SLE123 Physics for the Life Sciences

Week 6

Waves

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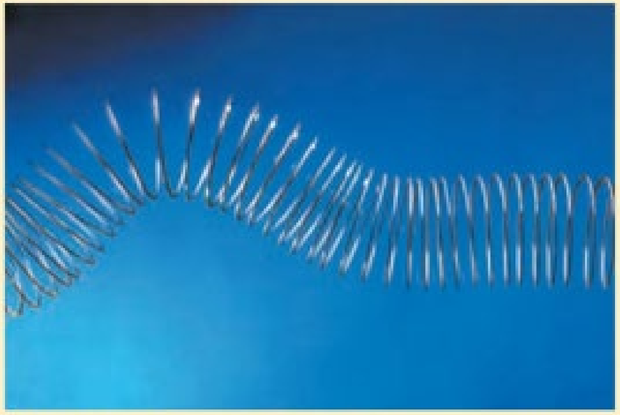
Looking Ahead

Traveling Waves

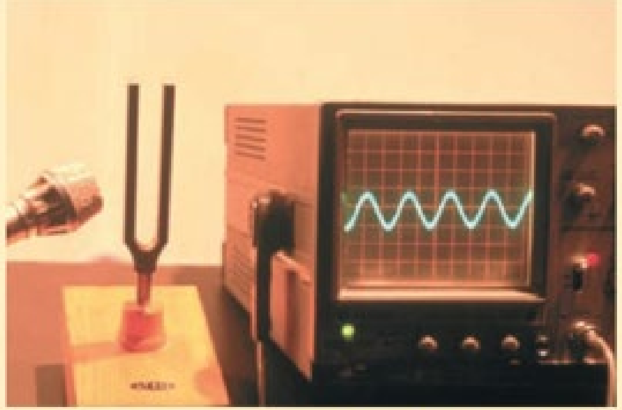
Shaking one end of the spring up and down causes a disturbance—a **wave**—to travel along the spring.



You'll learn the **wave model** that describes phenomena ranging from light waves to earthquake waves.

Describing Waves

The microphone picks up the vibrating tuning fork's sound wave. The signal is *sinusoidal*, a form we've seen for oscillations.



The terms and equations used to describe waves are closely related to those for oscillations, as you'll see.

Superposition

Where the two water waves meet, the motion of the water is a sum, a **superposition**, of the waves.

You'll learn how this **interference** can be constructive or destructive, leading to larger or smaller amplitudes.

Waves in the universe

- Physical phenomena that we can measure can be divided into:
- **Waves**: light, sound, mechanical waves etc...
- **Matter:** anything with mass eg atoms, particles
- and we will see later that waves and matter may be interconverted in some conditions.
- So the study of waves in physics is fundamental.

What Is a Wave?

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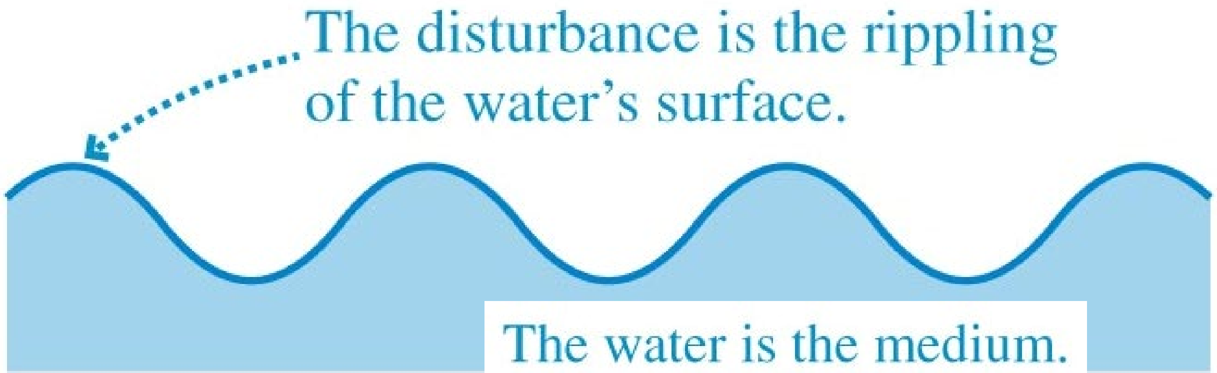
Waves

- A wave is a vibrational, trembling motion in an elastic, deformable body.
- Waves are caused by:

• a disturbance e.g. a stone falling into a pond, an earthquake

• a vibration (sound waves generated by larynx vibration, a tuning fork, instrument string etc).



Waves and energy

- Waves can move through large distances, but the medium through which the wave travels has only a limited movement.

- <u>All waves carry energy</u>.

- <u>Energy transported by a wave</u> is proportional to the square of its amplitude (similar to vibrations).

- So waves are a part of energy transformation in the universe

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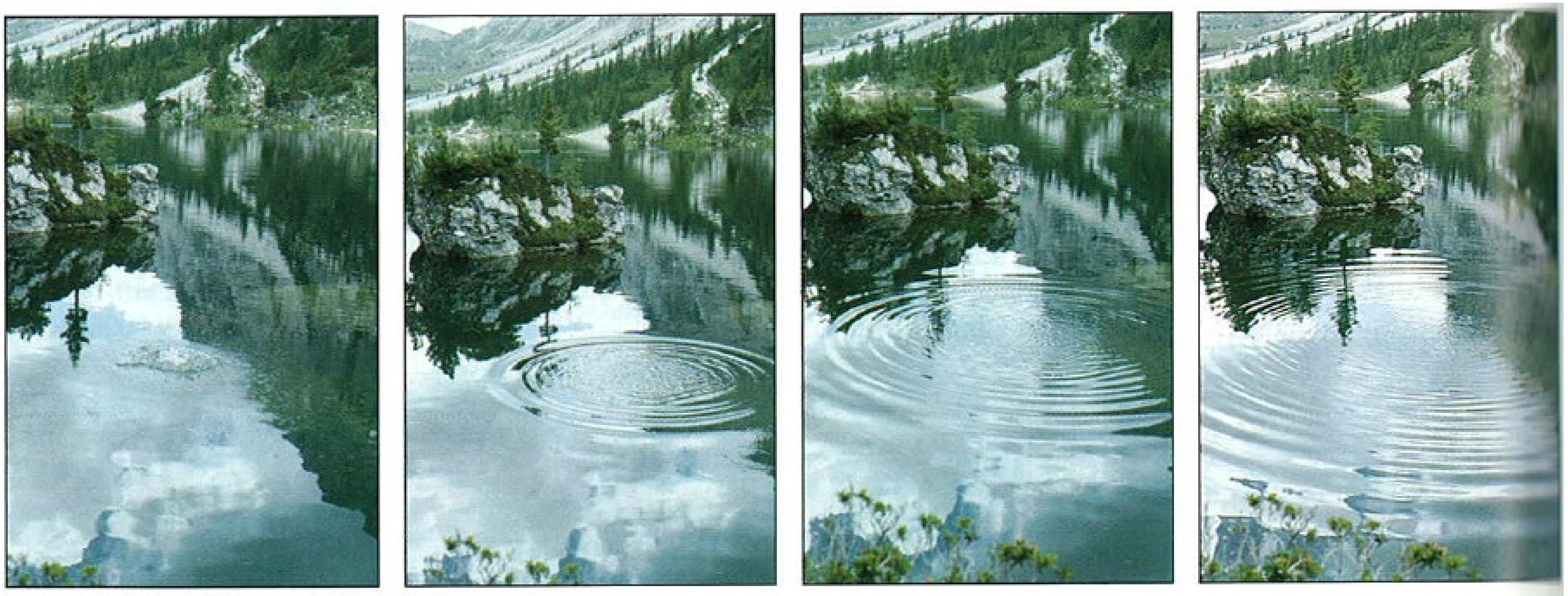
Waves

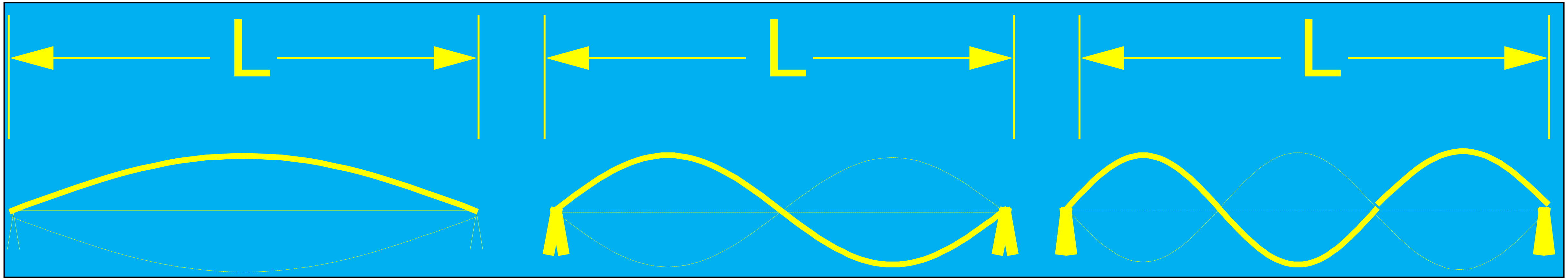


A stone thrown into a lake: Water waves spread outwards from the source.

Waves-travelling vs standing

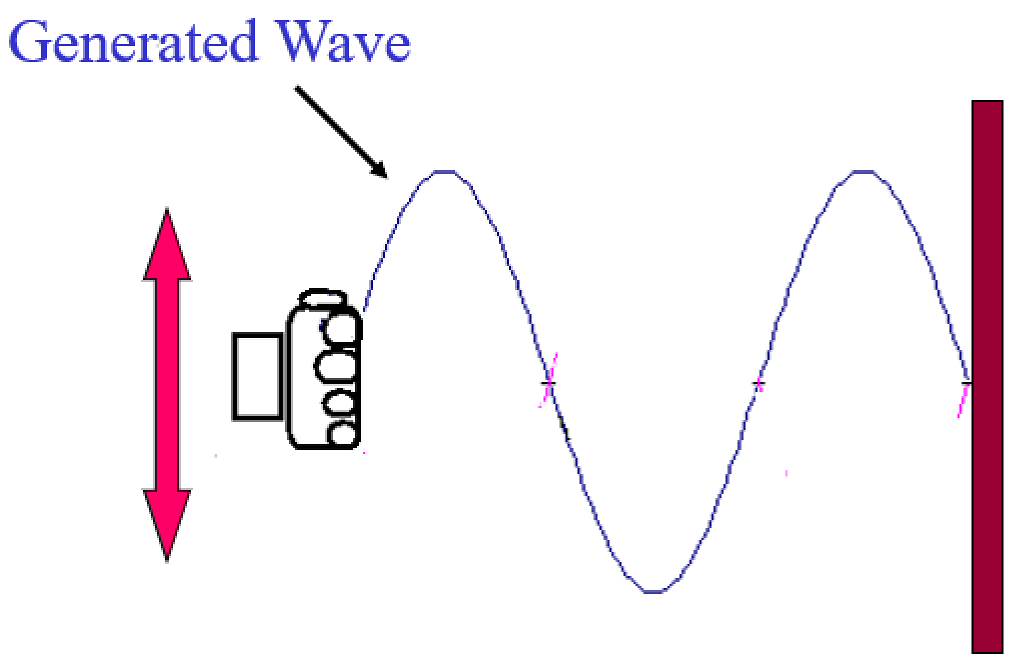
Travelling waves - e.g. light waves travel from the sun to earth

Standing waves - these are localised e.g. on a string,   they do not progress anywhere

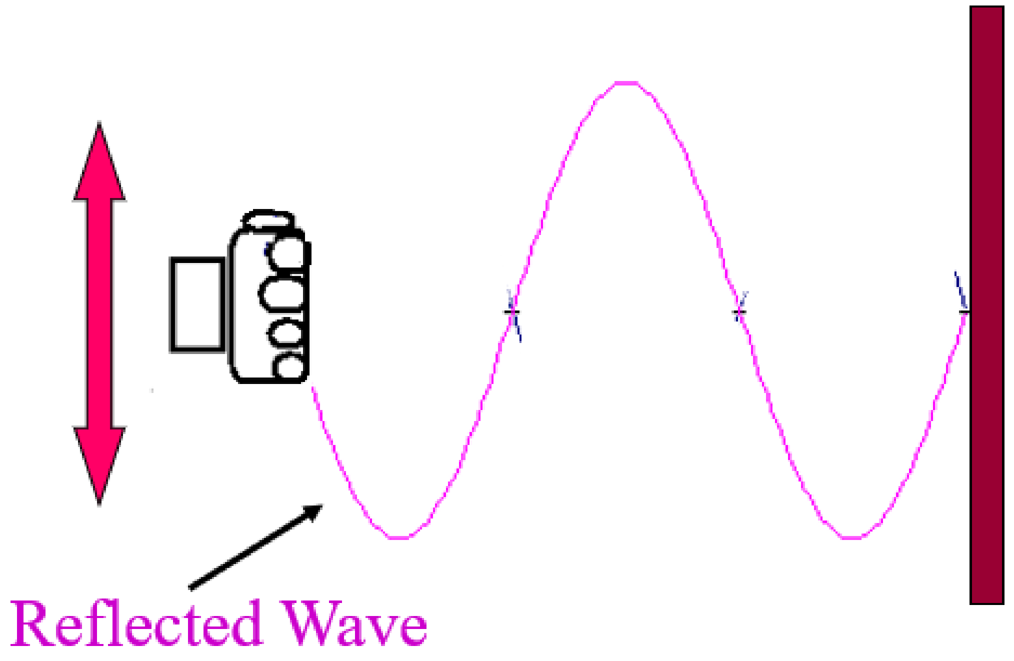


First, second and third harmonic waves on a string.

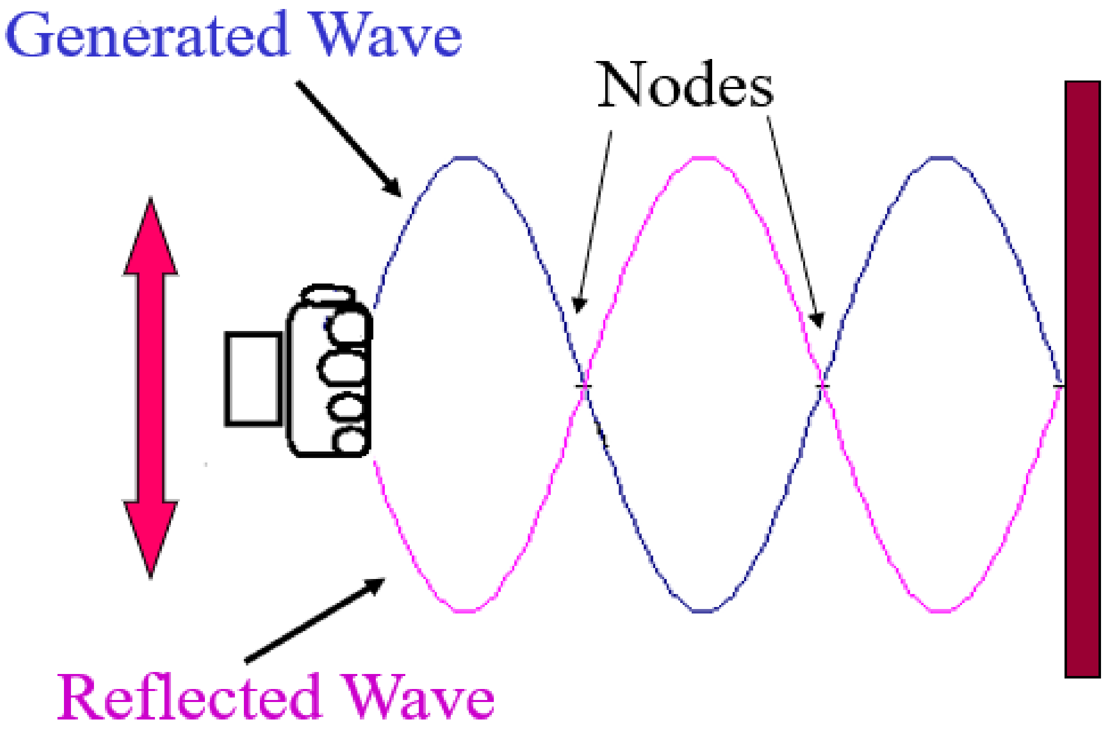
Standing Wave(1)



Standing Wave(2)



Standing Wave(3)



Wave propagation

- Waves can be *propagated* in gases, liquids, or solids, or in the case of electromagnetic waves only, in a vacuum.

- When waves are propagated the particles vibrate (but do not move with the wave).

- In the case of electromagnetic waves, the electric and magnetic fields vibrate, which may also induce vibrations of particles such as electrons.

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Wave propagation (cont.)

- Waves travel at different speeds depending on the type of wave and the medium.
- <u>Wave speeds</u>
- Sound waves in air: $\boldsymbol{v}_{\textbf{sound}}$ **= 343m/s at 20°C**
- E.M. waves all travel at the <u>speed of light</u>.
- $\boldsymbol{v}_{\textbf{light}}$ **= 3×10⁸ m/s in vacuum**
- Light waves travel about a million times faster than sound waves - this is why lightening appears before thunder is heard.

Example 15.3 How far away was the lightning?

- During a thunderstorm, you see a flash from a lightning strike. 8.0 seconds later, you hear the crack of the thunder. How far away did the lightning strike?

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Example 15.3 How far away was the lightning? (cont.)

SOLVE We will assume that the speed of sound has its room temperature (20°C) value of 343 m/s. During the time between seeing the flash and hearing the thunder, the sound travels a distance

$$d = v\,\Delta t = (343\ \text{m/s})(8.0\ \text{s}) = 2.7 \times 10^3\ \text{m} = 2.7\ \text{km}$$

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Wave characteristics

- These include, *period, frequency, angular frequency* and *amplitude* as for vibrations. Also wavelength and wavespeed.

- Period is the time for one cycle (second , s)
- Frequency is number of cycles per second (hertz Hz)
- Wavelength (m) is the distance between the peaks of a wave or the troughs of a wave.
- Wave speed, v (m/s), is the speed at which the particular type of wave is propagated.
- e.g. v_{sound} = 343m/s; v_{light} = 3×10^8m/s in vacuum.

Fundamental wave equation

- The most fundamental and important equation for a wave relates its frequency, f (Hz), wavelength λ (m) and wave speed v (m/s).

$$f = \frac{1}{T} \quad (\text{SI unit Hz} = \text{s}^{-1})$$

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

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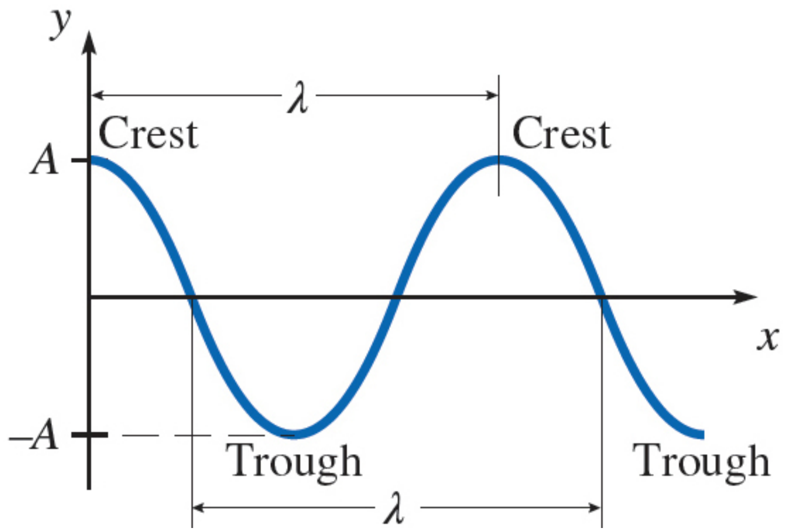

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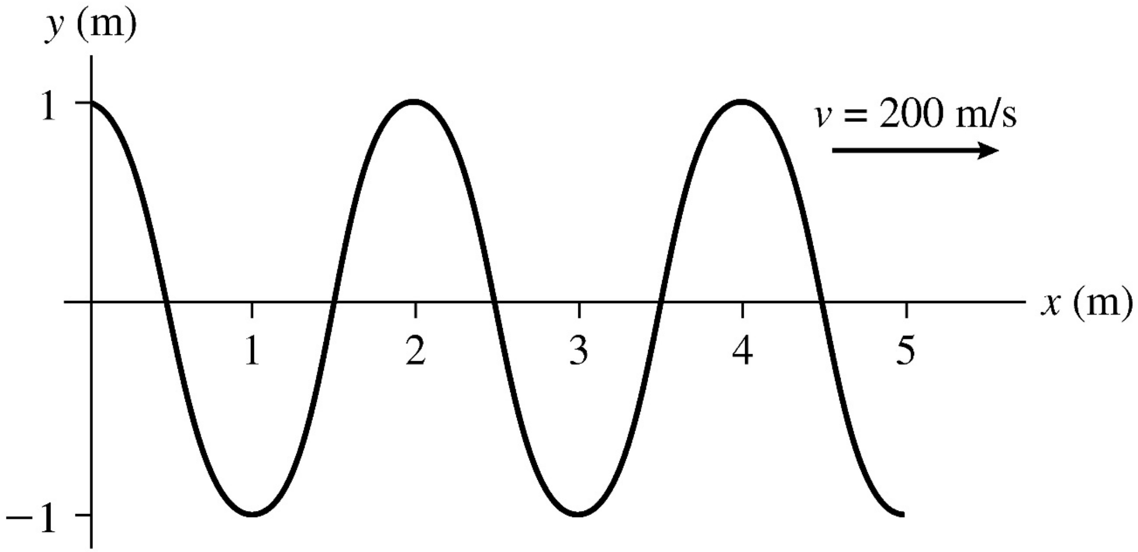
QuickCheck 1

For this sinusoidal wave, what is the amplitude?

- 0.5 m
- 1 m
- 2 m
- 4 m



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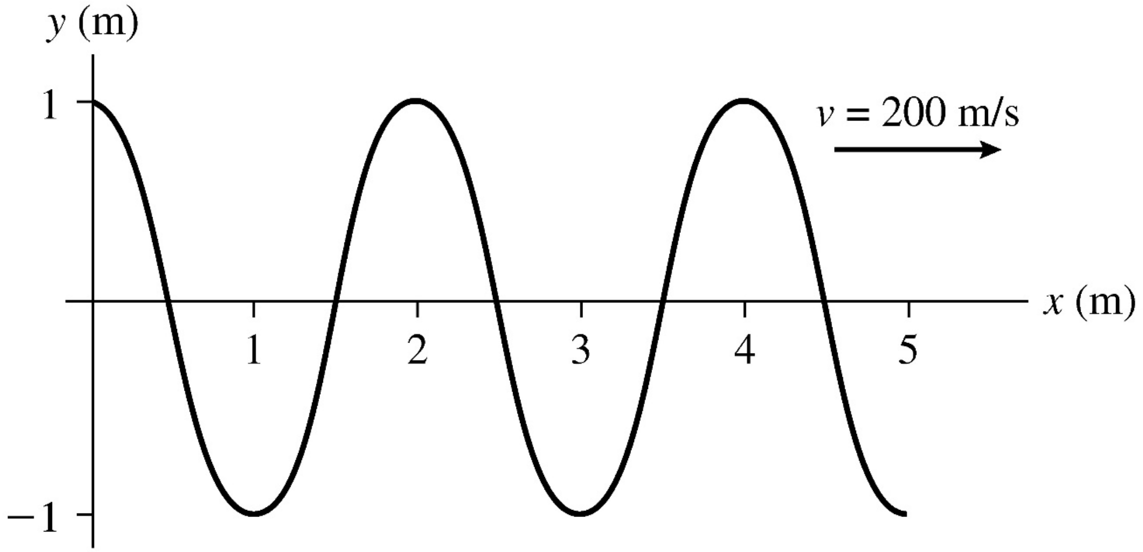
QuickCheck 1

For this sinusoidal wave, what is the amplitude?

- 0.5 m
- 1 m ✔
- 2 m
- 4 m



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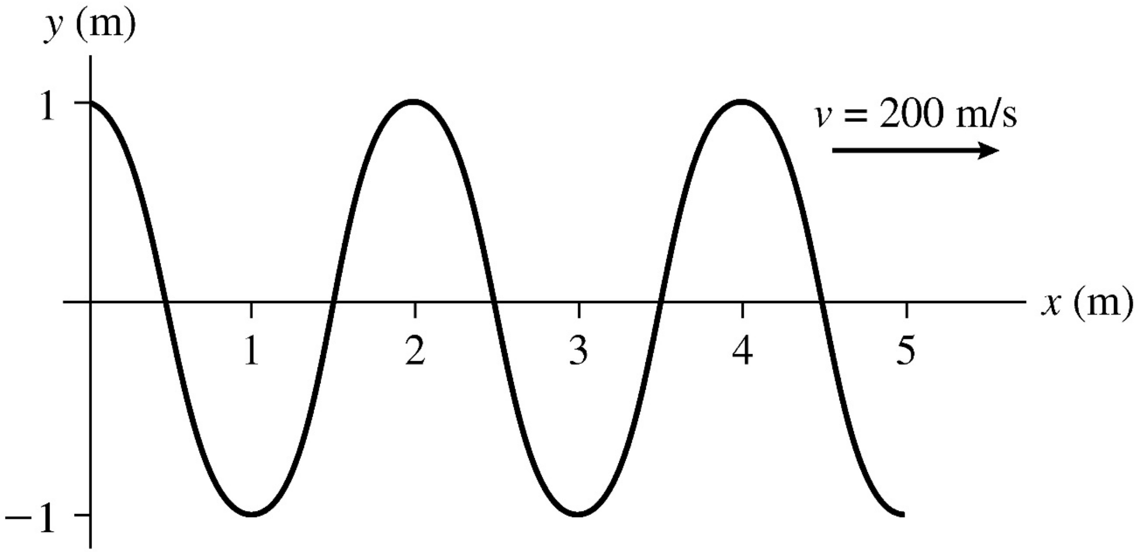
QuickCheck 2

For this sinusoidal wave, what is the wavelength?

- 0.5 m
- 1 m
- 2 m
- 4 m



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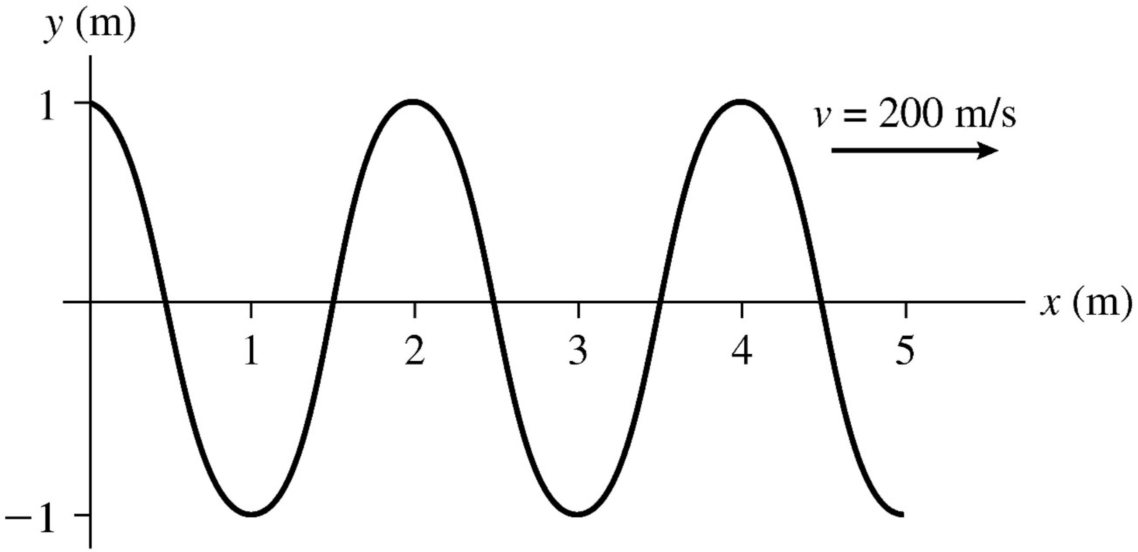
QuickCheck 2

For this sinusoidal wave, what is the wavelength?

- 0.5 m
- 1 m
- 2 m ✔
- 4 m



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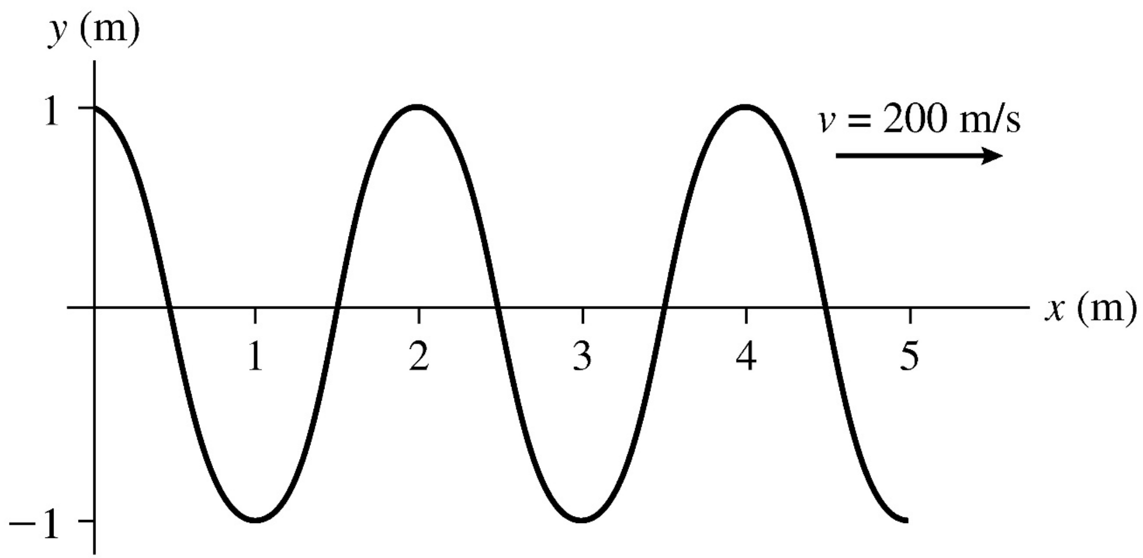
QuickCheck 3

For this sinusoidal wave, what is the frequency?

- 50 Hz
- 100 Hz
- 200 Hz
- 400 Hz



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QuickCheck 3

For this sinusoidal wave, what is the frequency?

- 50 Hz
- 100 Hz ✔
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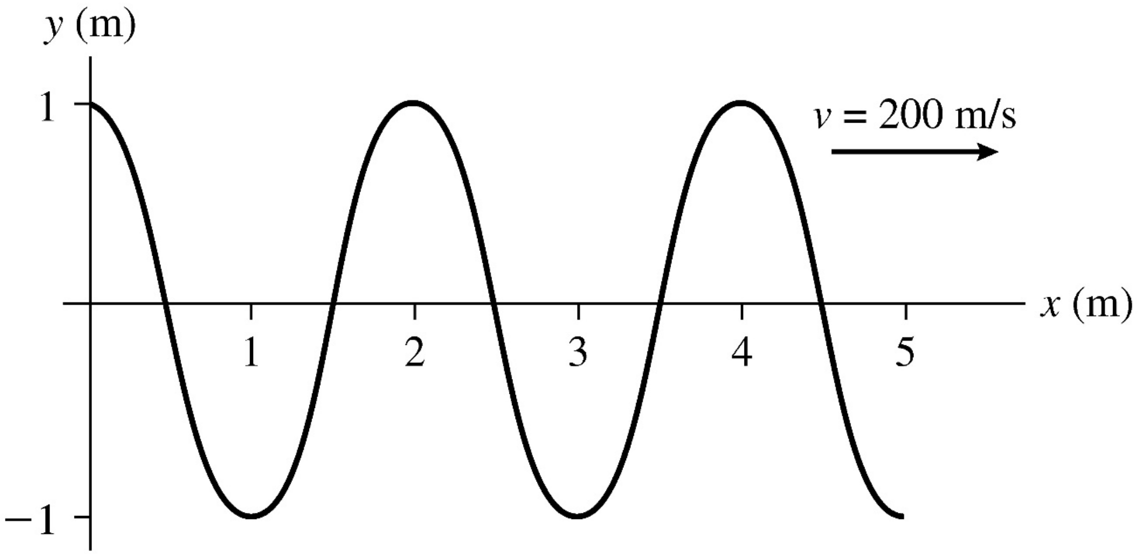

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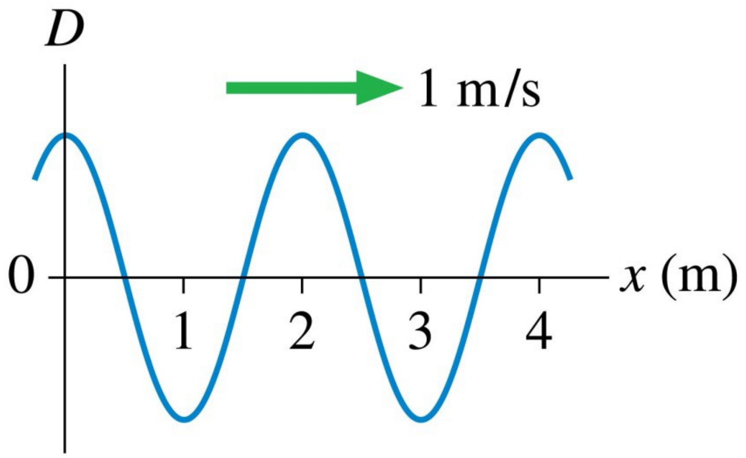
QuickCheck 4

The period of this wave is

- 1 s
- 2 s
- 4 s
-



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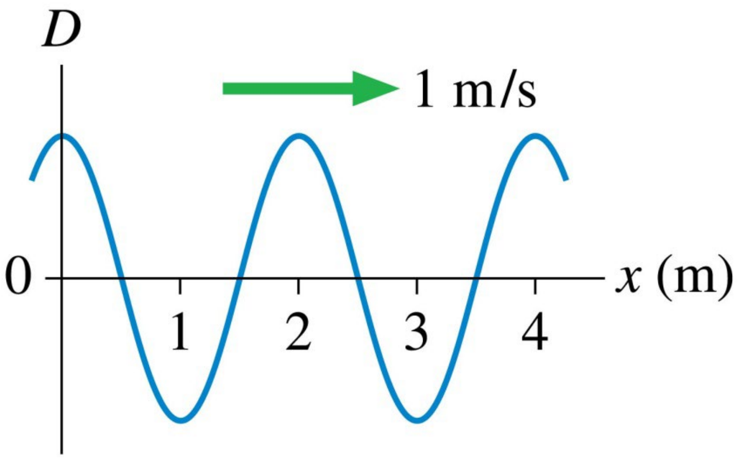
QuickCheck 15.7

The period of this wave is

- 1 s
- 2 s ✔
- 4 s
-



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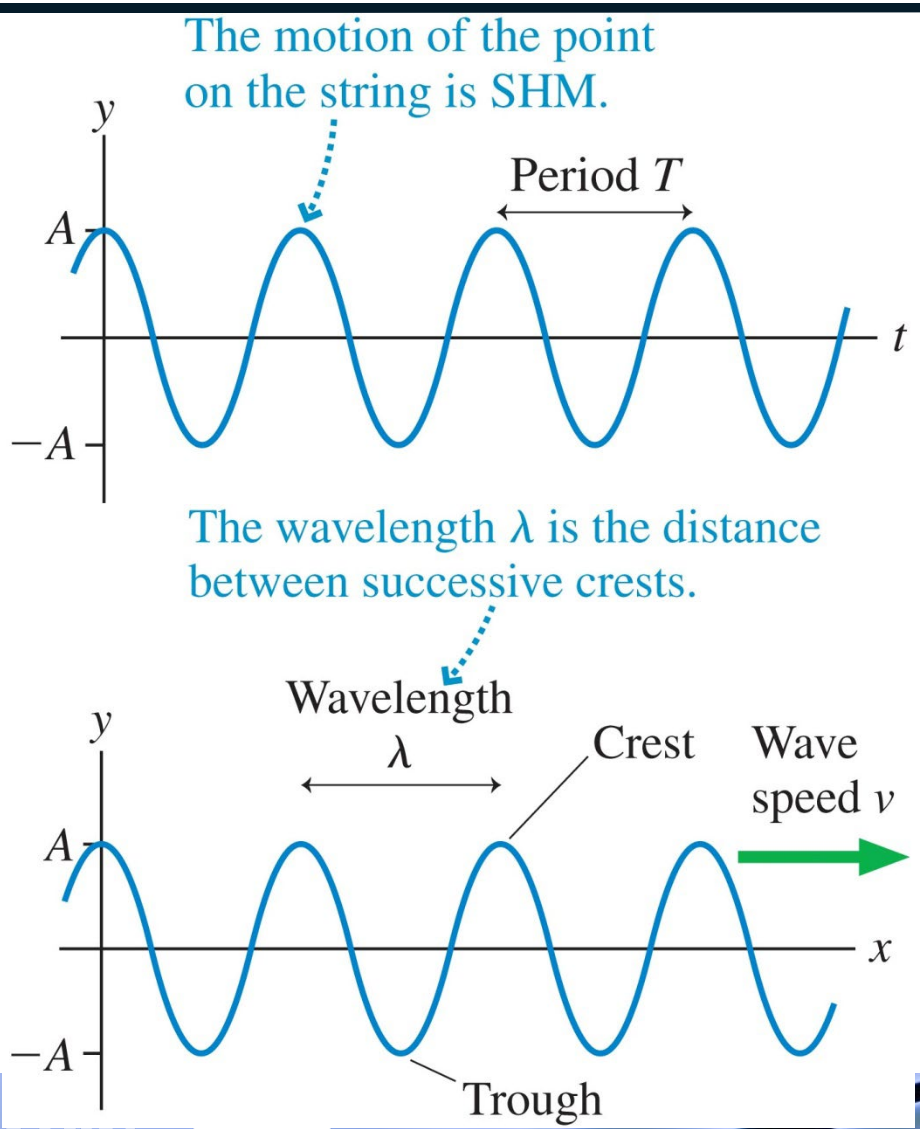
Study guide 6:

Wave equation

problems

Sinusoidal Waves



$$v = \lambda f$$

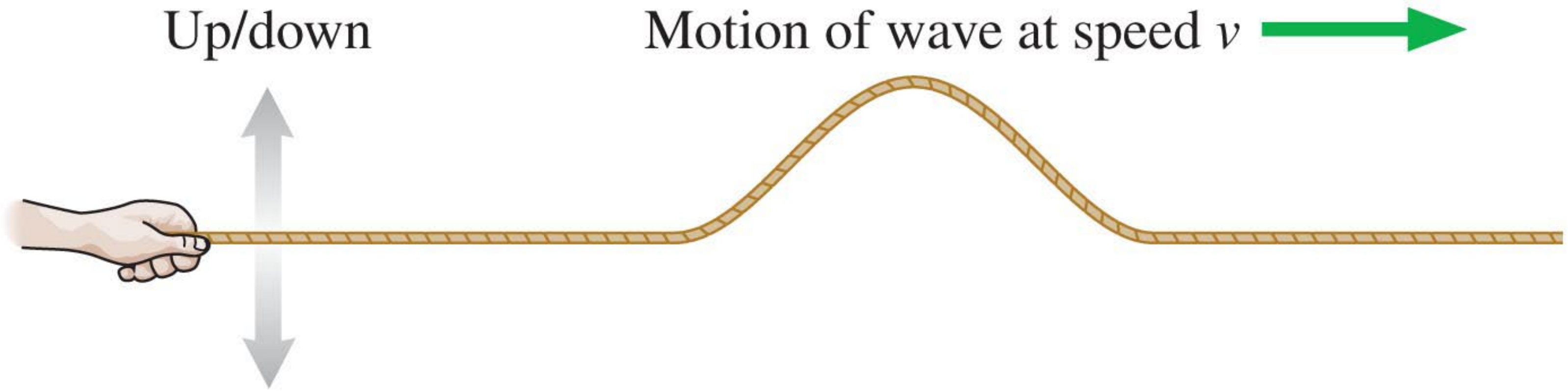
Relationship between velocity, wavelength, and frequency for sinusoidal waves

$$y(x, t) = A\cos\left(2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right)$$

Displacement of a traveling wave moving to the right with amplitude A, wavelength λ, and period T

The total wave motion is a function of both time and horizontal displacement.

Types of Waves – transverse & longitudinal



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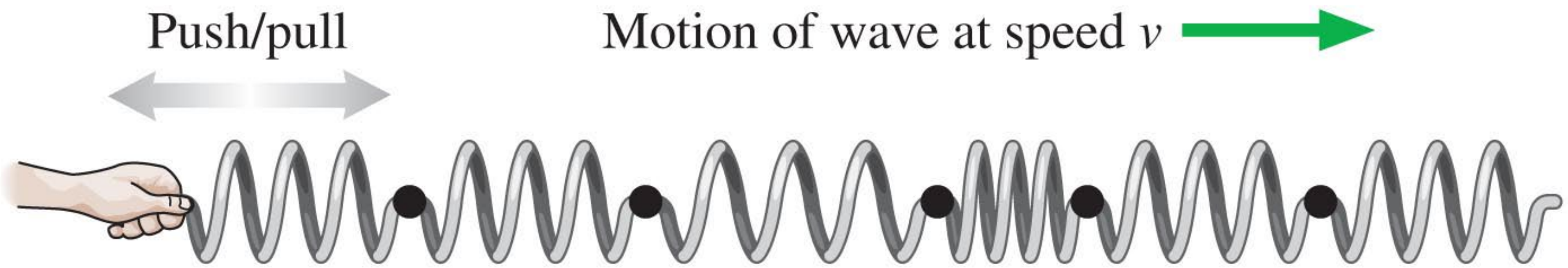

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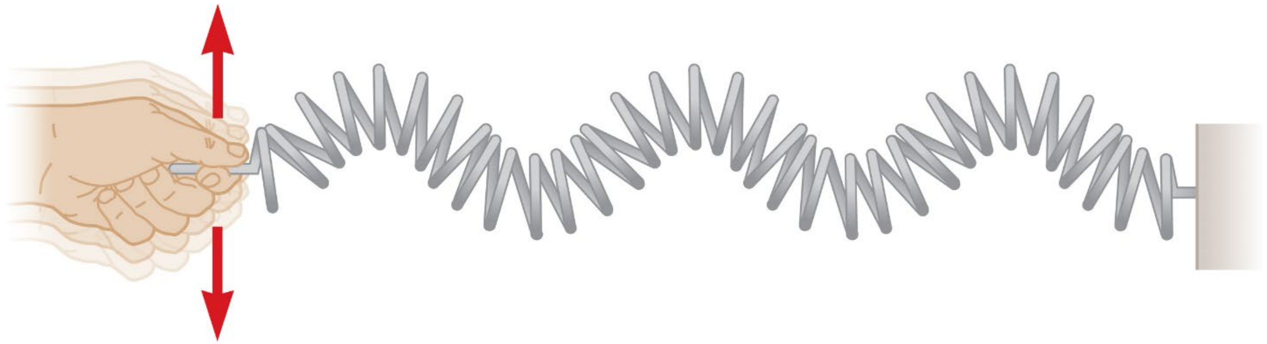
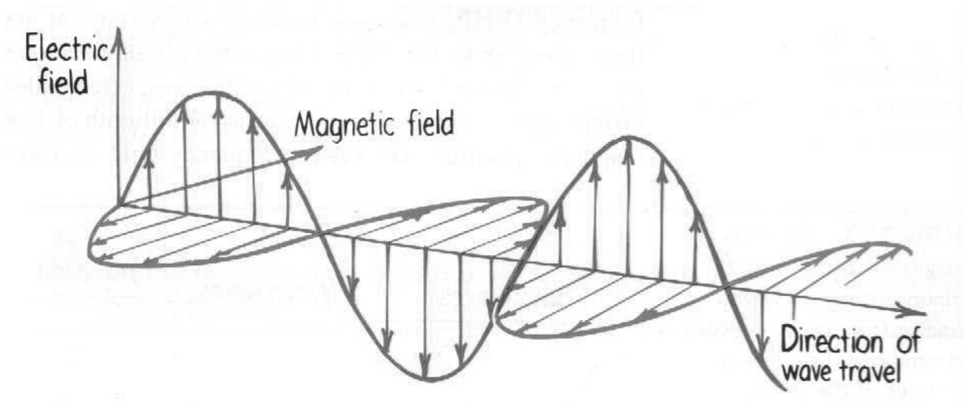
Two types of waves:

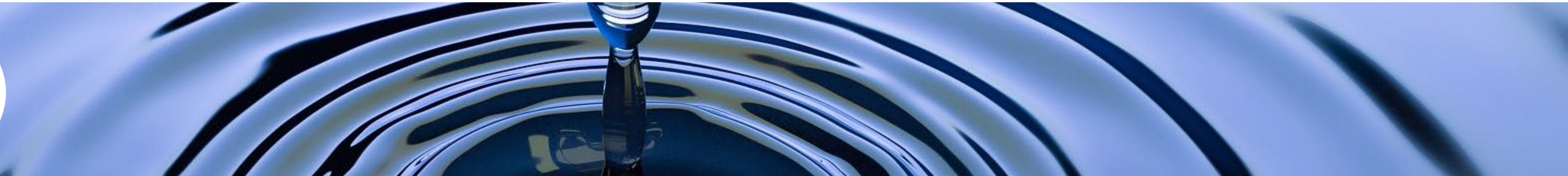
Transverse waves: the particles or fields vibrate at right angles to the direction of propagation of the wave.



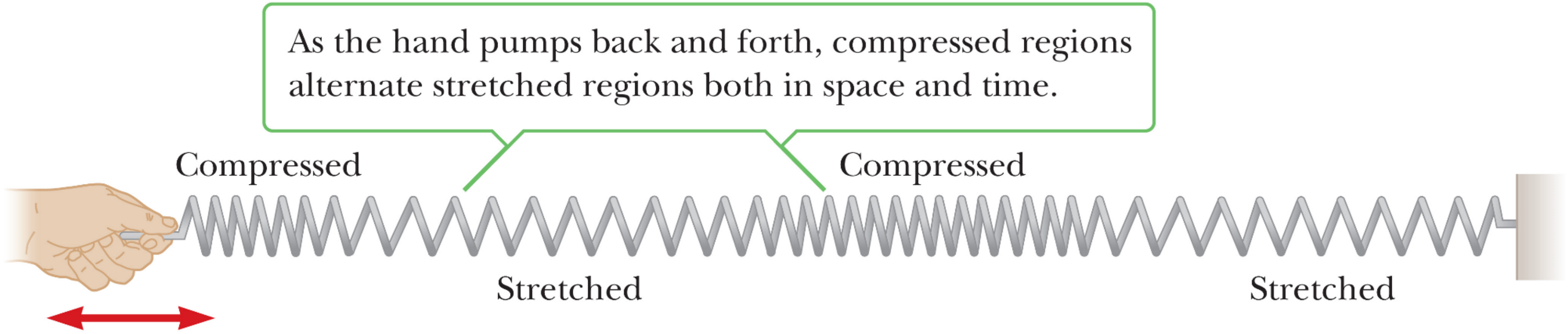
Transverse wave

Electromagnetic waves are also transverse waves.





- <u>Longitudinal waves:</u> the particles or fields vibrate in the same direction as the wave is propagated.
- Example: sound waves are pressure waves moving through a gas (air) liquid or solid.



Longitudinal wave

- Representation of a longitudinal wave (pressure or sound wave). The lines closest together represent regions of highest pressure.

- <u>A few points.</u>

- Water <u>surface</u> waves may be considered to be a mixture of transverse and longitudinal.

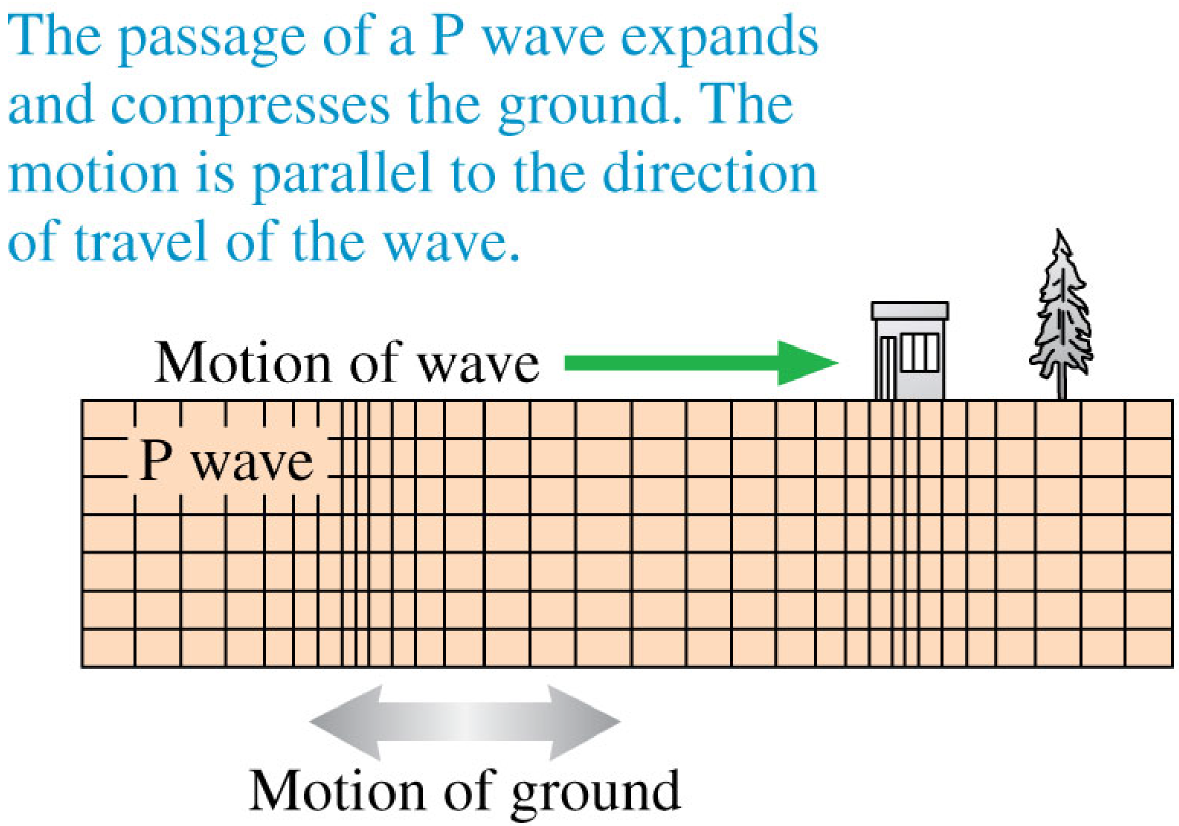
- Transverse <u>matter</u> waves cannot propagate <u>inside</u> a liquid or gas (because fluids cannot support a shear force).

- E.M waves (which are not matter waves) can propagate in solids, liquids or gases [e.g. radio waves]

- Seismic (earthquake) waves may be transverse or longitudinal.

Transverse and Longitudinal Waves

- The two most important types of earthquake waves are S waves (transverse) and P waves (longitudinal).



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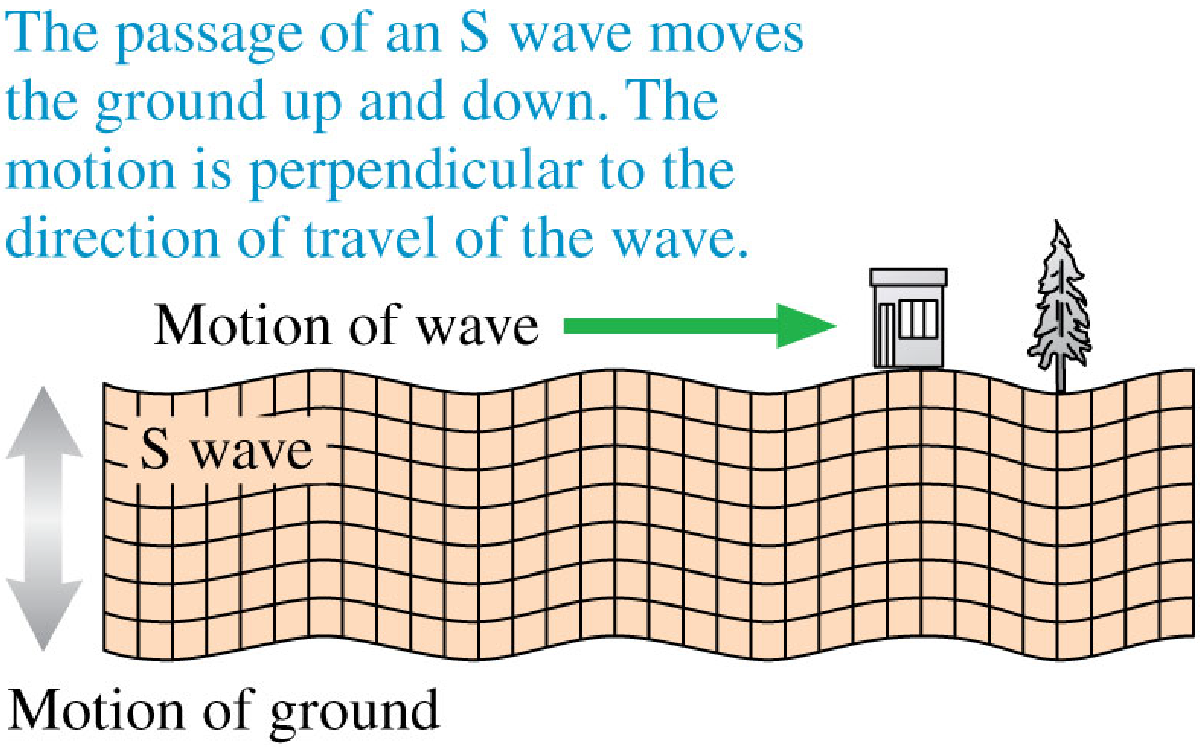
Transverse and Longitudinal Waves

- The P waves are faster, but the S waves are more destructive.



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Speed of Transverse Waves on a String

For a transverse wave in a string of length *L* and mass *m* is under tension *F*:

$$v = \sqrt{\frac{FL}{m}}$$

$$\mu = \frac{m}{L} \quad \textbf{linear mass density}$$

$$v = \sqrt{\frac{F}{\mu}}$$

More restoring force makes faster waves; more inertia makes slower waves.

Example 11.1

A string of length 2.0 m has a mass of 125 mg. The string is attached to the ceiling and a piñata of mass 4.0 kg hangs from the other end.

A child whacks the piñata sideways with a stick; as a result, a transverse pulse travels up the string toward the ceiling.

At what speed does the pulse travel?

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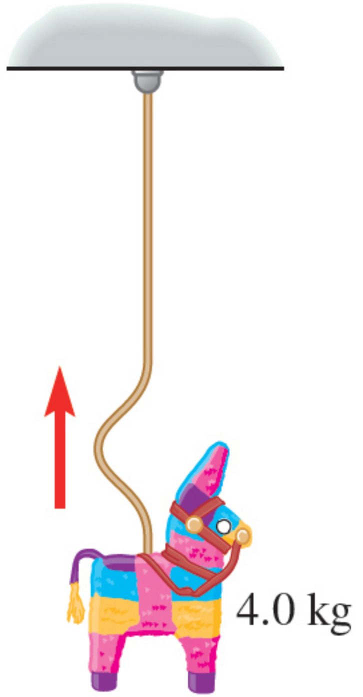

Example 11.1 Solution

$$v = \sqrt{\frac{F}{\mu}}$$

$$F = Mg$$

$$v = \sqrt{\frac{F}{m/L}} = \sqrt{\frac{(Mg)L}{m}}$$

$$= \sqrt{\frac{4.0 \text{ kg} \times 9.8 \text{ m/s}^2 \times 2.0 \text{ m}}{125 \times 10^{-6} \text{ kg}}} = 790 \text{ m/s}$$

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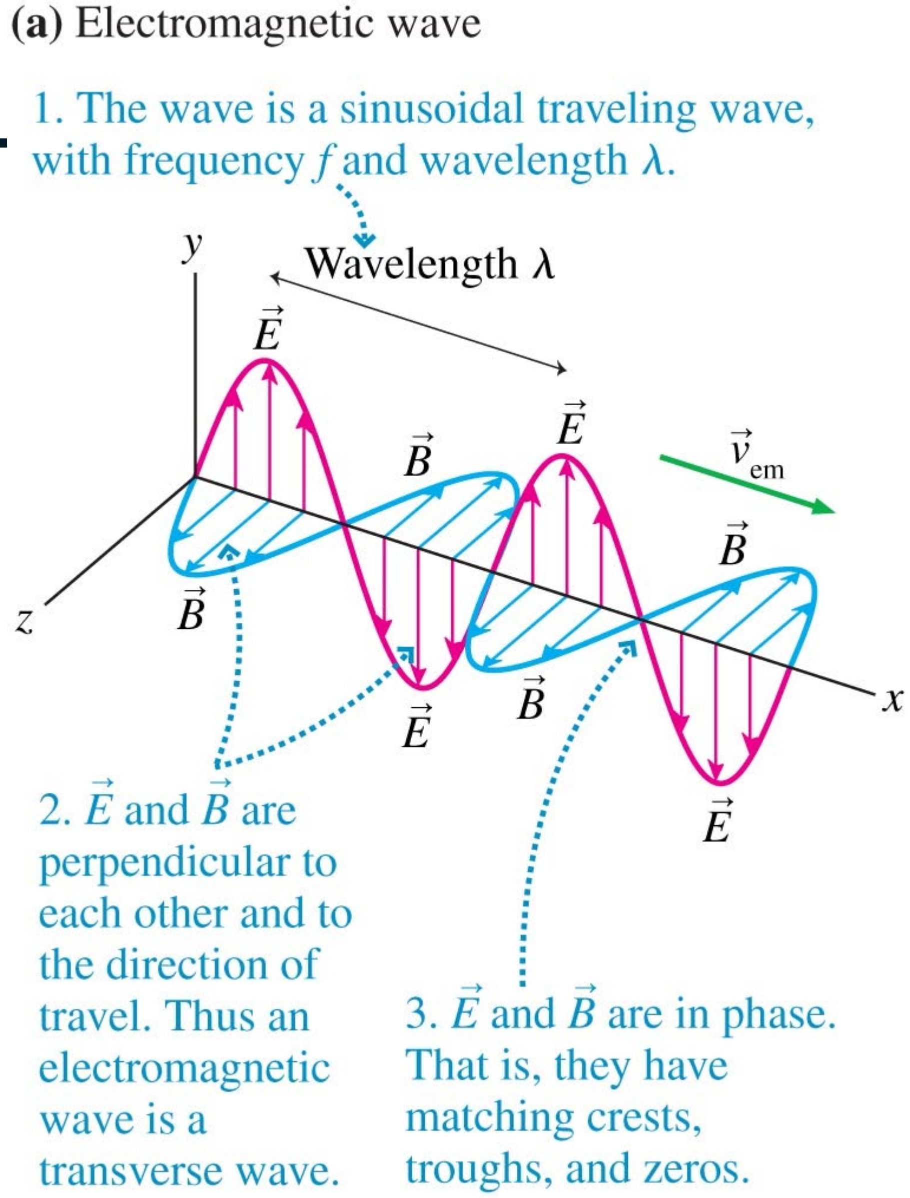
Light Waves

An electromagnetic (light) wave is an oscillating magnetic field travelling at right angles to an oscillating electric field. The 2 fields are in phase with each other.

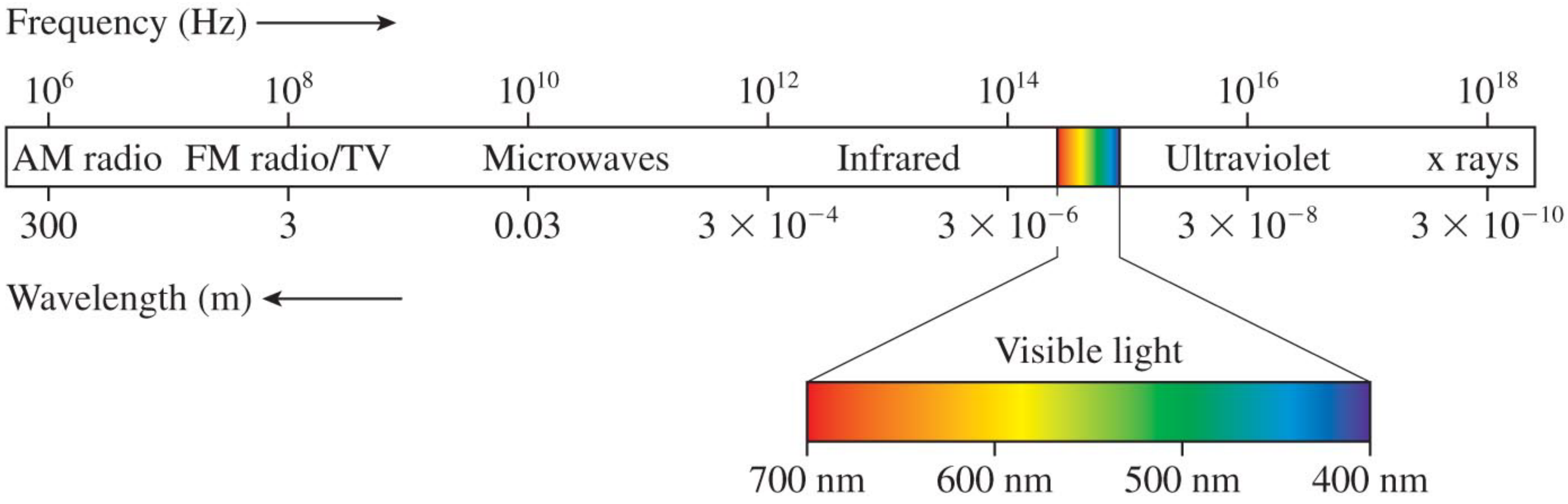
Light and other electromagnetic waves
in vacuum and in air
move at the same speed, 3.00 x 10^8 m/s.



(Knight, Jones, Field, figure 25.26, p. 847)

Light Waves

Light and other electromagnetic waves in vacuum and in air move at the same speed, 3.00 x 10^8 m/s.



(Knight, Jones, Field, section 15.4, p. 495)

Interference of Waves

Martin Dohrn/SPL/Science Source

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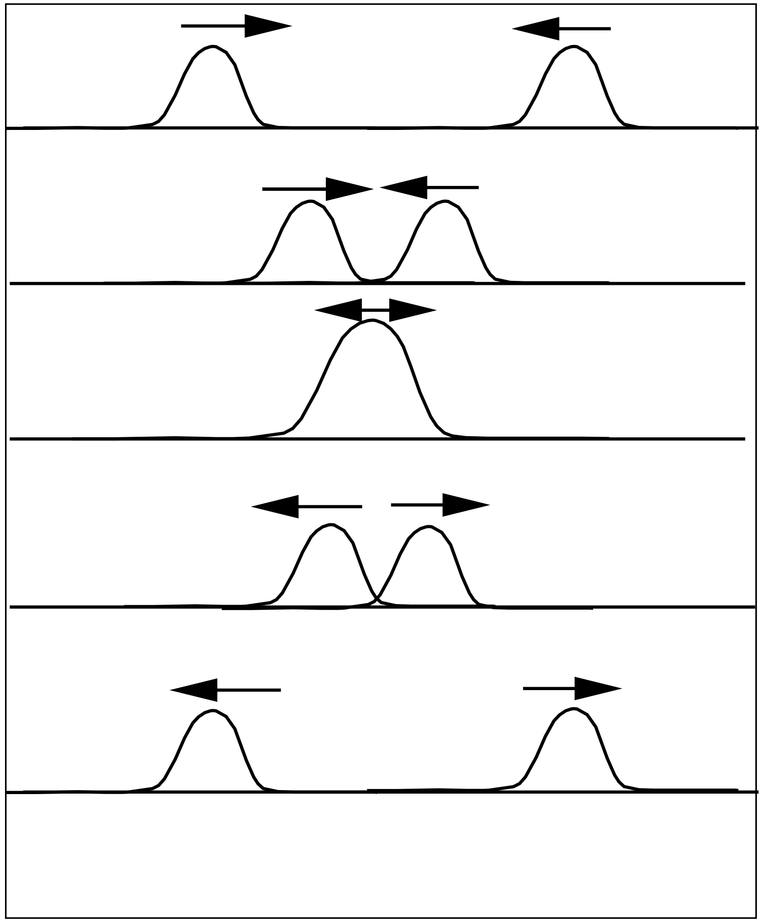
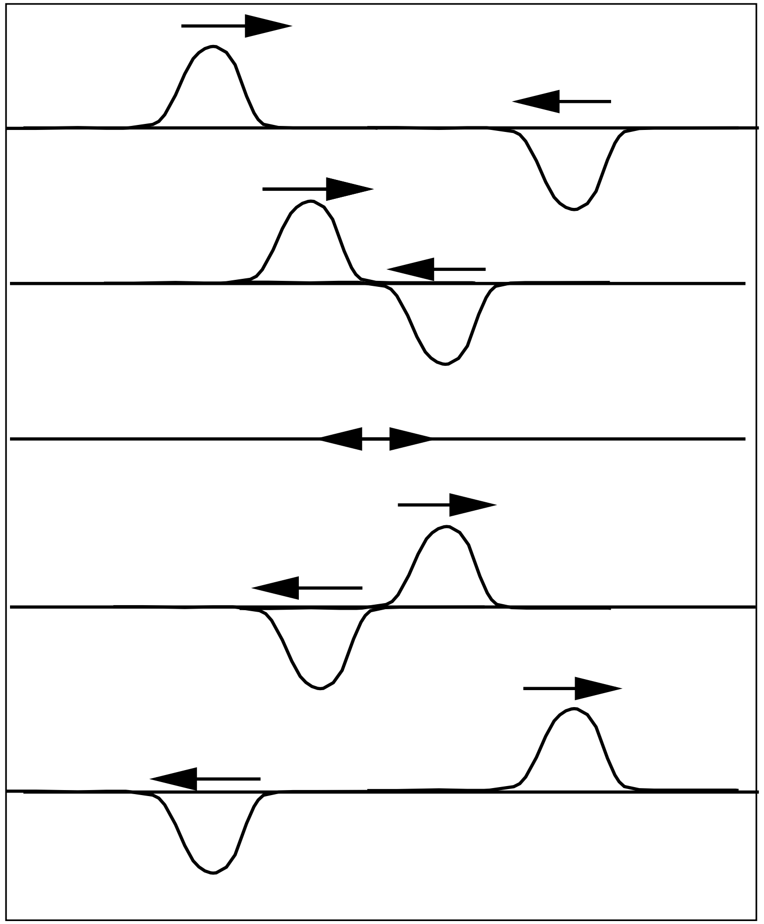
Wave behaviour

- **Interference** occurs when two or more waves pass through the same region and "interfere" without being altered.
- To analyse interference we use the principle of superposition:
- At any instant, the combined waveform of interfering waves is equal to the sum of the displacements of the individual waves.



Constructive interference
Reinforcement



Destructive interference
Cancellation

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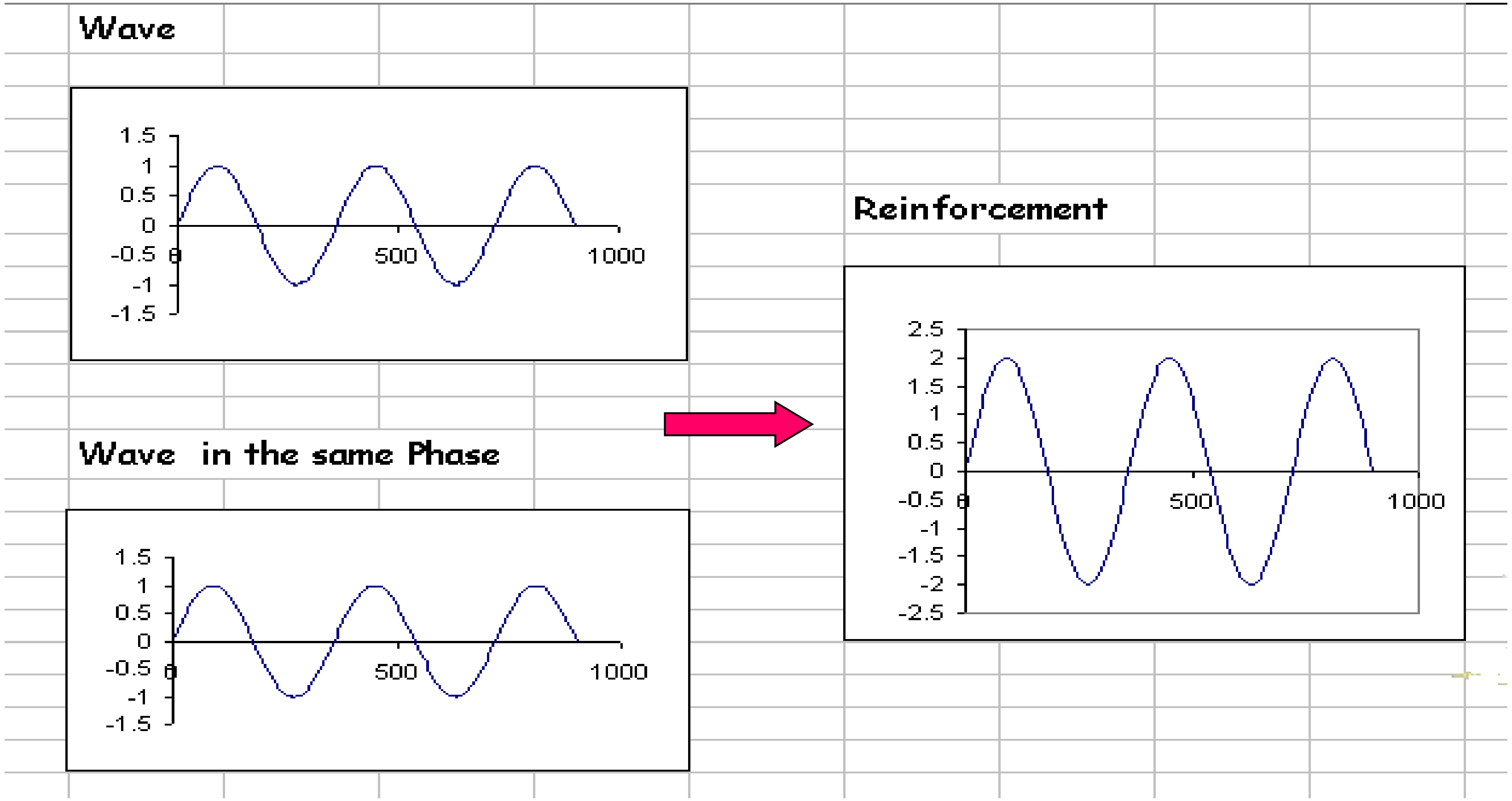
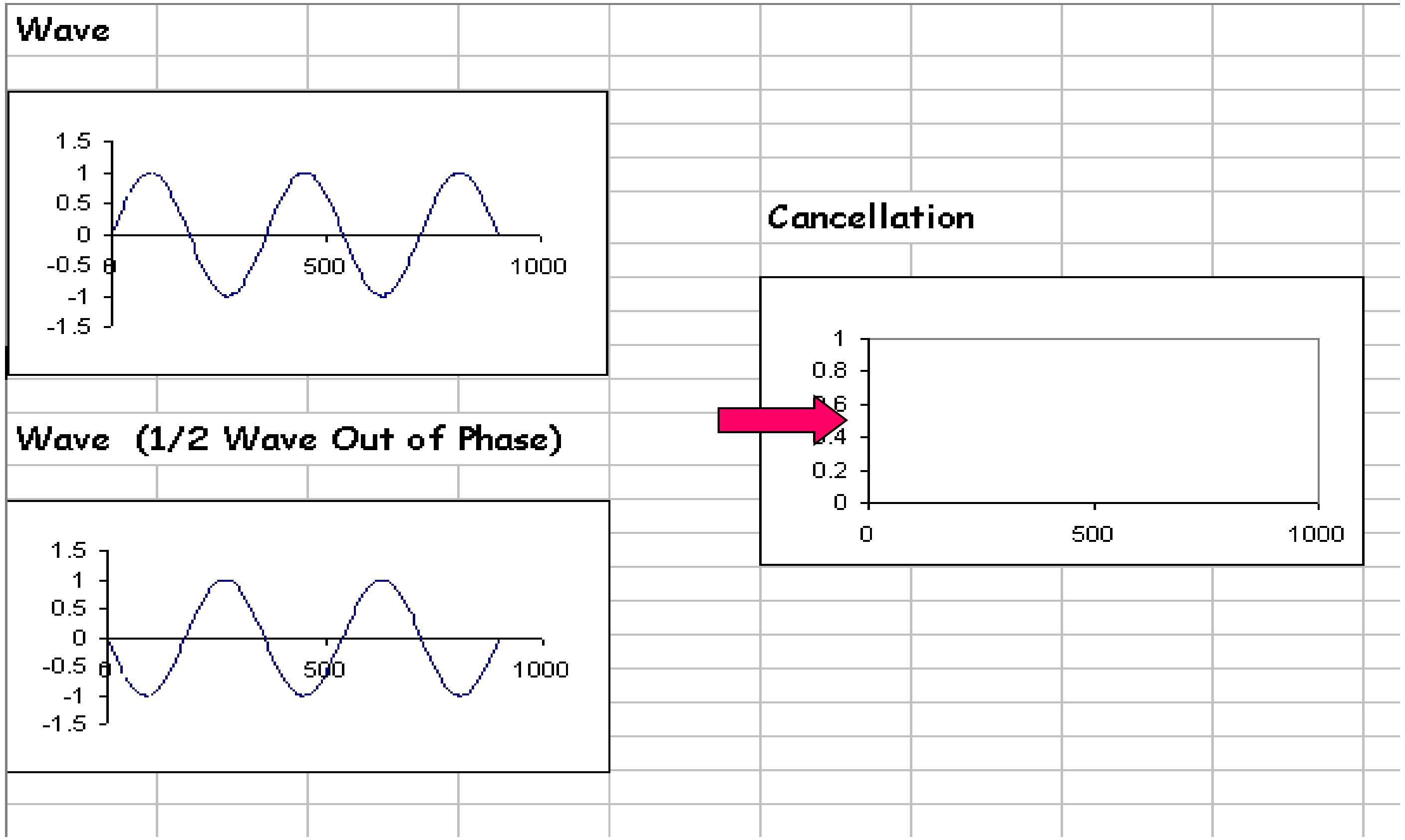
Reinforcement - constructive

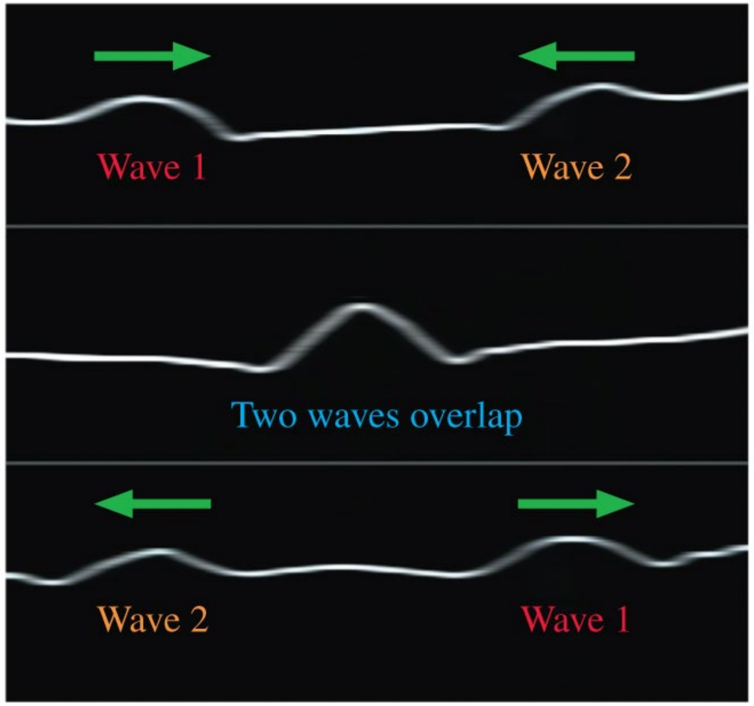


Cancellation - destructive



The Principle of Superposition

- When two or more waves are *simultaneously* present at a single point in space, the displacement of the medium at that point is the sum of the displacements due to each individual wave.

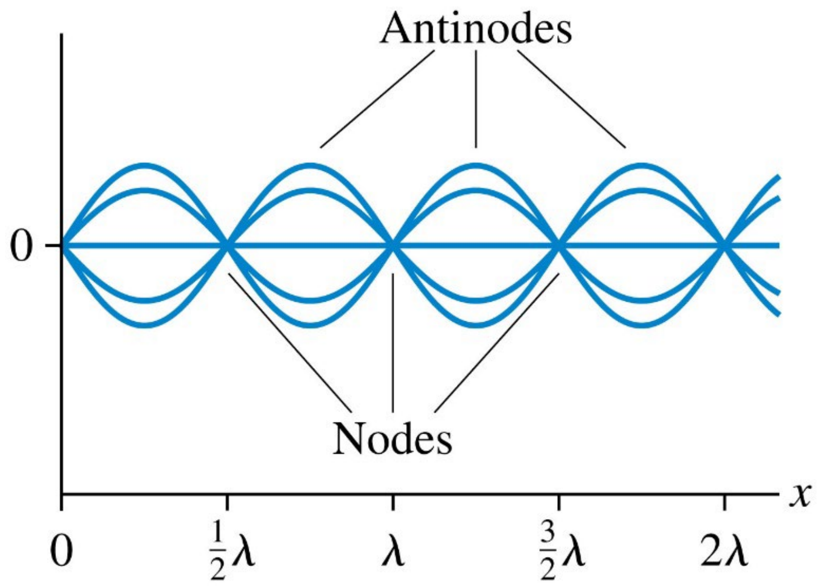


Standing Waves

- Waves that are "trapped" and cannot travel in either direction are called *standing waves*.
- **Individual points on a string oscillate up and down, but the wave itself does not travel.**
- It is called a **standing wave** because the crests and troughs "stand in place" as it oscillates.

Nodes and Antinodes

- In a standing wave pattern, there are some points that *never move*. These points are called **nodes** and are spaced $\lambda/2$ apart.
- **Antinodes** are halfway between the nodes, where the particles in the medium oscillate with maximum displacement.



The nodes and antinodes are spaced $\lambda/2$ apart.

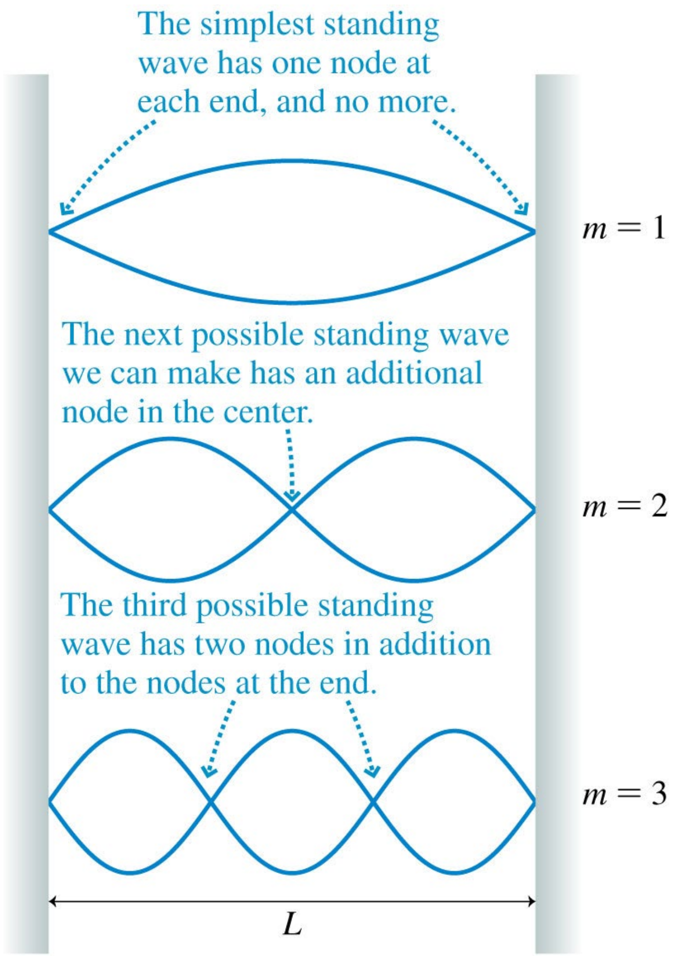
Creating a Standing Wave

- Different modes have different wavelengths.
- For any mode *m* the wavelength is given by the equation

$$\lambda_m = \frac{2L}{m} \qquad m = 1, 2, 3, 4, \ldots$$

Wavelengths of standing-wave modes of a string of length L

- **A standing wave can exist on the string *only* if its wavelength is one of the values given by this equation.**

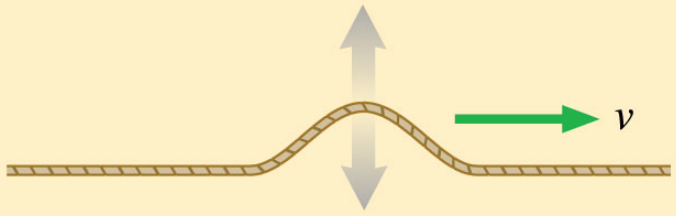


Summary: General Principles

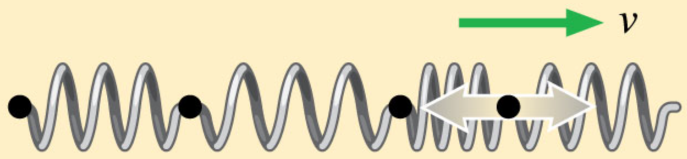
The Wave Model

This model is based on the idea of a **traveling wave,** which is an organized disturbance traveling at a well-defined **wave speed** v.

- In **transverse waves** the particles of the medium move *perpendicular* to the direction in which the wave travels.



- In **longitudinal waves** the particles of the medium move *parallel* to the direction in which the wave travels.



A wave transfers energy, but there is no material or substance transferred.