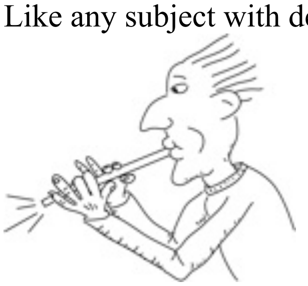
Physical Science 20 – Music Monday

The Science of Sound

The following material has been acquired from:
http://www.bashthetrash.com/Instruments_Intro/How_Instruments_Work_-_In_Depth.html

Saskatchewan Physical Science Curriculum outcomes applicable to the below lesson:
Properties of Waves
PS20-PW1 Investigate the properties and characteristics of one-, two-, and three-dimensional waves (e.g. mechanical, sound, and light) in at least three different media (e.g., springs, ropes, air, and water).

Lesson Content:
Like any subject with depth, acoustics (the scie

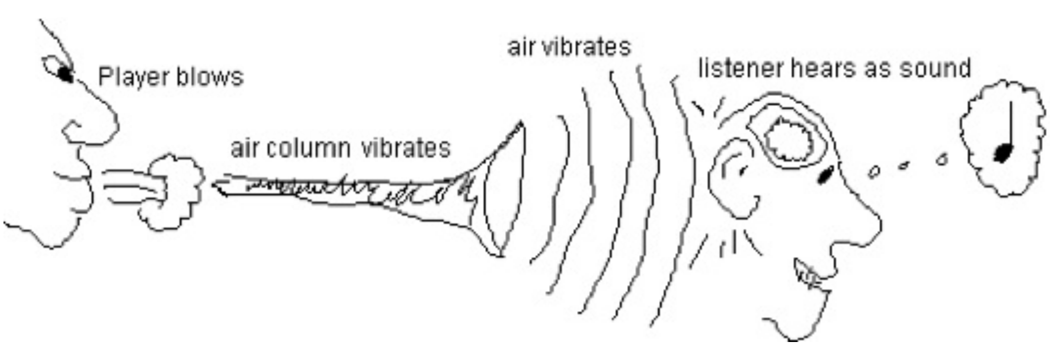


nce of sound) and organology (the science of musical instruments) get more complicated the deeper you go into them. In this section we're going to take a fairly superficial look at all the various systems involved to making, playing and hearing musical instruments.

We'll start with the **sequence of a sound**, then examine the role of **sound waves**, the different **types of musical instruments**, and then take a look at how to affect **pitch** and **volume** through instrument design.

The Sequence of a Sound

It is best to think about sound as having three distinct systems:
1. •the thing making a sound
2. •the medium through which the sound is transmitted to the listener (like the air)
3. •and the complex hearing apparatus (ears and brain) of the listener

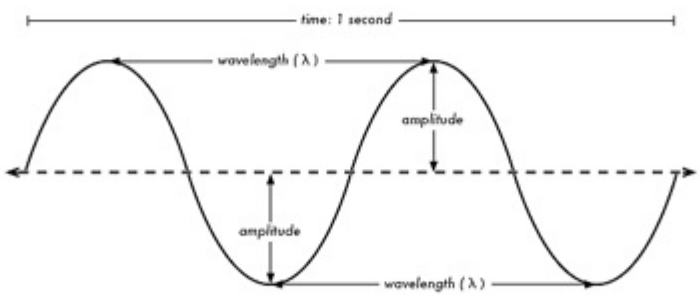


What seems like a nearly instantaneous sound – such as that of a musical instrument - actually has several cascading events, as shown in the illustration above.

1. •First, something must cause the vibration – the flutist blows, the violinist bows, the drummer hits his stick, etc. This is the "attack".
2. •The energy of the attack causes something to vibrate (air column, string, drum head, etc.). The sound can be a single attack like a drum hit, or long like a held note from a singer ("sustain").
3. •The medium (usually air or water) around the vibrating object vibrates in sympathy, causing waves of energy to travel through the surrounding molecules. These waves (decreasing in energy as they move through the medium – the "decay") travel the distance between the sound source and the listener and enter the ears.
4. •a series of sensitive and complex bio-mechanical devices in the ears converts the information into the chemical and electrical signals that the brain interprets as sound.

Waves

When something vibrates, anything that is in contact with that thing (such as molecules of air, water, wood, etc.) vibrate as well, creating something called "mechanical waves" (as opposed to "electromagnetic waves", such as radio waves, infrared waves, and microwaves, etc.).

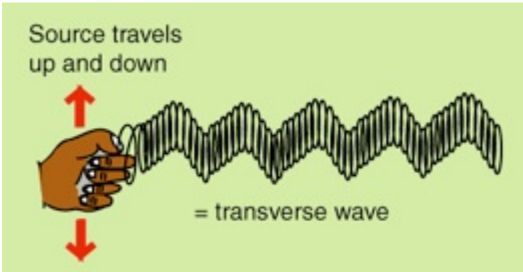


All mechanical waves have two components, the speed of the wave (frequency) and the amount of energy contained by the wave (amplitude).

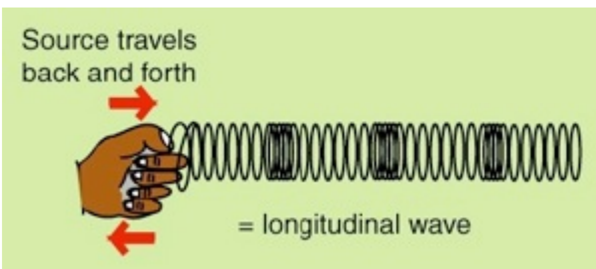
Frequency: Since most vibrations are not a single pulse of energy but rather a repeating series of pulses, these vibrations can be said to have a certain frequency – that is, the number of times per second that that thing vibrates. In a sound wave, the frequency of the vibrations determines the pitch – faster waves (higher frequency) produce high pitch; slower waves (lower frequency) produce low pitch. If you have ever daydreamed while driving on the interstate and run into those wake-up grooves along the side of the highway, you will notice that the faster you are driving the higher the perceived pitch of the grooves and vice versa.

Amplitude: The more energy put into the initial vibration, the more violent the resulting waves. This is true of tsunamis as well as sound waves. To make a louder sound, you generally strike, bow, or blow the instrument harder, although physical instrument design can also affect the volume of an instrument, as we'll see later.

It is a common misconception to think of sound waves as taking the same shape of the up-and-down water waves (which are called transverse waves), but in fact the individual molecules of the medium "accordion" back and forth, not bob up and down. This kind of wave is called a longitudinal or compression wave.



The two kinds of waves are easy to see by using a Slinky toy. Take a slinky and have someone hold the other end. Pull it reasonably tight, then shake your end up and down and you have transverse waves.



To see longitudinal waves, stretch the slinky tight again, pull a portion toward you slightly, then release. This will cause a ripple of movement to go toward the other end - a longitudinal wave. Once the ripple reaches the other end it may even bounce back toward you again, which is exactly what happens with sound waves when you hear an echo.

Types of Musical Instruments

The classification of musical instruments has always been a knotty issue. The ancient Chinese placed their instruments in eight groups depending on the material they were built from: skin, gourd, bamboo, wood, silk, earth/clay, metal and stone. Another ancient system from India, dating around the 1st century BCE, classified instruments by what is vibrating: strings, air, metal/wood, and skins (drum heads).

Western orchestral instruments were traditionally divided into the four instrument families still used today: Percussion, strings, brass, and woodwinds (although some instruments such as piano and the medieval Serpent – a lip-buzzed instrument with tone holes – were somewhat problematic).

But by the late 19th century organology (the study of musical instruments) needed a more specific classification system to deal with the discovery of increasing number of instruments from non-European cultures that did not fall neatly into the orchestral families. In 1888 the Belgian Victor-Charles Mahillon adopted a system quite similar to the ancient Indian system, by classifying instruments by what is vibrating. This idea was refined later by Erich von Hornbostel and Curt Sachs, and is now known as the Sachs-Hornbostel system.

The Sachs-Hornbostel system classified instrument in four main groups (later adding a fifth with the introduction of electronic instruments such as the theremin).

1. Idiophones – where the entire instrument vibrates (such as a xylophone bar, maracas, cymbals, etc.)
2. Membranophones – which produce sound by vibrating membranes (drums, kazoos)
3. Chordophones – vibrating strings
4. Aerophones – where air vibrates - horns, flutes, reeds, and some others
5. Electrophones – vibrations produced by electronic means

For a full listing of the Sach-Hornbostel instrument classifications click here:

For the purposes of making better instruments it is vital to know which kind of musical instrument you are building. As you build your instruments always keep in mind what is it that is vibrating - that will tell you which group your instrument falls in, and thus makes it easier to create new instrument designs and predict how they will sound.

Let's recap:

1. Something initiates the sound (the player hits the drum; bows the violin; blows the trumpet)

2. The energy of the initiation makes something vibrate on the instrument (the drumhead vibrates; the violin string vibrates; the air column inside the trumpet vibrates)
3. The vibrations from the instrument cause the air (or other medium) around it to vibrate
4. The vibrations wash across the listener's ear; various mechanisms in the ear translate the information to the brain, which interprets it as sound

For the instrument builder the most important thing is the second bullet point – the "something" vibrating on the instrument. Here the construction of a musical instrument can dramatically affect the way that instrument sounds.

As instrument builders, there are several things we must pay attention to:

1. How is the instrument activated? (struck, scraped, shaken, bowed, plucked, blown, etc.)
2. What is it that vibrates? (drum head, string, air column, etc.)
3. How can we get the sound louder by changing the instrument design?
4. How can we get different pitches by changing the instrument design?

Getting it louder

There are several strategies for making instruments louder (other than hitting harder, blowing harder, etc.):

2. general resonators – a mass of stuff that vibrates along with the material that originates the sound. Usually a thin-walled flexible dense material with air on both sides (like the box of a guitar or violin).
3.
4. specific resonators – containers of air that vibrate in sympathy with a specific pitch – think of the tubes of various lengths

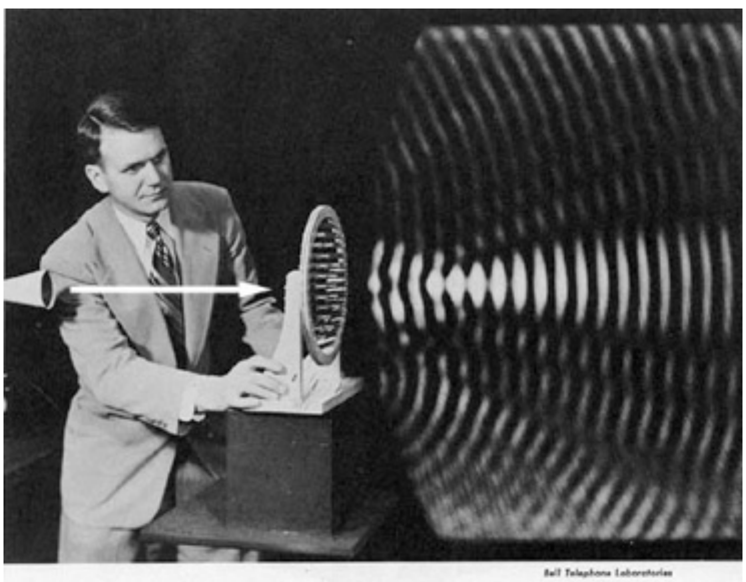
underneath a xylophone. Some string instruments have a set of "sympathetic strings" that are never physically played but only vibrate in sympathy with the played strings thus reinforcing the sound.

5.
6.
7.
8. Put a cone or funnel at the end (horns and reeds - no flutes - and

some others)

Getting Different Pitches

Frequency
Vibrations are contagious, i.e., when something is vibrating, whatever comes into contact with it will tend to start vibrating as well. For example, when our guitar string vibrates, the air that surrounds it will also start to vibrate. To be more specific, each time that the guitar string travels upwards, it compresses the air molecules into a slight "thickening" of molecules called a "wave front."



Each time the guitar string oscillates, it creates another wave front. This series of wave fronts travels through the air eventually hitting the complex apparatus that is the human ear. The number of waves that hits the human ear in a given period (which is variously called frequency, cycles per second [cps] or hertz) determines whether we perceive the pitch as high or low. The fewer cps, the lower the pitch and vice versa.

Humans can hear pitches down to about 16 - 20 cps – what we would perceive as a low rumble. The upper range of human hearing is about 20,000 cps – which if you're lucky you may have heard the last time you had your ears tested.

Instrument Pitches

Instruments can be made to sound different pitches (high and low) by three main strategies (and a few minor ones). Here are the main strategies:

1. Make the thing that vibrates bigger/small or longer/short - fingerholes on a flute; a slide on a trombone; different size keys on a xylophone; strings on a piano; putting fingers down on a violin string
2. Tighter and Looser (tension) - tightening or loosening the string on a guitar, or pushing on a drumhead while playing it
3. Density - The harder a material is, the higher it sounds. For example, with equal sized blocks of oak (hardwood) and maple (softwood) the denser oak would sound higher

Overblowing, the Harmonic Series, and Partials

With certain long and narrow lengths of tubing one can get different pitches just by blowing harder or softer and simultaneously changing the tightness of your lips. This is similar to someone playing "Reveille" on a bugle (which, unlike a trumpet, has no valves to change the length of the tubing). You can also get a similar effect by blowing harder or softer through a length of corrugated tubing such as a sports-bottle straw.

This works because of the nature of a vibrating object. When something vibrates - such as an air column (or a string, or a metal bar, etc.) - it creates not a single pitch but an entire series of pitches that sound together (called the "Harmonic Series"). This is because the entire length of the vibrating thing creates a certain pitch, while a third of the object is also simultaneously vibrating and creating a different pitch, and a fifth of the object is vibrating and creating a different pitch, etc. In reality, the whole thing is vibrating at almost any given point (with two exceptions that we'll get to later), but because of the patterns of vibrations certain areas give off more energy than others. These are the areas that help to define (more or less) the intervals of some musical scales – octaves, seconds, thirds, fourths, and fifths.

Each of these portions of the thing vibrating (called "partials") creates a separate and predictable pitch. It is hard for us to hear these pitches distinctly since the vibration of the entire object has by far the greater amount of energy and thus is loudest (creating a tone called the "fundamental"). But the presence of those partials makes the sound of musical instruments warm and rich and complex, as opposed to the thin and cheesy sound of early electronic synthesizers that did not replicate those harmonic overtones.

Going back to our air column - when you are blowing a tube of a certain length, the tube "wants" to create a certain note – the fundamental for that particular amount of air enclosed by the tube. When you blow harder, the pitch doesn't slide up to the next note in the series, it just jumps there abruptly. This is akin to your automatic shift car shifting gears as you press the accelerator. The gears don't "slide," but shift abruptly to the next level.

One way to demonstrate the overtone series is to take a metal pipe about 3 feet long and hold it vertically between thumb and forefinger at the halfway point while striking it with the broomstick mallet. The pitch that you hear is the sound of half the pipe vibrating. Let the pipe slowly slip through your fingers while striking it repeatedly. At every point you will hear a different tone – some higher, some lower. At a certain point as you begin to approach the end of the pipe (about a fifth of way down), you will hear a pure and low pitch – this is the lowest pitch that this pipe can make, called the "fundamental". You are able to hear this while holding the pipe because you are holding the pipe at the point where it is vibrating the least – this point is called the "node." A bar of a xylophone, for example, is attached to the frame of the instrument at the two nodal points of the bar of wood. This allows it to vibrate and still be attached.

Whew! Well, there's a lot more about musical instruments online and in print. If you survived the above and want more (you masochist, you) try these books:

Fundamentals of Musical Acoustics by Arthur H. Benade, 1976 by Dover Publications, Inc., New York
Musical Instrument Design by Bart Hopkin, 1996 by See Sharp Press, Tucson Arizona

Okay, let's go build some instruments!

©2013 Bash the Trash® Environmental Arts LLC
All rights reserved
"Bash the Trash" and the musical garbage can are registered trademarks
bashthetrash@mac.com