Waves

Physics 211
Syracuse University, Physics 211 Spring 2023
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April 25, 2023

Announcements

- HW9 due Friday (not Wednesday)
- "Second chance" review assignments due on the final (not Friday)
- Help schedule for this week posted
- General help this week:
  - Today, 3-5
  - Wednesday, 3-5
  - Thursday, 3-6
  - Friday, 10-1:30

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- General help this week:
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  - Friday, 10-1:30
- There is an opportunity to earn two percentage points extra credit on your final by participating in a research study; you'll get an email Thursday from someone else about this. (It's legit.)

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I owe a lot of people email. Sorry about that – I am working to catch up, but most of my time is spent face-to-face with students these days.

Waves, an overview

- This class and the next are going to focus on the physics of waves
- We'll use strings and tubes – musical instruments – as examples
- ... but all waves behave the same!
  - Light waves
  - Radio waves: an antenna is just like waves on a string!
  - Sound waves
  - Water waves

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  - Sound waves
  - Water waves
  - Matter waves in quantum mechanics: s, p, d, f orbitals!

Waves in 1D – modeling

- Start with something empirical: can we model a vibrating string based on what we know so far?

Which equation that you've learned could be used as a starting point to understand a vibrating string?

- A: $\vec{x}_f = \vec{x}_i + \vec{v}_0 t + \frac{1}{2}\vec{a}t^2$
- B: $\vec{p}_i = \vec{p}_f$
- C: $F = -k(x - x_0)$
- D: $F_c = m\omega^2 r$

Waves in 1D – modeling

- Hooke's law describes elasticity, right?
- Connect some Hooke's law springs between two points (simple3.c)

Waves in 1D – modeling

- Hooke's law describes elasticity, right?
- Connect some Hooke's law springs between two points (simple3.c)
- This isn't very flexible, is it?

How could we make this more accurate using the physics we know?

- Make the springs curved
- Use a smaller amount of time between "steps"
- Use more individual springs
- Use a larger spring constant

Waves in 1D – modeling

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- How much math is our computer doing here?
  - 10 segments
  - X and Y directions
  - Position, velocity, Hooke's-law force
  - Calculating r requires a square root – computer has to sum a power series
  - Even drawing those little arrows requires trig, which means more power series
  - This is a **lot** of math

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  - Even drawing those little arrows requires trig, which means more power series
  - This is a **lot** of math
  - Computers can do a few hundred million operations a second! This is cake.
- Like pixels on a digital display: we forget that they’re there!
- Now, what can we learn from how this behaves?

Waves in 1D – learning from our model

Some important properties: (pulse.c: width/stiffness/tension)

- Pulses (regardless of their size or shape) go at a constant speed
- **The wave speed** v refers to how fast pulses travel down the string
- Empirically, we see that the wave speed depends on the **tension** (one of the inputs to my model)
- The property of **linearity:** (twopulse.c)
  - Multiple pulses can pass through each other without interference
  - We will take this as absolutely true for our study here
  - Often not quite true for real waves, but it is close enough
- Does a real string do this?

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- Does a real string do this?
  - Wave speed v goes up with more tension!

Sine waves

- We're particularly concerned with waves that look like sines and cosines (sines.c: wavelength/c/A1/A2/xlabel)
- Any general wave can be written as a combination of sines and cosines
- This is called "Fourier's theorem" and you'll learn much more about it in other classes
- These waves have two new properties: **wavelength** λ and **frequency** f
  - Wavelength: distance from crest to crest
  - Frequency: how many crests go by per second, equal to $1/T$ (T = period)

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  - Frequency: how many crests go by per second, equal to $1/T$ (T = period)
  - Speed = distance $\times$ time

$$v = \lambda f$$

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$$\frac{\text{meters}}{\text{second}} = \frac{\text{meters}}{\text{wave}} \times \frac{\text{waves}}{\text{second}}$$

Frequency – "waves per second" – is measured in Hertz (Hz).

For sound, higher frequencies sound higher pitched (a violin or flute, many women's voices); lower frequencies sound lower pitched (a bass or tuba, many men's voices)

Suppose I have a speaker beeping at 500 Hz.

The speed of sound in air is about 340 m/s. What is the wavelength of the sound?

- A: About a meter
- B: About 60 cm
- C: About 1.5 m
- D: About 2 m
- E: About 0.5 m

Suppose I have a speaker beeping at 500 Hz.

What happens if I put it underwater ($c \approx 1500$ m/s) instead of air ($c \approx 340$ m/s)?

- A: The frequency will go up
- B: The frequency will go down
- C: The wavelength will go down
- D: The wavelength will go up

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- D: The wavelength will go up
- E: Sam will be mad at me, since I broke the speaker

Standing waves

What kind of sine and cosine waves can we put on our string?

- Not any wavelengths will do, since the ends have to be fixed
- I clearly can't do this with just one sine wave

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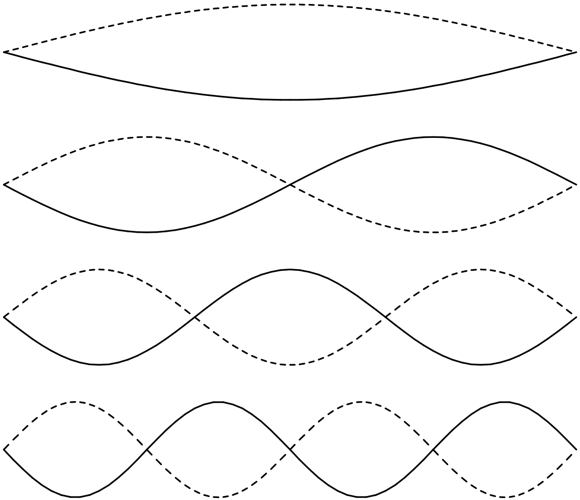
What kind of sine and cosine waves can we put on our string?

- Not any wavelengths will do, since the ends have to be fixed
- I clearly can't do this with just one sine wave
- I need two, one going in each direction!

Are there other wavelengths of standing waves that will work?

- A: Twice the wavelength
- B: Half the wavelength
- C: Three times the wavelength
- D: One-third the wavelength

Standing waves, in more detail



Fundamental: $\lambda = \frac{2L}{1}$

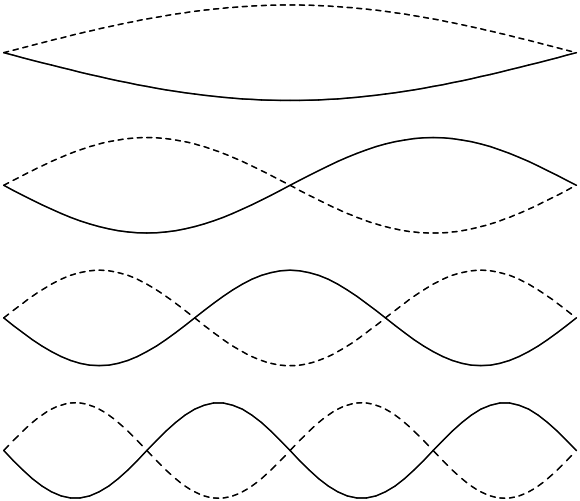
2nd harmonic: $\lambda = \frac{2L}{2}$

3rd harmonic: $\lambda = \frac{2L}{3}$

4th harmonic: $\lambda = \frac{2L}{4}$

Can we write these wavelengths in terms of f using $v = f\lambda$?

Standing waves, in more detail



Fundamental: $f_1 = \frac{v}{2L}$

2nd harmonic: $f_2 = 2f_1$

3rd harmonic: $f_3 = 3f_1$

4th harmonic: $f_4 = 4f_1$

Standing waves, in more detail

A simulation: harm.c and resonances.c

The takeaways

Sound waves (and other waves) are traveling disturbances:

- We are especially concerned with sine/cosine waves
- Three properties:
  - Wave speed v – how fast the wave moves (meters/second)
  - Wavelength λ – how long the waves are (meters)
  - Frequency f – how many waves per second pass a point (waves/second or Hertz)

Often we trap waves in a cavity, like a violin string or a pipe (organ pipe, flute, trombone):

- Only particular wavelengths “fit”, called *resonant modes* or *normal modes* or *harmonics*
- Their wavelengths are the ones that have nodes at the ends
- Their frequencies are integer multiples of the lowest frequency, called the *fundamental*
- The fundamental frequency depends on the length of the string/pipe and the wave speed

Much more next time!