

Module 9: Waves and Oscillations (PHY 1200)

Introduction

Many physical systems involve motion that repeats over time. Examples include:

- a vibrating guitar string
- sound traveling through air
- ocean waves moving toward the shore
- light traveling through space

These phenomena involve waves, which are disturbances that transfer energy from one place to another.

Understanding waves allows scientists to explain many important natural processes, including sound, light, and electromagnetic radiation.

In this module we will explore the basic properties of waves and the mathematical relationships that describe them.

Oscillations

An oscillation is motion that repeats itself in a regular pattern.

Examples include:

- a swinging pendulum
- a vibrating spring
- a guitar string after it is plucked

Oscillations involve motion back and forth around an equilibrium position.

Equilibrium Position

The equilibrium position is the point where the net force acting on an object is zero.

When an oscillating object moves away from equilibrium, restoring forces act to bring it back.

These restoring forces cause the motion to repeat.

Period and Frequency

Two important quantities describe oscillating motion:

Period (T)

The period is the time required for one complete cycle of motion.

Units: seconds (s)

Frequency (f)

The frequency is the number of cycles that occur each second.

Units: hertz (Hz)

1 Hz = 1 cycle per second.

Relationship Between Period and Frequency

Frequency and period are related by the equation:

$$f = 1 / T$$

or

$$T = 1 / f$$

Example

If an oscillation has a period of 0.5 seconds, what is the frequency?

$$f = 1 / T$$

$$f = 1 / 0.5$$

$$f = 2 \text{ Hz}$$

The system completes 2 cycles per second.

Waves

A wave is a disturbance that transfers energy through space or through a medium.

Examples of waves include:

- sound waves
- water waves
- light waves

Waves carry energy but do not permanently move matter from one location to another.

Types of Waves

Two common types of waves are:

Transverse Waves

In transverse waves, the motion of the medium is perpendicular to the direction of wave travel.

Example:

Light waves.

Longitudinal Waves

In longitudinal waves, the motion of the medium is parallel to the direction of wave travel.

Example:

Sound waves in air.

Basic Wave Properties

Three important quantities describe waves:

- wavelength
- frequency
- wave speed

Wavelength (λ)

The wavelength is the distance between repeating points in a wave.

Examples of repeating points include:

- crest to crest
- trough to trough

Wavelength is measured in meters (m).

Frequency (f)

Frequency describes how many wave cycles occur per second.

Units: hertz (Hz).

Wave Speed (v)

Wave speed describes how fast the wave travels.

Units: meters per second (m/s).

The Wave Equation

The relationship between wave speed, frequency, and wavelength is:

$$v = f\lambda$$

where:

v = wave speed

f = frequency

λ = wavelength

This equation is fundamental in wave physics.

Worked Example

A wave has a frequency of 500 Hz and a wavelength of 0.68 meters.

Find the wave speed.

$$v = f\lambda$$

$$v = 500 \times 0.68$$

$$v = 340 \text{ m/s}$$

The wave speed is 340 meters per second.

Example: Finding Wavelength

A sound wave travels at **340 m/s** and has a frequency of **170 Hz**.

Find the wavelength.

$$\lambda = v / f$$

$$\lambda = 340 / 170$$

$$\lambda = 2 \text{ meters}$$

Energy in Waves

Waves transfer energy from one location to another.

The amount of energy carried by a wave depends on its amplitude.

Amplitude

The amplitude of a wave is the maximum displacement from equilibrium.

Greater amplitude corresponds to greater energy.

For example:

- louder sounds have greater amplitude
- brighter light waves have greater amplitude

Interference

When two waves overlap, they combine according to the principle of superposition.

This combination is called interference.

Constructive Interference

Constructive interference occurs when two waves combine to produce a larger amplitude.

This happens when wave crests meet wave crests.

Destructive Interference

Destructive interference occurs when waves combine in a way that reduces amplitude.

This happens when a crest meets a trough.

Standing Waves

A standing wave forms when two waves traveling in opposite directions interfere with each other.

Standing waves occur in systems such as:

- vibrating guitar strings
- air columns in musical instruments

Standing waves contain points called nodes, where no motion occurs.

Worked Example

A wave has a frequency of 250 Hz and travels at 500 m/s.

Find the wavelength.

$$\lambda = v / f$$

$$\lambda = 500 / 250$$

$$\lambda = 2 \text{ meters}$$

Practice Problems

1. A wave has a frequency of 400 Hz and wavelength 0.5 meters.
Find the wave speed.
2. A sound wave travels at 340 m/s and has frequency 170 Hz.
Find the wavelength.
3. If a wave has frequency 5 Hz, what is its period?
4. If the period of an oscillation is 0.2 seconds, what is the frequency?

Challenge Problems

1. A wave travels at 300 m/s and has a wavelength of 1.5 meters.
Find the frequency.
2. A wave has frequency 600 Hz and wave speed 300 m/s.
Find the wavelength.
3. An oscillation has frequency 4 Hz.
Find the period.