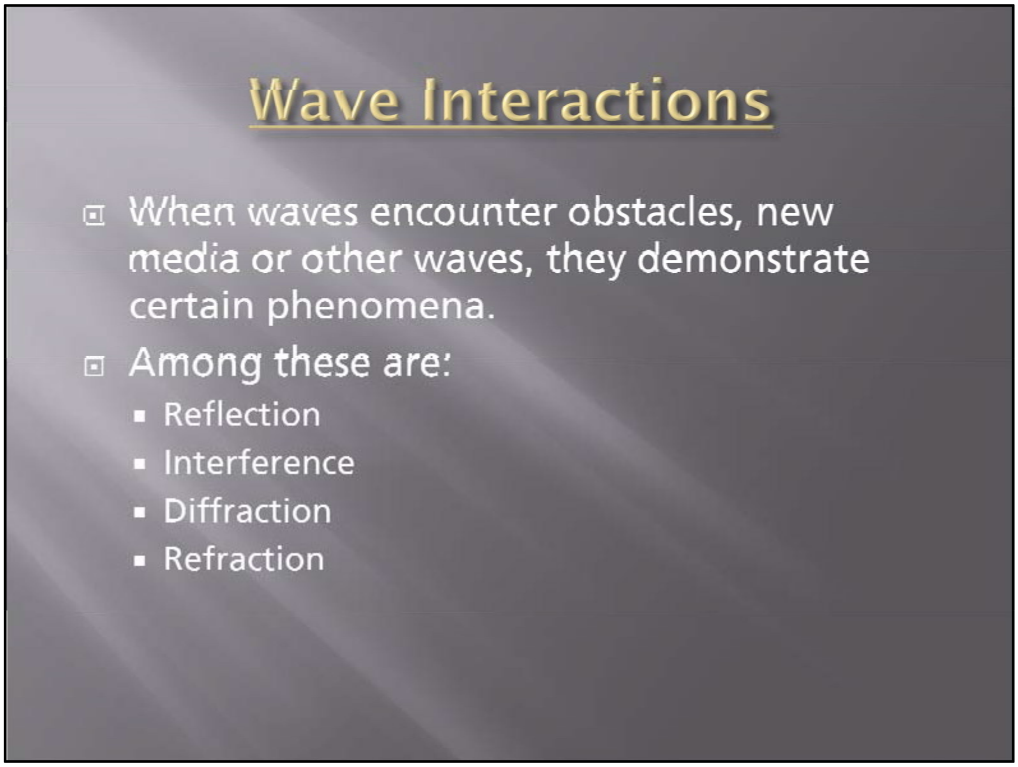
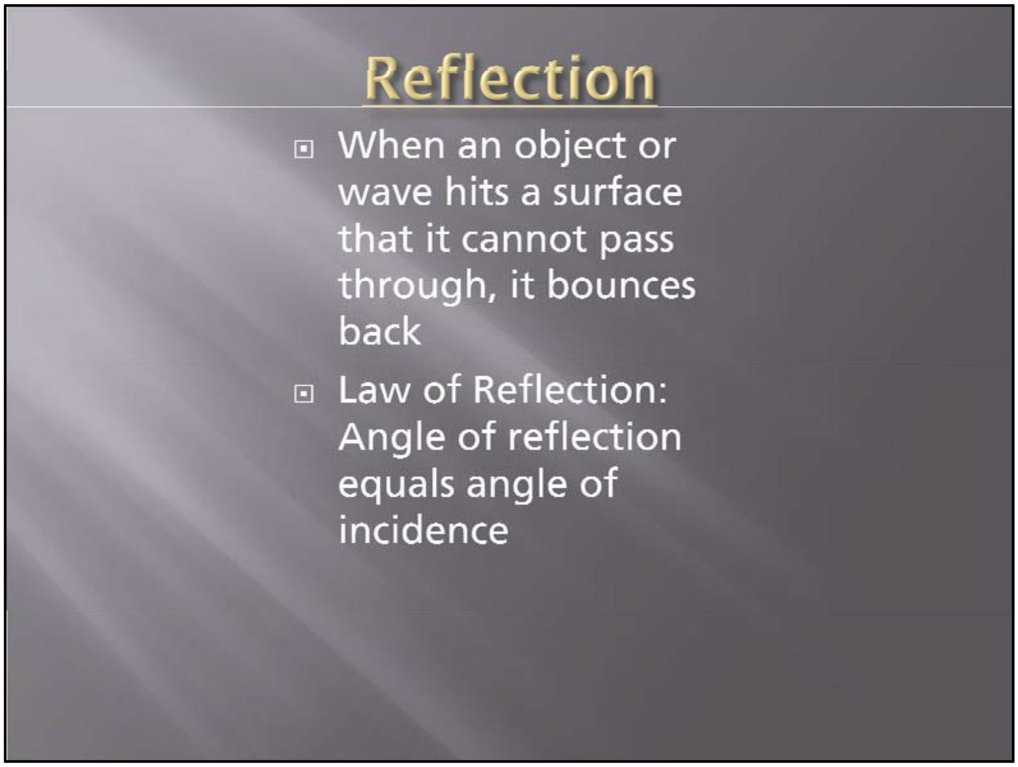
Module 6: Waves
Topic 2 Content: Wave Interactions Presentation Notes

Wave Interactions

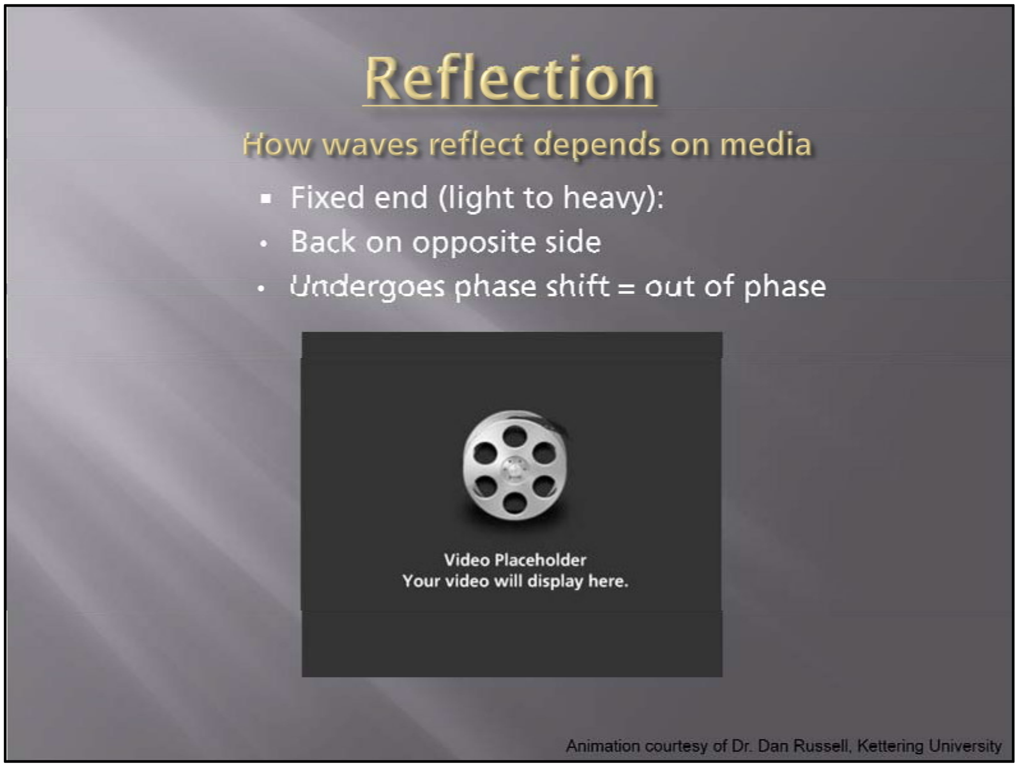


Waves can interact in several ways when they encounter obstacles, new media or other waves. The phenomena we observe include reflection, interference, diffraction and refraction. These interactions produce interesting examples of wave behavior in the world around us.



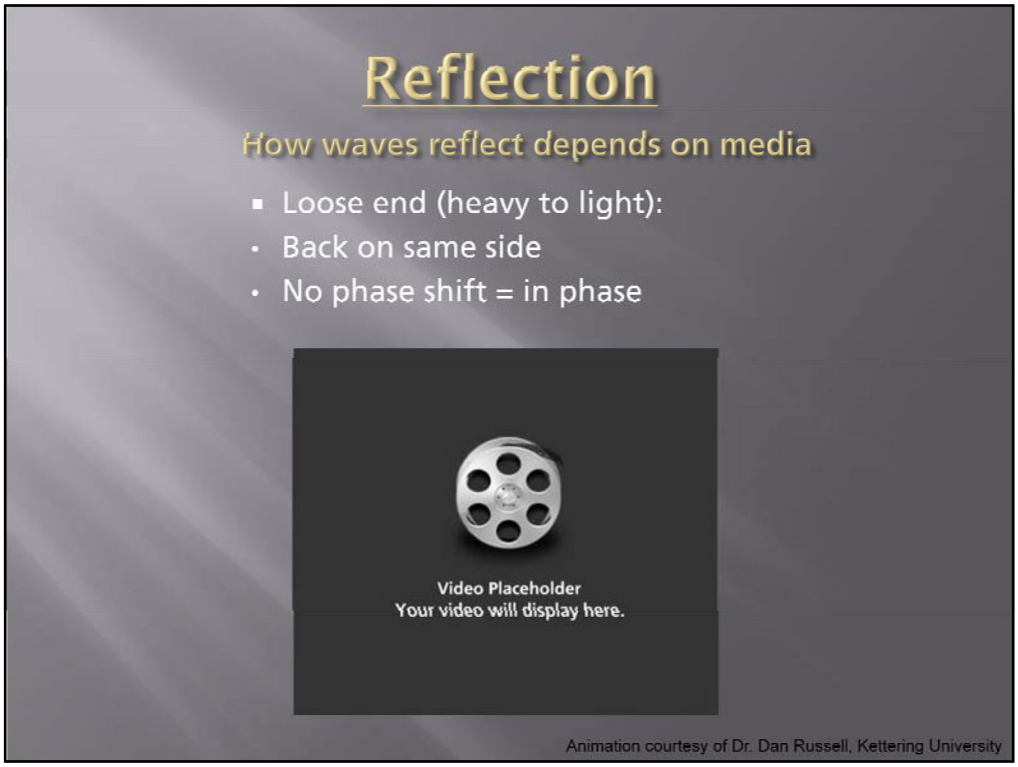
When a wave hits a surface that it cannot pass through, it will bounce back. This is called reflection.

When a wave reflects, it obeys the law of reflection. The law of reflection states that the angle of reflection will be equal to the angle of incidence. The angles are both measured from a line called a normal that is perpendicular to the surface. The greater the angle of incidence, the greater the angle of reflection.

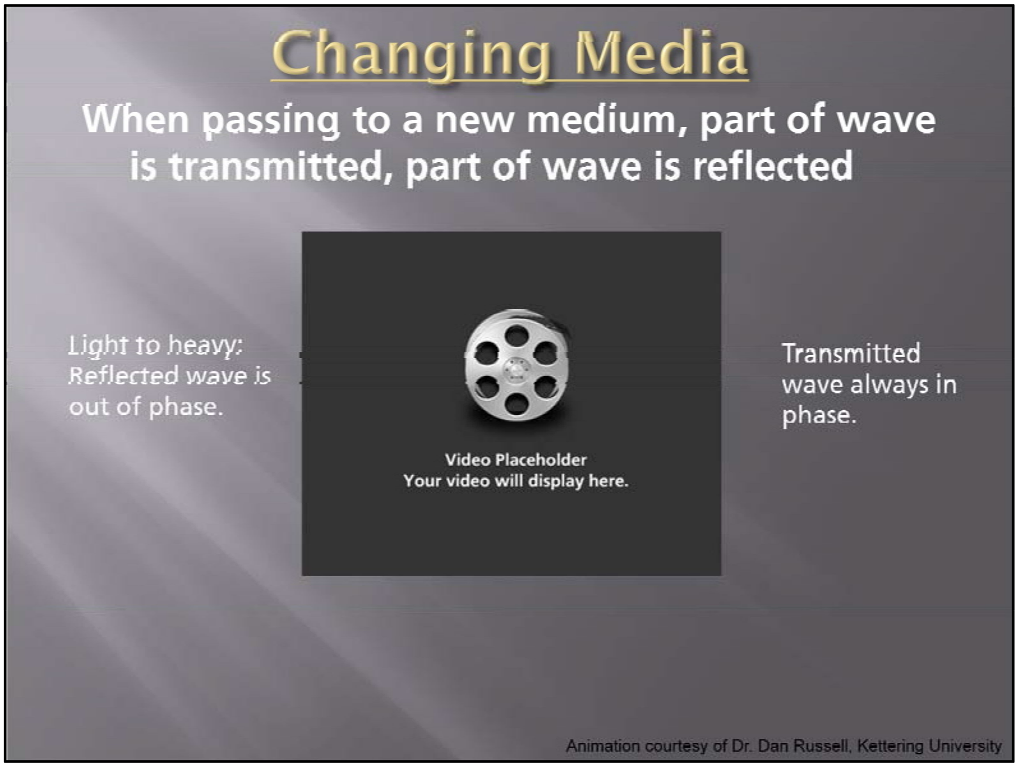


Certain properties of waves change upon reflection.

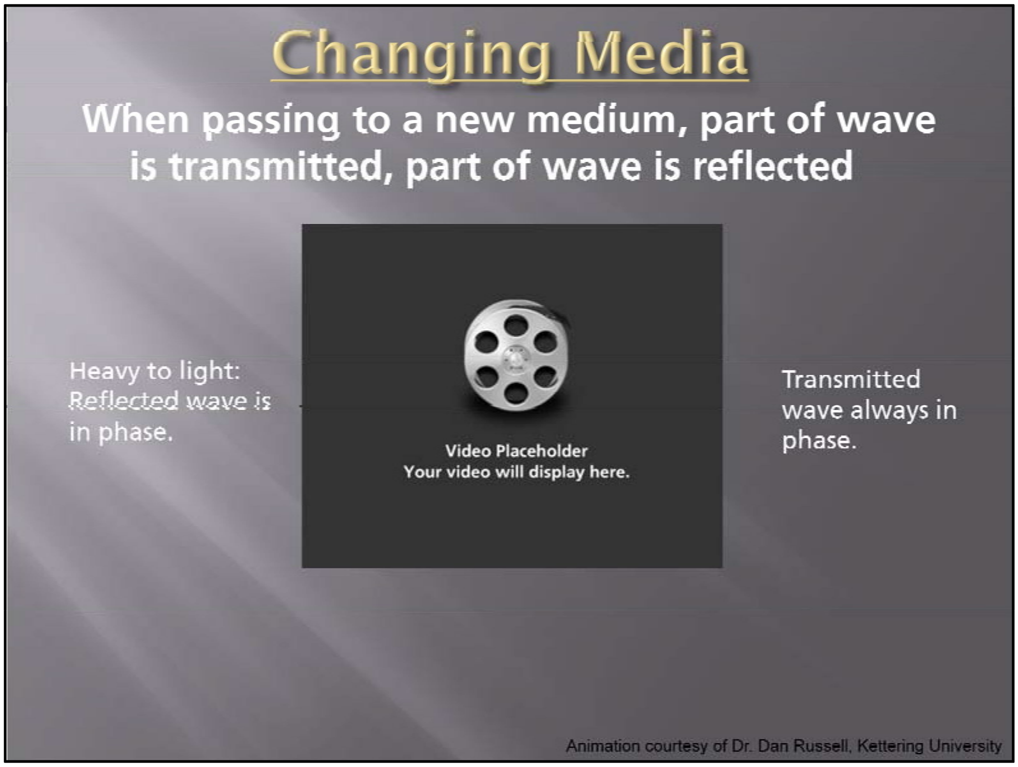
If a wave reflects off of a solid boundary, the reflected wave will be inverted compared to the incident wave. This is called a phase shift, and the reflected wave is out of phase compared to the original wave. We can demonstrate this with a rope with one end fixed to the wall. When the wave pulse reflects, you can see that it reflects on the opposite side of the rope.



If the rope were attached with a frictionless ring to a pole, allowing the end to be loose, the reflected wave is on the same side of the rope as the incident wave. This would be an example of no phase shift, with the reflected wave in phase with the original wave.



When a wave passes into a new medium, some of its energy is reflected and some if its energy is transmitted. If the new medium is more dense than the original medium, the reflected portion of the wave will be phase shifted and inverted. This is similar to how a wave reflects off of a fixed boundary. The transmitted portion of the wave does not change phase and remains on the same side of the medium.



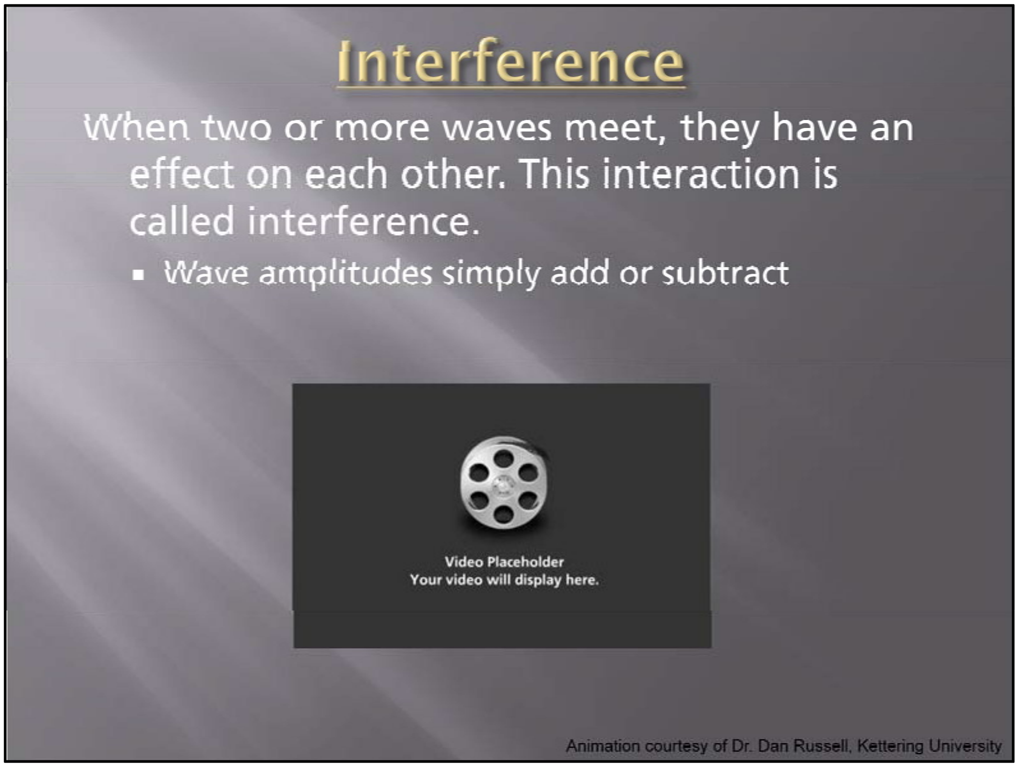
If the new medium is less dense than the original medium, the reflected portion of the wave will not be phase shifted and will return on the same side of the medium. This is similar to how a wave reflects off of a loose end.

The transmitted portion of the wave never changes phase, remaining on the same side of the medium.

The amplitude of a wave is related to the energy carried by the wave. Notice how the amplitude of the reflected portion of the wave is smaller than the amplitude of the incident wave in both cases. This is because only a portion of the energy is reflected at the boundary while some is transmitted. The law of conservation of energy still applies.

But how can the amplitude of the wave increase in this second example? Does this violate the law of conservation of energy?

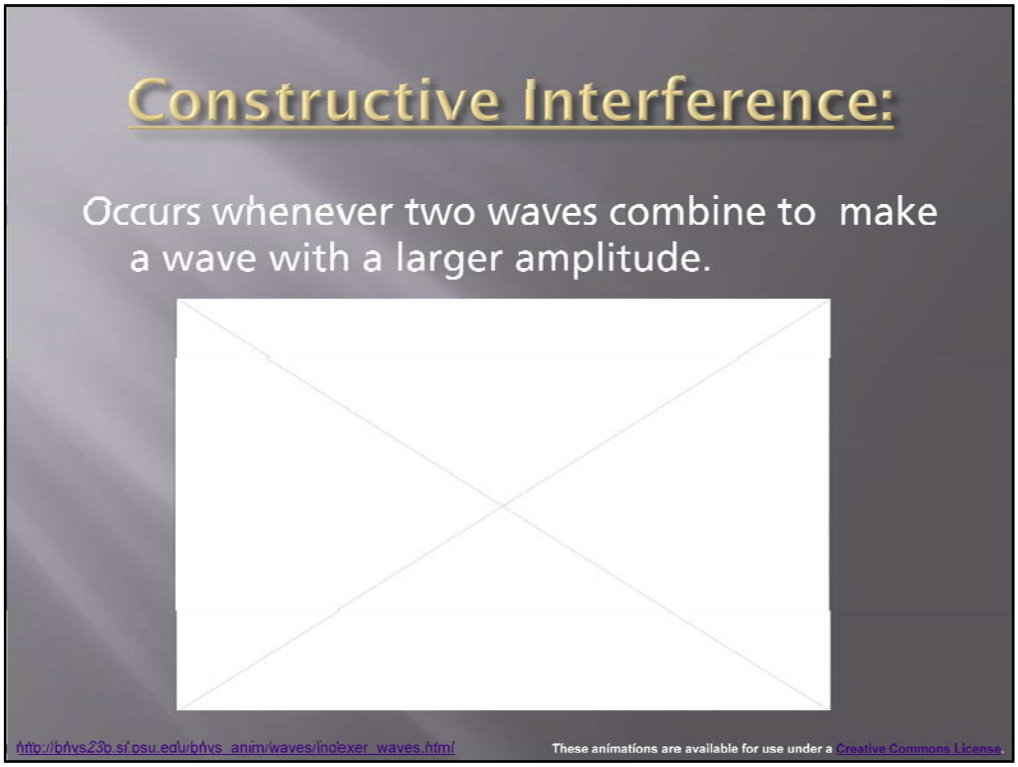
It does not, since we can only easily relate the amplitude to the energy within a single medium. In a less dense medium, it takes less energy to lift the string, so a larger amplitude is created with the same energy. So as the wave passes from a more dense medium to a less dense medium, we should not be surprised if the amplitude of the transmitted wave is larger than the amplitude of the incident wave.



The interaction between two waves is called interference. When two or more waves meet in a medium, they have an effect on each other. Since the medium cannot be in two places at the same time, the amplitudes of each wave are simply added to one another. In this animation, the two waves on the top are interacting to form the resulting wave on the bottom. You can see that when they are in phase, with crest meeting crest, the resulting wave is twice as large as each individual wave.

When the waves are out of phase, with crest meeting trough, the resulting wave form is momentarily level.

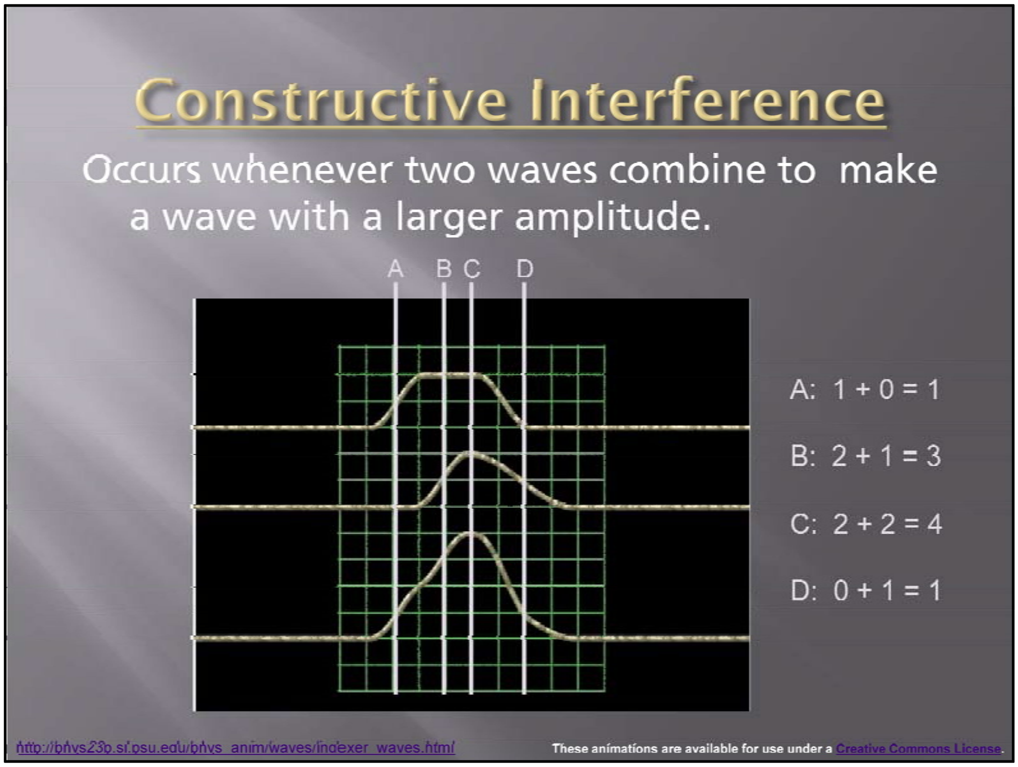
The black dots represent particles of the medium, to show that the medium is merely oscillating up and down while the waves are transmitted to the right.



Interference can either be constructive or destructive.

Constructive interference occurs whenever two waves combine to make a wave with a larger amplitude. Again, in the animation, the wave on the bottom represents the interference of the two waves above. Notice how the amplitude of each of the top waves is added to produce the bottom wave.

It is also interesting to observe how the waves seem to pass right through each other once they are done interacting. Notice that the waves don't reflect off of one another, but each continues along in its original direction.



If we momentarily freeze the animation, you can look point by point along each original wave to see how they interfere to form the resulting wave.

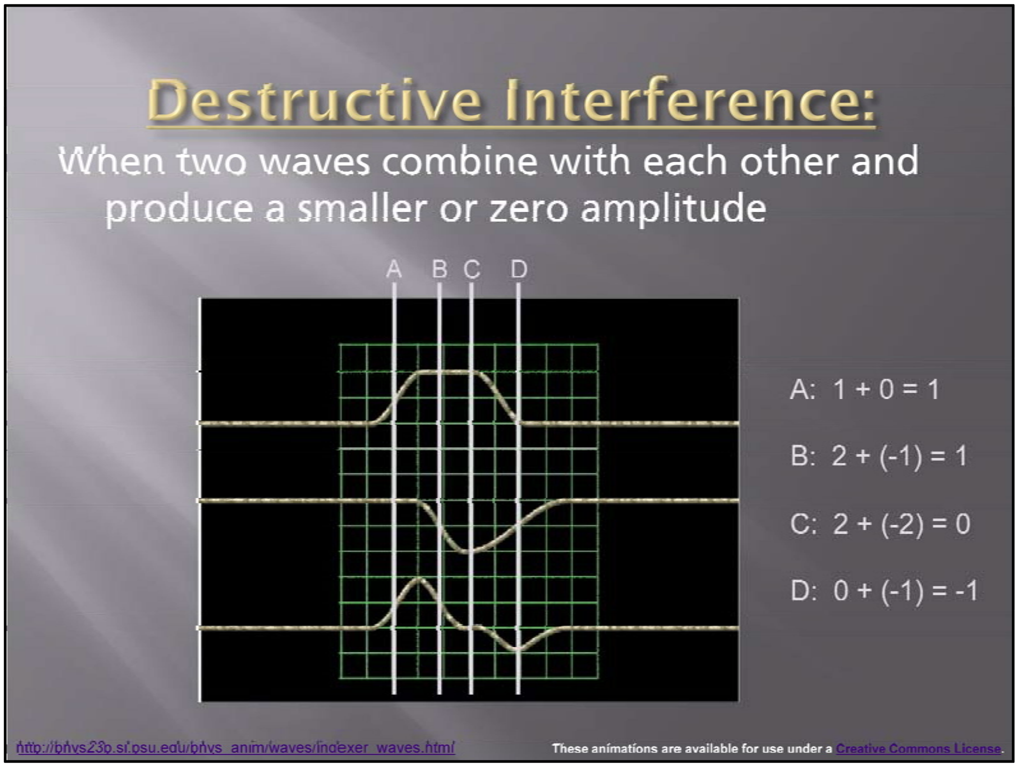
At point A, the top wave has an amplitude of one and the middle wave has an amplitude of zero, resulting in the bottom wave having an amplitude of one.

At point B, the top wave now has an amplitude of two and the middle wave has an amplitude of one, resulting in the bottom wave having an amplitude of three.

At point C, both the top wave and the middle wave have amplitudes of two, resulting in the bottom wave having an amplitude of four.

And at point D, the top wave now has an amplitude of zero and the middle wave has an amplitude of one, resulting in the bottom wave having an amplitude of one.

Destructive interference occurs when two waves combine with each other to produce a wave with a smaller or zero amplitude. Again, we have the two top waves interfering to create the wave on the bottom. As the waves pass through each other, the medium reacts by representing the mathematical sum of the two waves.

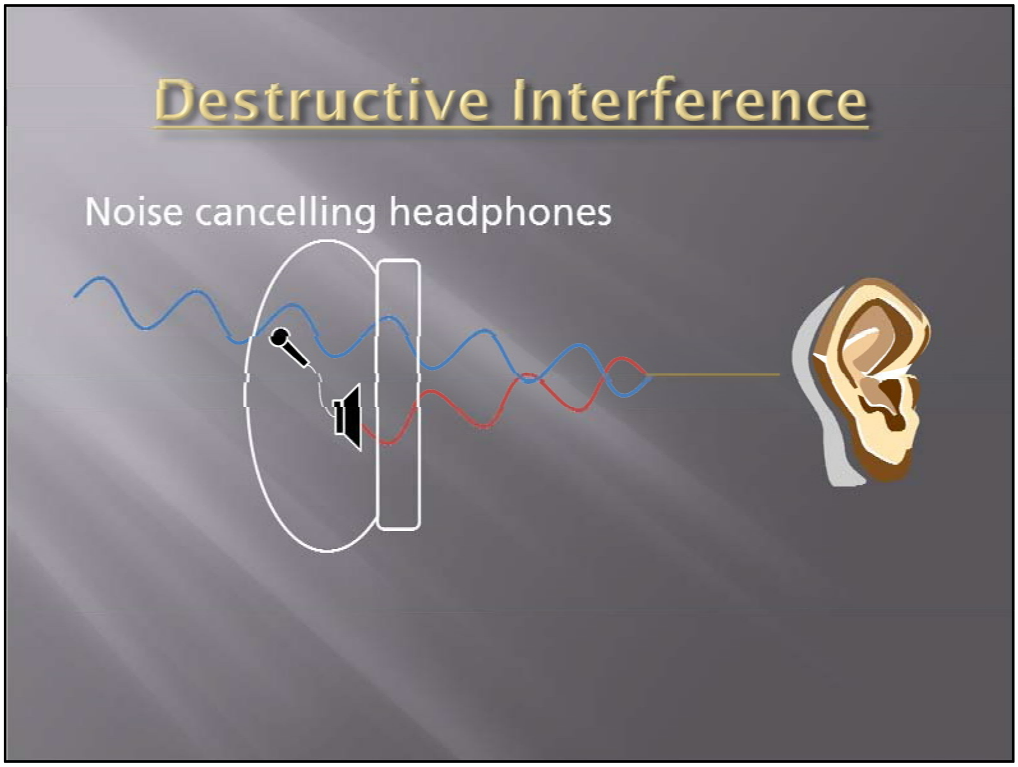


If we momentarily freeze this animation, you can again look point by point to see how the two upper waves interfere to create the wave on the bottom.

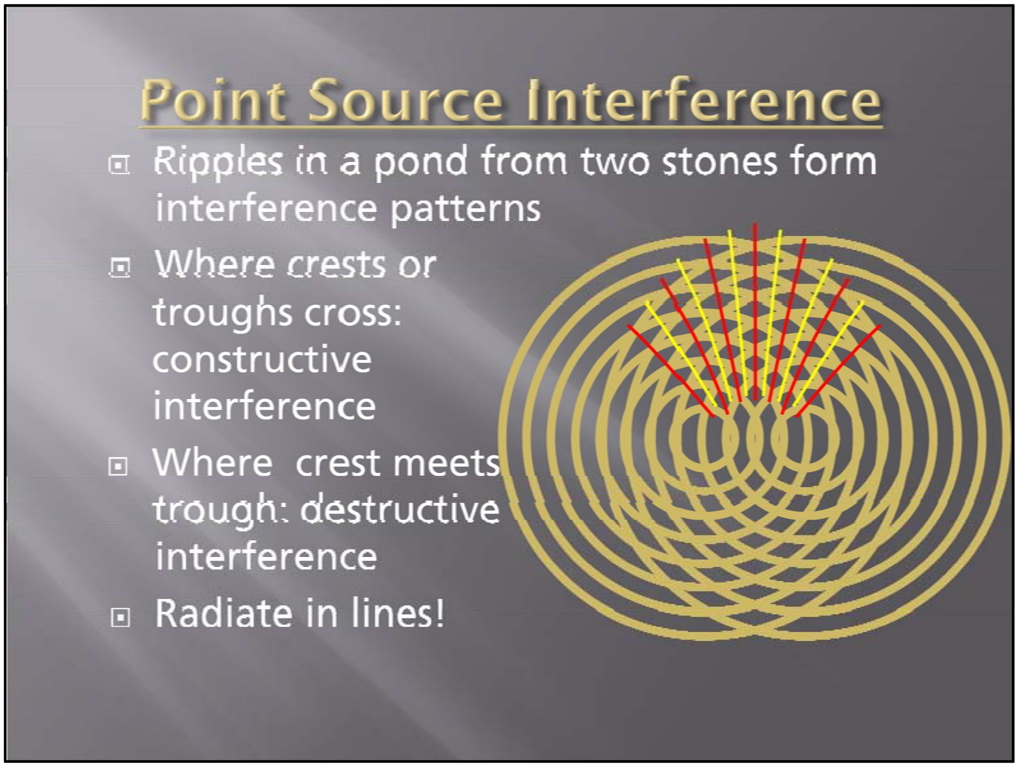
Point A shows the top wave at amplitude one and the middle wave at amplitude zero, resulting in the bottom wave having an amplitude of one.

Point B shows the top wave with amplitude two and the middle wave with amplitude negative one resulting in the bottom wave having amplitude one.

Point C shows the top wave with amplitude two and the middle wave with amplitude negative two, resulting in the bottom wave having amplitude zero. Finally, at point D, the top wave has amplitude zero and the middle wave has amplitude negative one, resulting in the bottom wave having amplitude negative one.



Destructive interference is the concept behind noise cancelling headphones. Inside each earpiece is a small microphone that listens to the outside environment. A speaker inside the headset immediately produces sound of equal volume and out of phase with any incoming sound. The two waves interfere destructively, resulting in a noticeable decrease in the noise level.



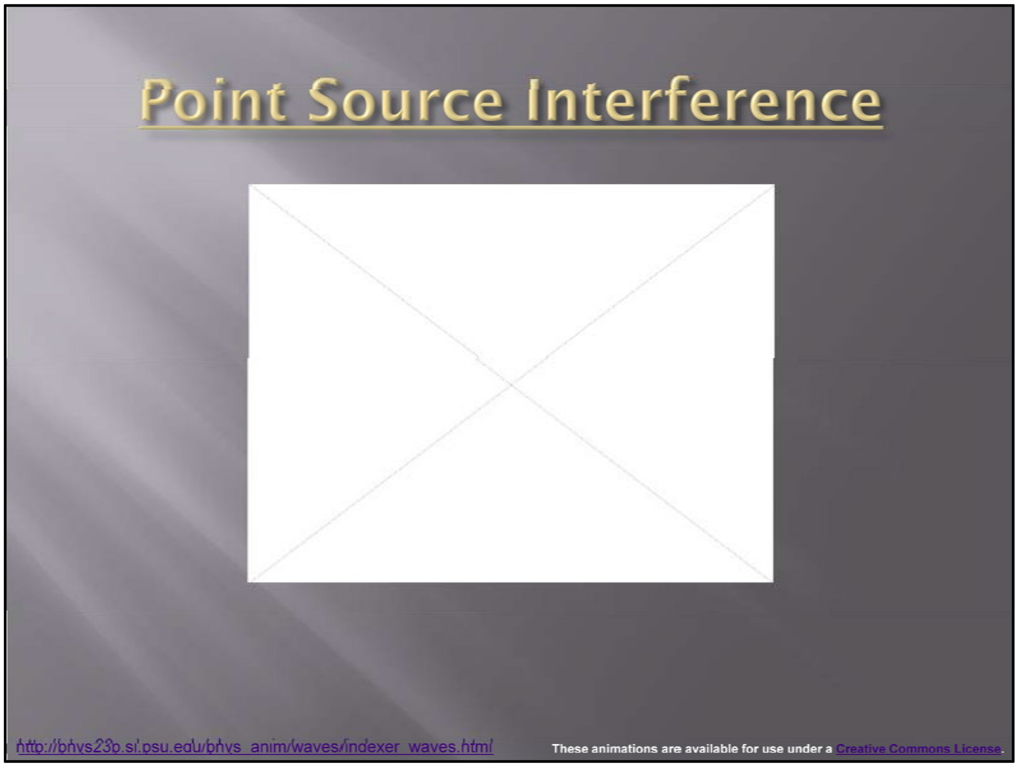
Interference also can be observed in two dimensions in what is called point source interference.

If you toss a pebble into a pond, you will see ripples spread out in increasing circles. In this picture, the **yellow lines** represent the crests of waves and the **grey space in between** represents troughs.

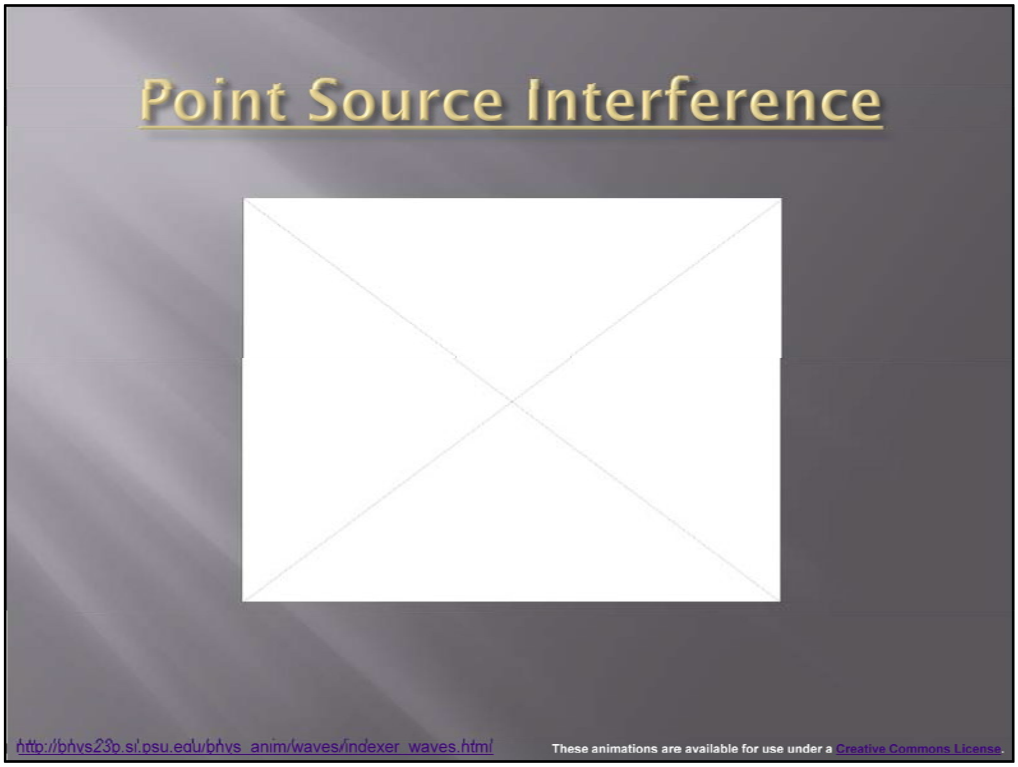
If you were to throw two pebbles in the water, side by side, the spreading circles would interact with each other and interfere.

Where crests from one pattern meet crests from the other, or troughs meet troughs, you will get constructive interference, resulting in larger amplitude waves.

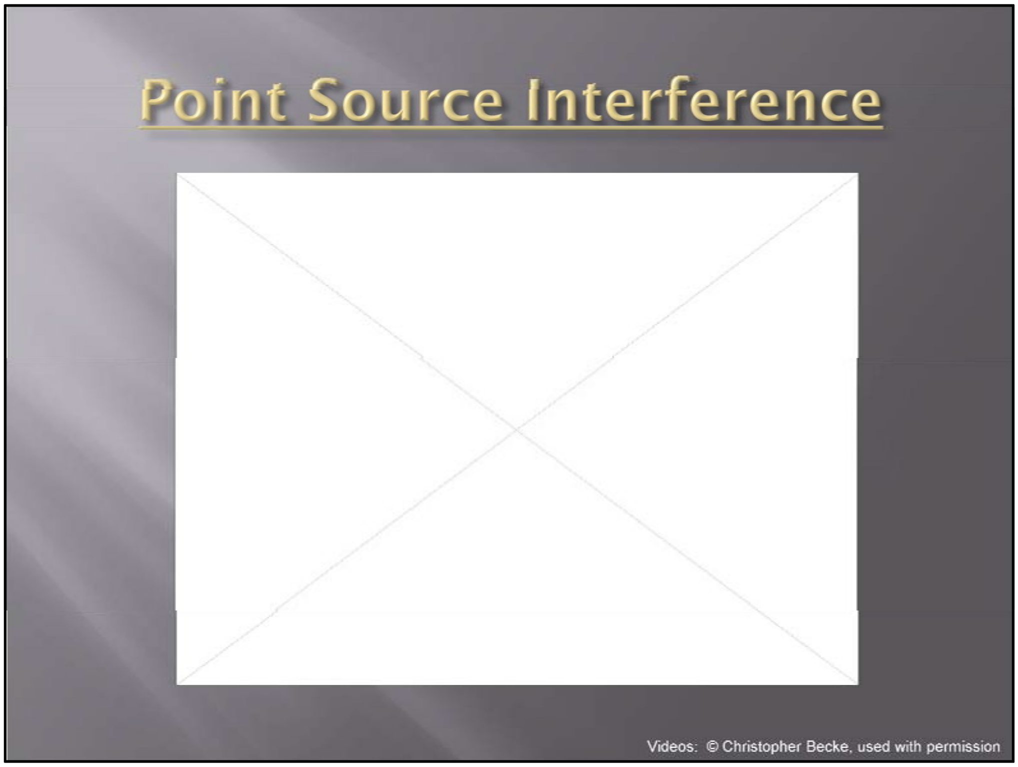
However, where crests from one wave meet troughs from the other, you will get destructive interference, resulting in spots where the surface remains calm. The areas of constructive and destructive interference radiate out from the center in lines.



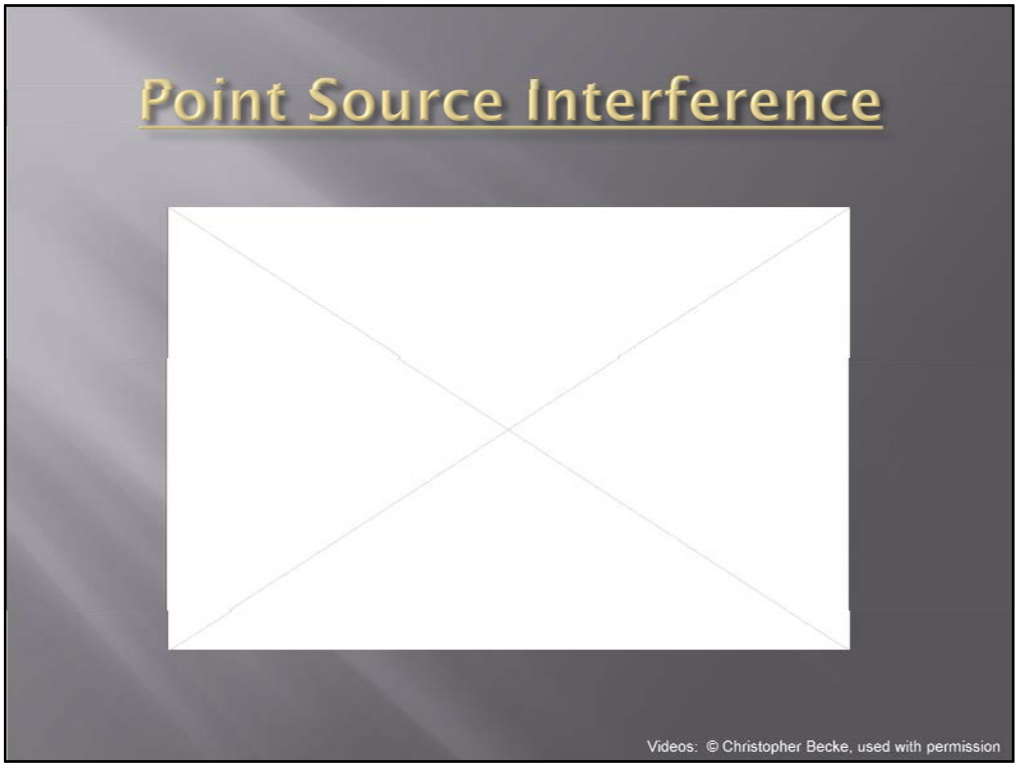
This animation shows ripples expanding from a single repeated disturbance in the center.



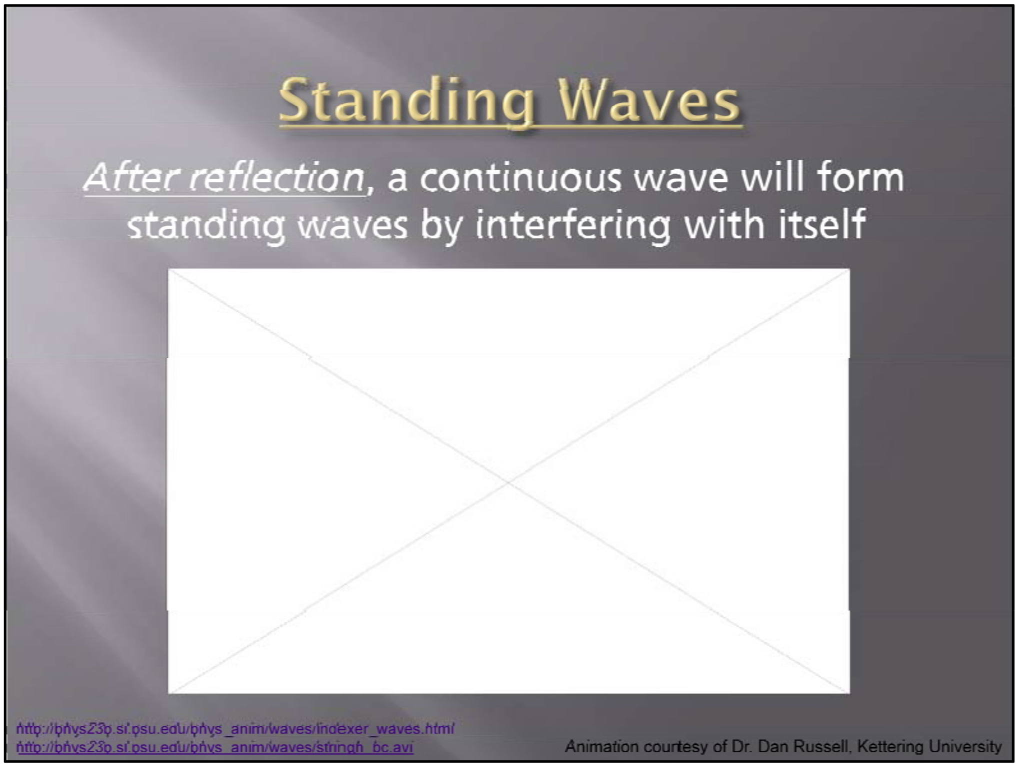
This animation shows the resulting waves from two sources. Notice the lines where the waves cancel out.



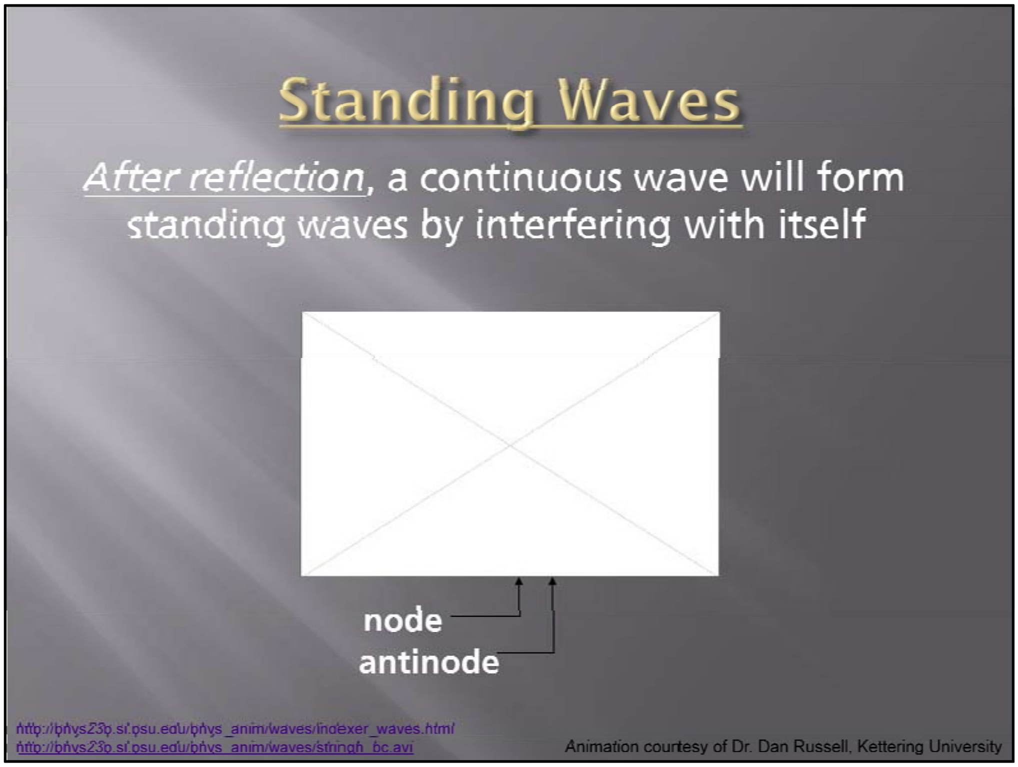
But you don't have to rely on animations to view this phenomenon. In fact, all you need is a calm patch of water and something to make a regular disturbance. In this video, you should notice the circular pattern of waves forming from the single moving foot.



Yet, in this video clip, you should be able to see an interference pattern similar to the one in the animation, with radiating lines of relative calm.

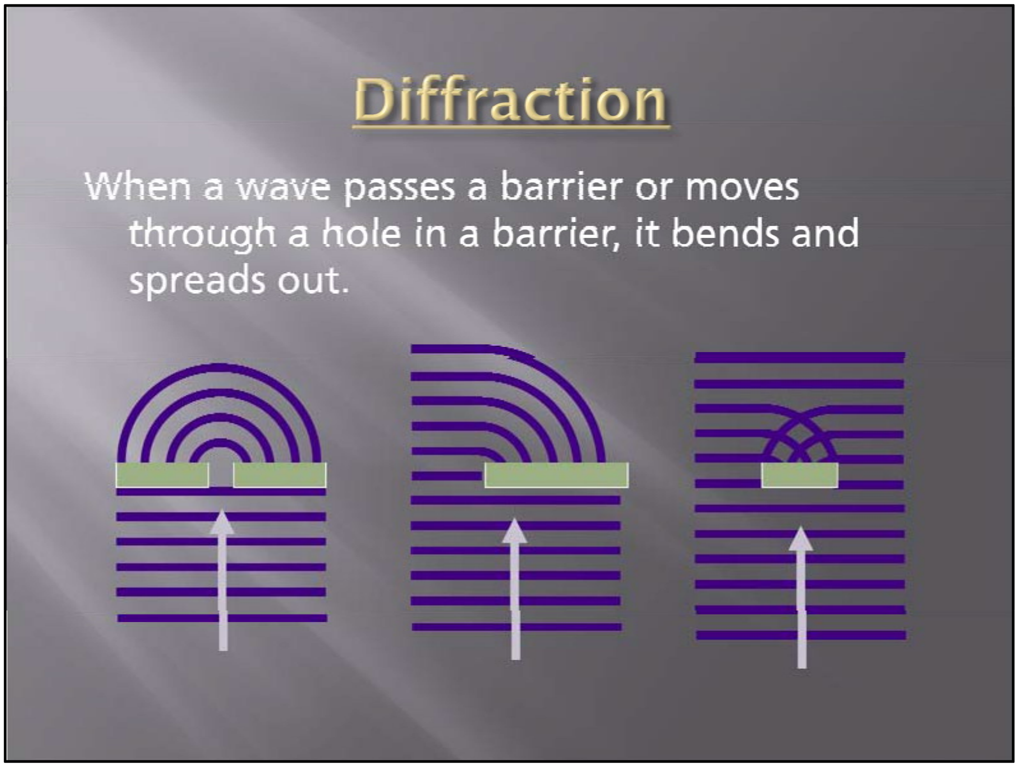


This animation shows part of a wave reflecting and interfering, creating a short-lived standing wave. It is often difficult to tell which direction a standing wave is moving, since it is a combination of waves moving in both directions.



In this animation, you can clearly see that some points always remain at rest, while others oscillate up and down with a large amplitude. Any place where the medium remains at rest is called a node, and where the medium oscillates with maximum amplitude, you find an antinode. The distance between two adjacent nodes or two adjacent antinodes is one half wavelength.

It is difficult to tell which direction a standing wave is moving, since it is a combination of waves moving in both directions.

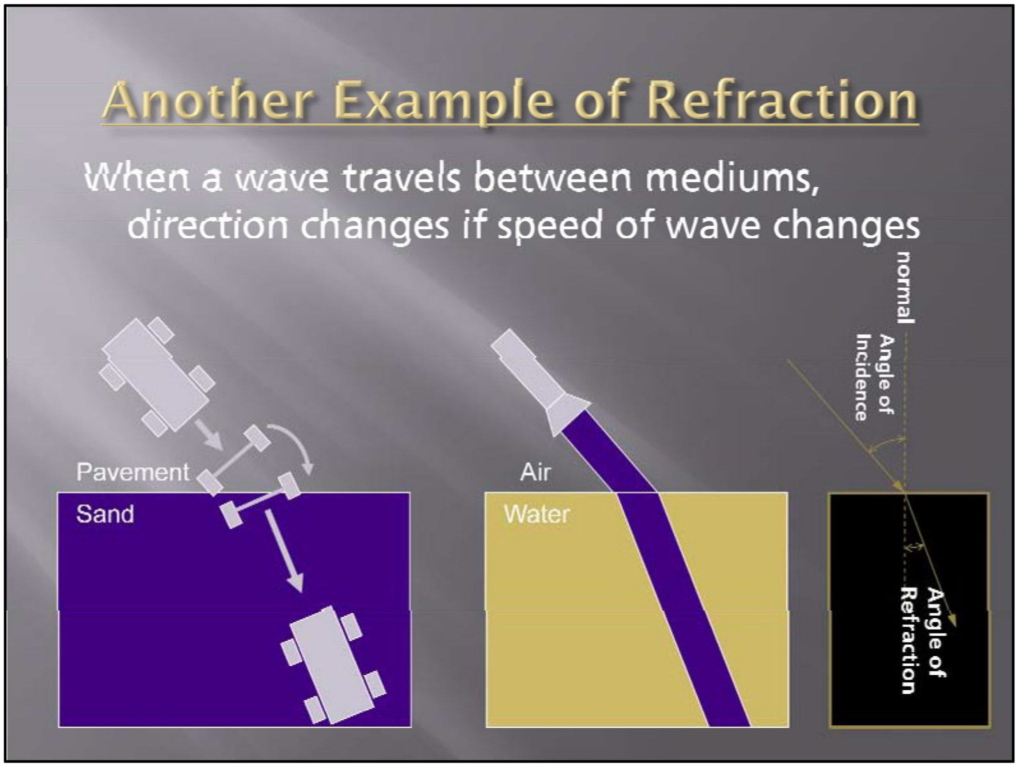


In addition to reflecting and interfering, waves can also diffract.

Diffraction occurs when a wave encounters a barrier that partially blocks its progress. The wave will continue past the edge or through the opening, with the edge of the barrier acting as a point source, so the waves will appear to bend around the edges and spread out. When waves spread out from both sides of a barrier in the middle, you should recognize the point source interference pattern that results on the far side of the barrier.

Diffraction of sound waves is one reason you are able to hear somebody talking to you from another room. The sound waves spread out as they meet the edges of the door opening.

This picture was taken on a hotel balcony in Tel-Aviv, Israel. You can clearly see the water waves coming in parallel to the breakwaters. As they pass through the openings, the waves spread out demonstrating diffraction on a large scale.



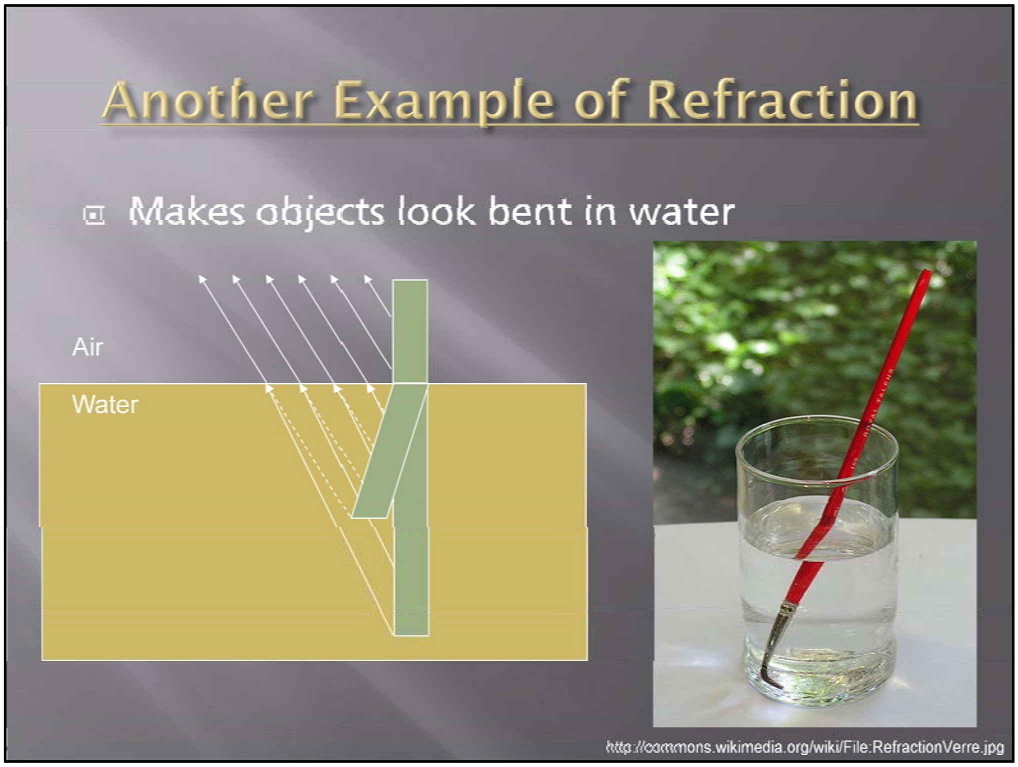
Our final wave phenomenon occurs when waves travel from one medium to another. If the speed of the wave changes as it moves between media, the direction can change as well.
This is called refraction.

Imagine that you are driving your Jeep from the pavement onto the sand at an angle. As your right-front wheel crosses onto the sand, it will slow down, but your left-front wheel will continue moving at a faster rate. This will cause the Jeep to turn to the right. Once both wheels are on the sand, they will again be travelling the same speed and you will continue on in a straight line, but in a new direction.

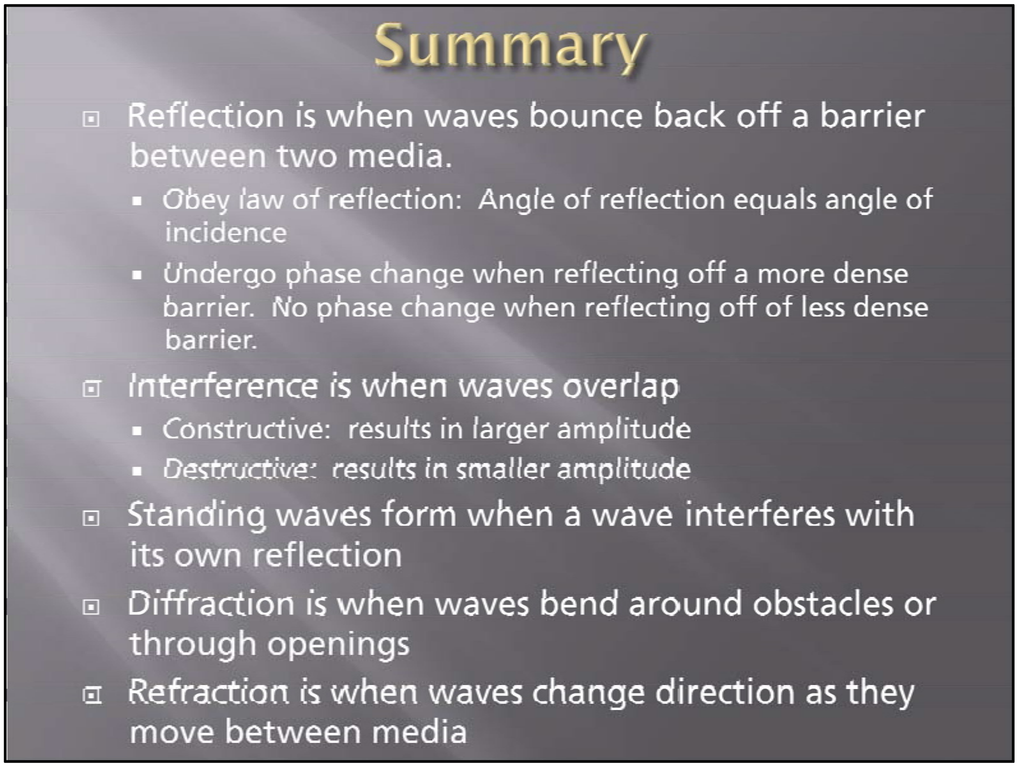
Something similar happens when light travels from air to water. The speed of light in water is less than the speed of light in air, so when the light hits the water, it also changes direction as it slows down. The amount of bending depends on the materials involved and on the angle at which the wave hits the boundary.

Notice that if the Jeep were moving from the sand to the pavement, the right wheel would speed up before the left, and the Jeep would turn to the left. The same would happen for light exiting the water. The light would bend away from the vertical and towards the surface as it sped up.

The amount of refraction is measured by the size of the angle the light ray makes with a line drawn perpendicular to the boundary between the two surfaces. This line is called the normal.



Refraction is the phenomenon that makes objects look bent in water. As the light leaving the object travels from water to air, its direction changes and you may perceive it as broken or bent.



In summary, reflection occurs when waves bounce back off of a barrier or a boundary between two media. When reflection occurs, the law of reflection tells us that the angle of reflection will be equal to the angle of incidence. When waves reflect off of a more dense medium, the reflected wave undergoes a phase change and is inverted with respect to the original wave. If waves reflect off of a less dense medium, the reflected wave does not undergo a phase change.

Interference results when two or more waves overlap within a single medium. The amplitudes of the waves simply add at every point. If the result is a larger amplitude, that is called constructive interference, and if the amplitude of the resulting wave is smaller, that is called destructive interference.

Standing waves result when a wave interferes with its own reflection. It is impossible to tell what direction a standing wave is moving since it is a combination of two waves moving in opposite directions. Standing waves have nodes and antinodes at fixed positions.

Diffraction occurs when waves pass through openings or around edges of barriers and spread out.

Refraction occurs when waves pass from one medium to another. Velocity changes when the medium changes, resulting in a change in wave direction.