Ch12 Sound

12-1

	v
air	343 m/s
0°C	331
He	1005

ex1 ("1 mile for every 5 s before thunder heard")

($c = 3\times10^8$ m/s instantaneous)

1 mile = 1.6 km

Hear 5 s later, how far away?

$$d = v_{sound} \times 5 = 1715\ m$$

343

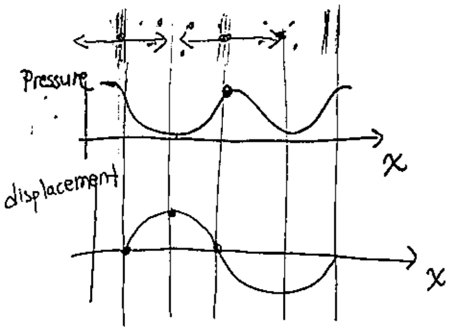
- Loudness ~ intensity
- Pitch ~ frequency

20 Hz ~ 20000 Hz — Humans

infrasonic — 10 kHz — ultrasonic

- resonate w/ body organs
- machinery troublesome

- Longitudinal



Note: $\frac{1}{4}$ wavelength out of phase

12-2 Intensity of Sound: Decibels

-(Try it! 12-3)

$$I = \frac{\text{power}}{\text{area}} \quad \frac{\text{Watts}}{m^2} \quad \sim A^2 \quad \sim \frac{1}{r^2}$$

ear: 10^{-12} W/m² ~ 1 W/m² (pain)

Loud × 2 ~ I × 10

decibel (Alexander Graham Bell)

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

sound level

$(I_0 = 10^{-12}\ W/m^2)$ Threshold of hearing

	β		$\frac{I}{I_0}$
Threshold	0 dB	$= 10\log_{10}(1)$	
leaves	10 dB	$= 10\log_{10}\left(\frac{10 I_0}{I_0}\right)$	×10
3× Louder	20 dB		×10
whisper	30 dB (+10)	$= 10\log_{10}\left(\frac{1000 I_0}{I_0}\right)$	×1000
Noisy restaurant	70 dB	$= 10\log_{10}\left(\frac{10^7 I_0}{I_0}\right)$	×10⁶

+6×10

★ +10 dB ⇒ ×10 I

ex3

ex4 ★ engineering, $SNR(dB) = 10\log_{10}\left(\frac{S}{N}\right)$

why is 3 dB special? "3 dB cutoff frequency" etc

(for sounds, 3 dB difference means...)

$$3dB = \beta_2 - \beta_1 = 10\log(I_2/I_1) \Rightarrow \frac{I_2}{I_1} = 10^{3/10} \approx 2$$

★ 3 dB difference means intensity $\times\boxed{2}$

Ⓐ 6 dB difference means intensity ... ×4

ex5 1 trumpet 75dB
3 more

(NO CALC) $\beta = ?$ $I \times 4 \Rightarrow dB + 6 = \boxed{81 dB}$

(B) 1 person : 65dB
2 people ⇒ 68 dB . $I \times 2 \Rightarrow 65 + 3 dB$

ex6

30 m from plane , 140 dB
estimate sound level at 300m.

$\boxed{\begin{array}{l} +3dB, \ I\times 2 \\ +10dB, \ I\times 10 \end{array}}$

Soln. (NO CALC) a) $10\times$ far $\rightarrow \frac{1}{100} I \rightarrow dB - 20 \rightarrow \boxed{120 dB}$

b) By eqns.

$$I_2 = \frac{1}{100} I_1 \qquad \overset{140}{\beta_1} = 10\log_{10}\left(\frac{I_1}{I_0}\right) \Rightarrow I_1 = I_0 10^{14}$$

$$\beta_2 = 10\log_{10}\left(\frac{I_2}{I_0}\right) = 10\log_{10}\left(\frac{\cancel{I_0} 10^{14}/100}{\cancel{I_0}}\right)$$

$$= 120 \, dB$$

ex7 air molecules' displacement?
sound freq 1000 Hz
at threshold of hearing

(Eqn 11-18 $I = 2\pi^2 \rho v f^2 A^2$)

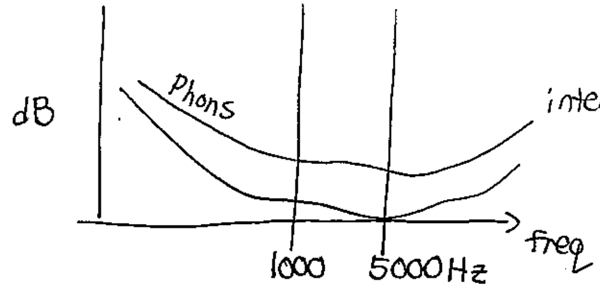
$$A = \frac{1}{\pi f}\sqrt{\frac{I}{2\rho v}} = \frac{1}{\pi(10^3)}\sqrt{\frac{10^{-12}}{2(1.29 kg/m^3)(343 m/s)}}$$

Table 10-1

$= 1.1\times 10^{-11} m$ < atom diameter $10^{-10} m$
(& human ear can detect!)

12-3 Human ear

- see SmartBoard?
- Loudness level (phons) by frequency ★Try It!



- same phon for less dB means ear sensitive to freqs 1000 ~ 5000 Hz

12-4 Vibrating Strings & Air Columns (Sources of Sound)

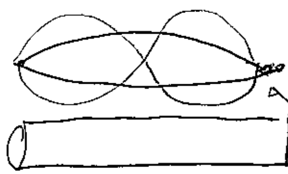
- Vibrate

★Standing wave at natural fundamental freq $v = \sqrt{\frac{T}{\mu}}$

(Show fork on SmartBoard) sounding Board (force plane to f_1) louder

Pluck

tube



$f_1 = \frac{v}{\lambda_1}$, $\lambda_1 = 2l$

$f_2 = 2f_1 = n\frac{v}{2l}$

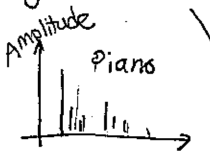
harmonics set up too!

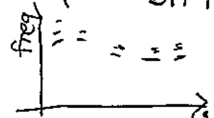
- timbre ~ strength of higher harmonics
- noise vs note

★ Frequency Table 12-3

octave freq × 2 ★!

(Show) FS FT DFT FFT STFT DTFT





sharper sound

• Why ①

violin

② • Why?
- ear resonates maybe at note
$f_1 \times 2$ harmonic gives same sense

Push twice freq still resonates.

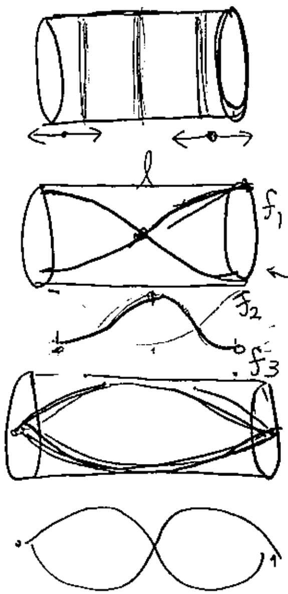
Wind instruments

★ demo/measure pink whirly tube? (~~half open/closed~~) ← measure $\ell \Rightarrow f = \frac{343\ m/s}{4 \times \ell}$ Hz ?

↳ Length ℓ freq
I think it's both open

$C = 262 Hz$
make note
⇓
$\ell = 0.327\ m$?

open Tube, flute, organ



displacement
- free to move in/out
- antinodes

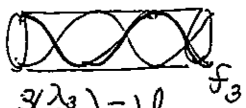
← fundamental standing wave
$2\left(\frac{\lambda_2}{2}\right) = 1\ell$

pressure
at ends, atmospheric won't change!

$f_1 = \frac{v}{2\ell} = \frac{343\ m/s}{2(0.5m)} \approx 343\ Hz$?
Tape Notes down? C 262 Hz → 0.655 m
Play Scale! song D 294 Hz → 0.583 m

$f_1 = \frac{v}{\lambda_1} = \frac{v}{2\ell}$

$f_n = n\frac{v}{2\ell}$



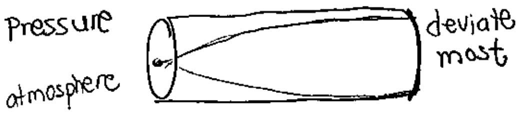
$3\left(\frac{\lambda_3}{2}\right) = 1\ell$

Displacement

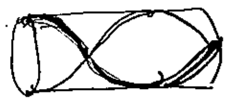
$\ell = \frac{\lambda_1}{4}$

$f_1 = \frac{v}{4\ell}$

Pressure



Try Sketching



$3\left(\frac{\lambda_3}{4}\right) = \ell$

$\ell = 5\left(\frac{\lambda_5}{4}\right)$

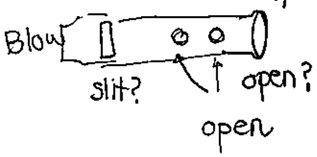
$f_3 = \frac{v}{\lambda} = 3\left(\frac{v}{4\ell}\right)$

$\Rightarrow 3^{rd}$ harmonic!

$f_5 = 5f_1$

★ $\boxed{\text{ODD}}$ harmonics only!

Why wave? What reflects? (atmospheric pressure)
How in flute??



$\lambda\uparrow,\ f\downarrow$
More fingers, Longer tube, lower sound

ex8 Piano

high string freq = 150 × Low freq

$l_H = 5.0\,cm$ $\quad l_L = ?$

(T, μ same)

$\lambda_{Low} = 2 l_{Low}$

$v = \lambda_H f_H = \lambda_L f_L$

$$l_{Low} = \frac{1}{2}\lambda_{Low} = \frac{1}{2}\left(\lambda_H \frac{f_H}{f_L}\right)$$

$$= \frac{1}{2}(2 \underset{0.05}{l_H} \times 150) = 7.5\,m = 750\,cm$$

ridiculous

$\therefore \mu_{Low}$ heavier

$(l_{Low} < 3\,m)$

(why? $\mu \uparrow \Rightarrow v \downarrow$ $\cancel{\Rightarrow \lambda f \downarrow}$ $\quad \lambda = \frac{v\downarrow}{f\downarrow}$ won't be so big)

ex9 violin

$l = 0.32\,m$

A = 440Hz (Note resonates!)

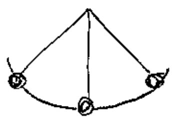
a) $\lambda = ? \; = 2l = 0.64\,m = 64\,cm$

b) $f_1 = ?$ of sound? same 440Hz

λ of sound? $= \frac{v_{sound}}{f} = \frac{343\,m/s}{440\,1/s} = 78\,cm$

c) Why different? v different

d) higher harmonics



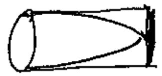
Push at right time still.

Like 2 matched tuning forks

★ (Push 2× freq, Still resonates!)

ex10 f_1, 1st 3 overtones for 26cm-long organ pipe at 20°C

a) open $\quad$ b) closed



$\lambda_1 = 2l$ $\quad \lambda_1 = 4l$

$$f_1 = \frac{v}{\lambda_1} = \frac{343\,m/s}{2(0.26\,m)} = 660\,Hz$$

1 octave higher!

$$f_1 = \frac{343}{4(0.26)} = 330\,Hz$$

$f_2 = 2f_1 \quad 1320$

$f_3 = \quad 1980$

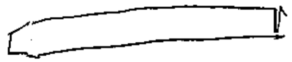
$f_4 \quad 2640$

$f_3 = 3f_1 = 990\,Hz$

$f_5 = \quad 1650$

$f_7 = \quad 2310$

ex11 All covered, middle C (262Hz)



$l = ?$

(both open)

$\lambda_1 = 2l$

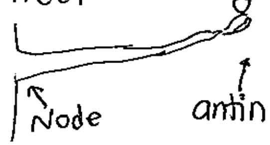
$$f_1 = \frac{343\,m/s}{2l} = 262\,Hz$$

$\therefore l = \boxed{0.655\,m}$

ex12 Tree, Chimney air column

- wind shakes tree, makes sound of same freq!
- The branch itself vibrates

(like string but one end's antinode!)



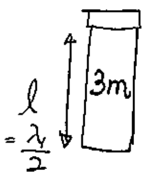
Node $\quad$ antinode

$l = 2\,m$

$$f_1 = \frac{v_{wood}\,?!}{4l} = \frac{4000}{4(2)} = \boxed{500\,Hz}$$

$v_{sound\ in\ wood} = 4000\,m/s$

$\therefore \frac{1}{4}\lambda_1$



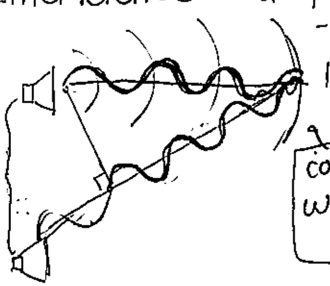
$l = \frac{\lambda}{2}$ $\quad$ 3m

Chimney. Both open

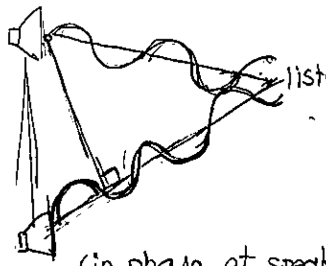
$$f_1 = ?\ \frac{343\,m/s}{2(3m)} = \boxed{57\,Hz}$$

12-6

Interference - as previously seen on water ripple photo. (CISE)
- See Picture in Book



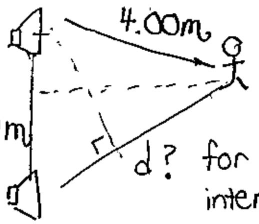
constructive when distance traveled difference $\boxed{\Delta d = n\lambda}$



(in phase at speakers)

destructive when $\boxed{\Delta d = n\frac{\lambda}{2}}$ (n odd)

ex13



($T = 20°C$ $v = 343\ m/s$)

$\Delta d = (2n+1)\frac{\lambda}{2}$

$= \frac{(2n+1)}{2}\left(\frac{v}{f}\right) = (2n+1)0.15$ $\left(\frac{343}{1150} = 0.30m\right)$

$f = 1150 Hz$

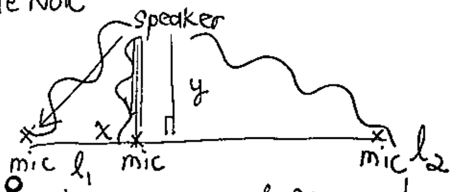
$d = 4 + \Delta d$

$= 4 + odd \cdot 0.15$

$= 4.15,\ 4.45,$ m away

3.85

Side Note

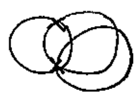


- microphone array & source location?

time delay $x = ?$ $y = ?$

$t_1 = \frac{\sqrt{l_1^2+y^2}}{v}$ $vt_2 = \sqrt{(x-l_2)^2+y^2}$ $\Rightarrow$ Solve x & y?

$vt_3 = \sqrt{(x-l_3)^2+y^2}$



Beats - see applet & precal bonus sheet
- wikipedia sounds

(ear: $\Delta f \sim$ few Hz
$< 20 Hz \rightarrow$ loud/soft
$> 20 Hz$, separate low tone)

- Fix position x
- 2 sounds of similar frequency interfere to hear beats (loud/soft ...)
- Serway & Beichner Ch18

almost like standing waves but envelope in time loud/soft sounds

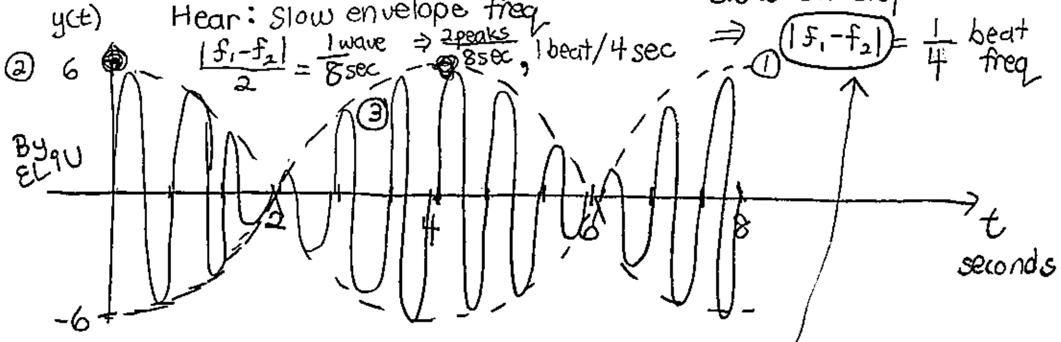
$$\boxed{\sin 2\pi f_1 t + \sin 2\pi f_2 t = 2\sin 2\pi\left(\frac{f_1+f_2}{2}\right)t \cos 2\pi\left(\frac{f_1-f_2}{2}\right)t}$$

(A+B) (A−B)

② $f_1 \approx f_2$ $\underbrace{\quad}_{\text{slow envelope.}}$ 0

Hear: slow envelope freq

$\frac{|f_1-f_2|}{2} = \frac{1\ wave}{8\ sec} \Rightarrow \frac{2\ peaks}{8\ sec}$, 1 beat/4 sec $\Rightarrow$ ① $\boxed{|f_1-f_2|} = \frac{1}{4}$ beat freq



① $\frac{f_1-f_2}{2} = \frac{1}{8}$ $\Rightarrow$ $f_2 = 1.375 Hz = \frac{11}{8} Hz$

③ $\frac{f_1+f_2}{2} = \frac{3\ waves}{2\ sec}$ $f_1 = 1.625 Hz = \frac{13}{8} Hz$

ex Ch18 note C 523 Hz, Piano tuner tries to get C note but hears 2 beats/sec between piano & reference oscillator.

a) Possible frequencies of piano?

$|f_p - f_R| = 2$

$f_p = 523 \pm 2$

$= \boxed{521 \text{ or } 525 Hz}$

b) 3 beats/s $\Rightarrow f_p$ $\boxed{520 \text{ or } 526 Hz}$

c) is more or less beats better?

(Less beats envelope flatter $f_1 - f_2 \approx 0$)

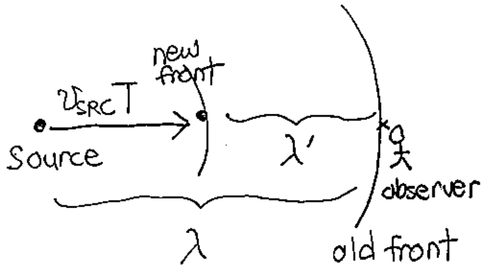
12-7 Doppler Effect . Idea CISE

$v_{SRC} < v_{SND}$

Source Moves, Observer not

$\star$ v same

$\Delta\lambda$ = changes



Source moves at v_{source}

$\lambda' = ?$ in terms of stationary λ

$f' = ?$ of stationary f

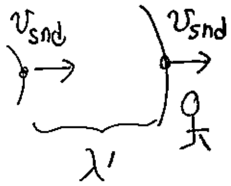
Time T same wait

$$\star \quad \boxed{\lambda - \lambda' = v_{SRC}T} = \frac{v_{SR}}{v_{snd}}\lambda$$

shortens wavelength

$$(v_{SND} = \lambda f)$$

$$\lambda' = \lambda\left(1 - \frac{v_{source}}{v_{sound}}\right)$$



$$\Rightarrow f' = \frac{v_{snd}}{\lambda'} = \frac{v_{snd}}{\lambda\left(1 - \frac{v_{SRC}}{v_{snd}}\right)}$$

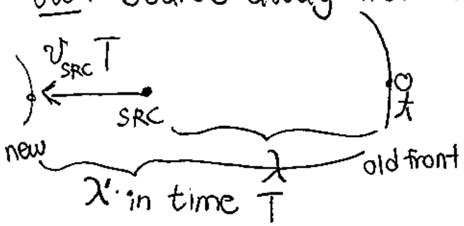
High pitch

$$\boxed{f' = \frac{f}{1 - \frac{v_{SRC}}{v_{snd}}}}$$

source toward observer $> f$

$v_{SRC} < v_{snd}$

OW: source away from observer



$$\Rightarrow \lambda' - \lambda = v_{SRC}T \qquad \left(v_{snd} = \frac{\lambda}{T}\right)$$

$$= \frac{v_{SRC}}{v_{SND}}\lambda$$

$$\lambda' = \lambda\left(1 + \frac{v_{SRC}}{v_{SND}}\right)$$

$$\Rightarrow f' = \frac{v_{snd}}{\lambda'} = \boxed{\frac{f}{1 + \frac{v_{SRC}}{v_{snd}}}} < f$$

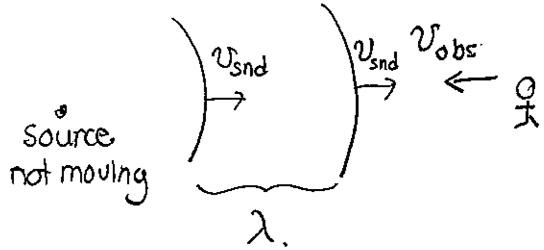
(source away)

Low Pitch

Source still, observer moves

$\star$ v changes

λ same



$$\boxed{v_{snd} + v_{obs} = \lambda f'} \Rightarrow \boxed{f' = f\left(1 + \frac{v_{obs}}{v_{snd}}\right)} > f$$

$$= \frac{v_{snd}}{f} f'$$

observer toward

$$\frac{v_{snd} + v_{obs}}{v_{snd}}$$

Away:

$$v_{snd} - v_{obs} = \lambda f' \Rightarrow \boxed{f' = f\left(1 - \frac{v_{obs}}{v_{snd}}\right)} < f$$

$$= \left(\frac{v_{snd}}{f}\right) f'$$

Both Moving

$$f' = f\left(\frac{v_{snd} \pm v_{obs}}{v_{snd} \mp v_{SRC}}\right) \quad \begin{matrix}\text{toward} \\ \text{away}\end{matrix}$$

APPS

- em for Light formula similar but diff – see ch 33
  - weather forcast, radar. freq shift $\Rightarrow$ storm speed & dir.
  - radar, car speed
  - Light: away, Doppler red shift
    farther galaxies move faster away. Universe is expanding
    See Ch 33 Big Bang basis

ex15 Siren $f = 1600 Hz$
Car $v = 25.0 m/s$

a) Toward
freq = ?

$$f' = f\left(\frac{v_{snd} + \cancel{v_{obs}}}{v_{snd} - v_{source}}\right) = \frac{f}{1 - \frac{v_{SRC}}{v_{SND}}} = \frac{1600}{1 - \frac{25}{343}}$$

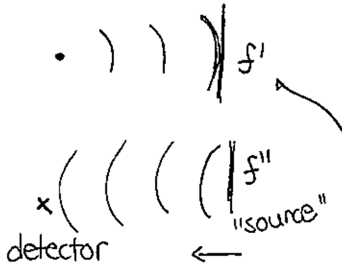
$$= 1726 Hz \approx 1730 Hz$$

b) away
$f' = ?$

$$f\left(\frac{v_{snd} - \cancel{v_{obs}}}{v_{snd} + v_{SRC}}\right) = \frac{1600}{1 + \frac{25}{343}} = 1491 \approx \boxed{1490 Hz}$$

(Bats similar, echolocation)

ex16 5000 Hz sound source stationary
Reflects from object moving 3.50 m/s toward source
Frequency of reflected wave detected at source?



$$f'' = \underset{\cancel{5000}}{\overset{5051}{f'}}\left(\frac{1}{1 - \frac{3.50}{343}}\right) = \boxed{5103 Hz}$$

freq wave heard/received is freq bounced back

$$f' = f\left(1 + \frac{v_{obs}}{v_{snd}}\right) = 5000\left(1 + \frac{3.5}{343}\right) = 5051$$

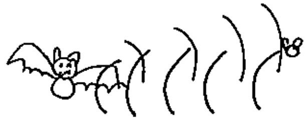
$f'' \approx f$ beats!

ⓖ Observer at rest. Toward,
$v_{SRC} = ?$ for f' to be 1 octave higher?

$$f' = 2f \Rightarrow \frac{1}{1 - \frac{v_{SRC}}{v_{SND}}} = 2 \Rightarrow v_{SRC} = \frac{1}{2} \times 343$$

a) $\boxed{\frac{1}{2} v_{SND}}$

12-9 Apps.



reflection $t_{delay} = \frac{2d}{v}$

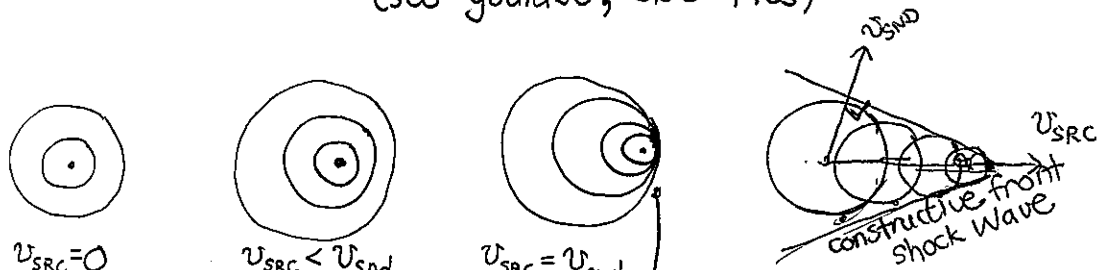
- echolocation (ear 20 ~ 20k Hz)
  - bat
  - dolphin
  - sonar. Ship ocean depth
  - whales (sidenote elephant feet)
  - ultrasound 1 ~ 10 MHz
    (reflect at organ interface)
    ⇒ image from distances
  - dolphins might sing an ultrasound image for others to hear/see!

- Bat, radar gun, weather storm (radar)

difference in freq from reflection ⇒ object's speed & direction
(beats ⋆)

12-8 $v_{obj} > v_{snd} \Rightarrow$ Shock Wave. Heard as sonic boom

(see youtube, clse Pics)



$v_{SRC} = 0$ $\quad$ $v_{SRC} < v_{snd}$ $\quad$ $v_{SRC} = v_{snd}$ $\quad$ $v_{SRC} > v_{snd}$

$v_{SRC} = v_{snd}$:

★extra thrust to break thru sound barrier (build-up, wavefront)

- once past, no more impedance

$v_{SRC} > v_{snd}$:

- always there
- see bird on lake
- heard as boom

$$\sin\theta = \frac{v_{sound}}{v_{source}}$$