Waves
Wave Behaviors
Sound

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Last time

- pendula and SHM
- waves
- kinds of waves
- sine waves

Overview

- refraction
- diffraction
- standing waves
- sound and musical instruments
- the Doppler effect

Refraction

When waves pass from one medium into another, they can change direction.

Refraction

If a wave enters a medium where it moves more slowly, what happens?

1. the frequency cannot change – the source still “updates” the medium about a new wave front every T seconds.

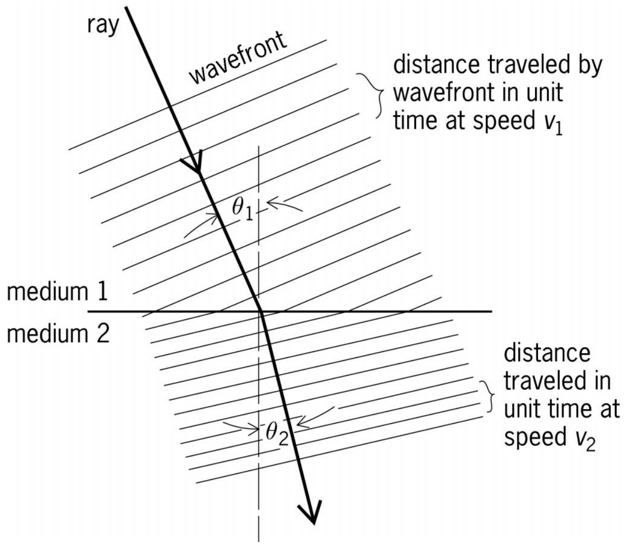
Refraction

If a wave enters a medium where it moves more slowly, what happens?

1. the frequency cannot change – the source still "updates" the medium about a new wave front every T seconds.
2. the wavelength changes ($v = f\lambda$)

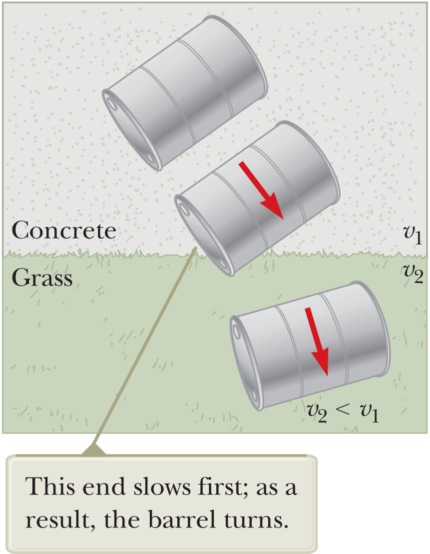
When the wavefronts slow, they bend.

Refraction



[1]McGraw-Hill Concise Encyclopedia of Physics. © 2002 by The McGraw-Hill Companies, Inc.

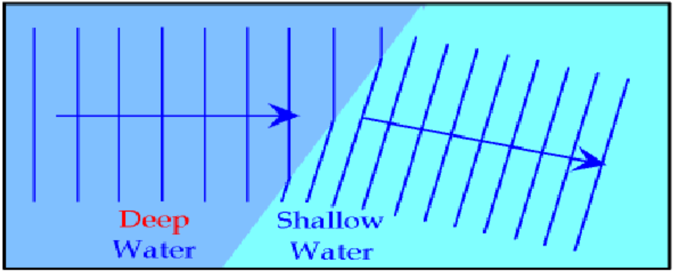
Refraction



[1]Serway & Jewett, 9th ed, page 1066.

Refraction

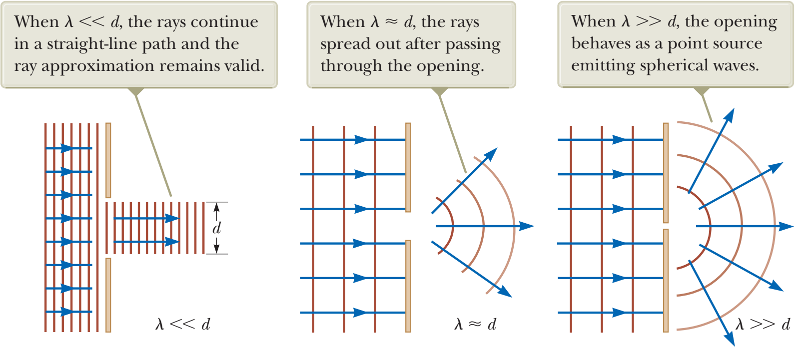
The same thing happens when waves move into shallower water on a beach.



[1]http://astarmathsandphysics.com/o-level-physics-notes/297-refraction-of-waves.html

Diffraction

Light and other waves that travel through a small gap ($< \lambda$) diverge, and that the smaller the gap, the more divergence.



This is called **diffraction**.

The effect is particularly pronounced when the gap is about the size of the wavelength or smaller.

Diffraction

Visible light have wavelengths of ~ 500 nm $= 5 \times 10^{-7}$ m.

Sound waves have wavelengths ~ 1 m. (centimeters – meters).

Diffraction

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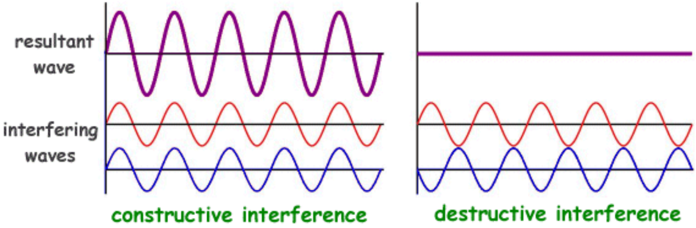
Sound waves have wavelengths ~ 1 m. (centimeters – meters).

Why can you hear someone yelling from around a corner, but you can't see them?

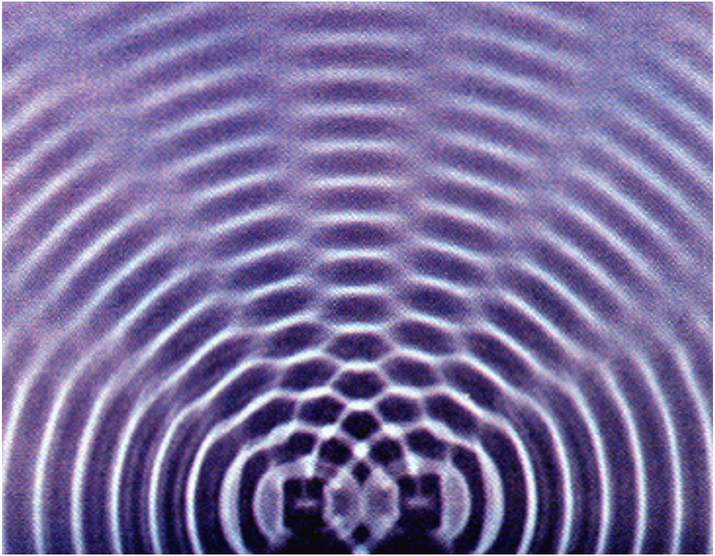
Interference of Waves

When two wave disturbances interact with one another they can amplify or cancel out.

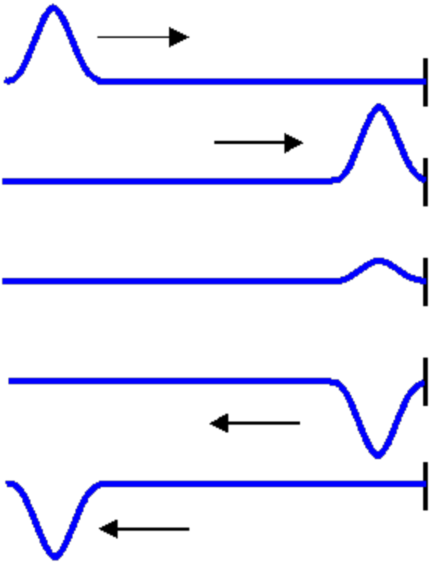
Waves of the same frequency that are "in phase" will reinforce, amplitude will increase; waves that are "out of phase" will cancel out.



Interference of Waves

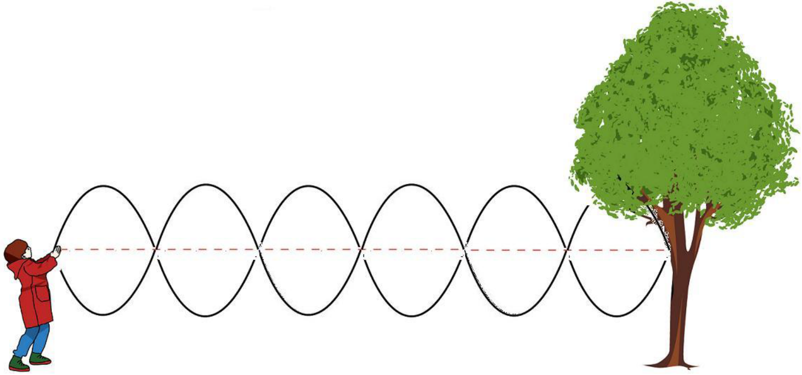


Wave Reflection



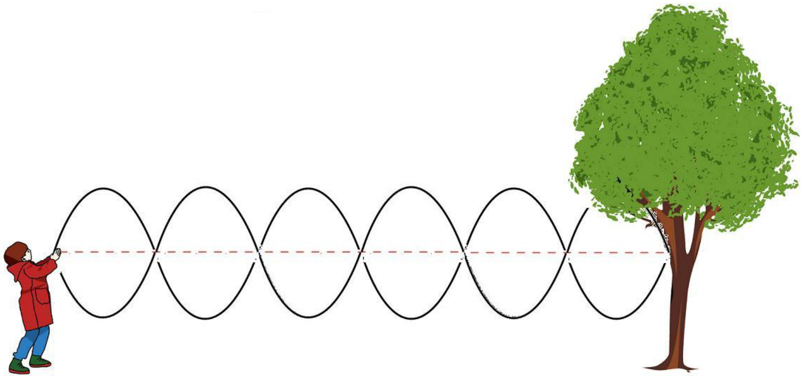
Standing Waves

It is possible to create waves that do not seem to propagate.



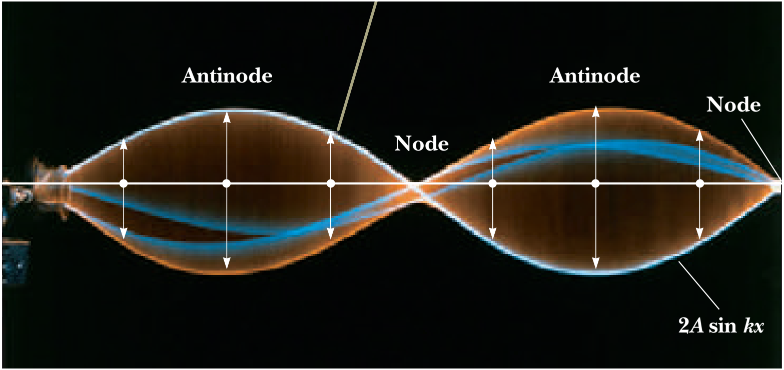
They are produced by a wave moving to the left interfering with the wave reflected back the right.

Standing Waves

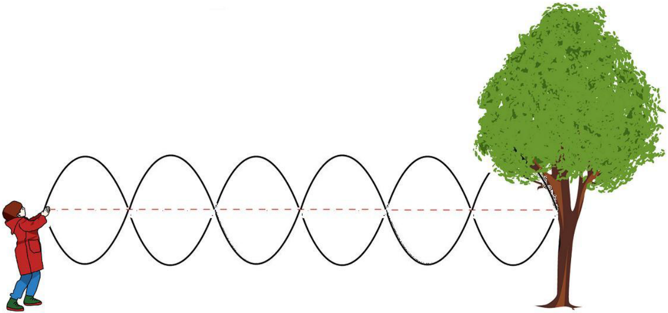


Notice that there are a whole number of half wavelengths between the child and the tree.

Nodes and Antinodes



Standing Waves and Resonance

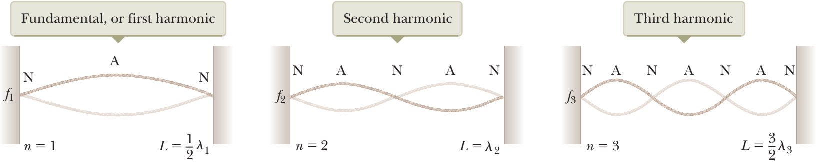


Standing wave motions are called **normal modes**.

normal mode

A pattern of motion in a physical system where all parts of the system move sinusoidally with the same frequency and with a fixed phase relation.

Standing Waves and Resonance on a String



The **natural frequencies** of a string are given by:

$$f_n = \frac{nv}{2L}$$

where n is a positive natural number, L is the length of the string, and v is the speed of the wave on the string.

A long string has a low fundamental frequency.

A short string has a high fundamental frequency.

Standing Waves and Resonance on a String

When a string is plucked, resonant (natural) frequencies tend to persist, while other waves at other frequencies are quickly dissipated.

Stringed instruments like guitars can be tuned by adjusting the tension in the strings.

Changing the tension changes the speed of the wave on the string. That changes the natural frequencies.

While playing, pressing a string against a particular fret will change the string length, which also changes the natural frequencies.

Sound

Sound is a longitudinal wave, formed of pressure fluctuations in air.

At sea level at 20°C, sound travels at 343 m/s.

All sound waves will travel at this speed relative to the rest frame of the air.

$$v = f\lambda$$

A low frequency means a longer wavelength.

[1] In higher layers, the speed of sound varies with the temperature.

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Sound can travel at different speeds in other materials. It travels faster in water, and slower at higher altitudes in the atmosphere (troposphere layer).[1]

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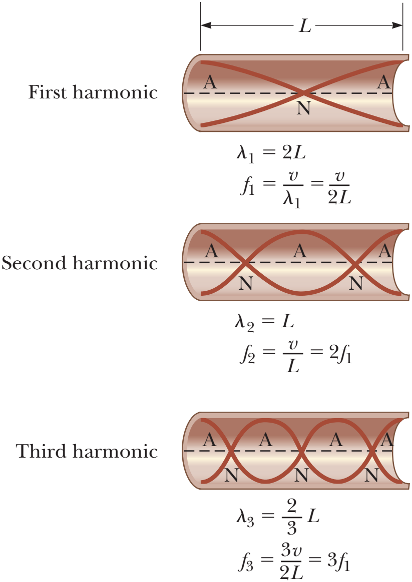
Standing Sound Waves in air columns



Standing sound waves can be set up in hollow tubes.

This is the idea behind how pipe organs, clarinets, didgeridoos, *etc.* work.

[1]Figure from Serway & Jewett, page 547.

Musical Instruments

Didgeridoo:

Longer didgeridoos have lower pitch, but tubes that flare outward have higher pitches and this can also change the spacing of the resonant frequencies.

[1]Matt Roberts via Getty Images.

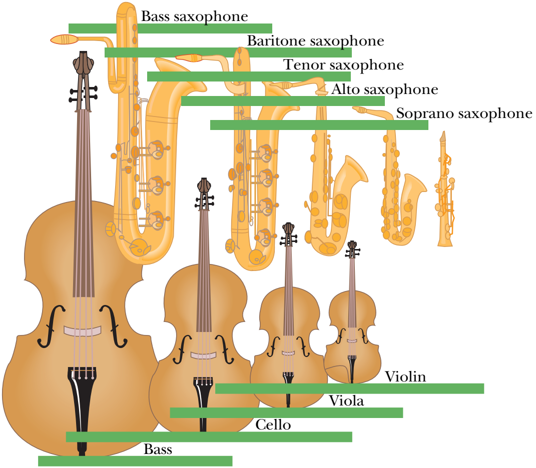
Musical Instruments, Pipe Organ

The longest pipes made for organs are open-ended 64-foot stops (tube is effectively 64 feet+ long). There are two of them in the world. The fundamental frequency associated with such a pipe is 8 Hz.

32' stops give 16 Hz sound, 16' stops give 32 Hz, 8' stops give 64 Hz, *etc*.

[1]Picture of Sydney Town Hall Grand Organ from Wikipedia, user Jason7825.

Musical Instruments



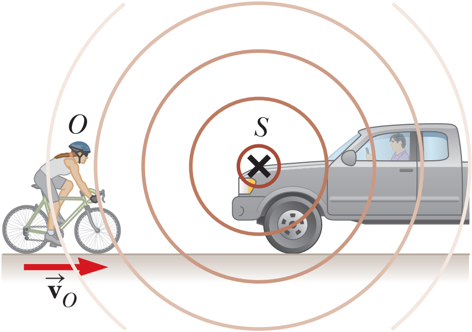
In general, larger instruments can create lower tones, whether string instruments or tube instruments.

[1] Halliday, Resnick, Walker, 9th ed, page 458.

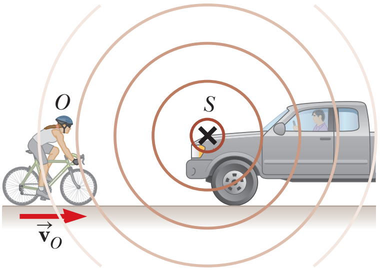
The Doppler Effect

The frequency of a sound counts how many wavefronts (pressure peaks) arrive per second.

If you are moving towards a source of sound, you encounter more wavefronts per second → the frequency you detect is higher!



The Doppler Effect



The speed you see the waves traveling relative to you is $v' = v + v_O$, while relative to the source the speed is v.

$$f' = \frac{v'}{\lambda} = \left(\frac{v + v_O}{v}\right) f$$

(v and v_O are positive numbers.)

The Doppler Effect

The speed you see the waves traveling relative to you is $v' = v + v_O$, while relative to the source the speed is v.

$$f' = \frac{v'}{\lambda} = \left(\frac{v + v_O}{v}\right) f$$

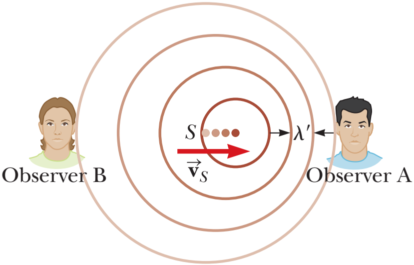
(v and v_0 are positive numbers.)

Moving *away* from the source, the relative velocity of the detector to the source decreases $v' = v - v_O$.

$$f' = \left(\frac{v - v_O}{v}\right) f$$

The Doppler Effect

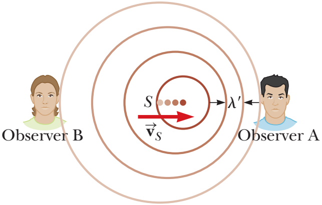
A similar thing happens if the *source* of the waves is moving.



In the diagram, the source is moving toward the wavefronts it has created on the right and away from the wavefronts it has created on the left.

This changes the wavelength of the waves around the source. They are shorter on the right, and longer on the left.

The Doppler Effect

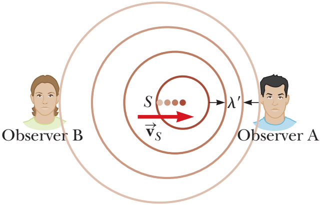


Observer A detects the wavelength as $\lambda' = \lambda - v_S T = \lambda - \frac{v_S}{f}$.

For A:

$$f' = \frac{v}{\lambda'} = \left(\frac{v}{v/f - v_S/f} \right) = \left(\frac{v}{v - v_S} \right) f$$

The Doppler Effect



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$$f' = \frac{v}{\lambda'} = \left(\frac{v}{v/f - v_S/f}\right) = \left(\frac{v}{v - v_S}\right) f$$

For Observer B:

$$f' = \left(\frac{v}{v + v_S}\right) f$$

The Doppler Effect

In general:

$$f' = \left(\frac{v \pm v_O}{v \mp v_S} \right) f$$

The top sign in the numerator corresponds to the observer/detector moving *towards* the source.

The top sign in the denominator corresponds to the source moving *towards* the observer/detector.

The bottom sign in the numerator corresponds to the detector moving *away from* the source.

The bottom sign in the denominator corresponds to the source moving *away from* the detector.

The Doppler Effect

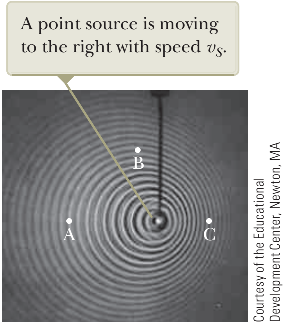
In general:

$$f' = \left(\frac{v \pm v_O}{v \mp v_S}\right) f$$

Summary: top sign if *towards*, bottom sign if *away*.

The Doppler Effect

Quick Quiz 17.4[2] Consider detectors of water waves at three locations A, B, and C in the picture. Which of the following statements is true?



(A) The wave speed is highest at location C.

(B) The detected wavelength is largest at location C.

(C) The detected frequency is highest at location C.

(D) The detected frequency is highest at location A.

[2] Serway & Jewett, page 520.

The Doppler Effect

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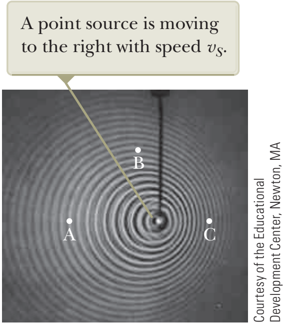

(A) The wave speed is highest at location C.

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(D) The detected frequency is highest at location A.

[2]Serway & Jewett, page 520.

The Doppler Effect Question

A police car has a siren tone with a frequency at 2.0 kHz.

It is approaching you at 28 m/s. What frequency do you hear the siren tone as?

Now it has passed by and is moving away from you. What frequency do you hear the siren tone as now?

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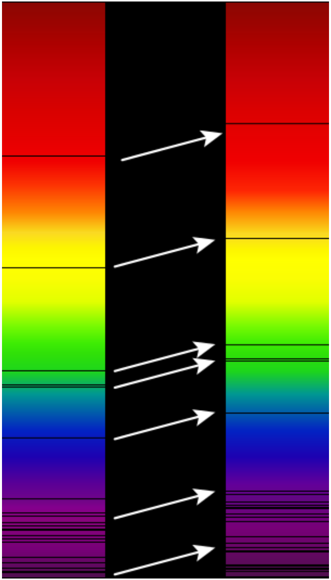
The Doppler Effect and Astronomy



[1] Image from Wikipedia by Georg Wiora.

Summary

- refraction
- diffraction
- standing waves
- sound and musical instruments
- the Doppler effect

Final Exam Tuesday Dec 11, 9:15–11:15am, S16.

Extra Office Hour Monday, 1:30-3pm.

Homework

- Ch 17 Prob: 5, 39a,c,d(not b), 41, 43, 55, 57, 59
- extra credit multiple choice on website (optional)