# MAKING MUSIC

PES 1000 – PHYSICS IN EVERYDAY LIFE

# THE PITCH FROM A VIBRATING STRING

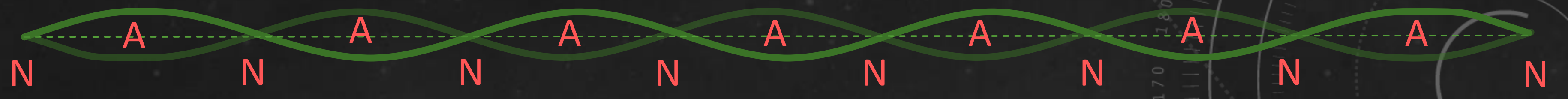
- Creating a standing wave in a string:
  - Energy can be added to the string by strumming, bowing, striking, etc.
  - Waves of many frequencies (and wavelengths) are created, but the only ones that ‘survive’ are the ones with wavelengths that ‘fit’ the length of the string in exact inte

- Our ear and brain interpret sound wave frequency as a pitch.
  - Higher frequency means higher pitch, and vice versa.
  - Recall that in a string, $v = \sqrt{T/\mu}$ and $v = f * \lambda$, so

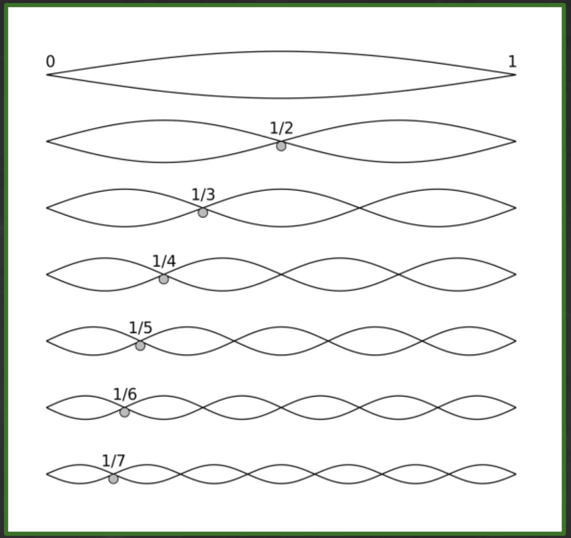
$$f = \frac{1}{\lambda} * \sqrt{\frac{T}{\mu}}$$

- So how can we modify the string to get the pitch that we want?
  - $\lambda$ is related to the string length: A longer string makes a lower frequency.
  - Frets serve to shorten the vibrating portions of the string, raising the frequency
  - Tuning a stringed instrument: Increasing the tension makes the frequency go up.
  - Mass of the string: A more massive string has a larger density, $\mu$, which lowers the frequency.

# STRING




- In a vibrating string, the ends must be nodes, and nodes must be separated by an anti-node. The simplest possible standing wave is then Node/Anti-node/Node.
  - The frequency of this wave is called the fundamental frequency (f0), or the first harmonic.
  - The simplest standing wave contains just one ‘loop’, like a jump rope.
  - Each ‘loop’ represents one half of the wavelength of the wave.  The length of the string is therefore half of the wavelength of the wave.
- The second harmonic (1st overtone) has two ‘loops’.
  - Its wavelength is thus the length of the string. Its frequency is twice the fundamental frequency.
- In general, the nth harmonic has *n* loops, and its frequency is *n*(fundamental frequency)*.

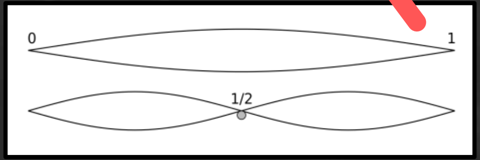



1st Harmonic, (fundamental)
2nd Harmonic, (1st overtone)
3rd Harmonic, (2nd overtone)
4th Harmonic, (3rd overtone)
5th Harmonic, (4th overtone)
6th Harmonic, (5th overtone)
7th Harmonic, (6th overtone)

# STRINGED INSTRUMENTS

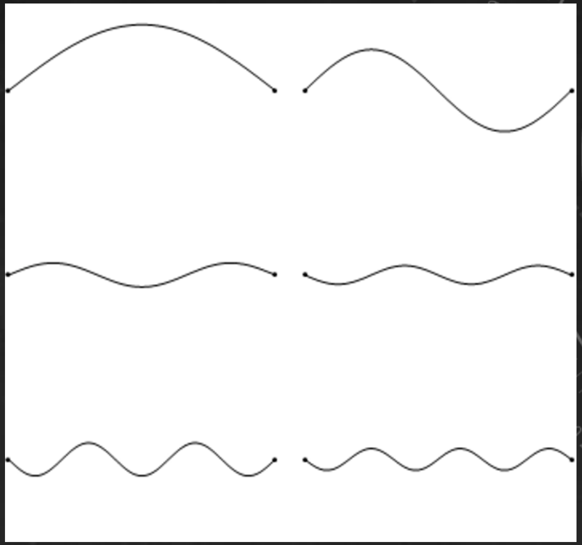
- Here is a table of frequencies of some musical notes.
- The ratio of frequencies for some pairs is very nearly the ratio of two small integers, like 3/2 or 4/3.
- These note pairs sound pleasant to our ears because of the similarity of their wave forms.
  - These form the intervals familiar in music, especially the perfect fifth, present in the music of almost all cultures.
  - Notably, a string with half the length of another will produce double the frequency of the other, which is one octave.
  - Ratios close to 1/1 (like 9/8) sound more dissonant.
- Fingering may be used to shorten the vibrating part of a string and increase its frequency.
  - Vibrato (slightly modulating the frequency about a target frequency) can be used to cause two instruments playing similar frequencies to become consonant.

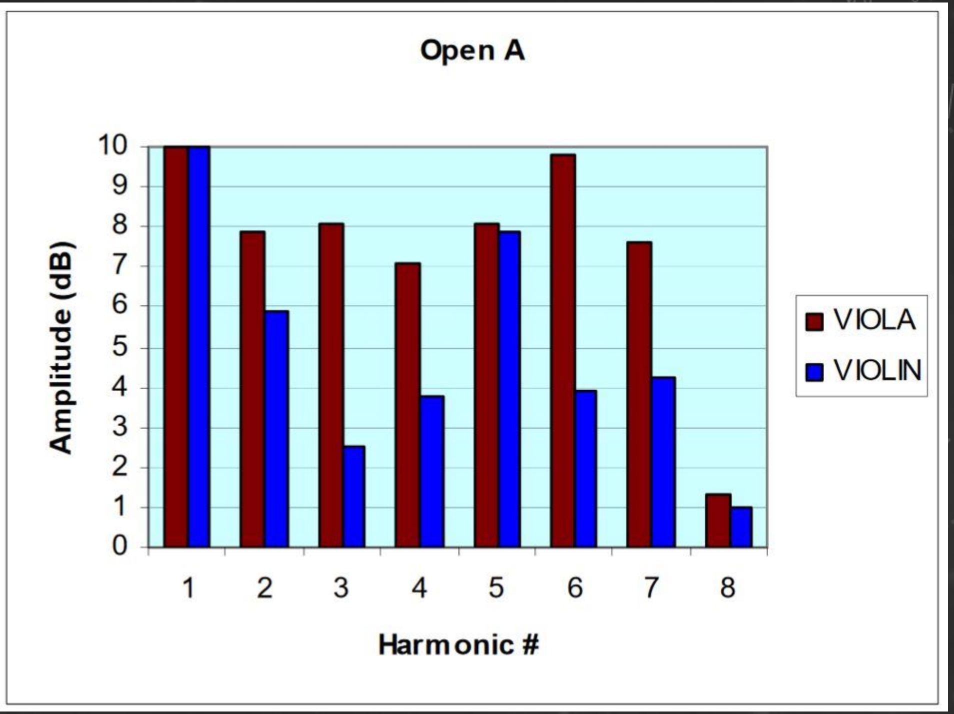
| Note | Frequency (Hz) | Ratio (Just Temperament) | Interval |
|---|---|---|---|
| A | 440 | 1/1 | |
| B flat | 466 | | |
| B | 494 | 9/8 | Second |
| C | 523 | | Minor third |
| C sharp | 554 | 5/4 | Major third |
| D | 587 | 4/3 | Perfect fourth |
| D sharp | 622 | | |
| E | 659 | 3/2 | Perfect fifth |
| F | 698 | | |
| F sharp | 740 | 5/3 | |
| G | 784 | | |
| A flat | 831 | 15/8 | Major seventh |
| A | 880 | 2/1 | Octave |



# THE 'VOICE' OF AN INSTRUMENT

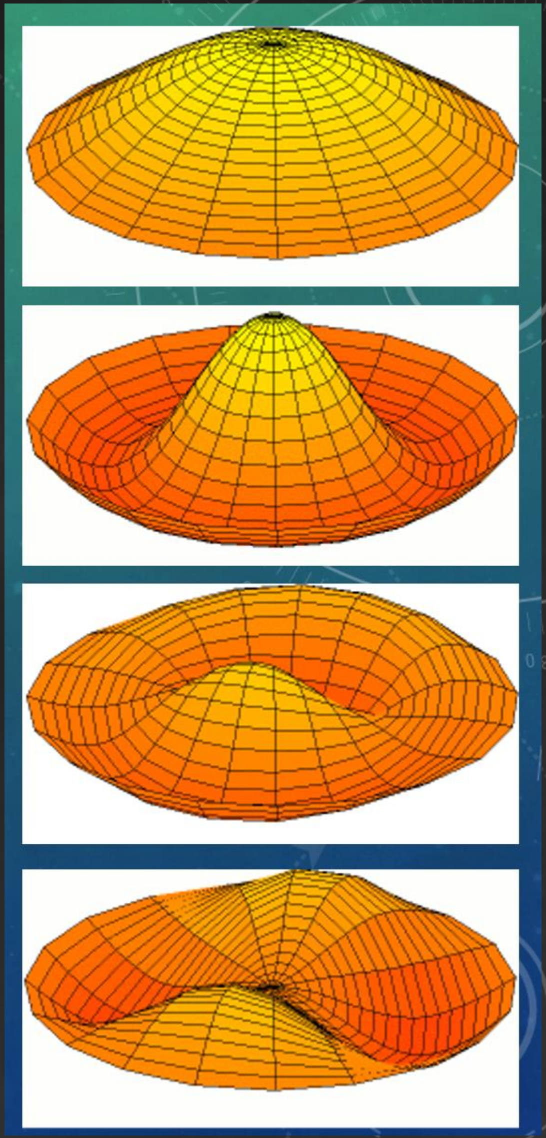
- All the harmonics that can resonate on a stringed instrument will be present in different intensities.
- The mix of these intensities is what give the instrument its 'voice', or particular sound when played.
- Here is a harmonic breakdown of two instruments: a violin and a viola.
- In a piano, some strings, when struck, will cause sympathetic vibrations in other strings which have similar harmonics to the original string.





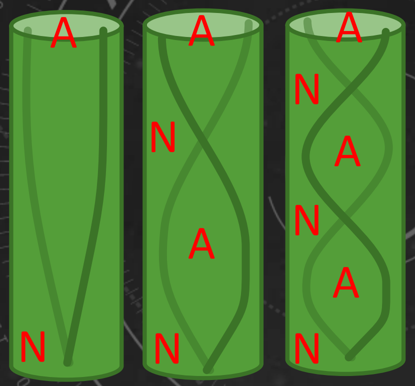

# DRUMS AND OTHER MEMBRANES

- A vibrating drum head has a two-dimensional version of the same harmonics as a string.
- All of these harmonics can be affecting the drum membrane at the same time.
- In most cases, the vibrations don’t produce pure tones like a string or tuning fork would, but do have a characteristic pitch range.
- Tympani (or kettle drums) have membranes with adjustable tension, which allows its pitch range to be adjusted while being played.
- Our eardrums react to sound waves by vibrating in these membrane harmonic patterns.
  - Another name for the eardrum is the *tympanic membrane*.



# PIPE INSTRUMENTS

- A pipe-like instrument works by having sound (pressure) waves within the tube.
- In a tube, nodes form at closed ends, and anti-nodes form at open ends.
- Wind is blown across the top of a tube or across reeds in the mouth of a pipe.
  - This sets up vibrations which fill the tube.
  - The open end is an anti-node.
- For a tube with one closed and one open end (like a jug or pan flute):
  - The simplest standing wave has one node and one anti-node.
  - For the fundamental (1st harmonic), the tube holds one fourth of a complete wave.
  - The second harmonic is ¾ of a complete wave, the third harmonic is 5/4 of a complete wave, etc.
- Longer tubes produce longer wavelengths and thus lower frequencies.




# PIPE INSTRUMENTS

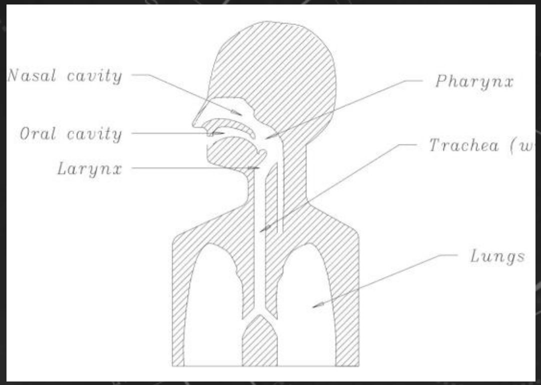

- For a tube with both ends open (like a simple flute), there are anti-nodes at each end.
  - Air blowing over the mouthpiece sets up vibrational sound waves in the tube.
  - The mouthpiece is an anti-node.
  - The fundamental wave is Anti-node/Node/Anti-node.
    - This is somewhat like the string, whose fundamental is Node/Anti-node/Node.
    - The tube length is ½ the fundamental wavelength.
  - Openings along the tube change the location of one of the anti-nodes.
  - As with other instruments, all the harmonics that fit a particular length will be present at the same time.

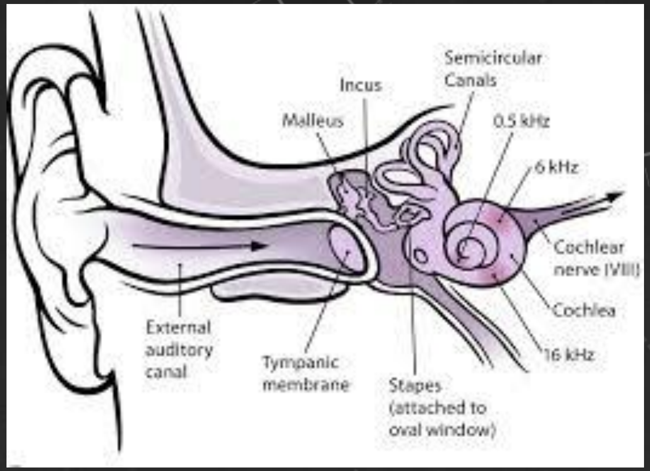
# RESONANCE IN MUSIC

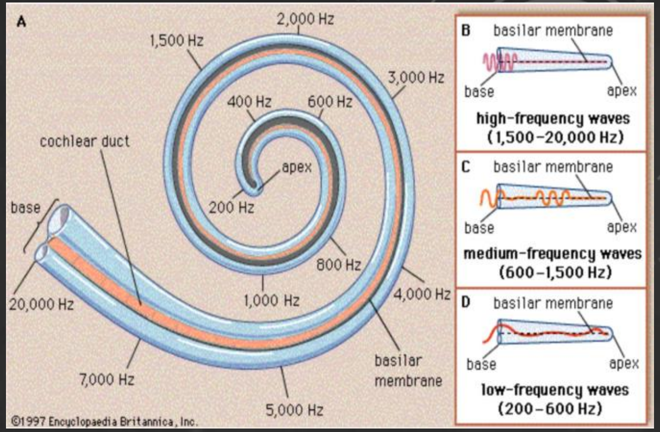
- In an enclosed chamber, sound energy added at a compatible wavelength & frequency will re-enforce itself and increase in intensity.  Incompatible wavelengths die away.
  - Many different harmonics can be amplified by one resonance chamber.
- In many stringed instruments, (acoustical guitar, violin, etc.) vibrational energy is transferred from the strings to the resonance chamber via a sounding board.
- In tube instruments, the tube itself serves as a resonance cavity.
- For the human voice, the chest, mouth and nasal passages form resonance cavities.
- Given enough intensity, sound vibrations can set up resonant vibrations in a wine glass with amplitudes so large it causes it to shatter.

# HUMAN VOICE AND HEARING

- The body produces sound by running air past the vocal cords in the larynx, causing them to vibrate.
  - These sounds are modulated by the resonance cavies in the chest and head, and accentuated by movements of the mouth, teeth, and tongue.
  - Our voice can produce a frequency range of around 500 Hz to 8000 Hz.
- Sound waves are collected by the outer ear and directed to the inner ear.
  - The tiniest bones in the body are in the ear, and transfer vibrations of the eardrum to the fluid-filled cochlea.
  - Different frequencies stimulate the sound-sensitive hairs called cilia at different locations along the cochlea. (This is analogous to waves crashing on the beach.)
  - Our ears can detect frequencies in the range of 200 Hz to 20000 Hz.



# CONCLUSION

- Producing music from an instrument involves a great deal of complex physics, but the basics of frequency harmonics and resonance help us begin to understand how notes are formed.
- Generally, the physical characteristics and vibrational qualities of the instrument govern what frequencies and harmonics are generated and sustained.
    - String length and density, tube length and volume, resonant cavity shape and size, etc.
- Layered on top of the physics is the artistry and presentation of the musician, which adds entirely new dimensions to the enjoyment of music.

Image attributions:

- Violin: http://ru.mobogenie.com/download-violin-war-violin-tuner-13078.html
- Zither: http://www.parvazensemble.co.uk/qanoun.html
- Guitar 1: https://pixabay.com/en/guitar-music-rock-1180744/
- Linear harmonics: (tba)
- String harmonics (http://commons.wikimedia.org/wiki/File:Moodswingerscale.jpg) Public Domain
- Violin/Viola harmonic analysis: https://courses.physics.illinois.edu/phys193/NSF_REU_Reports/2012_reu/Meredith_Powell/Meredith_Powell_Final_Paper.pdf
- Piano: http://assets.classicfm.com/2015/21/steinway-piano-strings-1432657041.jpg
- Membrane harmonics: https://commons.wikimedia.org/wiki/Category:Drum_vibration_animations
- Snare drum: https://www.pinterest.com/shanchris71/sonor-drums/
- Pipe organs: https://pixabay.com/en/organ-pipes-church-music-cathedral-1550156/
- Pan Flute: https://en.wikipedia.org/wiki/Gaston_de_Roquemaurel#/media/File:Flute_de_Pan_Des_Salomon_MHNT_ETH_AC_NH_29_Roquemaurel.jpg
- Bamboo flute: Betelgeuse (https://commons.wikimedia.org/wiki/File:Bansuri_bamboo_flute_23inch.jpg), „Bansuri bamboo flute 23inch“, https://creativecommons.org/licenses/by-sa/3.0/legalcode
- Guitar 2: http://amosaicworld.blogspot.com/2012/11/fine-art-photography-explained.html
- Wine glass: https://openclipart.org/detail/189847/white-wine-glass
- Physics of human music - lecture notes, J. V. Noble: http://galileo.phys.virginia.edu/classes/304/lects.htm
- Musical notes: https://openclipart.org/user-detail/jaschon