Physics 9 — Monday, September 10, 2018

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  Thu 6:30–8:30pm DRL 2C8 (Grace)
- For today you read PTFP ch7 ("waves, including UFOs . . .")
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Waves

Waves can be *transverse* or *longitudinal*, depending on whether the motion of the individual oscillators is $\perp$ or $\parallel$ to direction of wave propagation. You can make a slinky transmit either kind of wave.

You can make a single *pulse* propagate as a wave, or you can have *periodic* waves that repeat again and again. (We'll talk more about this difference next time.)

Periodic waves at a single frequency f ("harmonic waves") are sinusoidal and have *wavelength*

$$\lambda = \frac{v}{f}$$

Usually people remember this as $v = \lambda f$.

Question (to wake everyone up!)

Suppose that I am wiggling one end of a taut string to create sinusoidal waves. If I double the frequency f at which I wiggle the end, how does the wavelength λ change?

(A) The new wavelength is double the original wavelength

(B) The wavelength does not change

(C) The new wavelength is half the original wavelength

Waves

The ideal situation for a wave pulse is to propagate forever down an infinitely long string (or wave machine). When you shout into a completely open field, there is no echo!

But sometimes the wave runs into an obstacle. The three easiest cases to analyze are

- The far end of the string is clamped, immobilized:
  reflected pulse has opposite sign as incident pulse
- The far end of the string is unconstrained ("free"):
  reflected pulse has same sign as incident pulse
- The far end has a "terminator" or "dashpot" or "damper" that perfectly absorbs all of the incoming wave's energy:
  no reflected pulse

Interference / superposition

A weird property of waves is that two waves can pass right through one another. Whereas particles bounce off of one another, a wave is not an obstacle to another wave. The two waves' displacements add up (algebraically), including their signs.

- A peak and a peak add to a larger peak
- A peak and a trough can add to zero
- Whether they add constructively or destructively depends on the relative phases of the two waves

In one dimension, the big consequence of interference is that one wave traveling to the right and an equal-size wave traveling to the left will add up to form a *standing wave*.

In 2 and 3 dimensions, it gets much more interesting: if you have two separated speakers playing the same tone, there will be some places in the room where the amplitude is twice as large, and some places in the room where the amplitude is zero! Noise-canceling headphones use destructive interference of waves.

Wave movies

(I just re-wrote my wave "movies" as Processing sketches. I used the Python version of Processing rather than the original Java version of Processing that some of you learned last year, as I hear that Python is more useful to you than Java. I will plan to do a lecture on the Python version of Processing on the day before Thanksgiving, when turnout tends to be light. You can then try it yourself for extra credit if you wish.)

- `wave1py` : two pulses passing through each other
- `wave2py` : wave pulse reflected by boundaries
- `wave3py` : two traveling waves add, forming standing wave if magnitudes are same
- `wave6py` : standing waves

Question

Looking at the reflections in the animation `wave2py`, do the left and right ends of the string appear to be fixed or free? (Sketch should be playing on screen.)

(A) Left and right ends are both held fixed

(B) Left and right ends are both free

(C) Left end is free and right end is fixed

(D) Left end is fixed and right end is free

Standing waves

If you clamp both ends of a string of length L, then for harmonic waves λ is forced to obey (where $n = 1, 2, 3, \ldots$)

$$n \cdot \frac{\lambda}{2} = L \quad \Rightarrow \quad \lambda = \frac{2L}{n} \quad \Rightarrow \quad f = \frac{v}{\lambda} = n \cdot \frac{v}{2L}$$

A whole number of **half-wavelengths** must fit in length L. That's because $\sin(n\pi) = 0$, and we need the wave function $D(x, t)$ to equal zero at $x = 0$ and at $x = L$. (More about wave functions later.)

Combining this with $\quad v = \sqrt{\frac{T}{m/L}} \quad$ we get

$$f_n = \frac{n}{2L}\sqrt{\frac{T}{m/L}}$$

More massive wire $\rightarrow$ lower f. Higher tension $\rightarrow$ higher f.
Make string shorter with fingertip $\rightarrow$ higher f.

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We have length $L = 1.7 \ \mathrm{m}$ and tension T equals the weight of an 0.4 kg block. (How much tension is that?)

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So we expect a "fundamental" frequency around 13 or 14 Hz. (You'll see that in real life we're pretty close — off by about 10%.)

What do you expect the shape of the "fundamental" standing wave to look like? How would you describe it mathematically?

Question

Suppose that a guitar string is tuned to play at 330 Hz. Now suppose I replace the string with another string that is made of the same material, has the same tension, but has three times the diameter of the original string? What will the new fundamental frequency be?

(A) 36 Hz

(B) 110 Hz

(C) 191 Hz

(D) 330 Hz

(E) 572 Hz

(F) 990 Hz

(G) 2970 Hz

- Mazur §16.6: The wave function $D(x,t)$ for a harmonic (i.e. single-frequency) traveling wave moving from left to right is

$$D(x,t) = A\sin(kx - \omega t) \;= A\sin(\frac{2\pi x}{\lambda} - 2\pi f t) = A\sin(\frac{2\pi}{\lambda}(x - vt))$$

where $\omega = 2\pi f$ and $k = 2\pi/\lambda = \omega/v$.

- while a traveling wave moving from right to left is

$$D(x,t) = A\sin(kx + \omega t)$$

- When two harmonic traveling waves of same amplitude, same freq., and opposite direction meet, they form a standing wave:

$$D(x,t) = A\sin(kx - \omega t) + A\sin(kx + \omega t) = 2A\sin(kx)\cos(\omega t)$$

$$D(x,t) = 2A\ \sin(\frac{2\pi x}{\lambda})\cos(2\pi f t)$$

http://positron.hep.upenn.edu/p9/files/wave3py.pyde

- Standing wave (I dropped the factor of 2 out front):

$$D(x,t) = A\ \sin(\frac{2\pi x}{\lambda})\cos(2\pi f t)$$

- This expression can represent standing waves on a guitar string of length L.
- We need $D(x=0,t)=0$ and $D(x=L,t)=0$, because both ends of the string are immobilized by the frets.
- The first is easy: $\sin(0)=0$.
- When else is the sine function equal to zero?

http://positron.hep.upenn.edu/p9/files/wave6py.pyde

Sound waves in room-temperature air travel at a wave speed of 343 m/s. (Much more on sound in the next two weeks!)

Digression: About how long does it take for a pulse of sound (maybe a clap of thunder or the sound of a baseball bat hitting a ball) to travel 1 km?

What about a mile (1.61 km $\approx$ (5/3) km)?

What about one foot ((1/3.28) meter, or (1/5280) mile)?

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Sound waves in air travel 1 km in 3 s, 1 mile in 5 s,
1 foot in 1 millisecond.

Sound waves in room-temperature air travel at a wave speed of 343 m/s. At a frequency of about 34 Hz (near the lower end of the range of frequencies people can hear), what is the wavelength?

(Young human ears can hear roughly 20 Hz — 20 kHz.)

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It turns out that the conventional telephone network only transmits sounds in the frequency range 300 Hz — 3400 Hz. What's the wavelength (for sound in air) at 343 Hz? At 3430 Hz?

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