Vibrations and Waves

A vibration is a periodic linear motion of a particle about an equilibrium position.

When many particles vibrate and carry energy through space, this is a wave. A wave extends from one place to another.

Examples are:
- water waves
- light, which is an electromagnetic wave
- sound

Discussion Question
Two pendula have the same length, but different mass. The force of gravity, \( F_{mg} \), is larger for the larger mass. Which will have the longer period?
A. the larger mass
B. the smaller mass
C. neither

Amplitude and Wavelength

Amplitude
- distance from the midpoint to the crest or to the trough

Wavelength
- distance from the top of one crest to the top of the next crest, or distance between successive identical parts of the wave

Period
- Time to complete one vibration

Frequency
- \( \frac{1}{\text{period}} \)

Chs. 19 & 20 Pre-Class Quiz Results

- 97 students wrote the pre-class quiz; the average was 3.67/4.
- A “transverse” wave is one whose vibrations move perpendicular to the motion of the wave. If “Do the wave!!”
- Some comments:
  - “I have issues with the forced vibrations and resonance part.”
  - “Difference between resonance and vibration?”: Resonance is a special kind of vibration.
  - “nodes, antinodes, doppler effect”

Student Emails

- Questions via email:
  - “How can I get to know the multiple choice’s mark of midterm?”
  - The mid-term test was out of 50, and there was no mark adjustment. To determine the mark you get on the multiple choice part, take the mark shown on portal and subtract the long-answer problem marks shown on the front of the test which you get handed back to you this week.
  - If you wish to check your bubble sheet, you must go to MP129 and ask April Seeley. She can show you your bubble sheet or give you a copy of it for your records.
  - Please let me know if there are any mistakes in the marking and I will correct them.

Problem Set 2 is due right now.
Last Chance for no late penalty!

- Any Problem Sets not turned in by now will receive the 10% per day (or portion thereof) late penalty.

Vibrations of a Pendulum

- The time of one to-and-fro swing is called the period.
- The longer the length of a pendulum, the longer the period

\[ \text{Period} = \frac{1}{\text{frequency}} \]
A sound wave has a frequency of 500 Hz. What is the period of vibration of the air molecules due to the sound wave?

A. 1 s  
B. 0.01 s  
C. 0.002 s  
D. 0.005 s  

Wave speed
- Describes how fast a disturbance moves through a medium
- Related to frequency and wavelength of a wave

Example:
A wave with wavelength 1 meter and frequency of 1 Hz has a speed of 1 m/s.

Wave speed \( \equiv \) frequency \( \times \) wavelength

A wave with wavelength 10 meters and time between crests of 0.5 seconds is traveling in water. What is the wave speed?

A. 0.1 m/s  
B. 2 m/s  
C. 5 m/s  
D. 20 m/s  

Transverse waves
- Medium vibrates perpendicularly to direction of energy transfer
- Side-to-side movement

Examples:
- Vibrations in stretched strings of musical instruments
- Electromagnetic waves, such as light and radio

What is the wavelength of a transverse wave?

A. successive compressions  
B. successive rarefactions  
C. Both A and B  
D. None of the above.

Longitudinal waves
- Medium vibrates parallel to direction of energy transfer
- Backward and forward movement consists of compressions (wave compressed) and rarefactions (stretched region between compressions)

Example: sound waves in solid, liquid, gas

Sound is a longitudinal wave.
- Compression regions travel at the speed of sound.
- In a compression region, the density and pressure of the air is higher than the average density and pressure.
**Wave interference** occurs when two or more waves interact with each other because they occur in the same place at the same time.

**Superposition principle:** The disturbance due the interference of waves is determined by adding the disturbances produced by each wave.

**Wave Interference**

**Constructive interference:** When the crest of one wave overlaps the crest of another, their individual effects add together to produce a wave of increased amplitude.

**Destructive interference:** When the crest of one wave overlaps the trough of another, the high part of one wave simply fills in the low part of another. So, their individual effects are reduced (or even canceled out).

**Standing Waves**

- **Nodes** are the regions of minimal or zero displacement, with minimal or zero energy.
- **Antinodes** are the regions of maximum displacement and maximum energy.
- Antinodes and nodes occur equally apart from each other.

**Standing Waves on a String**

- A standing wave on a string vibrates as shown at the top.
- Suppose the frequency is doubled while the tension and the length of the string are held constant. Which standing wave pattern is produced?

**Waves in 2D or 3D**

- As wave energy leaves a source, the regions of crests are circles or spheres around the source, which spread out at the speed of the wave.

**Doppler Effect**

- If a sound source is not moving relative to you, you hear the "rest frequency" of the emitted sound.
- If the source is moving toward you, you will hear a frequency that is higher than the rest frequency.
- If the source is moving away from you, you will hear a frequency that is lower than the rest frequency.
- By measuring the difference between the observed and known rest frequencies, you can determine the speed of the source.
Valerie is standing in the middle of the road, as a police car approaches her at a constant speed, \( v \). The siren on the police car emits a "rest frequency" of \( f_0 \).

Which statement is true?

Valerie is standing in the middle of the road, listening to the siren of a police car approaching her at a constant speed, \( v \). Daniel is listening to a similar siren on a police car that is not moving.

A. The frequency Daniel hears is lower than the frequency Valerie hears.
B. The frequency Daniel hears is higher than the frequency Valerie hears.
C. The frequencies that Daniel and Valerie hear are exactly the same.

Origin of Sound

Most sounds are waves produced by the vibrations of matter.

Examples:
- In a piano, a violin, and a guitar, the sound is produced by a vibrating string;
- in a saxophone, by a vibrating reed;
- in a flute, by a fluttering column of air at the mouthpiece;
- in your voice due to the vibration of your vocal chords.

Frequency and Pitch

- The frequency of a sound wave is the same as the frequency of the vibrating source.
- The subjective impression about the frequency of sound is called pitch.

- The ear of a young person can normally hear pitches corresponding to the range of frequencies between about 20 and 20,000 Hertz.
- As we grow older, the limits of this human hearing range shrink, especially at the high-frequency end.

Infrasound and Ultrasound

- Sound waves with frequencies below 20 hertz are infrasonic (frequency too low for human hearing).
- Sound waves with frequencies above 20,000 hertz are called ultrasonic (frequency too high for human hearing).
- We cannot hear infrasonic and ultrasonic sound.

Wavelength of sound

- Distance between successive compressions or rarefactions

How sound is heard from a radio loudspeaker

- Radio loudspeaker is a paper cone that vibrates.
- Air molecules next to the loudspeaker set into vibration.
- Produces compressions and rarefactions traveling in air.
- Sound waves reach your ears, setting your eardrums into vibration.
- Or it reaches a microphone and sets up vibrations there, which are converted to an electric signal.

Media That Transmit Sound

- Any elastic substance — solid, liquid, gas, or plasma — can transmit sound.
- In liquids and solids, the atoms are relatively close together, respond quickly to one another’s motions, and transmit energy with little loss.
- Sound travels about 4 times faster in water than in air and about 15 times faster in steel than in air.

Speed of Sound in Air

- Depends on temperature, pressure and humidity
- Speed in 0°C dry air at sea level is about 330 m/s.
- In warm air sound travels faster than in cold air.
- Each degree rise in temperature above 0°C, speed of sound in air increases by 0.6 m/s
You hear thunder 3 seconds after you see a lightning flash. How far away is the lightning?

A. About 340 m  
B. About 660 m  
C. About 1 km  
D. More than 2 km  
D. There’s no way to tell.

Speed of Sound in Air

- Note that light travels almost instantaneously (300,000 km/s) and sound travels about 1/3 km/s.
- So if you count the number of seconds between seeing a flash and hearing the thunder, you can divide by 3 and get the distance to the storm in kilometres.

Reflection of Sound

- Process in which sound encountering a surface is returned
- Often called an echo
- Multiple reflections—called reverberations

Reverberations are best heard when you sing in a room with

A. carpeted walls.  
B. hard-surfaced walls.  
C. open windows.  
D. None of the above.

Reflection of Sound

- Acoustics is the study of sound and architecture
- A concert hall aims for a balance between reverberation and absorption.
- Some have reflectors to direct sound

Refraction of Sound

- Bending of waves—caused by changes in speed affected by temperature variations.

When air near the ground on a warm day is warmed more than the air above, sound tends to bend

A. upward.  
B. downward.  
C. at right angles to the ground.  
D. None of the above.

In the evening, when air directly above a pond is cooler than air above, sound across a pond tends to bend

A. upward.  
B. downward.  
C. at right angles to the ground.  
D. None of the above.

Natural Vibrations

- Every object has its own unique frequency that it naturally tends to vibrate at.
- Dependent on
  - Elasticity
  - Mass of object
  - Shape of object
  - Size of object
Forced Vibrations
• Setting up of vibrations in an object by a vibrating force
• Examples:
  • Factory floor vibration caused by running of heavy machinery
  • Table vibration from paint shaker

Resonance
A phenomenon in which the frequency of forced vibrations on an object matches the object’s natural frequency
Examples:
• Swaying in rhythm with the natural frequency of a swing
• Tuning a radio station to the “carrier frequency” of the radio station
• Troops marching in rhythm with the natural frequency of a bridge (a no-no)

Tacoma Narrows Bridge Collapse 1940
Dramatic example of wind-generated resonance!

Interference
The superposition of two identical transverse waves in phase produces a wave of increased amplitude.
The superposition of two identical longitudinal waves is a point source of wave of increased intensity.
Two identical transverse waves that are out of phase destroy each other when they are superimposed.
Two identical longitudinal waves that are out of phase destroy each other when they are superimposed.

Example
Two speakers, A and B, are “in phase” and emit a pure note with a wavelength 2 m. The speakers are side-by-side, 3 m apart. Point C is 4 m directly in front of speaker A. Will a listener at point C hear constructive or destructive interference?

In Class Discussion Question
Two speakers, A and B, are “in phase” and emit a pure note with a wavelength 2 m. The speakers are side-by-side, 3 m apart. Point C is 4 m directly in front of speaker A. How many wavelengths are between Speaker A and Point C?
A. 0.5    B. 1.0    C. 1.5    D. 2.0    E. 2.5

In Class Discussion Question
Two speakers, A and B, are “in phase” and emit a pure note with a wavelength 2 m. The speakers are side-by-side, 3 m apart. Point C is 4 m directly in front of speaker A. How many wavelengths are between Speaker B and Point C?
A. 0.5    B. 1.0    C. 1.5    D. 2.0    E. 2.5

In Class Discussion Question
Two speakers, A and B, are “in phase” and emit a pure note with a wavelength 2 m. The speakers are side-by-side, 3 m apart. Point C is 4 m directly in front of speaker A. At point C, what is the path difference between the sounds received from speakers A and B, as measured in wavelengths?
A. 0.5    B. 1.0    C. 1.5    D. 2.0    E. 2.5
In Class Discussion Question

Two speakers, A and B, are “in phase” and emit a pure note with a wavelength 2 m. The speakers are side-by-side, 3 m apart. Point C is 4 m directly in front of speaker A. At point C, there will be
A. Constructive interference (Amplitude at C =2A)
B. Destructive interference (Amplitude at C =zero)

Before Class 7 on Monday

• Please read Chapters 21 and 22, or at least watch the 20-minute pre-class video for class 7
• Pre-class reading quiz on chapters 19 and 20 is due Monday June 10 by 10:00am

• Something to think about:
  • When you record the sound of music or a voice, what data is actually being stored in your computer? What is it about the sound that is being recorded?