1.2 Waves

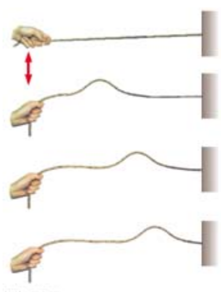
- Wave properties
  - speed
  - wavelength
  - Superposition of waves
  - Reflection of waves at an interface
- Wave on a string
  - Speed of wave on a string
- Sound waves
  - Sound Frequencies
  - Speed of Sound
  - Intensity of Sound Waves

Waves

- A disturbance that carries energy
- Mechanical Waves- water wave, sound – must propagate through matter.
- Electromagnetic Waves – radio, x-ray, light – can propagate through a vacuum.

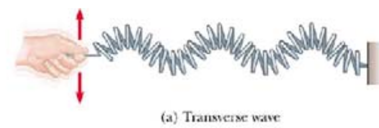
Wave on a string

increasing time

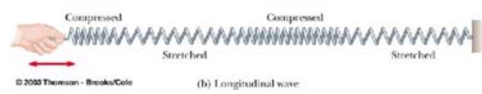


Transverse and Longitudinal Waves

Transverse Wave - The displacement is perpendicular to the direction of propagation



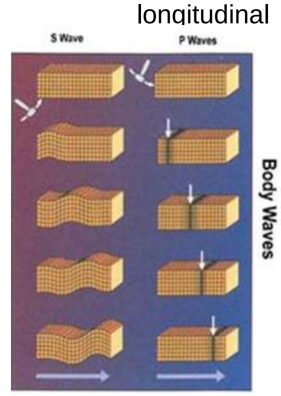
Longitudinal Wave- The displacement is parallel to the direction of propagation



Examples

- Transverse waves
  - Transverse wave on a string
  - Electromagnetic waves (speed = 3.00×10^{8} m/s)
- Longitudinal waves
  - Sound waves in air (speed = 340 m/s)

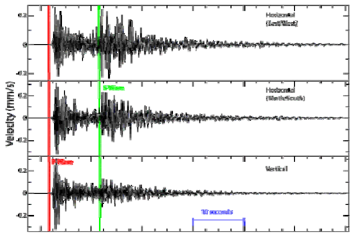
Seismic waves are transverse and longitudinal



P waves- longitudinal
faster
v~ 5000 m/s (granite)

S waves – transverse
slower
v~ 3000 m/s (granite)

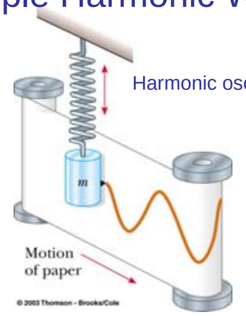
Seismograph record after an earthquake.



Time →

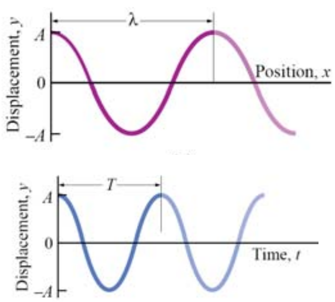
P S

Simple Harmonic Waves



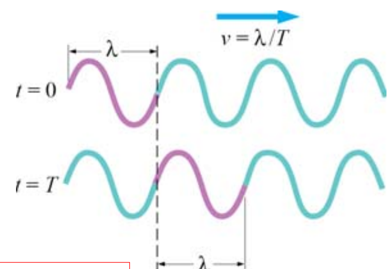
Periodic displacement vs distance

Wavelength - Spatial Period



Wave travels distance λ during one period T

Wave velocity



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

The wave travel at a velocity of one wavelength in one period.

Units

$$v = \frac{\lambda(\text{meters})}{T(\text{seconds})}$$ meters/second

$$v = \lambda(\text{meters}) f(1/\text{seconds})$$ meters/second

$$f = \frac{1}{T} = \frac{v(\text{meters/second})}{\lambda(\text{meters})}$$ 1/seconds

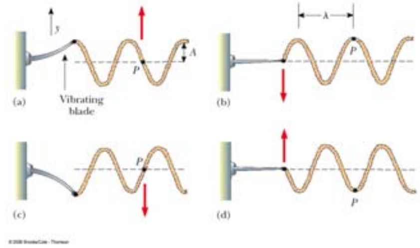
Example

A radio station transmits at a frequency of 100 MHz. Find the wavelength of the electromagnetic waves. (speed of light $=3.0\text{x}10^8$ m/s)

$$v = \lambda f$$

$$\lambda = \frac{v}{f} = \frac{3.0\text{x}10^8}{100\text{x}10^6} = 3.0\text{m}$$

Transverse wave on a string



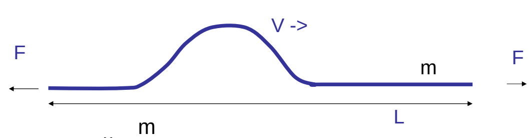
Transverse wave simulation

transverse wave simulation

http://www.surendranath.org/applets/waves/twave01a/twave01aapplet.html

For a transverse wave each segment undergoes simple harmonic motion.

Speed of the transverse wave on a string.



$\mu = \frac{m}{L}$ mass density

$v = \sqrt{\frac{F}{\mu}}$ speed of transverse wave on a string depends on the tension on the string and the mass density

Example

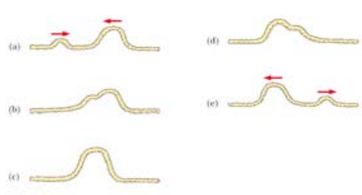
A transverse wave with a speed of 50 m/s is to be produced on a stretched spring. If the string has a length of 5.0 m and a mass of 0.060 kg, what tension on the string is required.

$$v = \sqrt{\frac{F}{m/L}}$$

$$F = \frac{v^2 m}{L} = \frac{(50m/s)^2(0.060kg)}{5.0m} = 30N$$

Superposition Principle

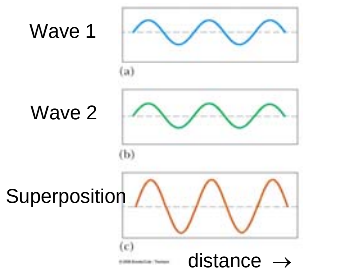
- When two waves overlap in space the displacement of the wave is the sum of the individual displacements.



Interference

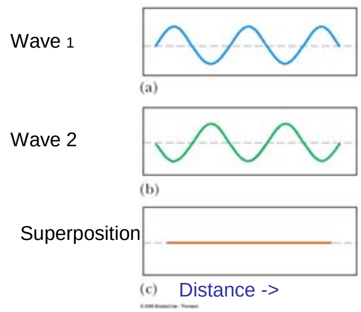
- Superposition of harmonic waves depends on the relative phase of the two waves
- Can lead to
  - Constructive Interference
  - Destructive Interference

Constructive Interference



The two waves have the same phase

Destructive Interference



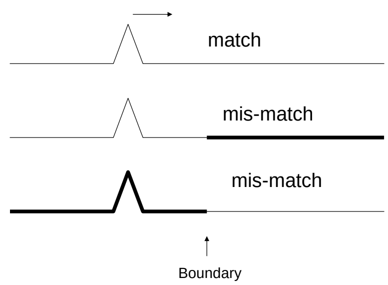
The two waves are out of phase (by 180º , or π)

Reflection and Transmission.

- When a wave reaches a boundary, part of the wave is reflected and part of the wave is transmitted.
- The amount reflected and transmitted depends on how well the media is matched at the boundary.
- The sign of the reflected wave depends on the "resistance" at the boundary.

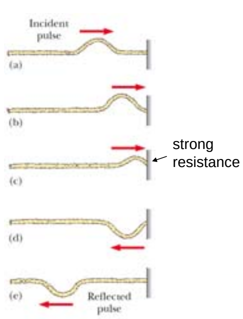
Mis-match at the boundary

part of the wave will be reflected at the boundary

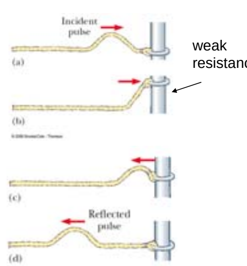


Reflection

Fixed End-
Inversion

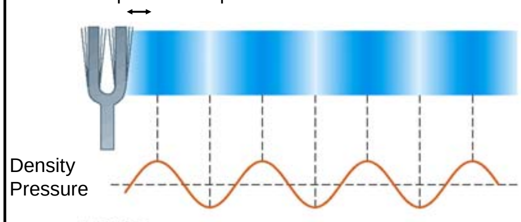


Free End-
No Inversion



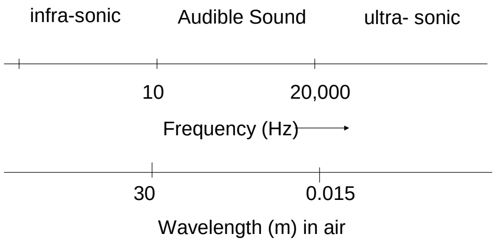
Sound waves

Displacement- parallel



•Produced by compression and rarefaction of media (air)
•Sound waves are longitudinal
resulting in displacement in the direction of propagation.
• The displacements result in oscillations in density and pressure.

Frequencies of sound wave



Speed of sound

Speed of sound in a fluid

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

$$B = -\frac{\Delta P}{\Delta V / V} \quad \text{Bulk modulus}$$

$$\rho = \frac{m}{V} \quad \text{Density}$$

Similarity to speed of a transverse wave on a string

$$v = \sqrt{\frac{elastic\_property}{intertial\_property}}$$

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

Why is the speed of sound higher in Helium than in air?
Why is the speed of sound higher in water than in air?

TABLE 14.1

Speeds of Sound in Various Media

Medium	v (m/s)
Gases	
Air (0°C)	331
Air (100°C)	386
Hydrogen (0°C)	1 290
Oxygen (0°C)	317
Helium (0°C)	972
Liquids at 25°C	
Water	1 490
Methyl alcohol	1 140
Sea water	1 530
Solids	
Aluminum	5 100
Copper	3 560
Iron	5 130
Lead	1 320
Vulcanized rubber	54

Speed of sound in air

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

γ is a constant that depends on the nature of the gas γ =7/5 for air.

P - Pressure
ρ - Density

Since P is proportional to the absolute temperature T by the ideal gas law. PV=nRT

v is dependent on T $\quad v = 331\sqrt{\frac{T}{273}}$ (m/s)

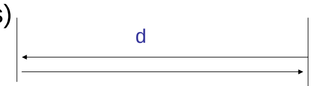
Find the speed of sound in air at 20^{o} C.

$$v = 331\sqrt{\frac{T}{273}}$$

$$v = 331\sqrt{\frac{273+20}{273}} = 343 m/s$$

Example

You are standing on one side of a canyon and shout. You hear your echo 3.0 s later. How wide is the canyon? (v_{sound} = 340 m/s)



$$2d = vt$$

$$d = \frac{vt}{2} = \frac{(340 m/s)(3.0 s)}{2} = 510 m$$

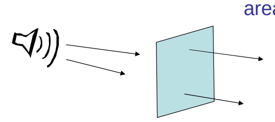
Example

The maximum sensitivity of the human ear is for a frequency of about 3 kHz. What is the wavelength of the sound at this frequency?

$$\lambda = \frac{v}{f} = \frac{340 m/s}{3x10^3 Hz} = 0.11m = 11cm$$

Energy and Intensity of sound waves

power $P = \frac{energy}{time}$



Intensity $I = \frac{power}{area} = \frac{P}{A}$ (units W/m^2)

Sound intensity level

$$\beta = 10 \log\left(\frac{I}{I_o}\right)$$ decibels (dB)

$I_o = 10^{-12}$ W/m^2 the threshold of hearing

decibel is a logarithmic unit. It covers a wide range of intensities.

The ear is capable of distinguishing a wide range of sound intensities.

TABLE 14.2

Intensity Levels in Decibels for Different Sources

Source of Sound	β(dB)
Nearby jet airplane	150
Jackhammer, machine gun	130
Siren, rock concert	120
Subway, power mower	100
Busy traffic	80
Vacuum cleaner	70
Normal conversation	50
Mosquito buzzing	40
Whisper	30
Rustling leaves	10
Threshold of hearing	0

Question

What is the intensity of sound at a rock concert? (W/m^2)

$$\beta = 10 \log\left(\frac{I}{I_o}\right) = 120$$

$$\log\left(\frac{I}{I_0}\right) = \frac{120}{10} = 12$$

$$\frac{I}{I_0} = 10^{12}$$

$$I = 10^{12} I_0 = 10^{12} \cdot 10^{-12} = 1 \quad W/m^2$$

The sound intensity of an ipod earphone can cause damage to the ear. How is this possible?

The earphone is placed directly in the ear. The intensity at the earphone is the power divided by a small area can be a high as 120 dB (1W/m^2)

Say the area is about 1cm^2.

$$P = IA = 1w/m^2(10^{-4} m^2) = 10^{-4} W$$

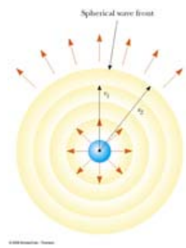
A small amount of power produces a high intensity.

Spherical and plane waves

$A = 4\pi r^2$ area of sphere

For a point source the intensity decreases as $1/r^2$

$$I = \frac{P}{4\pi r^2}$$



P = power of source

Suppose you are standing near a loudspeaker that can is blasting away with 100 W of audio power. How far away from the speaker should you stand if you want to hear a sound level of 120 dB. (assume that the sound is emitted uniformly in all directions.)

$$I = \frac{P}{A} = \frac{P}{4\pi r^2}$$

$$r = \sqrt{\frac{P}{4\pi I}} = \sqrt{\frac{100W}{4\pi(1W/m^2)}} = 2.8m$$