Waves
Sound Level
Doppler Effect

Lana Sheridan

De Anza College

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Last time

- nonsinusoidal waves
- intensity of a wave

Overview

- power of a sound wave
- sound level & perception of sound with frequency
- the Doppler effect

Power and Intensity of Sound Waves

$$\text{Power} = \mathbf{F} \cdot \mathbf{v}$$

Consider a sound wave traveling in the x direction. $\mathcal{A}$ **is area.**

$\mathbf{F} = (\Delta P)\mathcal{A}\mathbf{i}$ and $\mathbf{v} = \frac{\partial s}{\partial t}\mathbf{i}$

$$\begin{aligned} \text{Power} &= (\Delta P)\mathcal{A}\frac{\partial}{\partial t}\left(s_{\text{max}}\cos(kx - \omega t)\right) \\ &= \rho v \omega \mathcal{A} s_{\text{max}} \sin(kx - \omega t)\left(\omega s_{\text{max}} \sin(kx - \omega t)\right) \\ &= \rho v \omega^2 \mathcal{A}\, s_{\text{max}}^2 \sin^2(kx - \omega t) \end{aligned}$$

Power and Intensity of Sound Waves

$$\text{Power} = \rho v \omega^2 \mathcal{A}\, s_{\text{max}}^2 \sin^2(kx - \omega t)$$

To find the average power, we need to average this power arriving at a point over a full cycle, time period T.

Consider a fixed position so that x is a constant.

$$\begin{aligned}
\text{Power}_{\text{avg}} &= \frac{1}{T}\int_0^T \left(\rho v \omega^2 \mathcal{A}\, s_{\text{max}}^2 \sin^2(kx - \omega t)\right) \mathrm{dt} \\
&= \rho v \omega^2 \mathcal{A}\, s_{\text{max}}^2\, \frac{1}{T}\int_0^T \sin^2(kx - \omega t)\, \mathrm{dt} \\
&= \rho v \omega^2 \mathcal{A}\, s_{\text{max}}^2\, \frac{1}{T}\int_0^T \frac{1}{2}(1 - \cos(2kx - 2\omega t))\, \mathrm{dt}
\end{aligned}$$

Power of a sound wave:

$$\text{Power}_{\text{avg}} = \frac{1}{2}\rho v \omega^2 \mathcal{A}\, s_{\text{max}}^2$$

Power and Intensity of Sound Waves

Power of a sound wave:

$$\text{Power}_{\text{avg}} = \frac{1}{2} \rho \mathcal{A} \omega^2 s_{\text{max}}^2 v$$

Dividing this by the area gives the intensity of a sound arriving on that area:

$$I = \frac{1}{2} \rho v (\omega s_{\text{max}})^2$$

This can be written in terms of the pressure variation amplitude, $\Delta P_{\text{max}} = \rho v \omega s_{\text{max}}$:

$$I = \frac{(\Delta P_{\text{max}})^2}{2 \rho v}$$

Decibels: Scale for Sound Level

The ear can detect very quiet sounds, but also can hear very loud sounds without damage.

(Very, very loud sounds do damage ears.)

As sound that has twice the intensity does not "sound like" it is twice as loud.

Many human senses register to us on a logarithmic scale.

Decibels: Scale for Sound Level

Decibels is the scale unit we use to measure loudness, because it better represents our perception than intensity.

The sound level β is defined as

$$\beta = 10 \log_{10} \left(\frac{I}{I_0} \right)$$

- I is the intensity
- $I_0 = 1.00 \times 10^{-12}$ W/m^2 is a reference intensity at the threshold of human hearing

The units of β are decibels, written dB.

A sound is 10 dB louder than another sound if it has **10 times** the intensity.

Question

Quick Quiz 17.3[1] Increasing the intensity of a sound by a factor of 100 causes the sound level to increase by what amount?

(A) 100 dB

(B) 20 dB

(C) 10 dB

(D) 2 dB

[1] Serway & Jewett, page 515.

Question

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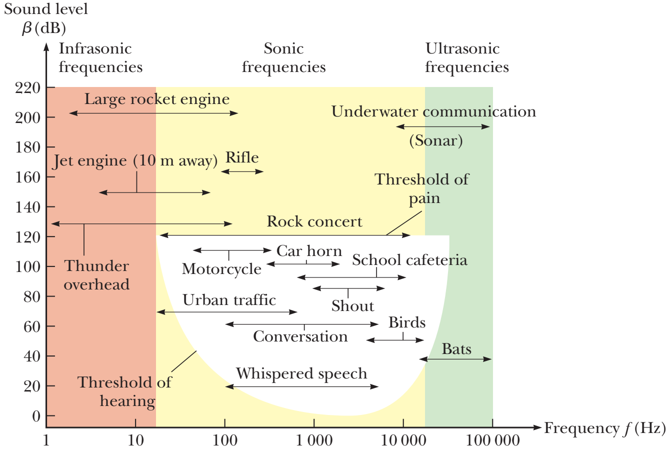
[1] Serway & Jewett, page 515.

Perception of Loudness and Frequency

Human hearing also depends on frequency.

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



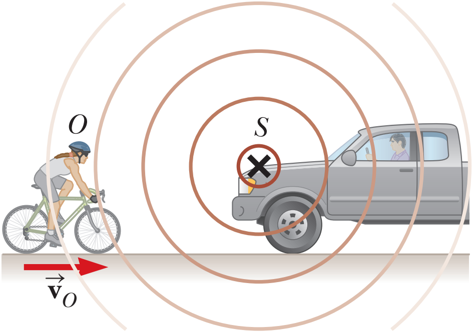
Low frequency sounds need to be louder to be heard.

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

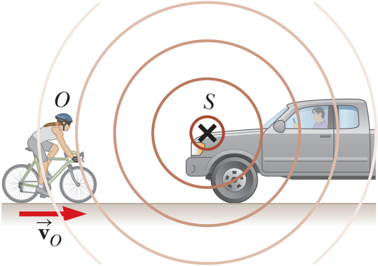
The Doppler Effect

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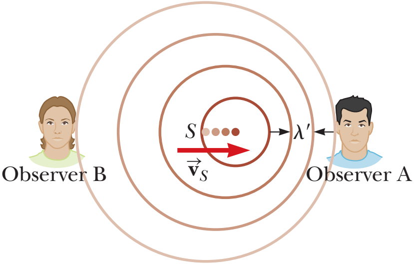
Moving *away* from the source, the relative velocity of the detector to the source decreases $v' = v - v_0$.

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

The Doppler Effect

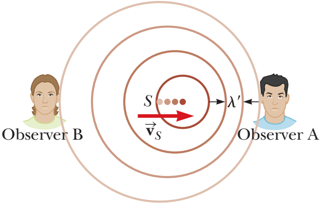
A similar thing happens if the *source* of the waves is moving.



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

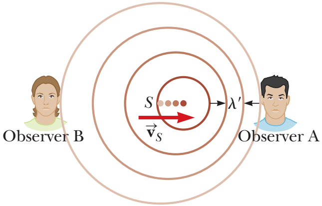


Observer A detects the wavelength as $\lambda' = \lambda - v_s T = \lambda - \frac{v_s}{f}$.

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

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.

Summary

- power of a sound wave
- sound level
- the Doppler effect

5th Test Tuesday, June 9.

Homework Serway & Jewett (suggested):

- Ch 17, onward from page 523. Probs: 54, 71 (can wait to do)