PHYS 1441 – Section 004
Lecture #24

Monday, May 3, 2004

Dr. Jaehoon Yu

- Waves
- Speed of Waves
- Types of Waves
- Energy transported by waves
- Reflection and Transmission
- Superposition principle

Final Exam Next Monday, May. 10!

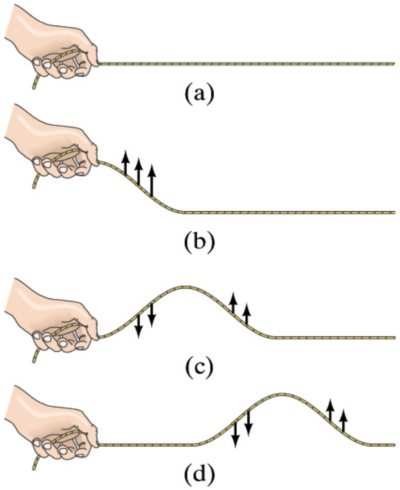
Announcements

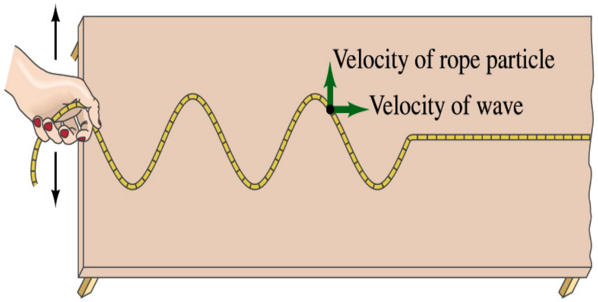
- Quiz results
  - Average score: 47.9/100
    - Other quizzes: 38.2, 41, 57.9 and 52.4
  - Top score: 90
- Final exam Monday, May 10
  - Time: 11:00am – 12:30pm in SH101
  - Chapter 8 – 11
  - Mixture of multiple choices and numeric problems
  - Pick up your exercise problems
- Review this Wednesday, May 5.

Wave Motions

- Waves do not move medium rather carry energy from one place to another

- Two forms of waves
  - Pulse
  - Continuous or periodic wave



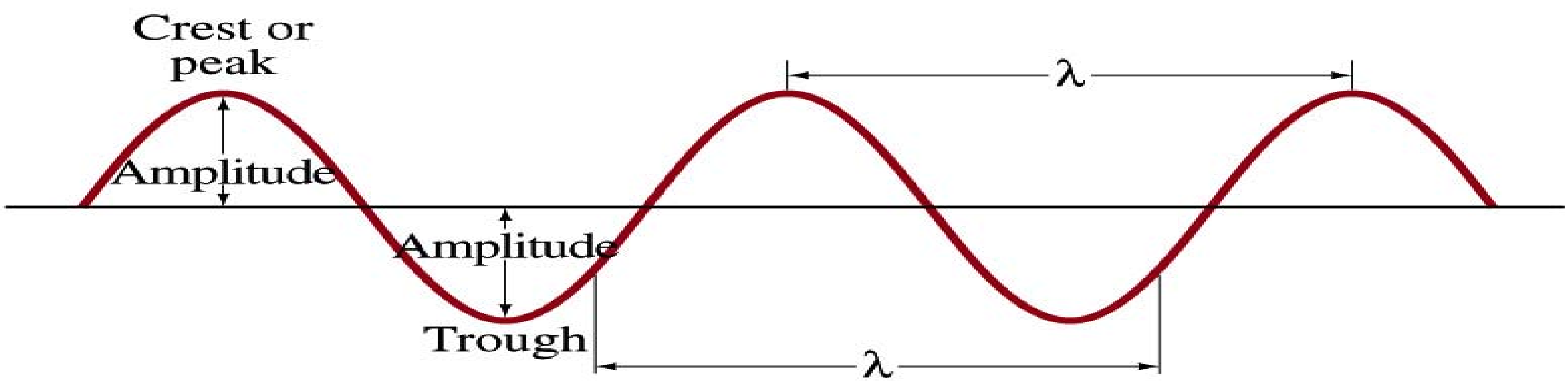


Mechanical Waves

Characterization of Waves

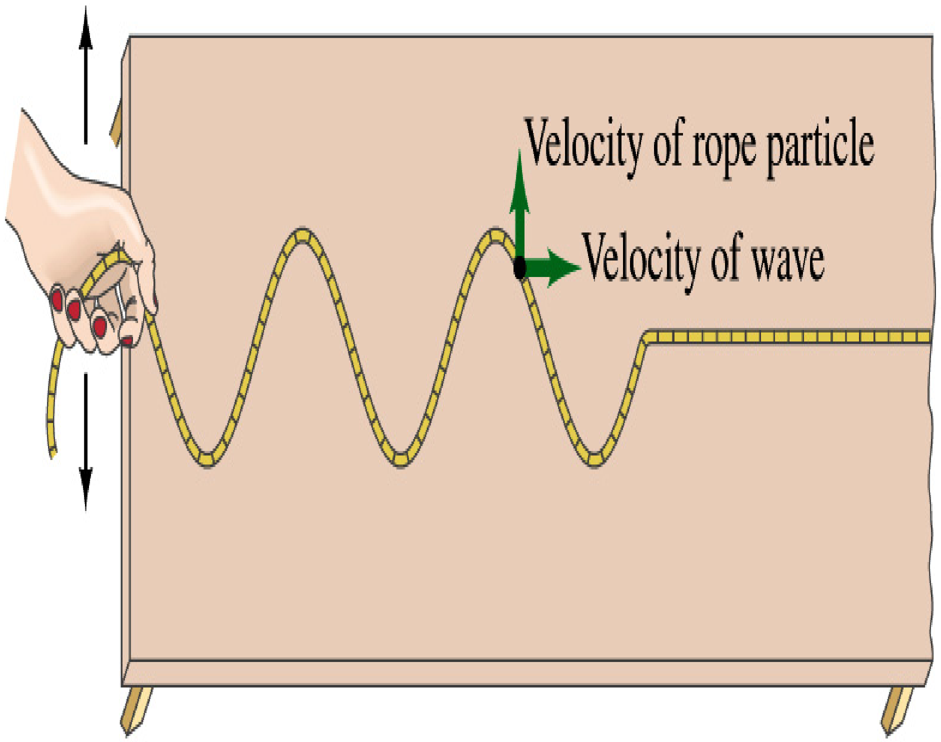
- Waves can be characterized by
  - Amplitude: Maximum height of a crest or the depth of a trough
  - Wave length: Distance between two successive crests or any two identical points on the wave
  - Period: The time elapsed by two successive crests passing by the same point in space.
  - Frequency: Number of crests that pass the same point in space in a unit time
- Wave velocity: The velocity at which any part of the wave moves

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



Waves vs Particle Velocity

Is the velocity of a wave moving along a cord the same as the velocity of a particle of the cord?



No. The two velocities are different both in magnitude and direction. The wave on the rope moves to the right but each piece of the rope only vibrates up and down.

Speed of Transverse Waves on Strings

How do we determine the speed of a transverse pulse traveling on a string?

If a string under tension is pulled sideways and released, the tension is responsible for accelerating a particular segment of the string back to the equilibrium position.

So what happens when the tension increases?

The acceleration of the particular segment increases

Which means?

The speed of the wave increases.

Now what happens when the mass per unit length of the string increases?

For the given tension, acceleration decreases, so the wave speed decreases.

Which law does this hypothesis based on?

Newton's second law of motion

Based on the hypothesis we have laid out above, we can construct a hypothetical formula for the speed of wave

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{T}{m/L}}$$

T: Tension on the string
μ: Unit mass per length

Is the above expression dimensionally sound?

T=kg m/s^2. μ=kg/m
$(T/\mu)^{1/2}=[m^2/s^2]^{1/2}$=m/s

Example 11 – 10

Wave on a wire. A wave whose wavelength is 0.30m is traveling down a d 300-m long wire whose total mass is 15 kg. If the wire is under a tension of 1000N, what is the velocity and frequency of the wave?

The speed of the wave is

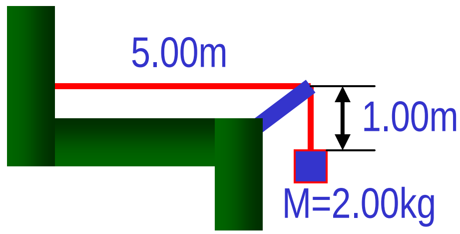
$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{1000}{15/300}} = 140 m/s$$

The frequency of the wave is

$$f = \frac{v}{\lambda} = \frac{140 m/s}{0.30 m} = 470 Hz$$

Example for Traveling Wave

A uniform cord has a mass of 0.300kg and a length of 6.00m. The cord passes over a pulley and supports a 2.00kg object. Find the speed of a pulse traveling along this cord.



Since the speed of wave on a string with line density μ and under the tension T is $v = \sqrt{\frac{T}{\mu}}$

The line density μ is $\mu = \frac{0.300\,kg}{6.00\,m} = 5.00 \times 10^{-2}\,kg/m$

The tension on the string is provided by the weight of the object. Therefore

$$T = Mg = 2.00 \times 9.80 = 19.6 kg \cdot m/s^2$$

Thus the speed of the wave is

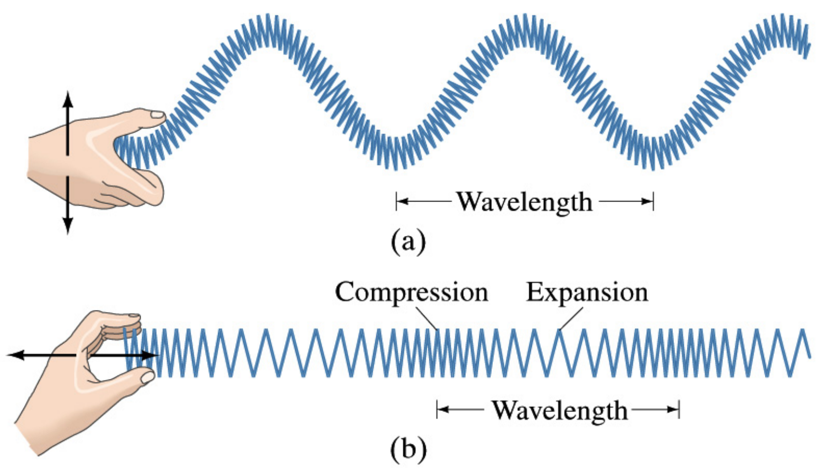
$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{19.6}{5.00 \times 10^{-2}}} = 19.8 m/s$$

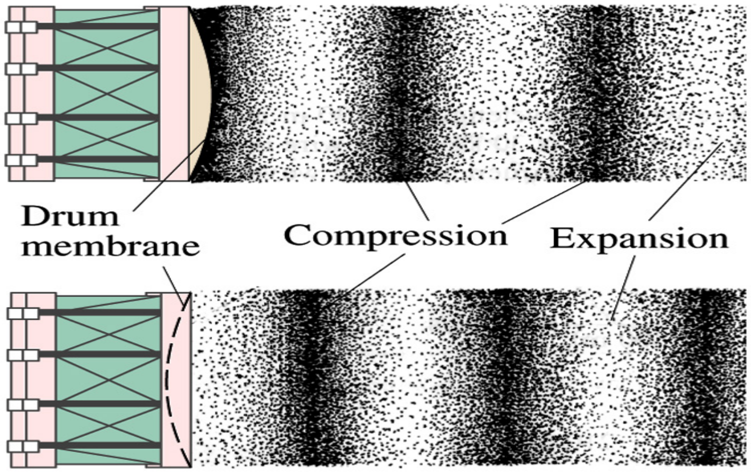
Type of Waves

- Two types of waves
  - Transverse Wave : A wave whose media particles move perpendicular to the direction of the wave
  - Longitudinal wave: A wave whose media particles move along the direction of the wave
    - Speed of a longitudinal wave $v = \sqrt{\dfrac{\text{Elastic Force Factor}}{\text{inertia factor}}}$

For solid $v = \sqrt{\dfrac{E}{\rho}}$ E:Young's modulus
ρ: density of solid

liquid/gas $v = \sqrt{\dfrac{B}{\rho}}$ E: Bulk Modulus
ρ: density





Example 11 – 11

Sound velocity in a steel rail. You can often hear a distant train approaching by putting your ear to the track. How long does it take for the wave to travel down the steel track if the train is 1.0km away?

The speed of the wave is

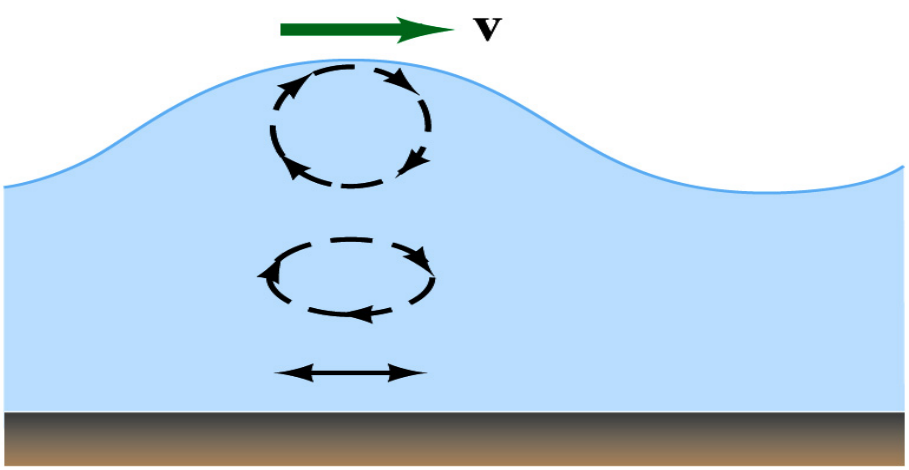
$$v = \sqrt{\frac{E}{\rho}} = \sqrt{\frac{2.0\times10^{11}N/m^2}{7.8\times10^{3}kg/m^3}} = 5.1\times10^{3}m/s$$

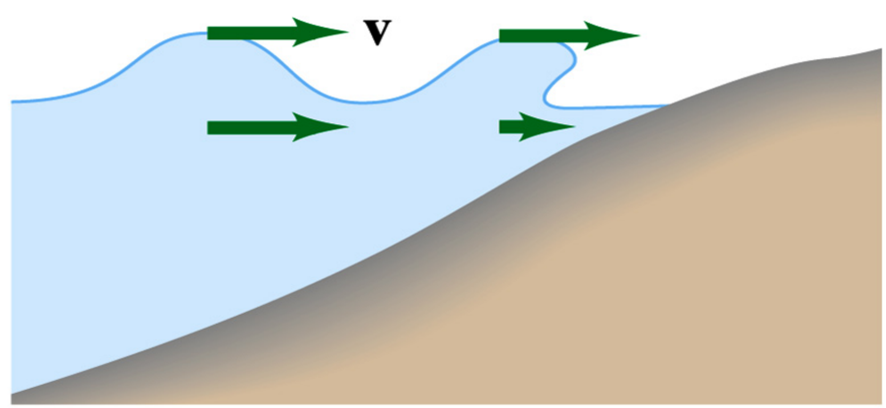
The time it takes for the wave to travel is

$$t = \frac{l}{v} = \frac{1.0\times10^{3}m}{5.1\times10^{3}m/s} = 0.20s$$

Earthquake Waves

- Both transverse and longitudinal waves are produced when an earthquake occurs
  - S (shear) waves: Transverse waves that travel through the body of the Earth
  - P (pressure) waves: Longitudinal waves
- Using the fact that only longitudinal waves goes through the core of the Earth, we can conclude that the core of the Earth is liquid
  - While in solid the atoms can vibrate in any direction, they can only vibrate along the longitudinal direction in liquid due to lack of restoring force in transverse direction.
- Surface waves: Waves that travel through the boundary of two materials (Water wave is an example)➔ This inflicts most damage.





The Richter Earthquake Scale

- The magnitude of an earthquake is a measure of the amount of energy released based on the amplitude of seismic waves.
- The Richter scale is logarithmic, that is an increase of 1 magnitude unit represents a factor of ten times in amplitude. However, in terms of energy release, a magnitude 6 earthquake is about 31 times greater than a magnitude 5.
  - M=1 to 3: Recorded on local seismographs, but generally not felt
  - M=3 to 4: Often felt, no damage
  - M=5: Felt widely, slight damage near epicenter
  - M=6: Damage to poorly constructed buildings and other structures within 10's km
  - M=7: "Major" earthquake, causes serious damage up to ~100 km (recent Taiwan, Turkey, Kobe, Japan, California and Chile earthquakes).
  - M=8: "Great" earthquake, great destruction, loss of life over several 100 km (1906 San Francisco, 1949 Queen Charlotte Islands) .
  - M=9: Rare great earthquake, major damage over a large region over 1000 km (Chile 1960, Alaska 1964, and west coast of British Columbia, Washington, Oregon, 1700).

Energy Transported by Waves

Waves transport energy from one place to another.

As waves travel through a medium, the energy is transferred as vibrational energy from particle to particle of the medium.

For a sinusoidal wave of frequency f, the particles move in SHM as a wave passes. Thus each particle has an energy

$$E = \frac{1}{2}kA^2$$

Energy transported by a wave is proportional to the square of the amplitude.

Intensity of wave is defined as the power transported across unit area perpendicular to the direction of energy flow.

$$I = \frac{energy/time}{area} = \frac{power}{area}$$

Since E is proportional to A^2.

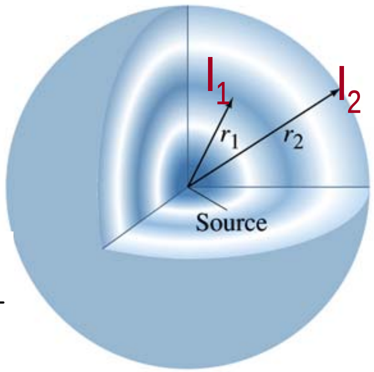
$$I \propto A^2$$

For isotropic medium, the wave propagates radially

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

Ratio of intensities at two different radii is

$$\frac{I_2}{I_1} = \frac{P/4\pi r_2^2}{P/4\pi r_1^2} = \left(\frac{r_1}{r_2}\right)^2 \xrightarrow{\text{Amplitude}} \frac{A_2}{A_1} = \frac{r_1}{r_2}$$



Example 11 – 12

Earthquake intensity. If the intensity of an earthquake P wave 100km from the source is $1.0\times10^{7}W/m^{2}$, what is the intensity 400km from the source?

Since the intensity decreases as the square of the distance from the source,

$$\frac{I_2}{I_1}=\left(\frac{r_1}{r_2}\right)^2$$

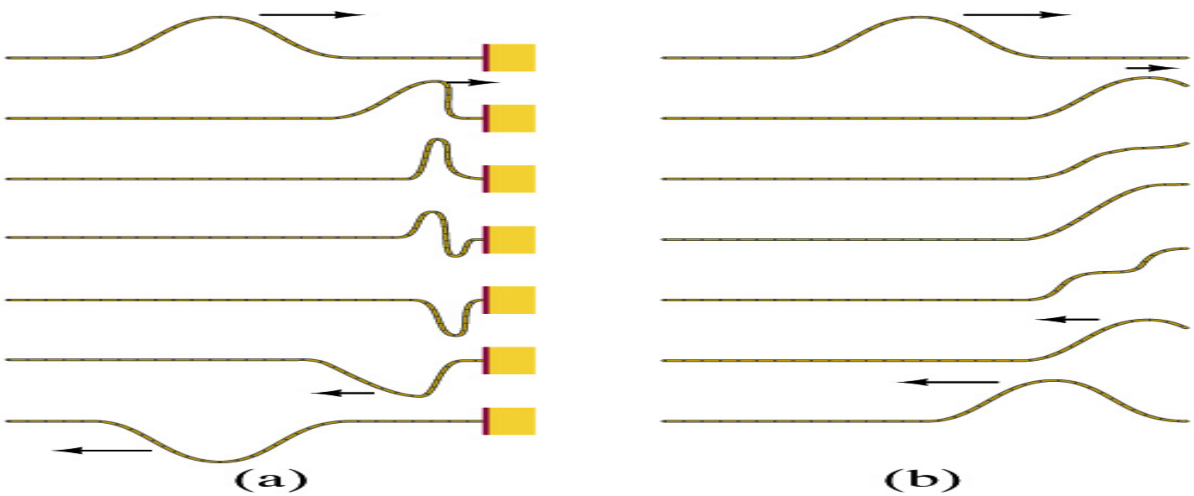
The intensity at 400km can be written in terms of the intensity at 100km

$$I_2=\left(\frac{r_1}{r_2}\right)^2 I_1=\left(\frac{100km}{400km}\right)^2 1.0\times10^7 W/m^2=6.2\times10^5 W/m^2$$

Reflection and Transmission

A pulse or a wave undergoes various changes when the medium it travels changes.

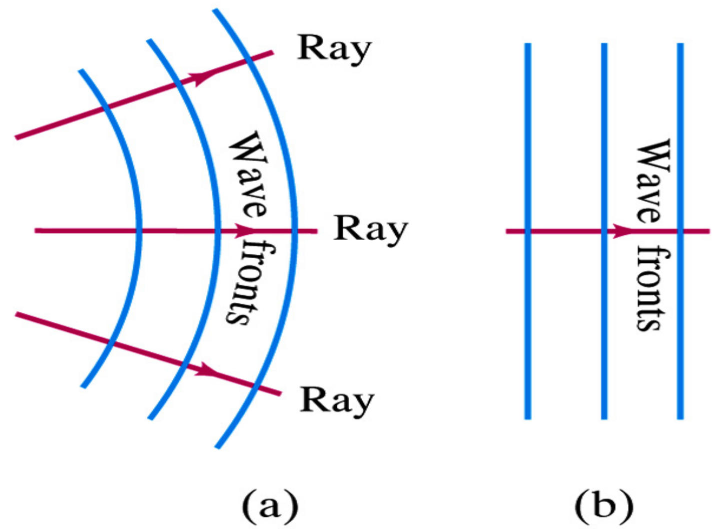
Depending on how rigid the support is, two radically different reflection patterns can be observed.



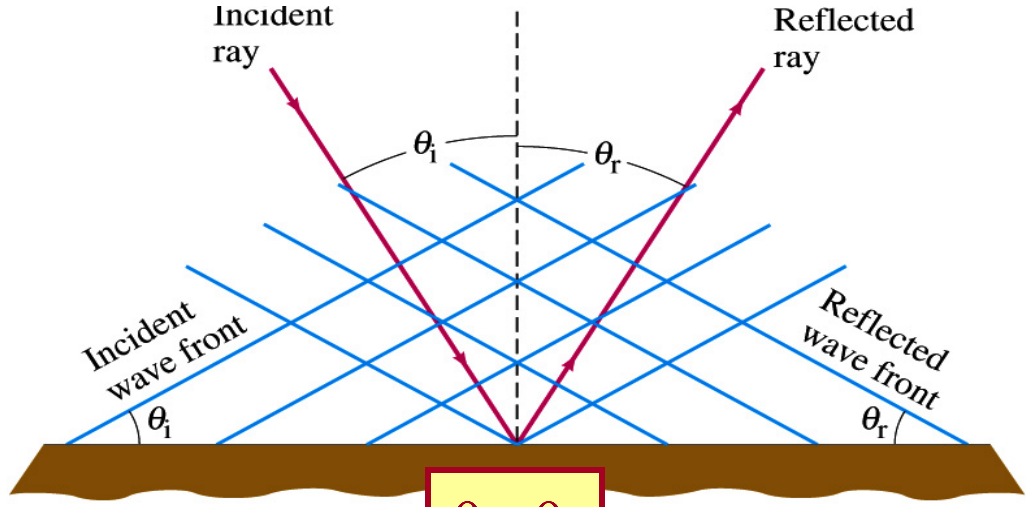
1. The support is rigidly fixed (a): The reflected pulse will be inverted to the original due to the force exerted on to the string by the support in reaction to the force on the support due to the pulse on the string.
2. The support is freely moving (b): The reflected pulse will maintain the original shape but moving in the reverse direction.

2 and 3 dimensional waves and the Law of Reflection

- Wave fronts: The whole width of wave crests
- Ray: A line drawn in the direction of motion, perpendicular to the wave fronts.
- Plane wave: The waves whose fronts are nearly straight



The Law of Reflection: The angle of reflection is the same as the angle of incidence.



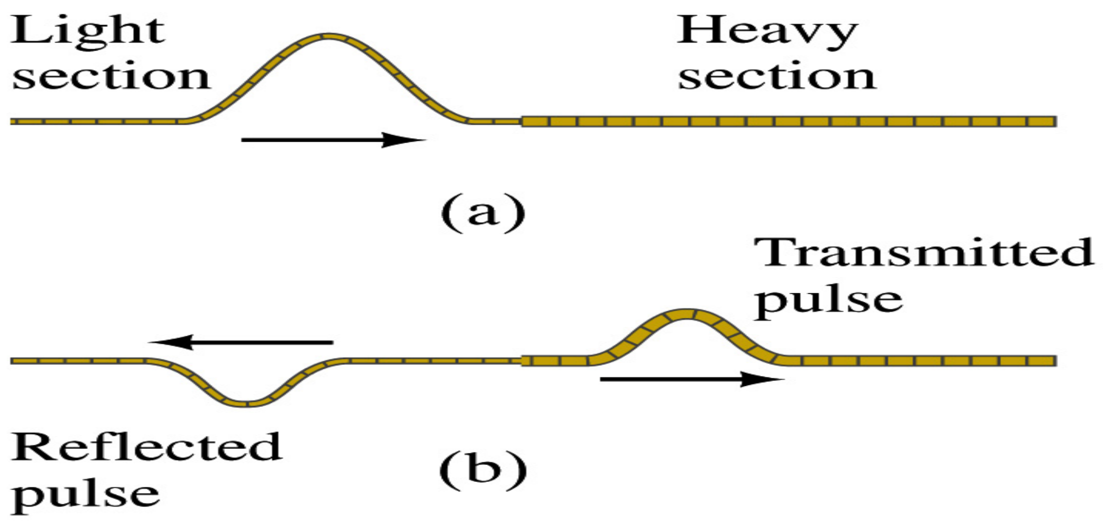
$$\theta_i=\theta_r$$

Transmission Through Different Media

If the boundary is intermediate between the previous two extremes, part of the pulse reflects, and the other undergoes transmission, passing through the boundary and propagating in the new medium.

When a wave pulse travels from medium A to B:

1. $v_A > v_B$ (or $\mu_A < \mu_B$), the pulse is inverted upon reflection
2. $v_A < v_B$ (or $\mu_A > \mu_B$), the pulse is not inverted upon reflection



Superposition Principle of Waves

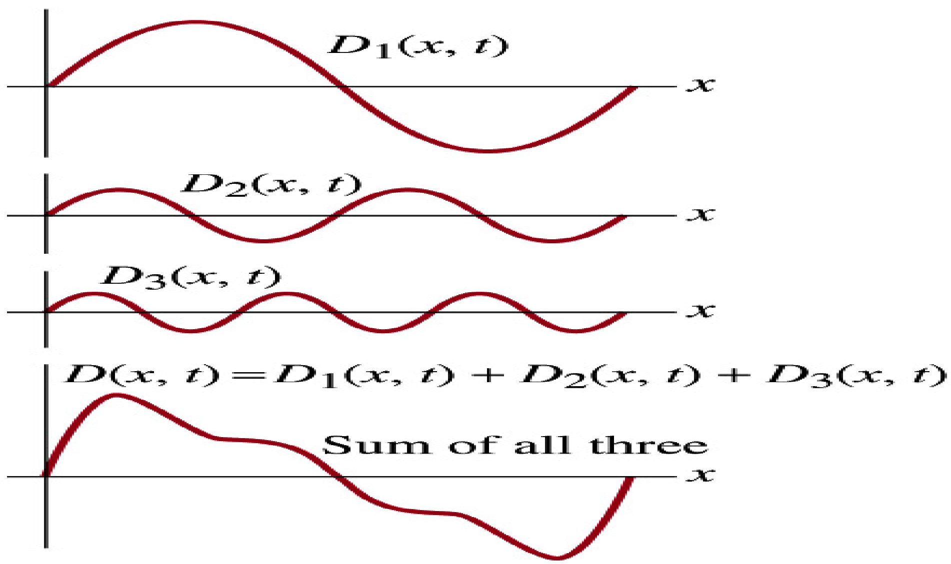
If two or more traveling waves are moving through a medium, the resultant wave function at any point is the algebraic sum of the wave functions of the individual waves.

Superposition Principle

The waves that follow this principle are called ***linear waves*** which in general have small amplitudes. The ones that don't are ***nonlinear waves*** with larger amplitudes.

Thus, one can write the resultant wave function as

$$y = y_1 + y_2 + \cdots + y_n = \sum_{i=1}^{n} y_i$$



Wave Interferences

Two traveling linear waves can pass through each other without being destroyed or altered.

What do you think will happen to the water waves when you throw two stones in the pond?

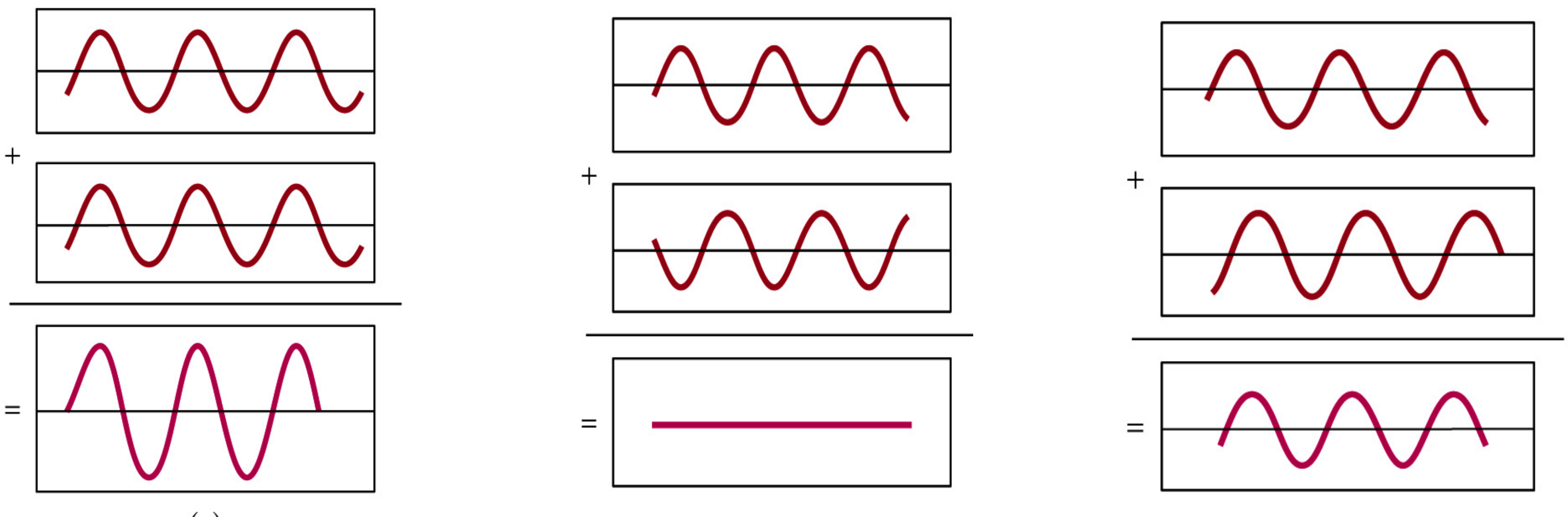
They will pass right through each other.

What happens to the waves at the point where they meet?

The shape of wave will change ➔ Interference

Constructive interference: The amplitude increases when the waves meet

Destructive interference: The amplitude decreases when the waves meet



In phase ➔ constructive

Out of phase by $\pi/2$ ➔ destructive

Out of phase not by $\pi/2$ ➔ Partially destructive

Congratulations!!!!

You've become as good a physicist as anyone!!

It was a great pleasure for me to work with you through the semester!!

Good luck with your exams!!!

Have a safe summer!!