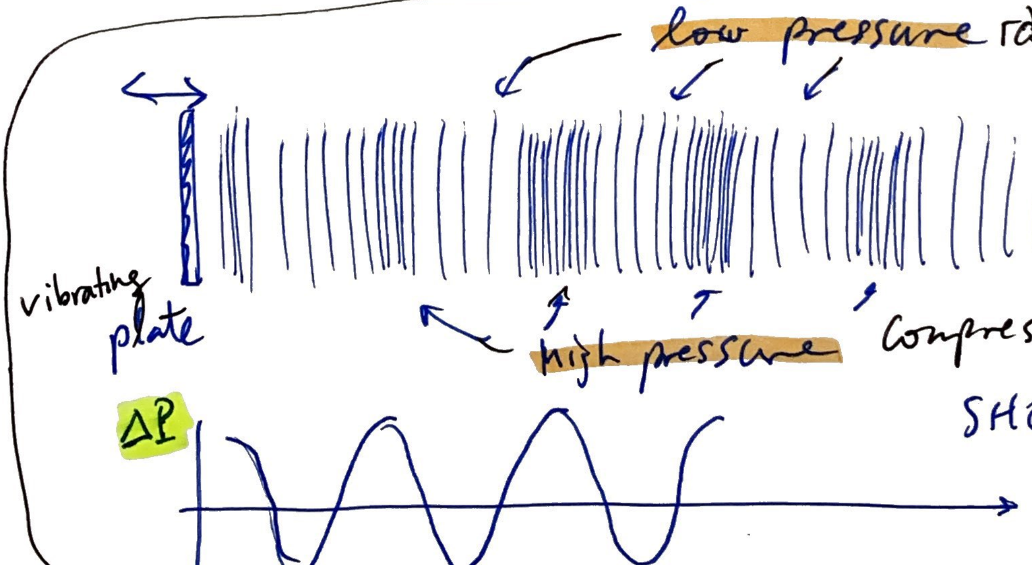
Chapter 12 A Sound – an application of Oscillation ①

We focus on oscillatory disturbances in air.
We call these "sound waves"

- Sound is probably best refered to those disturbances we can hear with our ears. Dogs can hear higher frequencies than people {ultrasonic Sound}
- Sound can travel in other medium like steel.

Sound propagates by a disturbance at one layer of atoms, and by cohesion to the next layer, passes the propagation onto that layer: "Stadium Wave" Fashion

The medium is often considered to be a liquid so the sound waves are pressure waves (longitudinal)



SHOscillation mean the shape is a sine wave.

The speed of sound depends on the density of the medium "In Space No One can hear you scream"

air @ 20°C	343 m/s		gas
air @ 0°C	331 m/s	← most dense	gas
He	1005 m/s		gas
H	1300 m/s	← least dense	gas
water	1440 m/s		liquids
salt water	1560 m/s		liquids
Iron/Steel	5000 m/s		solids
Glass	4500 m/s		solids
Aluminum	5100 m/s		solids

In air $\boxed{V \approx 331 + 0.60T}$ celcius °C

EX How many seconds does it take a lightning bolt's sound to reach our ears if it is at 1 mile distance?

use 20°C $\quad v = 331 + 0.60(20) = \underline{343 \text{ m/s}}$

- $v = \dfrac{d}{t} \rightarrow t = \dfrac{d}{v} = \dfrac{1\,\text{mi}\left(\frac{1.6\,\text{km}}{\text{mi}}\right) * 1000\,\frac{\text{m}}{\text{km}}}{343\,\text{m/s}} = \underline{4.7 \text{ seconds}}$

about 5 seconds travel/mi distance.

Sound Intensities

- **Loudness** is related to **intensity, I** $= \frac{\text{power}}{\text{area}}$

- **Pitch** is related to frequency: flute vs. Tuba

Humans can hear 20Hz to 22000Hz ← good ears

- Subwoofers produce vibrations that may (will) go below 20Hz then we just feel the disturbance (L^ow^F^req.^Events) this range is called Infrasonic {some cultures use this range for healing}
- Tweeters produce the high frequencies

- Ultrasonic Sound: higher than 22,000Hz

  dogs up to 50,000Hz
  bats up to 100,000Hz

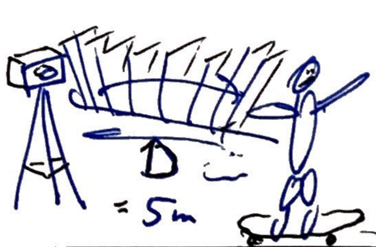
EX Some autofocus mechanisms in cameras use ultrasonic sound pulses.

Q: From the time the exposure button is pushed until the camera captures the image is

Down and Back

$$2 * D = 2\left(\frac{d}{v}\right) = 2\left(\frac{5m}{340 m/s}\right) = 0.029\ s$$

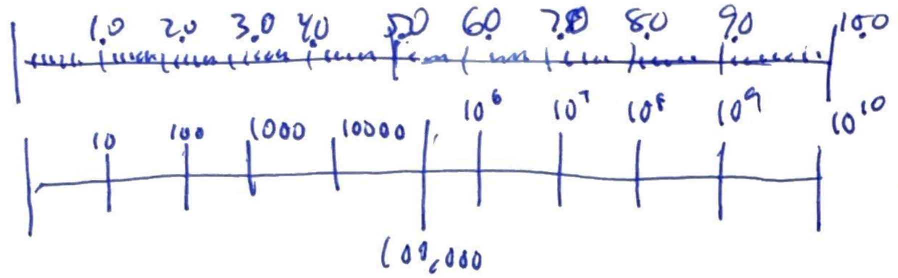
$$\boxed{29 ms}$$



Intensity: The "Decibel"

The average human ear can hear sound disturbances as quiet as $10^{-12}\ W/m^2$; and as loud as $\boxed{1\ W/m^2 \text{ before hearing loss occurs.}}$

This is quite a range so physicists use logarithms



← 10

← 10 billion

The integer becomes a power of 10.

Harvey Fletcher – acoustics – came up with a measuring scale called ~~the~~ $\underbrace{\text{deci}}_{10}$ bell ← Alexander Graham Bell

function of "I"

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

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

threshold of human hearing

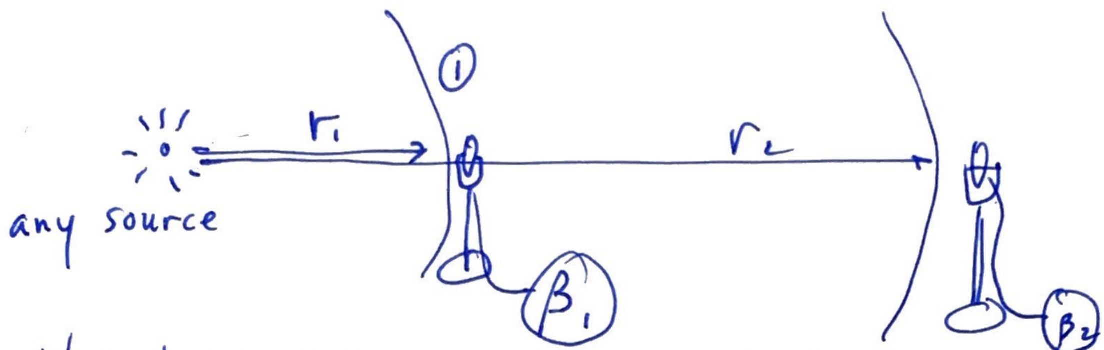
EX

Threshold	$\beta = 0$ dB	since $\log(1) = 0$
Leaves	$\beta = 10$ dB	
whispers	30 dB	
Talking	65 dB	
Noisy Restaurants	70 dB	
Siren	100 dB	
Rock Concert	120 dB	
Pain	120 dB	

Jet on the tarmac 140 dB

Comparing Sound Intensities.

We usually have some kind of reference sound. Then as we travel further away from the source we hear a lesser loudness.



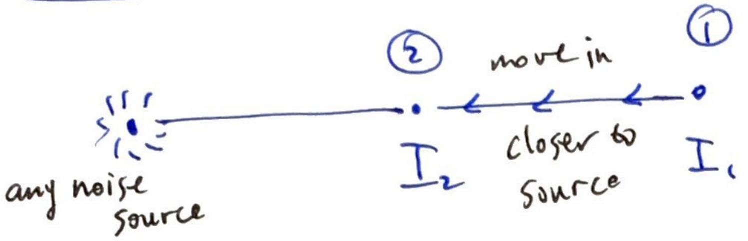
The difference in decibels between the two locations is

$$\Delta\beta = \beta_2 - \beta_1$$
$$= 10\log\left(\frac{I_2}{I_0}\right) - 10\log\left(\frac{I_1}{I_0}\right)$$
$$= \log\left(\frac{I_2}{I_0}\right)^{10} - \log\left(\frac{I_1}{I_0}\right)^{10}$$
$$= \log\left(\frac{(I_2/I_0)^{10}}{(I_1/I_0)^{10}}\right)$$

$\log(a) - \log(b) = \log\left(\frac{a}{b}\right)$

$$\boxed{\beta_2 - \beta_1 = 10\log\left(\frac{I_2}{I_1}\right)}$$

EX By what $\Delta\beta$ will sound intensity double as you approach a loud source?



- Sound Intensity $= I$, Sound level usually is "β"

$$I_2 = 2I_1$$

then $$\Delta\beta = 10\log\left(\frac{I_2}{I_1}\right)$$

$$= 10\log\left(\frac{2\cancel{I_1}}{\cancel{I_1}}\right)$$

$$= 10\log(2) = 10(0.301) \approx 3\,dB$$

Q: what about tripling the sound intensity?

$$I_2 = 3I_1$$

$$\Delta\beta = 10\log(3) = 4.8\,dB$$

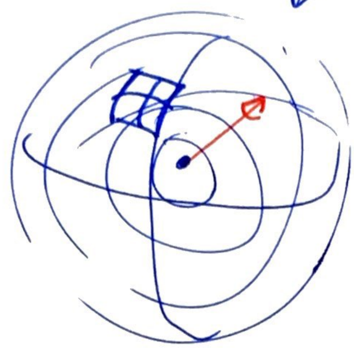
small dB changes will double & triple intensity!!

((Review))

⊛ Sound Decay

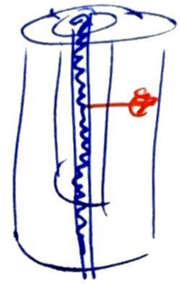
spherical shells

$\boxed{\text{3-D}}$ point source



$\boxed{I \propto \frac{1}{r^2}}$

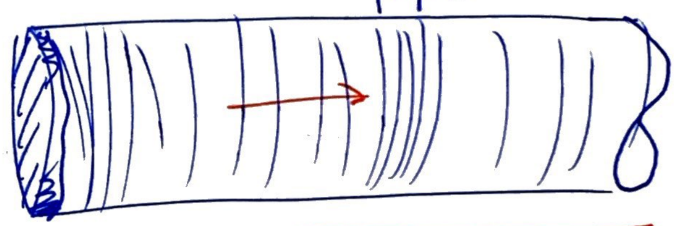
$\boxed{\text{2-D}}$ Line source



$\boxed{I \propto \frac{1}{r}}$

$\boxed{\text{1-D}}$ source

pipe



$\boxed{I = \text{const.}}$

EX A trumpeter plays @ 75 dB @ 10 m away from us. Now 3 more trumpets join in. What is the new sound level in dB

- Rule of thumb: 3 dB doubles

so 1 trumpet + 1 = 2 trumpets : $75 + 3 = \underline{78}$ dB

so 2 trumpets + 2 = 4 trumpets : $78 + 3 = \boxed{81\text{ dB}}$

- Analytical approach

$$\beta = 10 \log\left(\frac{4I_1}{I_0}\right) = 10 \log\left(\overset{a}{4} \cdot \overset{b}{\frac{I_1}{I_0}}\right)$$

$$= 10\left[\log(4) + \log\left(\frac{I_1}{I_0}\right)\right]$$

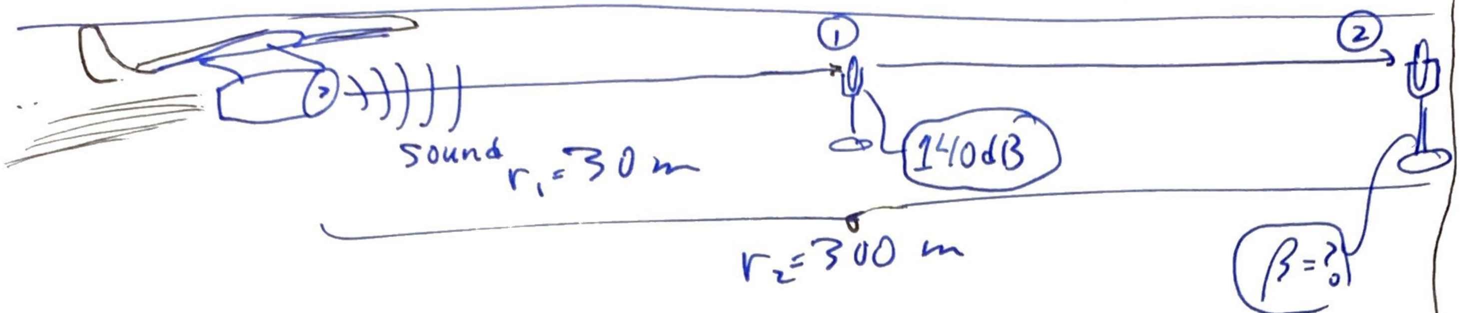
$$= \underbrace{10\log(4)}_{6.02} + \underbrace{10\log\left(\frac{I_1}{I_0}\right)}_{75\text{ dB}}$$

$$= \boxed{81.02\text{ dB}}$$

$\log(a) + \log(b) = \underline{\log(a \cdot b)}$

EX 30 m from a jet we measure 140 dB sound level (9)

Q: What is the sound level @ 300 m from the source?



(i) Find I_1 : $\beta_1 = 10\log\left(\frac{I_1}{I_0}\right)$

$$140\,dB = 10\log\left(I_1/I_0\right) \quad \div 10$$

$$14 = \log\left(I_1/I_0\right)$$ raise both sides as powers of 10

$$10^{14} = 10^{\log(I_1/I_0)}$$

math: $10^{\log(x)} = x$

$\log 10^{y} = y$

$$10^{14} = I_1/I_0$$

So $\underbrace{I_1}_{\text{intensity @ 1}} = 10^{14}(10^{-12}) = \boxed{100\ W/m^2}$

(ii) Use point-source decay to get I_2

$$\boxed{I_2 = \left(\frac{r_1}{r_2}\right)^2 I_1} = \left(\frac{30m}{300m}\right)^2 100\frac{W}{m^2} = \boxed{1\ \frac{W}{m^2}}$$

$I_0 \rightarrow \frac{I_0}{r_1^2} = I_1$

$I_0 \rightarrow I_0/r_2^2 = I_2$

$$\frac{r_2^2}{r_1^2} = \frac{I_1}{I_2}$$

$$\boxed{I_2 = \left(\frac{r_1}{r_2}\right)^2 I_1}$$

(iii) $\beta_2 = 10\log\left(\frac{I_2}{I_0}\right)$

$$= 10\log\left(\frac{1}{10^{-12}}\right) = 10\log(10^{12}) = 10 \cdot 12$$

$$= \boxed{120\,dB\ @\ ②\ 300\,m}$$

Amplitude (chpt 11) & Intensity

$$\boxed{A = \frac{1}{f\pi}\sqrt{\frac{I}{2\rho V}}}$$

I = intensity
f = frequency of sound
V = velocity of sound
ρ = density of medium

EX Find the displacement of an air molecule vibrating @ 1000 Hz
For threshold of sound 10^{-12} W/m²

with density $\rho_{air} = 1.29$ kg/m³

$V_{air} = 343$ m/s

we get
$$A = \frac{1}{\pi(1000\,Hz)}\sqrt{\frac{10^{-12}\,W/m^2}{2(1.29\,kg/m^3)(343\,m/s)}}$$

$$\boxed{A = 1.07\times10^{-11}\,m} = 10^{-8}\,mm \quad \tfrac{1}{10} \text{ of a billionth of a mm}$$

back and forth motion of the air atom

EX Repeat for pain level sound ; 120 dB

$$\beta = 10\log\left(\frac{I}{I_0}\right) \rightarrow 120\,dB = 10\log\left(\frac{I}{10^{-12}}\right) \rightarrow \boxed{I = 1\,W/m^2}$$

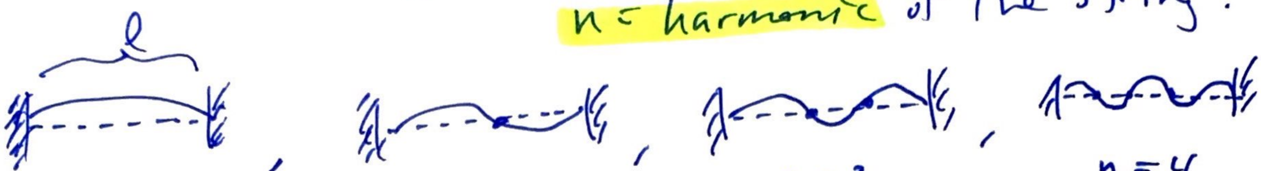
So then
$$A = \frac{1}{1000\,Hz\,\pi}\sqrt{\frac{1\,W/m^2}{2(1.29)(343)}} = 1.07\times10^{-5}\,m$$

or $\boxed{A = 0.011\,mm}$ or $\frac{1}{100}$ of a mm

⊛ Strings as a source of Sound (Review)

strings (chpt 11) $\boxed{f_n = n f_1 \ , \ \text{but } f_1 = \frac{v}{2l} \ , \ n = 1, 2, 3 \cdots}$

n = harmonic of the string.



$n=1$, $n=2$, $n=3$, $n=4$

· Tension of the string $\boxed{v = \sqrt{\frac{F_T}{\mu}}}$ wave speed.

Heavier strings have slower wave speeds.

· wavelength $\boxed{f_1 = \frac{v}{\lambda_1} \ , \ \lambda_1 = 2l \ , \ \lambda_n = \frac{2l}{n}}$

Ex If a piano used the same string material for all keys (notes) how long would the lowest note string need to be?

Set-up

High note is 150 times the freq. of the lowest note.

If the strings have the same tension and the same mass densities then

$$\boxed{F_{T_{low}} = F_{T_{high}}} \quad \& \quad \boxed{\mu_{low} = \mu_{high}}$$

So $\Rightarrow$ $\boxed{v = \sqrt{\dfrac{F_T}{\mu}}} \Rightarrow v_{low} = v_{high}$

then $\boxed{f = \dfrac{v}{\lambda} = \dfrac{v}{2l}}$ ← 1st harmonic

In this piano... frequency is only a factor of length

ratio

Consider the ratio $\dfrac{f_{low}}{f_{high}} = \dfrac{v/2l_{low}}{v/2l_{high}} \Rightarrow \boxed{\dfrac{f_l}{f_h} = \dfrac{l_h}{l_{low}}}$

So if we have factor the $\dfrac{1}{150} = \dfrac{l_{high}}{l_{low}}$

$$\Rightarrow \boxed{l_{low} = 150\, l_{high}}$$

So if the top key has a string 5 cm in length, the the low note would need $150 \cdot 5\text{cm} = \boxed{75\text{m}}$

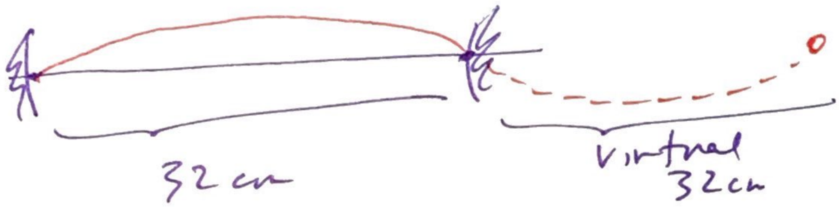
75 m →

EX A 0.32m long $\boxed{\text{violin string}}$ is tuned to play the "A" note above middle C (440Hz).

(a) what is the wavelength of this "A" on the string?

$$\lambda_1 = \frac{2l}{n}\Big|_{n=1} = \frac{2l}{1}, \quad 2 * 0.32m = 0.64m$$

or 64cm



(b) what is the wavelength when the sound hits our ear via the air?

$$\lambda = \frac{V_{medium}}{f} = \frac{343\ m/s}{440Hz} = 0.78m \text{ or } 78\text{ cm}$$

(c) why the difference? The frequencies of the string and the sound at our ears are the same. but the medium (steel vs air) is different thus the wavelength is different.

{ end 12 A - string sound
{ next 12 B - pipe sound