Puzzler

Imagine that you have three boxes, one containing two black marbles, one containing two white marbles, and the third, one black marble and one white marble. The boxes were labeled for their contents – BB, WW and BW – but someone has switched the labels so that <u>every box is now incorrectly labeled</u>. You are allowed to take one marble at a time out of any box, without looking inside, and by this process of sampling you are to determine the contents of all three boxes. What is the smallest number of drawings needed to do this?

Solution: One !!!

The key is that <u>every box is incorrectly labeled</u>.

Draw a marble from the box labeled BW

Assume it is black. – you now know which box has 2 black marbles.

Therefore you know the contents of the box labeled WW must be BW (it can't be labeled correctly!)

Then the third box labeled BB must hold WW marbles

Introduction to Audio and Music Engineering

Lecture 7

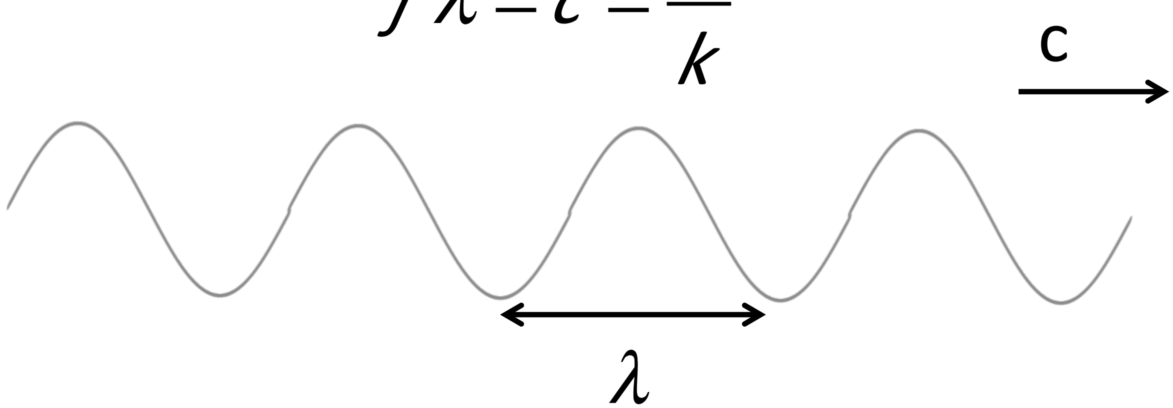
- Sound waves
- Sound localization
- Sound pressure level
- Range of human hearing
- Sound intensity and power

Waves in Space and Time

Period:	T	Seconds
Frequency:	$f = 1/T$	Hertz (cycles per second)
Angular Frequency:	$\omega = 2\pi f$	Radians per second
Spatial Wavelength:	λ	Meters
Spatial Wavenumber:	$k = 2\pi / \lambda$	Radians per meter

On a string the frequency of oscillation and the wavelength are connected through the speed of propagation of a bending wave.

$$f\lambda = c = \frac{\omega}{k}$$

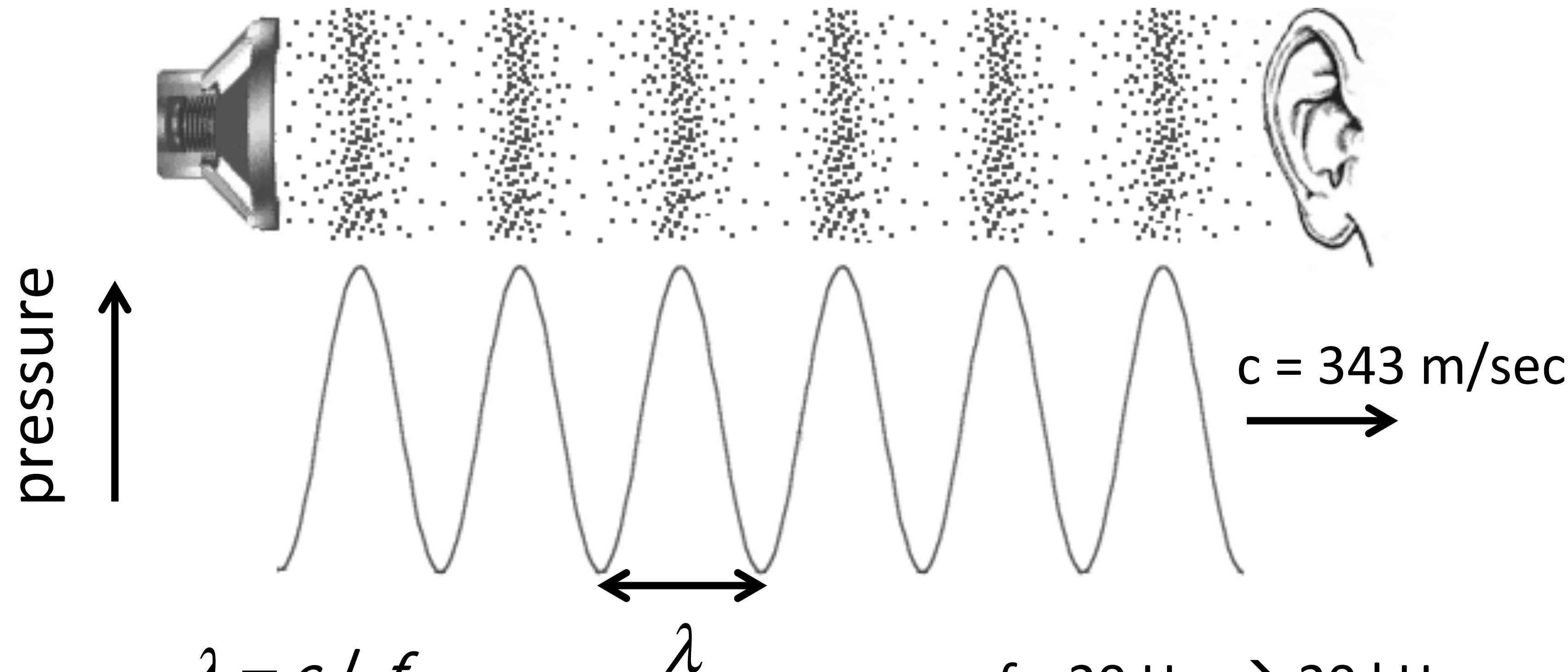


Sound waves

Sound is a Longitudinal Wave: Disturbance varies along the direction of propagation.

Transverse wave: (string) Disturbance varies in a direction perpendicular to the direction of propagation.

Density of air = 1.21 kg/m^3



$\lambda = c / f$

$f \approx$ 20 Hz → 20 kHz

Question

What is the wavelength of a sound wave of frequency 20 Hz?

$c = 343$ m/sec

17.15 meters

Wavelength = 1.715 cm @ 20 kHz

$$20 \text{ Hz} \leq f \leq 20 \text{ kHz}$$

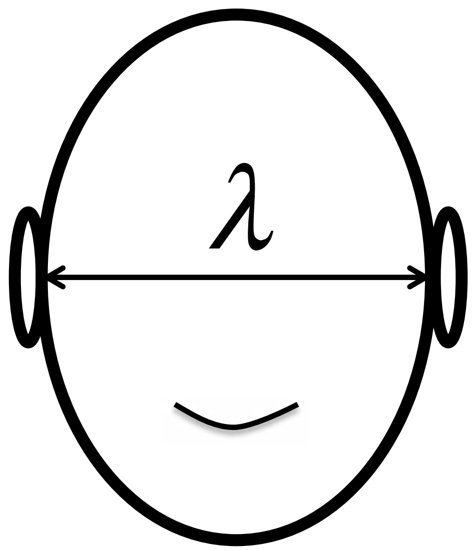
$$17 \text{ m} \leq \lambda \leq 1.7 \text{ cm}$$

$c = 343$ m/sec = 1125 ft/sec → about 1 foot per millisecond

Remember this!

Human ability to localize sound

Distance between human ears is ≈ 22 – 24 cm



$$f = c / \lambda$$

$f \approx$ 1430 Hz

Sound localization

f < 1500 Hz	f > 1500 Hz
Wavelength is larger than distance between ears	Wavelength is smaller than distance between ears

Humans determine directionality of sound by two basic methods:

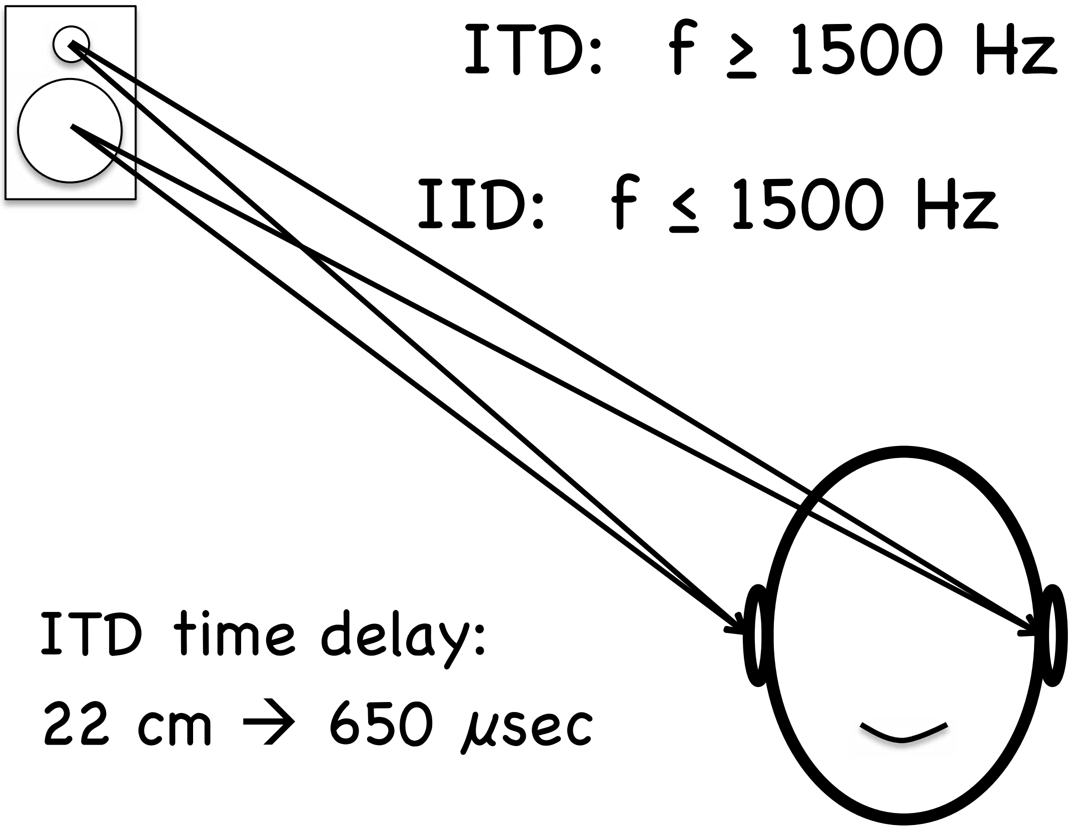
Interaural Time Difference (ITD)	*Interaural Intensity Difference (IID)*
f < 1500 Hz	f > 1500 Hz

But there is some overlap of methods in the range 800:1600 Hz

IID and ITD

ITD: f $\geq$ 1500 Hz

IID: f $\leq$ 1500 Hz



ITD time delay:

22 cm → 650 μsec

The shape of the outer ear (pinna) plays a significant role in 3D audio; Head Related Transfer Function: HRTF

Head shadows the sound at more distant ear.

Sound Pressure Level

$$SPL = 20\log_{10}\frac{P}{P_{ref}}$$

P is the measured pressure

P_{ref} = 20 μPa (micro-Pascals)

1 Pascal = 1 Newton/meter^2

Sound pressure of 20 μPa → 0 dB SPL

Sound pressure of 20 Pa → 120 dB SPL

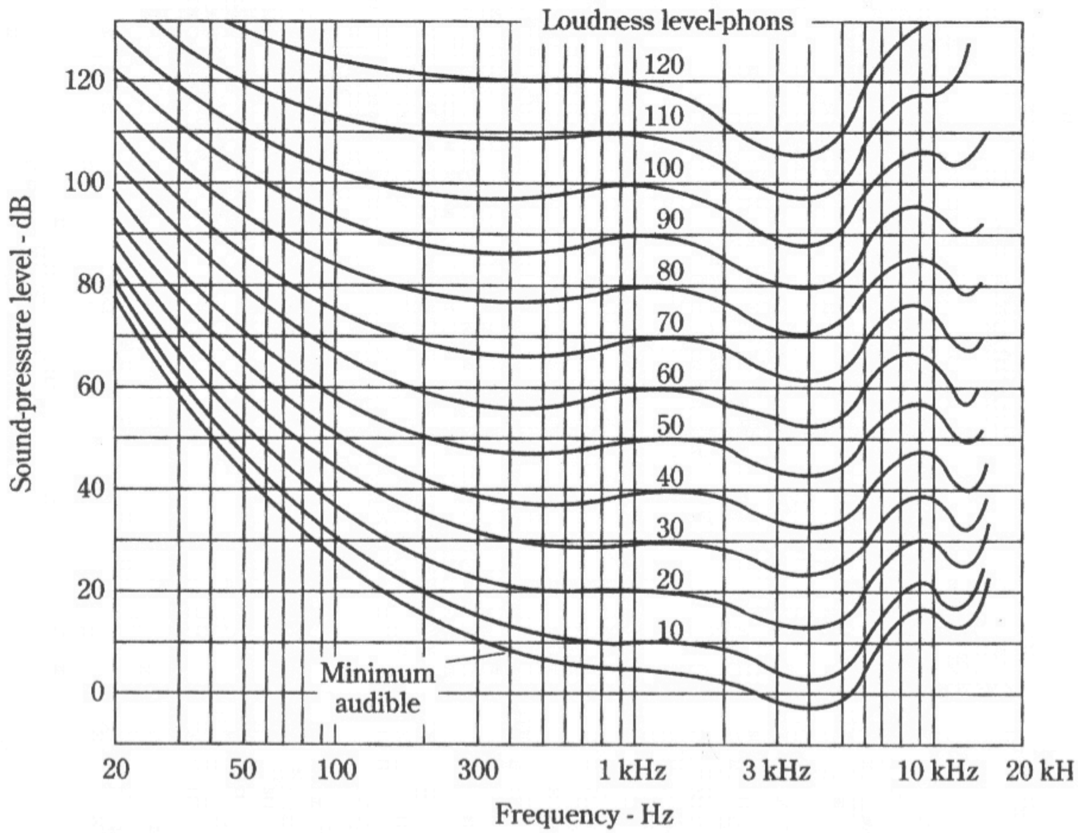
1 Atmosphere = 14.7 lbs/in^2 = 1.01 x 10^5 Pascals

1 Atmosphere = 194 dB SPL

Range of Human Hearing

Average Home Hi-Fi Level	90
Average Factory	80
	70
Average Conversation	60
Average Office	50
Residential Ambient Noise	40
Quiet Whisper (5 feet)	30
	20
	10
Threshold of Hearing 0.0002 Dyne/Sq. cm	0

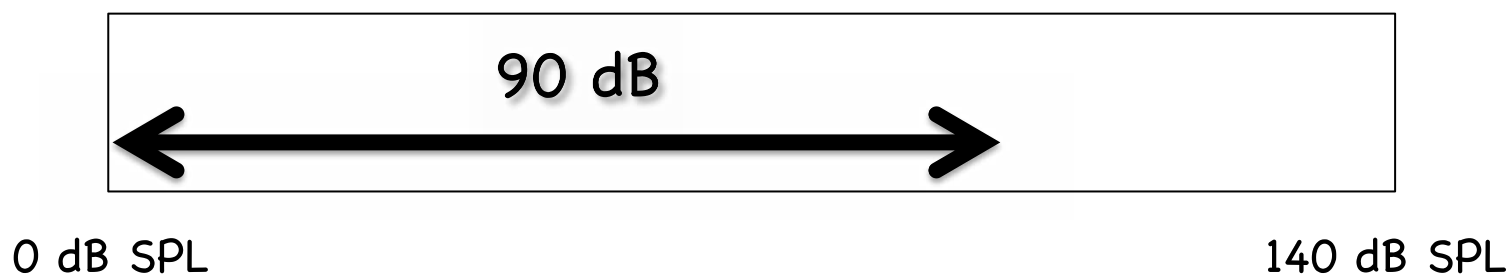
dbSPL Table



3-6 Equal-loudness contours of the human ear. These contours reveal the relative lack of sensitivity of the ear to bass tones, especially at lower sound levels. Inverting these curves give the frequency response of the ear in terms of loudness level. (After Robinson and Dadson.[8])

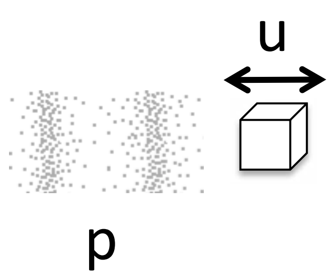
Adaptation of Human Hearing

At any given time we hear over a dynamic range of about 90 dB. Our auditory system adapts our hearing sensitivity to the average SPL – much like our eye adjusts to different lighting conditions.



Sound Intensity and Power

Sound Intensity: When a pressure wave propagates through air the air moves slightly.



$I = p \times u$

Dimensional Analysis

$$\frac{Nt}{m^2}\frac{m}{\sec} = \frac{Nt \cdot m}{\sec}\frac{1}{m^2} = \frac{energy}{\sec}\frac{1}{area} = \frac{power}{area}$$

$$u = \frac{p}{\rho c}$$

Density of air → ρ; c ← Speed of sound

ρc "Impedance" of air

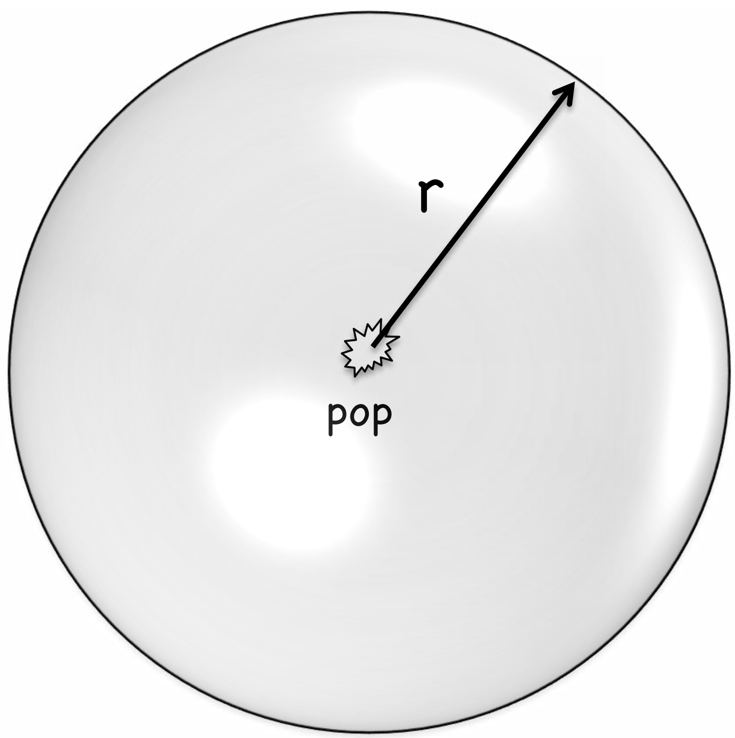
Small → air moves a lot

Large → air moves little

So … $I = \dfrac{p^2}{\rho c}$

Sound Intensity ≈ Pressure^2

Inverse Square Law



Power = I x $4\pi r^2$

I = Power / $4\pi r^2$

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

Total Radiated Sound Power
<u>of Musical Instruments</u>

Entire Orchestra ≈ 75 Watts

Trombone ≈ 6 watts

Violin ≈ 0.1 W