Physics 101H

General Physics 1 – Honors

Lecture 46 – 12/01/22

Doppler Effect

Summary

Topics

Yesterday: Sound [chapter 17]

- Sound
- Intensity
- Sound perception

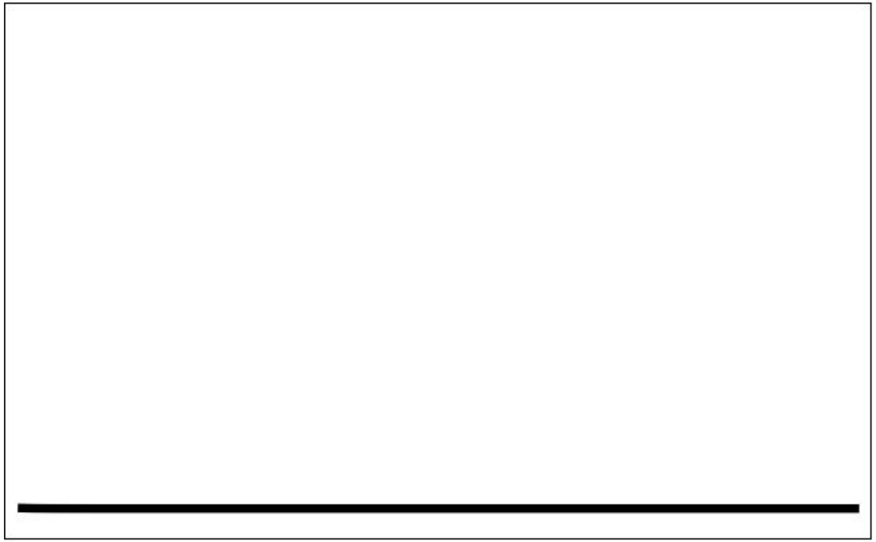
Today: Doppler effect [chapter 17]

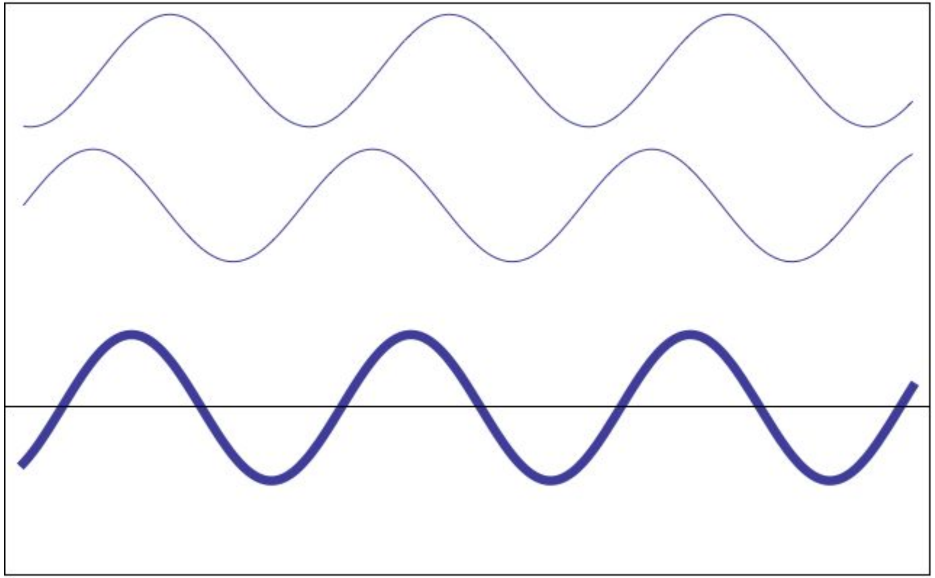
- Beats
- Standing sound waves
- Doppler effect

Announcements

Wednesday December 6: **Problem Set 9 due**

Superposition and interference

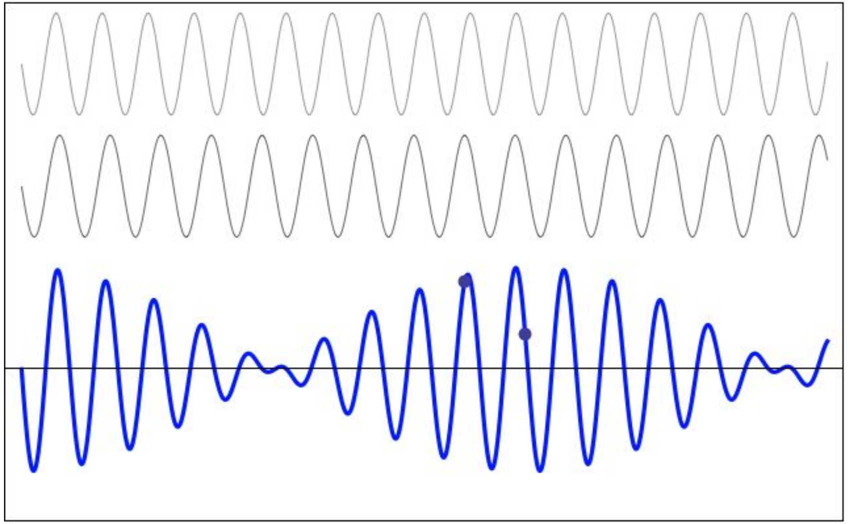




Sound wave superposition

Beats are created when sound waves of different frequencies are superposed

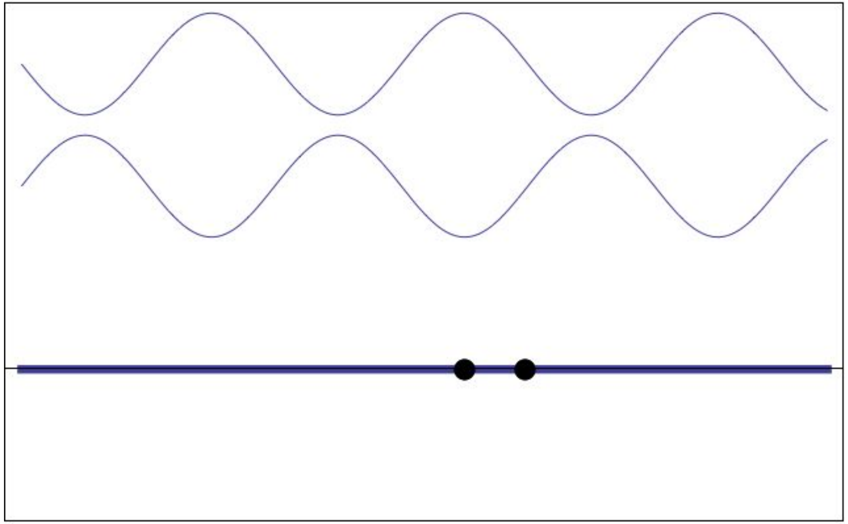
Beats are the periodic variation of the sound wave amplitude



Sound wave superposition

Superposition of sound waves can also lead to **longitudinal standing waves**

- pressure in the pipe varies along the length of the pipe
- properties of the standing sound wave depend on the boundary conditions



Sound wave superposition

Doppler shift

Multiple choice

Instructions: Consider the following question. After you have had a chance to think, I will ask you to raise your hands to indicate your answer.

Question: Three observers are listening to a moving source of sound. The lines in the figure represent the wavecrests (areas of high pressure). Which is correct?

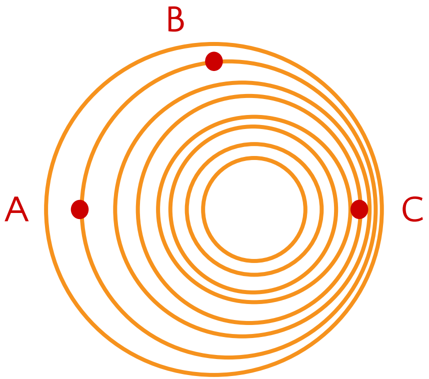
a) Sound waves move faster at A than at B and C

b) Sound waves move faster at C than at A and B

c) Frequency of sound is highest at A

d) Frequency of sound is highest at B

e) Frequency of sound is highest at C



Want more practice?

Try the following problems **Chapter 15** of the textbook:

- Conceptual questions: 1, 5, 11, 13, 17
- Simple harmonic motion: 25, 27, 29, 33, 37
- Circular motion: 39, 41
- Pendulums: 43, 47, 49

Answers are provided for questions with **blue** numbers (odd numbered)

Click on the number to be taken to the answer.

But make sure you at least **try** the problem first!

Want more practice?

Try the following problems **Chapter 16** of the textbook:

- Conceptual questions: 3, 5, 11, 13, 15, 19, 23, 27, 31, 33
- Travelling waves: 35, 39, 41, 47, 51, 57, 59, 61, 65, 69, 73
- Energy and power: 77, 83, 85, 89
- Interference: 91, 95, 99
- Standing waves: 103, 107, 113

Answers are provided for questions with blue numbers (odd numbered)

Click on the number to be taken to the answer.

But make sure you at least **try** the problem first!

Want more practice?

Try the following problems **Chapter 17** of the textbook:

- Conceptual questions: 3, 5, 9, 11, 13, 15, 21, 23, 25
- Sound waves: 31, 35, 41, 43, 45, 51, 55
- Sound intensity: 59, 63, 71, 75, 77
- Standing sound waves and beats: 81, 83, 87, 89, 95, 101, 105
- Doppler effect: 111, 115, 119, 121

Answers are provided for questions with blue numbers (odd numbered)

Click on the number to be taken to the answer.

But make sure you at least **try** the problem first!

Course evaluations

Please complete your course evaluations! They make a difference.

- Provides helpful feedback for me to improve the course
- Used as part of faculty evaluation (AKA pay raises)

I see completion rate (as a percentage), but not who has responded or the evaluations.

If we reach 90% completion rate by the last day of class, there will be a reward.

Course evaluations - some tips

For those of you filling out course evaluations for the first time – please:

- Be constructive in your comments and criticism
  - Explain **why** and **what can be improved**
- Be aware that evidence suggests that student evaluations show gender bias [1]
  - Female faculty tend to be judged more harshly and viewed as less competent, on average; this is especially true for faculty of colour
  - Be conscious of this when thinking about what you are commenting on and how you are phrasing your feedback
  - Comments on personal appearance are not appropriate

[1] See, e.g., this summary discussion: https://www.insidehighered.com/news/2021/02/17/whats-really-going-respect-bias-and-teaching-evals, based on a peer-reviewed meta analysis in Kreitzman & Sweet-Cushman, J. Acad. Ethics 20 (2022) 73

Summary

Topics

Today: Doppler effect [chapter 17]

- Beats
- Standing sound waves
- Doppler effect

Tomorrow: Special relativity

- Galilean relativity
- Special relativity
- Time dilation

Announcements

Wednesday December 6: **Problem Set 9 due**

PHYSICS 101 - HONORS

Lecture 46   12/1/22

Sound wave superposition (slide 3)

To see how **beats** arise, consider two waves at $x = 0$

$$y_1 = A\sin(k_1 x - \omega_1 t)\big|_{x=0} = A\sin(-\omega_1 t)$$

$$y_2 = A\sin(k_2 x - \omega_2 t)\big|_{x=0} = A\sin(-\omega_2 t)$$

$$\Rightarrow y_{tot} = y_1 + y_2$$

$$= A\sin(-\omega_1 t) + A\sin(-\omega_2 t)$$

$$= -A\left(\sin(\omega_1 t) + \sin(\omega_2 t)\right)$$

$$= \underbrace{-2A\cos\left[\left(\frac{\omega_2-\omega_1}{2}\right)t\right]}_{\text{amplitude modulation}}\ \underbrace{\sin\left[\left(\frac{\omega_2+\omega_1}{2}\right)t\right]}_{\text{wave with average frequency } \frac{\omega_1+\omega_2}{2}}$$

The maximum amplitude occurs at $\cos\left[\left(\frac{\omega_2-\omega_1}{2}\right)t\right] = \pm 1$

We hear the "**beats**" at these loudest points, with frequency $f_{beat} = |f_1 - f_2|$

Pipe with one closed end

- pressure is P_{atm} remains constant
- pressure node
- displacement node

- rigid at closed end
  air cannot move longitudinally
- displacement node
- pressure antinode

Boundary conditions are $P(x=0,t)=0$
$P(x=L,t)=\pm A$

$\Rightarrow \sin(kL)=\pm 1$

$\Rightarrow kL = \frac{n\pi}{2}$ with n odd $\Rightarrow \frac{2\pi}{\lambda}L = \frac{n\pi}{2}$

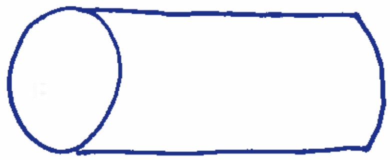
or $\lambda = \frac{4L}{n}$

Since $v = f\lambda \Rightarrow f = \frac{v}{\lambda} = \frac{nv}{4L}$

$n = 1, 3, 5, \ldots$

these are the resonant frequencies of a tube closed at one end

Pipe with two open ends



Boundary conditions are

$$P(x=0,t) = P(x=L,t) = 0$$

$$y(x=0,t) = y(x=L,t) = 0$$

$$\Rightarrow \sin(kL) = 0$$

$$kL = n\pi \qquad n \text{ an integer}$$

$$\Rightarrow \frac{2\pi}{\lambda} L = n\pi \quad \text{or} \quad \lambda = \frac{2}{n} L$$

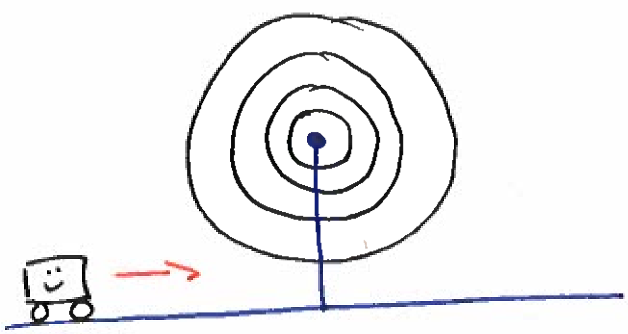
← only "integer" fractions allowed

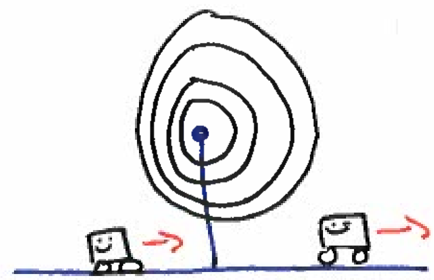
$$\text{Since } v = f\lambda \Rightarrow f = \frac{v}{\lambda} = \frac{nv}{2L}$$

↑ natural frequencies are all integral multiples of the <u>fundamental frequency</u> $\frac{v}{2L}$

Doppler shift (slide 5)

If either the source, or the observer, is moving relative to the medium, the observer will hear a different frequency than that emitted.





Moving towards source:

- observer encounters wave crests and troughs **more** frequently than emitted
- hear a **higher** frequency

Moving away from source:

- observer encounters wave crests and troughs **less** frequently than emitted
- hear a **lower** frequency

Most general case

$$f' = \frac{v + v_o}{v - v_s} f$$

- f': observed frequency
- f: emitted frequency
- v: speed of sound
- v_s: speed of source relative to the medium
- v_o: speed of observer

Only observer moving

$$f' = \frac{v + v_o}{v} f \quad \text{moving toward}$$

$$f' = \frac{v - v_o}{v} f \quad \text{moving away}$$

Only source moving

$$f' = \frac{v}{v - v_s} f \quad \text{moving toward}$$

$$f' = \frac{v}{v + v_s} f \quad \text{moving away}$$