Superposition of waves

Select LEARNING OBJECTIVES:

- Understand the principle of superposition.
- Understand the definitions of constructive versus destructive interference and how they relate to perceived loudness.
- Understand that interference is a defining characteristic of a wave.

TEXTBOOK CHAPTERS:

- Boxsand :: Superposition of waves

WARM UP: Light is a traveling wave. The type of wave is an electromagnetic wave (electric and magnetic fields oscillate perpendicular to each other and to the direction of travel). Does light experience Doppler effects? If not explain. If so, explain and list some possible applications that may make use of the Doppler effect.

In the previous lectures we have considered scenarios where a source was only at one end of a medium while producing a traveling wave. As the source produced the traveling wave, the wave propagated through the medium from the source's location to locations far away from the source. But what happens if two sources at either ends of a medium produce traveling waves in opposite direction such that the waves are traveling towards each other? Both waves travel at the same speed since they are both propagating through the same medium. Eventually the waves will meet each other, then the question is; what happens when two waves try to occupy the same space at the same time? Consider to people at either ends of a long string. At t=0 they both send pulses of different amplitudes down the string. What you observe will look something like the first animation found here. Notice that the two wave pulses emerge after colliding as if nothing happened. The interesting part is during the collision where the string's amplitude (black line) seems to increase as the two wave pulses interact. *A careful analysis would show that the resulting displacement (black line) is a linear superposition of the two wave pulses (dashed blue and red lines) during the collision. Linear superposition is a fancy way to say that the displacement of colliding waves add linearly "point by point"*. Below is the mathematical representation of linear superposition for N waves interacting.

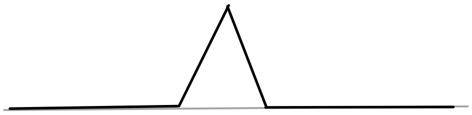
$$\boxed{D_{TOTAL}(x,t) = \sum_{i=1}^{N} D_i(x,t) = D_1(x,t) + D_2(x,t) + D_3(x,t) + \cdots + D_N(x,t)}$$

*LINEAR SUPERPOSITION OF WAVES

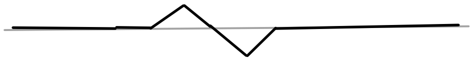
This looks very messy but really it is quite simple; treat each wave separately, draw a snapshot graph of each wave on a single plot, add up all the displacements at a given location in space, the resulting value is the displacement of the interacting waves. This linear superposition of waves is often referred to as interference. In other words, when two waves "meet" in space and time they interfere with each other. This interference is a defining characteristic of all waves. The concepts applied in this lecture are applicable to all types of waves, but of course there are waves in nature that deviate from our model here. However most waves we encounter can be modeled by this type of linear superposition.

PRACTICE: The image below shows two pulses in the same medium approaching each other (e.g. two pulses on a string). Which of the following most closely depicts what the superposition of the two pulses will be when they completely overlap?

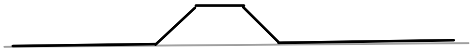
a.



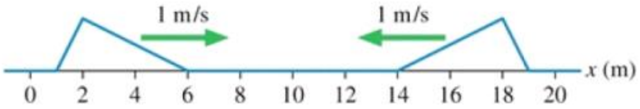
b.



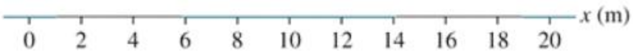
c.



PRACTICE: Two pulses on a string approach each other at speeds of 1 m/s. Sketch the shape of the string at t=6 s.



Approaching waves at $t = 0$ s

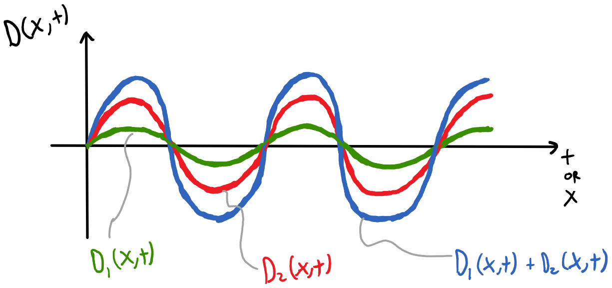


Approaching waves at $t = 6$ s

In general when waves interfere the resulting displacement can be larger or smaller than either of the two waves that are colliding. We therefore introduce two new terms to help communicate the general trend of the displacement when waves interference: constructive interference and destructive interference. Below is a quick overview of each type of interference.

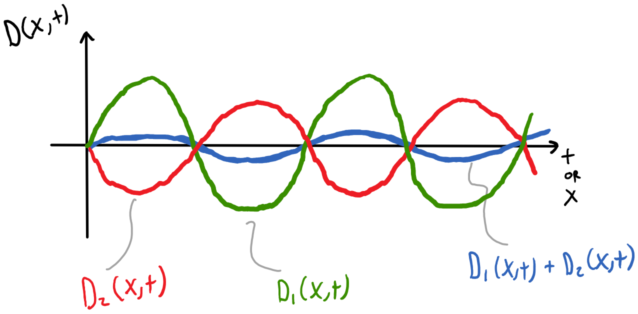
Constructive interference

- Louder, brighter…



Destructive interference

- Softer, less bright…



Interference of waves does not have to occur with two sources at either end of a medium. A single source can produce a traveling wave which then reflects off of a boundary and travels to the source interfering with any other waves that the source has produces during the time the first wave was traveling. It is therefore important to study the effects that boundaries have on traveling waves.

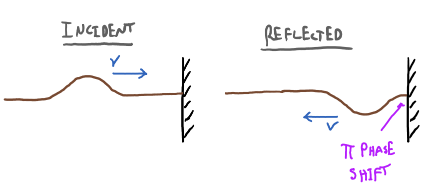
Reflections off of boundaries

When two sources (e.g. two people) are producing waves that travel towards each other, the phase of the waves are easily determined because you can adjust them however you wish. When an incident wave reflects off of a boundary, the reflected wave may then interfere with the next incident wave. However we do not necessarily know the phase relationship of the reflected wave. Below is a quick overview of the different types of phase changes upon reflection. Identifying boundary conditions will be a very important skill to have when analyzing standing wave patterns (which will be covered soon). Boundary conditions will also make an appearance again when we study optics. So now is a good time to introduce how incident waves are reflected off of boundaries.

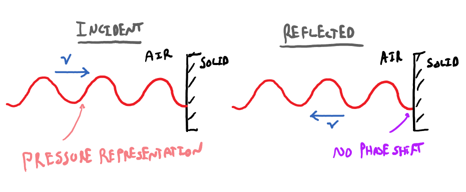
Hard boundaries:

- All reflected waves have same wavelength and frequency as incident wave.
- When incident waves strike a boundary, part of the wave is reflected and part is transmitted. Transmitted waves undergo no phase shifts.

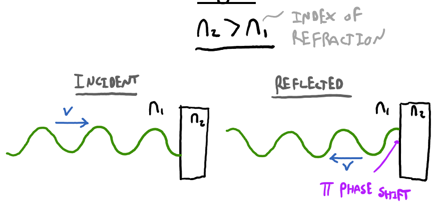
Waves on strings



Sound waves



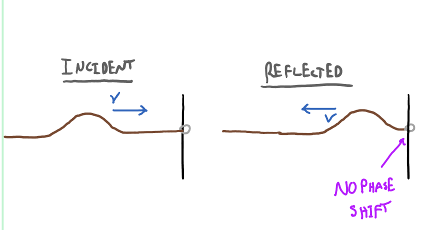
Light



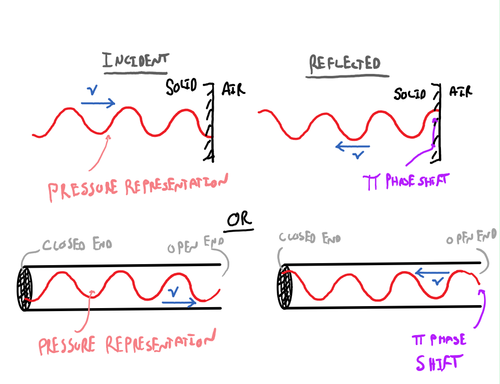
Soft boundaries:

- All reflected waves have same wavelength and frequency as incident wave.
- When incident waves strike a boundary, part of the wave is reflected and part is transmitted. Transmitted waves undergo no phase shifts.

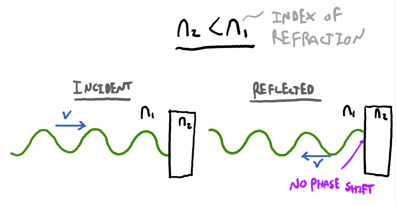
Waves on strings



Sound waves



Light



QUESTIONS FOR DISCUSSION:

(1) Can you set up two speakers such that they produce regions of no sound?
(2) What will happen when two surface water waves approach from different directions and run into each other? Will they cancel each other out? Will they bounce off each other? Explain.