Sound and stringed instruments

Special Guest: Nate Cook of the YAWPERS

Class 26:
Sound and strings
Music…

Reminders/Updates:
MT Long Answers due NOW up front.
HW due Mon
Next week: Quantum production of light

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Reading quiz

1. Sound energy travels through air as
   a. A density (pressure) wave
   b. An electromagnetic wave
   c. A water wave
   d. A heat wave

2. The frequency of a wave is
   a. The speed of the wave
   b. The time for one oscillation
   c. Measured in meters
   d. The same for all waves
   e. The number of oscillations per second

3. If the pitch of a musical note gets higher, the wavelength gets
   a. Shorter
   b. Longer
   c. Wavelength unrelated to pitch
   d. Can't tell without more information

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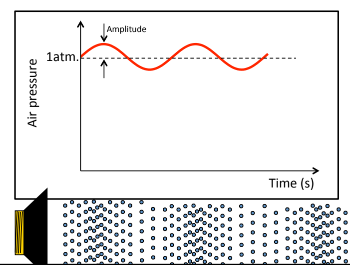
Sound so far

- Sound is a pressure or density wave carried by air molecules
- Sound wave is a very small fluctuation on the background pressure of 1atm or 100,000Pa
- Musical note: Regularly spaced series of high and low pressure regions.
- Volume of the note is determined by the AMPLITUDE of the pressure wave
- Pitch of the note is determined by the FREQUENCY of the pressure wave



Thinking about waves:

Frequency (f)	**# of oscillations/sec**	**(Hz = 1/s)**
Wavelength (λ)	**Distance of one complete cycle** (e.g. distance between pressure maximums)	**(m)**
Period (T)	**Time for one complete oscillation**	**(s)**
Speed (v)	**Distance traveled per second**	**(m/s)**

Relationships among these variables:

$v = \lambda \times f$

Distance per second = distance per oscillation × # of oscillations per second

$f = 1/T$

oscillations per second = 1/time for one oscillation

$v = \lambda / T$

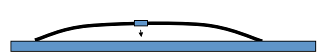
Sound and stringed instruments

- How does a violin (or other stringed instrument) produce sound?
- How do we get different notes from a violin?
- Why is the sound of each instrument unique?

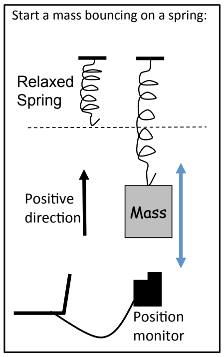
A musical note is a periodic variation of the air pressure

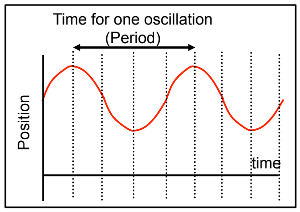
To create musical notes, all musical instruments have something that oscillates back and forth in periodic fashion.

Consider the violin. Each piece of string is like a little mass hooked to spring.



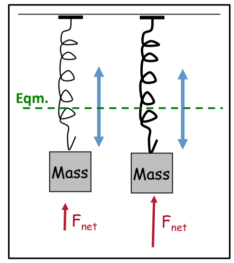
First lets think about springs a little bit

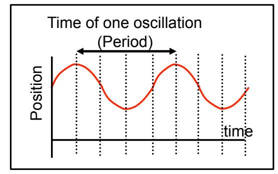




If the spring is stiffer, then …

a. the time per oscillation will increase
b. the time per oscillation will decrease
c. the time per oscillation unchanged



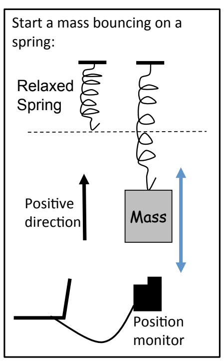


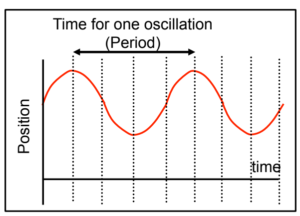
If the spring is stiffer, then …

a. time per oscillation will increase
b. time per oscillation will decrease
c. time per oscillation unchanged

- When masses are at rest, forces exert upwards by springs are equal.
- But if mass is displaced from rest position by distance x, stiffer spring exerts greater force (=kx) upwards:
  - → greater acceleration
  - → faster turn around time
  - → shorter period
  - → higher frequency

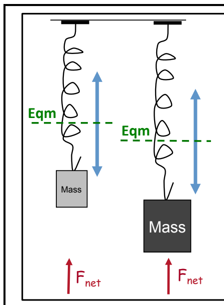
First lets think about springs a little bit

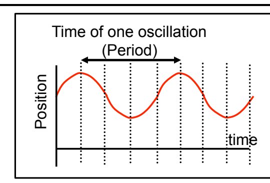




If the mass is heavier, then …

a. time per oscillation will increase
b. time per oscillation will decrease
c. time per oscillation unchanged





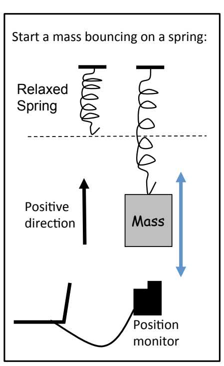
If the mass is heavier then …

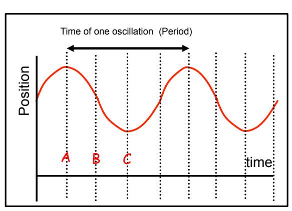
a. time per oscillation will increase
b. time per oscillation will decrease
c. time per oscillation unchanged

- The 2 masses are displaced same amount from rest position
- Net force up due to increase in spring force will be equal
  - ⇒ Heavier mass will have smaller acceleration
    - → slower turn around time
    - → longer period
    - → lower frequency

DEMO THICKER STRING

Now lets think about energy:





Given a mass, at what point (time) is the kinetic energy greatest?

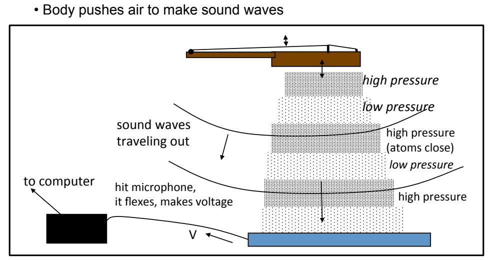
Answer is B … KE = ½ mv² … highest velocity!

Where does energy go at times A and C?

Into the spring or gravitational potential energy … Spring energy = ½ kx²

How a violin makes sound

- Strings oscillate up and down at certain frequency
- Make wooden body oscillate in and out,
- Body pushes air to make sound waves



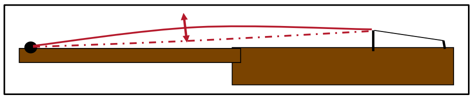
Note: we have 2 types of 'waves' going on:

1. Oscillatory (wave) motion of the string
3. Sound wave (pressure wave in the air) coming out from violin

Both waves have same frequency but different wavelengths and speeds

How do we get notes of different pitch from a violin?

Get the strings to vibrate at different frequencies
⇒ Must control the vibrations or 'wave motion' of the strings



Remember, for ANY wave: $v = f \times \lambda$

$\Rightarrow f = v / \lambda$

Frequency (pitch) of violin note — Speed of wave (on string) — Wavelength of string motion

To change the pitch (frequency) of a note we can

a) Change v - the speed of waves on the string
- change thickness or tension of the string

b) Change λ - the wavelength
- change the length of the string

a) Changing pitch by **speed of waves** on a string

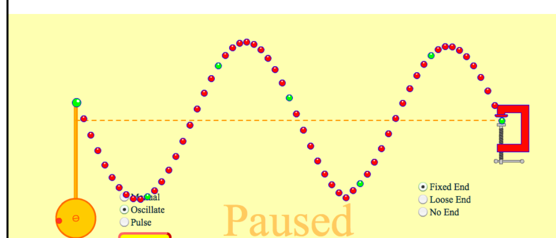
$$v_{string} \sim \frac{F_T}{m_L} \qquad f = \frac{V_{string}}{\lambda}$$

a) How do violinists tune their strings?
- Adjust the tension (F_T)
- Mass on spring tells us:
  → Increasing F_T like increasing the stiffness of the spring (same mass)
  → Bigger spring force ⇒ accelerates and oscillates more quickly

b) Why does the G string produce a lower note than the E string?
- G string is thick ⇒ large mass per length (m_L)
- E string is thin ⇒ small mass per length
- Mass on spring expts:
  → Thicker string like bigger mass (same spring)
  → More mass ⇒ accelerates and oscillates more slowly

String thickness on a violin / Guitar

Standing Waves

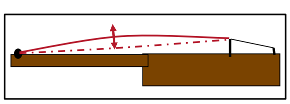


DEMO STRING / SPRING (optional)
Bunsen tube - NF
Nate Play Student who have tuned boomwhacke

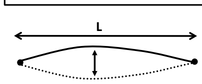
b) Change note by Wavelength of waves on a string

If we could only control the frequency of a violin string with thickness and tension, the violin would have 4 notes.....

But, $f = \frac{V_{string}}{\lambda}$ so we can also change the frequency by changing the wavelength



Simplest or fundamental oscillation of a violin string



How much of a wavelength does this fundamental motion demonstrate?

a) 1 wavelength
b) 2 wavelengths
c) ¼ wavelength
d) ½ wavelength

Wavelength of waves on a string

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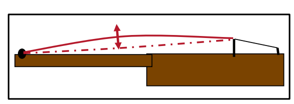

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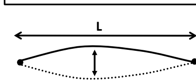

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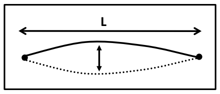

$L = ½ \lambda \Rightarrow \lambda = 2L$

$\Rightarrow f_1 = \frac{v_{string}}{\lambda_1} = \frac{v_{string}}{2L}$

- Fundamental wavelength and hence frequency directly related to length of string
- Can change fundamental frequency by shortening the string with fingers
- Fundamental frequency of string determines that pitch that we hear

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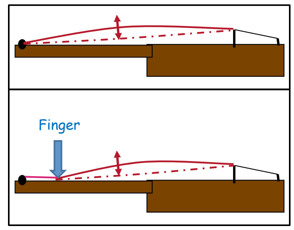
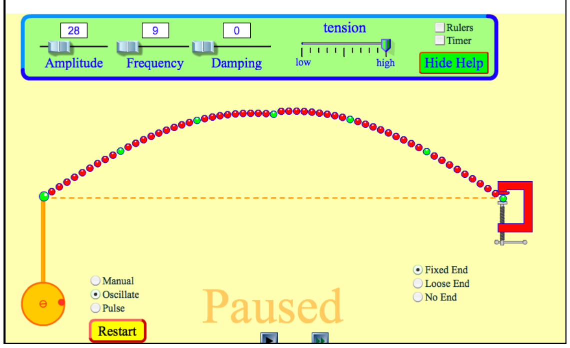


Longer string
Longer wavelength,
lower frequency

Shorter string
Shorter wavelength
Higher frequency

DEMO CAPO

Standing Waves



What makes each instrument sound unique?

Now lets compare a concert A played by the tuning fork and the violin on the ocilloscope.
Why does the trace from the violin look so different?

a. Violin is not playing a concert A but a single note of a different pitch
b. You are seeing the effect of all the strings on the violin vibrating
c. The A string is vibrating at multiple frequencies
d. The string produces a single note (A) but the wood is vibrating at multiple frequencies
e. None of the above

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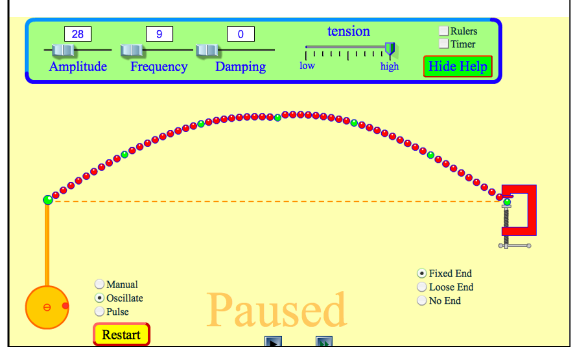
OSCOPE of string

Standing Waves



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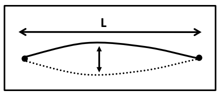
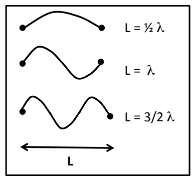
So we can also change the frequency by changing the wavelength





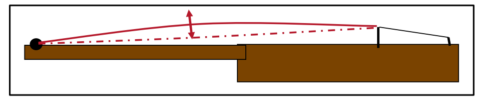
$$L = \tfrac{1}{2}\lambda \Rightarrow \lambda = 2L$$

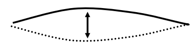
$$\Rightarrow f_1 = \frac{V_{string}}{\lambda_1} = \frac{V_{string}}{2L}$$

- Fundamental wavelength and hence frequency directly related to length of string
- Can change fundamental frequency by shortening the string with fingers
- Fundamental frequency of string determines that pitch that we hear

Harmonics

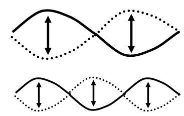
- String is tied down at each end.
- It oscillates back and forth.
- The simplest way for the string to flex is like this:





Fundamental frequency, 1st harmonic.
$f_1 = v_{string}/2L$

But it can also flex in more complicated ways and we call these higher harmonics



2nd harmonic:
half the wavelength, twice the frequency
$f_2 = 2f_1 = v_{string}/L$

3rd harmonic:
third the wavelength, three times the frequency,
$f_3 = 3f_1 = 3v_{string}/2L$

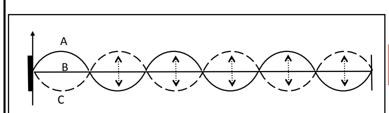
It is the mixture of harmonics that each instrument produces along with the fundamental that gives it its unique sound

DEMO STANDING WAVE

More questions on harmonics

A string is clamped at both ends and then plucked so that it vibrates in the mode shown below, between two extreme positions A and C. Which harmonic mode is this?

a. fundamental,
b. second harmonic,
c. third harmonic,
d. 6th harmonic

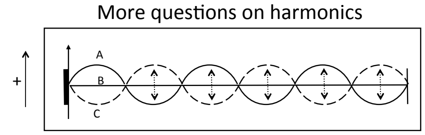


A, B and C are snapshots of the string at different times.

answer: 6th harmonic – there are 6 points of maximum displacement along the string

Harmonic demo

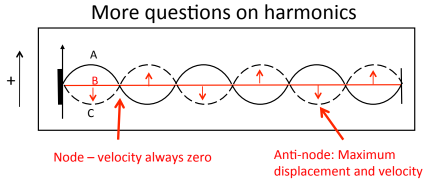
More questions on harmonics



When the string is in position B (instantaneously flat) the velocity of points along the string is...
(take upwards direction as positive)

A: zero everywhere.
B: positive everywhere.
C: negative everywhere.
D: depends on the position.

More questions on harmonics



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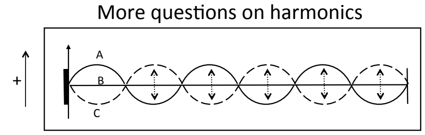
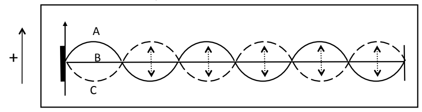


When the string is in position C (one of the 2 extreme positions) the velocity of points along the string is...

A: zero everywhere.
B: positive everywhere.
C: negative everywhere.
D: depends on the position.

More questions on harmonics



When the string is in position C (one of the 2 extreme positions) the velocity of points along the string is...

A: zero everywhere.
B: positive everywhere.
C: negative everywhere.
D: depends on the position.

String is instantaneously stationary. It has reached its maximum displacement at all points and at all points is turning around

More violin questions

When you pluck the string, what is making the sound you hear?

a. string, b. the wood, c. both about the same, d. the bridge

b. The wood. String makes wood vibrate, which in turn moves air to make the sound. The wood can push a lot more air.

What will happen if we touch tuning fork to the bridge?

a. no effect,
b. sound will be muffled (quieter),
c. sound will be louder,
d. sound will change frequency/tone

c. louder, because now the big wood panel is vibrating as well as the tuning fork prongs - more moving air, louder sound.

Putting this into practice