Doppler Effect
Bow and Shock Waves

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Last time

- nonsinusoidal waves
- intensity of a wave
- sound level

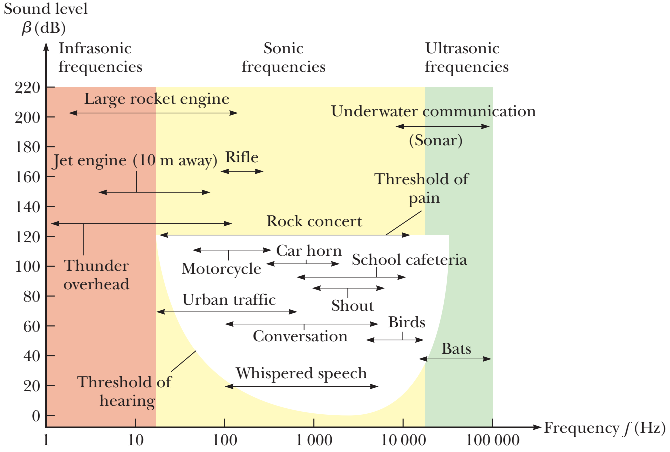
Overview

- sound level & perception of sound with frequency
- the Doppler effect
- bow and shock waves
- talk about waves

Perception of Loudness and Frequency

Human hearing also depends on frequency.

Humans can only hear sound in the range 20-20,000 Hz.



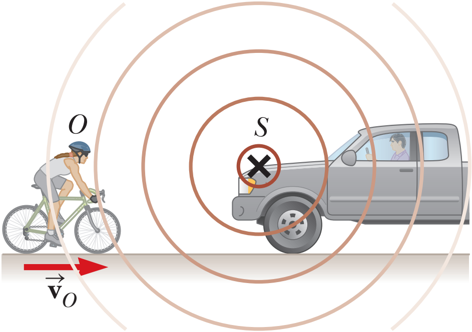
Low frequency sounds need to be louder to be heard.

[1]Figure from R. L. Reese, University Physics, via Serway & Jewett.

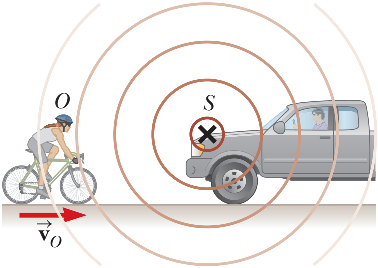
The Doppler Effect

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 $\rightarrow$ the frequency you detect is higher!



The Doppler Effect



The speed you see the waves traveling relative to you is $v' = v + v_0$, while relative to the source the speed is v.

$$f' = \frac{v'}{\lambda} = \left(\frac{v + v_0}{v} \right) f$$

(v and v_0 are positive numbers.)

The Doppler Effect

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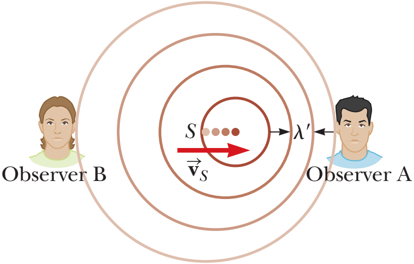
Moving *away* from the source, the relative velocity of the detector to the source decreases $v' = v - v_0$.

$$f' = \left(\frac{v - v_0}{v}\right) f$$

The Doppler Effect

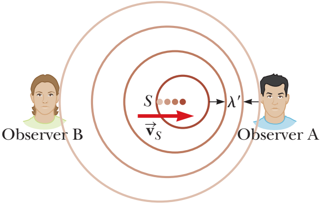
A similar thing happens if the *source* of the waves is moving.



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

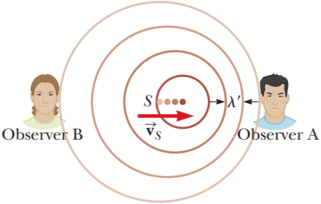


Observer A detects the wavelength as $\lambda' = \lambda - v_s T = \lambda - \frac{v_s}{f}$.

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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For A:

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

For Observer B:

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

The Doppler Effect

In general:

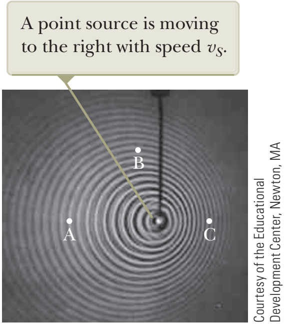
$$f' = \left(\frac{v \pm v_0}{v \mp v_s}\right) f$$

The top sign in the numerator and denominator corresponds to the detector and/or source moving *towards* on another.

The bottom signs correspond to the detector and/or source moving *away from* on another.

The Doppler Effect

Quick Quiz 17.4[1] 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.

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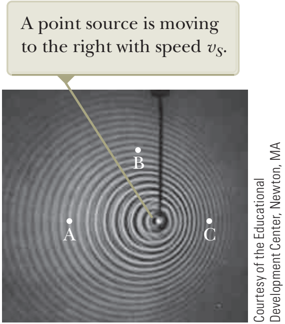
[1] Serway & Jewett, page 520.

The Doppler Effect

Quick Quiz 17.4[1] Consider detectors of water waves at three locations A, B, and C in the picture. Which of the following statements is true?



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(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.

[1] 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?

The Doppler Effect Question

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approaching: 2.2 kHz
receding (moving away): 1.8 kHz

The Doppler Effect for Light

Electromagnetic radiation also exhibits the Doppler effect, however, the equation needed to describe the effect is different.

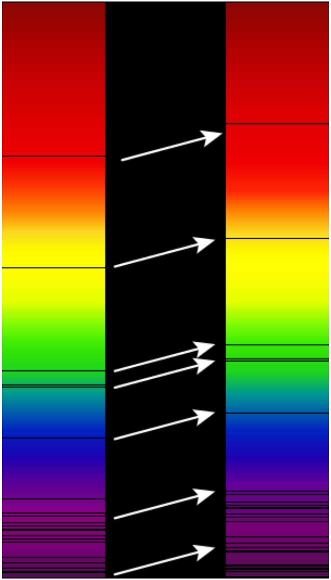
For em radiation:

$$f' = \frac{\sqrt{1 + v/c}}{\sqrt{1 - v/c}} f$$

Relativity is needed to derive this expression (hold on for Phys4D).

This can be used to determine how fast distant objects in space are moving toward or away from us.

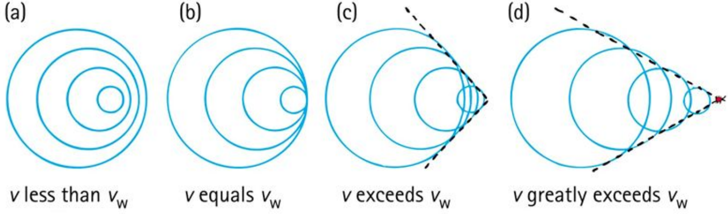
The Doppler Effect and Astronomy



[1] Image from Wikipedia by Georg Wiora.

Bow Waves and Shock Waves

Bow waves and shock waves can be detected by nearby observers when the speed of the wave source exceeds the speed of the waves.



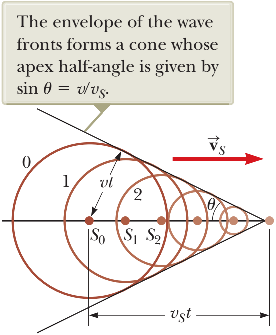
This effect happens when an aircraft transitions from subsonic flight to supersonic flight.

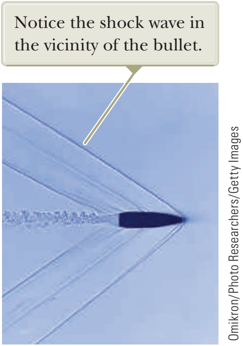
[1]Figure from Hewitt, 11ed.

Bow waves

Supersonic transition

Shock Waves





The angle which the shockwave makes is called the **Mach angle**.

$$\sin\theta = \frac{v}{v_s}$$

The ratio v_s/v is called the **Mach number**.

Shock Waves Question

Quick Quiz 17.6[2] An airplane flying with a constant velocity moves from a cold air mass into a warm air mass. What happens to the Mach number?

(A) it increases

(B) it decreases

(C) it stays the same

[2] Serway & Jewett, page 522.

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Hint:

$$v = 331\sqrt{1 + \frac{T_{\mathrm{Cel}}}{273}}\ [\mathrm{m/s}]$$

[2] Serway & Jewett, page 522.

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[2] Serway & Jewett, page 522.

Waves

Any questions about waves?

Summary

- the Doppler effect
- bow and shock waves

Drop Deadline Friday, June 1.

3rd Test Friday, June 1.

Homework Serway & Jewett:

- Ch 17, onward from page 523. Probs: 37, 41, 47, 54, 71
- Ch 18, onward from page 555. OQs: 3, 5; CQs: 3; Probs: 59, 77