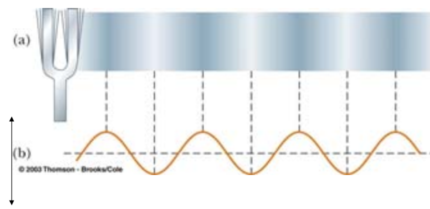
Sound
2.1

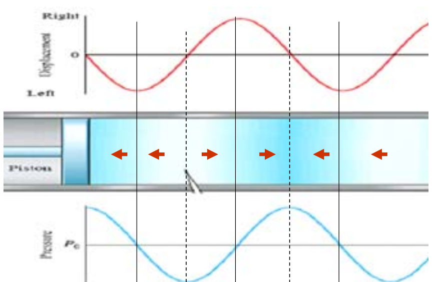
Sound Waves
Speed of Sound
Intensity of Sound
Reflection of waves

Sound Waves



- Longitudinal waves – displacement in direction of propagation
- The displacement produces pressure differences due to differences in density

Pressure and Displacement out of phase by $\pi/2$ (90^{O})

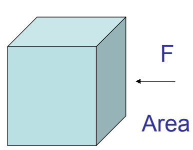


Pressure is related to the slope of the displacement

An instructive simulation of sound wave

http://www.kettering.edu/~drussell/Demos/waves/wavemotion.html

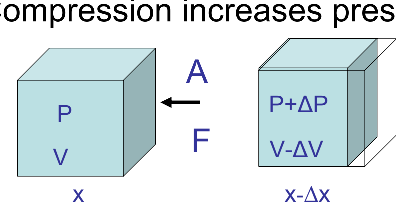
Pressure



$$P = \frac{\text{Force}}{\text{Area}}$$

Newton/m^2
Pascals

Compression increases pressure

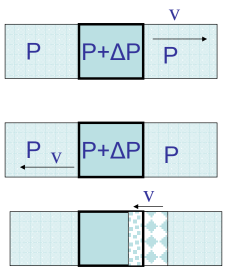


Bulk modulus - B

Units of B -Pascals

$$\Delta P = B\frac{\Delta V}{V} = B\frac{\Delta x}{x}$$

speed of sound

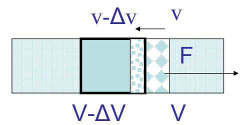


Pulse moves to right

In frame moving with the pulse medium flows to the left (in and out of the high pressure region)

mass segment moves from low P to high P.

F compresses gas and changes speed.



$$F = ma$$

$$F = \Delta P A \quad = ma = \rho A v \Delta t \left(\frac{\Delta v}{\Delta t} \right)$$

$$v = \frac{\Delta P}{\rho \Delta v} \quad \text{but} \quad \frac{\Delta v}{v} = \frac{\Delta V}{V}$$

$$v^2 = \frac{\Delta P V}{\sigma \Delta V} \quad = \frac{B}{\sigma}$$

$$v = \sqrt{\frac{B}{\rho}}$$ for a solid and liquid

$$\Delta P = B \frac{\Delta V}{V}$$ B is the bulk modulus

Speed of sound in a gas

The bulk modulus for slow compression of a gas is equal to P.

However, a sound wave compresses the gas quickly so that there is a temperature rise. (Adiabatic compression). For this case the bulk modulus is slightly larger by a factor of γ which varies according to the nature of the gas.

Speed of sound in a gas

$$v = \sqrt{\frac{\gamma P}{\rho}}$$

monatomic gas –He	5/3
diatomic gas O_2 , N_2	7/5
triatomic CO_2	4/3

Speed of sound in air

- Air is a mixture of mostly diatomic gases.

80% N_2, and 20% O_2

$$\rho_{air,20C} = 1.20 kg/m^3$$

$P_{air,\ 20C}$ = $1.01x10^5$ Pascals

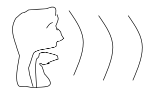
$$v = \sqrt{\frac{7x(1.01x10^5)}{5(1.20)}} = 343 m/s$$

Speed of sound in water

$$\rho_{water} = 1000 kg/m^3$$
$$B_{water} = 2x10^9 Pa$$
$$v = 1500 m/s$$

Speed of sound in water is about 5 times that in air. the higher bulk modulus compensates for the higher density

Donald Duck Talk



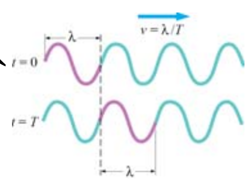
$$f = \frac{v}{\lambda}$$

Demonstrates the speed of sound in He is faster than in air. The wavelength of speech is governed by the length of the vocal cavity.

He = 4 gm/mole (monatomic)
Air ~ 30 gm/mole (diatomic)

$V_{sound, He}$ ~3 $v_{sound, air}$

Intensity of sound



average power is the energy in one wavelength / period

$$P_{av} = \frac{E(\lambda)}{T}$$

For a harmonic oscillator the average KE is equal to the average PE so the total energy is 2xKE =mv^2

$$s = s_o \cos(kx - \omega t)$$
$$dm = \rho A dx$$
$$v^2 = \omega^2 s_o^2 \sin^2(kx - \omega t)$$

$$P_{av} = \frac{\int_0^\lambda dmv^2}{T} = \frac{\rho A \omega^2 s_o^{\ 2} \int_0^\lambda \sin^2(kx - \omega t)dx}{T} = \frac{\rho A \omega^2 s_o^{\ 2} \lambda}{2T}$$

divide by A to get intensity

$$I_{av} = \frac{1}{2} \rho \omega^2 s_o^{\ 2} v$$

also

$$I_{av} = \frac{\Delta P_o^{\ 2}}{2\rho v}$$ see text.

Two expression for the intensity

Problem

The threshold of hearing is a sound intensity of about 1x10^{-12} W/m^2. What is the maximum displacement of a sound wave in air at a frequency of 1000 Hz at this intensity? (ρ_{air} =1.2 kg/m^2, speed of sound =340 m/s)

Sound Intensity and Hearing

- The human ear can perceive changes in sound intensity over a wide range of intensities. (12 orders of magnitude)
- The perception of sound is not linear but logarithmic.
- The decibel scale is a logarithmic scale of intensities that is useful for characterizing sound.

Decibel

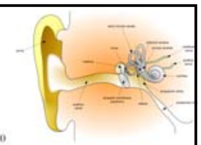
The unit of decibels β is a logarithmic description of sound intensity.

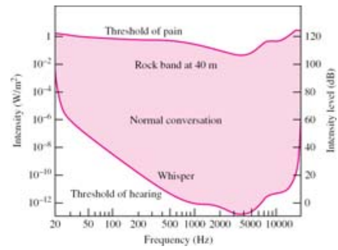
$$\beta = 10\log\frac{I}{I_o}$$

$$I_o = 10^{-12}\,w/m^2$$

- β is dimensionless, and increases as the log of the intensity
- I_o is the threshold for hearing.

Hearing





Hearing covers a wide dynamic range of intensities.
The maximum sensitivity is around 3 kHz.
low frequency vibrations require higher intensities.

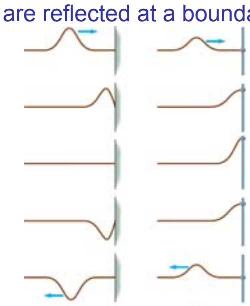
Question

The ear perceives changes in loudness by a factor of 2 for a 10 dB change in intensity. What is the intensity that is 4 times louder than an intensity of 10^{-8} w/m^2

a) 10^{-7} w/m^2
b) 10^{-6} w/m^2
c) 10^{-5} w/m^2
d) 10^{-4} w/m^2

Reflection of waves

Waves are reflected at a boundary

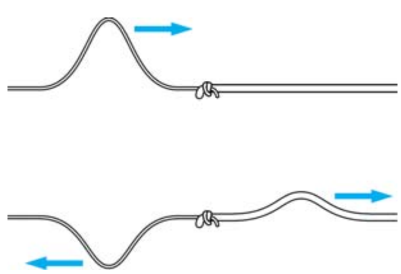


The wave cannot propagate across the boundary.

fixed end inversion

free end no inversion

Partial Reflection at the boundary



Reflection

- Reflections are important to understand properties of waves in different media, i.e. partial reflection of light by glass.
- Standing waves that are the basis for musical instruments are formed by wave reflection