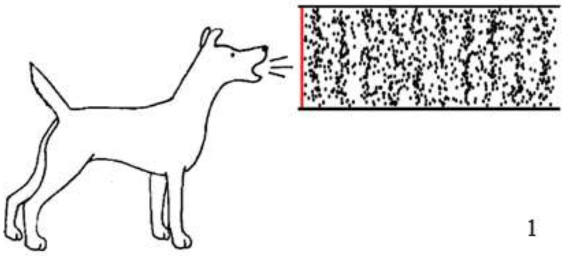
Chapter 17

Waves II

In this chapter we will study sound waves and concentrate on the following topics:

Speed of sound waves
Relation between displacement and pressure amplitude
Interference of sound waves
Sound intensity and sound level

The Doppler effect



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16-2 Types of Waves

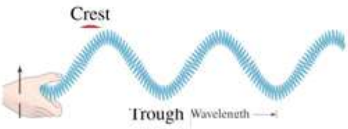
Waves can be classified to:

Mechanical waves
- Need medium to propagate

Matter waves

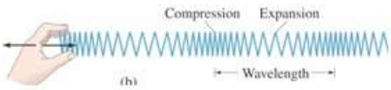
Electromagnetic waves
- Can propagate in vacuum

Transverse waves



Waves on a string
chapter 16

Longitudinal Waves



Sound waves
chapter 17

Sound wave propagate by longitudinal motion (compression/expansion), but not transverse motion (side-to-side)

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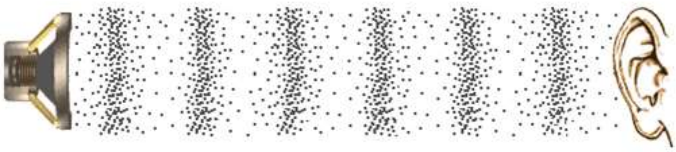
17-2 Sound Waves



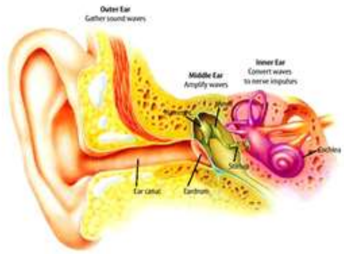
Sound waves exist as variations of pressure in a medium such as air. They are created by the vibration of an object, which causes the air surrounding it to vibrate. The vibrating air then causes the human eardrum to vibrate, which the brain interprets as sound.

How we hear

a. Outer ear collects sound.

b. Middle ear amplifies sound.

c. Inner ear converts sound.



A sound system has three components.

1. There is a sound source consisting of a vibrating object, for example, a speaker.
2. There is the medium through which the sound is transmitted, air in a room, for example.
3. There is the detector, the human ear.

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17-2 Sound Waves

Human hearing is limited to a range of sounds.

Sound waves are divided into three categories that cover different frequency ranges:

(2) *Infrasonic waves*

•They have frequencies below the audible range (below 20 Hz).
•They are felt rather than heard (earthquakes, heavy machinery).
•Elephants can use infrasonic waves to communicate with each other.

(1) *Audible waves*

•They lie within the range of sensitivity of the human ear.
• range from 20 Hz to 20,000 Hz.
•They can be generated in a variety of ways, such as by musical instruments, human voices, or loudspeakers.

(3) *Ultrasonic waves*

•They have frequencies above the audible range (greater than 20k Hz).
•Dogs can use ultrasonic waves to communicate with each other.(up to 35,000 Hz)
•Bats (over 100,000 Hz)
•Medical diagnosis

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17-2 Sound Waves

•Sound waves are the most common example of longitudinal waves.

•They travel through any material medium with a speed that depends on the properties of the medium.

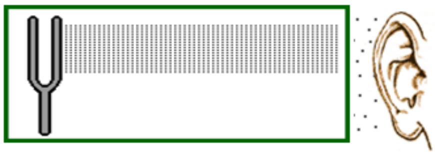
•As the waves travel through air, the elements of air vibrate to produce changes in density and pressure along the direction of motion of the wave.

•If the source of the sound waves vibrates sinusoidally, the pressure variations are also sinusoidal.

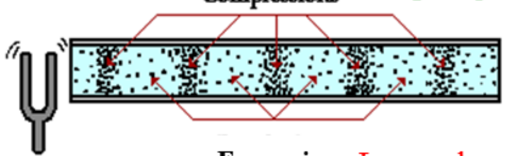
•The mathematical description of sinusoidal sound waves is very similar to that of sinusoidal string waves, which were discussed in the previous chapter.

17-2 Sound Waves

An important fact for understanding how our ears work is that *pressure variations control what we hear.*



Higher density
Higher pressure



Lower density
Lower pressure

2 areas

Compression ➔ **an area of high density and pressure**

Expansion ➔ **an area of low density and pressure**

The darker parts of the colored areas in this figure represent regions where the gas is compressed and thus the density and pressure are high. This compressed region, called a compression.

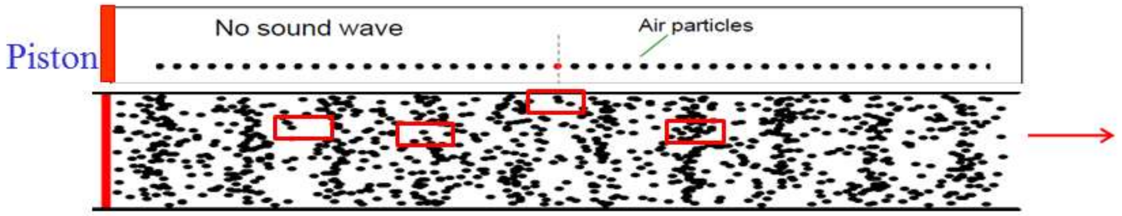
The lighter parts of the colored areas represent regions where the gas is expanded and thus the pressure and density are low. These low pressure regions, called expansions.

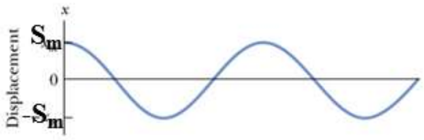
A sound wave is a wave of alternating high-pressure and low-pressure regions of air.

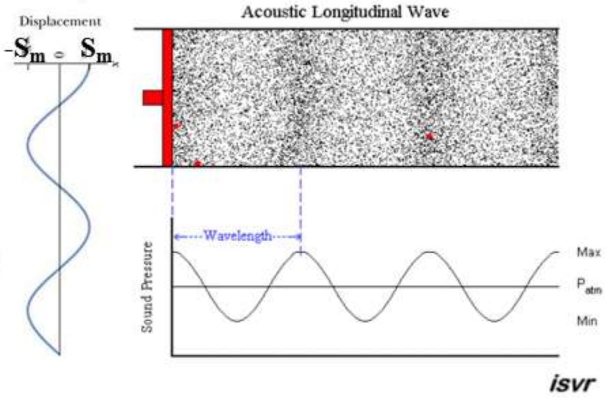
A sound is Pressure wave.

17-4 Traveling Sound Waves

One can produce a one-dimensional periodic sound wave in a long, narrow tube containing a gas by means of an oscillating piston at one end







The sound wave in the tube can be described using one of two parameters:

- Displacement S (*displacement wave*)
- Pressure variation ΔP (*pressure wave*)

17-4 Traveling Sound Waves

If $s(x,t)$ *is* the displacement of the particles in the medium, harmonic position function can be expressed as

$$s(x,t) = s_m \cos(kx - \omega t)$$

Displacement — $s(x,t)$; **amplitude** — s_m; **Oscillating term** — $\cos(kx - \omega t)$

s_m ➔ displacement amplitude of the wave (the maximum position of the element relative to equilibrium)

k ➔ *the wave* number

ω ➔ angular frequency of the piston.

The variation in the gas pressure ΔP *measured from the equilibrium value is also* periodic. For the position function, ΔP *is given by*

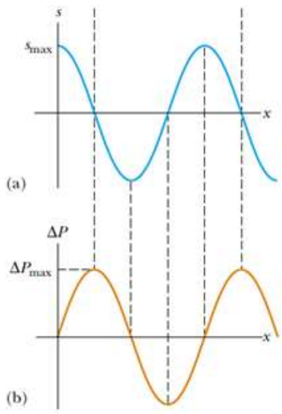
$$\Delta P(x,t) = \Delta P_m \sin(kx - \omega t)$$

Pressure variation — $\Delta P(x,t)$; **amplitude** — ΔP_m; **Oscillating term** — $\sin(kx - \omega t)$

ΔP_m ➔ the pressure amplitude (maximum change in pressure from the equilibrium value)

$$\Delta P_m = \rho\, v\, \omega\, s_m$$

17-4 Traveling Sound Waves



$$s(x,t) = s_m \cos(kx - \omega t)$$

$$\Delta P(x,t) = \Delta P_m \sin(kx - \omega t)$$

Graphs of these functions are shown in Figure. Note that:

- A comparison of $S(x,t)$ and ΔP shows that the pressure wave is $\frac{\pi}{2}$ out of phase with the displacement wave.
- The pressure variation is a maximum when the displacement from equilibrium is zero, and the displacement from equilibrium is a maximum when the pressure variation is zero.

Hint:

- **Positive ΔP means compression→ Pressure is higher than normal pressure.**
- **Negative ΔP means expansion→ Pressure is less than normal (atmospheric) pressure.**

Example 1

The maximum pressure amplitude Δp_m that the human ear can tolerate in loud sounds is about 28 Pa.

What is the displacement amplitude s_m for such a sound in air?

Density ρ = 1.21 kg/m³
Frequency =1000 Hz
Sound speed = 343 m/s

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17-3 The Speed of Sound Waves

Wave properties:

a. Wavelength - distance between any two repeating points on a wave (expansion-expansion, compression-compression).

b. Frequency - number of waves that pass a point in one second (expressed in Hz). (Wavelength has an inverse relationship to wave frequency)

d. Amplitude - size related to the energy carried by the wave.(how dense the medium is at the compressions & expansions). **measures DISPLACEMENT size of the disturbance**

e. Wave velocity depends on the type of wave (mechanical - electromagnetic) and medium. Sound is faster in more dense media and in higher temps.

$$v = \lambda \, x \, f$$

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17-3 The Speed of Sound Waves

The speed of any mechanical wave, transvere or longitudinal, in medium depends on both

inertial property of medium

Kinetic energy

Medium's mass

Density ρ

elastic property of medium

Potential energy

Medium's elasticity

Compressibility

If the medium is a liquid or a gas has a bulk modulus B

The speed of sound waves in medium is

$$v = \sqrt{\frac{\text{elastic property}}{\text{inertial property}}}$$

$$v = \sqrt{\frac{B}{\rho}}$$

$$B = -\frac{\Delta P}{\Delta V / V}$$

Bulk modulus — Change in pressure — Change in volume — Original volume

The bulk modulus

always positive

SI unit N/m² = Pascal (Pa)

17-3 The Speed of Sound Waves

The speed of sound also depends on the temperature of the medium. For sound traveling through air, the relationship between wave speed and medium temperature is

$$v = (331\ \text{m/s})\sqrt{1 + \frac{T_C}{273°\text{C}}}$$

where 331 m/s is the speed of sound in air at 0°C, and T_C *is the air temperature in degrees* Celsius.

Using this equation, one finds that at 20°C the speed of sound in air is

$v = 343$ m/s.

Example 2

(a) Find the speed of sound in water, which has a bulk modulus of 2.1×10^9 N/m² at temperature of 0^0C and density of 1000kg/m³.

(b) If the sound wave in water has frequency of 1000Hz, what is its wavelength?