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Title: Waves, Sound and Energy

Synopsis

Through a series of activities and demonstrations with simple household objects and musical instruments, participants will learn that waves transfer energy, how the parts of a wave affect our perception of the wave, and what sorts of things can carry waves. Waves as phenomena that occur in music and sound will be the main focus.

Audience

Middle school through adult.

For presenting to younger children, it would be best to focus only on the motions of transverse waves and observational examinations of how musical instrument size relates to pitch.

When presenting to adults, one can add in more information about transverse vs. longitudinal (pressure) waves and how they relate to horn instruments. One can also talk about how the velocity of the wave on the strings varies with the tension and mass density of the string.

Learning Goals

- Understand the difference between particles and waves
- Learn the common occurrences of waves in our everyday life:
    - Sound
    - Light
    - Water
    - Traffic
- Learn the basic features of a wave - wavelength, crest, trough, and frequency
- Understand why waves are important and how we use our knowledge of waves
- Musical instruments, tuning, music theory, invention
- Electromagnetic spectrum: WiFi, microwaves, x-rays, infrared (remote controls, night vision, cameras)

- Experiment with musical instruments and making waves with slinkies
- Waves vs. particles, transmitting energy
- Sound
- Graphs and functions
- Effect of materials on sound quality and type

Materials

- Long slinky/spring with bell
- Straws + scissors
- Stringed instrument (e.g. guitar, 5-string banjo, etc.)
- Wind instrument (e.g. clarinet (do not share reed instruments), tin whistle, recorder, etc.)
- Alcohol/sanitizing wipes - for sanitizing the whistle
- Apps
    - FrequenSee (Android) - graph of amplitude as a function of frequency
    - Piano Tuner (iOS) - tunes to a given note and displays frequency in Hz
- Poster board with graphics:
    - Electromagnetic spectrum
    - Plane and shockwave
    - X-ray machine
    - Noise canceling headphones
    - Diagrams of amplitude, frequency, wavelength
    - Pictures of instruments: tuba, trombone, clarinet, piccolo, baritone sax, piano, guitar, sitar, etc
    - Chart showing frequencies matched with notes
- Laptop for showing shock wave video (optional)

Preparation and Set-up

The activity will be supported by a tri-fold poster board with a variety of pictures of wave phenomena to help illustrate the concepts. See above for a list of suggestions.

To prepare, instruments should be tested to be in working condition. It is not necessary for the instruments to be tuned; during the demonstration, though, one could tune them and compare to the tuning app to illustrate frequency.

Guiding Questions

Prior knowledge

- Can you think of some examples of waves?
- What would you say characterizes a wave? How do waves behave?
- Do you play an instrument or sing? Have you ever had to “tune” as part of this activity?
- Have you heard of a harmonic, or “overtones”?

Engaging

- Do you like music?
- Would you like to make your own kazoo or simple lute?
- Want to try and use these slinkies to make standing waves? We can even make harmonics!
- Come and learn about the science of music!

Encouraging discussion and engaging in scientific reasoning

- When fans at a sports game do a wave in the stadium, how do the people move? How does the wave move?
- Do you think high frequency corresponds to high pitch, or low pitch, and why?
- (Looking at graphs) On this graph of a sound wave, which parts do you think represent the volume?
- What is the relation between horn length and pitch? Why do you think certain instruments, like tubas and trombones, look really complex, with lots of twists and turns in the tube?
- What’s the highest -pitched instrument you can think of?
- What do you think is going on with your vocal chords when you make a high-pitched shriek? How about when you grumble really low?

- What are some ways we can change the pitch of a horn without changing its length?
- Horn players actually CAN change the length of their instrument to adjust its pitch when tuning. What happens when I pull the barrel of the clarinet further out?
- How do you think the thickness of a string on a stringed instrument is related to its pitch/note?
- What happens if I make the string tighter? Will the pitch go up or down?

Checking for understanding

- What represents volume on the graph of a wave?
- What would various sounds look like when drawn?
- Are shorter horns generally higher pitched or lower pitched than longer horns?
- Check out these invented instruments (reference pictures on poster board). How do you think each one is played? How are they using the relationship between wavelength and frequency that we talked about?

Activity Description

It might be helpful to alert the visitors to the types of activities that exist and let them choose what they would like to interact with.

Types of waves

- Make a conga line or stadium wave if there are enough people
- Use a slinky to demonstrate a transverse wave and energy
- Demonstrate a longitudinal (pressure) wave by moving back and forth in a straight line or by talking about a tug--of--war and how the tuggers sometimes run into each other when being pulled over, or spread out when trying to pull

Sound

- Discuss features of a wave and ask guests to match them to the characteristics of sound they're familiar with like volume, pitch
- Discuss sound as a pressure wave of air: vibrations of air molecules interact with our eardrum
- Waves in a horn
    - Half a wavelength at fundamental frequency all fingers down

    - More wavelengths at other frequency - some fingers down - air escapes out the free holes; it has a shorter path
    - Length of tube determines the length of ½ wavelength - this is related to the air pressure at different points in tube
- Waves on strings
    - The vibration of string makes a wave shape
    - Changing the string length - the points where ends are fixed - to make a “shorter” string and therefore a higher sound
    - Role of thickness in pitch (Can be hard to explain without going into a bit of math-- best to restrict to older kids and adults)
    - Role of sounding box in amplifying sound and giving it timbre

Tuning

- Changing tension of string
- Lengthening or shortening horn
- Changing embouchure (mouth position)
- Matching sound to known pitch using technology
- Octaves are harmonics; frequencies are multiples of the fundamental frequency

Shock waves

- Create a massive amount of pressure in air
- Plane moves faster than its own sound - similar to lightning

Activities

- Cut simple kazoos for visitors using straws and scissors (cut one end of straw into a point). What happens if we cut the other end of the straw shorter? (Do this while they play the straw. Kids find it hilarious.)
- Let visitors try the tin whistle. Clean with alcohol wipes in between uses!
- Let visitors try the guitar.
- Work with a visitor to make a standing wave on the slinky. Try to get the 2nd and 3rd harmonics.

Teaching Strategies

It's easy to hit the "Engage" metric with this activity, as most people enjoy music and many will also play an instrument, have done so in the past or like to sing. Unless the visitors have studied physics, they may not know the science behind the frets on a guitar or the holes on a wind instrument. Querying visitors to learn their past experience with music is important.

Exploration occurs by prompting the visitors to think about what makes instruments sound different from each other and how the length of the string or horn is related to the sound. Instead of explaining the relation, have the visitors try various instruments and try to notice a pattern between what they are doing to the instrument and what sound is coming out. To make the relationship super clear, visitors can make their own wind instrument with straws, which can then be shortened just by cutting them down. This process also falls under the Express/Elaborate section, where students get to conduct activities to explore the topic at hand.

Evaluation is difficult in this activity since we avoid discussing the math too much. One way to check for visitor understanding is to ask them to observe some of the images on the poster board of other instruments and make predictions/observations about how each one sounds and how it is related to its shape, strings, method of playing and so forth. This is especially fun to do with pictures of invented instruments that we haven't necessarily seen before. Prompting the visitors to explore more at home the next time they listen to music or play music is a good tactic. In general, if visitors begin to understand the relationship between string length/horn length and pitch, and which waves carry more energy than others, the presentation may be considered successful.

As with many outreach activities, the best way to get visitors to interact well with the presentation is to get them talking. You don't have to have all the answers just because you're the resident scientist! Make sure to ask them questions about their experience with music and sound. Get them to predict what will happen when instruments are played a certain way, and then let them try it on the instrument. Make sure to include instruments that the visitors can touch and play themselves. It can become very "lecture-y" if visitors are not allowed to touch the instruments (for instance, not being able to play the clarinet). Having a non-reed instrument and strings helps this.

Vocabulary

- *Wavelength* - the length/distance it takes for a complete wave cycle, i.e. one crest and one trough together. On a string, the fundamental (lowest frequency) will occur when the wavelength is 2*length of string. This means the string only has one crest or one trough at a time, like a jump rope.
- *Frequency* - roughly, number of vibrations for second. Obtained mathematically by dividing the speed of sound in the medium by the wavelength. (Note: speed of sound in air is NOT the same as speed the string is vibrating at)
- *Amplitude* - the absolute value of the maximum vertical displacement of the wave. How far the crest or trough goes from equilibrium.
- *Crest* - Upward bump on a transverse wave.
- *Trough* - Downward bump on a transverse wave.
- *Phase shift* - When the crest of one wave is in the same location as the trough of another. They will cancel out and the net result is 0.
- *Velocity* - For the purposes of the demo, it's the same as speed. Velocity officially is a vector, which means it not only has a value (like 40 mph) but also a direction (40 mph to the east).
- *Pitch* - the colloquial descriptive word for frequency, identified as high or low.
- *Tension* - how tightly the string is pulled between the tuning peg and the bridge. Velocity of a wave on a string is directly proportional to the square root of the tension.
- *Linear mass density* - An innate quality to a string. It is equal to the amount of mass per unit length. An example is 1 gram per meter of string. Thicker strings have a higher linear mass density.
- *Shock wave* - a shock wave is a massive compression of air molecules caused by an object moving through air faster than the sound it is generating. The compression causes a loud bang/explosion noise. The wave travels tangent to the sound wave fronts, so it forms an actual visible cone following the airplane.
- *Mach* - terminology to represent multiples of the speed of sound. Mach 1 = speed of sound; Mach 2 = twice the speed of sound.
- *Hertz* - The unit of frequency in cycles per second. Ex.: humans can hear in a range of 20 - 20,000 Hz. This means we can hear things that vibrate 20 times per second but usually no lower, and things that vibrate 20,000 times per second, but usually no higher.

Science Content Background and Additional Resources

You may want to include these equations on a poster board to refer to occasionally. They are not totally necessary to understand the topics but may help older students who have become familiar with algebra.

$$v = \lambda f$$

Velocity of sound = wavelength * frequency

ex. $f = \frac{343 \frac{m}{s}}{2\,m}$

$f = 171.5\,Hz$

$$v = \sqrt{\frac{T}{\mu}}$$

Velocity of the wave on a string = square root of tension divided by square root of linear mass density

Ex. If tension goes up, v will go up.

If mu goes up (e.g. a very heavy string) velocity will go down.

Wikipedia article on Sound

HyperPhysics article on wave features

HyperPhysics article on standing waves (i.e. waves that occur in instruments)

HowItWorks on shock waves

Magic School Bus episode on sound! (great for getting an idea of how to talk to kids)

YouTube video with many clips of shock waves and an explanation (bonus: bring your laptop and loop it with infinitelooper.com)

Explanation of shock waves by an AP physics teacher

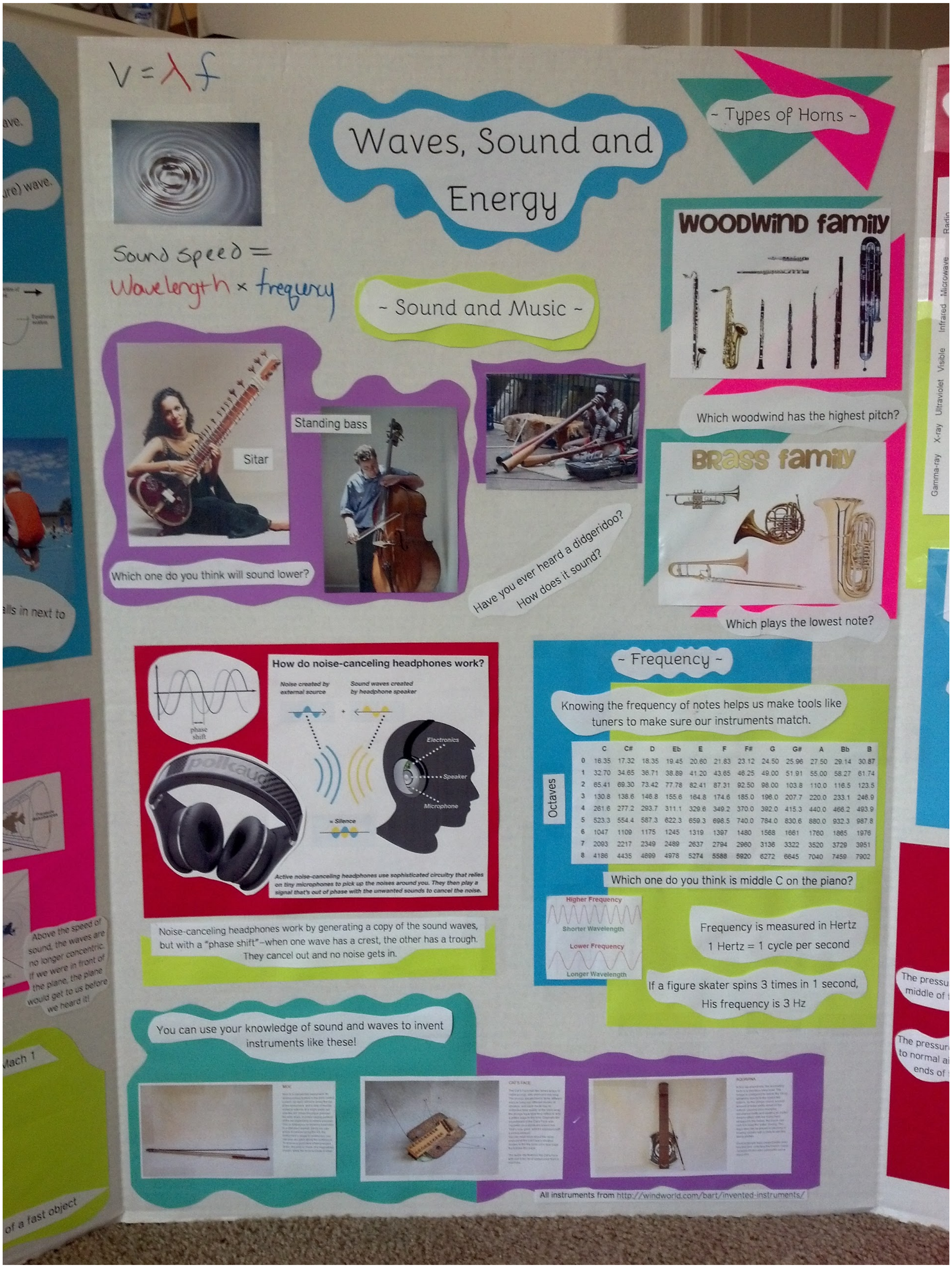
HyperPhysics on constructive vs. destructive interference (and phase shifts)

Hyperphysics on wave velocity and propagation (v = f*lambda)

HyperPhysics on velocity on a string - includes explanation of role of tension

HyperPhysics' quick and dirty electromagnetic spectrum

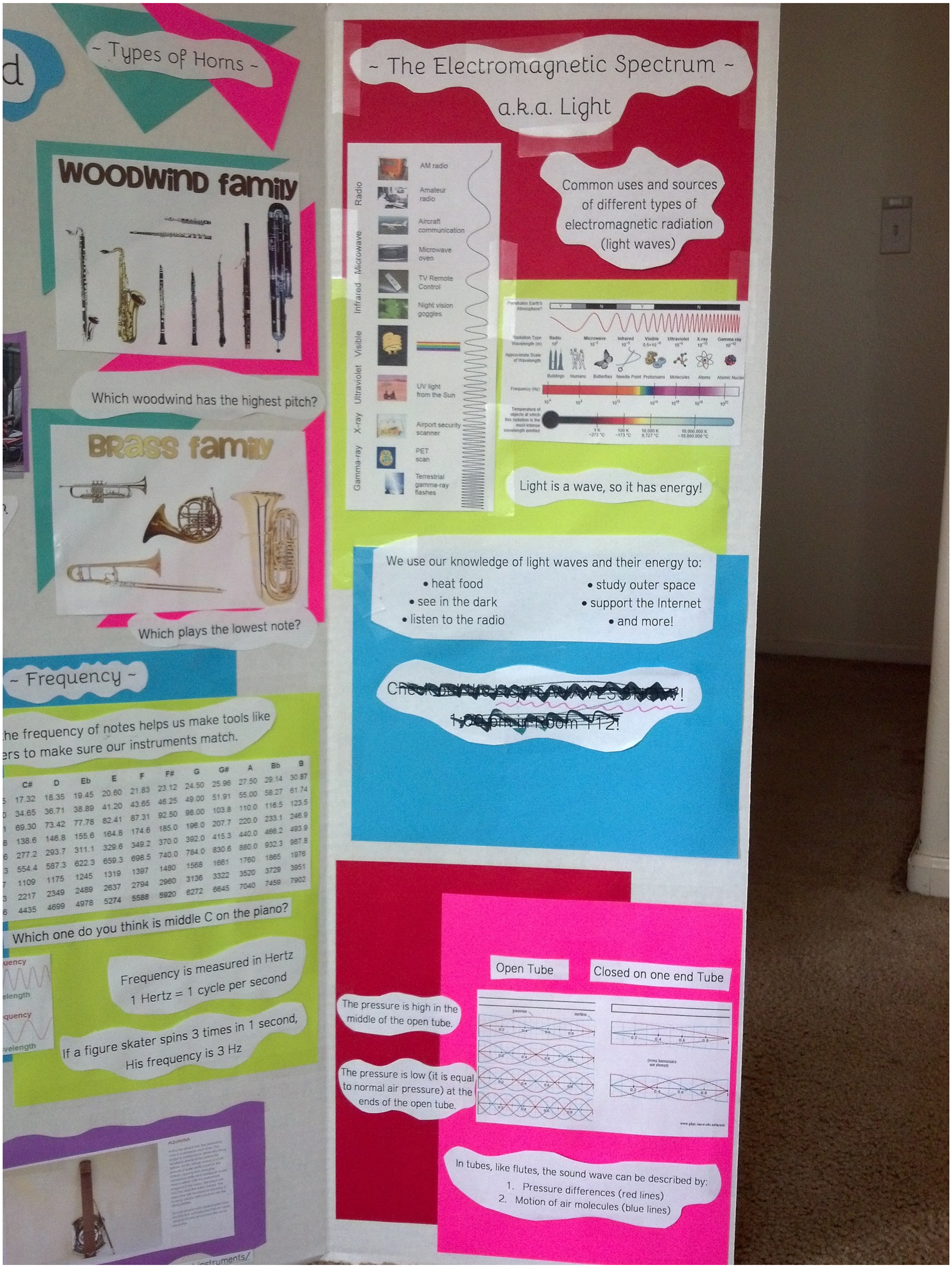
Invented Musical Instruments by Bart Hopkin



V=λf
Waves, Sound and Energy
~ Types of Horns ~
Sound Speed =
Wavelength × frequency
~ Sound and Music ~
WOODWIND family
Which woodwind has the highest pitch?
Standing bass
Sitar
Which one do you think will sound lower?
Have you ever heard a didgeridoo? How does it sound?
BRASS family
Which plays the lowest note?
phase shift
How do noise-canceling headphones work?
Noise created by external source
Sound waves created by headphone speaker
Electronics
Speaker
Microphone
= Silence
Active noise-canceling headphones use sophisticated circuitry that relies on tiny microphones to pick up the noises around you. They then play a signal that's out of phase with the unwanted sounds to cancel the noise.
Noise-canceling headphones work by generating a copy of the sound waves, but with a "phase shift"–when one wave has a crest, the other has a trough. They cancel out and no noise gets in.
~ Frequency ~
Knowing the frequency of notes helps us make tools like tuners to make sure our instruments match.
Octaves

	C	C#	D	Eb	E	F	F#	G	G#	A	Bb	B
0	16.35	17.32	18.35	19.45	20.60	21.83	23.12	24.50	25.96	27.50	29.14	30.87
1	32.70	34.65	36.71	38.89	41.20	43.65	46.25	49.00	51.91	55.00	58.27	61.74
2	65.41	69.30	73.42	77.78	82.41	87.31	92.50	98.00	103.8	110.0	116.5	123.5
3	130.8	138.6	146.8	155.6	164.8	174.6	185.0	196.0	207.7	220.0	233.1	246.9
4	261.6	277.2	293.7	311.1	329.6	349.2	370.0	392.0	415.3	440.0	466.2	493.9
5	523.3	554.4	587.3	622.3	659.3	698.5	740.0	784.0	830.6	880.0	932.3	987.8
6	1047	1109	1175	1245	1319	1397	1480	1568	1661	1760	1865	1976
7	2093	2217	2349	2489	2637	2794	2960	3136	3322	3520	3729	3951
8	4186	4435	4699	4978	5274	5588	5920	6272	6645	7040	7459	7902

Which one do you think is middle C on the piano?
Higher Frequency
Shorter Wavelength
Lower Frequency
Longer Wavelength
Frequency is measured in Hertz
1 Hertz = 1 cycle per second
If a figure skater spins 3 times in 1 second, His frequency is 3 Hz
You can use your knowledge of sound and waves to invent instruments like these!
All instruments from http://windworld.com/bart/invented-instruments/
Above the speed of sound, the waves are no longer concentric. If we were in front of the plane, the plane would get to us before we heard it!
Mach 1
of a fast object
Gamma-ray X-ray Ultraviolet Visible Infrared Microwave Radio


~ Types of Horns ~
WOODWIND family
Which woodwind has the highest pitch?
BRASS family
Which plays the lowest note?
~ Frequency ~
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ers to make sure our instruments match.
Which one do you think is middle C on the piano?
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~ The Electromagnetic Spectrum ~
a.k.a. Light
Common uses and sources of different types of electromagnetic radiation (light waves)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma-ray
AM radio
Amateur radio
Aircraft communication
Microwave oven
TV Remote Control
Night vision goggles
UV light from the Sun
Airport security scanner
PET scan
Terrestrial gamma-ray flashes
Light is a wave, so it has energy!
We use our knowledge of light waves and their energy to:
• heat food
• see in the dark
• listen to the radio
• study outer space
• support the Internet
• and more!
Open Tube
Closed on one end Tube
The pressure is high in the middle of the open tube.
The pressure is low (it is equal to normal air pressure) at the ends of the open tube.
In tubes, like flutes, the sound wave can be described by:
1. Pressure differences (red lines)
2. Motion of air molecules (blue lines)


~ Two Types of Waves ~
Transverse wave
Wavelength
Compression
Expansion
Longitudinal wave
Light is a transverse wave.
Sound is a longitudinal (pressure) wave.
~ Energy ~
Can you ring a bell without touching it?
Hint: Make a wave on a slinky!
If you are floating in a pool and your friend cannonballs in next to you, what happens?
(Other than getting splashed!)
~ Shock Waves ~
Sound Waves At Various Velocities
Stationary
Moving Slower Than the Speed of Sound
Moving at the Speed of Sound
Moving Faster Than the Speed of Sound
Overlapping
Shock Cone
Wavefronts
Subsonic speed
Mach One
Supersonic speed
At normal speed, the plane "chases" the sound waves it emits, so they become closer together as it emits more.
At the speed of sound, the plane catches up with each wave it emits.
Above the speed of sound, the waves are no longer concentric. If we were in front of the plane, the plane would get to us before we heard it!
Shockwave caused by traveling faster than Mach 1
V = λ f
Sound Speed =
Wavelength × frequency
Waves,
En
~ Sound and
Standing bass
Sitar
Which one do you think will sound lower?
Have yo
How do noise-canceling headphones work?
Noise created by external source
Sound waves created by headphone speaker
phase shift
Electronics
Speaker
Microphone
= Silence
Noise-canceling headphones work by generating a copy of the sound waves, but with a "phase shift"–when one wave has a crest, the other has a trough. They cancel out and no noise gets in.
You can use your knowledge of sound and waves to invent instruments like these!