L 21 – Vibration and Waves-2

- Vibrations (oscillations)
  - resonance
  - pendulum
  - springs
  - harmonic motion

- Waves
  - mechanical waves
  - sound waves
  - musical instruments

REVIEW: Vibrating systems

- Mass and spring on air track
- Mass hanging on spring
- Pendulum
- Torsional oscillator

All vibrating systems have one thing in common ➔ restoring force

Springs obey Hooke’s Law

- the strength of a spring is measured by how much force it provides for a given amount of stretch
- we call this quantity \( k \), the spring constant in N/m
- magnitude of spring force = \( k \times \text{amount of stretch} \)

\[ F_{\text{spring}} = k \times x \]

example

- A mass of 2 kg is hung from a spring that has a spring constant \( k = 100 \text{ N/m} \). By how much will it stretch?
- The downward weight of the mass is balanced by the upward force of the spring.
- \[ w = mg = k \times x \]
  \[ = 2 \text{ kg} \times 10 \text{ m/s}^2 \]
  \[ = (100 \text{ N/m}) \times x \]
  \[ 20 \text{ N} = 100 \text{ N/m} \times x \]
  \[ x = 0.2 \text{ m or 20 cm} \]

simple harmonic oscillator

- mass and spring on a frictionless surface

k is the spring constant, which measures the “stiffness” of the spring in Newtons per meter

Terminology

- AMPLITUDE \( A \): maximum displacement from equilibrium (starting position)
- PERIOD \( T \): time for one complete cycle
- FREQUENCY \( f \): number of complete cycles per unit time; one cycle per second = 1 Hertz (Hz)

- Frequency and period are not independent quantities, but are related inversely:
  \[ f = \frac{1}{T}, \quad T = \frac{1}{f} \]
follow the mass – position vs. time

period (T) and frequency (f) of the mass-spring system

Period and frequency of the pendulum

Energy in the simple harmonic oscillator

Waves → vibrations that move

Why are waves important?

- Waves are a means to transport energy from one place to another without transporting matter
- Electromagnetic waves (light, x-rays, UV rays, microwaves, thermal radiation) are disturbances that propagate through the electromagnetic field, even in vacuum (e.g. light from the Sun→ takes about 8 minutes to get to earth)
Wave Classification

- Classification based on the “medium”
  - Mechanical waves: a disturbance that propagates through a medium
    - waves on strings
    - waves in water (ocean waves, ripples on a lake)
    - sound waves – pressure waves in air
  - Electromagnetic waves → no medium required
- Classification based on how the medium responds
  - transverse
  - longitudinal
- Classification based on time history
  - single pulse (non-repetitive)
  - series of waves – harmonic wave (repetitive)

Transverse wave on a string

- jiggle the end of the string to create a disturbance
- the disturbance moves down the string
- as it passes, the string moves up and then down
- the string motion in vertical but the wave moves in the horizontal (perpendicular) direction → transverse wave
- this is a single pulse wave (non-repetitive)

Longitudinal waves

- instead of jiggling the spring up and down, you jiggle it in and out
- the coils of the spring move along the same direction (horizontal) as the wave
- This produces a longitudinal wave
- Sound waves are longitudinal waves

Speed of a wave on a string

- Note that the speed of the wave moving to the right is not the same as the speed of the string as it moves up and down.
- The wave speed is determined by:
  - the tension in the string → more tension → higher speed
  - the mass per unit length of the string (whether it’s a heavy rope or a light rope) → thicker rope → lower speed

Harmonic waves
produced by jiggling the end of the string up and down continuously

→ produces a continuous wavetrain

Sound – a longitudinal wave
Sound Waves

- Longitudinal pressure disturbances in a gas, (liquid, or solid)
- The air molecules jiggle back and forth along the same direction as the wave
- A series of high pressure regions (condensations) and low pressure regions (rarefactions)

No air \(\rightarrow\) no sound!

- Sound is a disturbance in a gas (air)
- In vacuum, there are no sound waves
- \(\rightarrow\) there is no sound in outer space

Human sense of hearing

- Sound waves cause our eardrums to vibrate
- The eardrum is sensitive to displacements on the order of the size of an atom
- Humans can hear sounds between about 30 Hz and 20,000 Hz
  - Sound below 30 Hz is called infrasound
  - Sound above 20,000 Hz is called ultrasound

The speed of sound

- Sound \(\rightarrow\) pressure waves in a solid, liquid or gas
- The speed of sound \(v_s\)
  - Air at 20 C: \(343 \text{ m/s} = 767 \text{ mph} \approx \frac{1}{5} \text{ mile/sec}\)
  - Water at 20 C: 1500 m/s
  - Copper: 5000 m/s
- Depends on density and temperature

5 second rule for thunder and lightning

Why do I sound funny when I breath helium?

- The speed of sound depends on the mass of the molecules in the gas
- Sound travels twice as fast in helium, because Helium is lighter than air
- The higher sound speed results in sounds of higher pitch (frequency)

Acoustic resonance