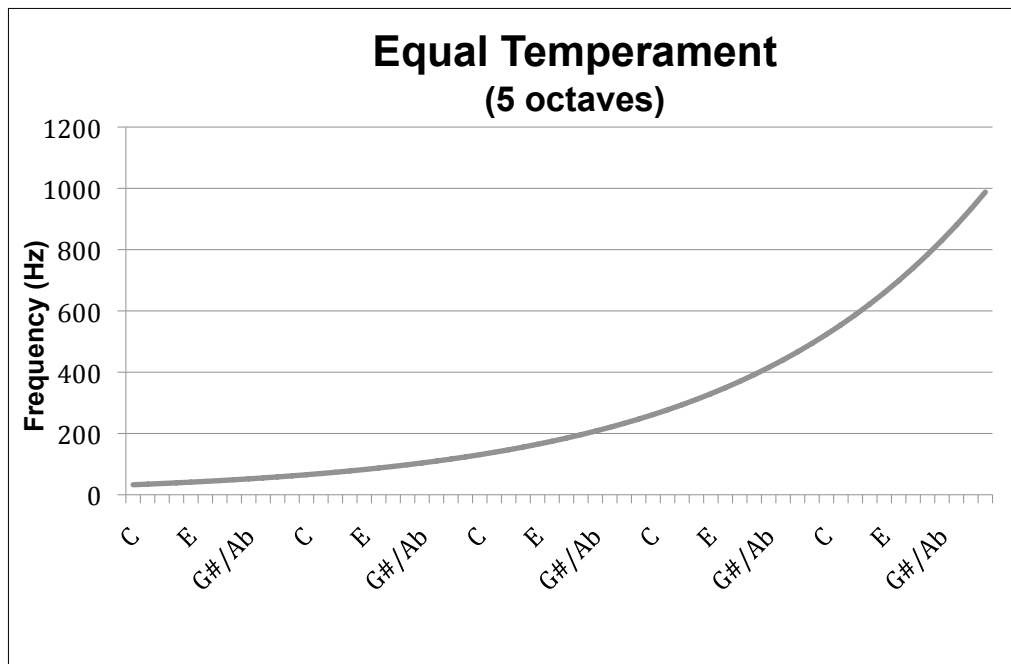
<i>If each interval in this chain is tuned pure (untempered),</i>	<i>the last note will be lower than the first by about</i>	<i>The name of this discrepancy is</i>
	41.1 cents.	lesser diesis.
	62.6 cents.	greater diesis.
	23.5 cents.	Pythagorean comma.
	21.5 cents.	syntonic comma.

Table illustrates notes acquiring commas

Lüxue Xinshuo, “...the new method enables the unending circulation of 12 tones in an orderly way, and this is an unprecedented achievement in the two thousand years of the history of music.”

Name	Equal Temp. Frequency (Hz)	Meantone Frequency (Hz)	Difference (Hz)
Unison (C)	32.70	32.54	0.17
Minor second (C#)	34.65	34.73	-0.08
Major second (D)	36.71	36.64	0.07
Minor third (D#)	38.89	38.71	0.18
Major third (E)	41.20	41.28	-0.08
Perfect fourth (F)	43.65	43.36	0.29
Augmented fourth (F#)	46.25	46.52	-0.28
Perfect fifth (G)	49.00	48.83	0.17
Minor sixth (G#)	51.91	51.85	0.06
Major sixth (A)	55.00	55.00	0.00
Minor seventh (A#)	58.27	57.79	0.48
Major seventh (B)	61.74	61.98	-0.24
Octave (C)	65.41	65.07	0.33

Equal temperament is based around the $2^{n/12}$ ratio. This seemingly abstract ratio was suggested in 1635 by Marin Mersenne in his expansive *Harmonie universelle*, concluding several decades of research. The importance behind the ratio is that it is exponential. Because equal temperament is exponential, not linear, each note has the same ratio, $2^{n/12}$, and not an increasing set number – in other words, equal temperament is not linear. Because of this, the ratio is preserved and can be applied to the entire scale.



Graph depicting Equal Temperament's exponential increase

In fact, it wasn't until well into the 18th century before the solution was widely accepted. This was due to the idea that all of the arts should be determined by ratios – a holdover from the medieval ages' inclination towards Pythagorean mathematics. The catalyst that kick started the inception of equal temperament began with Gioseffo Zarlino, the most famous Italian music theorist of the Renaissance. His *Le istituzioni harmoniche* helped create the ideal of "arithmetic vs. harmonic," which offered a different interpretation for the division of the octave, thus breaking the rule of Pythagorean mathematics over music.

Though Zarlino's book was primarily one of speculation, it nevertheless cast an enormous shadow over music theory. It has spawned countless tuning styles. It has been speculated that it, in fact, was what spawned meantone and just intonation – both of which became prevalent tuning styles... at least for a while.

Equal temperament eventually became universal. The style was widely adopted in France and Germany by the late 18th century and in England by the 19th. Though initially created to standardize keyboards, today one would be hard pressed to find other tuning systems utilized in instruments, anywhere in the world.

Chapter 9

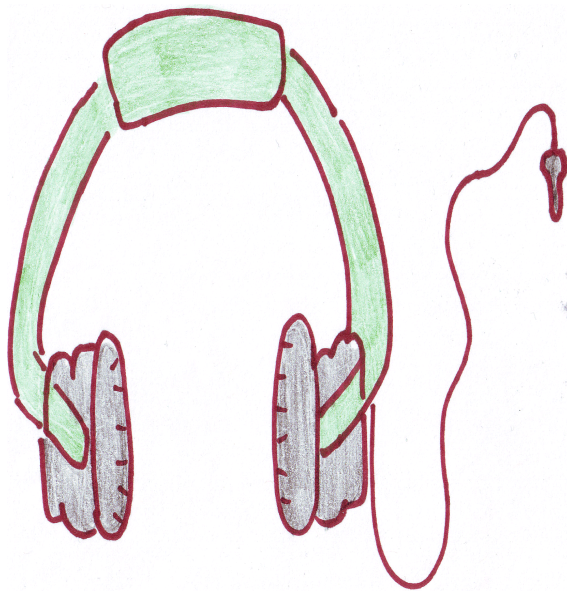
CONSONANCE AND DISSONANCE

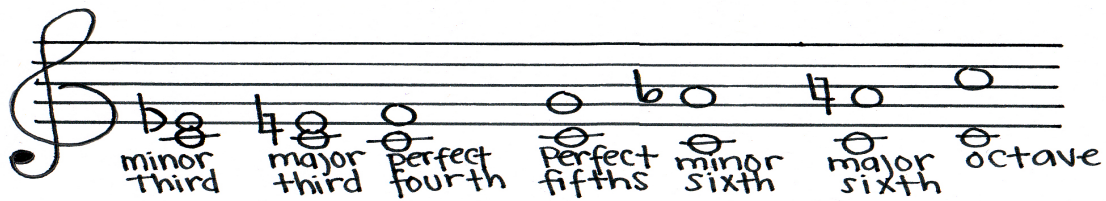
Alexandra Sandoval, Johnathan Ramirez

Imagine you are in a concert; the music being played soothes your ears. You are rocking back and fourth and moving with the music. Then, abruptly, you hear a change in the chord being played. It is an irritable noise, and very disturbing to everyone. Some members of the audience are covering their ears while others are still moving with the music. This is a practical example of consonance and dissonance.

Consonance is a chord, harmony or interval that is considered stable. Stable means that it sounds pleasant. Consonance to most people sounds constant, meaning that the notes played together sound appealing so when you listen to one for a long time you would feel that you don't have to change the chord, music, or note, due to the constant sound it carries. Consonance is referred to in "intervals". An interval is a number of half steps between two notes. They are known as major third (which is 4 half steps), perfect fifths (7 half steps), or octave. Simple intervals are the

ones to be considered constant which includes minor third, perfect fourth, perfect fifths, minor sixths, major sixths, and lastly octave. These intervals take a great part in consonance. It's what gives consonance its constant sound. On the other hand, Dissonance is a harsh sound made of a combination of other sounds. These notes usually sound unpleasant when played at the same time. Dissonance can sometimes sound pleasant to those who like horrific noises but to put it all together you are the judge to ones self to what sounds pleasant and what doesn't sound pleasant. For an example, Classical and Art music from the 20th century might be difficult for some people to listen to due to the unreleased tension. There are intervals that are considered to be dissonant, which include minor second, the minor seventh, as well as tritone, which is located between the perfect fourth and perfect fifth.





The picture above shows what a constant interval should look like. A constant interval should include the minor third, major third, perfect fourth, perfect fifths, minor sixth, as well as octave. This constant interval is not disrupting at all due to the organization of interval.

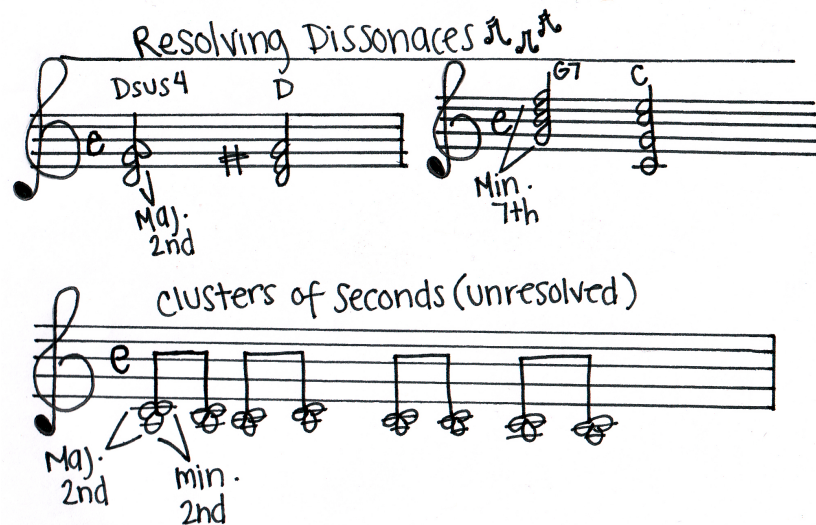
In the western hemisphere, commonly used intervals include the tritone octave, the fifth, the third, as well as many more chords that populate this chart of sounds. These chords all have a certain pitch and when played, they can be harmonious or dissonant, all this depending on what chords you do play. The three chords I said are all in augmented section of the western sounds. **Intervals** in music are referred to the distance between any two notes. A few of interval are Unison, Perfect, and Major. There are much more which create numerous unique sounds so that can be dissonant if the melody does not sound good or consonant. Intervals play a role in melody because they are the difference in distance from the scale steps. Please note that the western intervals have nothing to do with Western Music.



Tuning Consonance and Dissonance can be difficult at times. If you ever wanted to tune dissonance or consonance you would want to make sure all intervals that are octaves have a frequency ratio of 2:1. You would also want to make sure all fifths has a frequency ratio of 3:2, all major thirds would have a frequency ratio of 5:4 and so on. It may actually be impossible to have a perfect tuning system. There are intervals that are considered to be dissonant which include minor second, the major second, the minor seventh, as well as tritone, which is located between the perfect fourth and perfect fifth in dissonance.

Since dissonance has such an unpleasing sound, it causes the intervals to not be constant and since dissonance is not constant, it has earned the name unstable. On the other hand consonance is stable, by this we mean that consonance is very pleasing to listen to and is not disharmonic like dissonance. We can resolve dissonance though, yes there is a way. To resolve dissonance you would need to change the major second as you can tell in the picture below, the major second notes are not organized to resolve

this unorganized chord we would need to put them into a straight line going vertical. Another way to resolve this would be changing the minor sevenths, we would change this because the minor sevenths are so cluttered together we would want to space them out as shown below as well. Spacing them out on the vertical line they stand on would cause this note to be more pleasing. Lastly, we would want to resolve the major second and minor second but we wouldn't be able to due to the weird places they are all set at. Clusters of seconds would always be unresolved. Dissonances much like consonance have words that are applied with the name such as tonality, harmony, rhythm and meter. Dissonance is in many different cultures traditions and music styles. How the melody of sounds sound and how well things sound to the human ear. However, it does very to the human ear what sounds good. Other words that could describe dissonance would be unpleasant or grating, though even though all general music incorporates some portion of dissonance.



Frequency of vibration is a musical tone that happens to be very dominant. For example you could imagine a sin wave; it is measured in cycles per second or Hertz (Hz). Our ears perceive constant sound when two or more tones are sounded and that frequencies share a common factor. Our ears could hear any whole small number frequencies and due to this, our ear considers it constant. Whole ratios are commonly known to be constant. Just Intonation systems are tuning systems that are based on simple intervals. The frequency ratio theory is for explaining consonance and dissonance in the western music theory. Consonance pairs of tones when heard by the human ear have some regularity, which consists of tones that would be in the same interval, with that the tones would be at a harmonious tune not causing the ears irritable pain.

The table below is based on Nicola Vicentino's "just tuning".

Note	Frequency Ratio	Pitch (cents)
C	2/1	1200
B	15/8	1088
B $\flat$	16/9	0996
A	5/3	0884
A $\flat$	8/5	0814
G	3/2	0702
F $\sharp$	45/32	0590
F	4/3	0498
E	5/4	0386
E $\flat$	6/5	0316
D	9/8	0204
C $\sharp$	16/15	0112
C	1/1	0000

In the western scale, sounds or tones that are considered consonant are ones with simple ratios like 5th=G=3/2, 4th=F=4/3, and major 3rd=E=5/4 those that would be considered have more complex ratios is the major 7th=15/8, minor 2nd=C $\sharp$ =16/15 and tritone=F $\sharp$ =45/32. The ratios that make up the tritone tone is simply explained perfectly when it comes to calling tritone the Devil's Interval.

Consonance and Dissonance are both very different in their own ways. Consonance is constant and stable while dissonance is not constant nor stable which causes an irritable sound also known as a harsh sound. People may find dissonance disturbing (Classical and Art music) although others may find it enjoyable.

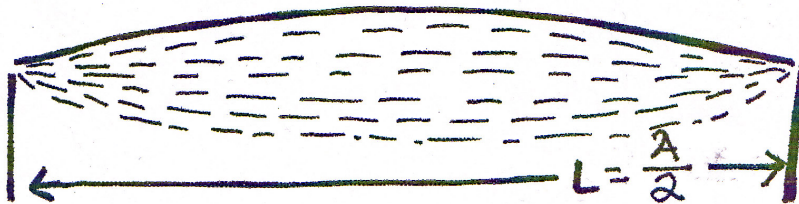
Chapter 10

RESONANCE

Kim Kirch, Lia Bruce, Shelma Soto

In this chapter, we will be discussing what resonance is and how it applies to different instruments and cavities. The definition of a resonant frequency is a natural frequency of vibration determined by the physical parameters of the vibrating object. In other words, it is representative of the frequency at which an object vibrates. An example of this would be that a vibrating object would pick out resonant frequencies from a complex excitation and vibrate at those frequencies, essentially “filtering out” other frequencies present in the excitation. If you were to whack a weighted stick on a spring, the initial motion may be complex, but the main response of the spring will be to bob up and down at its natural frequency. The blow with the stick is a complex excitation with many frequency components (as could be shown by Fourier analysis), but the spring picks out its natural frequency and responds to that.

A vibrating string produces a sound, which in most cases creates a constant frequency.



This is the equation for frequency of the string. This will be discussed in detail in Chapter 11.

$$f_1 = \frac{1}{2L} \sqrt{\frac{T}{m/L}}$$

T= string tension

m= string mass

L= string length

One can apply this equation in real life things for example an acoustic guitar. We picked one string from an acoustic guitar and measured its length and string mass. The length of L of the equation is 36 inches. The mass of the string is .04 inches. The string tension of an acoustic guitar is between 75-90 pounds. Let's plug it in!

$$f = \sqrt{\frac{85}{4/36}}$$

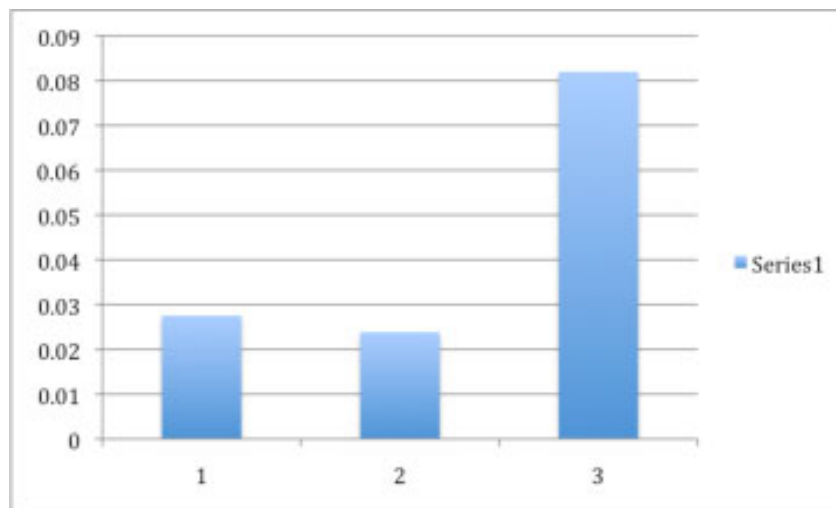
$$f = \sqrt{\frac{85}{14.4}}$$

$$f_1 = \sqrt{\frac{T}{m/L}} \quad f = \sqrt{6}$$

$$f = \frac{2.4}{2(36)}$$

$$f = \frac{2.4}{72}$$

$$f = .03$$



The mass of the string can also affect the frequency shown below in the graph. The numbers on the left show the mass of the string and the blue describes how the frequency grows.

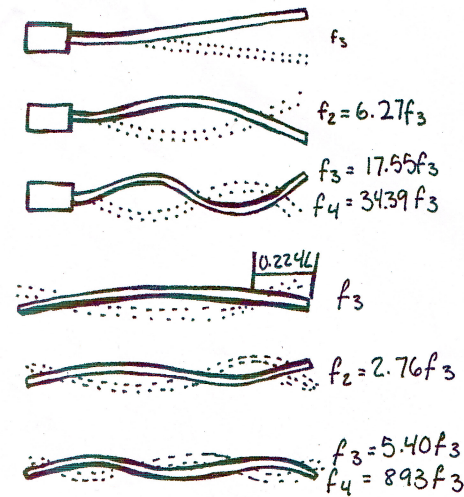
The resonant frequencies of air columns depend upon the speed of sound in air as well as the length and geometry of the air column. The velocity at which a small disturbance will propagate through the medium is referred to as “acoustic velocity” or “speed of sound”. The acoustic velocity is related to the change in pressure and density of the substance.

A harmonic of a wave is a component frequency of the signal that is an integer multiple of the fundamental frequency. Frequency is the number of occurrences of a repeating event per unit time. If you pluck your guitar string, you don't have to tell it what pitch to produce, it knows! That is, its pitch is its resonant frequency, which is determined by the length, mass, and tension of the string.

The modes of vibration associated with resonance in extended objects like strings and air columns have characteristic patterns called standing waves. These standing wave

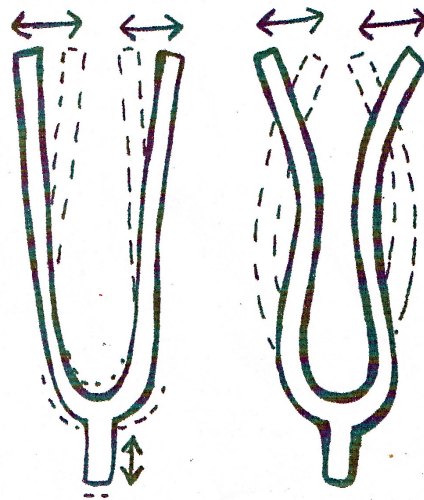
modes arise from the combination of reflection and interference such that the reflected waves interfere constructively with the incident waves.

Stretched membranes have many vibrational modes, some of which are harmonically related to the lowest pitch and some not. The preferred vibrational modes for a timpani are a subset of the modes of a circular membrane. The membrane produces harmonics, but also produces non-harmonic overtones. Where there are multiple segments, adjacent segments are moving in opposite directions during vibration. The vibrational modes of a circular membrane are very important musically because of drums, and in particular the timpani. The expression for the fundamental frequency of a circular membrane has some similarity to that for a stretched string, in that it depends on tension and density.

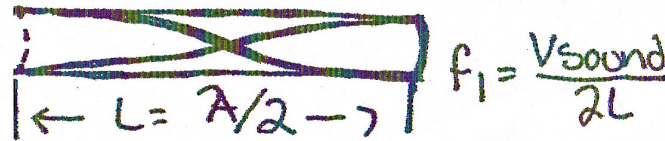


Clamped Bar Equations and Free Bar Equations

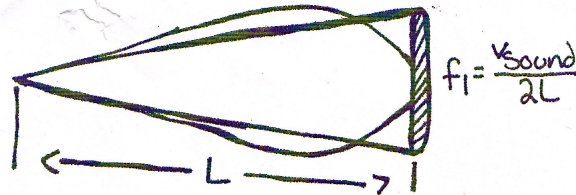
The two sides, or "tines," of the tuning fork vibrate at the same frequency but move in opposite directions at any given time. The two sound waves generated will show the phenomenon of sound interference.



The open air column can produce all harmonics. Open cylinders are employed musically in the flute, the recorder, and the open organ pipe. A closed cylindrical air column will produce resonant standing waves at a fundamental frequency and at odd harmonics.



A conical air column will produce the same fundamental frequency as an open cylinder of the same length and produce all harmonics.



Cavity resonance occurs when extra air is forced into a cavity (a hollow object with a single opening) and then released. The air will overshoot itself creating a vacuum in the cavity and the air goes in and out of the container at a natural frequency. Take for example a glass coke bottle you finish drinking. When you blow into the bottle the noise it makes is its natural frequency. Now add water to that bottle and blow again. The water in the bottle produces a different pitch.

Here is an equation:
$$\text{frequency} = \frac{v}{2\pi} \sqrt{\frac{A}{VL}}$$

v = sound speed

A = area

V = Volume

L = Length

With this equation, you can find the frequency of a regular water bottle.

Givens:

$$A = \left(\frac{3}{8}\right)^2 \pi \text{ inches}$$

$$V = 30.51 \text{ in}^3$$

$$L = 1 \text{ inch}$$

$$\text{Frequency} = ?$$

$$frequency = \frac{13,397.24in}{2\pi} \sqrt{\frac{\left(\frac{3}{8}\right)^2 \pi in}{30.51in^3 \cdot 1in}}$$

$$frequency = 2,132.236 \sqrt{\frac{0.44178}{30.51}}$$

$$frequency = 2,132.236 \sqrt{0.01448}$$

$$frequency = 2,132.236 \cdot 0.12$$

$$frequency = 256.5 \text{ Hertz}$$

This result means that the water bottle without any water in it will have a natural vibrating frequency, or resonance, of 256.5 hertz.

Taking the idea of cavity resonance, we are now going to apply it to vocal resonance and air resonance for string instruments. If we look at a vocal tract, it would have a 500-hertz frequency because it is usually 17-18 inches long. The voice articulator controls the resonance to make vowel sounds (cavity resonance). Just like vocal resonance, the bigger the cavity of the string instrument, the lower the pitch and frequency will be. Let's look at violin f holes and a guitar circular hole. The same equation and things apply. When the sound of the strings is pushed into the cavity and released, it overshoots itself and creates a bigger sound or louder sound.

Bass Reflex Speakers are closed containers that use cone resonance frequency. The acoustic absorbing material is inside the container. When tuning the frequency of the container to the cone resonance frequency it avoids back to front cancellation.

When looking at recording studio soundproofing (mentioned in chapter one) we see how carefully planned out everything has to be. This includes such menial things as air conditioning, room within room, windows, and doors that seal shut. Instead of trying to have the sound project throughout the room like an auditorium, the sound needs to be muffled. Any low frequency that might be unnoticeable may be very prominent in a recording. That is why in sound recording studios they have fabric or foam objects that can absorb middle to high frequencies.

Let's review! Resonance is a natural frequency of vibration determined by the physical parameters of the vibrating object. You can find out the frequency of different things like strings and cavities with a few simple equations. The next section of the chapter will talk about harmonics and explain the physics, and concepts behind it.

Chapter 10.2

HARMONICS

Eric Harmatz, Josh Jarboe

You learned in the first section of this chapter that resonance is oscillation at a natural frequency. The **natural frequency** – also referred to as the “fundamental frequency” – is the lowest frequency produced by an object, such as an instrument. We’ll use a guitar string as an example:

As you can see, there are two parts of the wave in Figure 10.2.1 in which there is no vibration. These are called the **nodes** or “zeros” of the wave. The first harmonic has two nodes, one on each end of the wave. A **harmonic series** is a series of frequencies that are integer multiples of a fundamental frequency. This works off of the principal that you learned in earlier chapters that

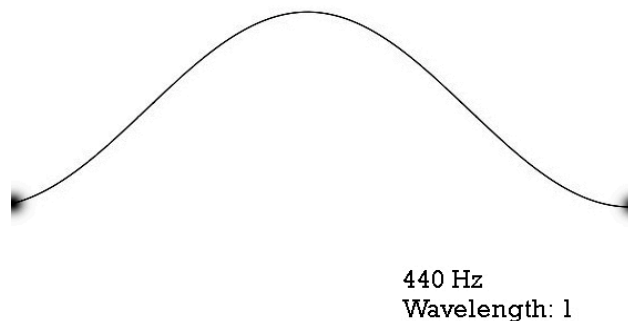
$$\text{Frequency} = \frac{1}{\text{Wavelength}}$$

Since this equation shows an *inverse* relationship between frequency and wavelength, when the wavelength is decreased by the frequency is increased. In Figure 10.2.2, a graph of the equation $y = \frac{1}{x}$ is shown to represent the Frequency equation. There is an asymptote whenever $x = 0$ as the denominator cannot be zero or the function is undefined. There is also an asymptote when $y = 0$ as there is no possible way of returning a value of 0 from $\frac{1}{x}$.

The frequency will get infinitely close to zero as wavelength is increased, however, it

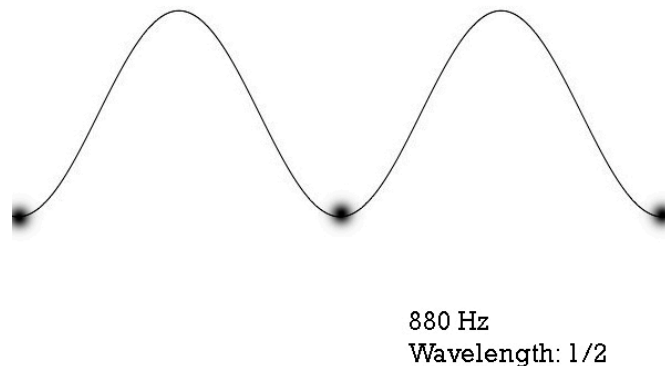
First Harmonic

Figure 10.2.1



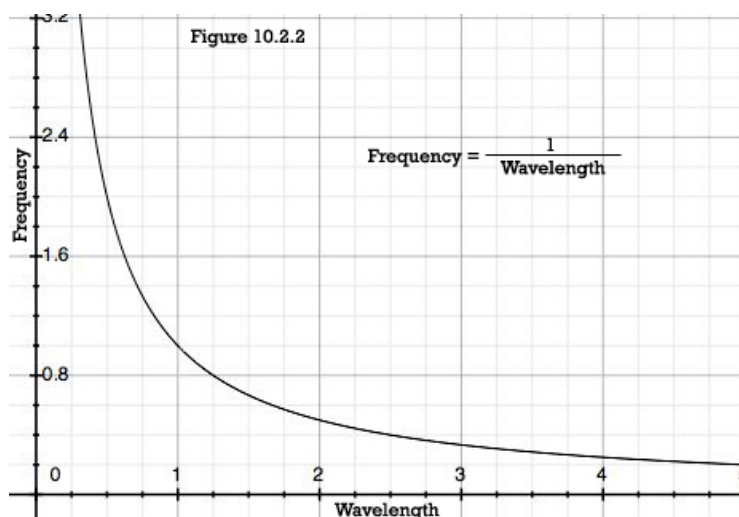
Second Harmonic

Figure 10.2.3



will never be zero. This makes sense, as no matter how many times we increase the wavelength, there will still be a frequency, although it will be very low.

Since wavelength and frequency are inversely related, whenever a node is added the wavelength is *decreased* resulting in an *increase* of frequency at the same proportion the wavelength was decreased. Let's assume our fundamental frequency, our first harmonic, is 440 Hz. If we divide this wave into two equal waves, we are splitting the wavelength while doubling the frequency. The frequency in our second harmonic is 880 Hz. In Figure 10.2.3 the second harmonic is shown.

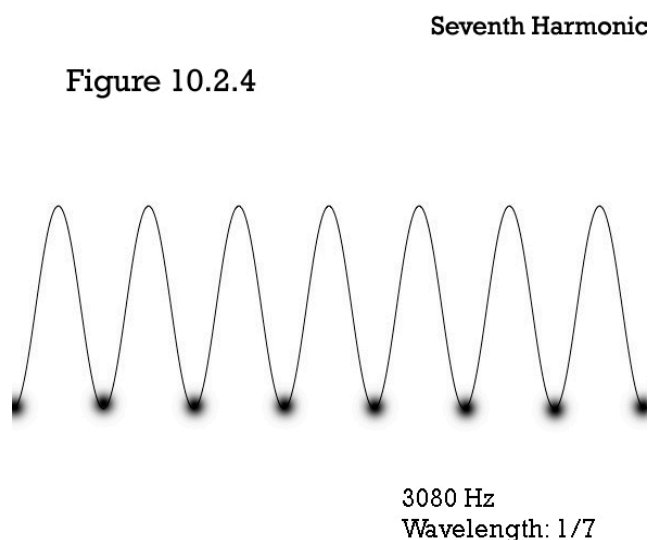


Note that there is another node, dividing the wave into 2 times the natural frequency, or $2f$. The third harmonic is the fundamental frequency times three, with one third of the wavelength. In the third harmonic, the frequency is 1320 Hz, which is the fundamental frequency, 440 Hz, times 3.

Do you recognize any patterns throughout the harmonics discussed above? What if we wanted to find the seventh harmonic? With the pattern above, we would divide the wavelength of the natural frequency by 7. We are multiplying the frequency by 7. This means that our seventh harmonic has a frequency of 3080 Hz (which is $440\text{ Hz} \times 7$). See figure 10.2.4 for a representation of the seventh harmonic.

When you listen to music from a guitar, you're not just hearing one frequency. Instead, you are hearing **overtones** of the natural frequency. An overtone is any harmonic greater than the first. The second harmonic is the first overtone, the third harmonic is the second overtone, etc. For example, when a guitar string is plucked, many overtones are present, and the natural frequency. The frequency, or **pitch**, that is audible is the highest overtone present.

Recall from *Chapter 2* that the



amplitude of the waves is what determines the volume of the sound being produced. For example a violin will produce waves with a lower amplitude than a guitar (see Chapter 11 for more detail about string instruments). Even though a violin and guitar may be playing the same frequency, the noise produced will sound different. This is due to the **timbre** of the instrument. Timbre (pronounced TAM-ber) is the way by which frequencies blend and produce a “color” of sound. There are many words that can be used to refer to the color of sound – timbre – such as “heavy”, “light”, “bold”, “brassy”, “clear”, “harsh”, “piercing”, and “flat”.

Different instruments of the same type can have different timbre. For example, two different guitars may play the same note but sound differently due to differences in resonance caused by the shape of the guitar. In the next chapter, we’ll explore different types of instruments, including the guitar.

Chapter 11.1

MATHEMATICS AND RELATIVE MUSIC THEORY

Of all instruments, stringed instruments are the easiest to assign mathematical concepts to because you can see exactly where the notes fall and all of the hardware for the most part is exposed. They also have the most variation in their produced sound.

Wavelength, frequency, and speed or tempo are linked together by the equation: Speed equals Frequency multiplied by wavelength. From previous chapters we learned that speed is measured in meters per second, frequency is measured in hertz, and wavelength is measured in meters.

$$F = \frac{n}{2L} \sqrt{\frac{T}{\mu}}$$

The equation above is the equation used to calculate string frequency,

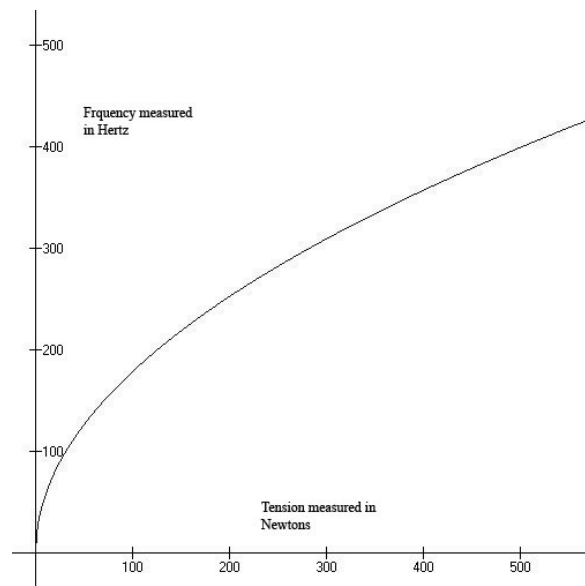
The variables are defined as follows:

F= Frequency	n= Harmonic Number (normally 1)	L= Length of string	T= Tension	μ = Linear Mass / Linear Density
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All of the terms above are directly related. A change in one of the variables will result in a change in pitch, and will affect another variable. For example, the unit μ can be changed by changing the string, whereas string tension can be changed just by manipulating the tuning keys. One of these direct proportionalities can be seen in the graph to the right.

When practically applied, we can use the equation above to find the frequency of a low E note played from a string by substituting for the variables.

$$330Hz = \frac{1}{2(.666m)} \sqrt{\frac{347N}{0.0018 \frac{kg}{m}}}$$



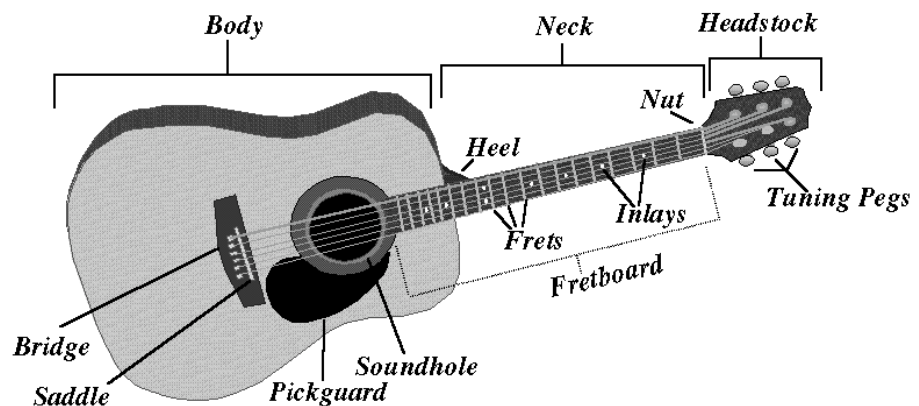
When the equation is worked out, we find that the frequency of a low E is 330 Hertz. If variables are missing, you can re-work the equation to get any of the desired variables. For example, we can say that tension is missing, you could use the below formula to solve for tension.

$$\mu 4F^2 L^2 = T$$

This is just one example of many that can be applied to solve for other variables, just by using simple algebra to isolate the variable you want. In terms of the above problems, the substituted equation would look like this.



The construction of stringed instruments usually follows a trend. Most stringed instruments are assembled with a body, neck, tuning keys, bridge, a sound hole, frets, and the strings. Instruments like the guitar and the violin are similar

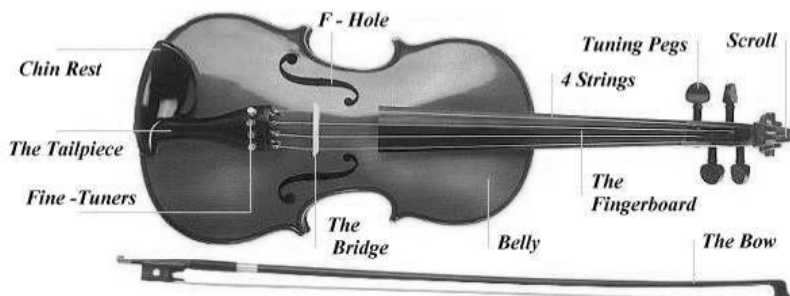


in construction because they both consist of all the above components. They differ in the numbers of tuning keys & strings, string diameter, and overall size.

In most string instruments the string is attached at the bridge and lead to the tuning key, where tuning begins. Here, you can manipulate your string to change the pitch of the strings open note.

The body of a stringed instrument is where most of the sound is produced and amplified. For this reason it is very important to find a material with a nice resonance. For instance, basswood is used because it is a softer wood meaning it silences higher treble notes, and preserves the bass driven foundation. Maple is a harder wood. The wooden body will produce louder sound and brighter highs.

The neck of your stringed instrument is normally directly proportional to the size of the body, for purposes



of structural integrity. If the neck is not made from a piece of nice solid wood, it will choke up the natural resonance of your instrument. The Indian sitar relies heavily on natural resonance, if the neck is not solid, then the instrument will falter.

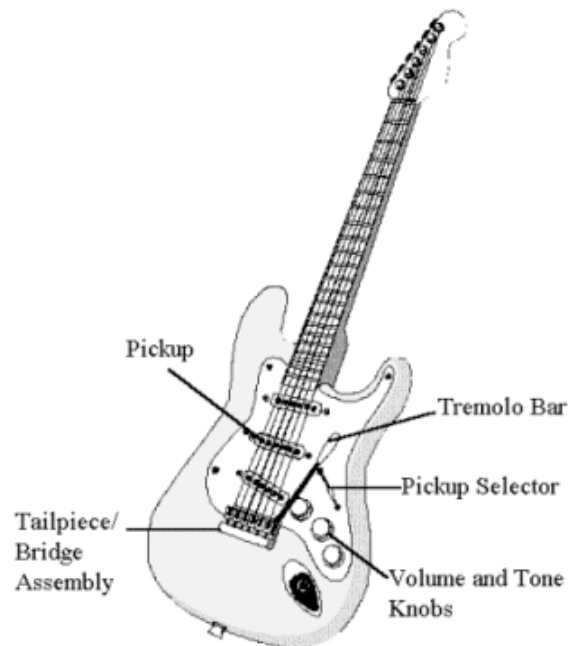
The bridge of your instrument is to hold the string in place, and in many cases to offer another point of fine-tuning. Bridges are normally in one to three pieces.

Frets are used to hit notes easily and precisely. Such instruments as the stand up bass have no frets making it more challenging to hit the note in exactly the right spot. Also the lack of a hard piece of metal for the string to bend over makes the sound a little less static, and softer. Round wound strings have a round tube in the center being wrapped by ether bronze or nickel, and are squeaky and bumpy.

Choice in strings is also important, different materials and winds create different sounds. For the most part, strings are made from a steel core, and are often wrapped in a soft metal. A few string materials include nylon, steel, and bronze, and each of which makes a more defined sound. Nylon for instance produces a mellower and warmer tone, common in Spanish flamenco guitar. Steel strings produce a more powerful and sharp tone, and Bronze strings creates a deeper and richer sound. When dealing with the texture of the string, flat wound strings have a mellower, jazzy sound and are easier on the fingers; where round wound strings have a more coarse output

The length of the string affects the frequency and the pitch; for example, a violin is one octave higher than a guitar because the string is half as long.

A string's diameter affects that strings frequency and the number of times that string goes back in forth. It also affects the sound of the note, if the string is thicker it will have a deeper richer sound, and if the string is thinner it will have a sharper and higher pitched note. The Electric guitar is made possible by a magnetic pickup that transforms the physical vibrations into sound by observing the disturbance in the electrical field around it. The pickup is created by wrapping a copper wire around a magnet, and attaching it to an amp. As the string is vibrated, the slight sound is picked up by micro phonic pickup and sent to the amplifier to create sound.



Chapter 11.2

WIND INSTRUMENTS

Jarrold Johnson, Kate Lee Newcomb

A wind instrument is an instrument that contains some type of resonator, usually a tube, in which a column of air is set into vibration by the player blowing into or over a mouthpiece set at the end of the resonator. The pitch of the vibration is determined by the length of a tube and by manual modifications of the effective length of the vibrating column of air. In the case of some wind instruments, sound is produced by blowing through a reed; others require buzzing into a metal mouthpiece. These instruments are typically known as aerophones. These types of instruments are separated into two different categories: woodwind (*Fig. 1*) and brass acoustics (*Fig. 2*). The most common emotion inflicted by the woodwind category is pacific and relaxing. While on the brass side the more common emotion is more upbeat and energetic.

Fig. 1



Fig. 2



Brass instruments are but one type of wind instrument. (*Fig. 2*). Brass instruments are usually broadly speaking, with relatively cylindrical, narrow-bore tubes. Noise is produced in brass instruments primarily by vibrating the player's lips against the mouthpiece, causing the air within the instrument to vibrate. Examples of the different types of brass instruments are the following: trumpet, tuba, trombone, euphonium, French horn and flugelhorn. The pitch of the vibration in brass instruments is determined by the length of the tube and by manual modifications of the effective length of the vibrating column of air. Thus changing the length of the vibrating air columns is like altering the length of the tube and through engaging valves – which route the air through additional tubing – increases the overall tube length, which subsequently lowers the fundamental pitch. The length of the vibrating air column can be lengthened and shortened by using a sliding mechanism; this method is used on the trombone and the slide whistle. Resonance, which was explained in full detail in Chapter 10.1, is a natural frequency of vibration determined by the physical parameters of the vibrating object; in this case for the brass instruments.

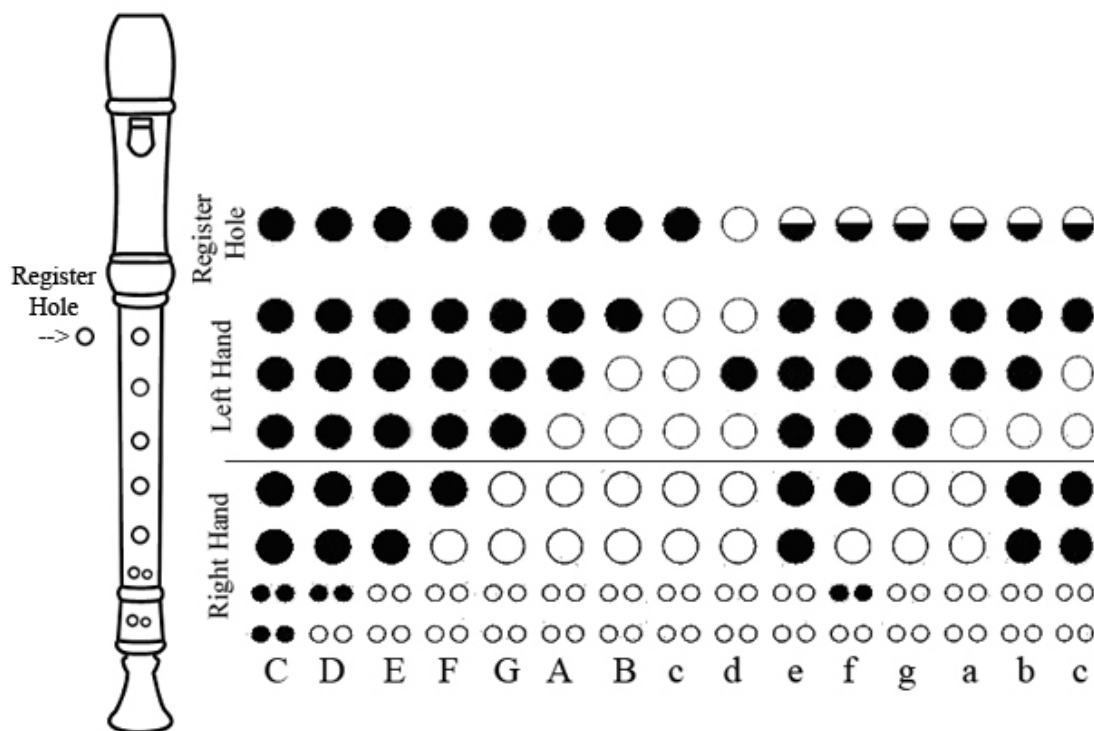
The second type of classification of wind instruments is the woodwind instruments (*Fig. 1*). Woodwinds are musical instrument that produce sound by vibration of the

mouthpiece. Noises made in woodwind instruments are usually one of the following methods:

1. Cause a reed to vibrate, which agitates the column of air (as in a clarinet or oboe)
2. Blowing against an edge or fipple (as in a recorder)
3. Blows across the edge of an open hole (as in a flute). (Wind Instrument₂)

Examples of woodwind instruments are the following: flute, piccolo, recorder, clarinet, oboe, bassoon and saxophone. (Woodwind Instruments) Changing the sound produced by a woodwind can be done by altering the length of the tube and by manual modifications of the effective length of the vibrating column of air. (Wind Instrument₂) This can also be done by changing the length of the vibrating air column, by changing the effective length of the tube through openings or closing holes in the side of the tube will change the pitch the musical instrument produced. This can be accomplished by covering the holes with fingers or pressing a key that then closes the hole (Fig. 3). This method is utilized in nearly all woodwind instruments.

Fig. 3



The chart above (Fig. 3) shows the finger positioning for a recorder that corresponds with the common music scale. The black circle represents the holes that are covered, while the white ones are representative of the holes that are open. The half white half black circles are for partially covered holes.

There are mathematical equations that can be used to identify the fundamental and length of these instruments; they are the following:

Open Cylinder Air Columns' fundamentals can be determined by the following equation, and the next consecutive equation is for length:

$$f_1 = \frac{v_{\text{sound}}}{2L} \qquad L = \frac{\lambda}{2}$$

Where, f_1 is equivalent to fundamental frequency, v_{sound} equals velocity of sound, L is length and λ (lambda) represents wavelength. Examples of the types of instruments these equations will work for are recorders and flutes.

A real life example of an open cylinder instrument is a recorder. If the velocity of sound is 34,000 centimeters per second and the wavelength is 60 centimeters, what is the length of the instrument in centimeters and what is the frequency in Hertz (Hz) produced by this instrument?

In order to solve this real life problem, the givens must be acquired. They are the following...

$$f_1 = \frac{v_{\text{sound}}}{2L} \qquad L = \frac{\lambda}{2}$$

Velocity of Sound: 34,000 cm/sec

Wavelength: 60 cm

In this case we can easily find missing variables by using the given information and equations.

First, solve for the length of the instrument in centimeters in order to determine the frequency produced by that length.

$$L = \frac{\lambda}{2}$$

Next, we plug in the given wavelength and then solve to find the length of the instrument in centimeters.

$$L = \frac{60}{2} \qquad L = 30$$

Now that the length of the instrument has been determined to be 30 centimeters, we can now solve for frequency.

$$f_1 = \frac{v_{\text{sound}}}{2L}$$

Just plug in the given variables and solve, the resulting answer will be the frequency produced from the instrument.

$$f_1 = \frac{34,000}{2(30)}$$

$$f_1 = \frac{34,000}{60}$$

$$f_1 = 566.\bar{6}$$

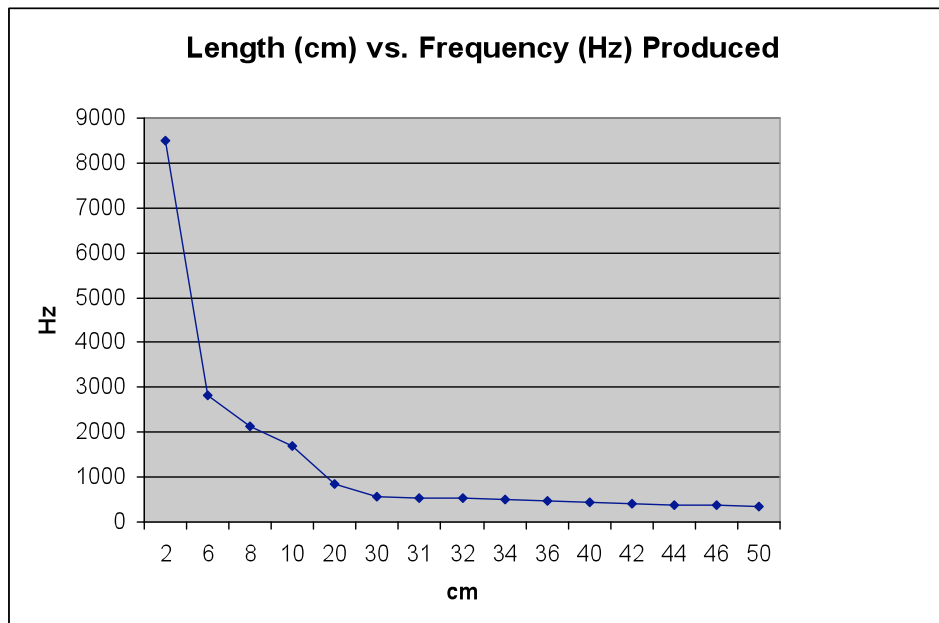
Now this real life problem has been solved and the answers were:

Length of Instrument: 30 cm

Frequency Produced: 566.6 Hz

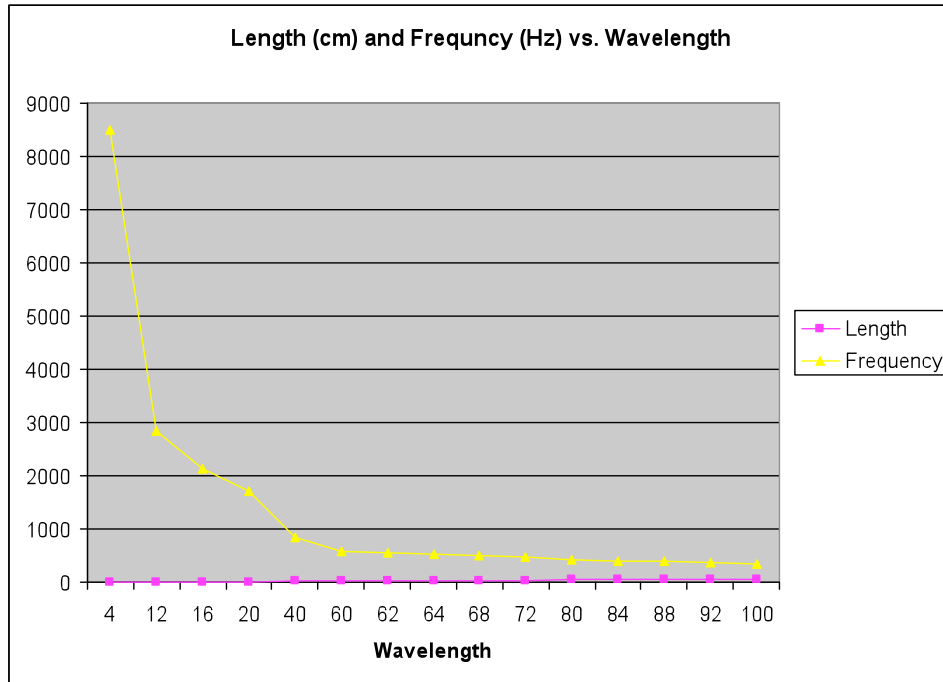
Below are graphs (*Fig. 4* and *Fig. 5*) that illustrate the relations of frequency, the length of instruments and wavelength.

Fig. 4



Explanation of *Fig. 4*: The graph above shows the correlation between the lengths of the open cylinder instrument to the frequency produced. As seen above, as the length increases the frequency decreases, which means these are inversely related. This graph is created by a rational equation because the variable is in the denominator.

Fig. 5



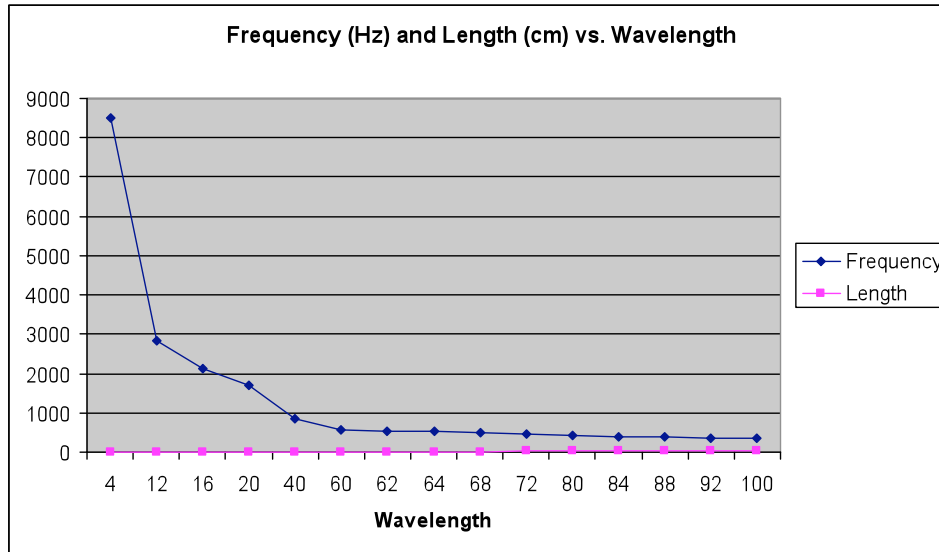
Explanation of Fig. 5: This graph above shows the correlation between the wavelength and length of instrument and the frequency produced. As seen, as the wavelength increases the length of the instrument is exactly half the wavelength. The frequency decreases as the length of the instrument increases, meaning that they are inversely related. This graph was also created by a rational equation, because the denominator has the variable.

Closed Cylinder Air Columns' fundamentals can be determined by the following equation, and the next consecutive equation is for length:

$$f_1 = \frac{v_{\text{sound}}}{4L} \qquad L = \frac{\lambda}{4}$$

Where, f_1 is equivalent to fundamental frequency, v_{sound} equals velocity of sound, L is length and λ (lambda) represents wavelength. An example of the type of instrument that these equations will work for is the clarinet. Below is a graph that shows the relationship of the equations above.

Fig. 6



Explanation of Fig. 6: The graph above shows the correlation between frequency and length of the instrument to the wavelength for the closed cylinder column. As seen the frequency and the wavelength and length of the instrument are inversely related. This graph is created by a rational equation because it has the variable in the denominator.

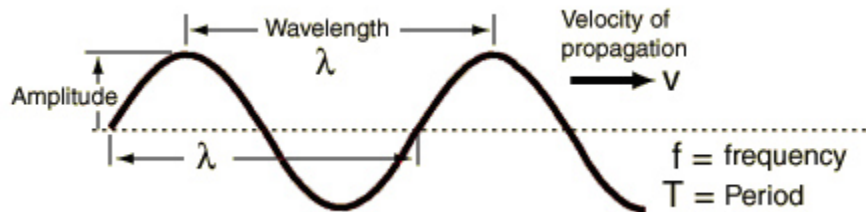
Conical Air Columns' fundamentals can be determined by the following equation, and the next consecutive equation is for length:

$$f_1 = \frac{v_{\text{sound}}}{2L} \qquad L = \lambda$$

Where, f_1 is equivalent to fundamental frequency, v_{sound} equals velocity of sound and L is length. Examples of the types of instruments these equations will work for are oboes, bassoons and saxophones. (Conical Air Column) If this equation was graphed, then it would be exactly the same as Fig. 3 since they share the same equation.

A single frequency-traveling wave will take the form of a sine wave. A snapshot of the wave in space at an instant of time can be used to show the relationship of the wave properties frequency, wavelength and propagation velocity. Below is a labeled diagram (Fig. 6) helps to show the relationships of the sine wave.

Fig. 7



The motion relationship "distance = velocity x time" is the key to the basic wave relationship. With the wavelength as distance, this relationship becomes $\lambda = vT$. Then using $f = \frac{1}{T}$ gives the standard wave relationship $v = f\lambda$. This general wave relationship applies to sound and light waves, other electromagnetic waves, and waves in mechanical media.

Although wind instruments create sound through a vibrating column of air, it can be deduced that they still create unique music. The two types of wind instruments, brass and woodwind, allow for a large variety of sounds. The projected frequencies can be predicted with the formulas discussed throughout Chapter 11.2 Wind Instruments. The wind instruments are best distinguished by their shapes and how they are operated. Therefore, musical instruments are not only made of different materials and structures, their sounds can be determined by their equations.

Chapter 11.3

PERCUSSION

Alex, Geraldine, Madisson

Music without rhythm cannot be enjoyed, as we do know. Rhythm gives music timing and structure. Many people believe that the word percussion refers to only drums but in reality, percussion describes instruments that make sound by plucking, striking, or shaking. Percussion in particular is what gives the sense of rhythm and beat to everyday music. But even though we think of a drum, plucking a string can be described as percussion. Not only beats are percussion but also the vibrations created by the string. Percussion itself means "to beat or to strike" which comes from the root or Latin term percussion with the musical intent. It is the musical ensemble's heartbeat and backbone. The roots of this instrument are as unknown to us as the world discovers more ancient cultures. Anthropologists have a great curiosity of where exactly the idea of percussion came from and are all uncertain.

Many cultures around the world contain pride of the development and creation behind their instruments that gives them uniqueness. Percussion stands alone with the idea of not having to be patriotic to a country or a specific culture. It was the first type of instrument ever made and it has no original roots to where was first made. 6000 B.C. is as far as the drum's origin can be calculated. As James Blades wrote in his book *Percussion Instruments and their History* "The rise and development of percussion instruments is closely linked with the history of mankind." Civilizations used objects such as rocks, sticks, hands and basically anything that was at their disposal to create the rhythm.

Percussion is any musical ensemble's heartbeat that keeps the rhythm together. Amongst the enumerable percussion instruments, there are only two classifications: idiophones and membranophones. Idiophones generate sound from the vibrations without the stretched membrane such as mallet instruments and rattles. The ones that adopt the stretching membrane are called membranophones like drums.

Percussion instruments have enriched cultures everywhere, they have been used for religious and political ceremonies as well as for battle symbols. Europe valued them as not just for rock concerts but even more in the past generations, where they were used in battle and for signals during the war years. Drums in Africa serve as a unity symbol, tribal custom and tradition. Africa offers the rest of the world with the most extensive variety of percussion instruments. Like the talking drums that can be heard from a very long distance to warn tribes. For other countries it has even become a symbol of freedom.

Percussion has various styles and backgrounds. As new generations continue to give in the percussion's charm, new instruments are designed and constructed. The ancient and the new share same passion for the beat. Percussion instruments can be

constructed with wood, metal and even clay. It all depends on the type of sound wanted. For the Italian dances only certain drums get chosen to appear in festivals. Castanets give the world a glimpse of the Spaniard culture; the flamenco dancers shake the handle, striking the shells on the free hand. They are many types of drums and interments such as the timpani drum when struck with felt-tipped wooden sticks or mallet the drum produces a pitch that is determined by the drum's size. By tightening the drum heads you can adjust the pitch and better tune the drum.

The Steel drum is made from the metal top of an oil drum with an array of flattened areas that produce different sounds when struck in those areas. The noise depends on whatever part of the drums is hit. The area closest to the center produces a much higher pitch than the outer area of the drum.

The bongo consists of two drums, one larger than the other. Both are usually combined together and played as one. Bongos originated in Africa and were used in the African tribes. When multiple bongos are together it produces a rhythm that many of the African tribes danced to.

Drums make different sounds and waves which depend on the size of the drum. There are so many different types of drums mainly because each creates its own unique sound. There are also many different equations used to measure sound, with the majority of instruments all having different equations. When measuring a xylophone or an instrument using vibrating plates and rods majority of them use the equation:

$F \approx 1.03kv/L^2$ while the majority of drums use the equation: $F \approx (0.765/D)(F/\mu)^{1/2}$. In these equations k is the constant that changes depending on the object, L is the length of the bar and V is the velocity of sound in the object. These equations measure the frequency of a certain instrument.

The snare drum has a diameter of 15-16 inches and a depth of 5 inches. The head of the drum is made out of either animal skin or plastic. Each head has two hoops, one on the top and one on the bottom. The bottom hoop is around the edge of the head. When the snare drum is struck it produces a vibration throughout the drum which causes the snare to rattle against the head which then produces a dry rattling noise.

The bass drum is constructed a lot like a snare drum but without snares. It is also much larger than the snare drum and is played on its side. This allows either head of the drum to be struck. When the drum is struck it produces a long but deep noise that is usually when in orchestra will usually be heard over other instrument.

$$F \equiv (0.765/D)(F/\mu)^{1/2}$$

$$F = (0.765/14)(2.2/.44)^{1/2}$$

$$F = (.05464286)(5)^{1/2}$$

$$F = (.05464286)(2.236067978)$$

$$F = 0.122185149 Hz$$

$$F \equiv 1.03kv/L^2$$

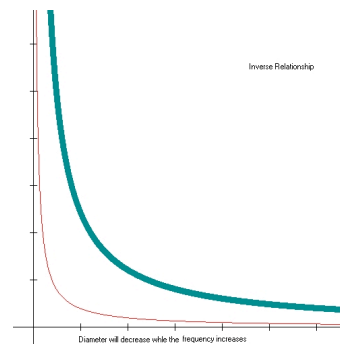
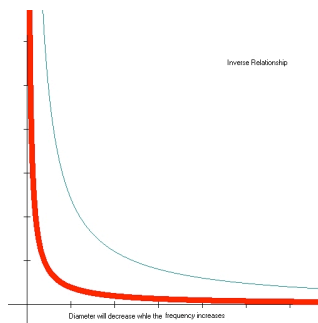
$$F \equiv 1.03\left(\frac{(2)(380)}{12}\right)^2$$

$$F \equiv 1.03\left(\frac{760}{12}\right)^2$$

$$F \equiv 1.03(4011)$$

$$F \equiv 4121.03 Hz$$

As mentioned before all drums produce a different sound frequency, thus giving each drum its unique sound. For example in the diagrams the Snare drum will have a much higher frequency than that of the bass drum. This is because the snare drum has a much smaller diameter than the bass drum thus producing smaller but much faster sound waves.



The graphs above show an inverse relationship between a drum's diameter and its frequency. As the diameter of the drum decreases the frequency will increase. The graph on the left shows a drum with a small diameter but a high frequency while the graph on the right shows a drum with a large diameter but low frequency.

Percussion surrounds all of us in our everyday lives and is considered the backbone of music itself. Many of our everyday surroundings can be used to create percussion sounds and because percussion can be made with countless items, there are many instruments that help provide us with the different sounds and variations of percussion. Percussion is extremely important in orchestras or in any music project for that matter, for this matter many instruments have been created to produce a different percussion sound.

Chapter 12.1

AMPLIFIERS

KJ Edwards, Kevin Palma

Amplifiers are a key part of every electronic device, working to make electrical signals stronger. There are many types of amplifiers, ranging from the insides of a computer, to a car stereo system. For the purposes of this book, we will limit our discussion to sound amplifiers. A key concept to understand when looking at sound amplifiers is the equation $V = I * R$.

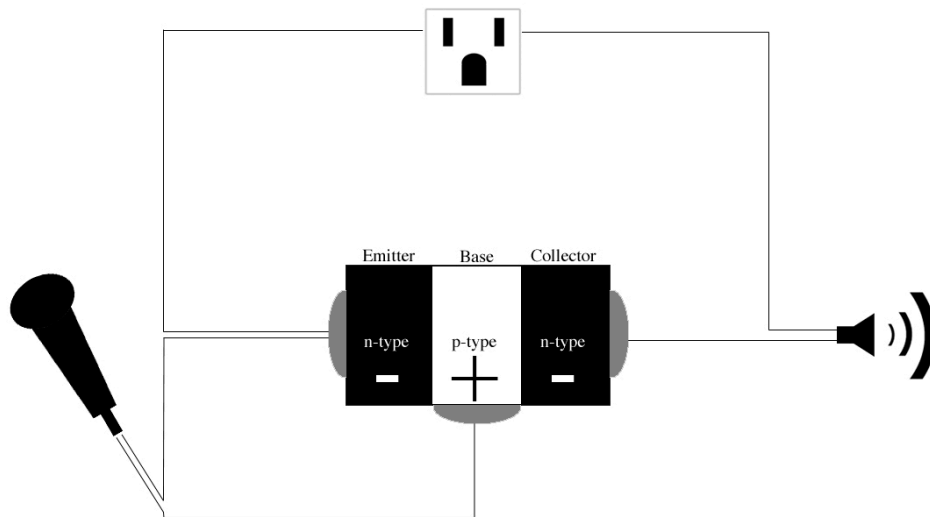
Voltage equals Current multiplied by Resistance or $V = I * R$ is an important equation relating to electricity that we will use here to talk about the relationship between the amplifier and the speaker. Before we get there, we must talk about the actual process of amplification. The electric guitar will be used to illustrate this process.

When a guitarist plays a note with an electric guitar, the string vibrates across a magnetic pickup creating a small electrical signal. This signal is nowhere near strong enough to drive a speaker, however, amplification of this signal can increase the power by a factor of two hundred thousand. There are two reasons this amplification is so large; one is the definition of power, and the other is, the sheer minuteness of the input signal compared to the output signal.

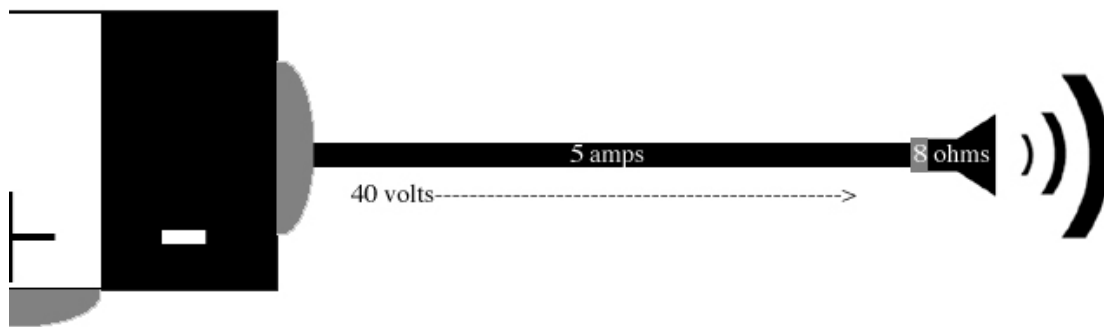
All signals have a voltage and current component, and by measuring an input signal, we might find a voltage of 1 volt and a current of 0.001 amps. The output signal in this example would be 40 volts with a current of 5 amps. The factors we multiplied the input signal by (40 and 5000) are the voltage amplification component and the current amplification component. When we multiply these two together we get power amplification.

This newly amplified signal, which is ideally an exact replica with bigger amplitude, is then checked for errors. This is done through negative feedback (nearly opposite of positive feedback). This process works to correct errors much as you would to keep your balance: by making small adjustments in the other direction of the error.

Now that you know what it does and a bit about how it works, we can look at the parts. There are two circuits in an amplifier: an input circuit, and an output circuit. The input circuit connects to an audio source and to the output circuit. The output circuit connects to a power supply and a speaker, and is modified by the input circuit. As we said earlier, the source signal can be very weak, so it sometimes needs to go through a pre amplifier (a smaller amplifier) before modifying the output circuit.



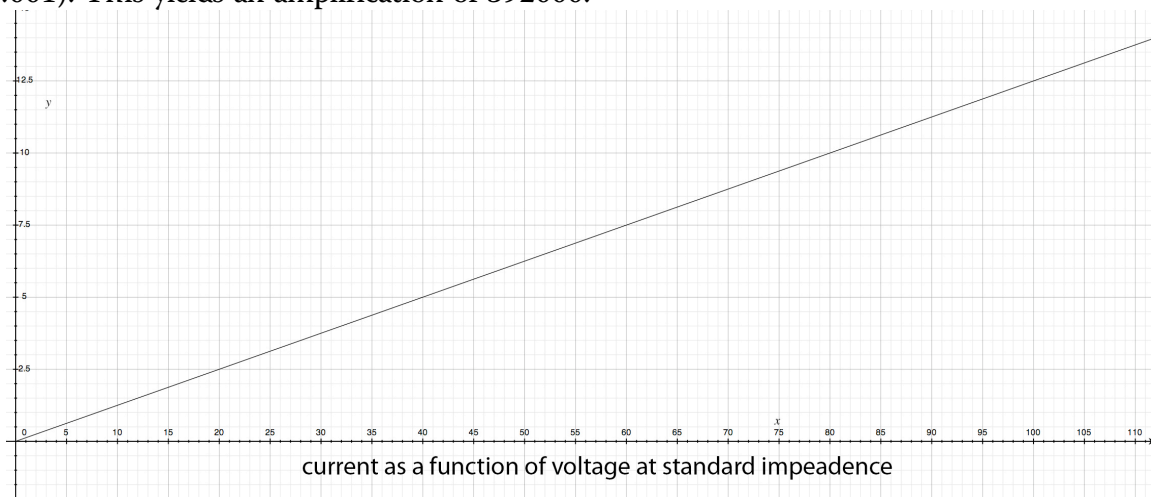
Modification of a larger signal by a smaller one is possible because of transistors and something called a *zone of depletion*. The zone of depletion naturally makes current flow difficult, but in the presence of an input current will make flow easier. As the input signal fluctuates, so will the output signal, and we get our amplified signal. This signal may be ready to go to the speakers or may go to another transistor as the input signal.



Using the example of the 40 volt 5 amp signal from earlier, we will look at the process of creating sound. By using the equation $V = I * R$ and manipulating it, we find that $\frac{V}{I} = R$ or $(\frac{40}{5} = 8)$. 8 Ohms also happens to be the typical resistance (or impedance) of a speaker. As the speaker moves to different frequencies, the resistance changes, and because the voltage cannot, the current has to. This is an inverse relationship. For an additional calculation of power rating, we can multiply the voltage by amperage, and in that particular situation, yielding 200 watts at 8 ohms.

Now, to recap what we have learned in this chapter lets work backwards. This time lets try a 392-watt sound system, at the standard 8 ohms. With some algebra, we can find an amperage of 7 and voltage of 56. If you compare the new example to the old, one you can see that as the impedance stays the same, both voltage and current go up. This is a direct relationship. If we go back even farther we know that an input signal would have a voltage of 1 volt, and a current of 0.001 amps so we can find the power increase by dividing the products of the output signal (7 and 56) by those of the input signal (1 and

.001). This yields an amplification of 392000.



Next are figures of merit, the quality by which a device, or in this case an amplifier, can be characterized for by a number of specifications for performance.

Gain is the ability of an amplifier to increase the magnitude of an input signal in terms of output/input magnitude gain ratio, symbolized by the letter “A”.

$$A_v = \frac{V_{\text{output}}}{V_{\text{input}}}$$

$$A_v = \frac{40V}{4v}$$

$$A_v = 10$$

For example, if an amplifier inputs a 4 volts RMS AC voltage and has an output of 40 volts RMS AC voltage, it has an AC voltage gain of 10. In addition, if we know the gain of an amplifier and the magnitude of the input signal, we can figure out what the magnitude of the output signal is.

If an amplifier which has an AC current gain of 4.5 is given an input signal of 20 mA RMS; the output will be 90 mA.

$$I_{\text{output}} = (A_i)(I_{\text{input}}) \quad I_{\text{output}} = (4.5)(20 \text{ mA}) \quad I_{\text{output}} = 90 \text{ mA}$$

The bandwidth is the width of frequency that the amplifier can most effectively amplify. It is the difference frequency limits of an amplifier and is measured in kilohertz, which equals 1000Hz, or 1000 periods per second.

$$BW = f_2 - f_1 \quad BW = 30 \text{ kHz} - 5 \text{ kHz} \quad BW = 25 \text{ kHz}$$

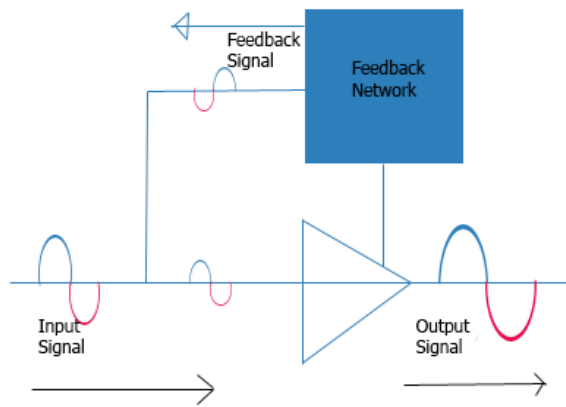
As an example, if the band of the frequency of the amplifier were between 5 kilohertz (kHz) to 30 kilohertz, then the bandwidth of the amplifier would be 25 kilohertz.

Efficiency is a measure of how much input power is usefully applied to the amplifier's output. The efficiency of an amplifier actually limits the amount of total output that is used. To show what this means, a Class-B amplifier, so it does not mean that the more efficient it is, the better the sound quality. The Class-A amplifiers, which is very inefficient and produces a lot of heat because of all the power wasted but usually provides a better sound quality. So a combination of two classes, like Class-AB amplifiers, which makes it so that it runs cooler because of better efficiency and has better sound quality.

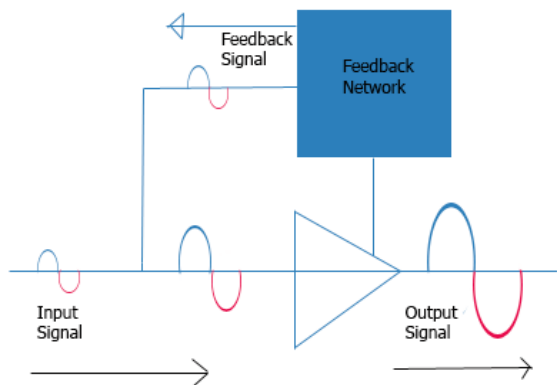
Impedance is the electrical characteristics of a speaker that impedes the flow of power from the receiver or amplifier. It means that impedance has a given amount of power flowing, and the receiver producing voltage and current. As the impedance grows and the voltage stays the same, the current drops and you get less power. To keep the power the same, the receiver has to provide more current. It means that lower impedance flow means it needs to have stronger amplifiers. However, if the impedance to the power is higher, the impedance to the voltage is also higher and pressure can build up which can make flow of current more difficult.

Feedback is the process of sending part of the output signal from an amplifier and back to the input of the amplifier. There are two types of feedback, positive feedback and negative feedback. The difference between the two is whether the feedback signal is in phase or out of phase with the output signal.

Linearity of an amplifier is the ability of an amplifier to deliver output power in exact, equal proportion to the input power.



The positive feedback signal will add to, or in other words, “regenerate”, the input signal. It results in a larger outcome of amplitude signals than normal and is the reason for the squealing, high pitch noise in from a speaker.



Negative feedback signal takes away from, or “degenerate”, the input signal. The result is a smaller than normal amplitude output signal

Chapter 13

SOUND RECORDING STUDIOS AND EQUIPMENT

Jesus Cisneros, Sara Brant

Recording studios are essential to an artist's successful career in the music industry. In the recording studio, an artist has the ability to record and produce music at a professional level. Recording studios are to be found anywhere, including apartment closets, basements, or even an abandoned church. When someone hears the word 'Recording Studio', many people associate it with a room full of high-end equipment used by hotshot producers in front of a large panel of keys. While most mainstream artists do use these elaborate recording studios, such music producing would not be possible if it weren't for certain pieces of equipment found in a recording studio. Mixing Consoles, Multi-track Recorders, Music Workstations, and the Digital Audio Workstations are all essential for any professional recording studio. The method in which a recording studio is designed - in terms of layout - is also just as important as any of the previously mentioned equipment.

All recording studios are designed with detail and precision. A few of the details that go into designing and constructing a recording studio include the use of sound foam to reduce echo, installing wooden floors to improve efficiency in transporting equipment as well as improving sound quality for certain instruments, and the placement speakers and monitors in the control room are at an certain angle and distance apart.

Figure 13.1



However, a studio is nothing without its equipment. The musical tools that can be found in the most well equipped studios are astounding in number. Many of these are incredibly expensive, incredibly specific pieces of equipment. However, a few pieces are considered the staples of a recording studio – they are, debatably, what defines a recording studio. Among these necessary pieces of equipment are: mixing consoles, the multi-track recorder, a music workstation, and the digital audio workstation.

The multi-track recorder does just as the name implies; records multiple tracks and combines them to make one full-length song. Without the multi-track recorder, a song would be much more difficult to edit because every track would be clumped together and little to no editing would be able to be done because of this. The

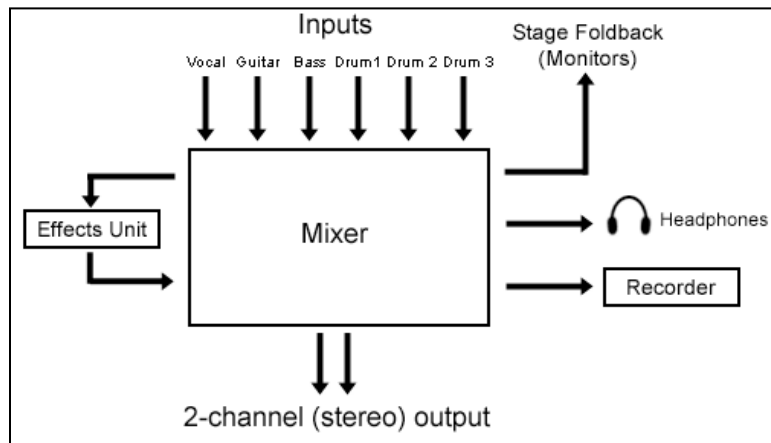
relationship between the mixer and the multi-track is a unique relationship that will be explained in better detail later in the chapter. *Figure 13. 2*

The music workstation is generally known by another term: the synthesizer. With the music workstation, synthetic effects can be added to a track to add a new set of effects. The keyboard helps add these synthesized effects and can be added onto a simple MP3 file. Similarly, the Digital Audio Workstation helps add effects and can help mix and play MP3s for DJ's to be able to play back for

parties or a radio station. Although not as complex and as capable as the mixer or multi-track recorder, DAW's are popular for their practicality mostly characterized by DJ's. Though all of the technological equipment compliments one another, no other two instruments such as the Mixing Console and Multi-track recorder compliment each other so well that they are, in true meaning, essential to the recording studio.

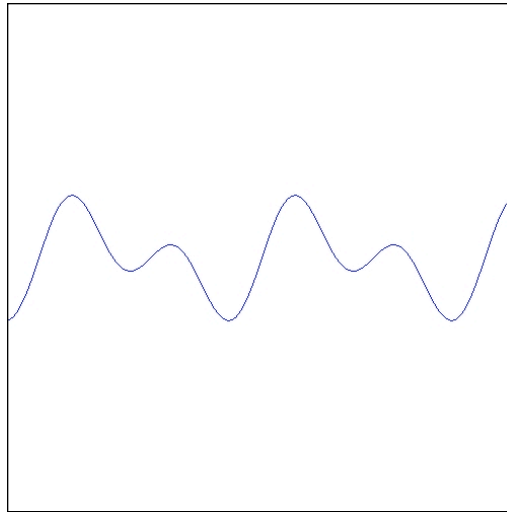
After all of the musical instruments are done recording, the tracks are sent to the mixers where one can edit, add effects, mix and blend, EQ and sound positioning, and route the tracks to multi-track recorders to put together a full-length song relationship is shown in Figure 13.2.

Before sending to multi-track recorders, one must be certain of the final edit because editing is limited within the multi-track recorder. When all of the recorded material for each instrument is complete, the multi-track recorder helps create a full-length song by putting each separate track together. Without the multi-track recorder, artists would have to play as a whole band in a recording studio and have to hit every note with as little mistakes as possible. One can imagine how tedious and difficult it must have been to edit each instrument individually. Figure 13.3 (shown below) depicts the sound waves of two instruments recorded at the same time:



The way this works is that all of the audio is brought into the mixer through inputs in which the mixer creates an output to send the tracks to the multi-track recorder.

Figure 13.3

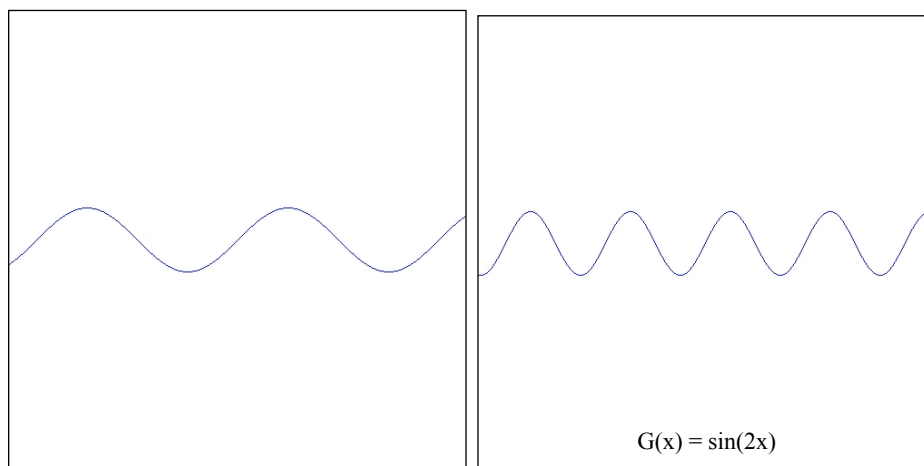


$$F(x) = \sin(x) + \sin(2x)$$

This function is comprised of two sin waves; it depicts how difficult it would be to edit or alter this sound wave when mixing and editing recorded music.

Thanks to the multi-track recorder, artists and recording producers can record separate instruments on separate occasions and be able to bring them together to make a full-length track. As one can imagine, the ability to re-record certain instruments gives room for errors and re-do's per instrument. The multi-track recorder's ability is presented in Figure 13.4.

Figure 13.4:



$$H(x) = \sin(x)$$

$$G(x) = \sin(2x)$$

(This function of a sin wave has a double frequency as the function of $H(x) = \sin(x)$; this makes the frequency quicker and higher)

As shown in Figure 13.4, the multi-track recorder splits the sound wave shown Figure 13.1 into two separate sound waves (each belonging to an instrument); as stated previously, the multi-track recorder gives musicians and music producers the ability to play and record instruments on separate occasions, thus giving being able to edit and mix each instrument individually.

Moving on to *Sound Effects*. Sound effects are utilized to emphasize action, suspense, humor, shock or specific effects in films, television shows, live performances, animation, video games, music, and other media. Sound effects are created in many different ways using environmental noises such as street noises, and an array of natural sounds such as ocean waves crashing on rocks, soothing calm waves, waterfalls, birds chirping, rainforests' noises, etc. A multifarious arrangement of sounds is manipulated with computers, mixers and synthesizers and mixing console to completely change the original note, melody and song to a unique sound effect.

Sound recordings and reproduction is the digital, electrical, or mechanical replication and re-creation of sound waves such as spoken voice, singers, instrumental music, or sound effects. The two main classes of sound recording technology are analog and digital recordings. Analog recording is achieved by using a microphone diaphragm that can detect changes in atmospheric pressure (acoustic sound waves) and record them on magnetic tape and vinyl records.

Figure 13.5



Figure 13.6



Figure 13.7

As you have already learned about the instruments and how frequency waves works from the previous chapters. These illustrations shown above are the frequency waves that are measured in the numbers of π . Π or the decimal notation is 3.14159 is the ratio of the circle. The difference between these frequency waves is the amount of speed of the sound waves traveling back and forth. In Fig. 13.5 (shown above), the range of the amplitude has a low frequency, in Fig. 13.6, is the medium frequency and Fig. 13.7 has a high frequency.



Electronically generated sound waves may also be recorded directly from devices such as an electric guitar pickup or a synthesizer, without the use of acoustics in the recording process this is known as digital recording where the sounds are recorded directly to digital media. **Equalizer (EQ)** is the process of using passive or active electronic elements to modify the frequency of the system. As you can see the image on the left, this is from the Audient ASP8024 Mixing console. The upper section has high and

low shelving EQ, the lower section has a set of measurable factors EQ.

Audio mixing is the process an audio engineer uses to achieve a balanced sound. Using their experience, equipment and techniques to balance the level of music in sound recordings. Audio editing is the manipulation of sound to take out, add to, or adjust the frequency of sound waves. Mixing can create many different sound effects from the original recording. Manipulation of the original sound can be done within various programs such as Garage Band and other software programs, ultimately combining different sound effects together to create a unique beat or a creative sound. These sounds can be customized and used in films or music or any other media use.

Sound studios are designed to absorb the sound in the room. This keeps the noises from bouncing off the walls and echoing in the room. Sound Proof walls are usually covered with foam or cork; both have very good sound absorption. The sound engineer can manipulate the sounds in many different ways such as removing unwanted sounds, adding new sounds, adjusting the pitch lower or higher and can completely change the finished product and effect, as you learned in the previous section.

Chapter 14

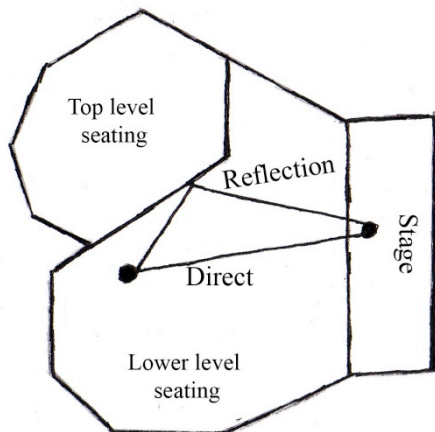
AUDITORY ACOUSTICS

Nicole Arenz, Alexis Barbieri

There are many different elements that help sound travels through an auditorium, as well as what designs work best for the sound to travel through. Clarity, loudness, background noise, refraction, reflection, and many other things all play a role in auditory acoustics.

In order to understand how sound works in an auditorium, you will need to understand the basics of how sound travels. As mentioned earlier in chapters 2 and 3, sound waves are created by the vibration of an object, which then causes the air to vibrate. Sound travels at an estimated 345 meters per second in the air. It takes 0.01 to 0.02 seconds for a sound wave to reach the listener anywhere in the room. An interesting fact about how sound travels is that sound waves travel the same through air as they do in water.

This shows reflection going back and forth from the stage to the

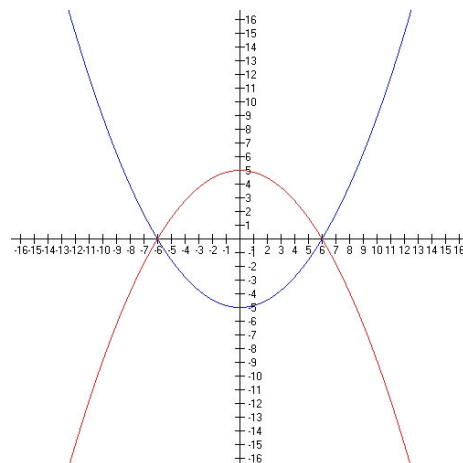


Refraction is the change in direction of a sound wave due to the change in its speed. Refraction happens most of the time when a sound wave passes from one medium to another. A medium is a substance that sound travels through. It is described by “Snell’s Law”, which states that the angle of incidence is related to the angle of refraction. The two equations for refraction are:

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{v_1}{v_2} = \frac{\eta_2}{\eta_1} \text{ and/or}$$

$$\eta_1 \sin \theta_1 = \eta_2 \sin \theta_2$$

In the two formulas above, v_1 and v_2 are the wave velocities through the respective media. Velocity is the distance travelled per unit time. θ_1 and θ_2 are the angles between the normal plane and the incident waves. n_1 and n_2 are the refractive indices. A refractive index of a medium measures how much speed of light is reduced inside the medium.



Reflection is the experience of a traveling sound wave being thrown back from a surface. The amount of reflection is dependent upon the difference of the two mediums. Reflected waves can interfere with incident waves, producing patterns of constructive and destructive interference. An example of reflection would be that echoes are the sound of your own voice reflecting back to your ears.

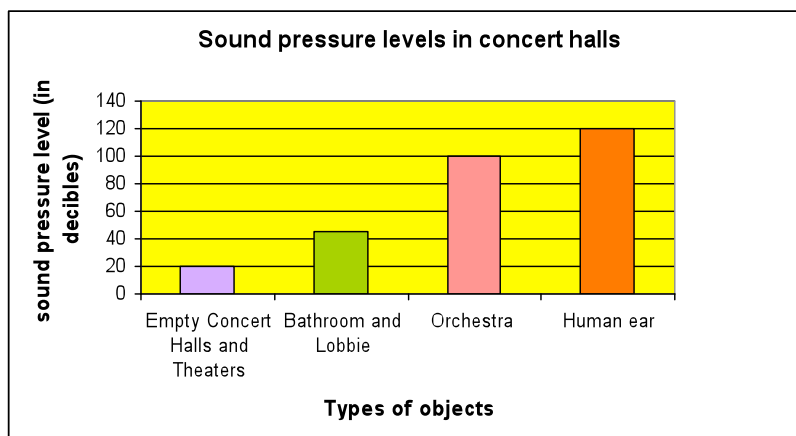
Having great auditory acoustics is important when building concert halls. That is why architects need to keep clarity, intimacy, spaciousness, background noise, and warmth and brilliance in mind when building them.

If you are in a hall that echoes a lot, the clarity level is too high. Clarity shows how clear the sound quality is in the room. “Early sound” occurs when the sound arrives to the listener within 80 milliseconds from the source of the sound. The logarithmic ratio of early sound is:

For this equation, C80 is the clarity index, which is best recommended value for any hall, 80 is the early sound, which arrives to the listener at 80 milliseconds and ms stands for milliseconds. Remember C80 is measured in dB (decibels).

$$C_{80} = 10 \log \frac{E_0 - 80ms}{E_{80} - \infty ms}$$

The audience needs to be able to hear the music but with comfort. Loudness is very important because it could affect the sound of other acoustics qualities and as well as make people feel uncomfortable. Loudness can be measured by the strength factor, G in decibels.



This graph illustrates that loudness is important because if any of the objects in a concert hall exceeds 120 dB it will be painful for the audience.

$$G = SPL_{hall} - SPL_{f req 10m}$$

In this equation, G is the strength factor, 10m is how far away you should be from the source of the music and SPL stands for sound pressure level. Remember G is different for each frequency and describes the loudness of the hall.

How to calculate loudness in a concert hall:

20 dB is the sound pressure of an empty concert hall

30 dB is the sound pressure of a calm room (in a house)

-10 dB is the loudness of the concert hall. If you're

wondering why we got a negative 10 it's because all low sounds (under the hearing threshold which is 120 dB) have a negative value

$$G = SPL_{hall} - SPL_{free}$$

$$G = 20\text{dB} - 30\text{dB}$$

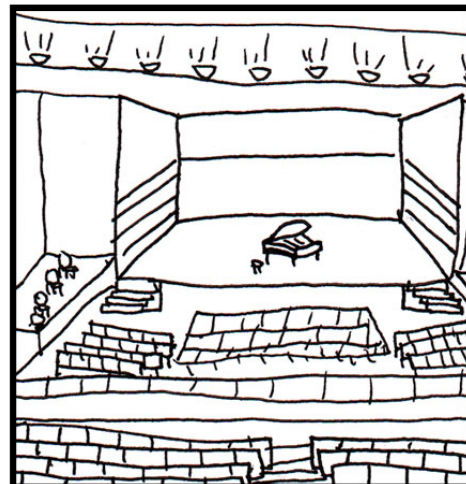
$$G = -10\text{dB}$$

Intimacy refers to the feeling of being close to the source of the music. Smaller halls have surfaces with shorter distances so reflections can happen more frequently. They want this because the sound would have a shorter initial time-delay gap.

Spaciousness shows the listener's feeling of being evolved in the music. There are two aspects of spaciousness. Auditory Source Width (ASW) describes how large and wide the sound source appears to the listener. Listener envelopment (LE) addresses how the listener feels surrounded by the music.

Background noise is a background sound that could be heard in the room. Examples of this are the air-conditioning system, vents, or outside noises. You could prevent this by using low air velocities or having a well balanced duct design with that being said you could have smooth transitions between ducts.

Warmth and brilliance describes as the smoothness of the music. To find the warmth and brilliance you need to balance the ratio of the low frequency reverberation time (RT) to high frequency (RT). The equation to measure warmth is:



$$BR = \frac{RT_{125Hz} + RT_{250Hz}}{RT_{500Hz} + RT_{1000Hz}}$$
 In this equation, BR is the bass ratio. RT is the reverberation time. RT in the numerator usually has an average measure in 125 Hz and 250 Hz octave bands. RT in the denominator usually has an average measured in 500 Hz and 1000 Hz octave bands.

Designing concert halls isn't easy work. Architects need to consider many things when building them. They need to look at the size of the hall, the wooden panel walls, even the marble floor. In a recent study, people preferred the sound of long narrow halls then larger halls. The differences in narrow and wide halls are in narrow halls the first sound you hear is the sound directly coming from the stage and the sound wave is being reflected from the nearest surface next to you and is also being reflected off the walls. In a wider hall, the first sound you hear is the sound being reflected off the ceiling, which produces similar signals to both your ears. In narrow halls, since the first sound reflection arrives from the left and right walls, the sound from your left and right ears differs slightly, because the consent is different for each sound wave.

The walls of concert halls are very important; they need to use specific materials such of wood. Wooden walls do not work well in concert halls because they reflect the sound waves too much and it causes them to bounce around the room. This creates an intense acoustics environment. In an auditorium, the ceilings are usually angled and have hard surfaces so that the sound reflects back to the stage properly. The sidewalls in the front of the room are hard surfaced, and the rear walls have special materials that absorb the sound waves. This is important because sound waves are not supposed to reflect back to your ears.

In summation, there many different elements that goes into auditory acoustics. You have learned that refraction, reflection, clarity, loudness, background noise, and intimacy are all very important things to keep in mind when talking about how sound travels through an auditorium. You have also learned that there are equations for auditory acoustics such as the clarity equation, the loudness equation, the warmth and brilliance equation, and the refraction equation. All of these equations and elements take part in the concert hall design, so that the sound travels perfectly to the audience's ear.

Chapter 15

DOPPLER EFFECT

Kelvin To, Lyric Tully

In 1842, Austrian mathematician and physicist Christian Doppler hypothesized that the wavelength and frequency of sound would change if the source of the sound were moving, relative to the position of the observer.

That same year, Buys Ballot tested for sound waves and the results were conclusive. Later, a man by the name of Hippolyte Fizeau discovered that Electromagnetic waves have the same characteristics regarding the Doppler effect.

Although it was originally created to test for sound, the Doppler effect can be adapted to solve for many problems. One of these adaptations is used when looking at the light spectrum. Utilizing techniques similar to those used for sound, it is possible to solve for light. The main difference between solving for light vs. sound would be that light does not have a medium. On the visible color spectrum, we have red on one side and violet on the other. Therefore, the term “red and blue” shift is not entirely accurate. When light is being emitted in front of a moving object the wavelength shortens resulting in a blue or violet shift, displayed in the graph to the right. On the other end of the moving object, the wavelengths are longer due to the speed of the source, which results in red.

Yet another use for the Doppler effect is in astronomy. Have you ever wondered how astronomers can calculate the speed of a planet we cannot even reach? This is done using the same techniques discovered by Christian Doppler. Once adapted, the calculations can be made. As stated before, the Doppler effect can be used to measure the light waves being emitted from a source. In this case, that source is a planet millions of miles away. In order to be able to solve for different elements regarding the Doppler effect, there are certain equations with which one must familiarize themselves. The key terms and equation



The comets represent sources of light coming from space. As the comet on the left approaches it emits a blue wave and as the right leaves it emits a red wavelength

Key Terms

F_o : frequency observed

F : emitted frequency

V : velocity of sound

V_t : Velocity of source toward you

$V > V_t$: If the speed of the source were equal to the speed of sound, you would be dividing by 0, which is impossible.

sets are essential to understand the remainder of this chapter. If necessary, revisit these charts until the concept is grasped.

The following equations explain how to calculate for the sound velocity, sound frequency, and wave velocity, in front and behind a moving vehicle or object of your choice that emits sound. What should be taken into account is that when calculating this type of problem, it is usually implying that the observer is standing in place, unless stated otherwise.

Equation Set 1

Source in motion approaching. Assuming that it is directly in front of you

In front of a moving source

$$\lambda_f = \frac{v - u_s}{f_o}$$

Wave Velocity

$$v = \lambda_f f_o + u_s$$

Sound Velocity

$$u_s = v - \lambda_f f_o$$

Sound Frequency

$$f_o = \frac{v - u_s}{\lambda_f}$$

Equations Set 2

Source behind a moving object. A car moving away from you, assuming that the car is moving in a straight line.

Wavelength behind

$$\lambda_o = \frac{v + u_s}{f_o}$$

Wave velocity

$$v = \lambda_o f_o - u_s$$

Sound Velocity

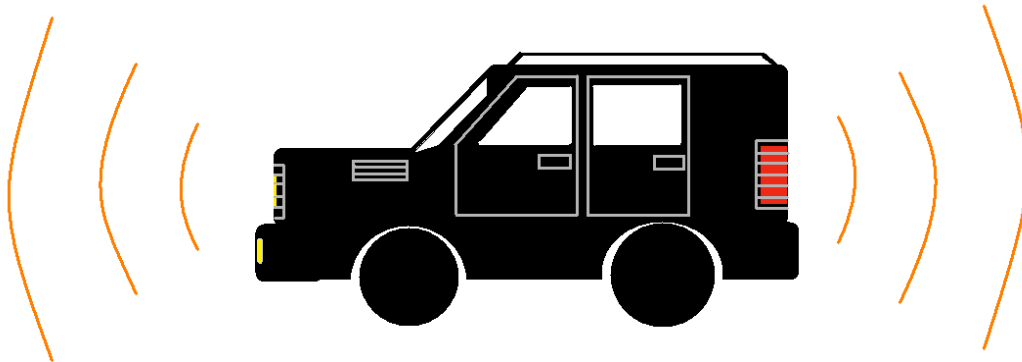
$$u_s = \lambda_o f_o - v$$

Sound frequency

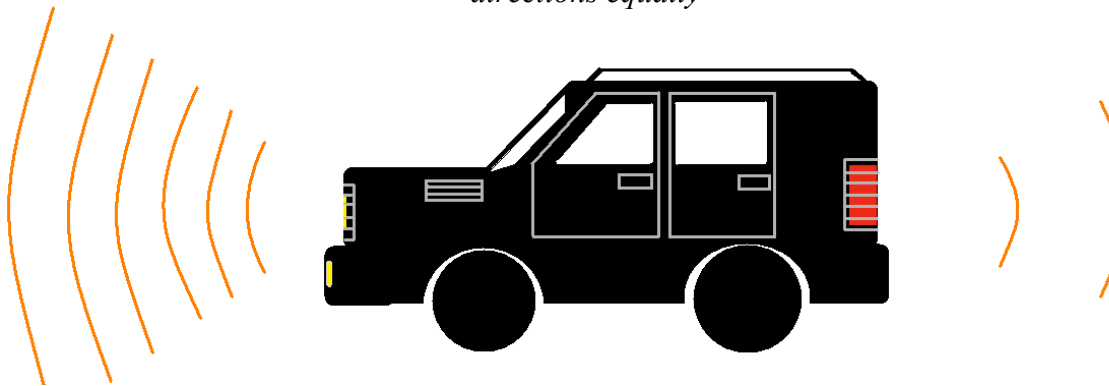
$$f_o = \frac{v + u_s}{\lambda_o}$$

We'll start with a real world example. Have you ever noticed that when an ambulance speeds by, the sound you hear seems to vary? That is due to the very principle we are studying here. Assuming that you are sitting in a car as the ambulance approaches you will note that the ambulance seems to get louder and louder, when in reality, the man in the ambulance isn't turning up the volume in the car just to confuse you. The change in sound you hear is due to your exact position from the ambulance and the speed at which the ambulance is traveling. It also depends on the amount of Hertz at which the siren is being blasted. As the ambulance approaches you, it is in a figure of speech pushing the sound waves closer together. Creating a shorter wavelength and a higher frequency. The opposite functions very similarly. As the ambulance hurries off to save a life, the sound of its siren seems to dissipate into the city buzz. Some of it is due to the drowning effect of the ambience but this is mostly due to the increase of size in the wavelengths and decrease in frequency.

Let's put it in an easy visualization. Suppose we attach a slinky to the bumper of our car and attach the other end to a stationary object. As we drive away, the slinky will expand and the loops will become long. That is exactly how the sound waves would look like. The following are examples of what these changes in wavelength and frequency look like.



STATIONARY
*Sound emitted
travels in all
directions equally*



MOVING FORWARD
*Sound in front of the vehicle
emitted at a higher
frequency*

Now that we have introduced you to these new equations, let's pull together all the information you have learned from this chapter and some of the previous ones to solve an equation.

Conversions

Example problem: If a vehicle is coming towards you at 69 km/hr (43 miles per hour) and sounds its horn that blares at 8500 Hz. What is the frequency of the sound you hear when the speed of sound is 340 m/s (1115 ft/s)?

V = Wave velocity -
Meter/second

U_s = Source velocity -
Meter/second

F_o = Source frequency -
Meter/second

Symbols & Definitions:

f_o : observed frequency

f : emitted frequency

V : velocity of sound

V_t : velocity of source toward

$V > V_t$: If the speed of the source were equal to the speed of sound, you would be dividing by 0, which is impossible.

λ : observed wavelength

λ^o : emitted wavelength

Step 1: Givens

69 Km/hr (43 mph)

8500 Hz

340 m/s (1115 ft/s)

Step 2: Conversions

Kilometers/hour $\rightarrow$ Meters/Sec

69 Km/hr $\rightarrow$ 69000 m/hr

69,000 m/hr = 69,000/3,600

Step 3: Calculate

$$f_o = \frac{fv}{(v - vt)} = \frac{8,000 * 340}{(340 - 19.16)}$$

$$f_o = 8,477.74 \text{ Hz}$$

The Doppler effect was an important discovery in the history of science and physics. It helped launch new studies into the stars and to further understand sound relative to position.

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