April 7, 2017 Physics 132 Prof. E. F. Redish

- **<u>Theme Music:</u> Barbara Streisand**
  Putting it together

From Sondheim's *Sunday in the Park with George*

- **<u>Cartoon:</u> Bill Amend**
  Foxtrot

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Outline

- Recap: waves on a string
- Superposition: Putting them together.
- Examples

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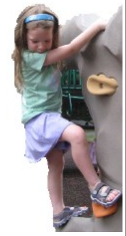
Foothold principles: Mechanical waves - 1



- *Key concept*: We have to distinguish the motion of the bits of matter and the motion of the pattern.
- *Pattern speed*: a disturbance moves into a medium with a speed that depends on the properties of the medium (but not on the shape of the disturbance)
- *Matter speed*: the speed of the bits of matter depend on both the size and shape of the pulse and on the pattern speed.
- *Mechanism*: the pulse propagates by each bit of string pulling on the next.

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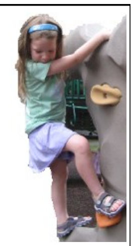
Foothold principles: Mechanical waves - 2



- *Superposition*: when one or more disturbances overlap, the result is that each point displaces by the sum of the displacements it would have from the individual pulses. (signs matter)

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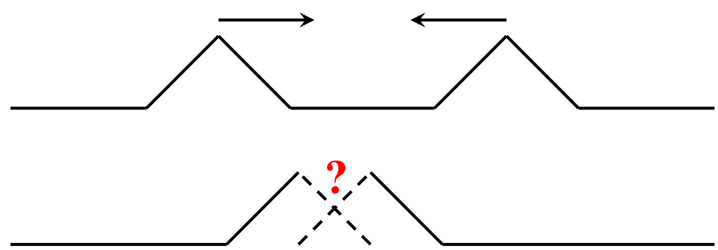
How do waves combine?

- We know how one wave moves.
  What happens when we get two waves on top of each other?



Superposition: A way of understanding the answer

- A pulse or a wave passing by a particular point on a string gives the string an instruction.
- If we have a pulse $y = f(x,t)$ it says to the bit of string labeled by x "displace the amount y at the time t".
- If more than one pulse is at a given point the result is the "sum of the messages."
- This rule is called ***superposition***. It means "the wave pulses add – at each point."

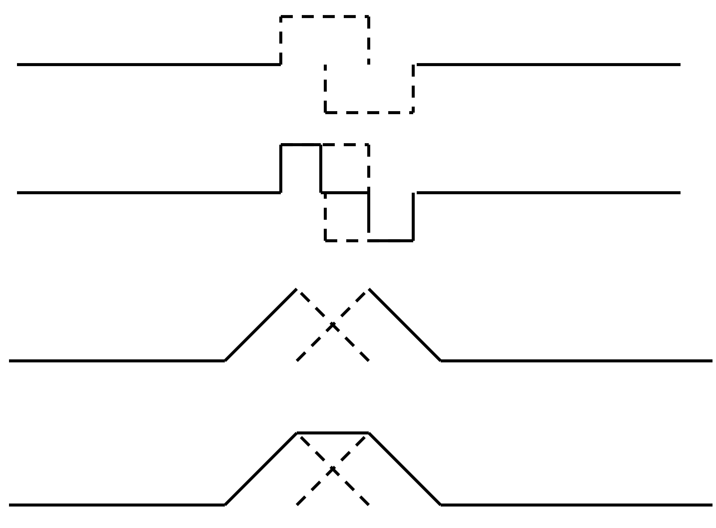
Hypothesis: Superposition

- Suppose we use the math to add two waves together:

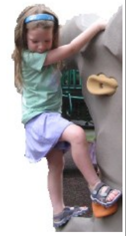
$$y(x,t) = f(x,t) + g(x,t)$$

- What does this say?
- At a given time *t* for a bit of the string labeled "*x*" the displacement is the arithmetic sum of the displacements it would have from each piece of the wave.

Answers (Theory)



Foothold principles: Mechanical waves



- *Key concept*: We have to distinguish the motion of the bits of matter and the motion of the pattern.
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- *Superposition*: when one or more disturbances overlap, the result is that each point displaces by the sum of the displacements it would have from the individual pulses. (signs matter)
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The math

- We express the position of a bit of string at a particular time by labeling which bit of string by its *x* position, so
  position of the bit at x at time $t = y(x,t)$.
- Since subtracting a *d* from the argument of a function ($f(x) \rightarrow f(x-d)$) shifts the graph of the function to the right by an amount *d*, if we want to set the graph of a shape $f(x)$ into motion at a constant speed, we just need to set $d = v_0 t$ and take

$$f(x) \rightarrow f(x - v_0 t)$$

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Sinusoidal waves

- Suppose we make a continuous wiggle. When we start our clock (t = 0) we might have created shape something like

$$y(x,0) = A\sin kx$$

Why do we need a "*k*"

- If this moves in the +*x* direction, at later times it would look like

$$y(x,t) = A\sin k(x - v_0 t)$$

What good are sinusoidal wiggles?

- Many systems naturally produce long strings of (nearly) sinusoidal wiggles.
  - Musical instruments (sound)
  - Electric power generators (AC current)
  - Animals
    - » dolphins
    - » birds
    - » people
  - Excited atoms (light)
    - » flames
    - » fluorescent lights
    - » stars
- Furthermore, (almost) any shape of signal can be made up by adding together sinusoidal wiggles.

Interpretation

$y = A\sin(kx - \omega t)$ $\omega \equiv kv_0$

Fixed time: Wave goes a full cycle when

$kx : 0 \to 2\pi$

$x : 0 \to \frac{2\pi}{k} \equiv \lambda$ (wavelength)

Fixed position: Wave goes a full cycle when

$\omega t : 0 \to 2\pi$

$t : 0 \to \frac{2\pi}{\omega} \equiv T$ (period)

Find the dog

$\omega = kv_0$?

Interpret

$\omega = 2\pi f = \frac{2\pi}{T}$ $k = \frac{2\pi}{\lambda}$

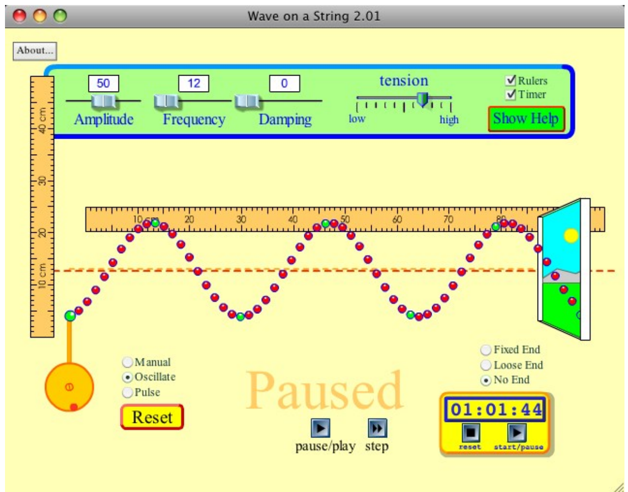
$\omega = kv_0 \quad \Rightarrow \quad 2\pi f = \frac{2\pi}{\lambda} v_0$ or

$f\lambda = v_0$ (famous wave formula)

Interpret

$\frac{1}{T}\lambda = v_0 \quad \Rightarrow \quad \lambda = v_0 T$

Explore with a simulation



http://phet.colorado.edu/simulations/sims.php?sim=Wave_on_a_String

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