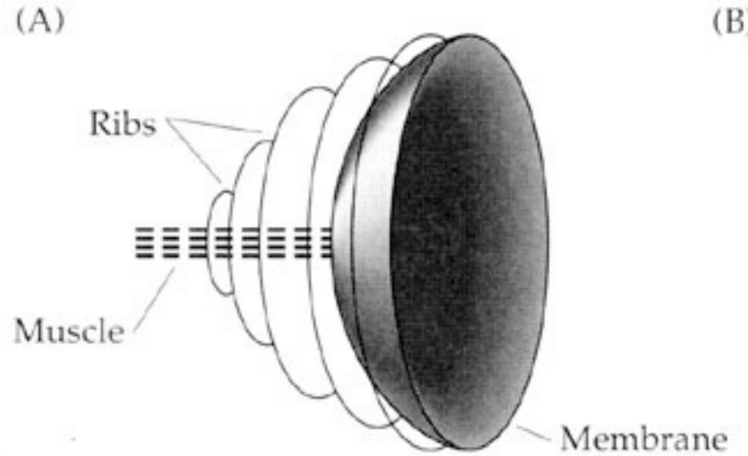
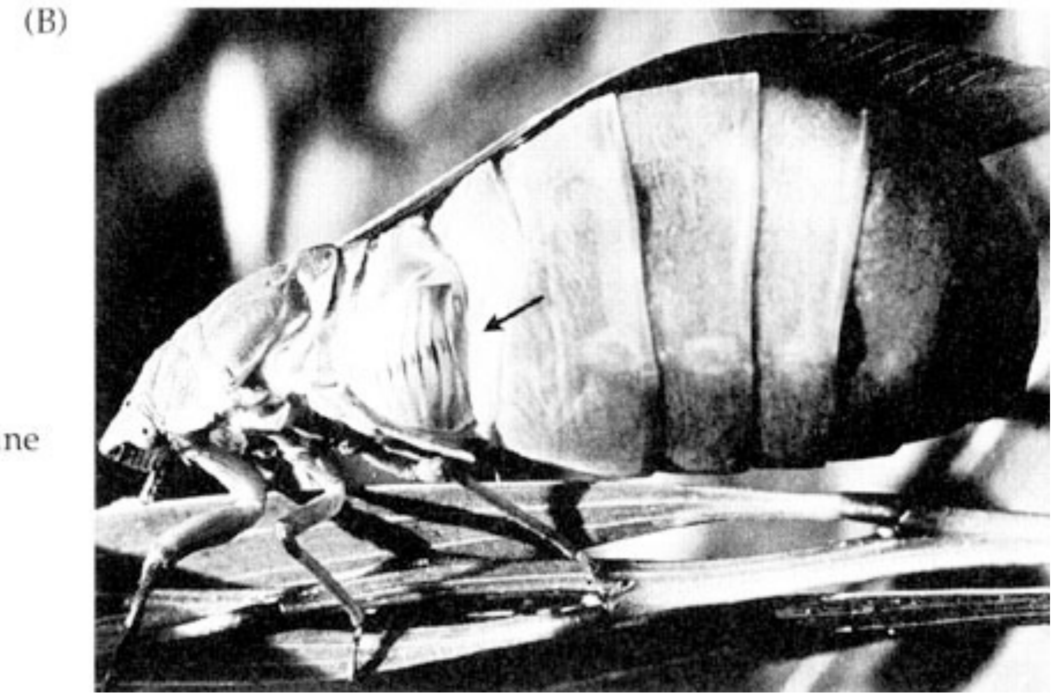
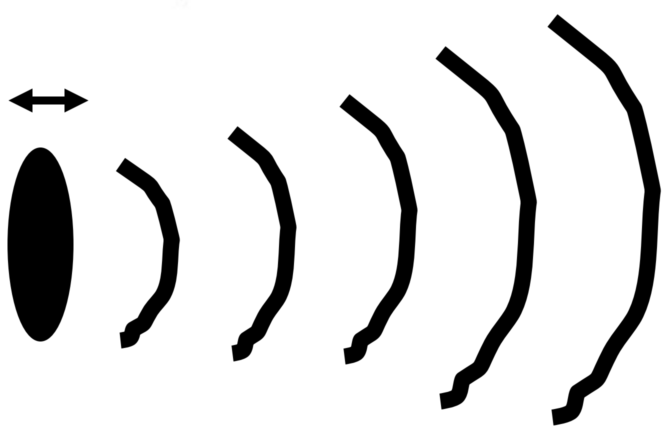
Properties of Sound

- What is sound?
- Wavelength, period, frequency
- Interference and the linearity of sound
- Sound attenuation
  - Spreading loss
  - Acoustic impedance
  - Scattering
- Reading in Chap 2
  - box 2.3 but not 2.1 or 2.2

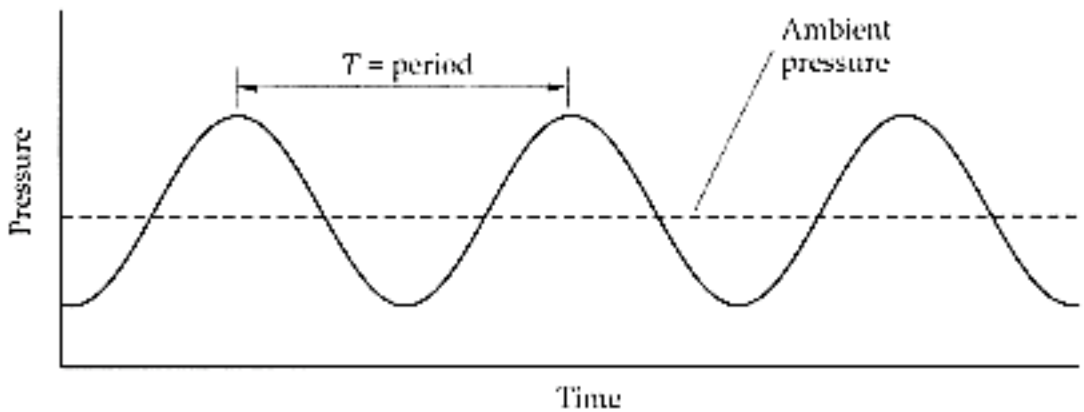
How does a cicada sing?





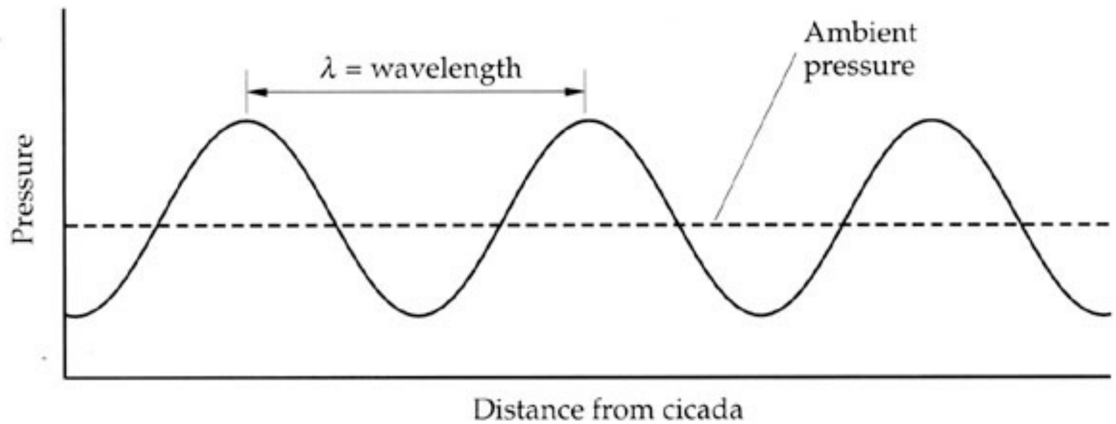


Sound is a pressure wave



- Period (τ) = the time between successive waveform peaks
- Frequency (in cycles/sec or Hertz) = 1/period,
- Thus $f = 1/\tau$

Wavelength depends on speed of sound



- Wavelength of a sound is the distance traveled in one cycle (or period)
- Wavelength = period • speed of sound in medium (c)
- Thus wavelength = c / frequency

Acoustical property comparisons

Property	Air	Water	Rock
Speed (m/s)	340	1500	2000-5000
Density (g/cm3)	0.001	1	2-3

Wavelength problem

Which sound has a shorter wavelength:

1 kHz in air or 3 kHz in water?

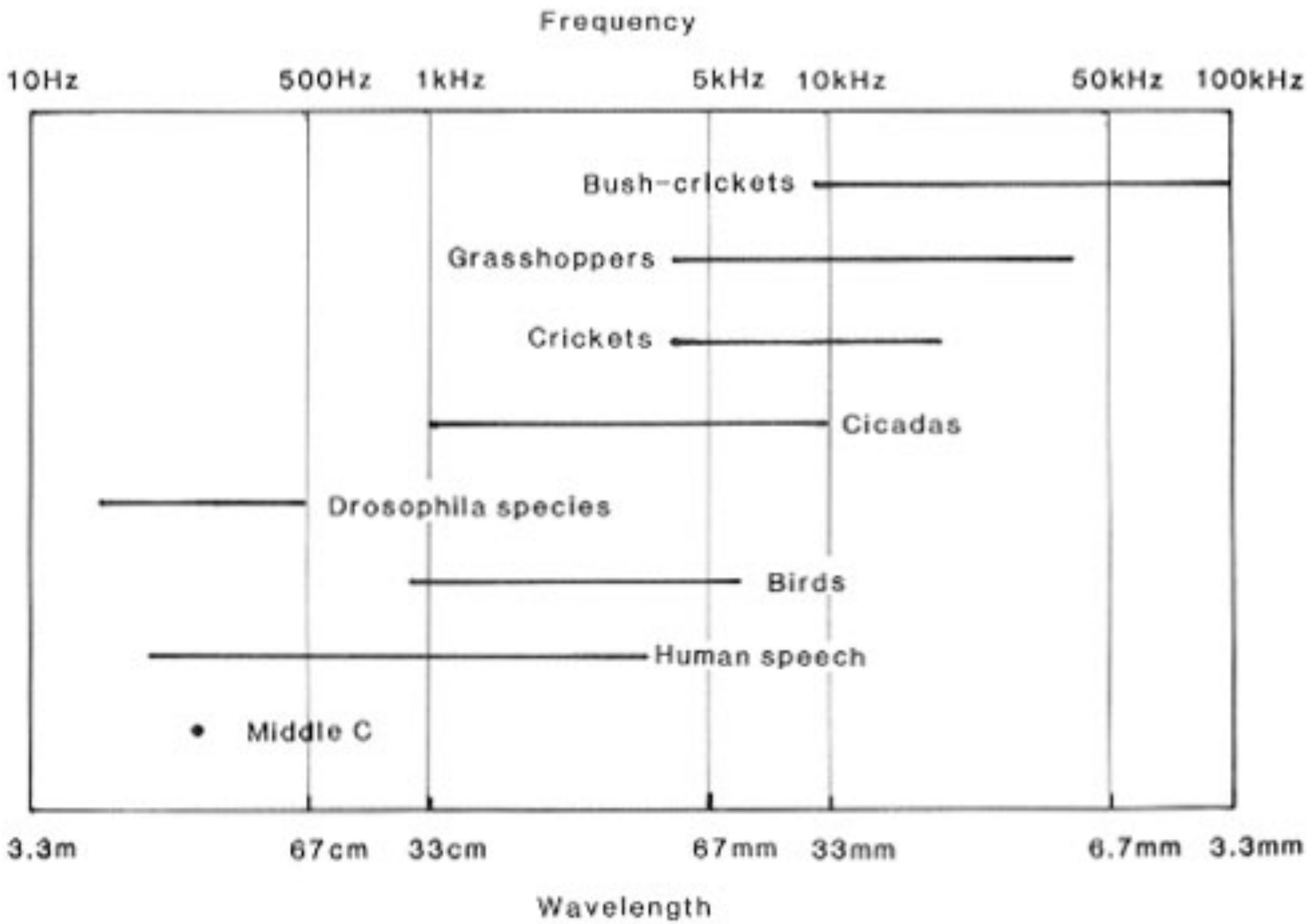
Wavelength = speed of sound / frequency

Air: 340 m/s / 1000 cycle/s = 0.34 m/cycle

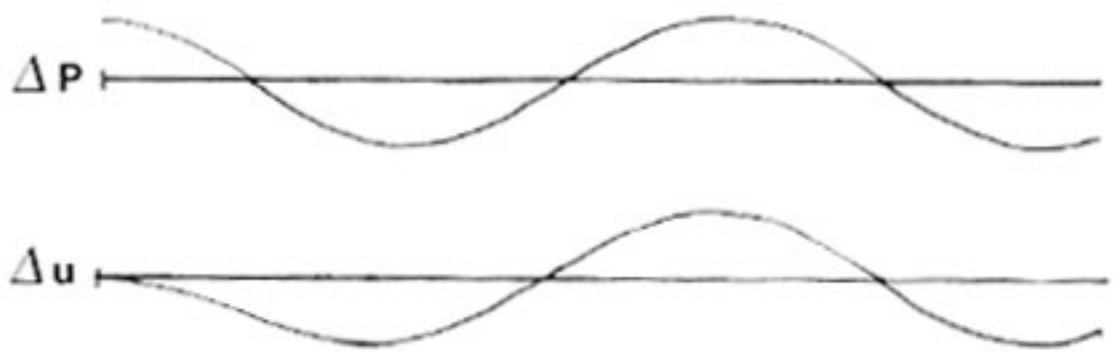
Water: 1500 m/s / 3000 cycle/s = 0.5 m/cycle

Therefore, the answer is 1 kHz in air

Frequencies and wavelengths in air



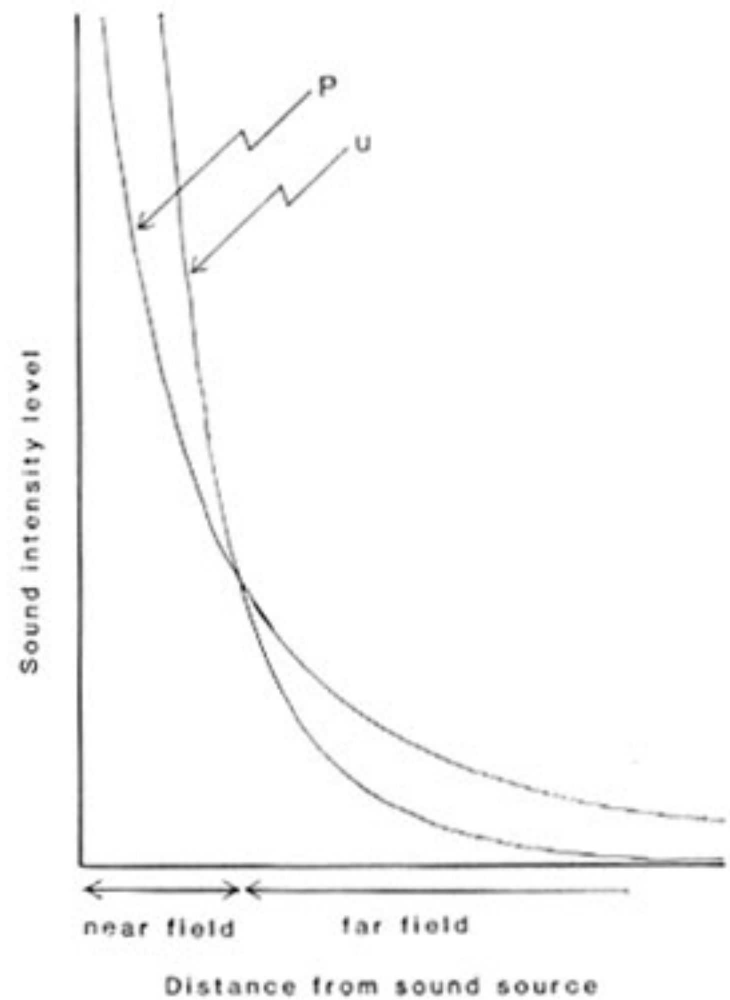
Pressure vs particle movements



Close to a sound source, pressure and particle displacement are out of phase, but one wavelength from source they are in phase

Near field vs far field

- Near field
  - molecular displacements > pressure differences
  - About 1-2 wavelengths from source
- Far field
  - pressure displacement > molecular displacements
  - travels as a wave away from source



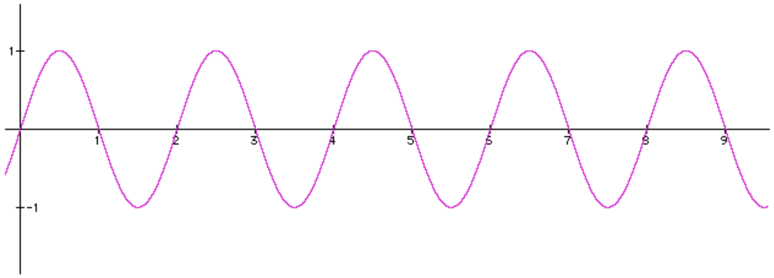
The Doppler shift

- When the sound source is moving, the frequency of the sound will be altered. This is known as the Doppler shift
- Approaching sounds are higher in frequency
- Receding sounds are lower in frequency
- See demonstration at
  - http://www.walter-fendt.de/ph14e/dopplereff.htm

Sound linearity and interference

- Sound pressure waves combine additively
- Waves that start together are in phase
  - Sounds in phase increase in amplitude (positive interference)
  - Sounds out of phase cancel each other out (negative interference)
  - Sounds partially out of phase create varying amplitudes (beats)

Positive interference



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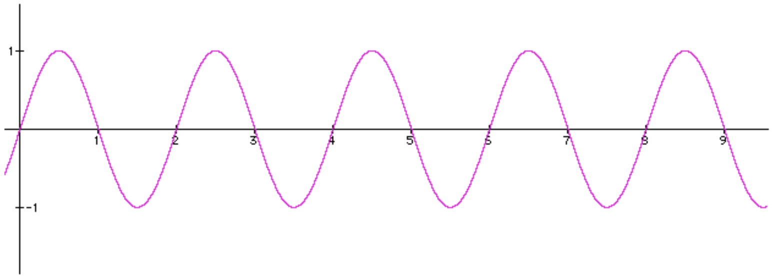
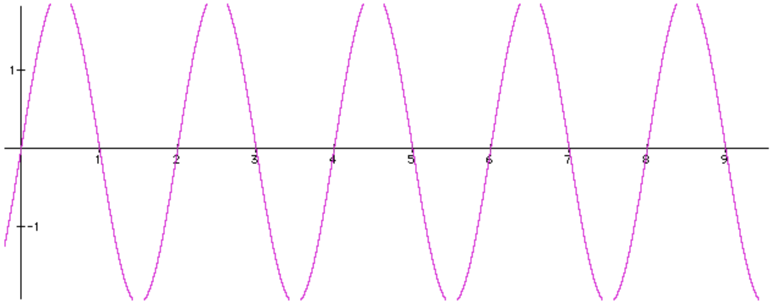
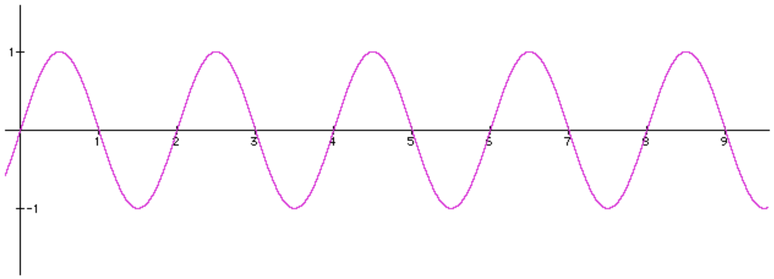




Summed Waveform

Negative Interference



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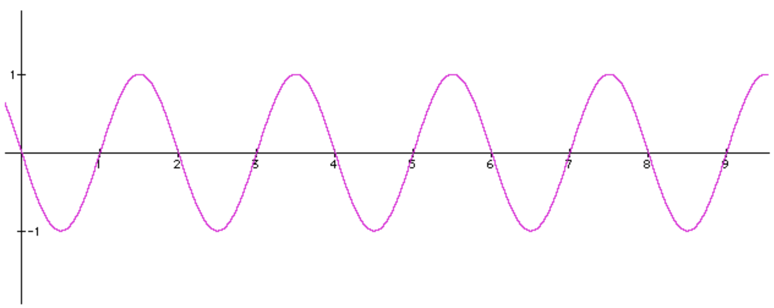
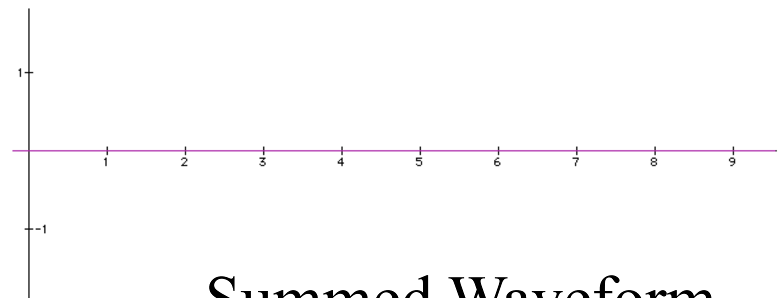
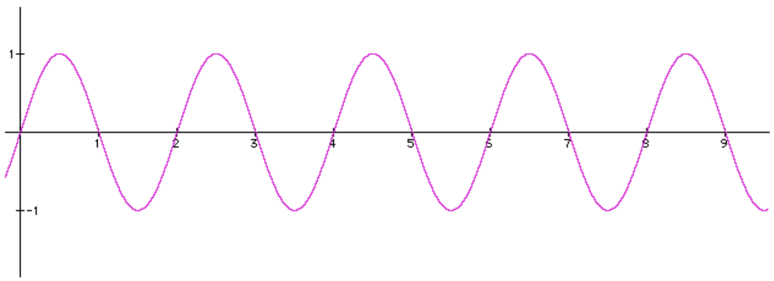




Summed Waveform

Interference produces Beats



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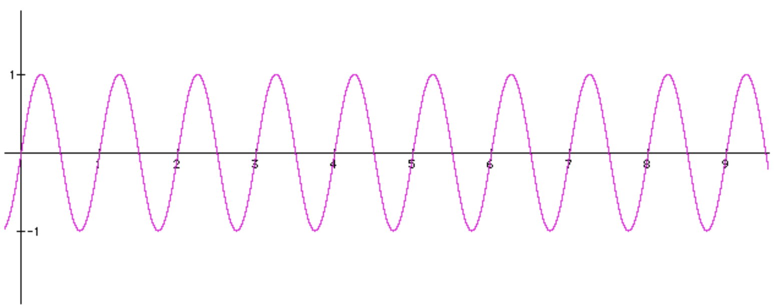
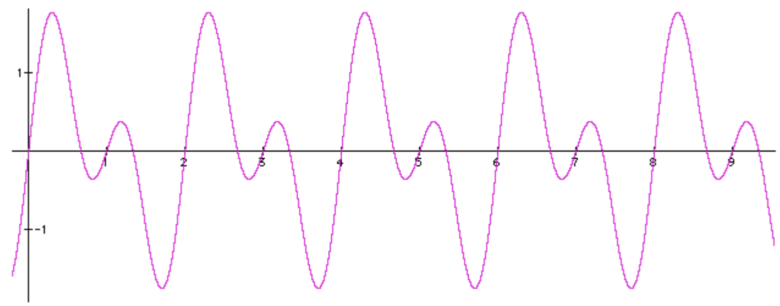
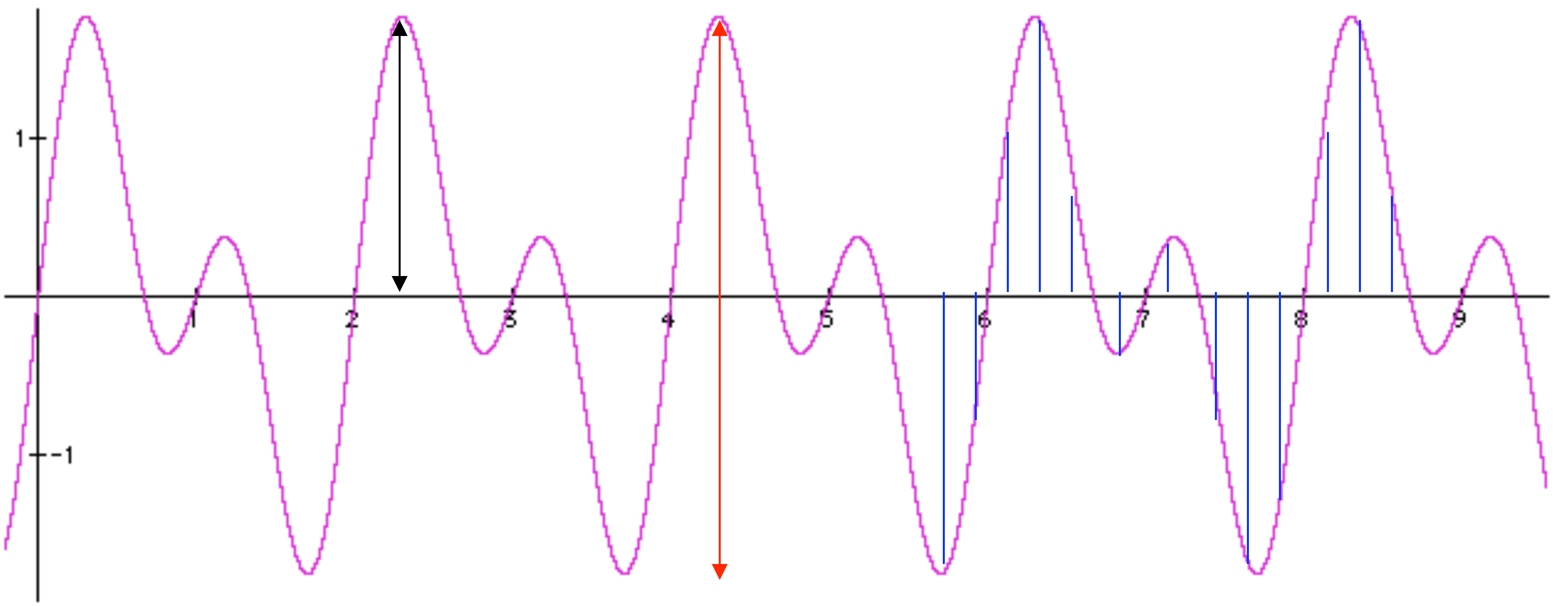




Summed Waveform

Amplitude measures

Peak Peak-to-peak Root-mean-squared (RMS)



Amplitude scale

- Sound pressure is measured in decibels (dB) on a $\log_{10}$ scale relative to a reference level
- $dB = 20 \log_{10} P_1/P_r$ where P_r is a reference pressure level
- A common reference pressure level is the threshold of human hearing at 1 kHz, referred to as sound pressure level (SPL)
- A sound with twice the SPL is 6 dB louder
  - i.e. $20 \log_{10} (2) = 20(0.3) = 6$

Sample sound pressure levels

• soft whisper	20 dB
• nearby songbird, office hum	50 dB
• barking dog	70 dB
• roaring lion , heavy truck	90 dB
• echolocating big brown bat	100 dB
• jet take-off	120 dB

Amplitude problems

- If sound A has 10 times the SPL of sound B, how much louder in dB is A than B?

  $dB = 20 \log_{10} 10 = 20$ dB louder
- If sound A is 100 db and sound B is 80 db, how much louder is A than B?

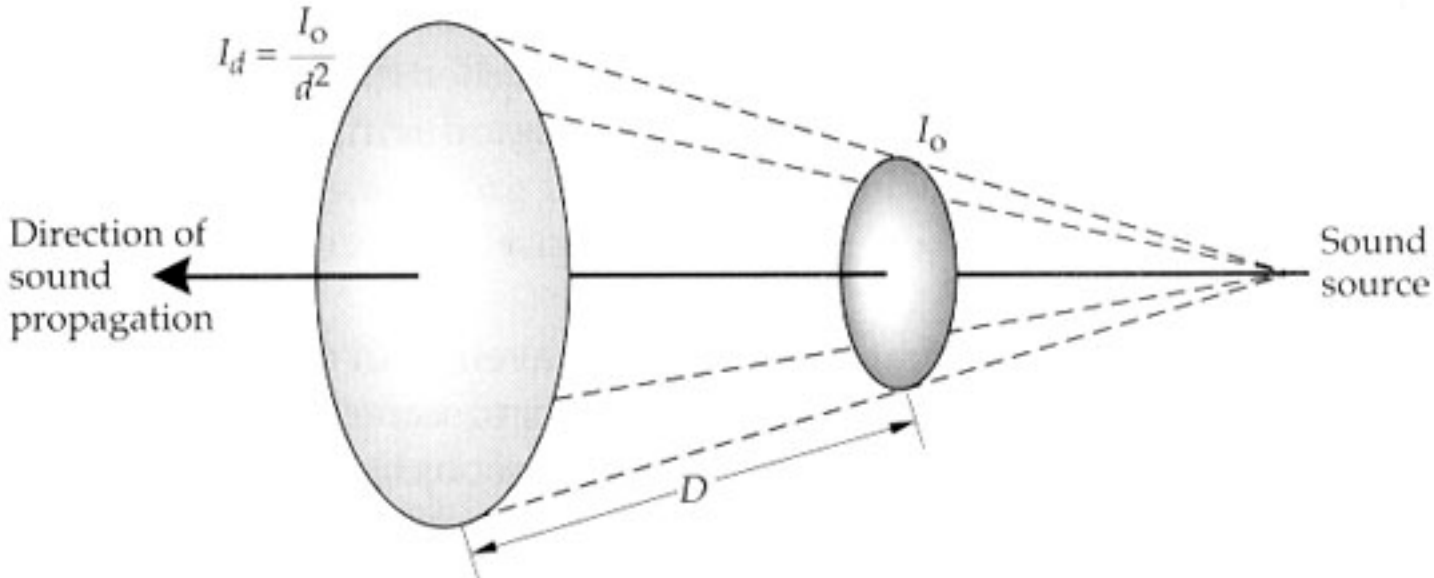
  20 db
- If an 80 db sound is combined with a 40 db sound, how loud is the sound (approximately)?

  80 db

Sound attenuation

- Spherical spreading
- Absorption
  - Temperature and humidity effects
- Reflective scattering
  - Due to impedance differences

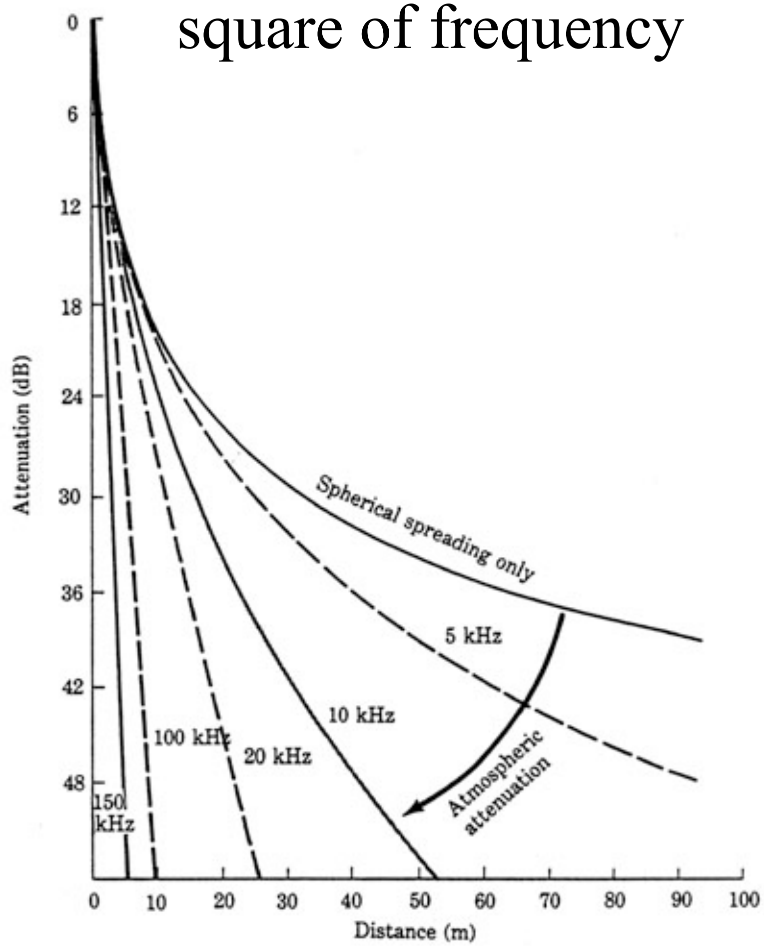
Spherical spreading



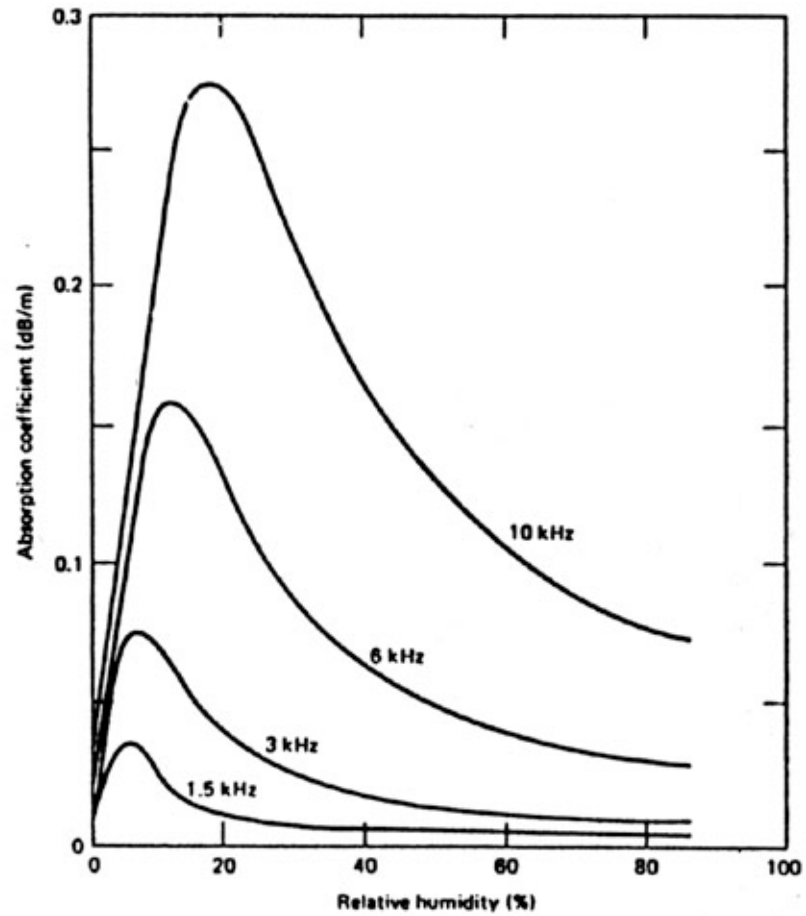
- Loss in sound intensity follows the inverse square law
  - pressure drops in half for each doubling of distance, i.e. for each doubling of distance sound is 6 dB less

Atmospheric attenuation

Increases with square of frequency



Nonlinear with humidity



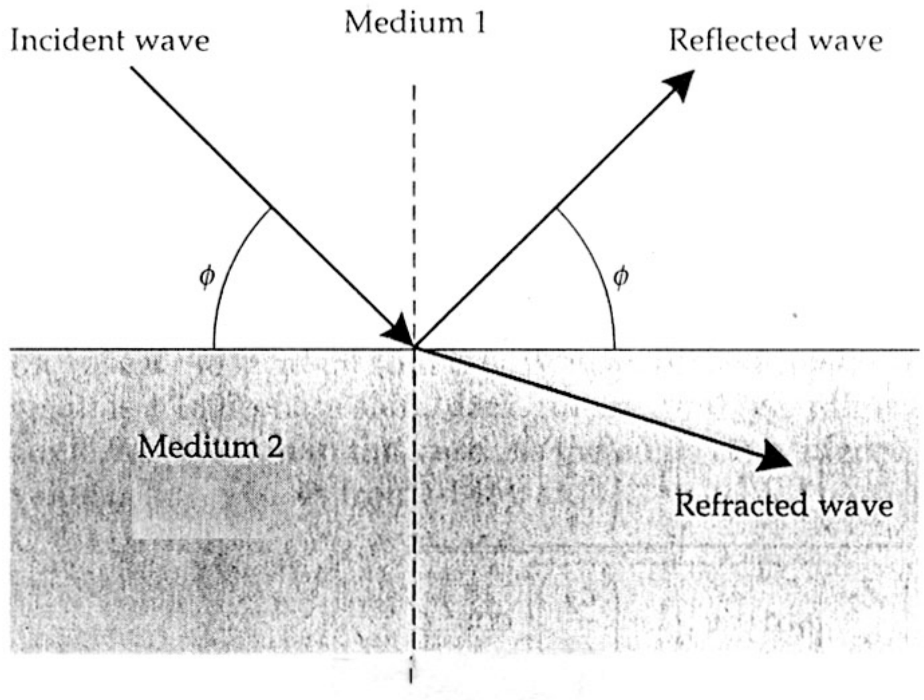
Acoustic impedance

- The degree to which a medium is compressible by sound pressure
- Acoustic impedance = speed of sound • density of medium
- Transmission between media with different impedances is difficult
  - Sounds reflect off animals in air, but can pass through them in water
- Dictates efficiency of sound production and reception by organisms

Acoustical property comparisons

Property	Air	Water	Rock
Speed (m/s)	340	1500	2000-5000
Density (g/cm3)	0.001	1	2-3
Impedance(rayls)	**30**	**1.5×10^5**	**$4\text{-}5 \times 10^5$**

Reflection and refraction

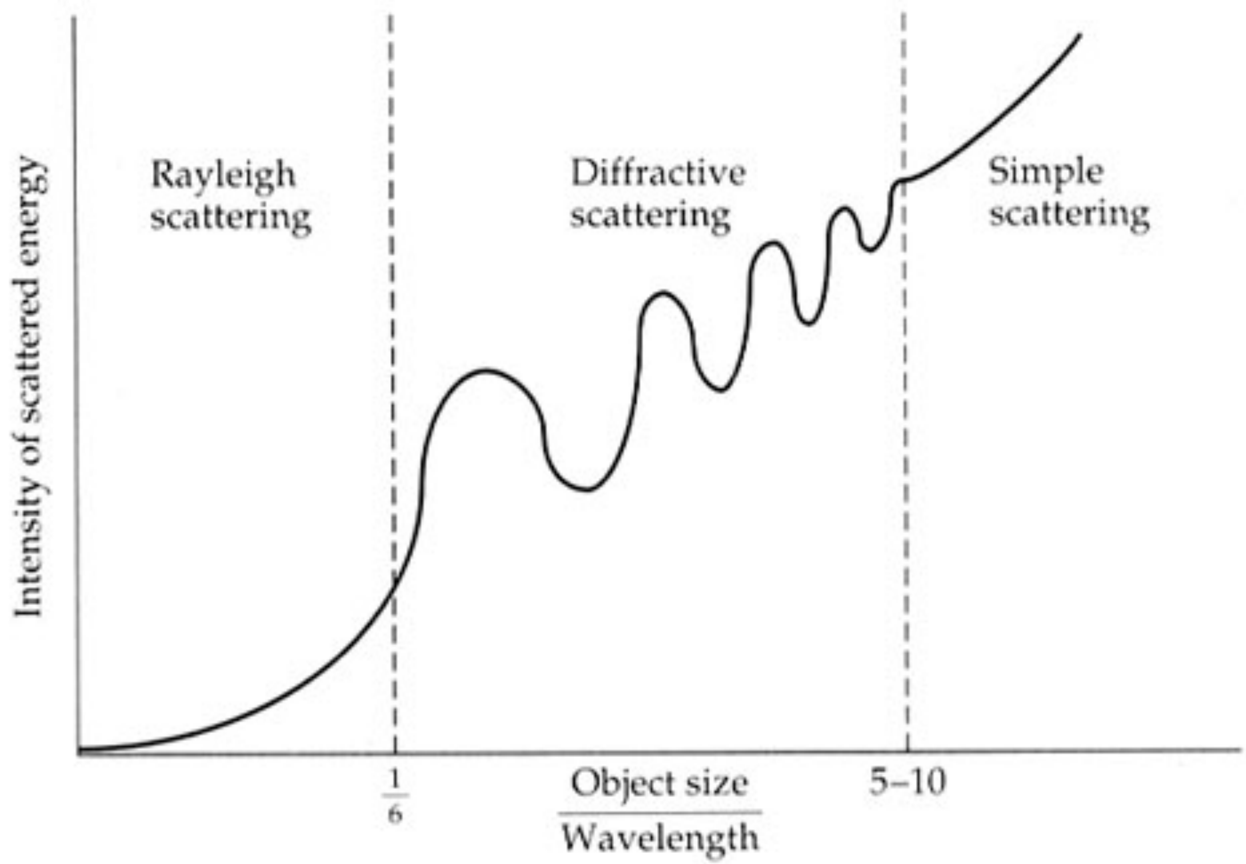


- If medium 2 is more dense than medium 1
  - Most of the energy in a sound wave will be reflected from the boundary between media
  - If the incidence angle exceeds a threshold (see book), some energy will be refracted into media 2, with a reduced angle
- Reflection depends on size of media 2 object

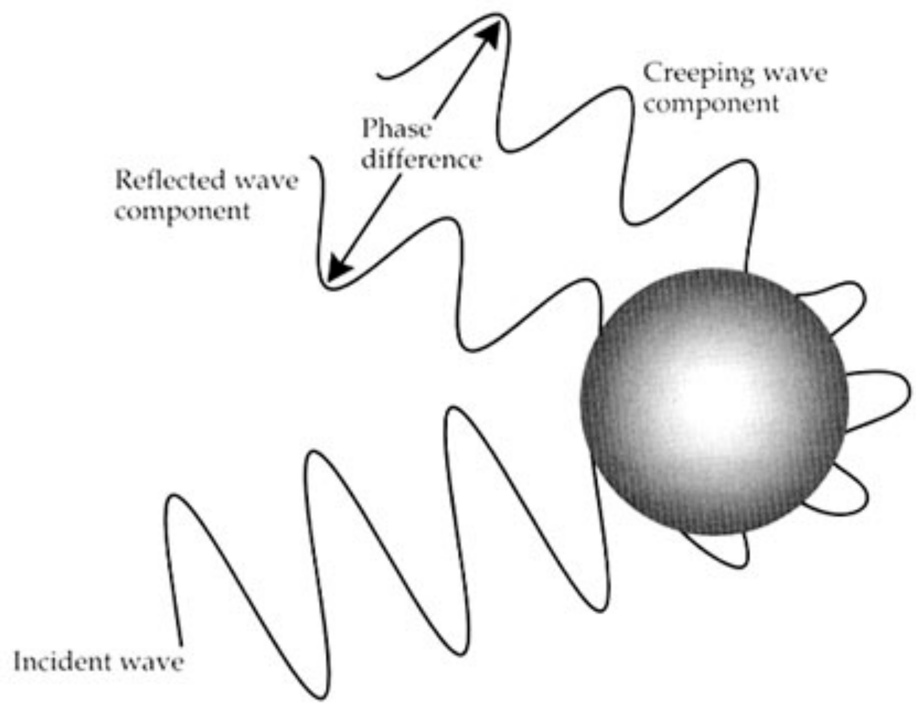
Reflective Scattering

- Type of scattering depends on ratio of wavelength and reflecting object
  - Rayleigh scattering (object << wavelength)
    - sound scattered equally in all directions
  - Diffractive or Mie scattering (object = wavelength)
    - both a reflected and diffracted wave
  - Simple scattering (object > wavelength)
    - single reflected wave

Scattering and wavelengths



Diffractive scattering



- Part of sound wave is diffracted around object (creeping wave)
- Reflected wave is out of phase with creeping wave.
- Can cause negative interference