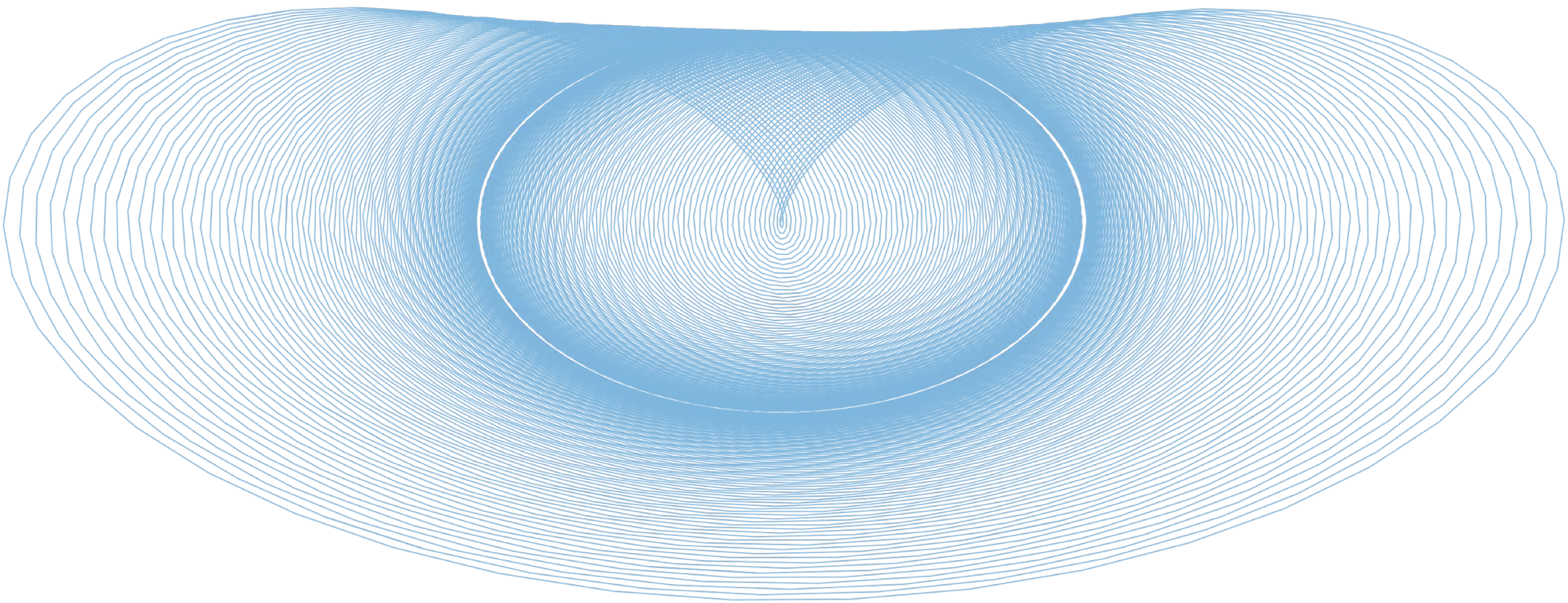
PHYS 1420 (F19)
Physics with Applications to Life Sciences



2019.11.20

Relevant reading:

Kesten & Tauck ch. 12.1-12.4

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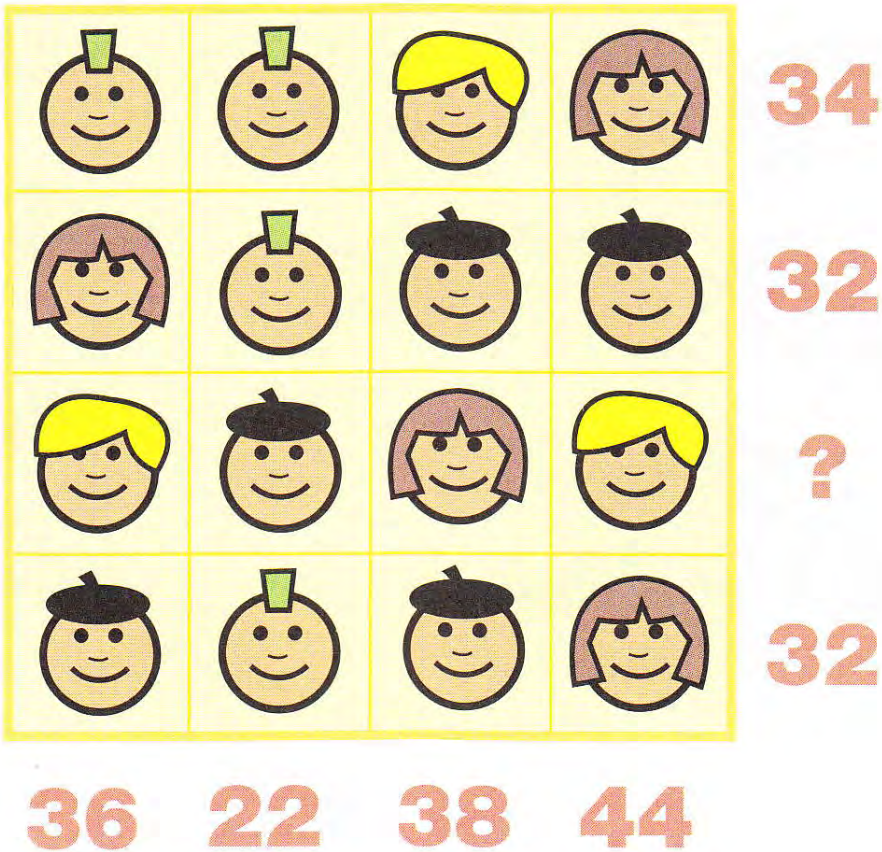
Ref. (re images):
Wolfson (2007), Knight (2017),
Kesten & Tauck (2012)

Sum People

Work out which number is represented by which person and fill in the question mark



Announcements & Key Concepts (re Today)

→ Online HW #8 (re fluids): Posted and due Friday (11/22)

→ Final exam: Saturday, Dec. 14 (start preparing!)

Some relevant underlying concepts of the day…

- Things that oscillate...
- Harmonic oscillator
- Oscillations: Basics
- Harmonic oscillator

THE YORKU BIOPHYSICS CLUB PRESENTS
IN PARTNERSHIP WITH DR. PETER BACKX

FROM STEM CELLS TO ARRHYTHMIA

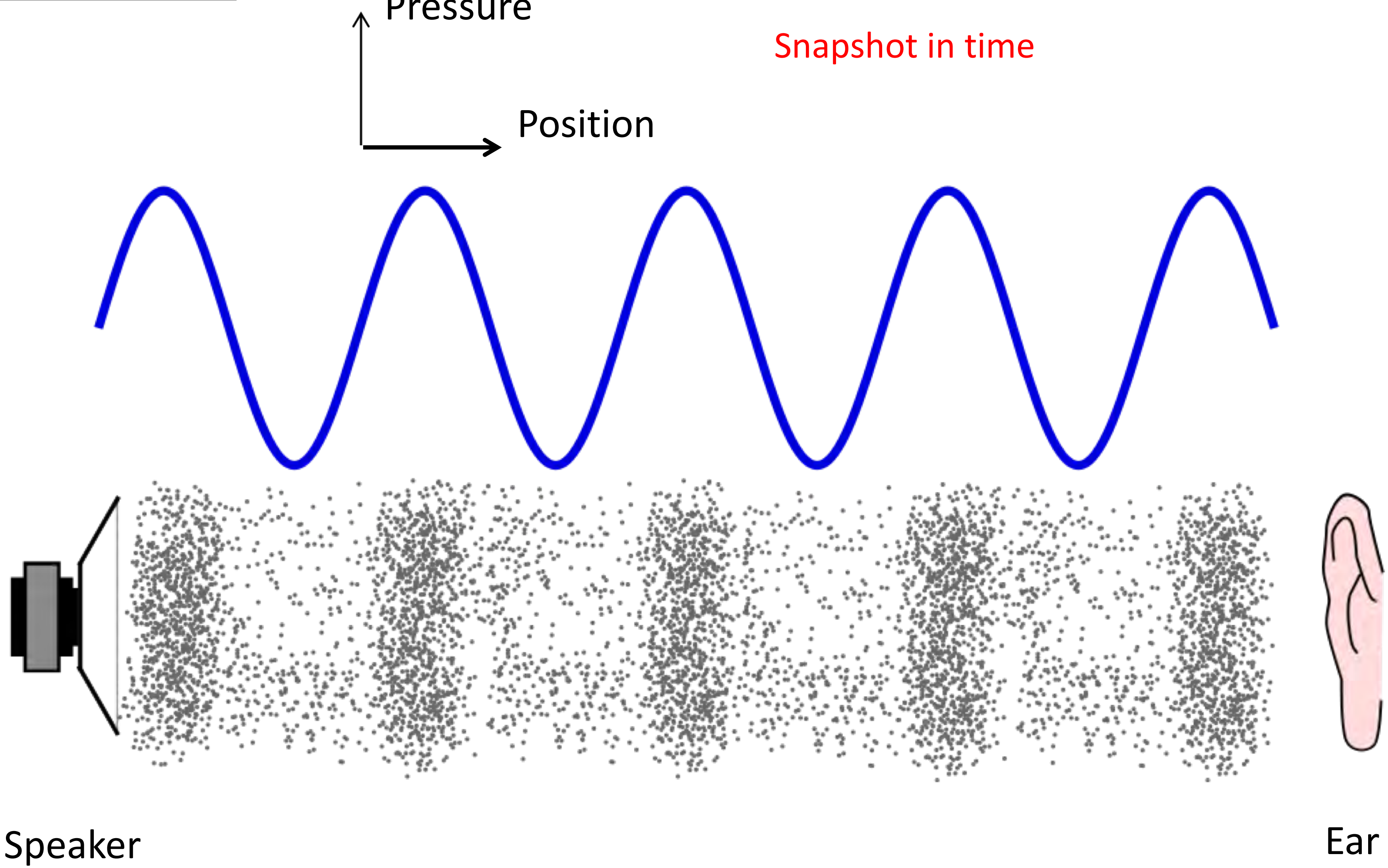
A LECTURE ON USING TISSUES GENERATED FROM STEM CELLS TO BETTER-UNDERSTAND CARDIAC ARRHYTHMIAS

THURSDAY, NOVEMBER 21ST
5:30-7:00PM
REFRESHMENTS PROVIDED

PETRIE SCIENCE & ENGINEERING BUILDING
RM 317

What is sound?

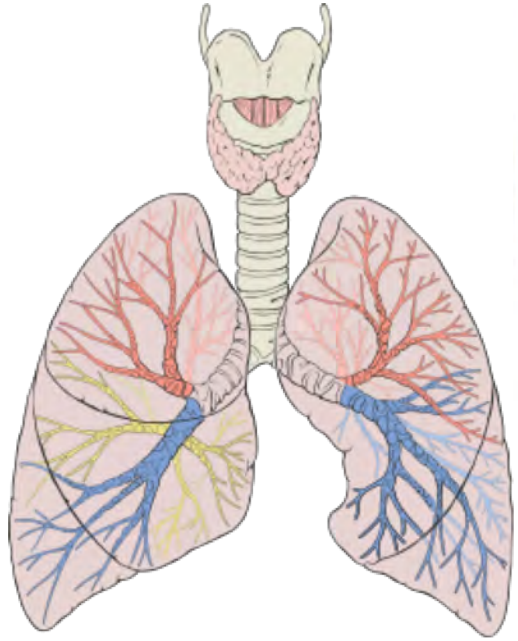
Snapshot in time

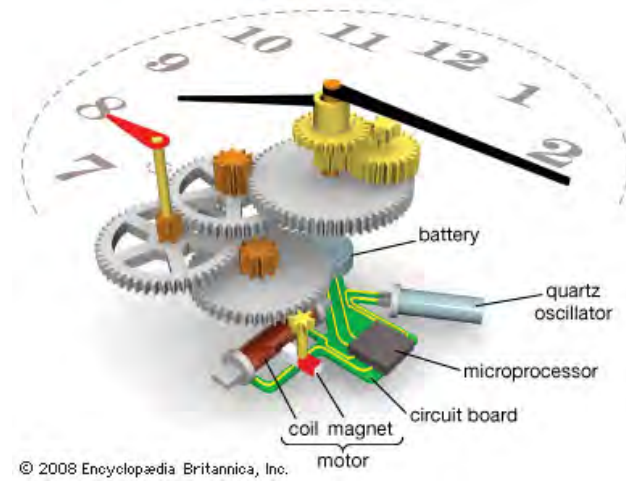


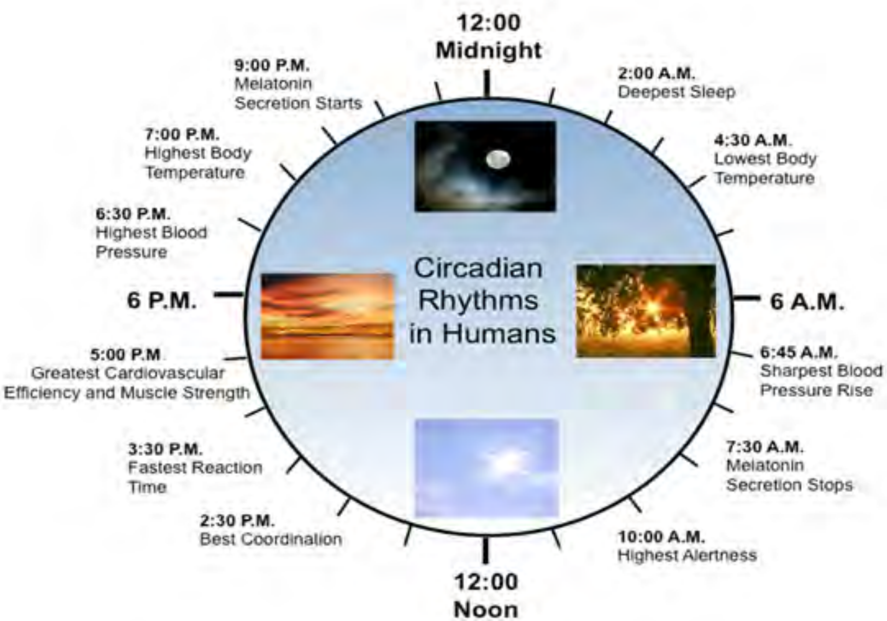
→ Note the periodic nature present....

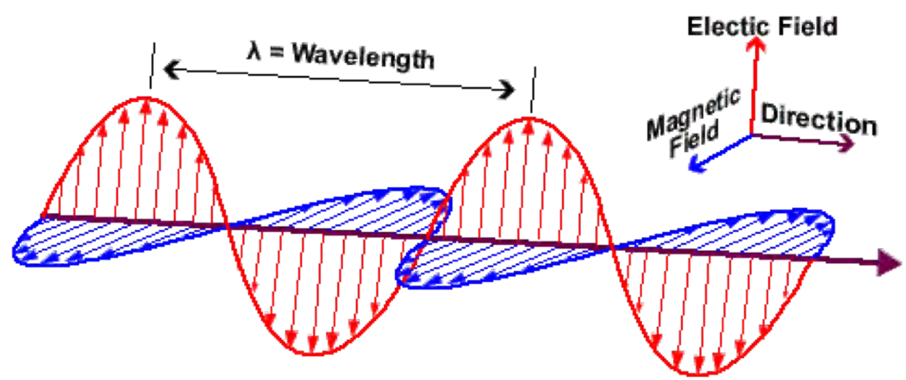
Pulkki & Karjalainen (2015)

Things that oscillate....

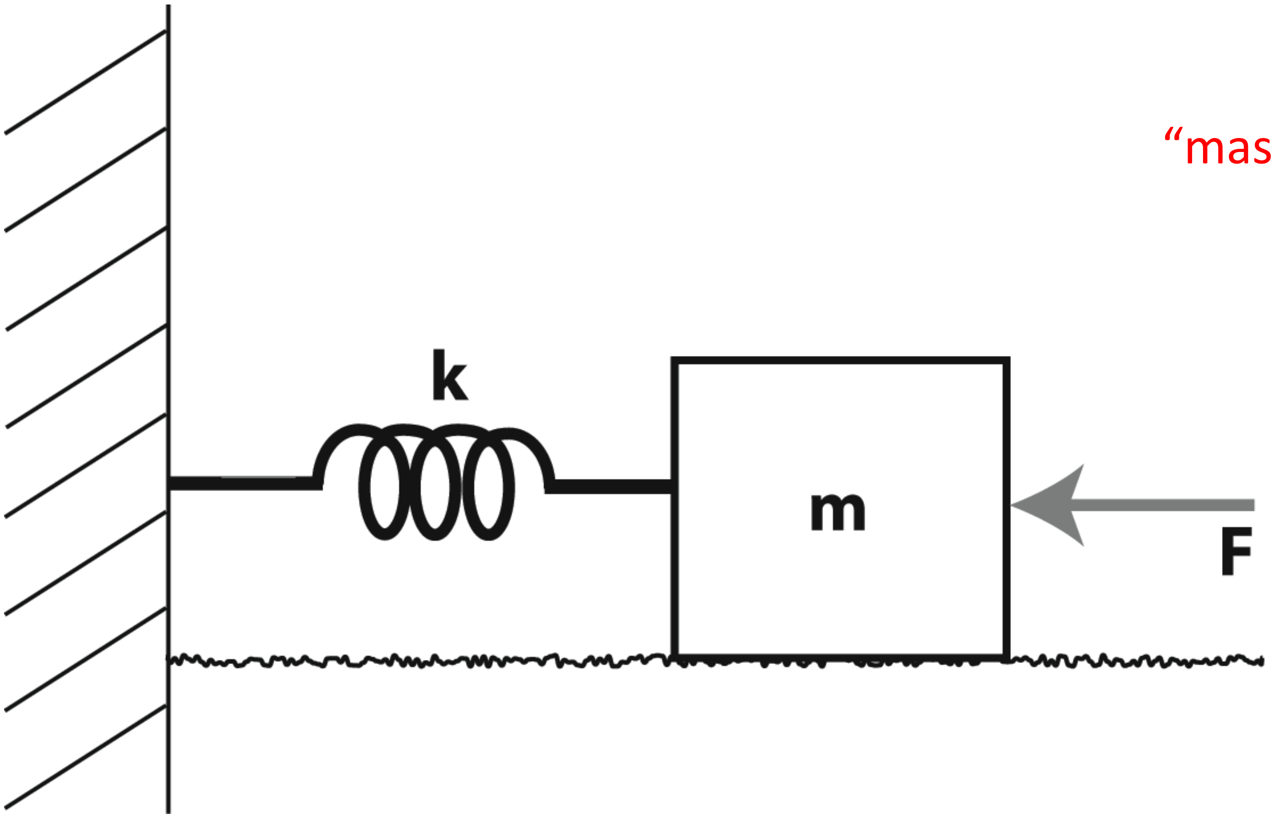








Harmonic oscillator



“mass-on-a-spring”

- One of the most fundamental/canonical problems in physics

Review (re "Measuring Force")

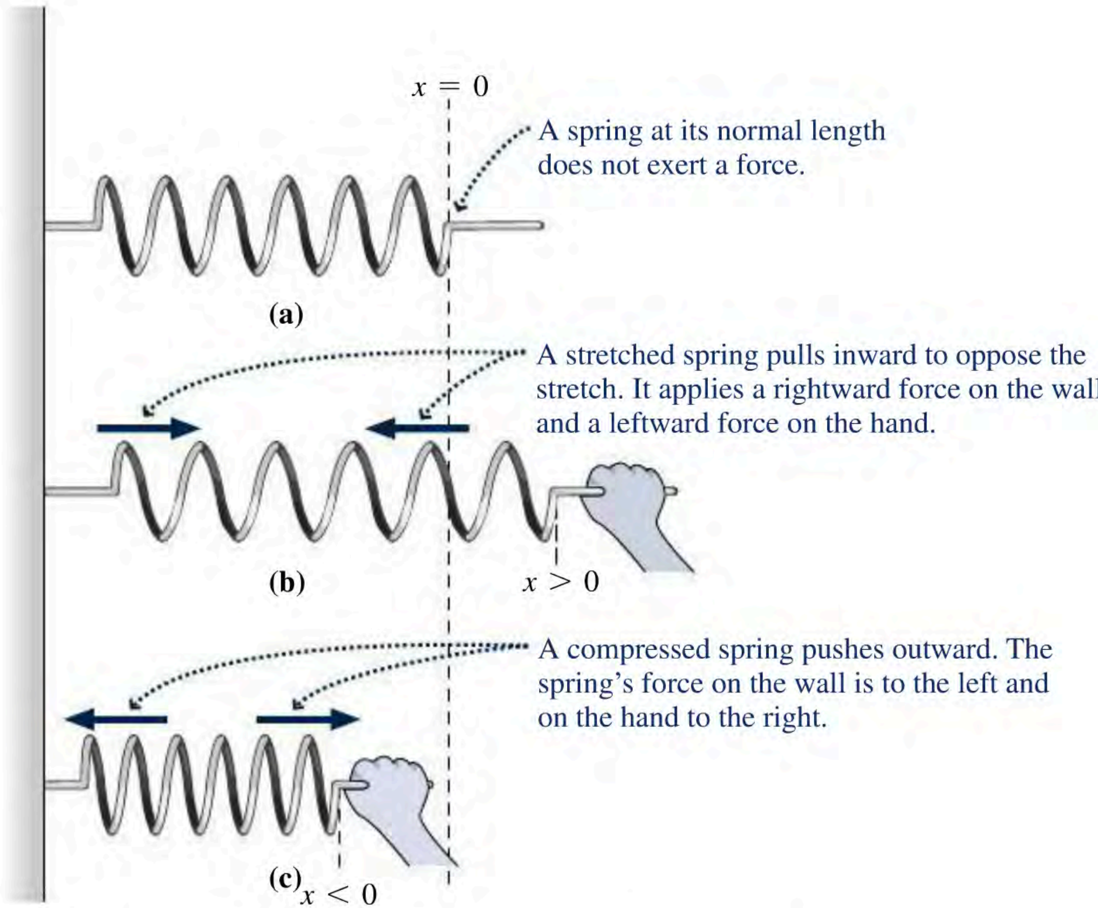


FIGURE 4.19 A spring responds to stretching or compression with an oppositely directed force.

- Springs are an intuitive means (i.e., compression/extension)

→ Implicit in this idea is the notion of **energy** (e.g., the spring stores energy as it is displaced from equilibrium). We'll revisit this idea soon...

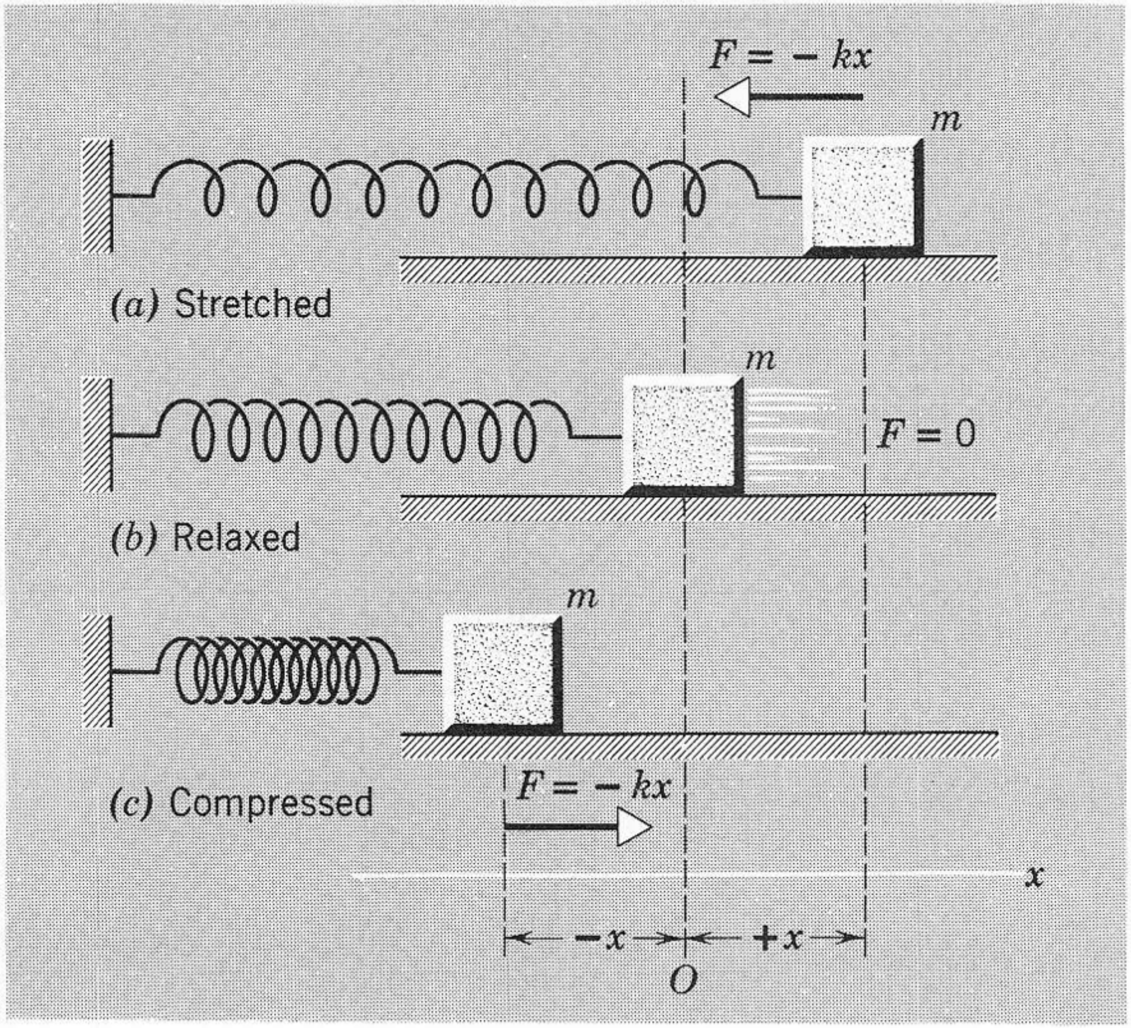
$$F_s = -kx$$

Hooke's Law
(ideal spring)

→ k is called the *stiffness*
(or "spring constant")

- If you know k, than measuring how much compression (i.e., x) tells you something about the associated forces

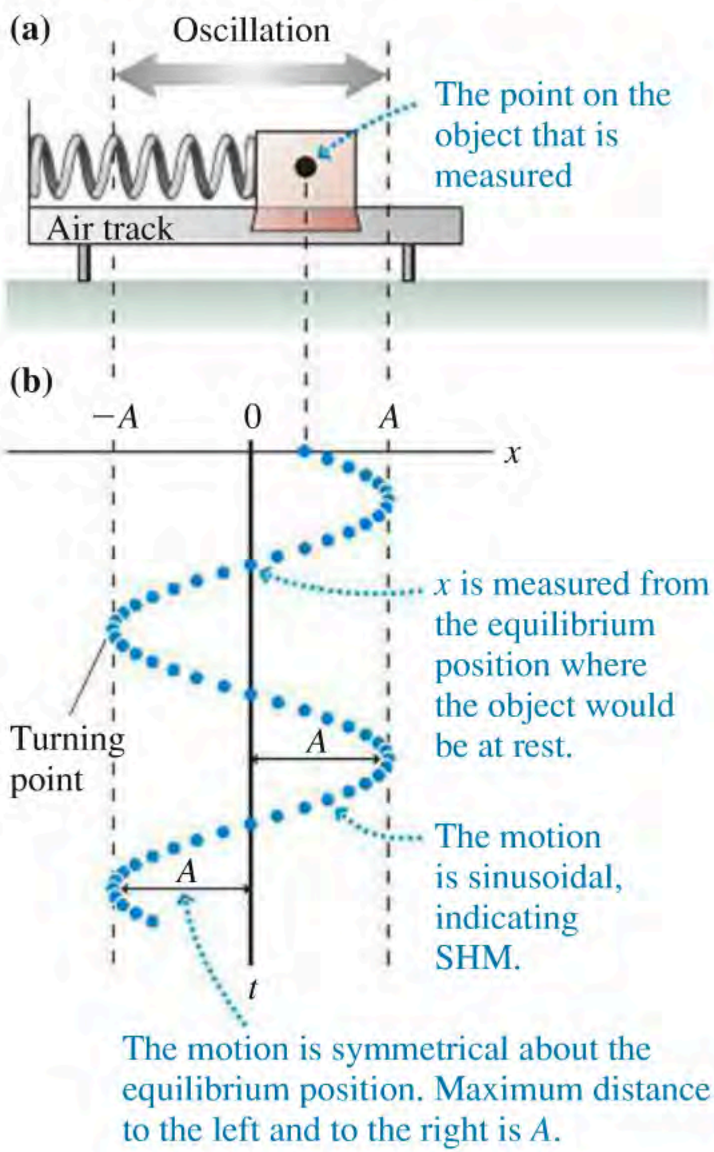
Harmonic oscillator: Free-body diagram



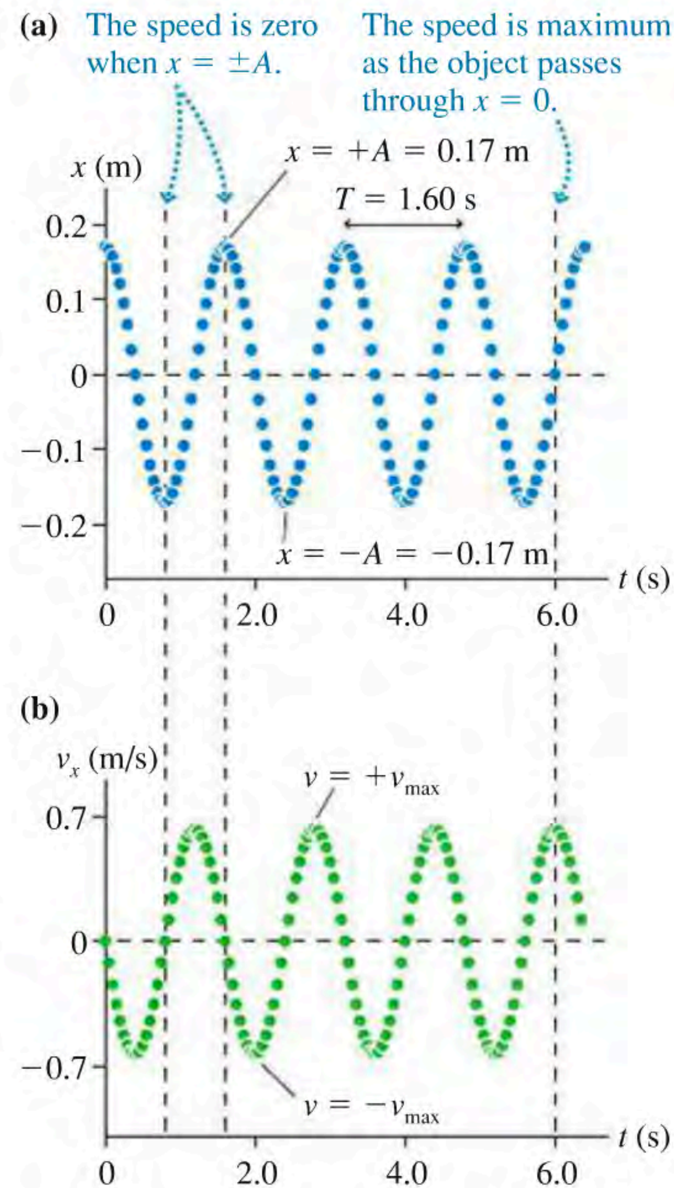
A simple harmonic oscillator. The force exerted by the spring is shown in each case. The block slides on a frictionless horizontal table.

Resnick & Halliday (1966)

A prototype simple-harmonic-motion experiment.

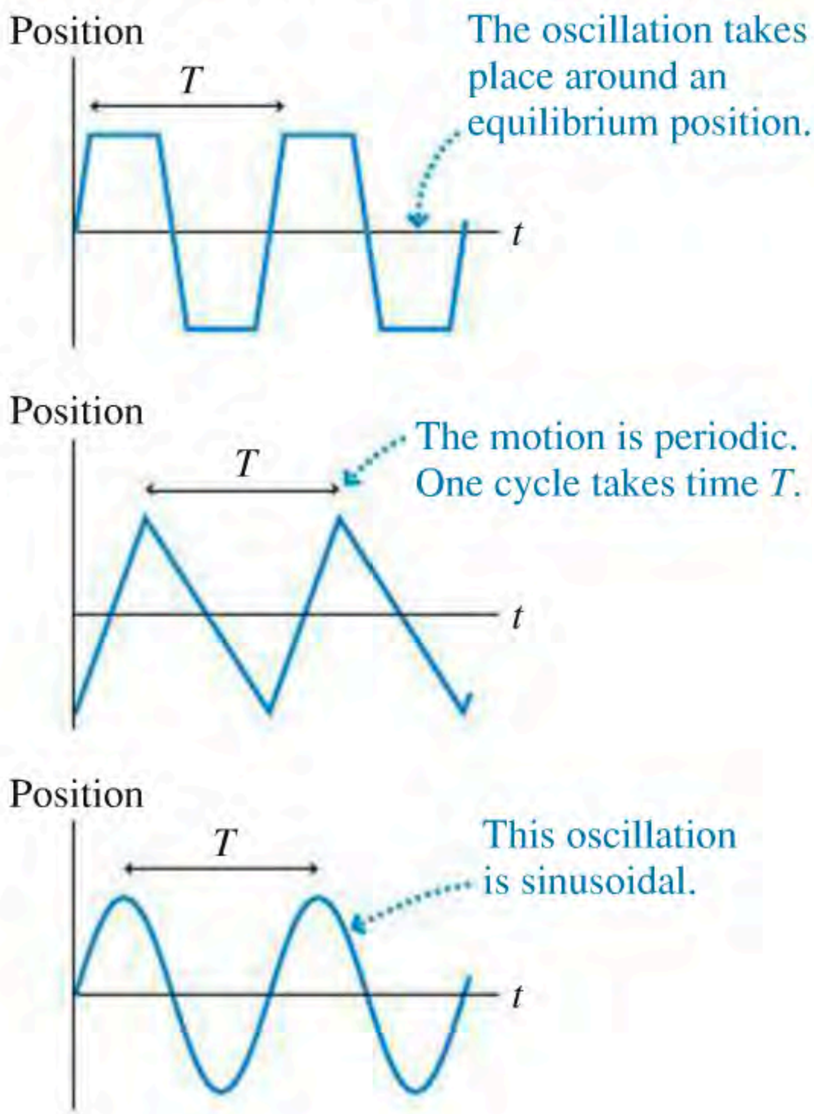


Position and velocity graphs of the experimental data.



Periodicity

Examples of position-versus-time graphs for oscillating systems.



Frequency & period

$$f = \frac{1}{T}$$

$$1\text{ Hz} \equiv 1\text{ cycle per second} = 1\text{ s}^{-1}$$

Units of frequency

Frequency	Period
10^3 Hz = 1 kilohertz = 1 kHz	1 ms
10^6 Hz = 1 megahertz = 1 MHz	1 μs
10^9 Hz = 1 gigahertz = 1 GHz	1 ns

Angular frequency

$$\omega\text{ (in rad/s)} = \frac{2\pi}{T} = 2\pi f\text{ (in Hz)}$$

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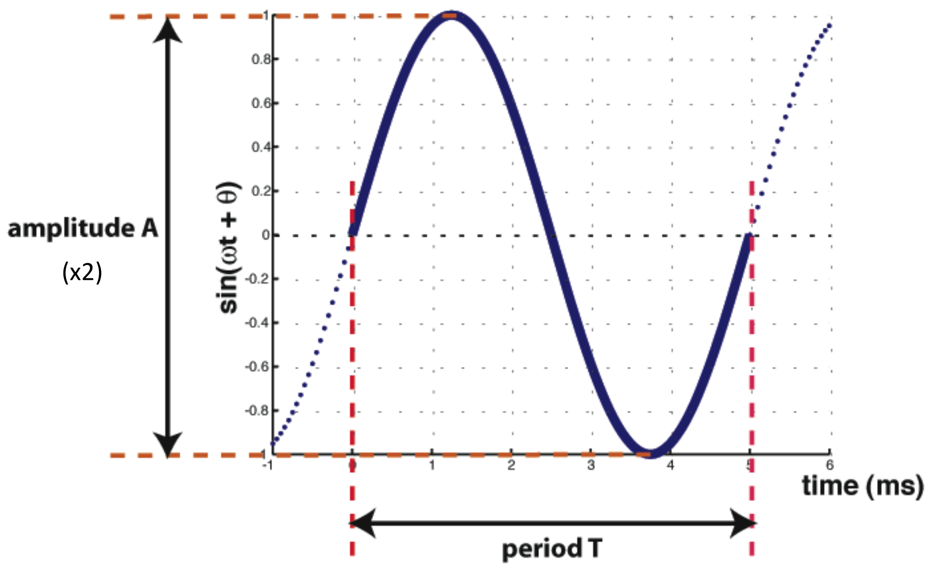
Trigonometry Review: Sinusoids

Sinusoid has 3 basic properties:

i. Amplitude - height

ii. Frequency = 1/T [Hz]

iii. Phase - tells you where the peak (needs a reference)

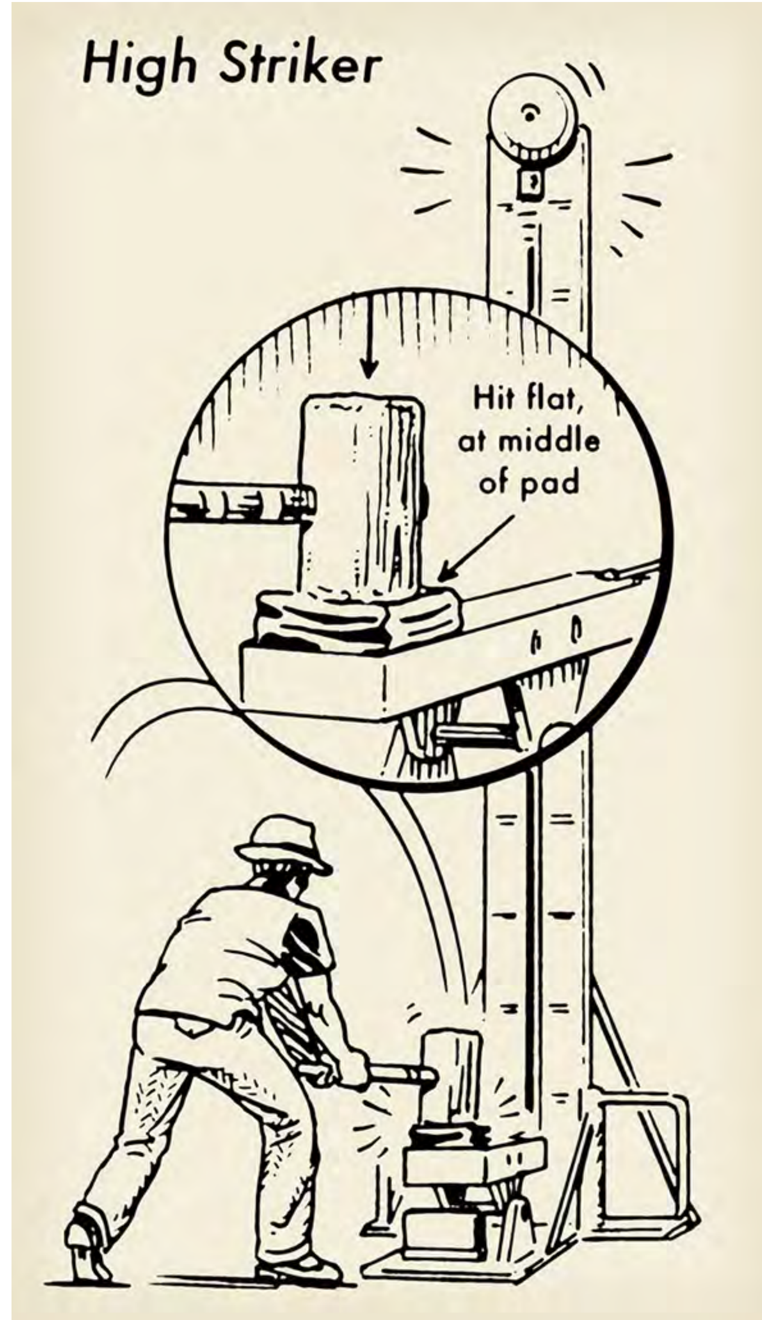


⇒ Phase reveals timing information

Trigonometry Review: Magnitude

→ *Size* is key here

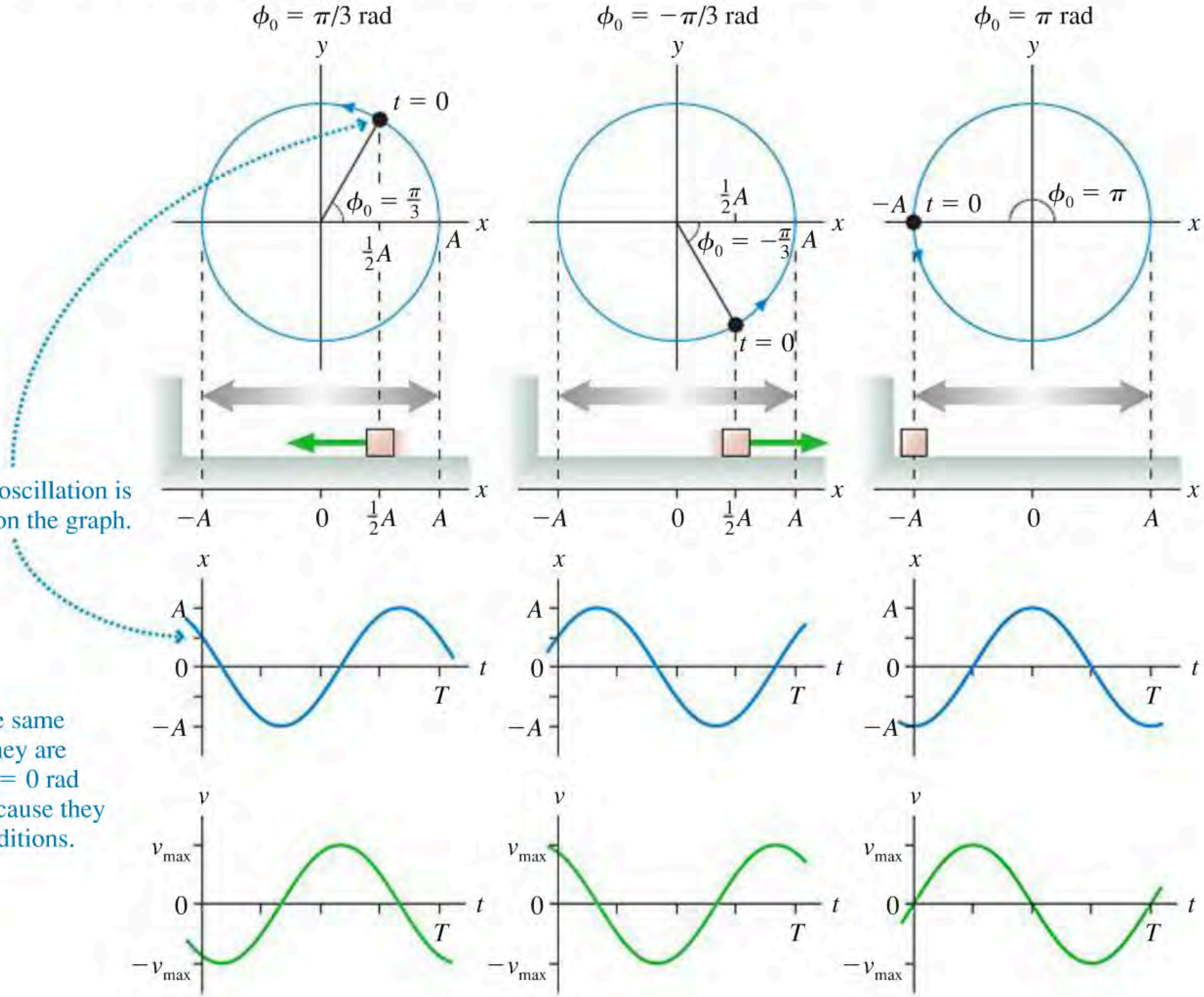
Magnitude = Amplitude



<u>Trigonometry Review</u>: Phase

→ 'Timing' is key here
(on a cycle-by-cycle basis)

Oscillations described by the phase constants $\phi_0 = \pi/3$ rad, $-\pi/3$ rad, and π rad.



The starting point of the oscillation is shown on the circle and on the graph.

The graphs each have the same amplitude and period. They are *shifted* relative to the $\phi_0 = 0$ rad graphs of Figure 14.5 because they have different initial conditions.

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Harmonic oscillator: Theory

- Let's consider the simplest case: Undamped, Undriven (aka "simple harmonic oscillator")

$$F = ma = m\ddot{x} = -kx$$

Newton's Second Law & Hooke's Law

$$\ddot{x} + \frac{k}{m}x = 0$$

Second order differential equation

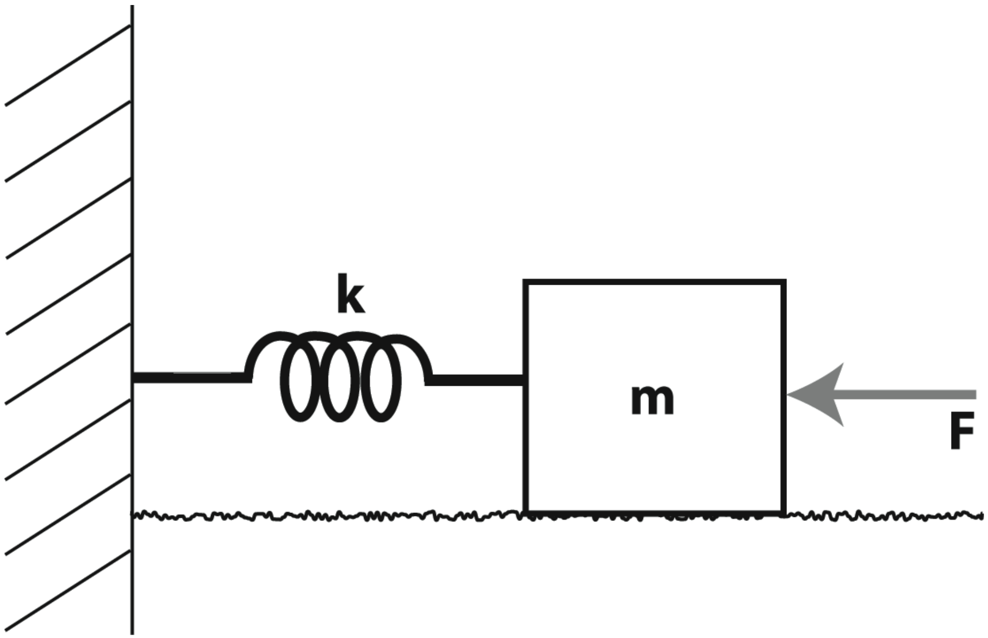
$$x(t) = A\cos\left(\omega_o t + \phi\right)$$

$\Rightarrow$ Solution is oscillatory!

$$\omega_o = \sqrt{k/m}$$

System has a *natural* frequency

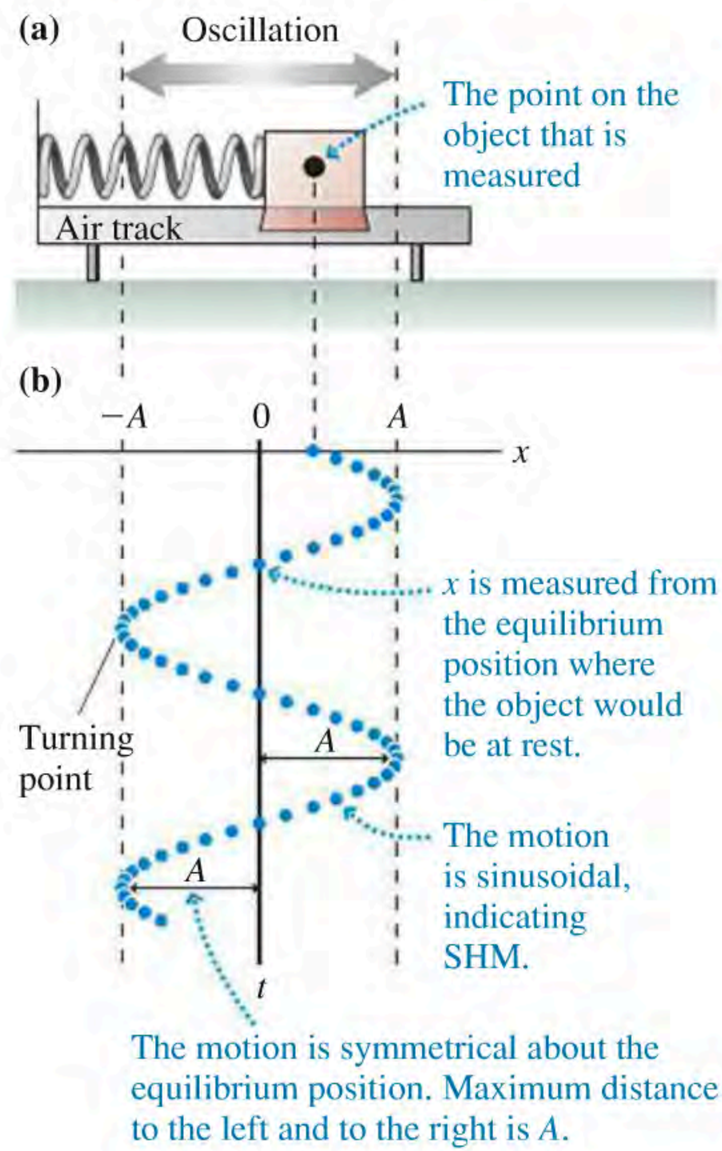
Harmonic oscillator



$$x(t) = A\cos(\omega_o t + \phi)$$

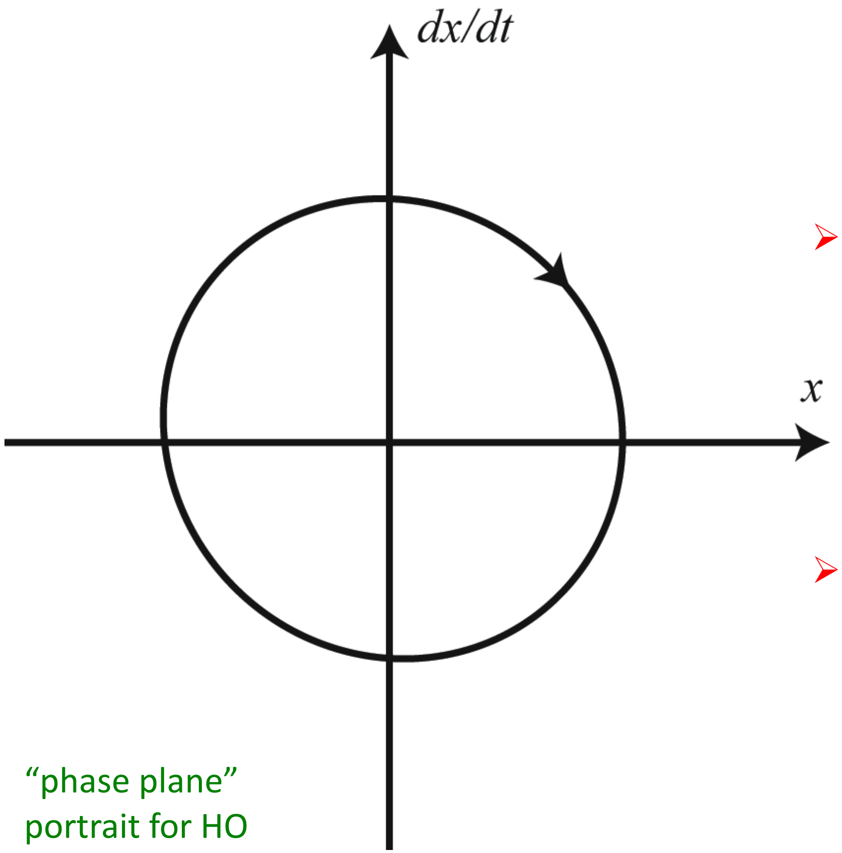
$$\omega_o = \sqrt{k/m} \qquad f = \frac{1}{T}$$

A prototype simple-harmonic-motion experiment.



Harmonic oscillator: Energy

Consider the system's energy: $$E = T + U = \frac{1}{2}m\dot{x}^2 + \frac{1}{2}kx^2$$

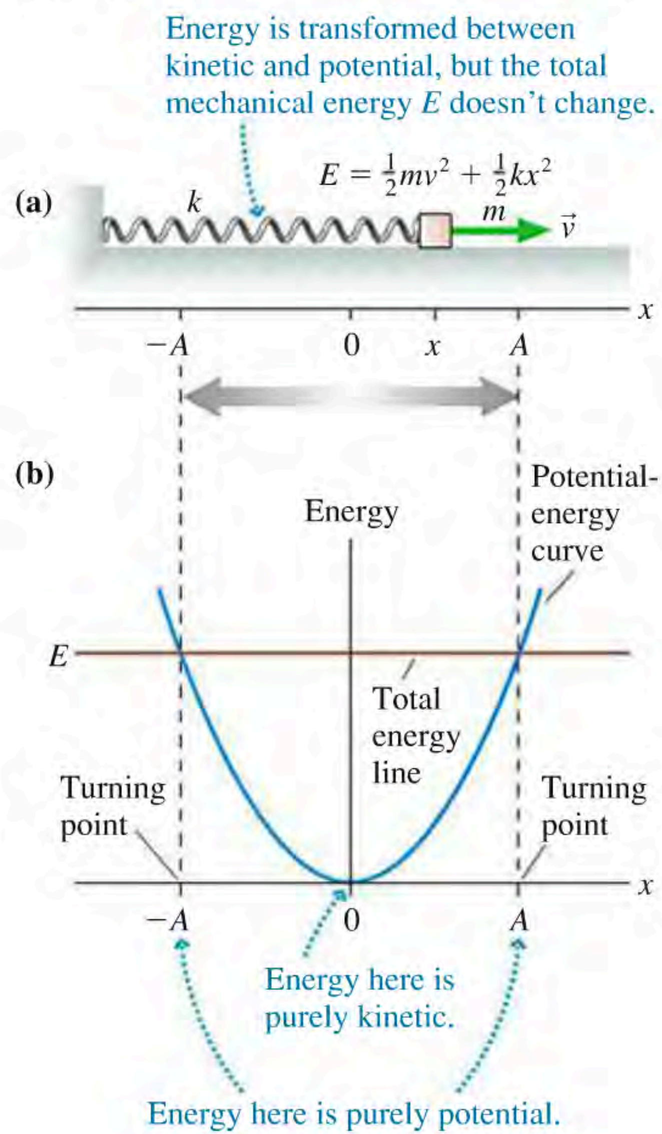


"phase plane"
portrait for HO

- Two means to *store* energy: mass and spring
- Oscillation results as energy transfers back and forth between these two *modes* (i.e., system is considered second-order)

Harmonic oscillator: Energy

The energy is transformed between kinetic energy and potential energy as the object oscillates, but the mechanical energy $E = K + U$ doesn't change.



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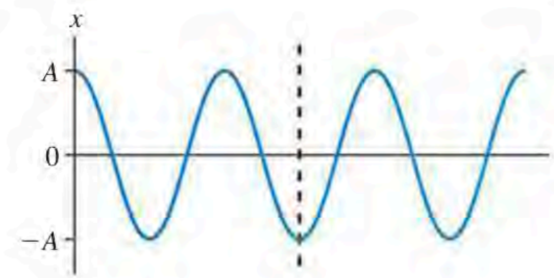
Ex.

STOP TO THINK 14.4 This is the position graph of a mass on a spring. What can you say about the velocity and the force at the instant indicated by the dashed line?



a. Velocity is positive; force is to the right.
b. Velocity is negative; force is to the right.
c. Velocity is zero; force is to the right.
d. Velocity is positive; force is to the left.
e. Velocity is negative; force is to the left.
f. Velocity is zero; force is to the left.
g. Velocity and force are both zero.

Ex. (SOL)

STOP TO THINK 14.4 This is the position graph of a mass on a spring. What can you say about the velocity and the force at the instant indicated by the dashed line?

a. Velocity is positive; force is to the right.
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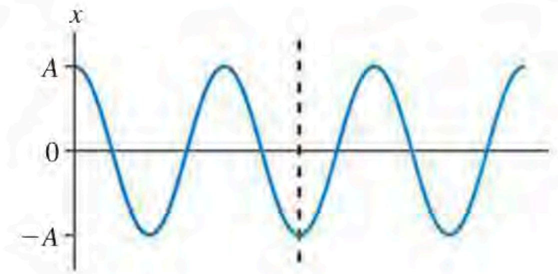
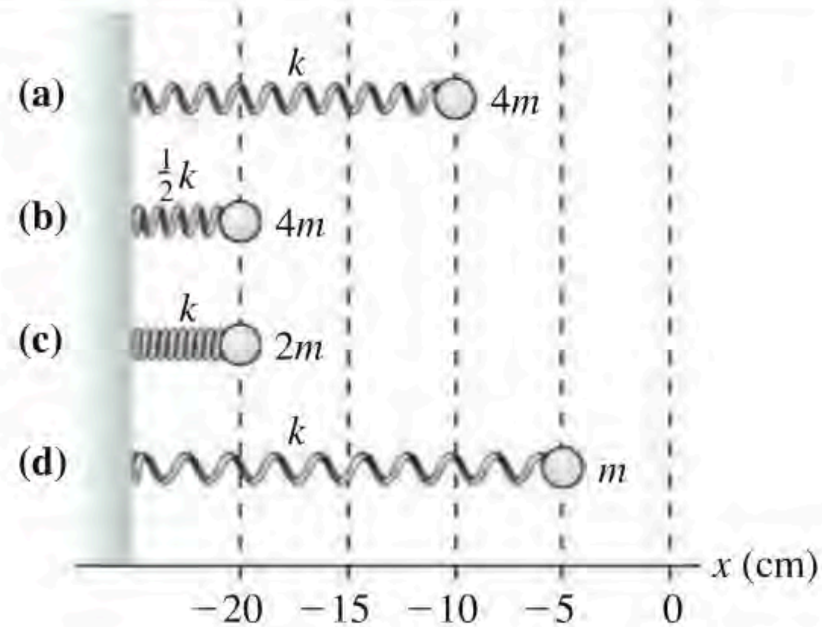


c

Ex.

STOP TO THINK 14.3

The four springs shown here have been compressed from their equilibrium position at $x = 0$ cm. When released, the attached mass will start to oscillate. Rank in order, from highest to lowest, the maximum speeds of the masses.



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Ex. (SOL)

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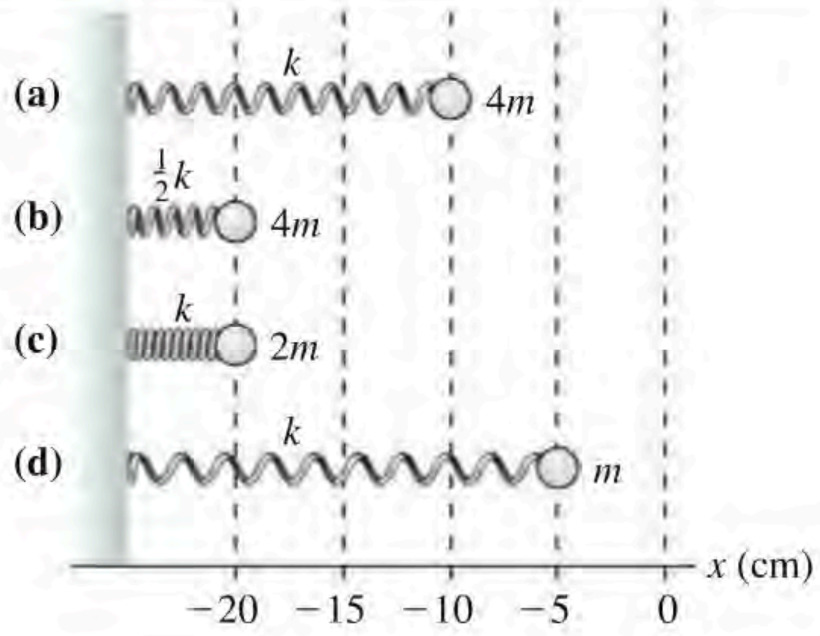

$$x(t) = A\cos(\omega_o t + \phi)$$

c > b > a = d

$$\omega_o = \sqrt{k/m}$$

$$E = T + U = \frac{1}{2}m\dot{x}^2 + \frac{1}{2}kx^2$$

c > b > a = d. Energy conservation $\frac{1}{2}kA^2 = \frac{1}{2}m(v_{max})^2$ gives $v_{max} = \sqrt{k/m}\,A$. k or m has to be increased or decreased by a factor of 4 to have the same effect as increasing or decreasing A by a factor of 2.

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Ex. "Frog's eardrum"

Example 12-1 Finding the Phase

Sound causes a frog's eardrum to move back and forth as shown in the plot of displacement versus time in Figure 12-7. In this case, displacement is given as a percentage of the amplitude of the oscillations. At the start of the measurements, the displacement is about 12% of the maximum in the negative direction. Find thephase angle ϕ if the displacement obeys $x(t) = A\cos(\omega_0 t + \phi)$ (Equation 12-4). (We will address the fact that the amplitude of the oscillations changes from one cycle to the next in Section 12-7.)

Note: This example would be better placed in sec.12.8 (as it is both a *forced* and *damped* oscillator situation)

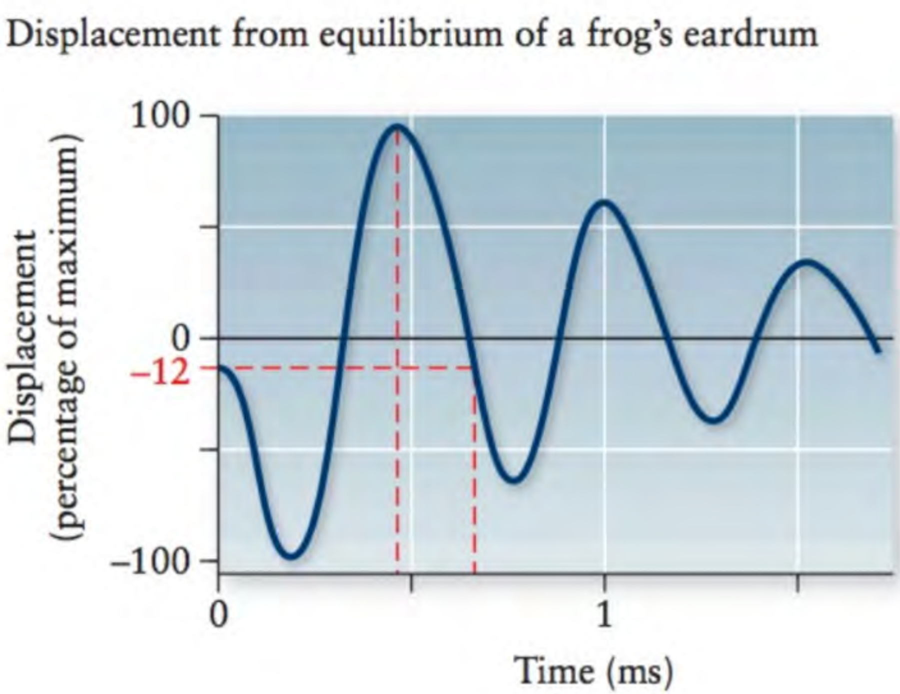

Figure 12-7 Sound causes a frog's eardrum to move back and forth, in (approximately) harmonic motion. The vertical dashed red line marks the beginning of a cosine cycle; the horizontal dashed red line marks –12% of the maximum displacement from equilibrium. The time interval between the two red arrows is just slightly more than one-quarter of a full cycle. (After Chung, Pettigrew, and Anson, (1981) *Proc. Royal Soc. London Ser. B Biol. Sci.* 212, No. 1189, pp. 459–485.)