Waves

Physics 211
Syracuse University, Physics 211 Spring 2017
Walter Freeman

April 20, 2017

Announcements

- HW9 posted tomorrow, due next Friday
- Extra credit homework assignment posted Friday, due by 5PM on May 2
  - Difficult analytical problems, like you've been doing
  - Conceptual applications to engineering – interpretation problems
  - Choose one of the two
  - Up to 2 points on your final course grade

Announcements

- HW9 posted tomorrow, due next Friday
- Extra credit homework assignment posted Friday, due by 5PM on May 2
  - Difficult analytical problems, like you've been doing
  - Conceptual applications to engineering – interpretation problems
  - Choose one of the two
  - Up to 2 points on your final course grade

Next Tuesday we're talking about the physics of musical instruments.
Want to demonstrate your instrument and study how it works? Come talk to me!

Exam 3 comments

Preparation for the final

- You can drop one exam
- You **can't** drop the final
- The final will involve more, easier problems
- You can expect more conceptual things and less algebra
- There will be lots of review sessions, etc.

Waves, an overview

- The next few classes 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

Waves, an overview

- The next few classes 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
    - Matter waves in quantum mechanics: s, p, d, f orbitals!

- 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 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

Use more springs and masses (simple10.c):

Waves in 1D – modeling

Use more springs and masses (simple10.c):

If we use very many of them, we should get "real" behavior

- 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

Waves in 1D – modeling

Use more springs and masses (simple10.c):

If we use very many of them, we should get "real" behavior

- 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
  - 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?

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

- Pulses (regardless of their size or shape) go at a constant speed
- **The wave speed** c 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 – very interesting behavior!
- Does a real string do this?

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** c 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 – very interesting behavior!
- Does a real string do this?
  - Wave speed c 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)
- 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)

Sine waves

- We're particularly concerned with waves that look like sines and cosines (sines.c: wavelength/c/A1/A2/xlabel)
- 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)
  - Speed = distance $\times$ time

$$c = \lambda f$$

Sine waves

Suppose I have this speaker here 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

Sine waves

Suppose I have this speaker here 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

Sine waves

Suppose I have this speaker here 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
- E: Sam will be mad at me, since I broke his 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

Standing waves

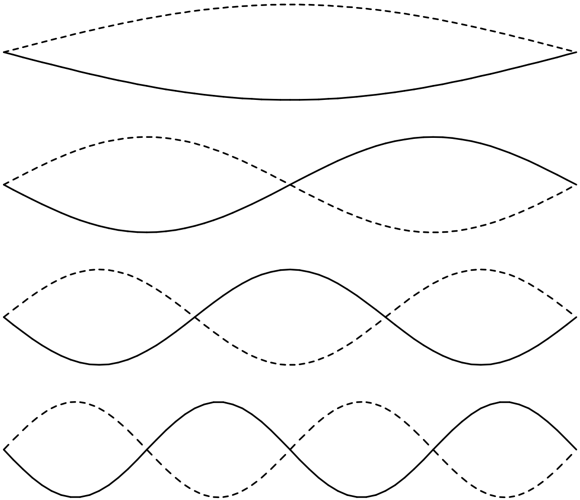
What kind of sine and cosine waves can we put on our string?

- Not any wavelengths will do, since the ends have to be fixed
- I clearly can't do this with just one sine wave
- 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: $\lambda = \frac{2L}{1}$

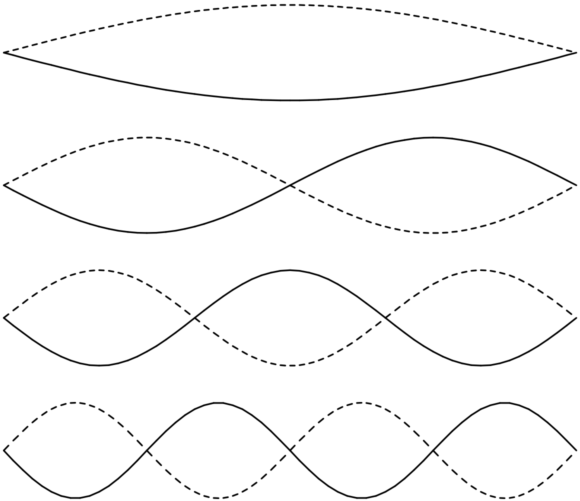
2nd harmonic: $\lambda = \frac{2L}{2}$

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

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

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

Standing waves, in more detail



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

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

Why do I have this blowtorch?