Introduction to Waves

"A bit of gossip starting in Washington reaches New York very quickly, even though not a single individual who takes part in spreading it travels between these two cities. There are two quite different motions involved, that of the rumor, Washington to New York, and that of the persons who spread the rumor. The wind, passing over a field of grain, sets up a wave which spreads out across the whole field. Here again we must distinguish between the motion of the wave and the motion of the separate plants, which undergo only small oscillations... The particles constituting the medium perform only small vibrations, but the whole motion is that of a progressive wave. The essentially new thing here is that for the first time we consider the motion of something which is not matter, but energy propagated through matter"

Albert Einstein and Leopold Infeld
*The Evolution of Physics*

A wave is a transfer of energy without the transfer of matter.

Classification of Waves

**Transverse Waves**
- The medium vibrates at a right angle to the direction of the wave.
- Only a solid can support transverse waves, since it requires shear force.
- The strings on a guitar carry transverse waves.

**Longitudinal (Compressional) Waves**
- The medium vibrates in the same direction of the wave.
- Solids, liquids, and gases can support longitudinal waves.
- Sound coming from a guitar to the ear is a longitudinal wave.

**Surface Waves**
- The medium vibrates in circles, only at the surface of a medium. Waves on the ocean are surface waves.
Types of Waves

Mechanical Waves

- Water waves, sound waves, and seismic waves, even human waves!
- Exist only within a medium, such as air, water, and earth.
- Governed by mechanical laws; properties (like speed) depend on the nature of the medium propagates the wave.

Electromagnetic Waves

- Visible light, infrared and ultraviolet light, radio and television waves, microwaves, X-rays, gamma waves, radar waves, and much more!
- Require no medium to propagate (travel) within.
- All move at the same speed, $c = 3.0 \times 10^8 \text{ m/s}$, in a vacuum.

Wave Reflection

Waves will reflect when they encounter a boundary. Two types of reflections exist.

Closed end reflection

- Occurs when a wave strikes a more dense medium
- Results in an inverted wave pulse

Open end reflection

- Occurs when a wave strikes a less dense medium
- Results in an upright wave pulse
Wave Reflection and Transmission

Waves partially reflect and partially transmit when they encounter a boundary between two different media. The amount of reflection depends on the difference between the media.

An “impedance match” device is used to propagate a wave from one medium to another with minimal reflection.

- the human ear
- electrical transformer
- optical coating for lenses

Human Ear

Principle of Superposition

Constructive Interference

- When two waves crest overlap.
- The height of the combined waves is the sum of the heights of the individual waves.

Destructive Interference

- When a crest and a trough overlap.
- The height of the combined waves is the difference of the heights of the individual waves.
Wave Properties

**Wavelength** \(\lambda\) – “lambda”

- The distance from the crest of one wave to the crest of the next wave.
- Measured in meters in the metric system.

**Amplitude** \(A\)

- The height (in meters) of the wave from the rest position (not from crest to trough.)

**Energy** \(E\)

- Depends on the square of the wave amplitude.

**Period** \(T\)

- Time elapsed (in seconds) between a wave crest and the next crest.

**Frequency** \(f\)

- Reciprocal of period.
- Rate that a wave repeats itself (number of wave crests per time) measured in sec\(^{-1}\) or Hertz (Hz).

**Wave speed** \(v\)

- The rate (distance per unit time) at which a wave crest travels, measured in meters per second.

\[
\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{\text{wavelength}}{\text{period}}
\]

\[
v = \frac{\lambda}{T} \quad \text{also} \quad v = \lambda f
\]

**Example** In one minute, 12 ocean waves arrive at the shore. What is the period? What is the frequency? If the wave crests are 10 meters apart, what is the wave speed?

\[
T = \frac{60 \text{ seconds}}{12} = 5 \text{ s}
\]

\[
f = \frac{1}{T} = \frac{1}{5} = 0.2 \text{ Hz}
\]

\[
v = (10)(0.2) = \frac{10}{5} = 2 \text{ m/s}
\]