Waves

- A wave is a transfer of energy, in a form of a disturbance usually through a material substance, or medium.
    - Electromagnetic Waves
    - Sound waves
    - Water waves
    - Pressure waves
    - Gravity waves
    - Matter waves

- When objects repeat a pattern of motion (e.g. a pendulum), we say that object is vibrating or oscillating. (wiimote demo)
    - The oscillation is repeated over and over with the same time interval each time.
    - One complete oscillation is called a cycle.
    - The number of cycles per second is called the frequency, f. The frequency is measured in Hertz (Hz).

⇨ The period, T, usually measured in seconds, is the time required for one cycle. The frequency and period are reciprocals of each other.

$$\text{frequency} = \frac{\text{cycles}}{\text{time}} = \frac{1}{T}$$

$$\text{period} = \frac{\text{time}}{\text{cycle}} = \frac{1}{f}$$

Examples

1. A pendulum completes 30 cycles in 15 seconds. Calculate its frequency and period.

$$f = \frac{\#\text{cycles}}{\text{time}} = \frac{30}{15} = \boxed{2\ Hz}$$

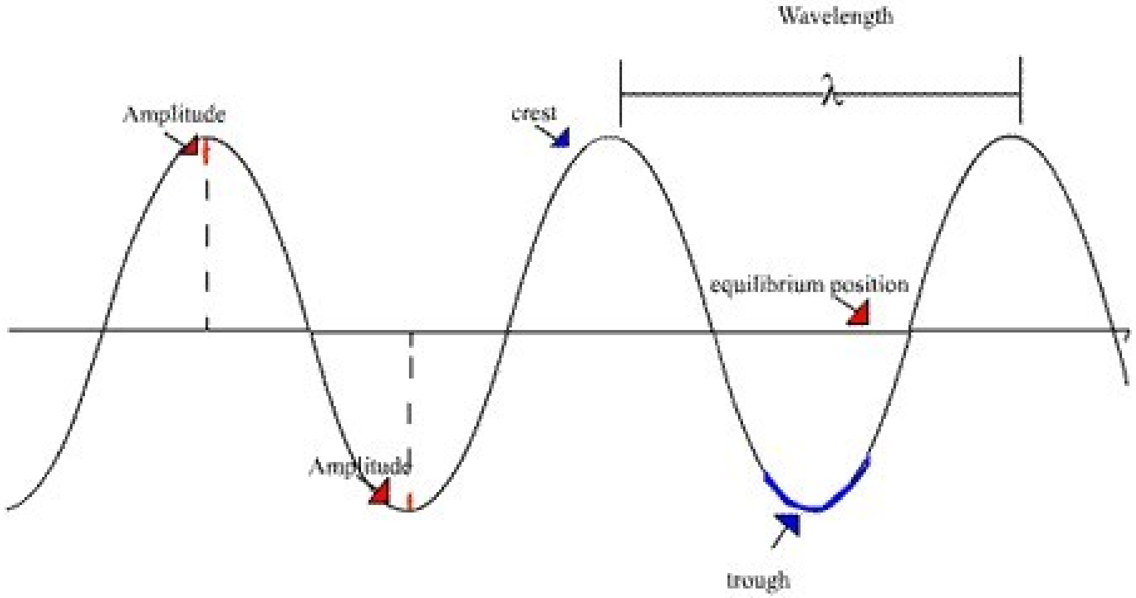
$$T = \frac{\text{time}}{1\ \text{cycle}} = \frac{15\ s}{30\ \text{cycle}} = \boxed{0.5\ s}$$

or

$$T = \frac{1}{f} = \frac{1}{2\ Hz} = \boxed{0.5\ s}$$

Transverse Waves

- ⇨ The particles in the medium vibrate at right angles to the direction in which the wave travels.
  - ⇨ The high section is called the crest, and the low section is called the trough.
  - ⇨ The height of the crest or depth of the trough, from the equilibrium position is called the amplitude.
  - ⇨ For periodic waves, the distance between successive crests and troughs is equal and is called the wavelength. The symbol for the wavelength is the Greek letter lambda, λ.
  - ⇨ The period of a transverse wave is the time it takes for one wavelength (one cycle) to pass a fixed point.
  - ⇨ The frequency is the number of wavelengths that passed a fixed point in one second.
  - ⇨ Examples include water waves and making vibrations on a rope.

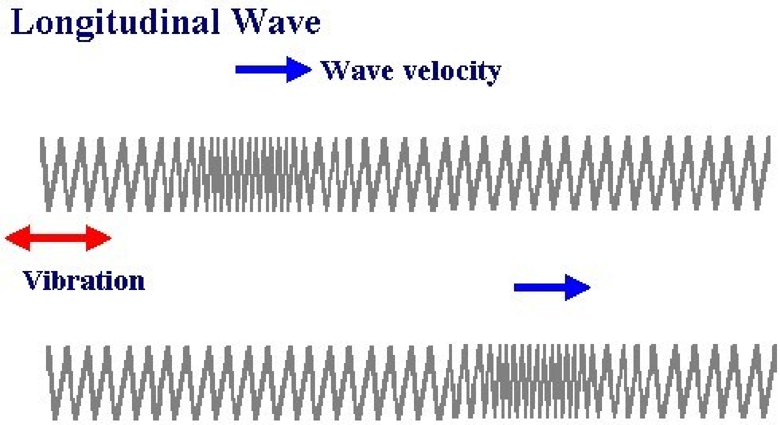


library.thinkquest.org/. ../Waves/basic.htm

Longitudinal Waves

- The vibrations of the particles are parallel to the direction of motion.
  - There are a compressions and rarefactions created in longitudinal waves.
  - One wavelength is the distance between the midpoints of successive compressions or rarefactions.
  - The amplitude is the maximum displacement of the particles from their rest position. Amplitude is a measure of the wave's energy.

- ⇨ The period of a longitudinal wave is the time it takes for one wavelength (one cycle) to pass a fixed point.
- ⇨ The frequency is the number of wavelengths that passed a fixed point in one second.
- ⇨ Sound waves, pressure waves are examples.



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Transmission of Waves

- ⇨ When a wave is generated in a spring or a rope, the wave travels a distance of one wavelength, λ, along the rope in the time required for one complete vibration of the source (the period). We can use the formula for velocity to derive the wave equation:

$$\text{velocity, } v = \frac{\text{change in distance, } \Delta d}{\text{change in time, } \Delta t}$$

and $\Delta d = \lambda$, and $\Delta t = T$

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

but $$f = \frac{1}{T}$$

Therefore $$v = f\lambda$$

⇨ The wave equation, $v = f\lambda$, applies to all waves, visible and invisible.

Examples

1. The wavelength of a water wave in a ripple tank is 0.080 m. If the frequency of the wave is 2.5 Hz, what is its speed?

$\lambda = 0.080\,m$

$f = 2.5\,Hz$

$v = f\lambda$

$= (2.5)(0.08)$

$= 0.2\,m/s$

2. The distance between successive crests in a series of water waves is 4.0 m, and the crests travel 9.0 m in 4.5 s. What is the frequency of the waves?

$\lambda = 4.0\,m$

$d = 9.0\,m$

$t = 4.5\,s$

$f = ?$

$v = \frac{d}{t} = 9/4.5 = 2\,m/s$

$v = f\lambda$

$2 = f(4)$

$0.5\,Hz = f$

PRACTICE PROBLEMS

MHR: Pg. 341 # 1-4.

1. A metronome beats 54 times over a 55 s time interval. Determine the frequency and period of its motion.
2. Most butterflies beat their wings between 450 and 650 times per minute. Calculate in hertz the range of typical wing-beating frequencies for butterflies.
3. A watch spring oscillates with a frequency of 3.58 Hz. How long does it take to make 100 vibrations?
4. A child swings back and forth on a swing 12 times in 30.0 s. Determine the frequency and period of the swinging.

PRACTICE PROBLEMS

Pg. 349 # 5 – 9.

5. A longitudinal wave in a 6.0 m long spring has a frequency of 10.0 Hz and a wavelength of 0.75 m. Calculate the speed of the wave and the time that it would take to travel the length of the spring.
6. Interstellar hydrogen gas emits radio waves with a wavelength of 21 cm. Given that radio waves travel at 3.00×10^8 m/s, what is the frequency of this interstellar source of radiation?
7. Tsunamis are fast-moving ocean waves typically caused by underwater earthquakes. One particular tsunami travelled a distance of 3250 km in 4.6 h and its wavelength was determined to be 640 km. What was the frequency of this tsunami?
8. An earthquake wave has a wavelength of 523 m and travels with a speed of 4.60 km/s through a portion of Earth's crust.
   (a) What is its frequency?
   (b) If it travels into a different portion of Earth's crust, where its speed is 7.50 km/s, what is its new wavelength?
   (c) What assumption(s) did you make to answer part (b)?
9. The speed of sound in air at room temperature is 343 m/s. The sound wave produced by striking middle C on a piano has a frequency of 256 Hz.
   (a) Calculate the wavelength of this sound.
   (b) Calculate the wavelength for the sound produced by high C, one octave higher than middle C, with a frequency of 512 Hz.

Problems for Understanding

Chapter Review Pg. 372 # 21 – 28.

21. A pendulum takes 1.0 s to swing from the rest line to it's highest point. What is the frequency of the pendulum?
22. By what factor will the wavelength change if the period of a wave is doubled?
23. A wave with an amplitude of 50.0 cm travels down a 8.0 m spring in 4.5 s. The person who creates the wave moves her hand through 4 cycles in 1 second. What is the wavelength?
24. A sound wave has a frequency of 60.0 Hz. What is its period? If the speed of sound in air is 343 m/s, what is the wavelength of the sound wave?
25. Water waves in a ripple tank are 2.6 cm long. The straight wave generator used to produce the waves sends out 60 wave crests in 42 s.
   (a) Determine the frequency of the wave.
   (b) Determine the speed of the wave.
26. A rope is 1.0 m long and the speed of a wave in the rope is 3.2 m/s. What is the frequency of the fundamental mode of vibration?
27. A tsunami travelled 3700 km in 5.2 h. If its frequency was 2.9×10^{-4} Hz, what was its wavelength?
28. A storm produces waves of length 3.5 m in the centre of a bay. The waves travel a distance of 0.50 km in 2.00 min.
   (a) What is the frequency of the waves?
   (b) What is the period of the waves?

Transmission and Reflection

Waves travel at uniform speed as long as the medium they are in does not change. (Note: If the tension changes, then that is a change in medium.)

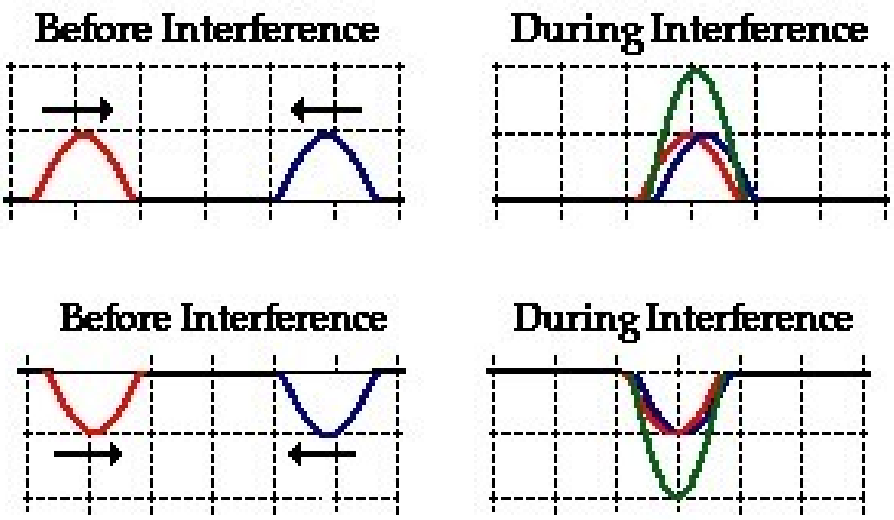
When waves propagate into a different medium, the frequency stays the same. The wave velocity changes.
Thus, the wavelength must change as well.v is directly proportional to λ .

Transmission of Waves

⇨ Wave interference is when two or more waves act simultaneously on the same particles of a medium.

⇨ Principle of Superposition: The resultant displacement of a given particle is equal to the sum of the displacements that would have been produced by each wave acting independently.

➢ Constructive interference results when two of more waves interfere to produce a resultant displacement greater than the displacement caused by either wave itself.



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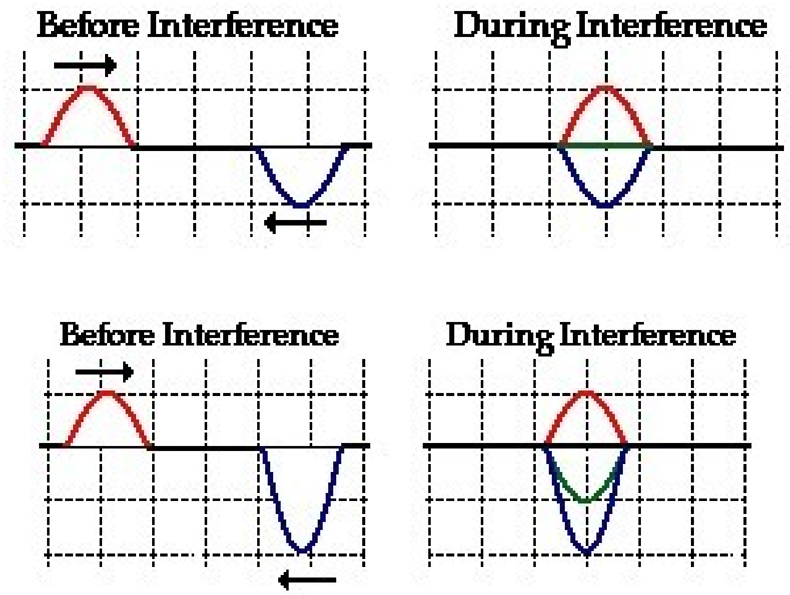
➢ Destructive Interference is when the resultant displacement is smaller than the displacement that would be caused by one wave by itself.



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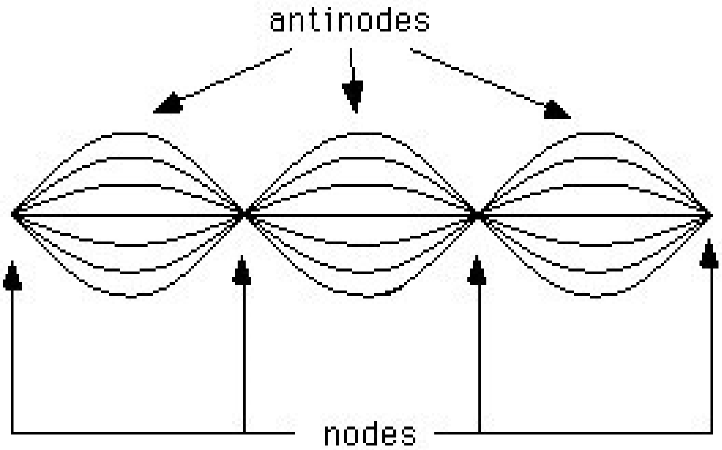
Standing Waves: Interference in One Dimension

⇨ A standing wave interference pattern occurs if interfering waves have the same amplitude, wavelength, frequency, and are traveling in opposite directions.

- Called a standing wave for short.



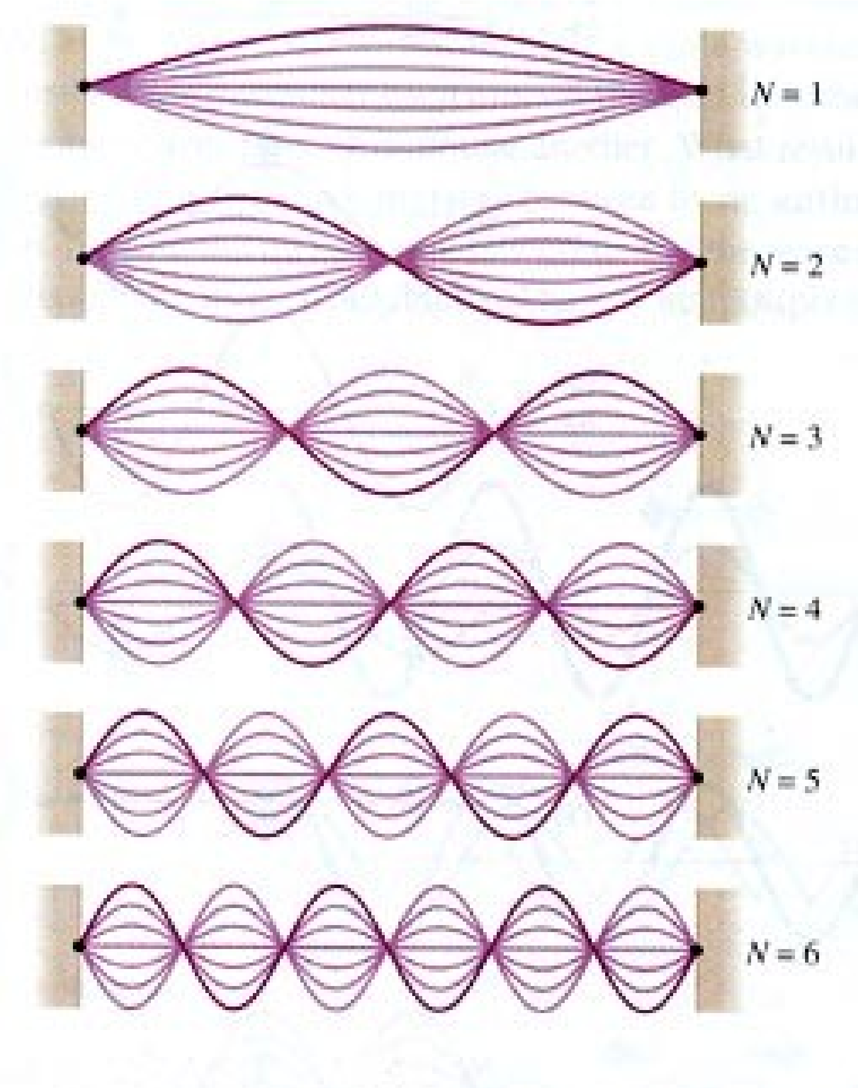
electron4.phys.utk.edu/ 141/dec1/December%201.htm

- The node, or nodal point , is where crests and troughs of equal amplitude interfere destructively. For one-dimensional waves the fixed ends are nodal points.

- The antinodes, or loops, are areas of constructive interference.

- The number of nodal points for a given medium depends on the physical structure of that medium, thus only certain frequencies will produce a standing wave pattern. Such frequencies are resonance frequencies for that medium.

⇨ If one antinode were created with a certain frequency, say f_1, then to create two or three antinodes (etc.) the frequency would have to be $2f_1$, or $3f_1$ respectively. Note the decrease in amplitude as more antinodes are created.

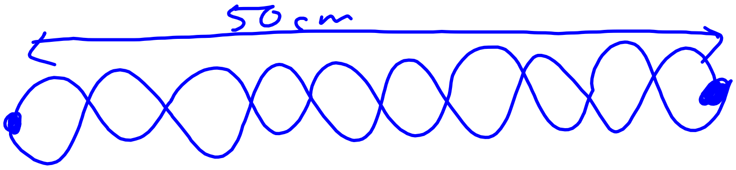


sol.sci.uop.edu/.../ soundinterference.html

- ⇨ The distance between two successive nodes in a vibrating string is ½λ.
- ⇨ The point of maximum displacement from a node is ¼λ.

Examples

1. What is the wave speed of a standing wave with containing 4.5 waves in 50 cm and waves are created 62 times each second?



$v = f\lambda$ $\lambda = ?$

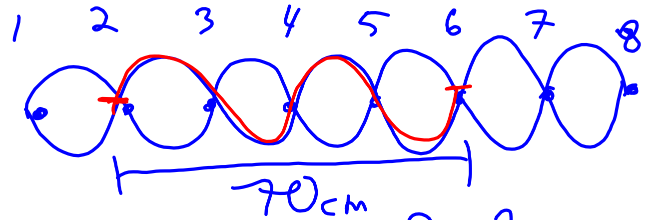
$f = 62\,Hz$ $50\,cm = 4.5\lambda$

$11.1 = \lambda$

$v = (62)(11.1)$

$690\,cm/s$

2. A standing wave pattern contains 8 nodes (with a node at the beginning and end. The distance between the second and 6th node 70 cm. The wave speed is 102 cm/s. What frequency is necessary to observe 3 nodes taking up the full length of the string?



$f_3 = ?$ ← to see 3 antinodes

$v = 102\,cm/s$

$f_7 = ?$

Find λ

$70\,cm = 2\lambda$

$35\,cm = \lambda$

$v = f\lambda$

$102 = f_7(35)$

$2.9\,Hz = f_7$

$f_1 = \frac{f_7}{7} = \frac{2.9}{7} = 0.42\,Hz$

$f_3 = 3f_1 = 3(0.42)$

$= 1.25\,Hz$