Physics 1240: Sound and Music

<u>Today (7/10/19)</u>: Hooke's Law, Oscillations, Resonance

<u>Next time</u>: Doppler Effect, Interference, Beats

Review

Base units:

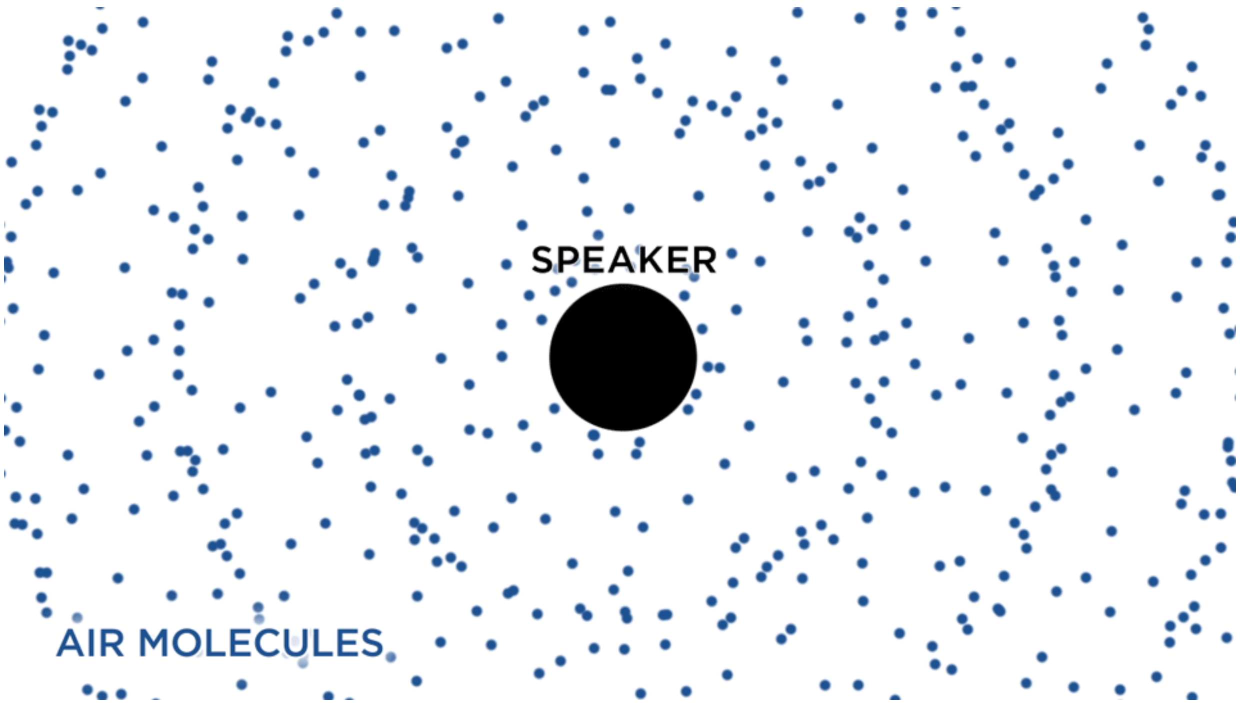
meters [m] (3.3 ft),   kilograms [kg] (2.2 lb),   seconds (s)

Prefixes:

milli (m)	0.001	1×10^{-3}
centi (c)	0.01	1×10^{-2}
deci (d)	0.1	1×10^{-1}
kilo (k)	1000	1×10^{3}
mega (M)	1,000,000	1×10^{6}

Review

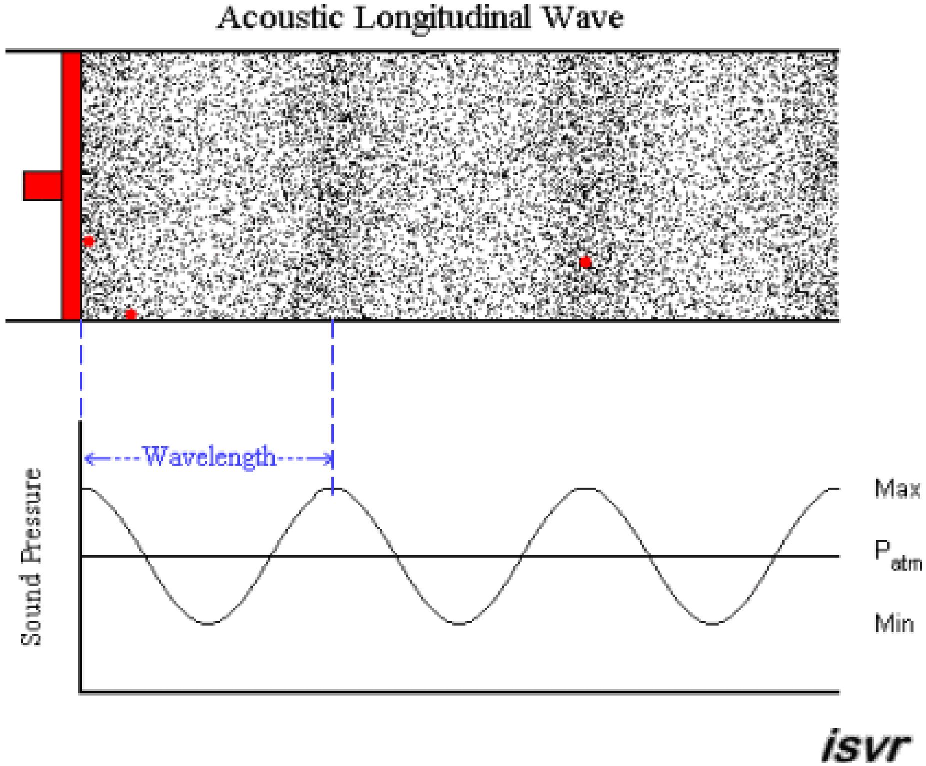
Sound is a mechanical disturbance of the **pressure** in a **medium** that travels in the form of a **longitudinal wave**.



Review

Wave properties:

- Speed (v=343 m/s for air at 20°C and 1 atm)
- Wavelength (λ in meters)
- Frequency (ƒ in hertz)
  - 1 Hz = 1 s^{-1}



$$v = \lambda f$$

[m/s] = [m] [Hz]

BA

Clicker Question 2.1

If there are 101325 pascals (Pa) in one atmosphere, how many megapascals (MPa) are there in one atmosphere?

A) 0.101325 MPa
B) 1.01325 MPa
C) 101.325 MPa
D) 1.01325×10^{8} MPa
E) 1.01325×10^{11} MPa

BA

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BA

Clicker Question 2.2

What type of waves are created when a guitar string is plucked?

A) Longitudinal in the string, transverse in the air
B) Longitudinal in the string and in the air
C) Transverse in the string, longitudinal in the air
D) Transverse in the string and in the air
E) Transverse in the string only

BA

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BA

Clicker Question 2.3

How fast does the air flow out of your mouth as you sing or speak?

A) 343 m/s
B) Much faster than 343 m/s
C) Much slower than 343 m/s
D) The air isn't actually "flowing" out

BA

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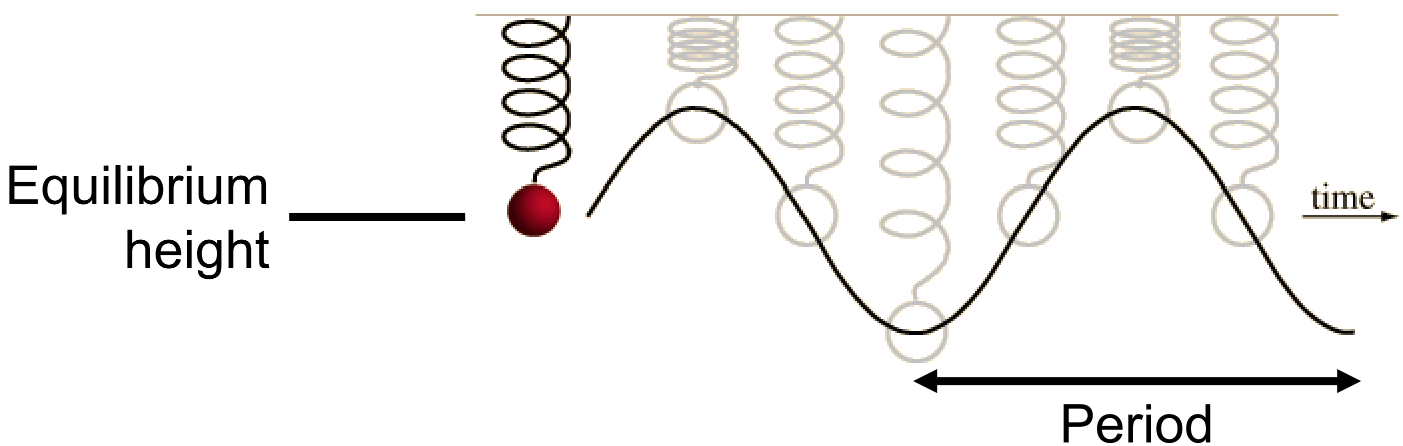
343 m/s = 770 mph
Category 5 hurricane = 70 m/s = 156 mph

Simple Harmonic Motion

- Mass displaced from equilibrium point oscillates about that point with periodic motion

- Period (T in seconds): time it takes to return to the same point of periodic motion

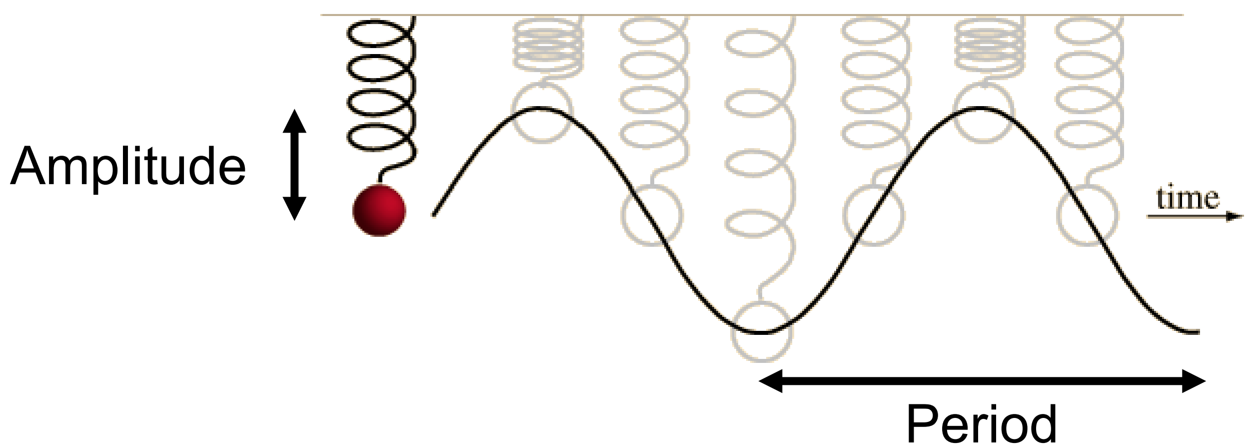
- Frequency (f in hertz): $$f = \frac{1}{T}$$ $$[\text{Hz}] = \frac{1}{[s]}$$



Simple Harmonic Motion

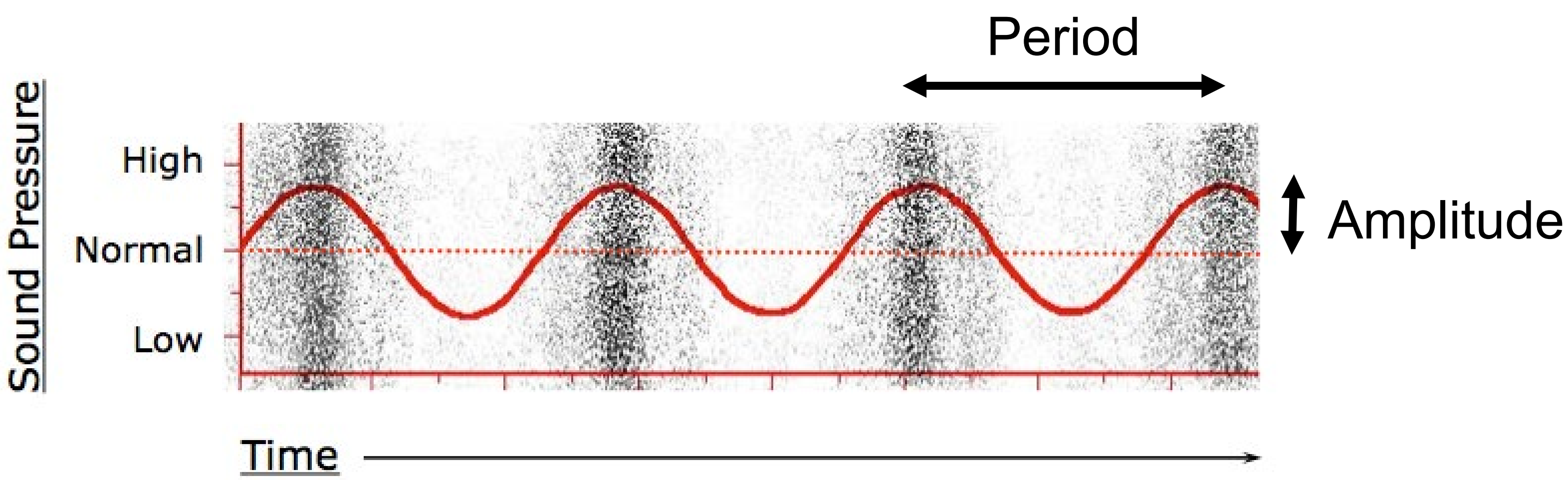
- <u>Amplitude</u> (*A* in meters): maximum displacement from equilibrium

- How are the amplitude and period related?



Relating back to sound:

- Amplitude ↔ loudness
- Frequency ↔ pitch



BA

Clicker Question 2.4

What is the period (in milliseconds) of a sound wave produced from a piano playing a middle C ($f \approx 262$ Hz)?

A) 262 ms
B) 3.8 ms
C) 3.8×10^{-3} ms
D) 1.3 ms
E) 2.62 ms

BA

Clicker Question 2.4

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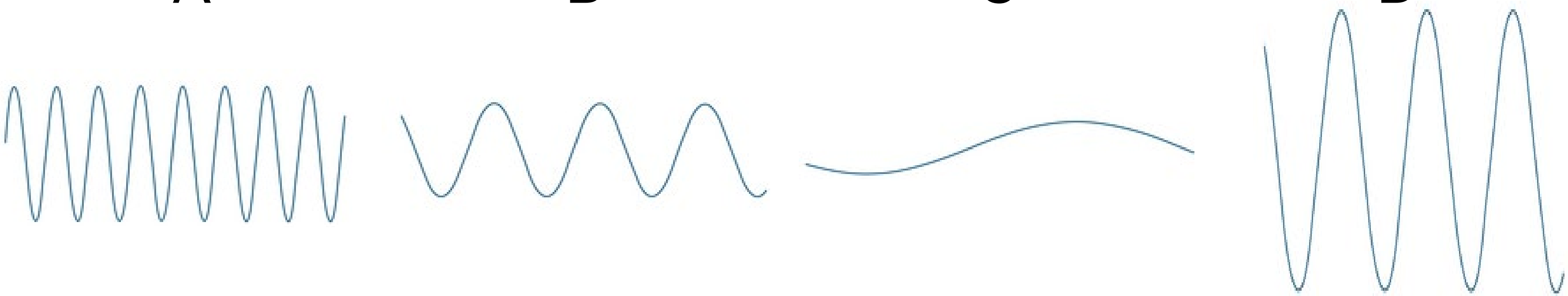
$$T = \frac{1}{f} = \frac{1}{262\ \text{Hz}} = 0.0038\ \text{s}$$

BA

Clicker Question 2.5

Which sound wave (plotted as air pressure vs. time) has the highest pitch?

A B C D



BA

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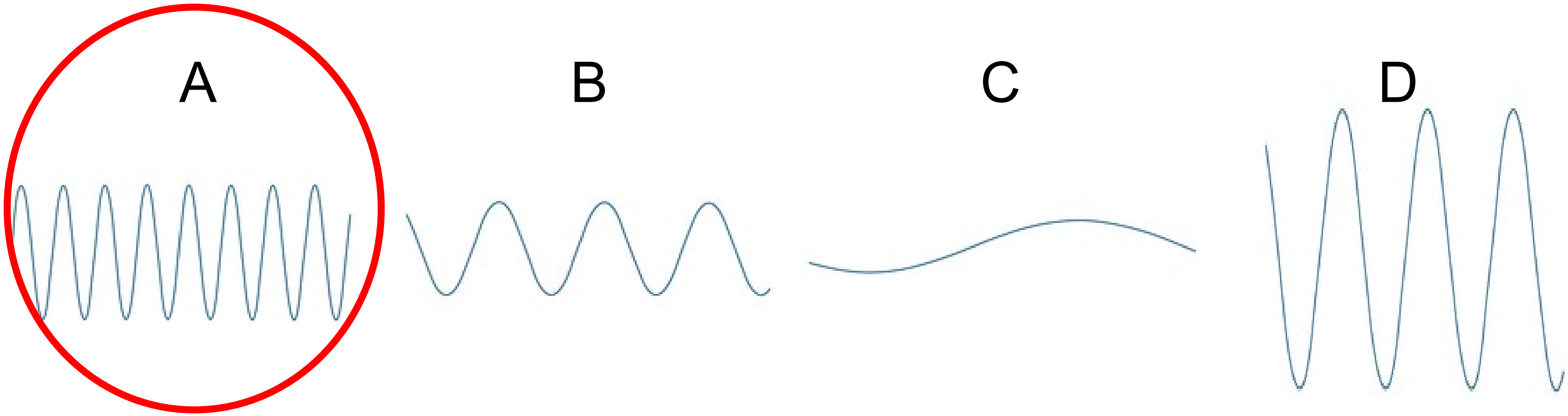
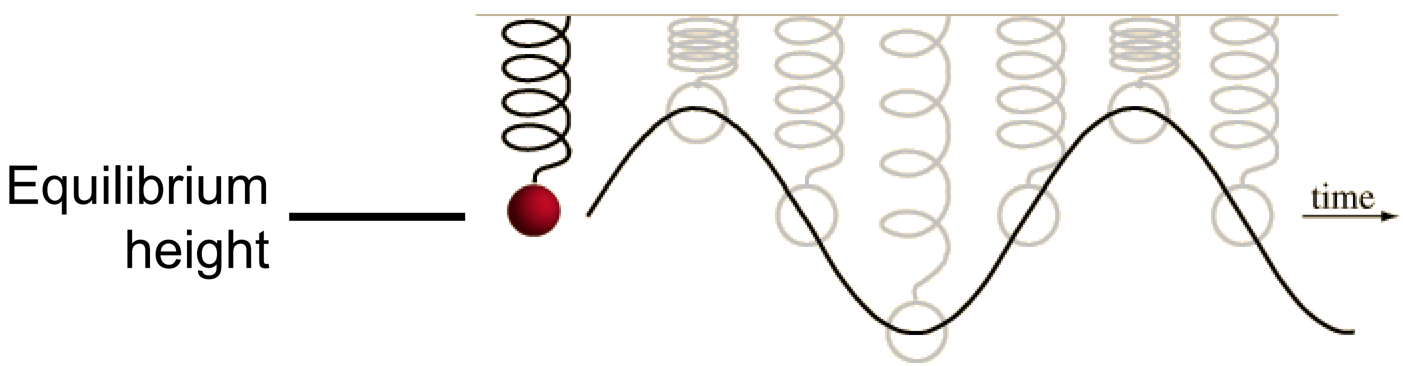


What causes simple harmonic motion?

- Elasticity (stiffness): causes system to return to equilibrium
  - Hooke's law: the farther you extend the system, the larger the restoring force (related linearly)

- Inertia (mass moving): causes system to overshoot equilibrium



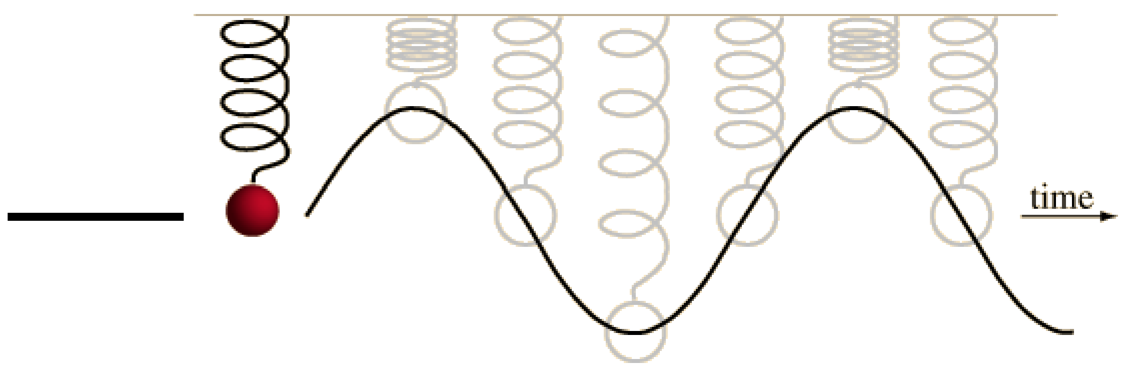
<u>What causes simple harmonic motion?</u>

k="spring constant"

(higher k = stiffer spring)

- $\text{frequency} = \sqrt{\frac{\text{stiffness}}{\text{mass}}}$ $\quad \left(f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \right)$
- Intuitive: trampoline, tight vs. loose string, tuba vs. flute

Equilibrium height



What causes simple harmonic motion?

- $\text{frequency} = \sqrt{\frac{\text{stiffness}}{\text{mass}}}$ $\qquad \left(f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \right)$

- Example: guitar

BA

Clicker Question 2.6

Two timpani (labelled A and B) produce sound by a mallet hitting a vibrating circular membrane. If A has a larger membrane than B, but A’s membrane is fitted more loosely, which will have a higher pitch?

A) A
B) B
C) Same pitch
D) Can’t tell without more info

BA

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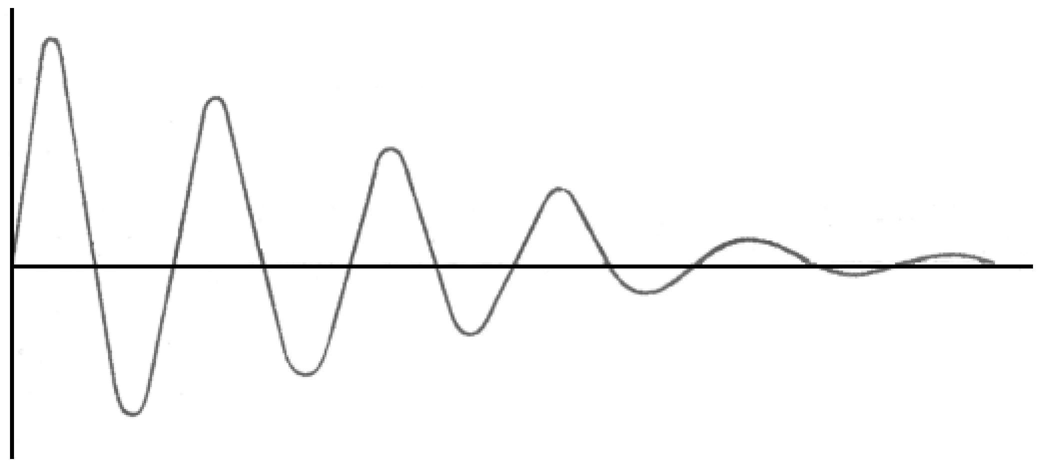
Deviations from simple harmonic motion

- Decreasing amplitude: damping
- Increasing amplitude: resonance

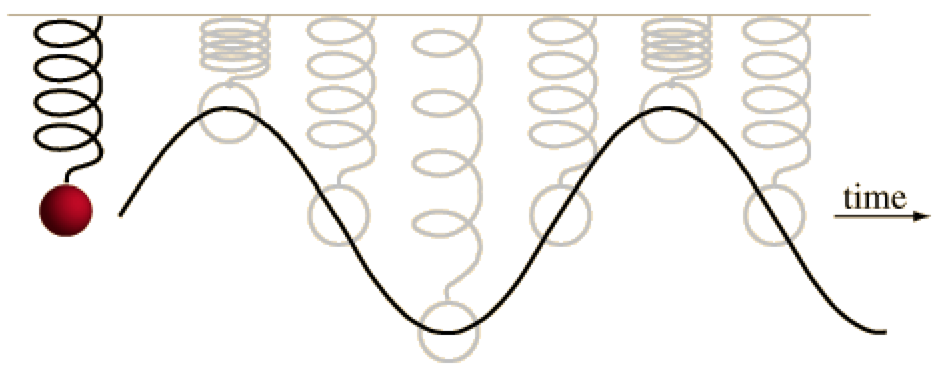
- Damping:
  - What causes sound to decay?
  - What happens to the frequency?



Resonance

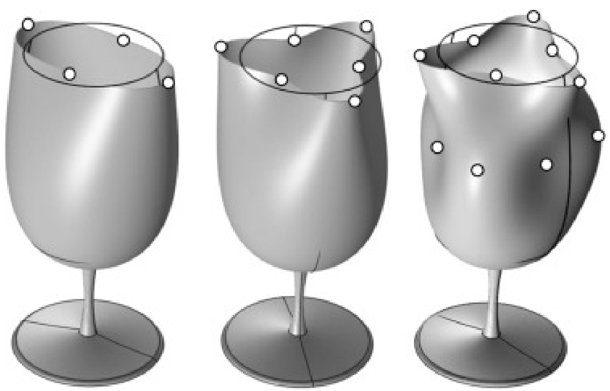
- Most objects have a natural (or resonant) frequency at which they tend to vibrate (depends on shape, material, inertia, etc.)

- Resonance: applying energy periodically to a system to amplify its natural frequency
  - e.g. child on swing, bridges, blowing on bottle

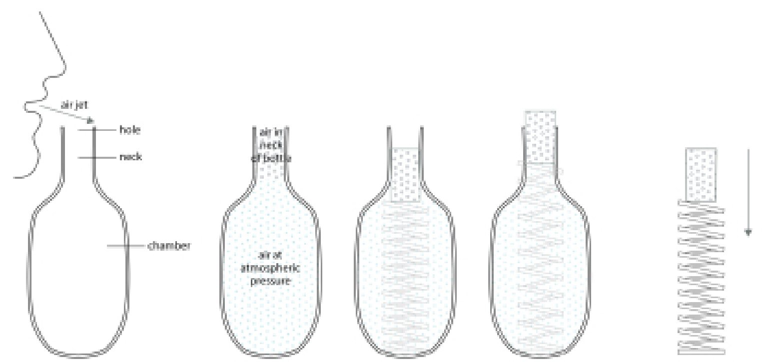


Demos: resonance boxes, wine glasses, bottles

Glass harmonica:
https://youtu.be/OztMMj4OF0w?t=37
https://youtu.be/QMe8e5GcY0c?t=137



(a) (b) (c)



Bottles: “Helmholtz resonance”
(also applies to whistles, ocarinas, guitar bodies, seashells, and a slightly open window in a car)