Chapter 9: Sound and Hearing

* Sound requires a medium for propogation.

Object vibrates ⟶ Adjacent particles displaced ⟶ Reaches ear.

→ disturbance produced by a source which is travelling in the medium.

* Sound Waves: are series of compressions and rarefactions

* Wave speed:

$$C_{sound} = \sqrt{\frac{B}{\rho}}$$

, B: Bulk modulus (N/m^2)
↓
how hard to compress.
it is a measure for stiffness.

* Two main factors about a medium that will determine the speed of the sound through that medium:

[1] Stiffness: how rigid it is

Stiffer medium = faster sound waves.

Stiff = Fast

Dense = Slow.

[2] Density:

Denser medium = slower sound waves.

$C_{solid} > C_{liquid} > C_{gas}$. (Because solids are more rigid ($B\uparrow$)).

Hotter air = Low Density Air = Faster sound waves.

* Acoustic Impedance:

→ is an object's resistance to the movement of a wave.

$kg \times m^{-2} \times s^{-1} \leftarrow Z = \rho c$

→ The ratio of amount of transmission to reflection depends on the impedances of the two materials.

$$\frac{(1-r)^2}{(1+r)^2} = R = \frac{I_r}{I_0} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2} \qquad r = \frac{Z_1}{Z_2}$$

→ R: fraction of reflection.

I_r: Intensity reflection.

I_0: Total intensity.

Proportion transmitted = 1 − proportion reflected.

* Frequency and Pitch:

→ Pitch: is how high or low a sound is.

Higher Frequency = Higher Pitch.

* Intensity and Amplitude:

→ Intensity: is a measure of the amount of energy per second per square meter.

$$I = \frac{\rho c A^2 (2\pi f)^2}{2}, \quad I = \frac{P^2}{2Z}$$ → pressure

* **Decibel scale**: is used to compare sound intensities, and it's a way of specifying a ratio.

→ For two intensities, I_1, I_2 the intensity ratio in decibels (dB) is:

$$\text{intensity ratio in dB} = 10 \log_{10} \frac{I_2}{I_1}$$

→ To give the sound intensity level in DB, we need to specify a refrence intensity, which is taken to be $10^{-12}\ W m^{-2}$:

$$L_I = 10 \log_{10} \frac{I}{10^{-12}\ (W m^{-2})}$$

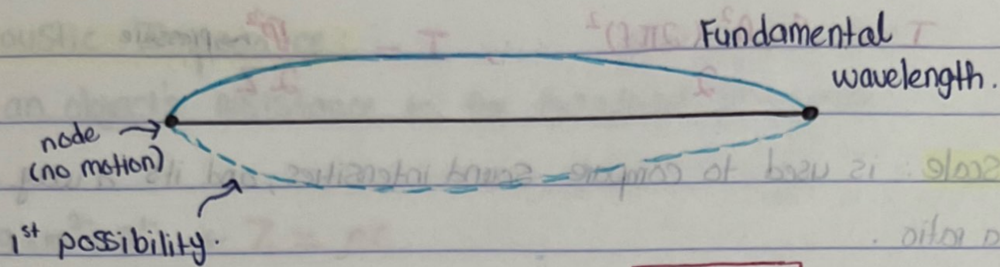
→ To find the sound pressure level in dB. The reference pressure is 2×10^{-5} Pa, which corresponds approximately to a sound intensity of $10^{-12}\ W m^{-2}$:

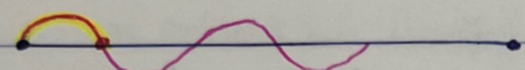
$$L_P = 20 \log_{10} \frac{P}{2\times10^{-5}\ (Pa)}$$

* **Phon**: is a unit that is related to the psychophysically measured response of a typical human ear. It is used to describe the loudness level of a given sound or voice.

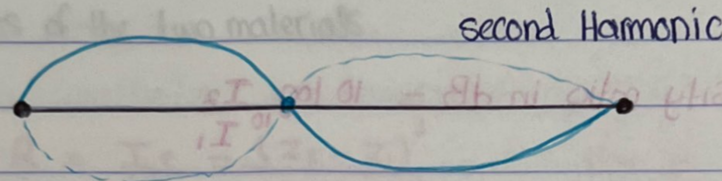
* **Sound Generation**: To generate sound, the only requirement is that something moves sufficiently to create an air pressure wave of enough intensity.

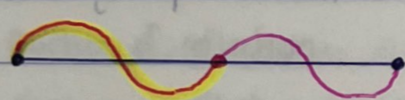
* Modes of Vibration of a String:



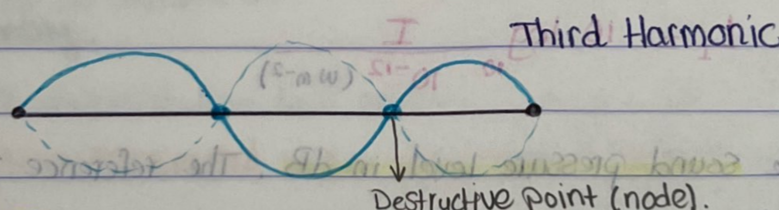


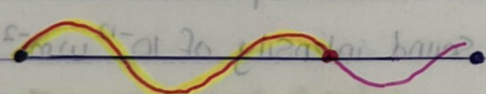
$$\boxed{\lambda = 2L}$$





$$\boxed{\lambda = L}$$





$$\boxed{\lambda = \frac{2}{3} L}$$

$$\lambda_n = \frac{2(L)}{n} \quad , \; n = 1, 2, 3, \ldots$$

(L) → The length of the string.

n → The number of the harmonic.

* We can use the equation for the wavelength of a harmonic and the fact that the velocity remains the same in the same material to find the frequency of each harmonic.

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→ f_1 is the frequency of the first Harmonic, is also called the fundamental frequency.

$$c = \lambda_n f_n$$

$$f_n = \frac{c}{\lambda_n} = \frac{c}{\frac{2}{n}(L)}$$

$$f_n = n \underbrace{\frac{c}{2L}}_{f_1} = n f_1$$

→ The speed of a wave along a wire such as a guitar string is:

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

, T: Tension in the wire.

μ: the mass per unit length.

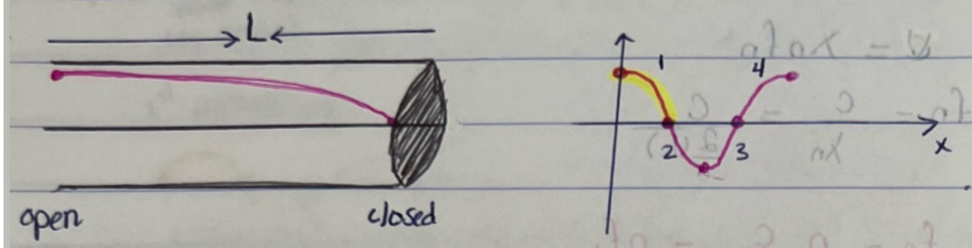
- the wave speed is lowered in thicker wires and increased as the wire is placed under more tension.
- As $v = \lambda f$, a lower speed will correspond to a lowered frequency, and a reduced pitch.
- The thicker guitar strings sound lower in pitch, and tightening the tuning pegs raises the pitch.

* Modes of vibration of an Open Pipe:

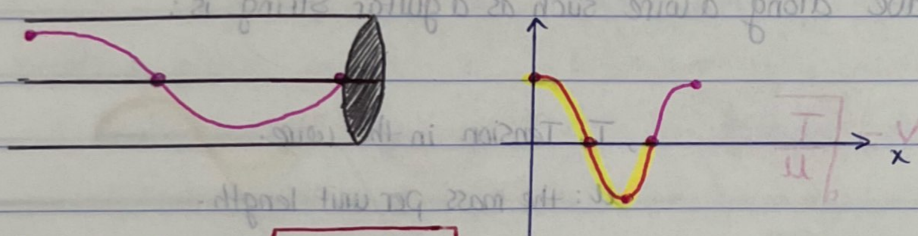
→ An open pipe acts in a very similar way to a string with both ends fixed.

$$f_n = n\frac{c}{2L} = n f_1 \quad , n = 1, 2, 3, \ldots$$

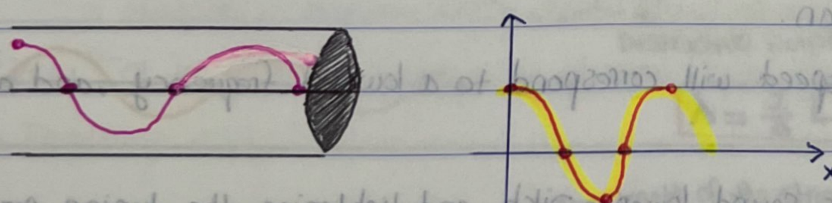
* Modes of vibration of a Half-Open pipe:



$L = \frac{\lambda}{4} \Rightarrow \boxed{\lambda = 4L}$ fundamental wavelength.



$L = \frac{3}{4}\lambda \Rightarrow \boxed{\lambda = \frac{4}{3}L}$



$L = \frac{5}{4}\lambda \Rightarrow \boxed{\lambda = \frac{4}{5}L}$

$\lambda_n = \frac{4L}{n}$, $n = 1, 3, 5, \dots$ (odd integars).

$nf_1 = f_n = n\frac{c}{4L}$, $n = 1, 3, 5, \dots$

* The Doppler Effect:

→ is a well-known and frequently observed phenomenon in which the apparent pitch of ~~the~~ a sound is changed by the relative motion between the sound source and the observer.

[1] Moving Source, Fixed Observer:

→ as the source approaches to the observer, the frequency increases when compared to the actual frequency of the sound source.

→ if the source is receding away from the observer, the frequency decreases.

frequency perceived by observer. $f' = f \frac{c}{c \pm V_s}$ → the speed of the source.

f → frequency of source.

→ The minus sign is used for an approaching sound source and a plus sign for a retreating source.

[2] Fixed Source, Moving Observer:

$$f' = f \frac{c \mp V_D}{c}$$ → velocity of the observer.

→ The plus sign indicates an approaching observer, and a minus sign indicates retreating.

* General Case: $f' = f \frac{c \mp V_D}{c \mp V_s}$