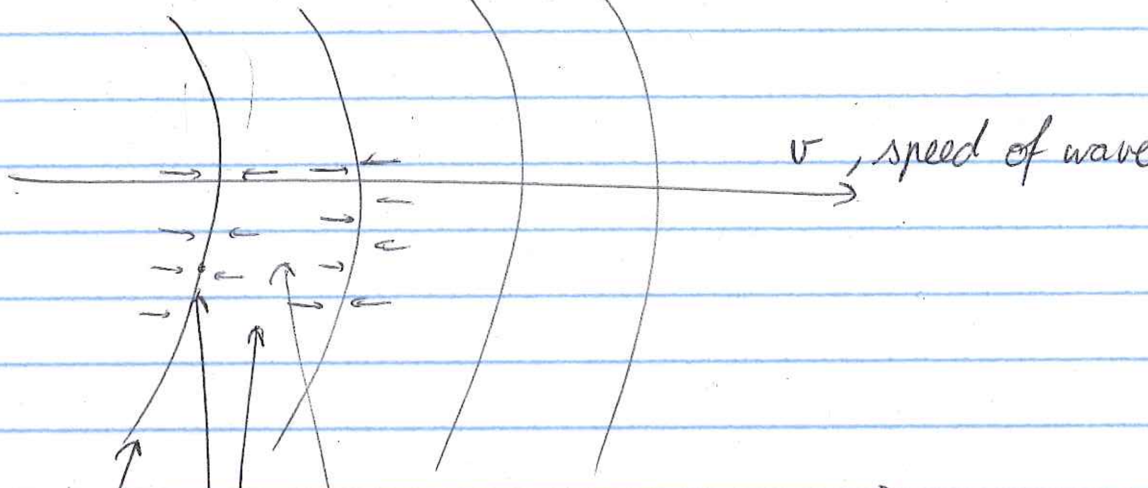
* Sound waves : longitudinal



higher pressure

↓

no movement of air molecules

lower pressure ("rarefaction")

↪ largest movement of air molecules → at the scale of nm, μm

pitch of sound waves ~ frequency

20 Hz → 20 000 Hz

20 kHz

lower frequencies
infrasound

higher frequencies
ultrasound

$\lambda \propto \frac{1}{f}$: speed of sound $\underline{v = \lambda f}$ = $\underline{\underline{331\ m/s \text{ at } 0°C}}$

long λ, long musical instrument → low frequency

short λ, → high frequency

$v_{air\,(at\,0°C)} = 331\ m/s$

$v_{water} = 1480\ m/s$

$v_{steel} = 5960\ m/s$

in any gas: $\underline{v \propto \sqrt{T}}$

T in Kelvin
= T in Celsius + 273 K

$0°C = 273K$
$20°C = 293K$

$$v = 331\ m/s \sqrt{\frac{T}{273K}}$$

$v_{air\ at\ 20°C} = 343\ m/s \quad (T = 293K)$

λ constant, changing $v_{He} \rightarrow$ change f

* Sound intensity : I in units of W/m^2

$I_0 = 10^{-12}\ W/m^2 \longrightarrow 10^{2}\ W/m^2$

threshold of human hearing — threshold of damage

0 dB — 140 dB

sound level in $\underline{d}B = \beta = 10\ {}^{10}\log \frac{I}{I_0}$

$I = 10^{-6}\ W/m^2 \rightarrow \beta = 10\ {}^{10}\log \frac{10^{-6}\ W/m^2}{10^{-12}\ W/m^2}$

$\beta = 10\ \underbrace{{}^{10}\log\ 10^{+6}}_{6}\ \cancel{W/m^2} = 10 \cdot 6 = \underline{60\ dB}$

if $A = 10^B$, then $B = {}^{10}\log A$

$\left(A = \underline{1000} = 10^3 \quad B = 3 \right)$ $\quad {}^{10}\log 10^3 = +3$

$A = 10^{-3} = 0.001$

$B = -3 \Big) \longrightarrow {}^{10}\log 10^{-3} = -3$

$\log_{10} 10^3$

${}^{10}\log \underline{1234} = +3.\ldots$

10000

$$\beta = 10\, {}^{10}\log \frac{I}{I_0} = 10\left({}^{10}\log I - {}^{10}\log I_0 \right) = 10\left({}^{10}\log I + 12 \right)$$

$$\log(A \cdot B) = \log A + \log B$$

$$\log\left(\frac{A}{B}\right) = \log A - \log B$$

$\Delta\beta = 10\,\text{dB} \longrightarrow 10\times$ higher intensity

(70 dB sound has $10\times$ higher intensity than a 60 dB sound)

$\Delta\beta = 100\,\text{dB} \longrightarrow 10^{10}\times$ higher intensity

$\Delta\beta = 20\,\text{dB} \longrightarrow 10\times10\times$ higher intensity $= 100\times$

$\Delta\beta = 30\,\text{dB} \longrightarrow 1000\times$ higher intensity

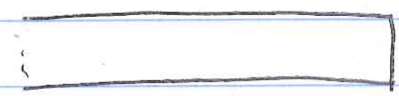
$I \to 2I$: $\quad \beta = 10 \log \frac{2I}{I_0}$

$$= \underbrace{10\log 2}_{3\text{dB}} + \underbrace{10 \log \frac{I}{I_0}}_{60\text{ dB}}$$

$= 63\,\text{dB}$

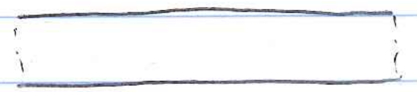
* Standing waves in pipes

2 cases



open   closed → zero motion of the air molecules

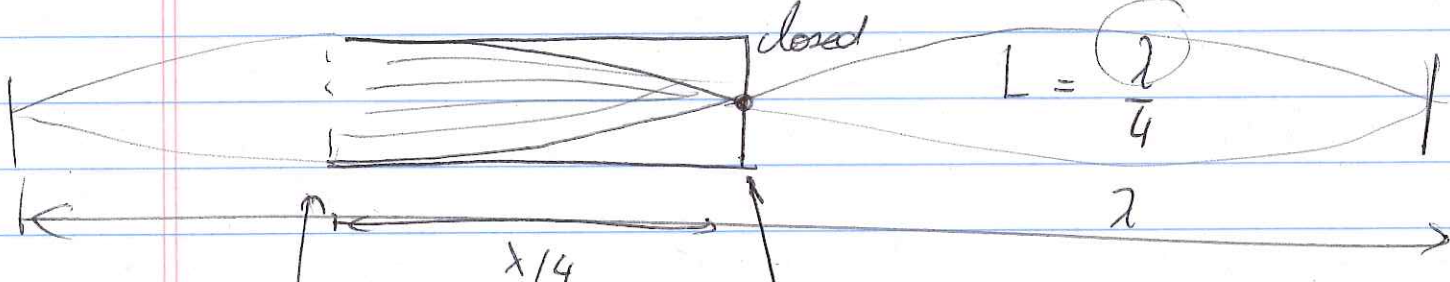
↳ maximum amplitude of the pressure



open   open → zero pressure

maximum amplitude of motion

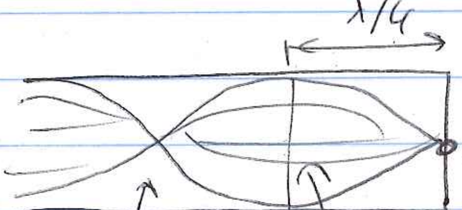
open/closed pipe



$L = \frac{\lambda}{4}$

antinode   node

fundamental, $n = 1$



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

antinode   node   1st overtone   antinode   node

2nd overtone $L = 5\frac{\lambda}{4}$

$\Longrightarrow L = n\frac{\lambda}{4}$, $n = 1, 3, 5, \ldots$ (odd)

$$L = n\frac{\lambda}{4} = \frac{n}{4}\frac{v}{f} \rightarrow \underline{f = \frac{nv}{4L}, \quad n = 1, 3, 5, \ldots \text{ (odd)}}$$

$$v = \lambda f \rightarrow \lambda = \frac{v}{f}$$

open/closed pipes