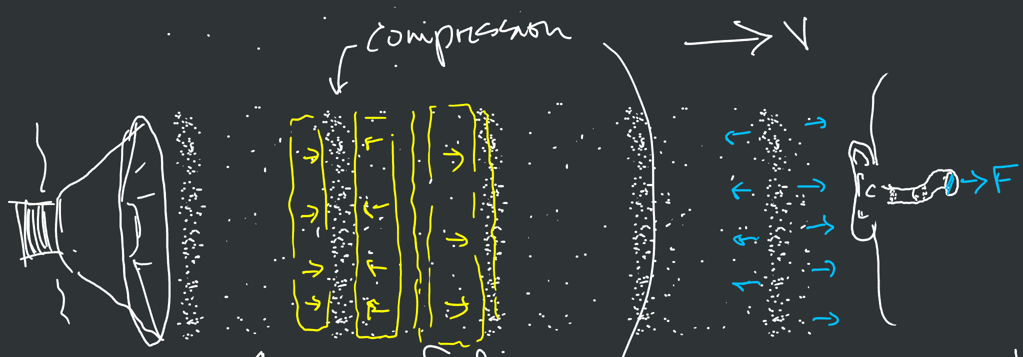
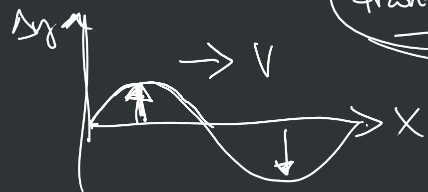
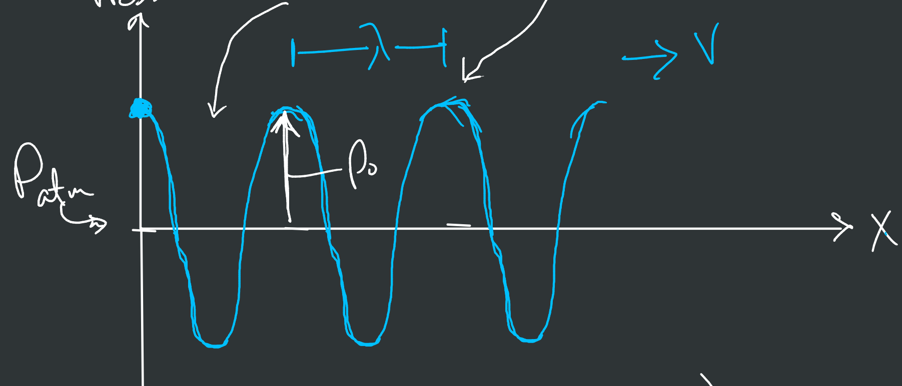
Chapter 12 - Sound

After this you can
- discuss and describe sound and its causes
- discuss what affects the speed of sound in materials

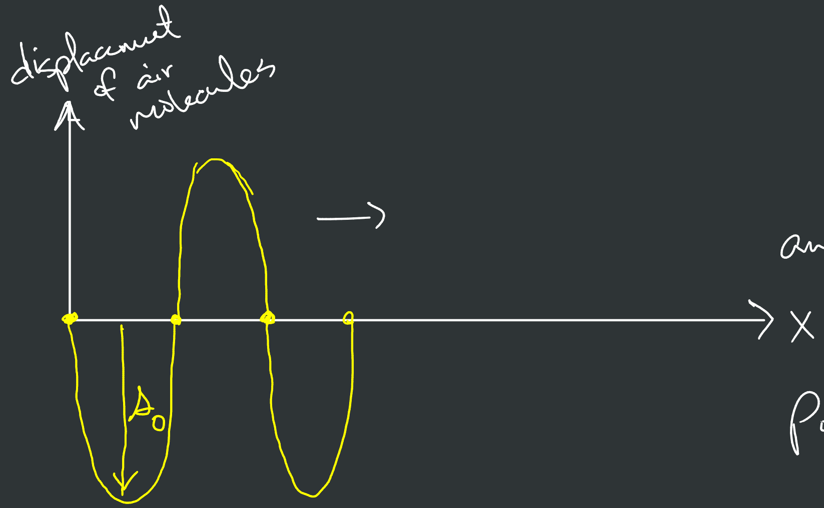
sound - a longitudinal wave of pressure that travels through a material







$$p(x,t) = p_0 \cos(kx - \omega t)$$



$$s(x,t) = -s_0 \sin(kx - \omega t)$$

angular freq

density

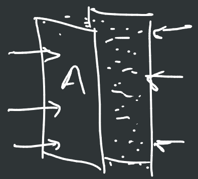
$$p_0 = \omega v \rho s_0$$

speed

Speed of Sound

volumetric stress + strain

$$\underbrace{\frac{F}{A}}_{\text{pressure}} = \underbrace{B}_{\text{bulk modulus}} \frac{\Delta V}{V}$$



$$\underbrace{\boxed{v = \sqrt{\frac{B}{\rho}}}}_{\text{true in all materials}}$$

solid, liquid, gas

gas:

$$B \propto \rho T$$

temperature

String

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

$$v \propto \sqrt{\frac{B}{\rho}} \qquad B \propto \rho T$$

$$v_{gas} \propto \sqrt{\frac{\cancel{\rho} T}{\cancel{\rho}}}$$

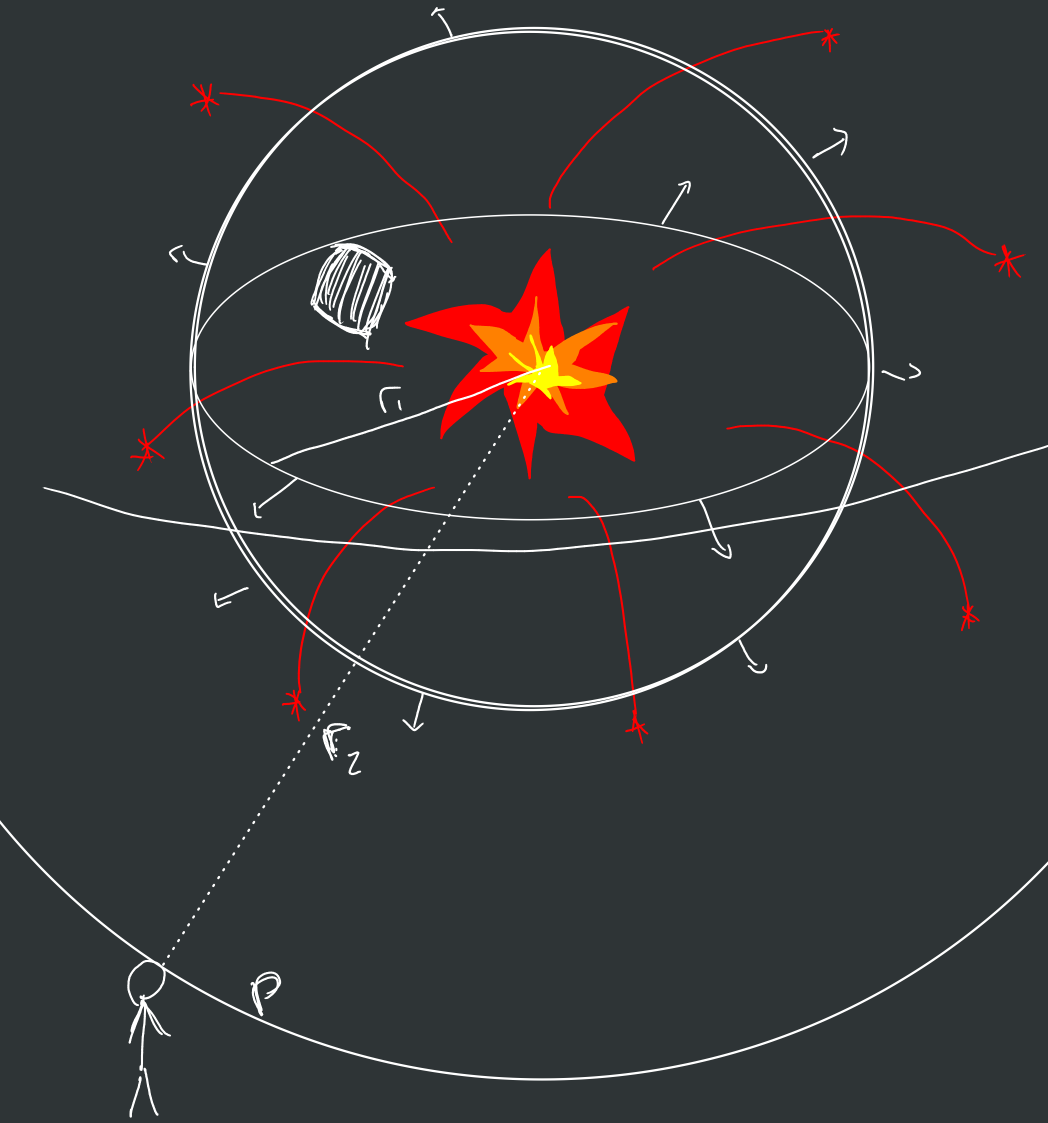
$$\boxed{v_{gas} \propto \sqrt{T}}$$

temperature (absolute temp) [Kelvin]

After this you can
- discuss how energy is carried by a wave.
- use the new quantity of intensity to describe how this energy is spread out throughout the wave.
- discuss the human perception of loudness and how it relates to intensity.

→ loudness + pitch → frequency

→ amplitude



Wave - transfer of energy w/o a transfer of matter

Energy

FROM: chemical potential energy

TO:
- heat
- light
- sound

Energy that sound carries spreads out spherically. (usually)

rate of energy emitted by the source
of delivered to the listener.

$$\underline{\text{Power}} = \cancel{\frac{\text{Work}}{\text{time}}}$$

$$\underline{\text{Power}} = \frac{\text{Energy emitted/delivered}}{\text{time}}$$

$$[\text{Watt}] = \left[\frac{\text{Joule}}{\text{sec}}\right]$$

$$\frac{\text{Power}}{\text{Area}} = \underline{\text{Intensity}} \qquad \left[\frac{W}{m^2}\right]$$

$$\frac{\mathbb{P}_{source}}{A_{sphere}} = \text{Intensity}$$

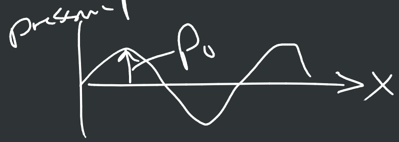
$$\frac{\mathbb{P}_{source}}{4\pi r^2} = I$$

distance from the source to the listener

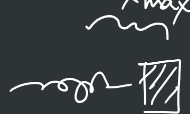
I decreases with the square of distance away from the source

$$\boxed{I \propto r^{-2}}$$

How does intensity relate to pressure amplitude?



$x_{max} \leftarrow$ amplitude



$$U_{SHM} = \frac{1}{2} k x^2$$

$$U_{SHM_{max}} = E_{total} = \frac{1}{2} k x_{max}^2$$

$$E_{total_{SHM}} \propto x_{max}^2$$

$$E_{total_{sound}} \propto p_0^2$$

$$E_t \propto P$$

$$P \propto I$$

$$\boxed{I \propto p_0^2}$$

How does intensity relate to the perception of loudness

loudness is proportional to the logarithm of intensity relative to the least intense sound the we can hear

$\hookrightarrow$ threshold of hearing, $I_0 \approx 10^{-12} \frac{W}{m^2}$

$$\beta = \underbrace{\log_{10}\left(\frac{I}{I_0}\right)}_{\text{usually small number}}$$

[bels]

Alexander Graham Bell

$$\boxed{\beta = 10 \cdot \log_{10}\left(\frac{I}{I_0}\right)}$$

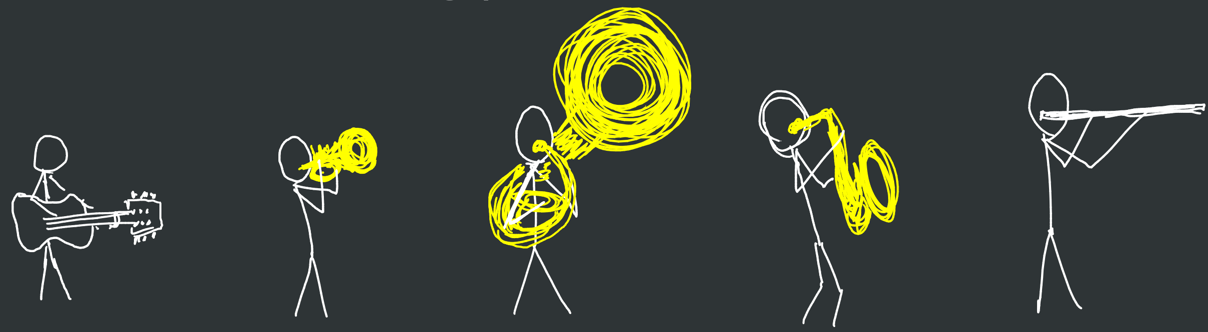
decibels (dB)

10 decibels = 1 bel

After this you can
- discuss the how all musical instruments work
- discuss how standing pressure waves can be formed in pipes

• strings
• pipes

} standing waves



strings

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

$v = \lambda \cdot f$

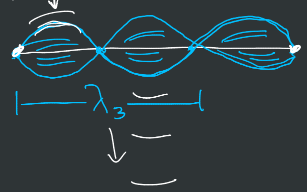
$f_n = \frac{nv}{2L}$

$f_{air} = f_{string}$

$\lambda_{air} \neq \lambda_{string}$

$v_{air} \neq v_{string}$

$v = \lambda \cdot f$

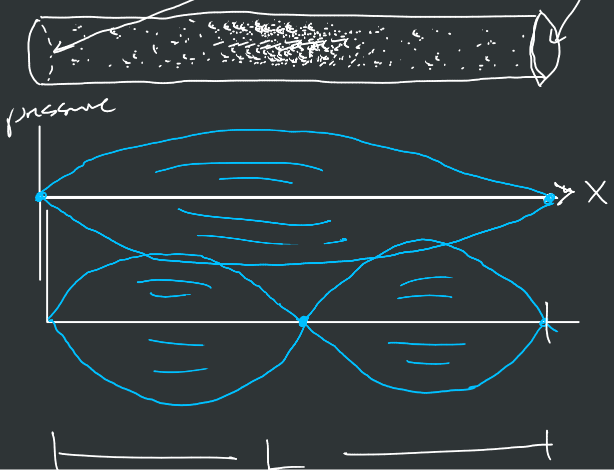


pipes → open on both ends (flute / some organ pipes)

pipes → closed on one end (brass / woodwind reed / some organ pipe)

open on both ends

open ends act like nodes in terms of pressure



$n = 1$

$n = 2$

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

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

$V_{air} = \lambda_n f_n$

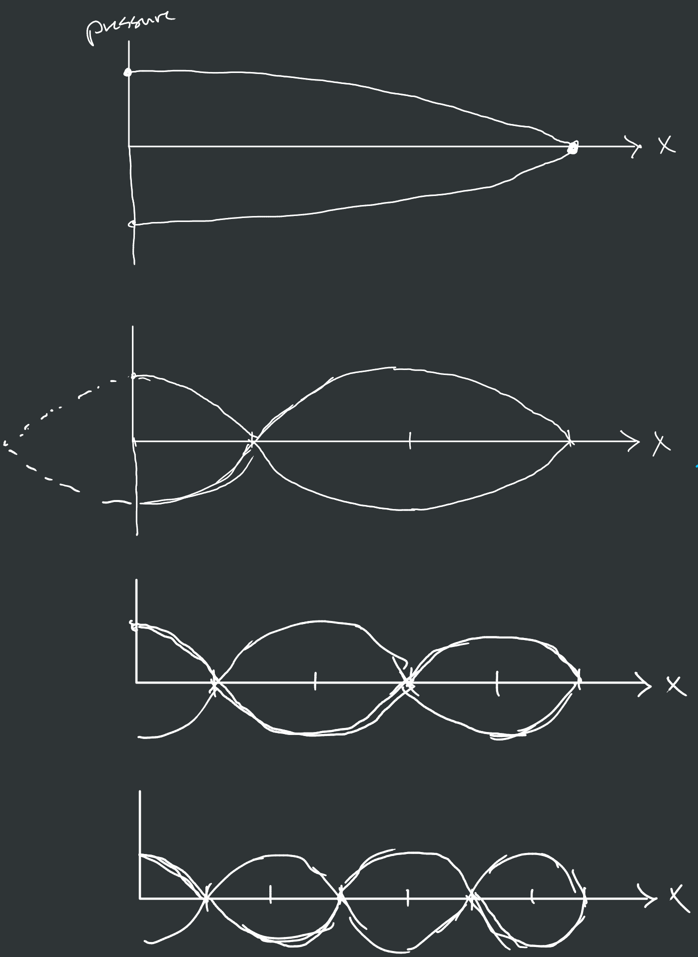
closed on one end

$\cancel{\lambda_n = \frac{2L}{n}}$

Odd values of n

$$\lambda_n = \frac{4L}{n} \quad \Big| \quad f_n = \frac{nv}{4L}$$

$n = 1, 3, 5, 7, \dots$



$\cancel{n = 1/2}$ $n = 1$

$\cancel{\lambda_{1/2} = \frac{2L}{1/2} = \frac{4L}{1} \quad \Big| \quad f_{1/2} = \frac{1v}{4L}}$

$\lambda_1 = \frac{4L}{1} \quad \Big| \quad f_1 = \frac{1v}{4L}$

$\cancel{n = 1\tfrac{1}{2} = 3/2}$ $n = 3$

$\cancel{\lambda_{3/2} = \frac{2L}{3/2} = \frac{4L}{3} \quad \Big| \quad f_{3/2} = \frac{3v}{4L}}$

$\lambda_3 = \frac{4L}{3} \quad \Big| \quad f_3 = \frac{3v}{4L}$

$\cancel{n = 2\tfrac{1}{2} = 5/2}$ $n = 5$

$\cancel{\lambda_{5/2} = \frac{2L}{5/2} = \frac{4L}{5} \quad \Big| \quad f_{5/2} = \frac{5v}{4L}}$

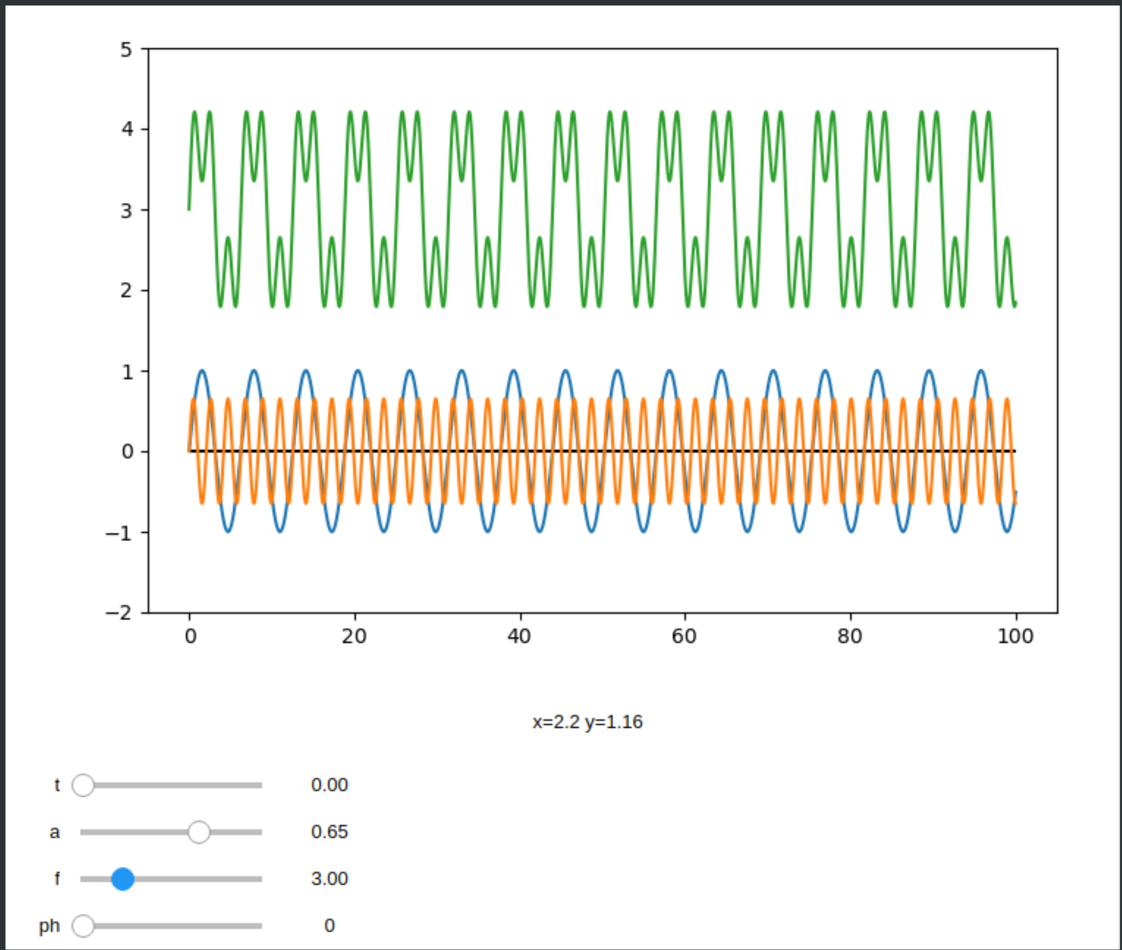
$\lambda_5 = \frac{4L}{5} \quad \Big| \quad f_5 = \frac{5v}{4L}$

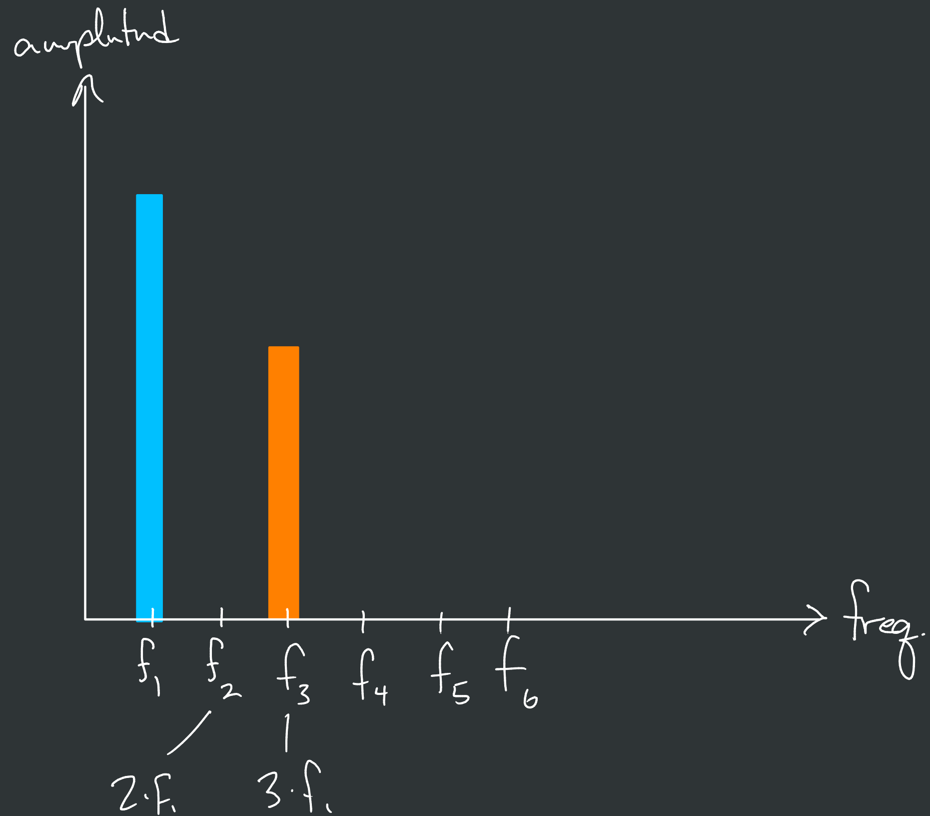
$\cancel{n = 3\tfrac{1}{2} = 7/2}$ $n = 7$

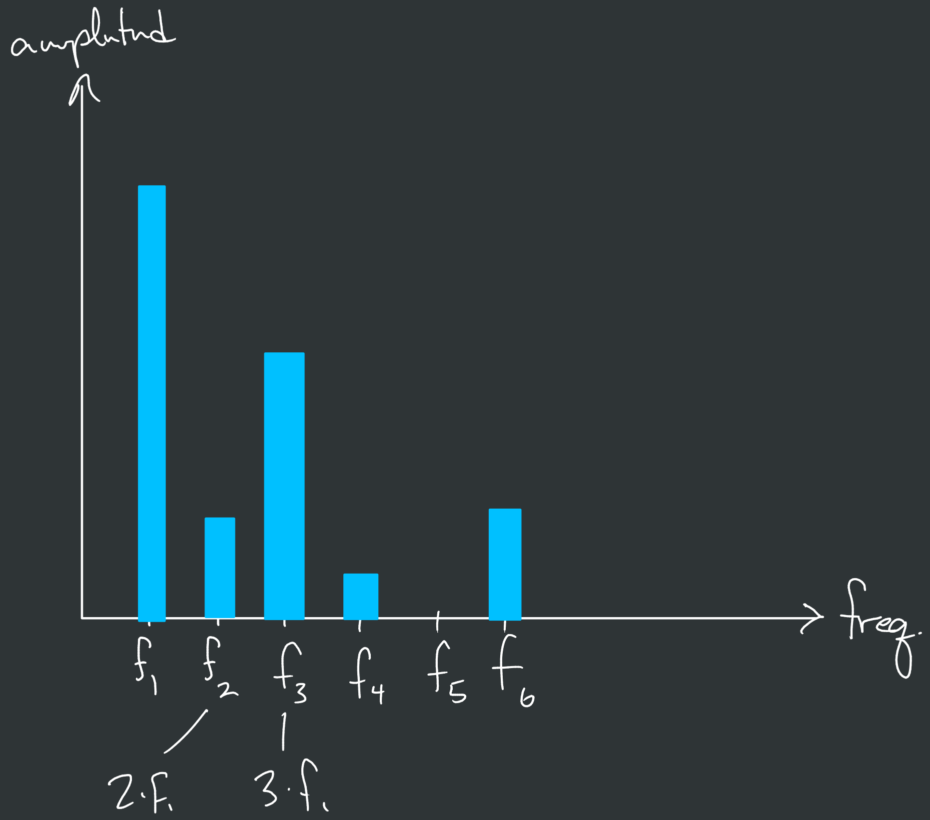
$\cancel{\lambda_{7/2} = \frac{2L}{7/2} = \frac{4L}{7} \quad \Big| \quad f_{7/2} = \frac{7v}{4L}}$

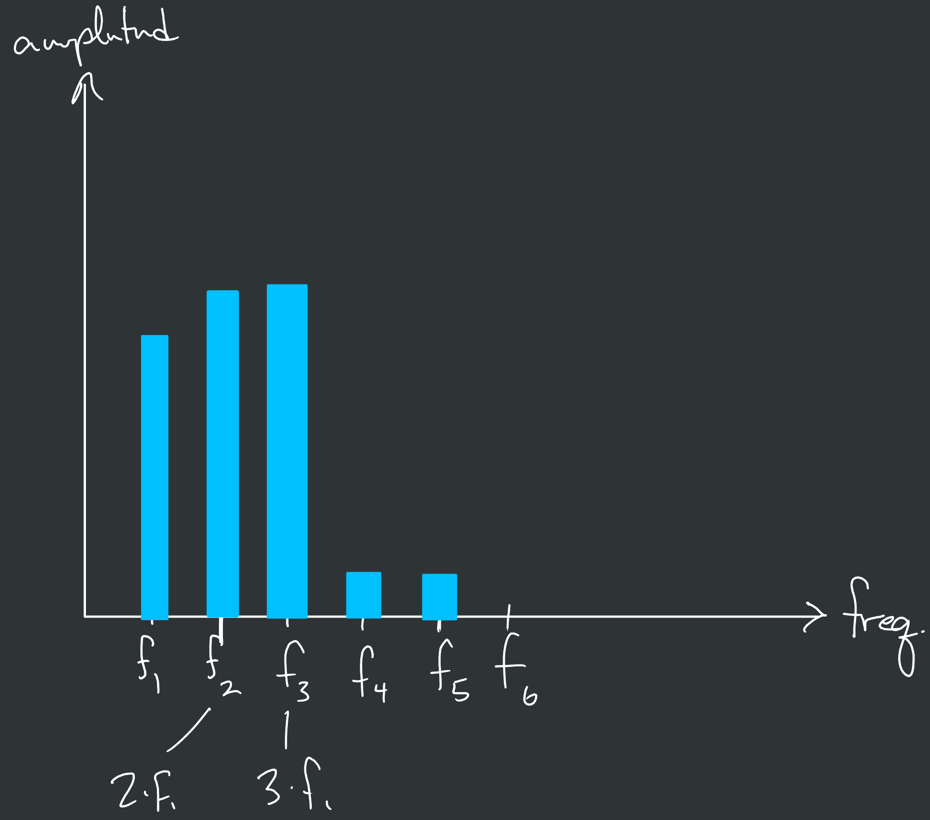
$\lambda_7 = \frac{4L}{7} \quad \Big| \quad f_7 = \frac{7v}{4L}$

After this you can
- discuss the tone quality or timbre of musical instruments
- discuss the effects of interference and the principle of superposition on sound with multiple waves present at the same time
- discuss the phenomenon known as frequency beating and its applications to musical instruments



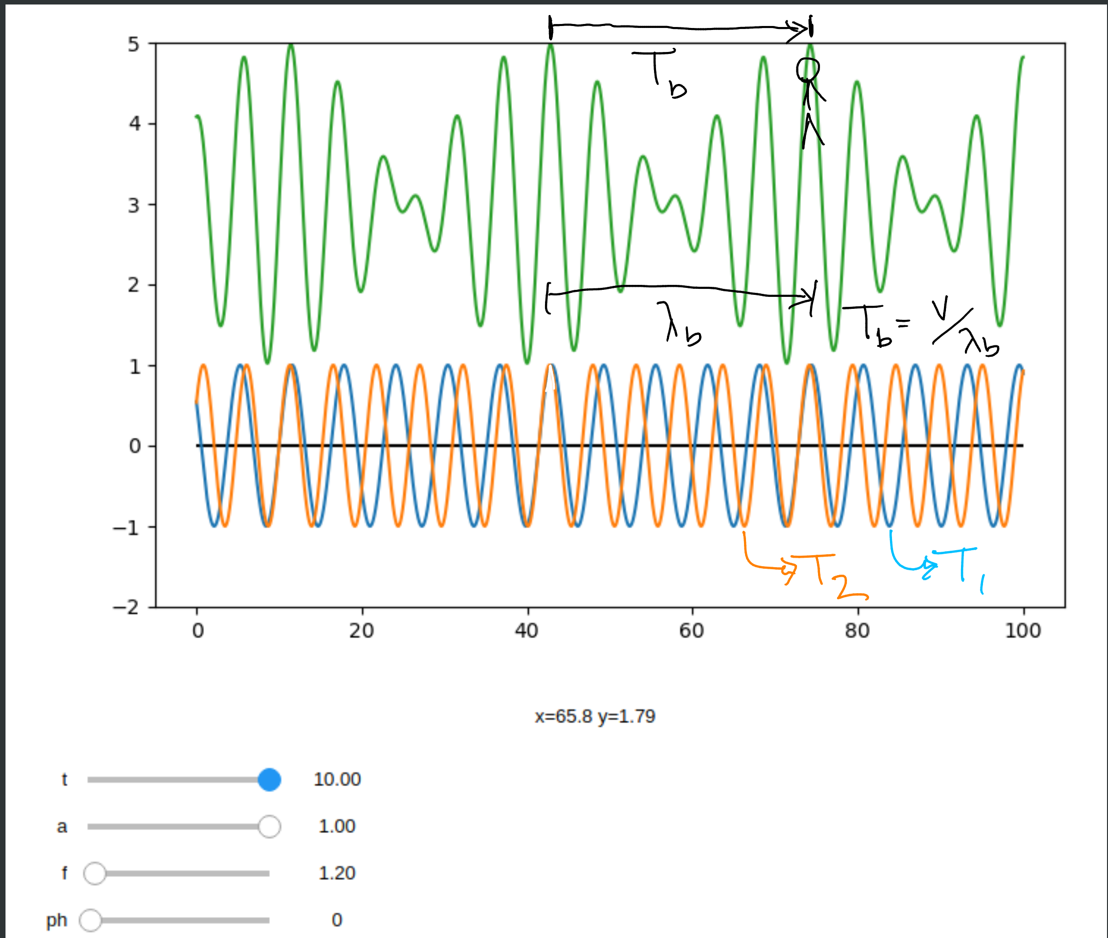






timbre – tone quality

Frequency Beating



\# of T_2 in T_b | \# of T_1 in T_b

$$\frac{T_b}{T_2} = \frac{T_b}{T_1} + 1$$

$$\frac{T_b}{T_2} - \frac{T_b}{T_1} = 1$$

$$T_b\left(\frac{1}{T_2} - \frac{1}{T_1}\right) = 1$$

$$\frac{1}{T_2} - \frac{1}{T_1} = \frac{1}{T_b}$$

$$|f_2 - f_1| = f_b$$

f_b → beat frequency