Phys 111: Lecture 28

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The 28$^{\text{th}}$ Day: “1 Red, 1 Blue, 3 Green”

Homework Wk #14 Due Today

Today’s Topics

1. Sound Intensity
2. Doppler Effect
3. Principle of Linear Superposition
4. Beats (not the Apple kind)

Brief Recap

We've been presented with wave qualities like

- period (T)
- frequency (f)
- wavelength (λ)
- and wave speed (v_w),

but we haven't directly considered the energy transferred by waves.

Motivation

How can we quantify the total energy (E) from the source if we can only measure values at single locations at a time per device?

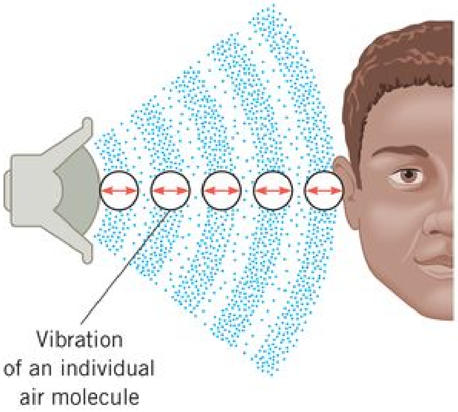


Figure: 28.1 Measurement at one location[1]

[1] C&J Figure 16.13

Intensity

It's relatively easy to measure the power at a single location or the power per area . This is called Intensity:

$$I = \frac{P}{A}$$

We then use our measurements to get total power and thus energy emitted by the source:

$$P = IA$$

$$P = \frac{\Delta E}{\Delta t}$$

Visualizing Intensity & Area

The sound **intensity** I is defined as the sound power P that passes perpendicularly through a surface divided by the area A of that surface:

$$I = \frac{P}{A}$$

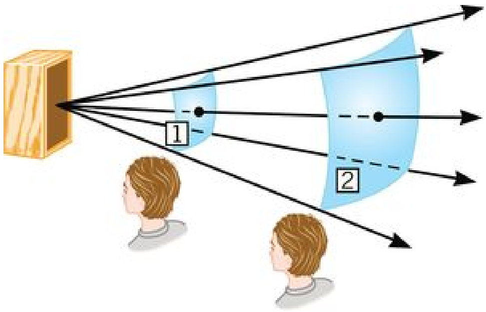


Figure: 28.2 Power through an area[2]

[2] C&J Figure 16.21

Exercise # 1

C&J 16.54 A source of sound is located at the center of two concentric spheres, parts of which are shown in the drawing. The source emits sound uniformly in all directions. On the spheres are drawn three small patches that may or may not have equal areas. However, the same sound power passes through each patch. The source produces $2.3\,W$ of sound power, and the radii of the concentric spheres are $r_A = 0.60\,m$ and $r_B = 0.80\,m$.

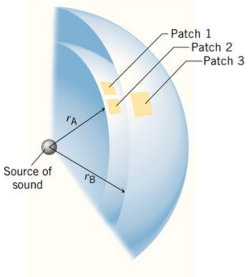


Figure: 28.3 Spherically generated sound[3]

[3] C&J Figure 16.P54

Exercise # 1 Questions

C&J 16.54 The source produces $2.3\ W$ of sound power, and the radii of the concentric spheres are $r_A = 0.60\ m$ and $r_B = 0.80\ m$.

a. Determine the sound intensity at each of the three patches.
b. The sound power that passes through each of the patches is $1.8 \times 10^{-3}\ W$. Find the area of each patch.

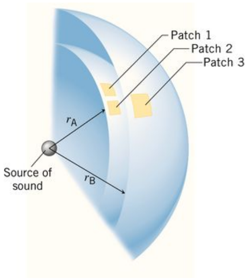


Figure: 28.3 Spherically generated sound[3]

[3] C&J Figure 16.P54

Exercise #1(a) Answer

C&J 16.54(a) Use the relationship for intensity to calculate three intensities.

Data: $P = 2.3\ W$, $r_A = 0.60\ m$, and $r_B = 0.80\ m$.

$$I = \frac{P}{A} = \frac{P}{4\pi r^2}$$

$$I_1 = I_2 = \frac{2.3\ W}{4\pi(0.60\ m)^2} = 0.51\ \frac{W}{m^2}$$

$$I_3 = \frac{2.3\ W}{4\pi(0.80\ m)^2} = 0.29\ \frac{W}{m^2}$$

Exercise #1(b) Answer

C&J 16.54(b) Use the relationship for intensity to calculate three areas.

Data: $P = 1.8 \times 10^{-3}\ W$, $I_1 = I_2 = 0.51\ \frac{W}{m^2}$, and $I_3 = 0.29\ \frac{W}{m^2}$.

$$A = \frac{P}{I}$$

$$A_1 = A_2 = \frac{1.8 \times 10^{-3}\ W}{0.51\ \frac{W}{m^2}} = 0.35\ cm^2$$

$$A_3 = \frac{1.8 \times 10^{-3}\ W}{0.29\ \frac{W}{m^2}} = 0.62\ cm^2$$

Relating Intensities

For us, it's usually easier to measure quantities in reference to some base amount. In this case the threshold intensity for human hearing I_o is used as our reference

$$I_o = 1.00 \times 10^{-12}\ W/m^2$$

The ratio of interest is our measured intensity over the threshold reference:

$$\frac{I}{I_o} = \frac{I}{1.00 \times 10^{-12}\ W/m^2}$$

You can see how numerically this may be hard to work with and it turns out there is a physical reason to report this relative intensity in terms of **decibels (dB)**.

Decibels

Human hearing doesn't scale linearly with the intensity ratio, it scales logarithmicly. Intensity level (β) is how we measure volume in general.

$$\beta = (10\ dB) \log \left(\frac{I}{I_o} \right)$$

From experiment it's been shown [to understand hearing rules of thumb]

- that a one-decibel (1-dB) change in the intensity level corresponds to approximately the smallest change in loudness that an average listener with normal hearing can detect.
- that if the intensity level increases by 10 dB, the new sound seems approximately twice as loud as the original sound.

Exercise #2

Suppose the background noise when a work space is 'quiet' is about $28.0\ dB$. How intense and how loud are the sounds produced by workers if the sound is measured to be

a. $44.0\ dB$

b. $28.5\ dB$

c. $56.0\ dB$

Exercise #2 Need To Know

We need to understand that the intensity level of the sound produced β will be the difference between when it is produced β_2 and when it's quiet β_1

$$\beta = \beta_2 - \beta_1.$$

$$\beta = (10\ dB)\log\left(\frac{I}{I_o}\right)$$

$$I = I_o 10^b$$

$$b = \frac{\beta}{10\ dB}$$

Exercise #2 Answers

The background intensity level is $\beta_1 = 28.0\ dB$.

a. $\beta_2 = 44.0\ dB$

$$\beta = 16\ dB$$

$$I = 40.0 \times 10^{-12}\ W/m^2$$

b. $\beta_2 = 28.5\ dB$

$$\beta = 0.5\ dB$$

$$I = 1.12 \times 10^{-12}\ W/m^2$$

c. $\beta_2 = 56.0\ dB$

$$\beta = 28\ dB$$

$$I = 631 \times 10^{-12}\ W/m^2$$

Exercise #2 Answers

a.

$$\beta = 16\ dB$$

$$I = 40.0 \times 10^{-12}\ W/m^2$$

b.

$$\beta = 0.5\ dB$$

$$I = 1.12 \times 10^{-12}\ W/m^2$$

c.

$$\beta = 28\ dB$$

$$I = 631 \times 10^{-12}\ W/m^2$$

Exercise #3

C&J 16.67 A listener doubles his distance from a source that emits sound uniformly in all directions. There are no reflections. By how many decibels does the sound intensity level change?

Exercise #3 Need to Know

C&J 16.67 Source emits sound spherically with no reflections so we can say

$$I = \frac{P}{4\pi r^2}$$

and we are going to want to use intensity level

$$\beta = (10\ dB)\log\left(\frac{I}{I_o}\right)$$

Exercise #3 Work

C&J 16.67 A listener doubles his distance from a source that emits sound uniformly in all directions. There are no reflections. By how many decibels does the sound intensity level change?

If distance doubles, then $r_1 = 2r_o$ is the only change that causes the change in intensity so

$$\frac{I_1}{I_o} = \frac{A_o}{A_1}$$

$$\frac{I_1}{I_o} = \frac{\pi r_o^2}{\pi(2r)^2}$$

$$\frac{I_1}{I_o} = \frac{1}{4}$$

Exercise #3 Answers

C&J 16.67 Therefore

$$\beta_1 = (10\ dB)\log\left(\frac{1}{4}\right)$$

Since I chose the initial intensity to be my reference then

$$\beta_o = 0.$$

Regardless of the choice of reference the difference in intensity level will be equal to

$$\beta = -6.00\ dB.$$

Wave Intensity & Power

Intensity and Power of Multi-wave phenomena

$$I = \frac{P}{A}$$

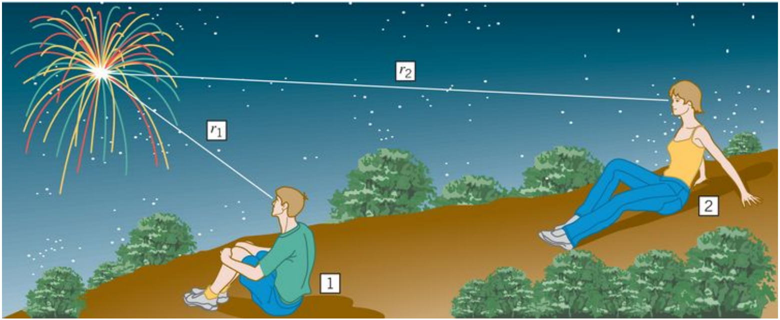


Figure: 28.4 Fireworks example of sound and light waves[4]

[4] C&J Figure 16.23

Doppler Effect Introduction

Moving source and stationary observer

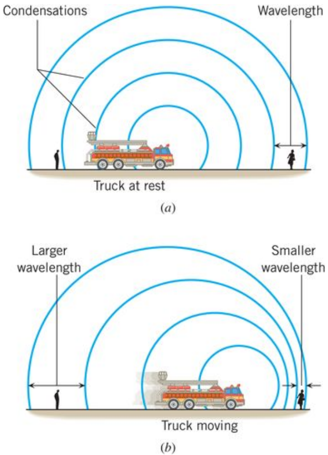


Figure: 28.5 Doppler effect with moving source and stationary observer[5]

[5] C&J Figure 16.27

Doppler Effect Case 1 Explanation

Analyzing perceived frequencies and wavelengths

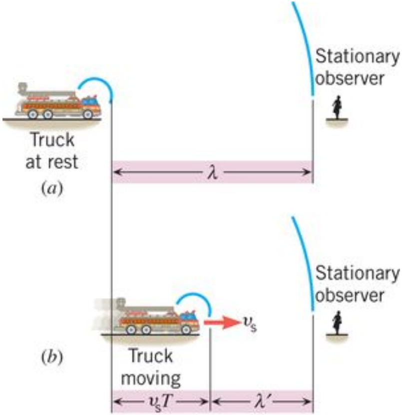


Figure: 28.6 Doppler effect on frequency from moving source[6]

[6] C&J Figure 16.28

Doppler Effect Case 2

Stationary source and moving observer

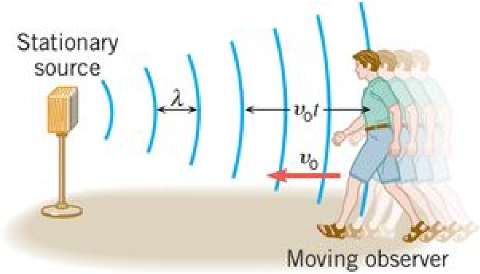


Figure: 28.7 Doppler effect stationary source and moving observer[7]

[7] C&J Figure 16.29

Explanation of Doppler Sound Equations

Source moving toward stationary observer

$$f_o = f_s\left(\frac{1}{1 - \frac{v_s}{v}}\right)$$

Source moving away from stationary observer

$$f_o = f_s\left(\frac{1}{1 + \frac{v_s}{v}}\right)$$

Observer moving towards stationary source

$$f_o = f_s\left(1 + \frac{v_o}{v}\right)$$

Observer moving away from stationary source

$$f_o = f_s\left(1 - \frac{v_o}{v}\right)$$

Doppler Effect Summary

Summary for simple cases

- Moving towards then frequency observed higher
- Moving away then frequency observed lower

Both effects apply when both move and all cases equations can be summarized with

$$f_o = f_s \left(\frac{1 \pm \frac{v_o}{v}}{1 \mp \frac{v_s}{v}} \right)$$

Doppler Effect Application

Doppler effect for radio waves used in NEXRAD (Next Generation Radar)

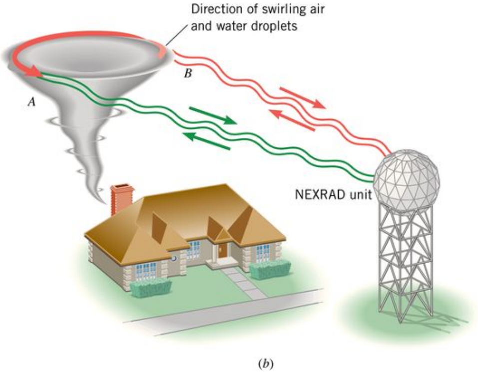


Figure: 28.8 Doppler effect weather application NEXRAD[8]

[8] C&J Figure 16.30

Combinations of Waves

The Doppler effect is a set of special cases of wave interactions. Let's now move onto wave combinations. First a short recap:

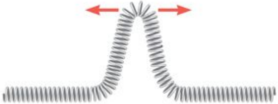
Interactions are "linear" if they scale by the number of inputs or actors interacting.

Quantities are "superposable" if you can account for each effect as if the rest weren't present at all and then add up each individual effect to predict/produce the net effect.

Slinky Example of Linear Superposition 1

Consider the two constructive input waves traveling through one medium.


(*a*) Overlap begins


(*b*) Total overlap; the Slinky has twice the height of either pulse


(*c*) The receding pulses

Figure: 28.9 Linear wave inputs[9]

[9] C&J Figure 17.01

Slinky Example of Linear Superposition 2

Now consider the two destructive input waves traveling.

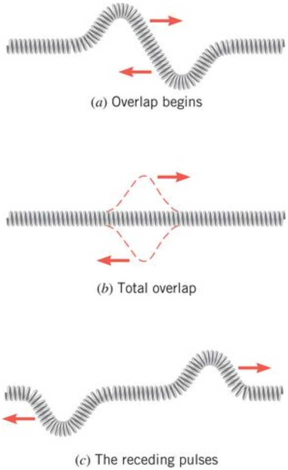


Figure: 28.10 Superpositional combination[10]

[10] C&J Figure 17.02

Formal Statement about Superposition

Principle of Linear Superposition: When two or more waves are present simultaneously at the same place, the resultant disturbance is the sum of the disturbances from the individual waves.

This principle can be applied to all types of waves, including sound waves, water waves, and electromagnetic waves such as light, radio waves, and microwaves. It embodies one of the most important concepts in physics, linear independent interactions.

Seems to be a reoccuring concept in physics. (It is!)

$$\sum_i \vec{\mathbf{F}}_i = m\vec{\mathbf{a}}_{net}$$

Constructive Interference

When the waves superpose to solely increase an effect, we say they constructively interfere.

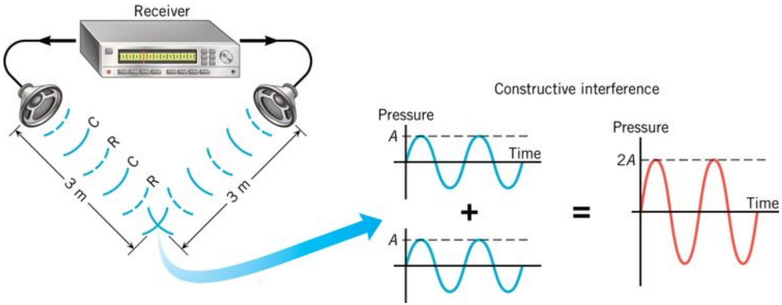


Figure: 28.11 Constructively interfering sound[11]

[11] C&J Figure 17.03

Destructive Interference

When the waves superpose to completely cancel, we say they destructively interfere.

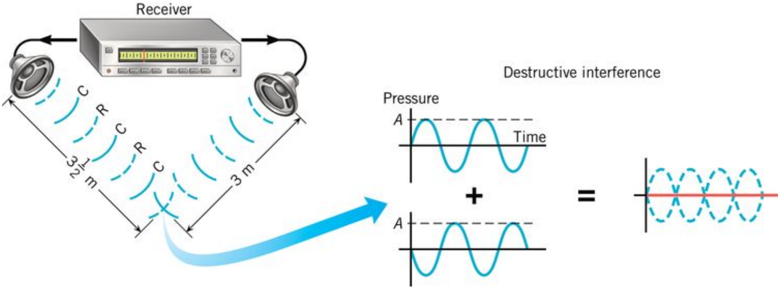


Figure: 28.12 Constructively interfering sound[12]

[12] C&J Figure 17.04

Have you ever tried to talk or sing while wearing noise-cancelling headphones?

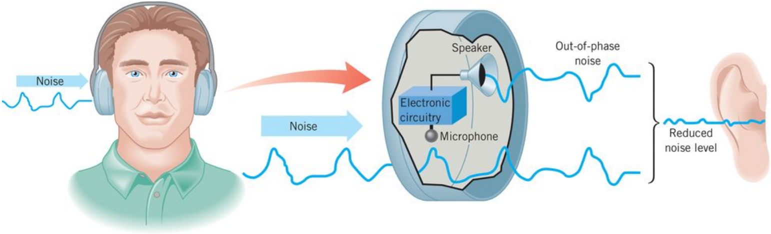


Figure: 28.13 Noise cancellation technology[13]

[13] C&J Figure 17.05

Special Case of Interference: Beats[15]

No, not the headphone company Apple acquired a few years ago!

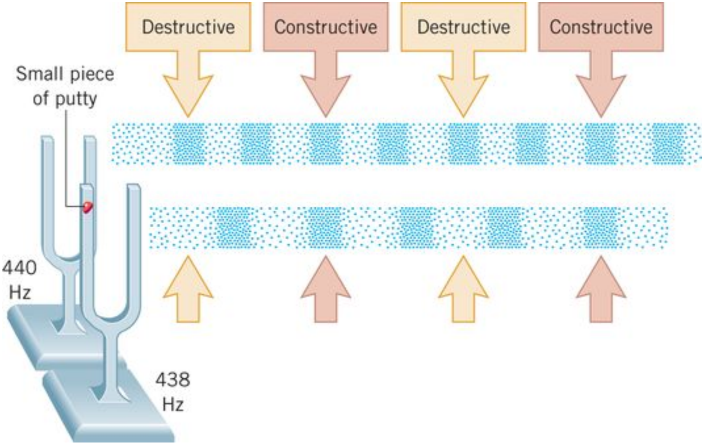


Figure: 28.14 Beats by tuning fork[14]

[14] C&J Figure 17.13

[15] `https://www.youtube.com/watch?v=V8W4Djz6jnY`

Beats Graphs & Examples

Ideal data for beats and another link[17].

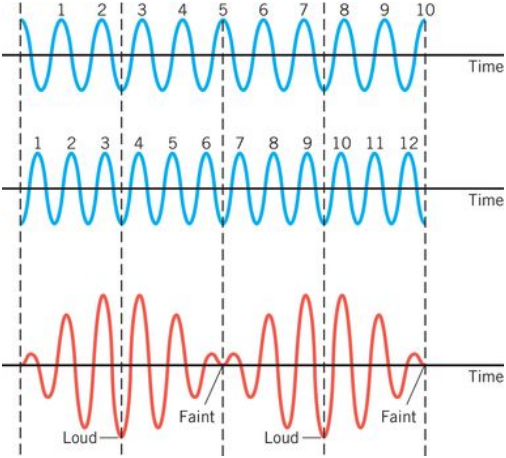


Figure: 28.16 Beats by tuning fork[16]

[16] C&J Figure 17.14

[17] `https://www.youtube.com/watch?v=I9f6bP3x_yo`

Summary

Sound

- Intensity level β rated in decibels dB
- Doppler effect has equations shown in previous slides
- Beats used to tune musical instruments

All Waves

- Intensity I is power P passing perpendicularly through an area A
- Intensity often compared to a reference
- Different Doppler effects for wave types and conditions
- Beats used for calibration and other measurements
- have interference patterns based on many factors

Please read[18] C&J 17.5-7 and prepare for the final exam.

[18] http://hyperphysics.phy-astr.gsu.edu/hbase/Audio/fourier.html