Waves and Sounds

General Wave Characteristics

- Transverse Wave**:** direction of particle oscillation is perpendicular to the **propagation** of the wave. Think above moving a string with a fixed point by moving hand up and down.
  - Includes electromagnetic waves like visible light, microwaves and x-rays.
  - In any wave form, energy is delivered in the direction of wave travel
- Longitudinal Waves: particles of wave oscillate parallel to the direction of transfer
  - Sound waves, causes air particles to oscillate through cycles of **compression** and **rarefaction (decompression)** along the direction of the wave.

Describing Waves

- Wavelength: Distance from one maximum (**Crest**) to another crest or valley to valley.
- Frequency: Number of wavelengths passing a fixed point per second [Hz].
- Propagation Speed: $v = f\lambda$
- Period: The inverse of frequency and is defined as the number of seconds per cycle.
- Angular Frequency: $\omega = 2\pi f = \frac{2\pi}{T}$\
- Equilibrium Position: Waves oscillate about this center point.
  - **Displacement** is how far a particular point on the wave is from the equilibrium position. Maximum magnitude is called the **Amplitude**.

Phase

- Can calculate a **phase difference** to compare two waves passing through the same phase.
- If completely out of phase, expressed as a difference of $\frac{\lambda}{2}$ or 180 degrees.

Principle of Superposition

- When waves interact with each other, the displacement of the resultant wave at any point is the sum of the displacements of the two interacting waves.
  - Constructive Interference: If waves are in-phase, the displacements always add together. Resultant amplitude will be 2x the original amplitudes.
  - Destructive Interference: Two out of phase waves cancelling each other out completely.

Travelling and Standing Waves

- Travelling Waves are when the waves are moving and can be modelled as a string with one free end and one fixed end.
- Standing Waves: Only apparent movement of string is fluctuation of amplitude at fixed points along the length of the string. Can be modelled by a string with two fixed end or an open ended pipe
  - Node: Where amplitude is constantly zero
  - Antinode: At midway point between nodes, fluctuate at maximum amplitudes.

Resonance

- Every object has a **natural (resonant) frequency** when struck and allowed to vibrate freely.

- Timbre: The quality of sound is determined by the natural frequency.
- Objects that produce multiple non-harmonious or unrelated frequencies produce **noise**.
- Musical sounds are usually objects that vibrate with multiple natural frequencies which are whole-number multiples of the fundamental frequency (**fundamental pitch & overtones**).
    - Can usually hear about 20-20000 Hz for healthy adult, high frequency hearing declines with age.
- If frequency of forced oscillated is close to or equal to natural frequency, amplitude of wave becomes exponentially higher (**Resonating**).
    - Amplitude would go to infinity without the presence of **damping**, which is caused by frictional forces.
    - Damping: The decrease in amplitude of a wave caused by a non-conservative force.

Sound

A longitudinal wave transmitted by the oscillation of particles in a deformable medium. Cannot travel through a vacuum. Speed of sound is given by:

$$v = \sqrt{\frac{B}{\rho}}, B \text{ is the bulk modulus (increases from gas to solid)}$$

Production of Sound

- The mechanical distribution of particles in a material along the sound wave's direction of propagation. Particles vibrate along an equilibrium position which causes area of compression and decompression.
    - Particles themselves do not move, but alternating areas allows for propagation of wave.

Frequency & Pitch

- **Pitch** is the same thing as frequency. A lower pitch indicates a lower frequency. We just perceive pitch while frequency is more mathematics.
- Soundwaves below 20 Hz are called **infrasonic** & soundwaves above 20,000 Hz are called **ultrasonic waves**

Doppler Effect

- Describes the differences between the actual frequency of a sound and the perceived frequency of a sound.
    - If the source and the detector are moving towards each other, then the frequency is perceived to be higher. Vice Versa for if they're moving away from each other.

$$f' = f\frac{v \pm v_D}{v \mp v_S}$$

        - *v* is the speed of sound in the medium, v_D is the speed of the detector, and v_s is the speed of the source.
        - Upper sign used when source moving towards, lower signs used when source moving away.

- Can be visualized as sound waves in front of a moving object as being compressed, while the sound waves behind the object are stretched out

Shock Waves

- If an object is producing sound and moving at a speed above the speed of sound, then wave fronts begin to build upon one another at the front of the object.
- Shock Wave: The highly condensed wave which creates a high pressure, followed by a low pressure (**sonic boom)**.

Intensity & Loudness of Sound

- Loudness is the way humans perceive the intensity of a sound.
- Intensity: the average rate of energy transfer per area across a surface that Is perpendicular to the wave. (Power transported per unit area)

$$I = \frac{P}{A}, P\ is\ the\ power\ \&\ A\ is\ the\ Area$$

- Intensity is proportional to the square of amplitude.
- Intensity is inversely proportional to the square of the distance from the source.
- Sound Level is measured in **decibels (dB)**: $\beta = 10 \log\left(\frac{I}{I_0}\right)$
  - I_0 is the threshold of hearing which is 1 x 10^{-12} W/m^2
  - If intensity is changed by some factor, can use: $\beta_f = \beta_i + 10 \log {}^{I_f}/_{I_i}$

Attenuation

- Real world measurements of sound will be lower than those expected from calculations. Which is a direct result of **damping/attenuation**.
- Since sound is simply oscillations in simple linear motion, they are subject to non-conservative forces which cause a decrease in amplitude as the oscillation progresses.
- Pitch does not change because of damping.

Beat Frequency

- When two sounds of slightly different frequencies are produced in proximity:

$$f_{beat} = f_1 - f_2$$

Standing Waves

- Occur when two waves of the same frequency are travelling in different directions and interfere with each other.

- As waves move in opposite directions, they interfere to produce new wave patterns characterized by alternating points of maximum amplitude (Antinode) & points of no displacement (node).
- Objects that support standing waves have boundaries at both ends
    - Closed Boundaries: do not allow oscillation and correspond to nodes.
    - Open Boundaries: Allow maximum oscillation and correspond to antinodes.

Strings

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

- *n* is an integer number called the **harmonic**, which corresponds to how many half-wavelengths are supported by the string. Equal to number of antinodes.

$$f = \frac{nv}{2L}$$

- The **fundamental frequency** is the lowest frequency of a standing wave. At n=2, the frequency is known as the first overtone or the second harmonic.
    - First overtone has half the wavelength and twice the frequency of the first harmonic.
- All possible frequencies that can be supported are known as the **harmonic series.**

Open Pipes

- Open pipes are open at both ends, while closed pipes have one end closed.
- These are basically the exact opposite of strings. The number of nodes, between the antinodes on each end, corresponds to what harmonic frequency the pipe is in.
- Same equations as above are used.

Closed Pipes

- A node on the closed end and an antinode on the open end. First harmonic is when there are only these two initial points. Corresponds to one quarter of a wavelength.
    - Each harmonic is equal to the number of **quarter-wavelengths** supported by the pipe. (half-wavelengths in open pipes and strings)
- There can only be odd numbered harmonics since an even number would require synonymous pipe ends.

$$\lambda = \frac{4L}{n} \quad \& \quad f = \frac{nv}{4L} \quad n\ can\ only\ be\ odd\ numbered\ integer.$$

Ultrasound

- Use high frequency sound waves outside the range of human hearing to compare the relative densities of tissues in the body.
- The transmitter produces a pressure gradient and acts as a receiver which processes the reflected sound.
- Ultimately relies on the reflection of the wave.
- Doppler Ultrasound: used to determine flow of blood within body by measuring the frequency shift that is associated with movement towards or away from the receiver.