Wave Interactions

Unit: Mechanical Waves

NGSS Standards/MA Curriculum Frameworks (2016): HS-PS4-1

AP® Physics 2 Learning Objectives/Essential Knowledge (2024): 14.2.A, 14.2.A.3, 14.3.A, 14.3.A.1, 14.3.A.1.i, 14.3.A.1.ii, 14.3.A.1.iii, 14.3.A.1.iv, 14.8.A.2

Mastery Objective(s): (Students will be able to…)

- Explain the behavior of waves when they pass each other in the same medium and when they reflect off something.

Success Criteria:

- Descriptions & explanations account for observed behavior.

Language Objectives:

- Explain what happens when two waves pass through each other.

Tier 2 Vocabulary: reflection

Labs, Activities & Demonstrations:

- waves on a string or spring anchored at one end
- large Slinky with longitudinal and transverse waves passing each other

Notes:

A wave that encounters a boundary between one medium and another can be transmitted or reflected.

transmission: when a wave continues traveling from one medium into another.

reflection: when a wave "bounces" back from the boundary between one medium and another.

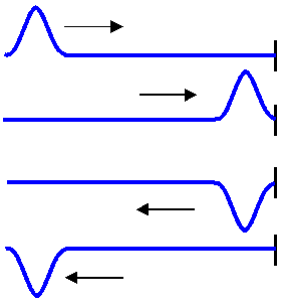
When a wave travels from one medium into another, its frequency does not change.

Reflection

When a wave is reflected:

- The wave is inverted (turned upside-down) if it travels into a wave that causes its speed to decrease.
- The wave is not inverted if it travels into a medium that causes its speed to increase.

An example of this is shaking a rope to send a pulse along it. If the rope is attached to a wall, the speed of the wave in the wall would be faster (because the wall is more dense), so the wave is reflected without inverting. If the rope is not attached to anything, the speed of the wave in air would be slower (because the air is less dense), so the wave is inverted when it is reflected.



Superposition

Waves are not physical objects. A wave is defined as a disturbance of the particles of a medium, but the waves are energy carriers, not the medium itself.

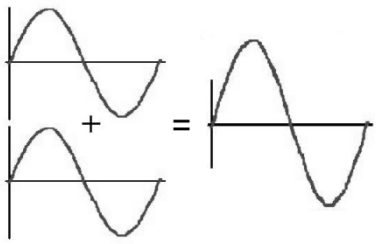
This means that:

- When two or more waves encounter one another, the medium at the meeting point is moved separately by each wave. This means that the displacement of each particle of the medium is the vector sum of the amplitudes of each separate wave.
- As the waves continue beyond the meeting point, the interactions caused by each wave continue with each wave. This means the waves "pass through" each other.

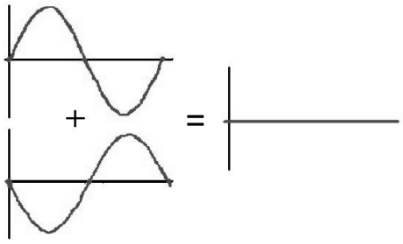
When waves are superimposed (occupy the same space), their amplitudes add.

constructive interference: when waves add in a way that the amplitude of the resulting wave is larger than the amplitudes of the component waves.

Because the wavelengths are the same and the maximum, minimum, and zero points all coïncide (line up), the two component waves are said to be "in phase" with each other.

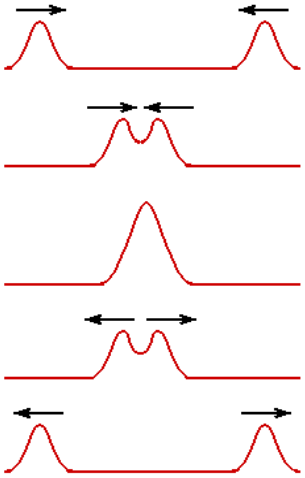


destructive interference: when waves add in a way that the amplitude of the resulting wave is smaller than the amplitudes of the component waves. (Sometimes we say that the waves "cancel" each other.)

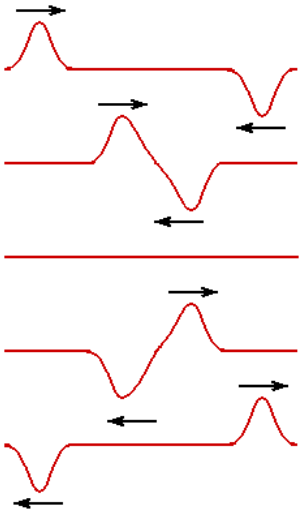


Because the wavelengths are the same but the maximum, minimum, and zero points do not coïncide, the waves are said to be "out of phase" with each other.

Constructive Interference

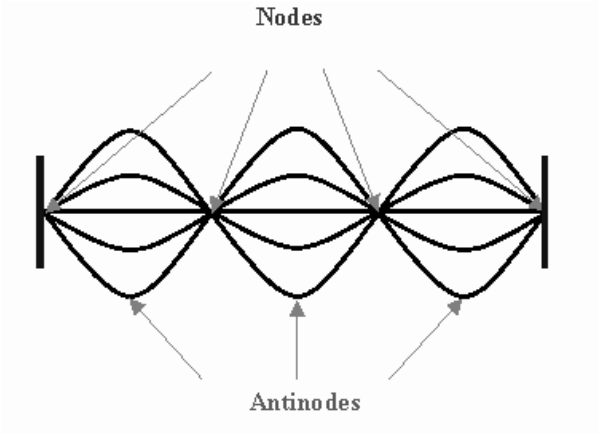


Destructive Interference



Standing Waves

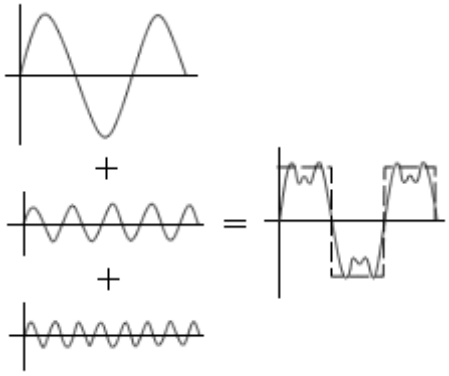
standing wave: when a reflected periodic wave is in phase with the incident (incoming) wave. When this happens, the reflections cause constructive interference, which amplifies the wave. This amplification is called "resonance", which will be discussed further in the *Sound & Music* topic, starting on page 329.



Because human eyes have a "frame rate" of 30–60 "frames" per second, standing waves appear stationary to us. Points along the wave with zero displacement (which appear not to be moving) are called "nodes". Points of maximum displacement are called "antinodes".

For a wave with boundaries to media that are denser at both ends, the wave is inverted when it is reflected. In these situations, standing waves occur when the medium is an exact multiple of half the wavelength.

When waves with different wavelengths and amplitudes are superimposed, the result can be complex:

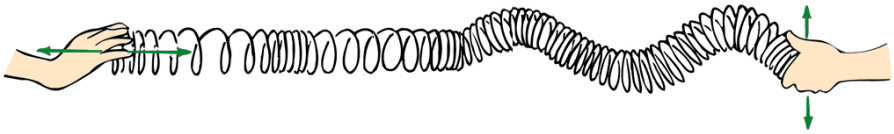


This is, for example, how it is possible to hear multiple sounds at once, even though the sounds share the same medium (the air between the source and your ears).

This is also how radio waves encode a signal on top of a "carrier" wave. Your radio's antenna receives ("picks up") radio waves within a certain range of frequencies. Imagine that the bottom wave (the one with the shortest wavelength and highest frequency) is the "carrier" wave. If you tune your radio to its frequency, the radio will filter out other waves that don't include the carrier frequency. Then your radio subtracts the carrier wave, and everything that is left is sent to the speakers.

Homework Problem

1. **(M)** A Slinky is held at both ends. The person on the left creates a longitudinal wave, while at same time the person on the right creates a transverse wave with the same frequency. Both people stop moving their ends of the Slinky just as the waves are about to meet.

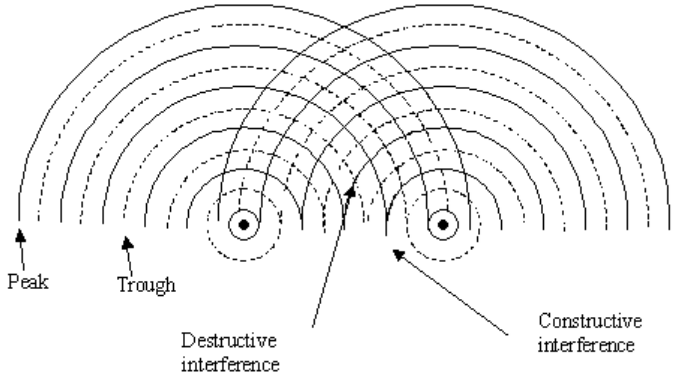


   a. Draw a picture of what the Slinky will look like when the waves completely overlap.

   b. Draw a picture of what the Slinky will look like just after the waves no longer overlap.

Two-Dimensional Interference Patterns

When two progressive waves propagate into each other's space, the waves produce interference patterns. This diagram shows how interference patterns form:

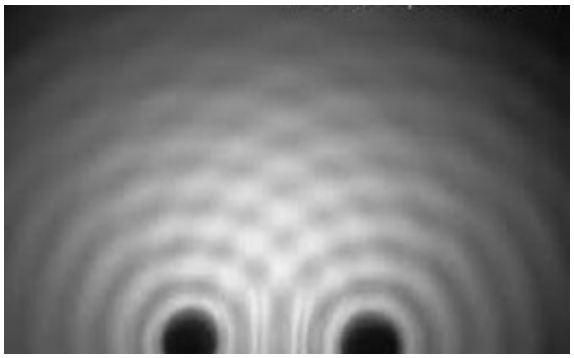


The following picture* shows an interference pattern created by ocean waves, one of which has been reflected off a point on the shore. The wave at the left side of the picture is traveling toward the right, and the reflected wave at the bottom right of the picture is traveling toward the top of the picture.

Because the sun is low in the sky (the picture was taken just before sunset), the light is reflected off the water, and the crests of the waves produce shadows behind them.

* Taken from Tortola in the British Virgin Islands, looking west toward Jost Van Dyke.

The English physicist Thomas Young performed an experiment in 1801 in which he passed light through two narrow slits and observed the following interference pattern:



In this picture, the bright regions are wave "peaks", and the dark regions are "troughs". The brightest intersections are regions where the peaks interfere constructively, and the darkest intersections are regions where the troughs interfere constructively.

Prior to Young's double slit experiment, the prevailing opinion, held by Isaac Newton, was that light was a particle. Young's experiment was conclusive proof that light has wave properties.