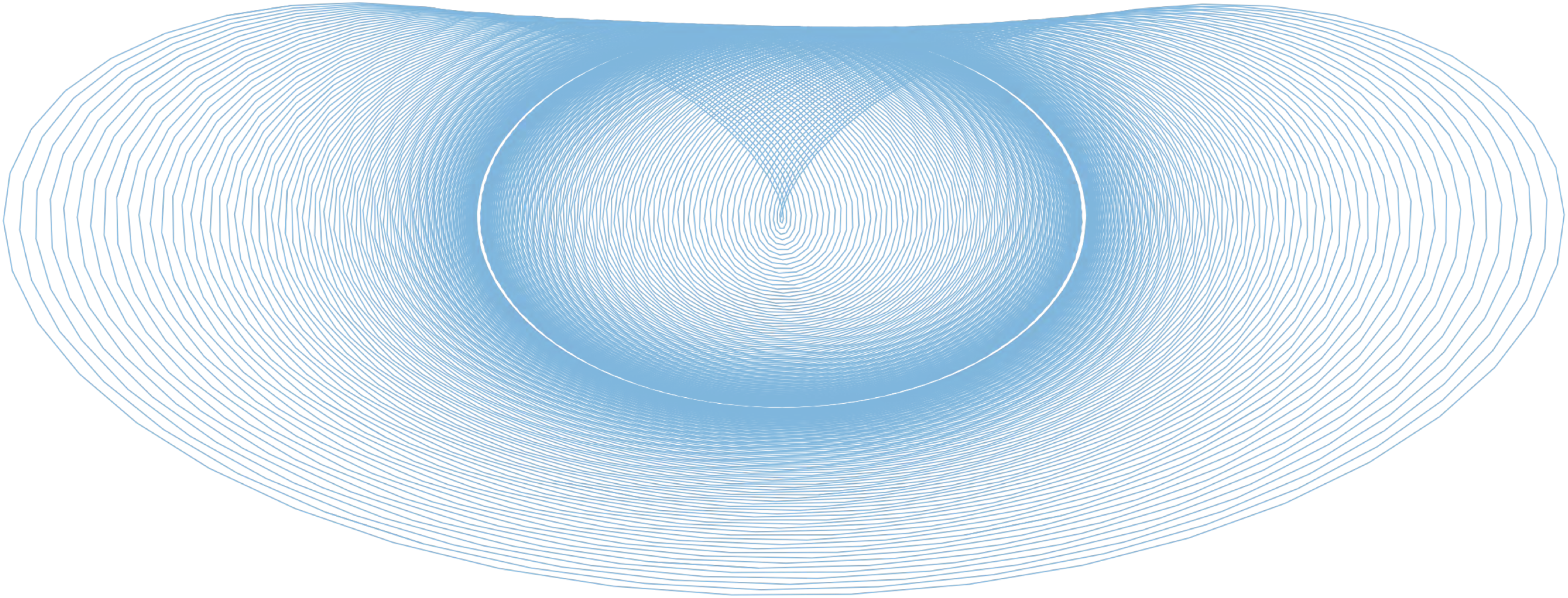
PHYS 1420 (F19)
Physics with Applications to Life Sciences



2019.11.18

Relevant reading:

Kesten & Tauck ch. 11.1-11.5, 12.1

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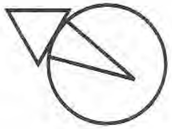
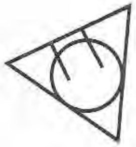
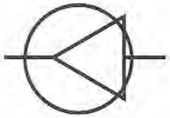
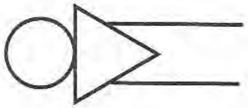
Ref. (re images):
Wolfson (2007), Knight (2017),
Kesten & Tauck (2012)

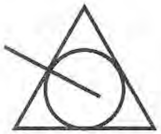
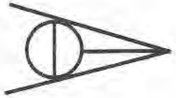
Jollos and Plotz

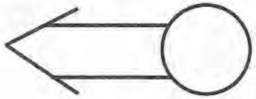
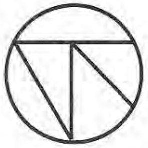
These are jollos:

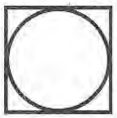
These are plotz:

Which are jollos and which are plotz?

A.



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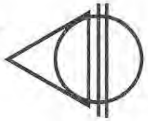

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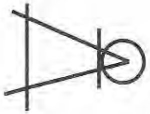

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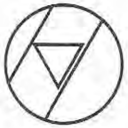


E.

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…

- ➢ Fluid (& Gas) basics
- ➢ Pressure
- ➢ Sound → Oscillations
- ➢ Harmonic oscillator

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

FROM STEM CELLS TO ARRHYTHMIA

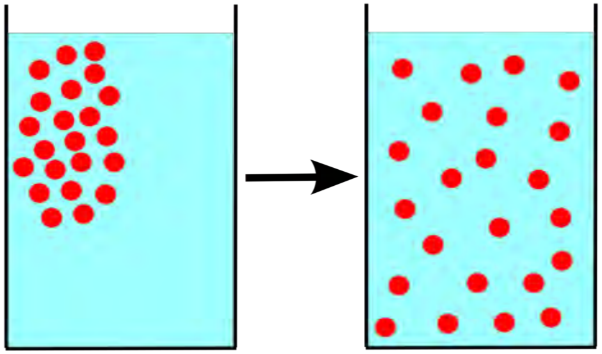
A LECTURE ON USING TISSUES GENERATED FROM STEM CELLS TO BETTER-UNDERSTAND CARDIAC ARRHYTHMIAS

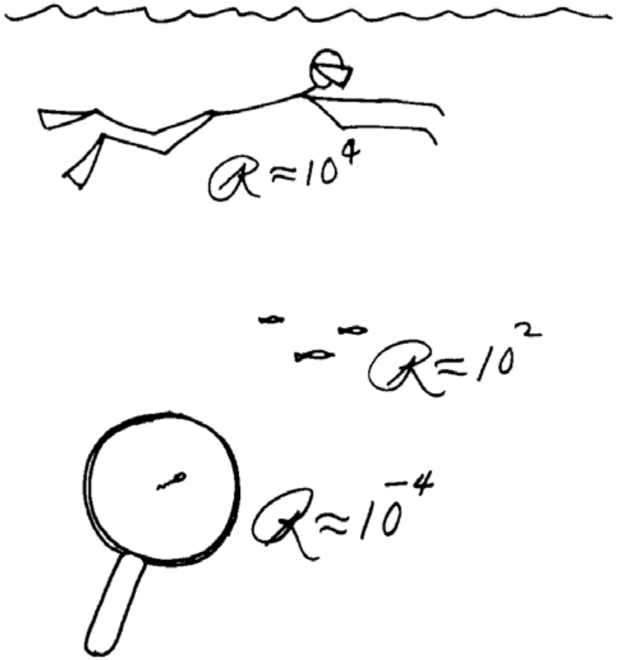
THURSDAY, NOVEMBER 21ST
5:30-7:00PM
REFRESHMENTS PROVIDED

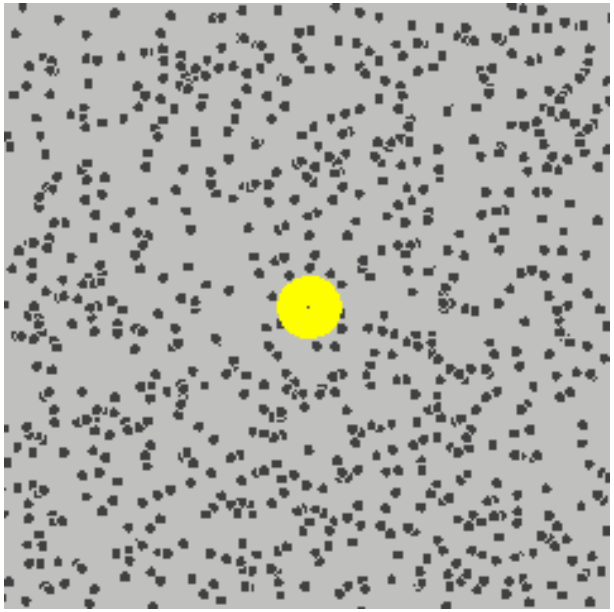
PETRIE SCIENCE & ENGINEERING BUILDING
RM 317

Fluids

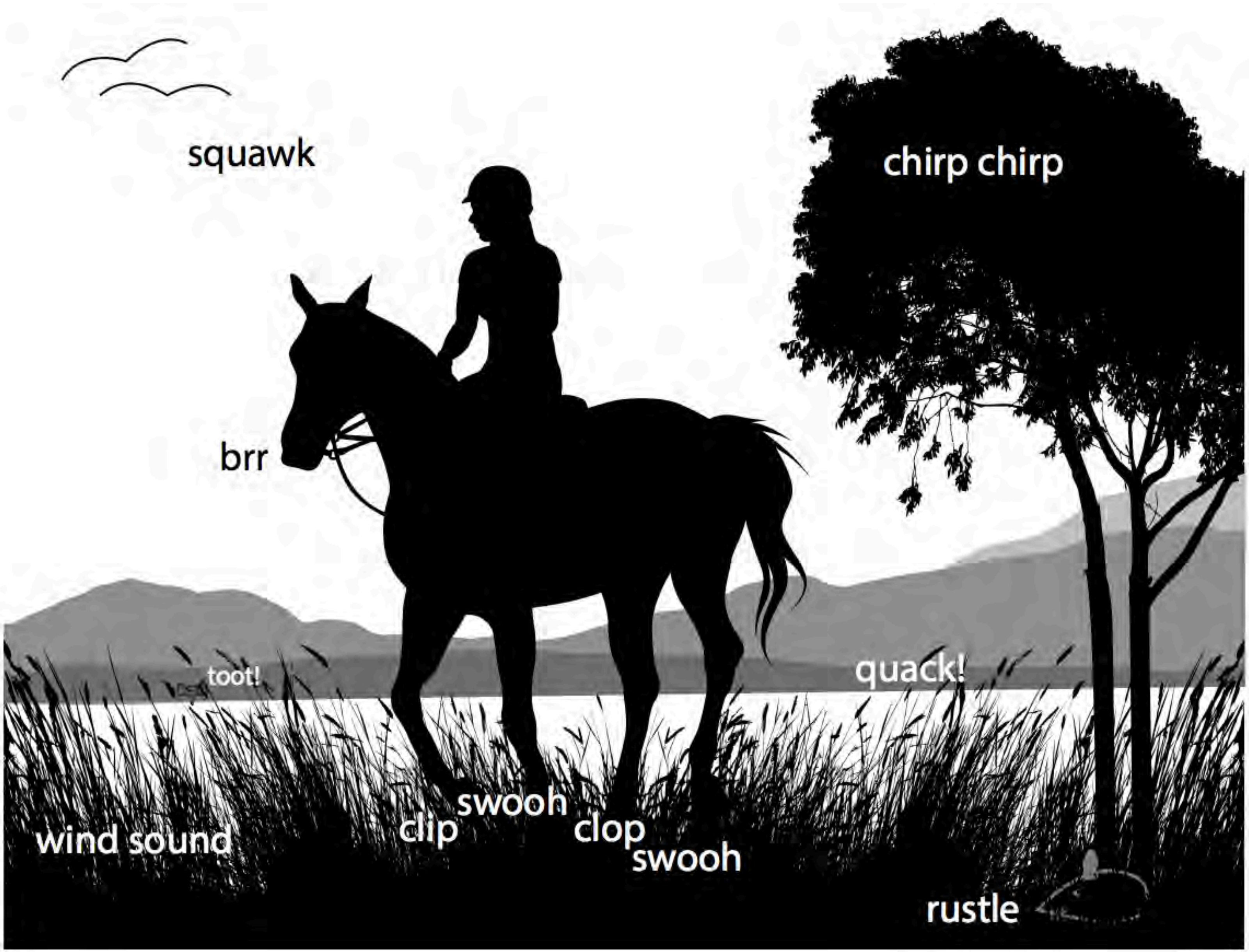
→ Implicitly or explicitly, much of our recents efforts have revolved around the notion of *fluids*...







Sound...

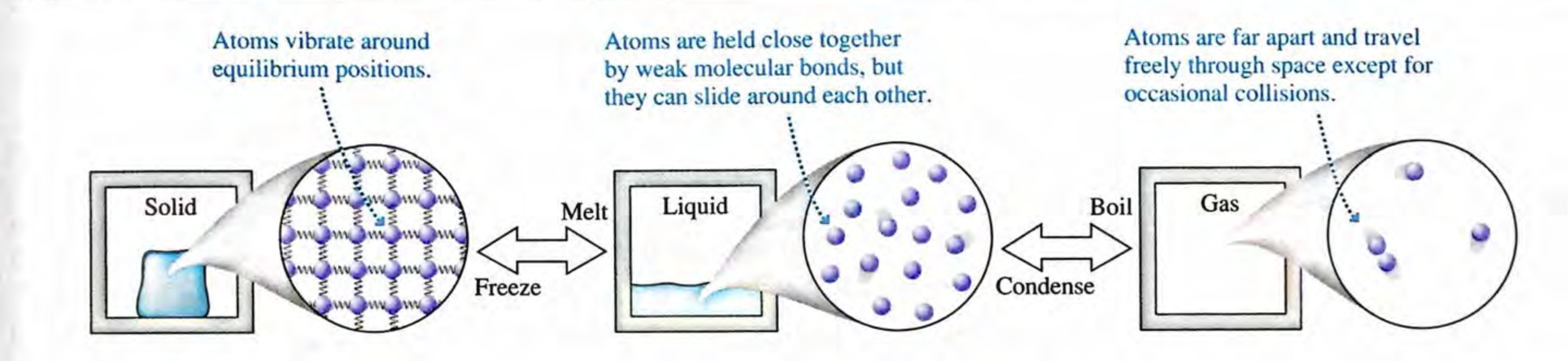


Pulkki & Karjalainen (2015)

Fluids vs Gases (vs Solids)

- What is a fluid?
- Sound only propagates in air, right? Which is a gas, right?
- Wait, what is a gas?

Solids, liquids, and gases



Atoms vibrate around equilibrium positions.

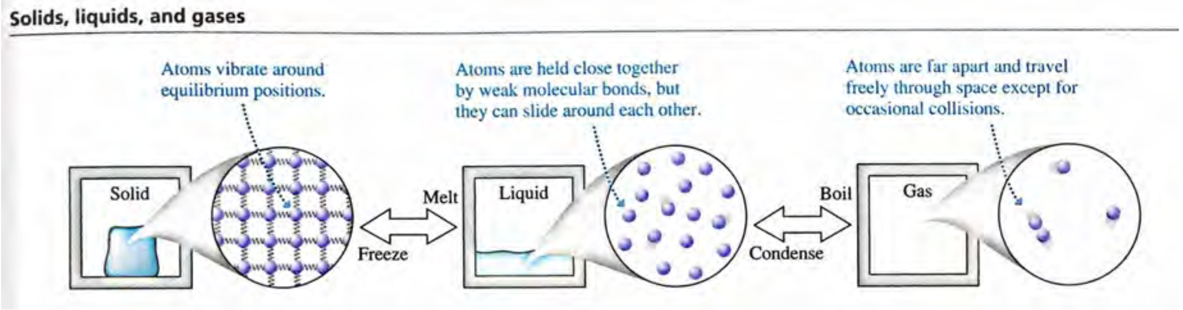
Atoms are held close together by weak molecular bonds, but they can slide around each other.

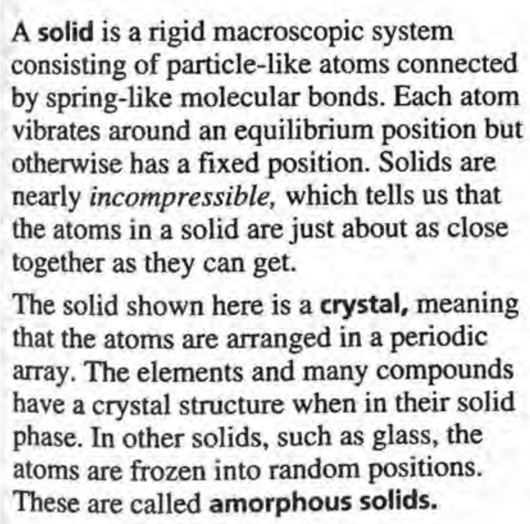
Atoms are far apart and travel freely through space except for occasional collisions.

"States of matter"

Knight

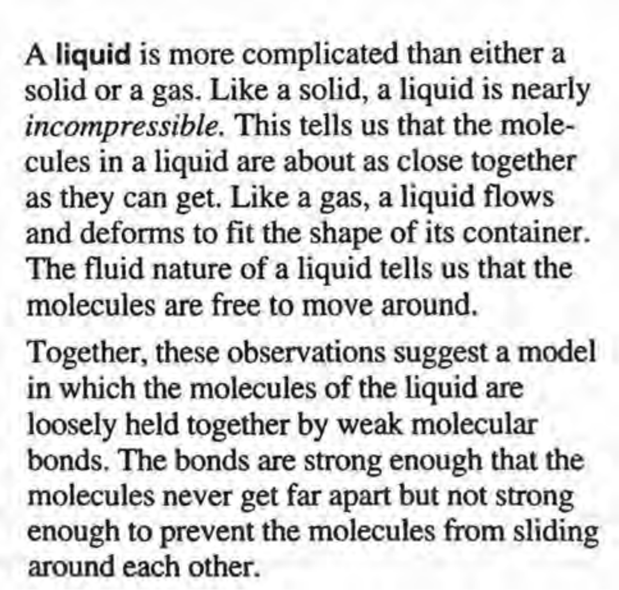
Fluids vs Gases (vs Solids)





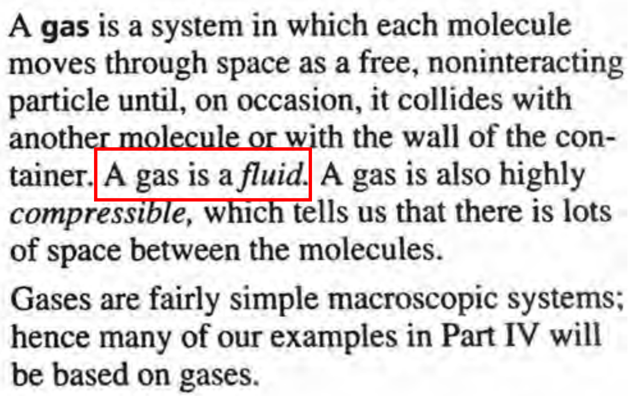
A **solid** is a rigid macroscopic system consisting of particle-like atoms connected by spring-like molecular bonds. Each atom vibrates around an equilibrium position but otherwise has a fixed position. Solids are nearly *incompressible,* which tells us that the atoms in a solid are just about as close together as they can get.

The solid shown here is a **crystal,** meaning that the atoms are arranged in a periodic array. The elements and many compounds have a crystal structure when in their solid phase. In other solids, such as glass, the atoms are frozen into random positions. These are called **amorphous solids.**



A **liquid** is more complicated than either a solid or a gas. Like a solid, a liquid is nearly *incompressible.* This tells us that the molecules in a liquid are about as close together as they can get. Like a gas, a liquid flows and deforms to fit the shape of its container. The fluid nature of a liquid tells us that the molecules are free to move around.

Together, these observations suggest a model in which the molecules of the liquid are loosely held together by weak molecular bonds. The bonds are strong enough that the molecules never get far apart but not strong enough to prevent the molecules from sliding around each other.



A **gas** is a system in which each molecule moves through space as a free, noninteracting particle until, on occasion, it collides with another molecule or with the wall of the container. A gas is a *fluid.* A gas is also highly *compressible,* which tells us that there is lots of space between the molecules.

Gases are fairly simple macroscopic systems; hence many of our examples in Part IV will be based on gases.

Knight

Aside: Phase transitions

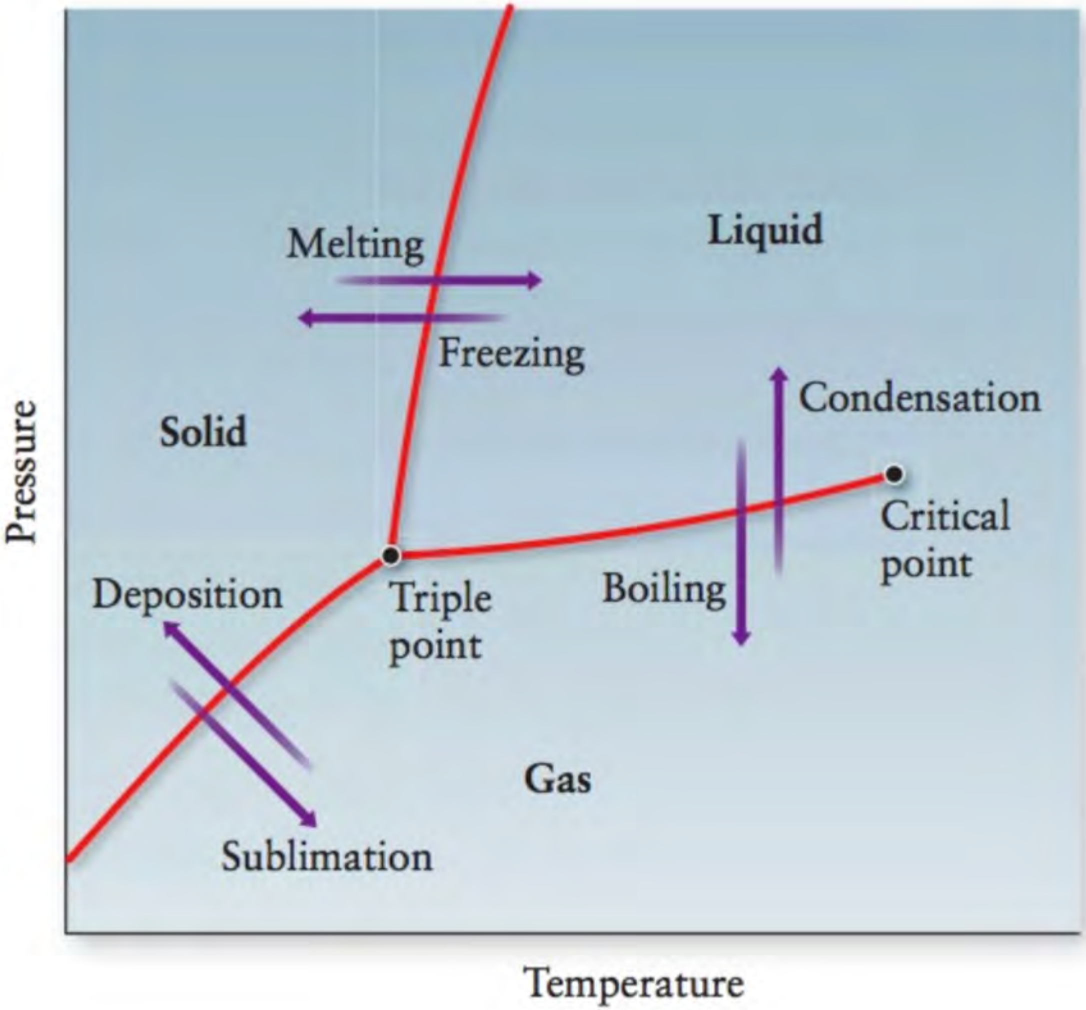
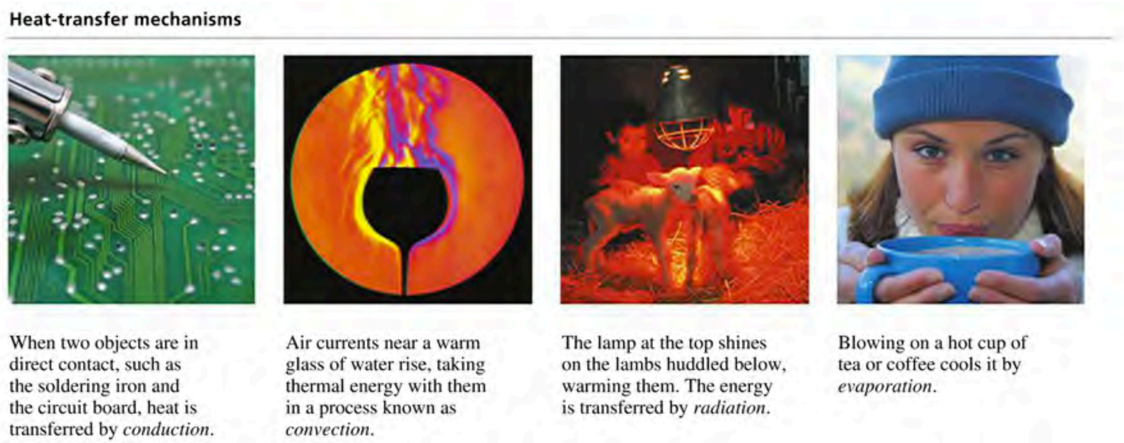


Figure 14-15 Phase diagrams show the relationship between pressure, temperature, and the phase of the substance. Each of the three lines in the figure marks a transition between two phases, effectively showing the transition temperature as a function of pressure. At the triple point, the substance can exist as a gas, liquid, or solid.

Kesten & Tauck

Fluids & Gases: Basic Considerations

- Density
- Pressure
- Pascal' Principle
- Buoyancy & Archimedes
- Fluid statcis vs dynamics
- Bernoulli → Convection REVISITED



Heat-transfer mechanisms

When two objects are in direct contact, such as the soldering iron and the circuit board, heat is transferred by *conduction*.

Air currents near a warm glass of water rise, taking thermal energy with them in a process known as *convection*.

The lamp at the top shines on the lambs huddled below, warming them. The energy is transferred by *radiation*.

Blowing on a hot cup of tea or coffee cools it by *evaporation*.

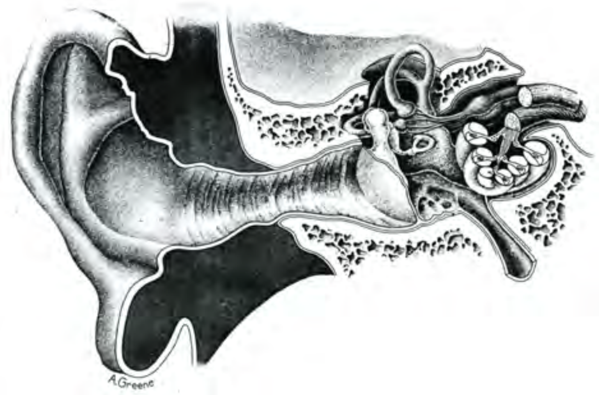
Knight

Recall (re pressure)

Kesten & Tauck ch.14

$$pV = NkT \quad \text{(ideal-gas law)}$$

- Pressure (a scalar, i.e., not a vector) is directly related to force
- But that must mean “area” is a vector too(!!?!)

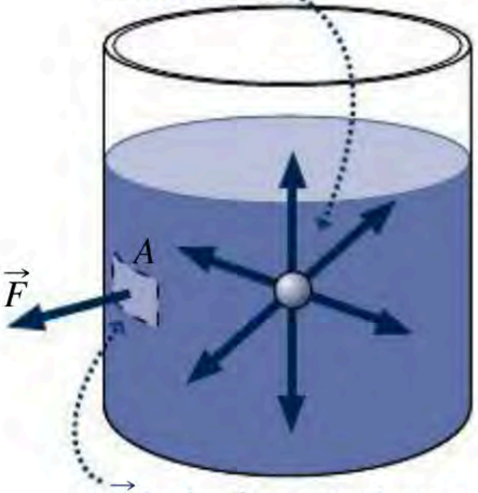


Changes in pressure is how sound energy propagates

Kesten & Tauck ch.11

$$p = \frac{F}{A} \quad \text{(pressure)}$$

The fluid exerts pressure internally as well as on the container. The internal pressure is the same in all directions.



$\vec{F}$ is the force on the area A, so the pressure is $p = F/A$.

FIGURE 15.1 Pressure, the force per unit area, is exerted equally in all directions.

Wolfson

Recall (re a barometer)

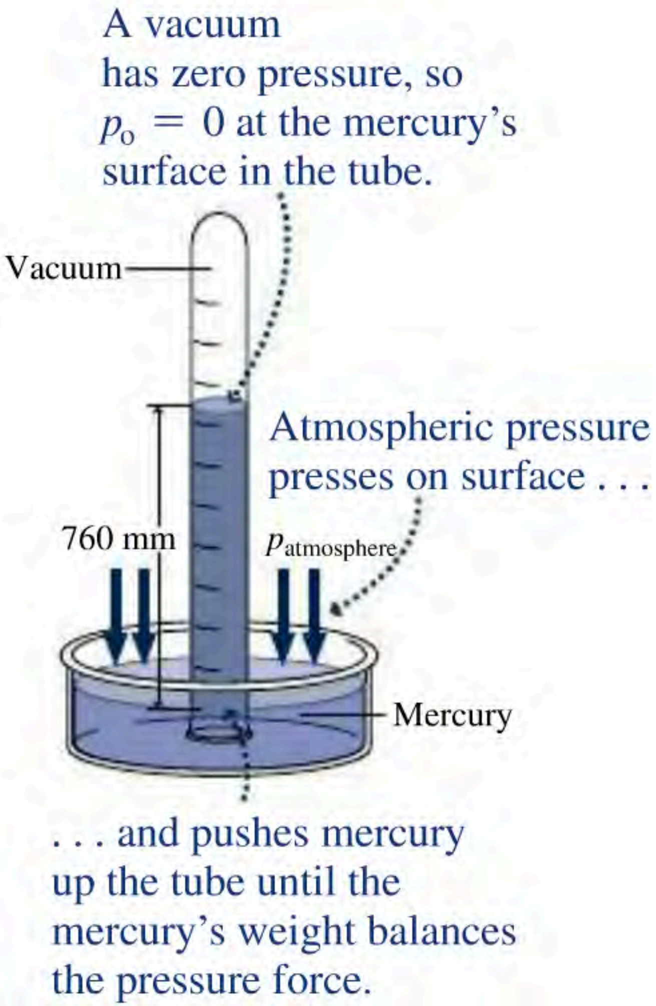


FIGURE 15.4 A mercury barometer.

→ Basic concepts stemming from Newtonian mechanics apply to fluids and gases too

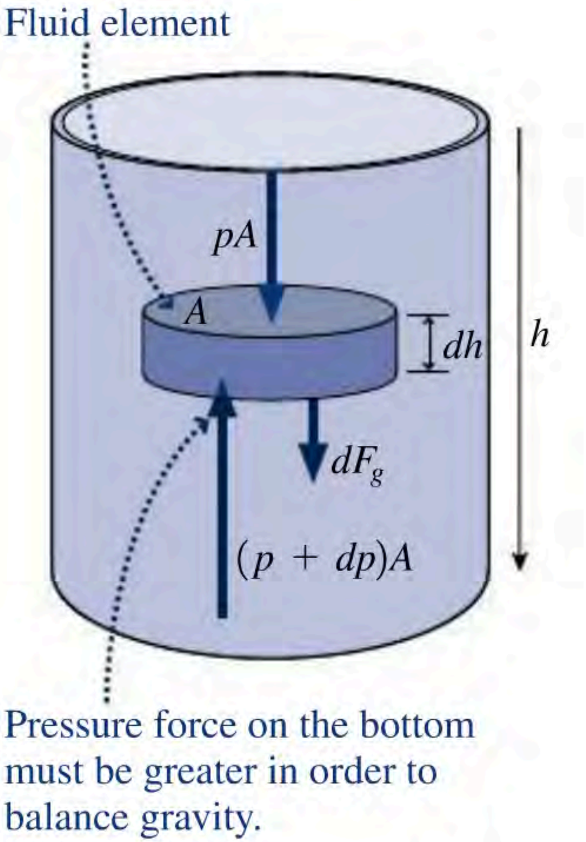


FIGURE 15.3 Forces on a fluid element in hydrostatic equilibrium.

Wolfson

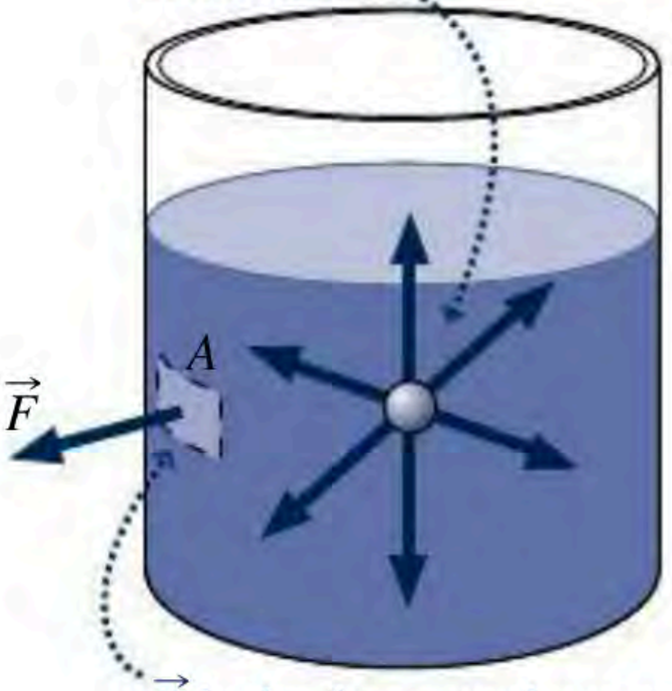
Fluids/Gases: Pressure

$$\vec{F} = P\vec{A}$$

$$1\ \mathrm{Pa} = 1\,\frac{\mathrm{N}}{\mathrm{m}^2}$$

So is it okay to divide two vectors then?

The fluid exerts pressure internally as well as on the container. The internal pressure is the same in all directions.



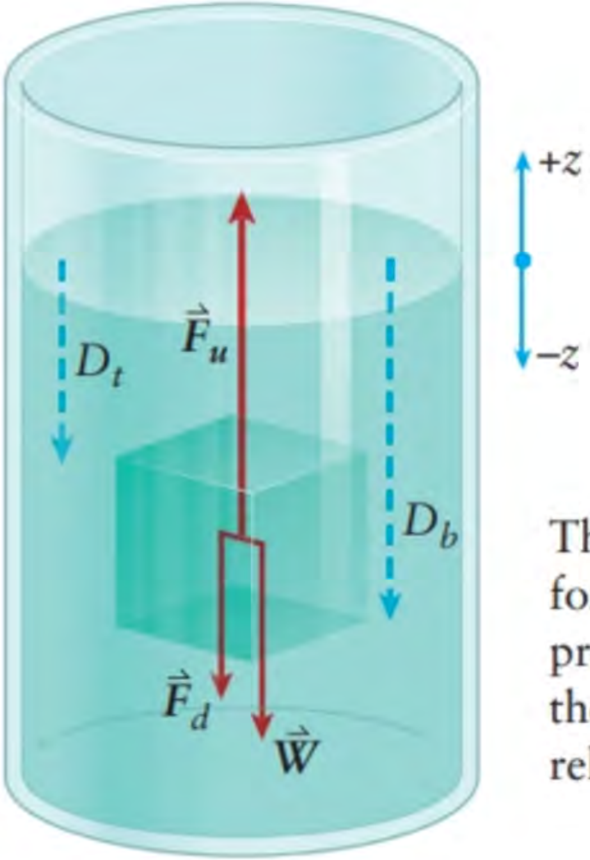
$\vec{F}$ is the force on the area A, so the pressure is $p = F/A$.

FIGURE 15.1 Pressure, the force per unit area, is exerted equally in all directions.

Fluids/Gases: Pressure & Depth (& Atmospheric pressure)

$$\vec{F}_u + \vec{F}_d + \vec{W} = 0$$

$$P = P_0 + \rho g d$$



The upward force $\vec{F}_u$ and the pressure below the volume are related.

The downward force $\vec{F}_d$ and the pressure above the volume are related.

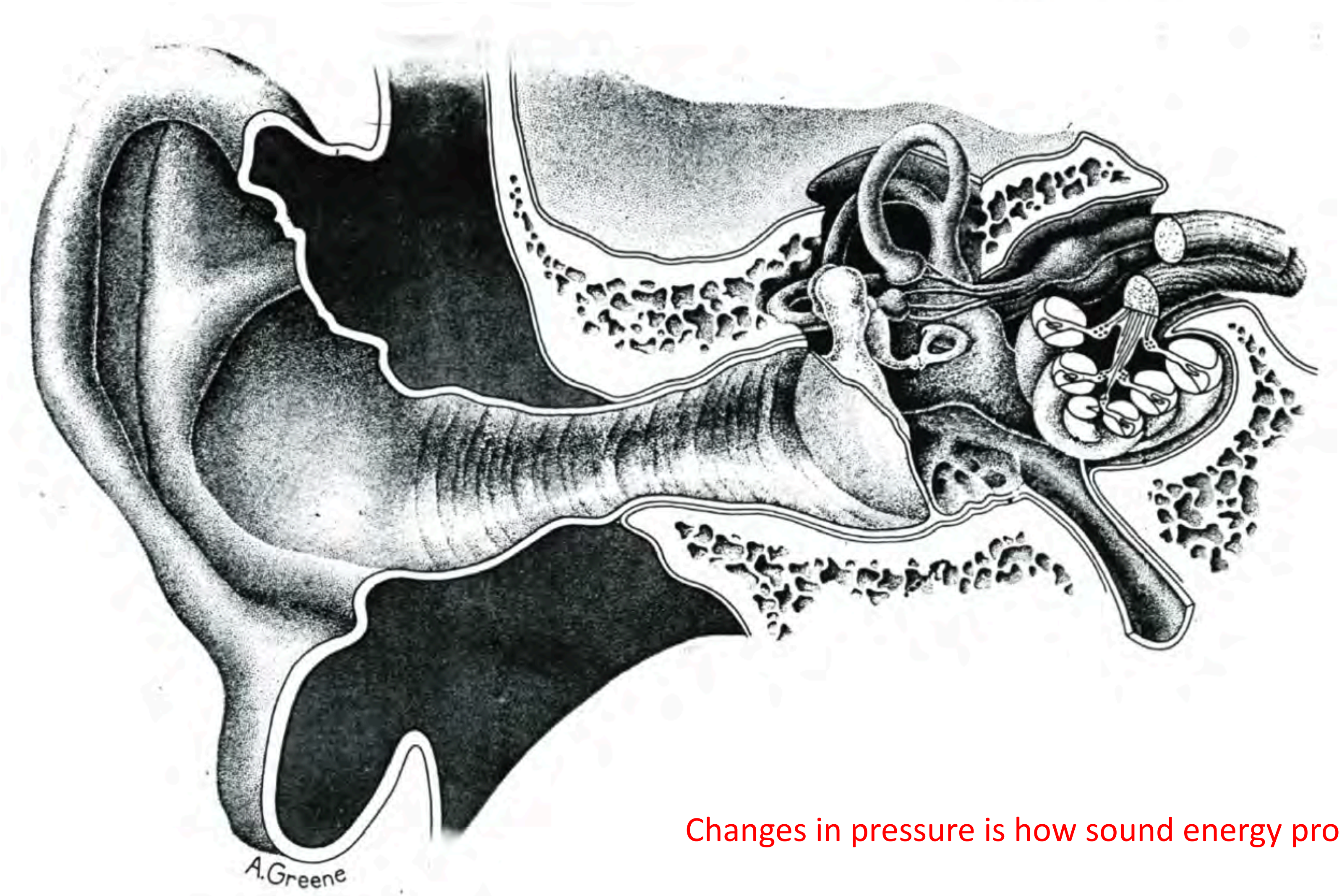
The imaginary volume is stationary because the net upward and downward forces cancel.

$$P_{\text{atm}} = 1 \text{ atmosphere} = 1 \text{ atm} = 1.01 \times 10^5 \text{ Pa}$$

Kesten & Tauck

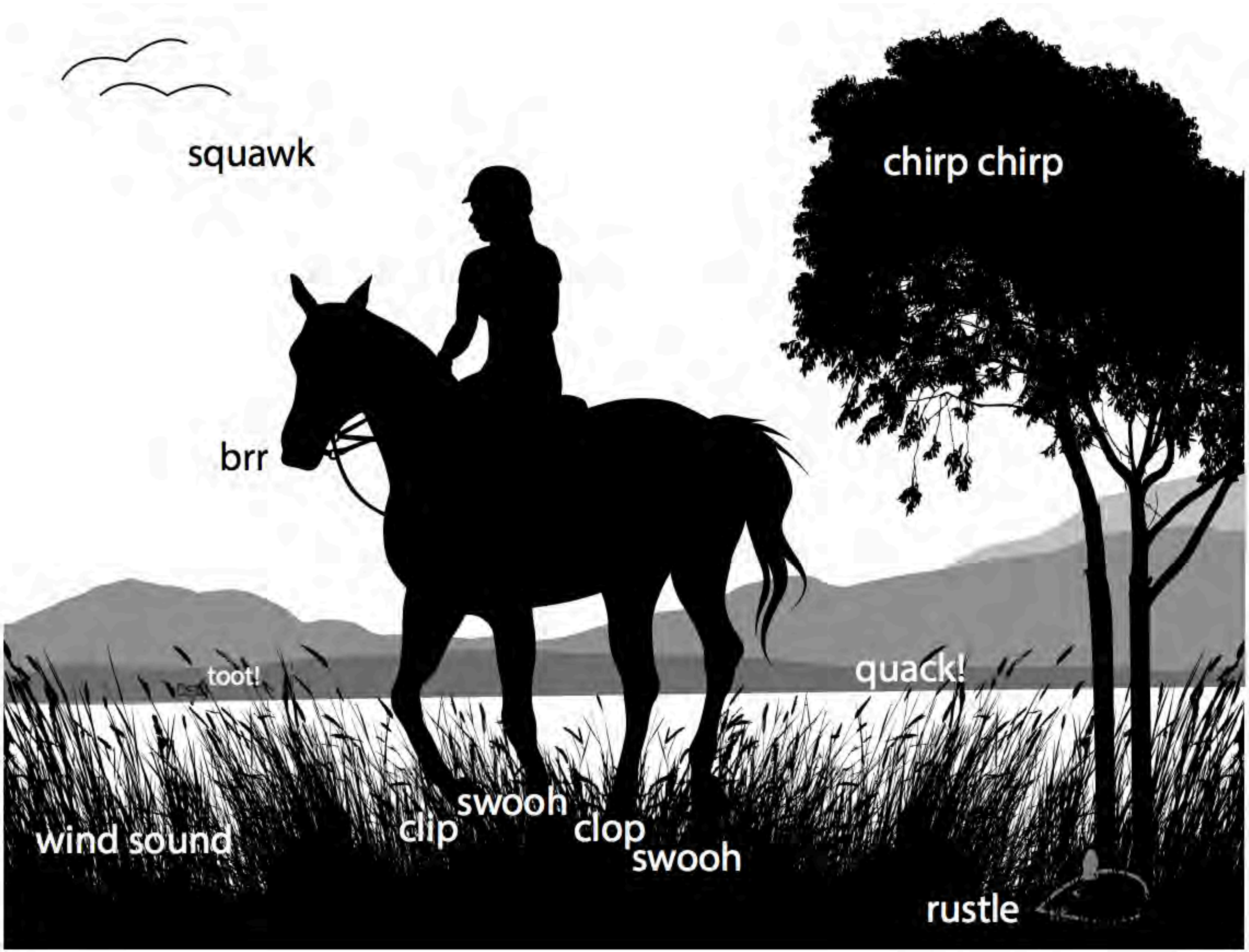
Fluids/Gases: Pressure difference

$$\vec{F}_{\text{net}} = \Delta P \vec{A}$$



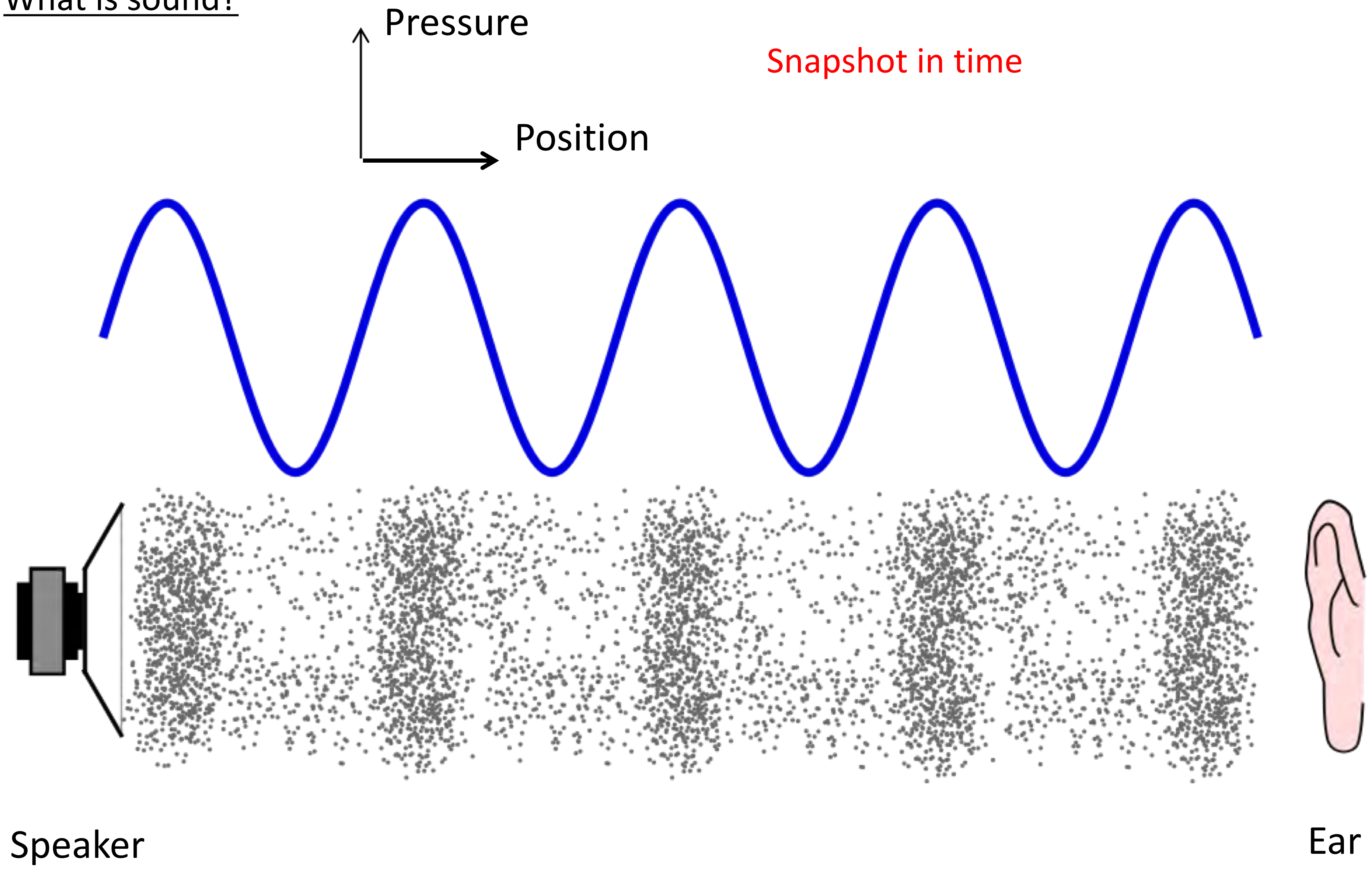
Changes in pressure is how sound energy propagates

Sound...



Pulkki & Karjalainen (2015)

What is sound?

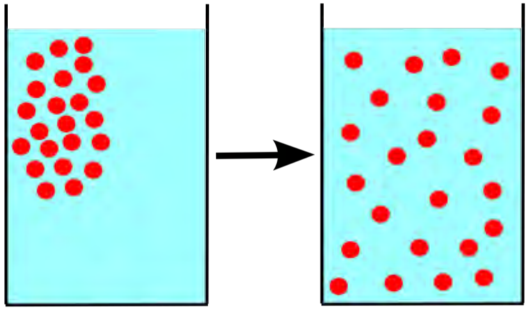


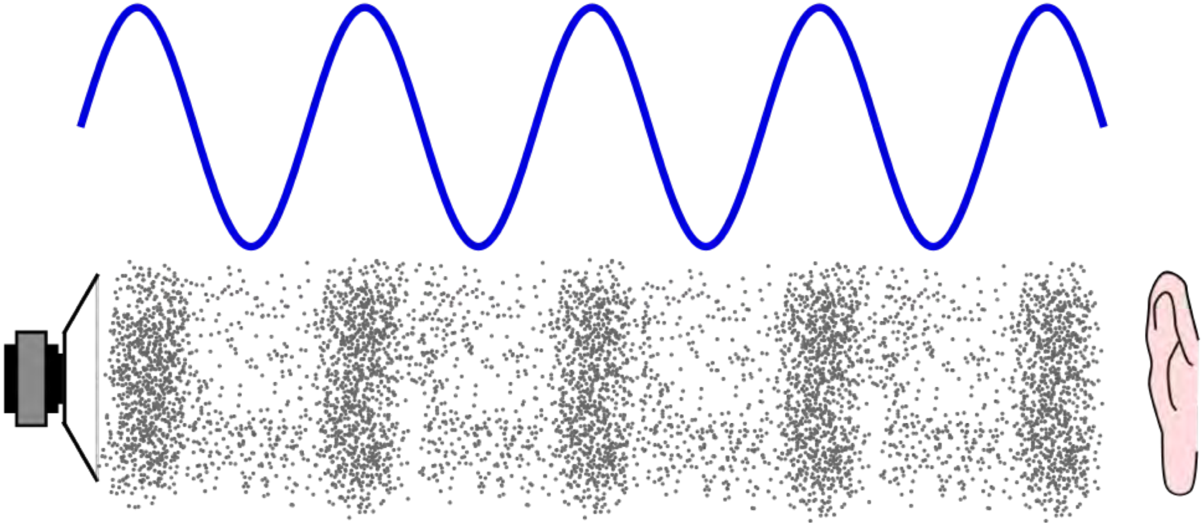
Snapshot in time

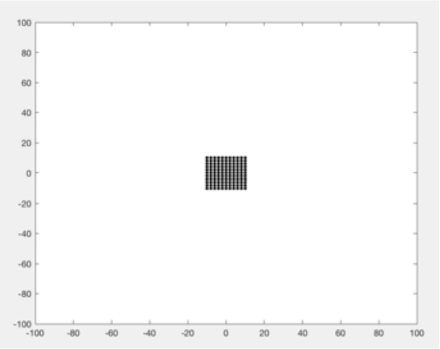
→ Note the periodic nature present....

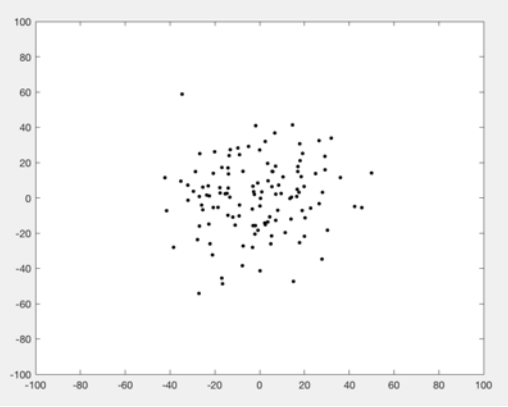
Pulkki & Karjalainen (2015)

Connection Point









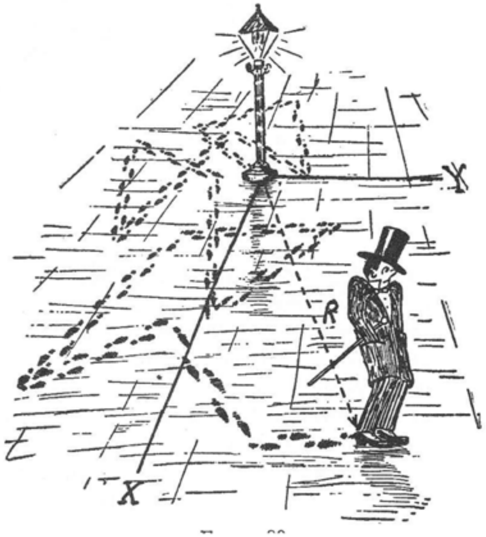
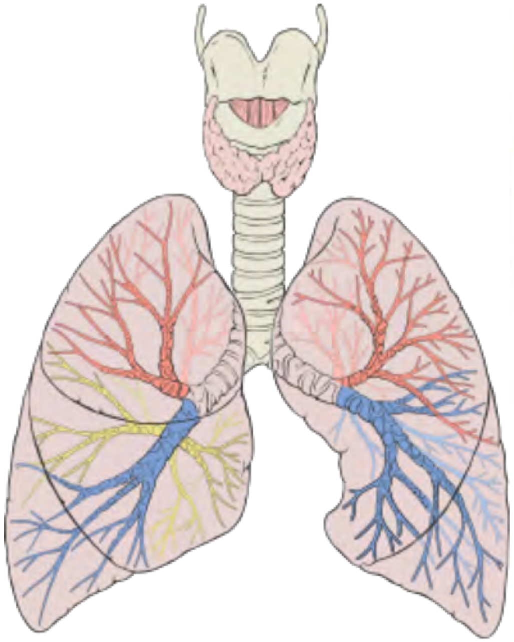
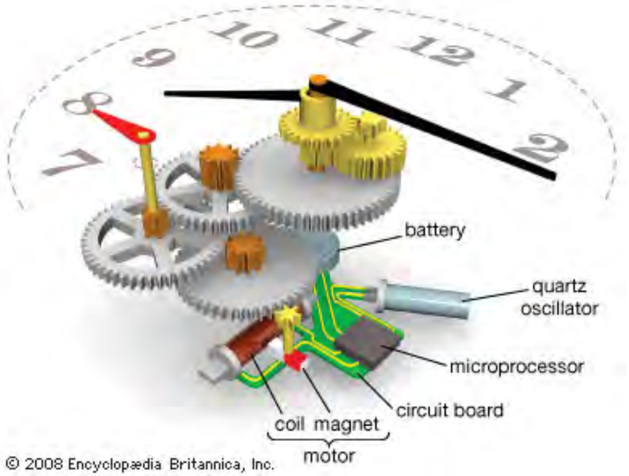


Figure 4.1: (Metaphor.) A random (or "drunkard's") walk. [Cartoon by George Gamow, from Gamow, 1961.]

→ Can think of sound as introducing a bit of a *bias*!

<u>Things that oscillate....</u>





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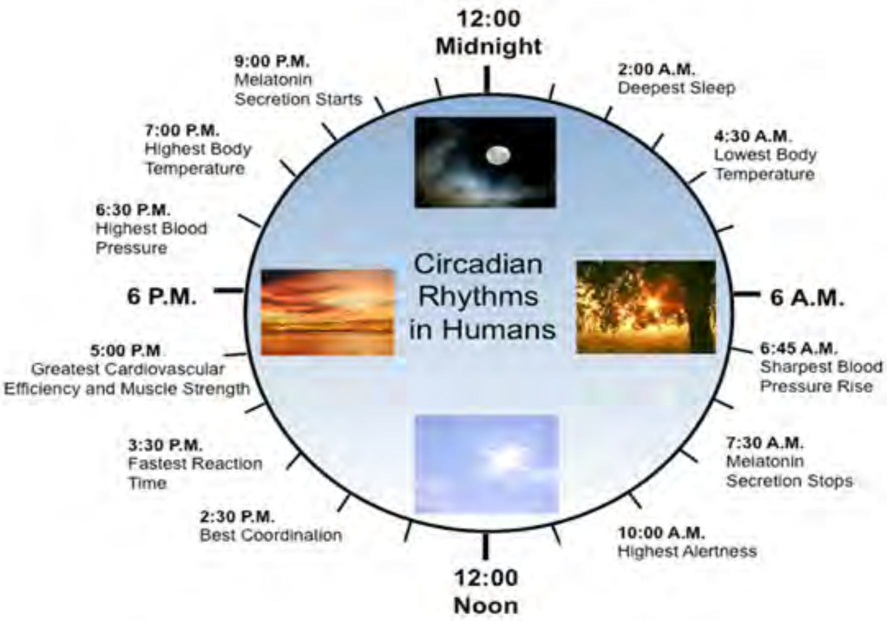
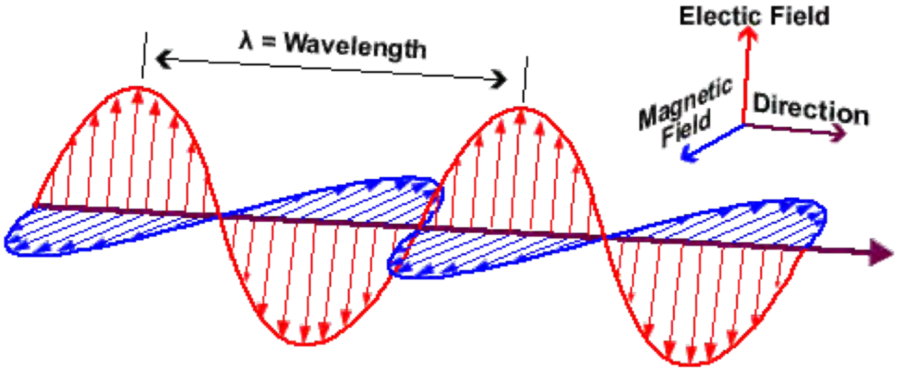
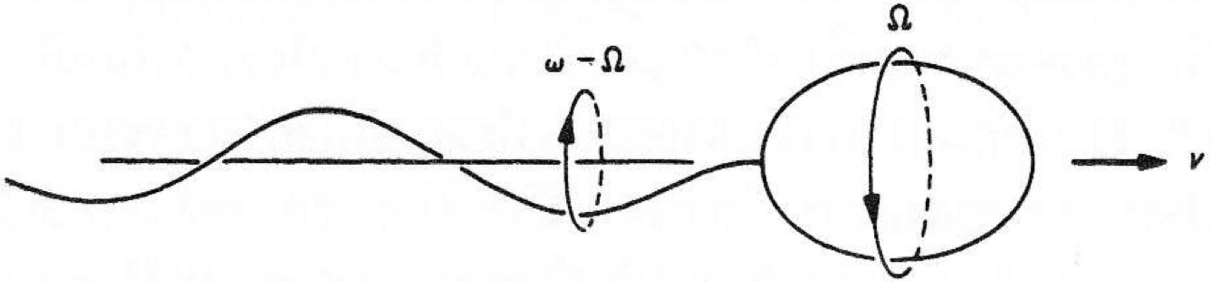




Things that oscillate....



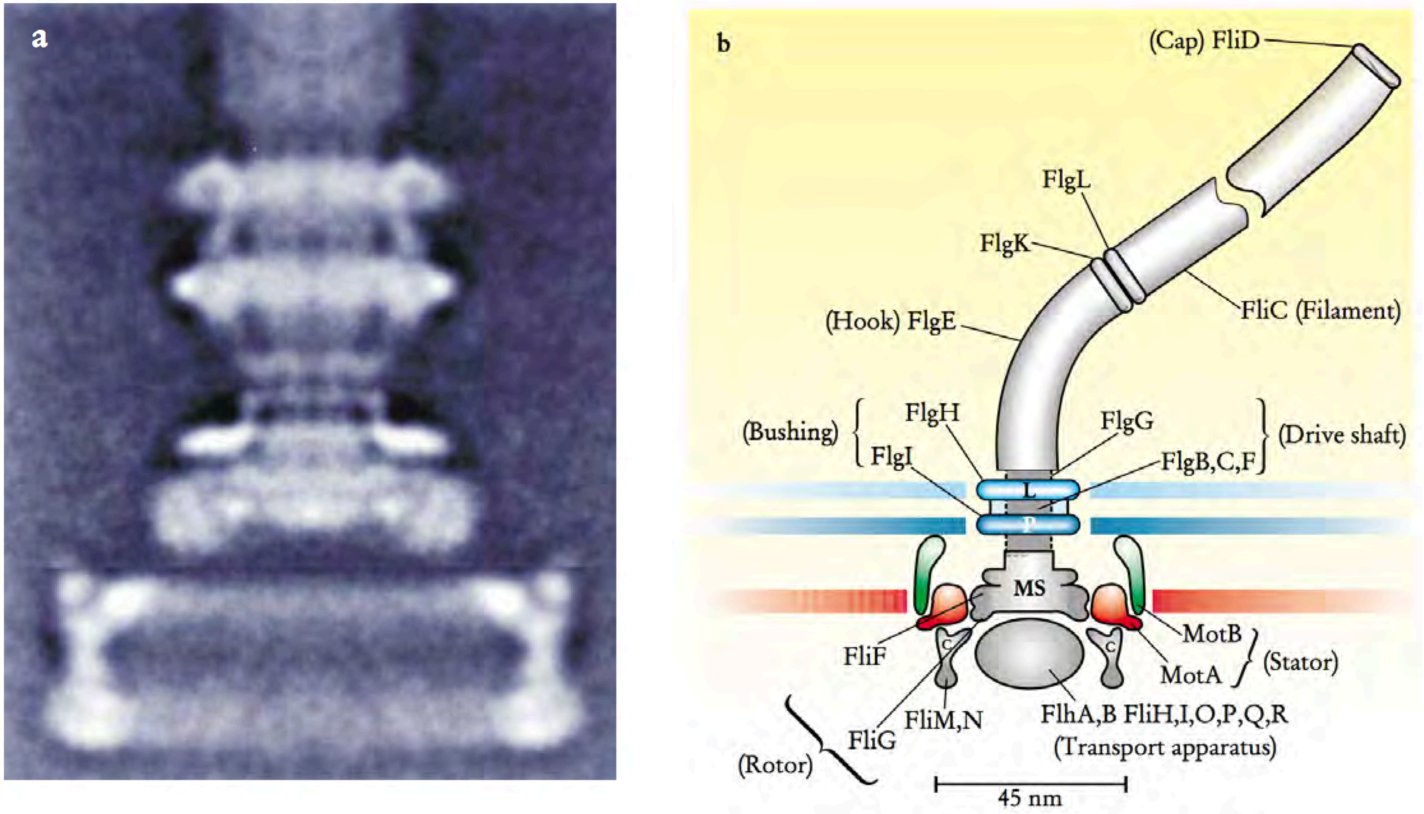
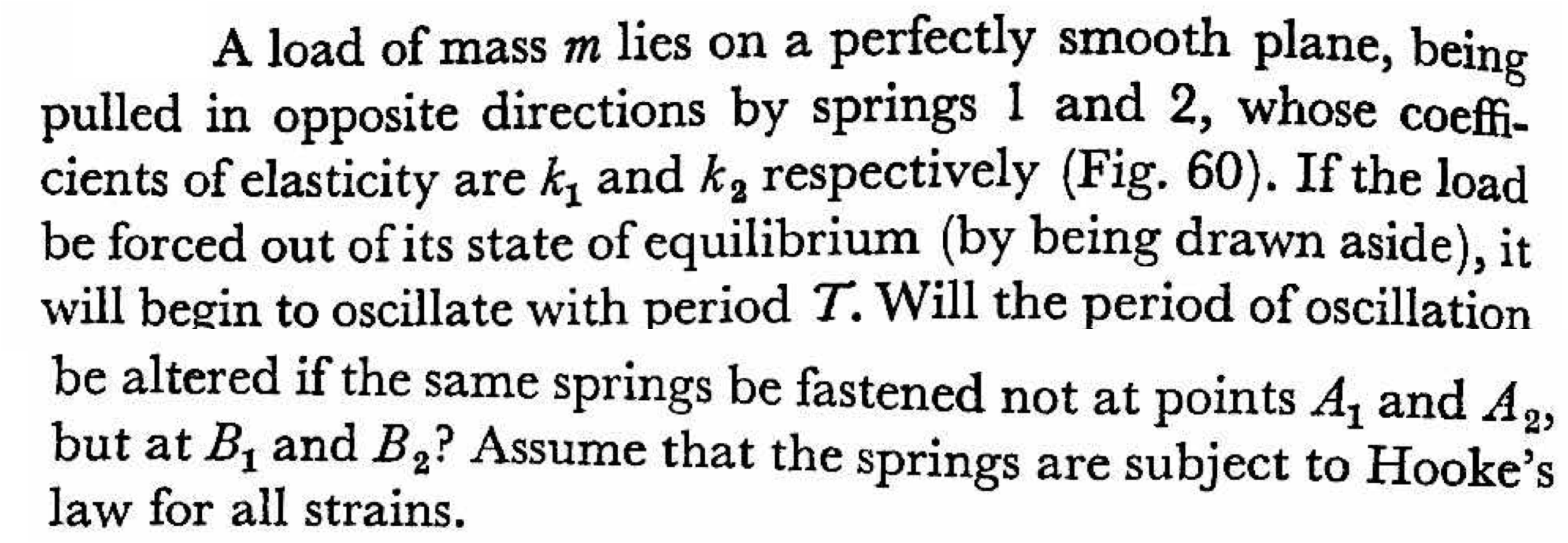


FIGURE 2. BACTERIAL MOTOR AND DRIVE TRAIN. (**a**) Rotationally averaged reconstruction of electron micrographs of purified hook-basal bodies. The rings seen in the image and labeled in the schematic diagram (**b**) are the L ring, P ring, MS ring, and C ring. (Digital print courtesy of David DeRosier, Brandeis University.)

Ex.



A load of mass m lies on a perfectly smooth plane, being pulled in opposite directions by springs 1 and 2, whose coefficients of elasticity are k_1 and k_2 respectively (Fig. 60). If the load be forced out of its state of equilibrium (by being drawn aside), it will begin to oscillate with period T. Will the period of oscillation be altered if the same springs be fastened not at points A_1 and A_2, but at B_1 and B_2? Assume that the springs are subject to Hooke's law for all strains.

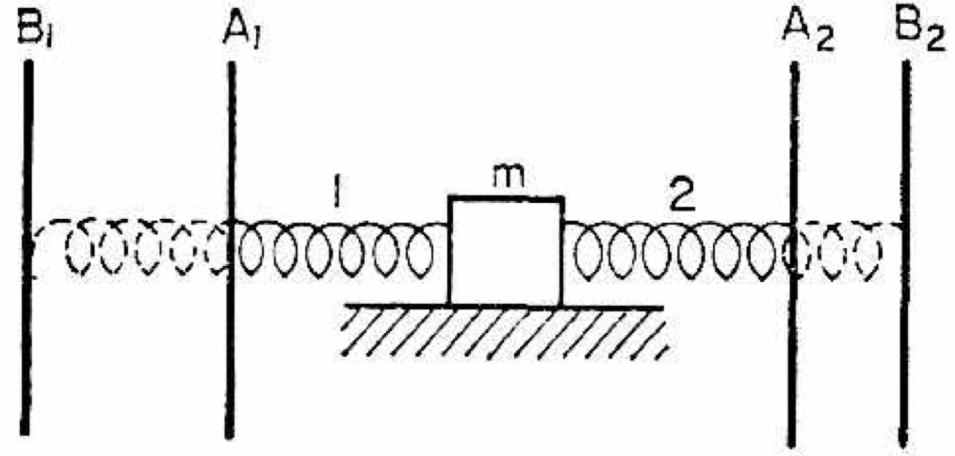
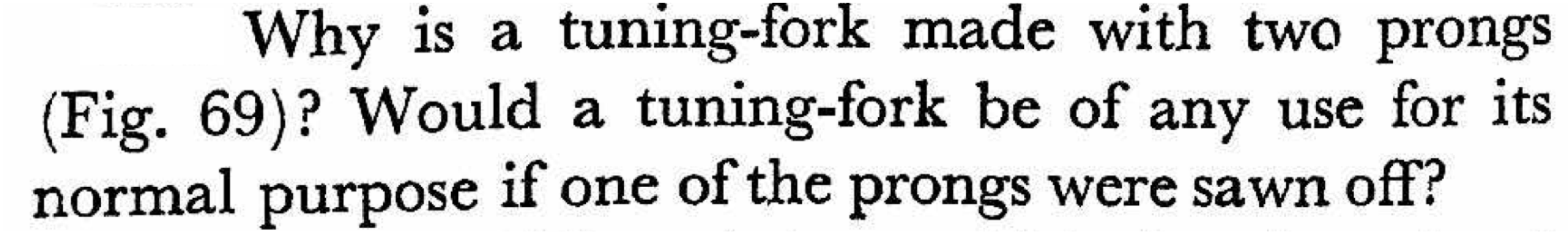


FIG. 60

Shaskol'Skaya & El'Tsin (1963)

Ex.



Why is a tuning-fork made with two prongs (Fig. 69)? Would a tuning-fork be of any use for its normal purpose if one of the prongs were sawn off?

Shaskol’Skaya & El’Tsin (1963)

Ex. (SOL)

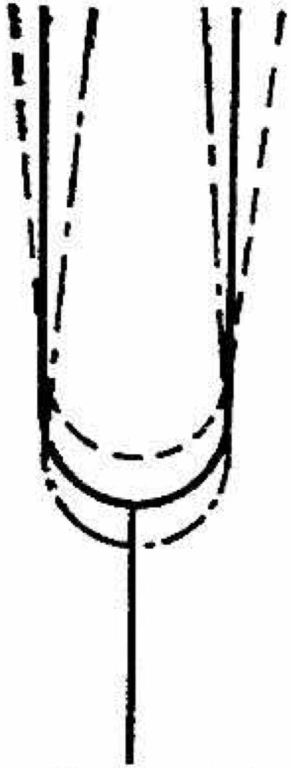
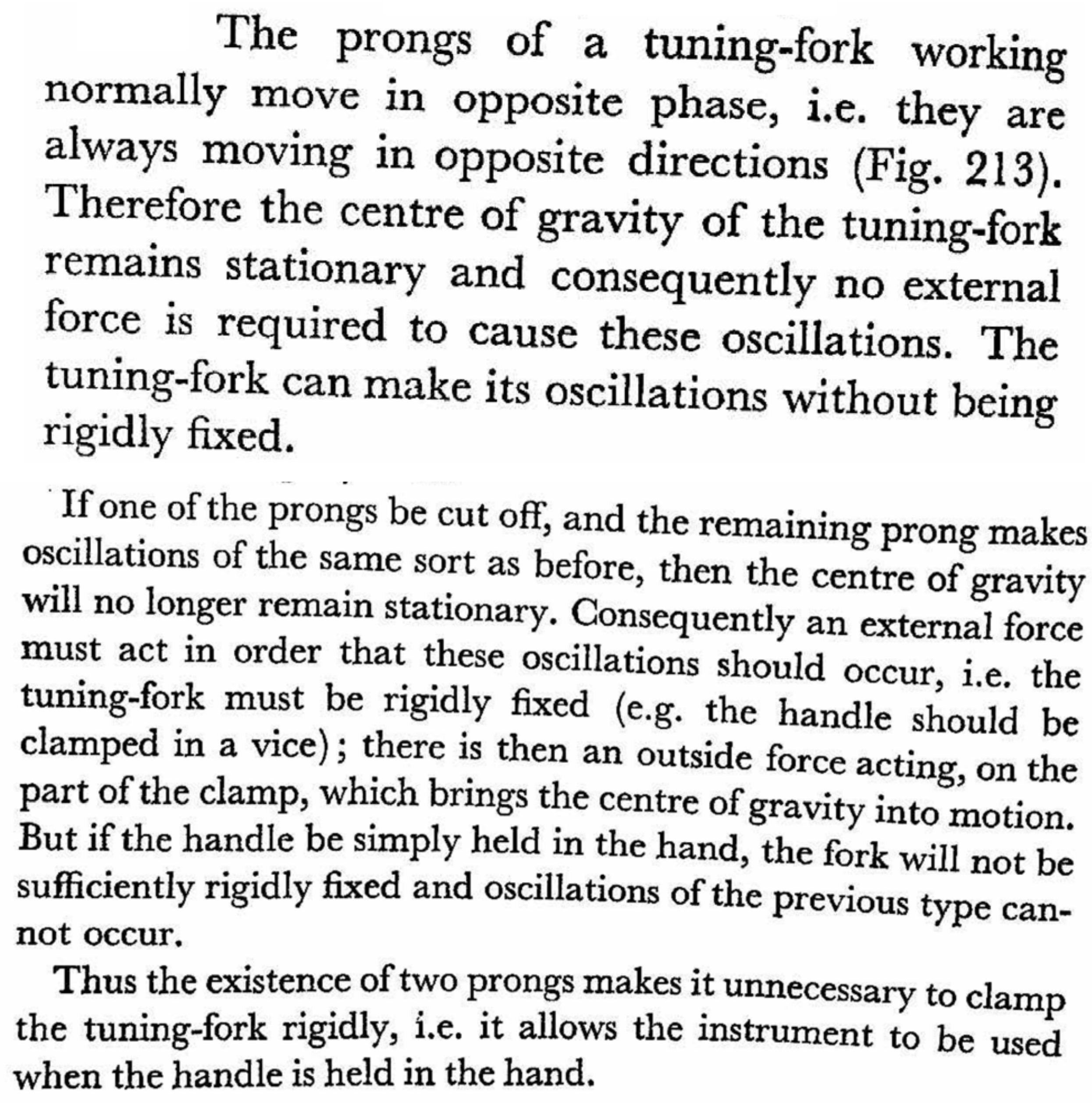


FIG. 213

→ This is actually a center-of-mass question!



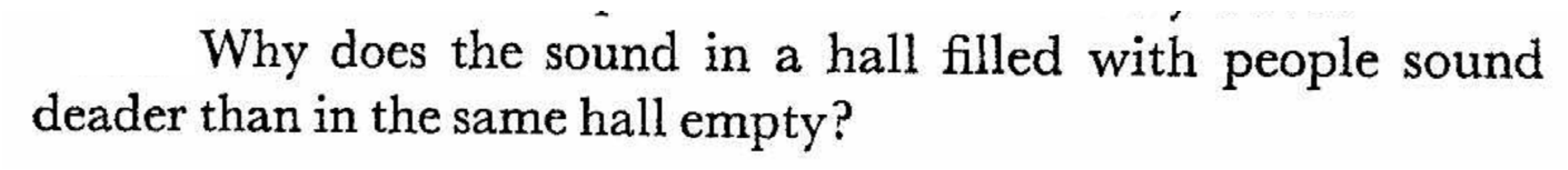
The prongs of a tuning-fork working normally move in opposite phase, i.e. they are always moving in opposite directions (Fig. 213). Therefore the centre of gravity of the tuning-fork remains stationary and consequently no external force is required to cause these oscillations. The tuning-fork can make its oscillations without being rigidly fixed.

If one of the prongs be cut off, and the remaining prong makes oscillations of the same sort as before, then the centre of gravity will no longer remain stationary. Consequently an external force must act in order that these oscillations should occur, i.e. the tuning-fork must be rigidly fixed (e.g. the handle should be clamped in a vice); there is then an outside force acting, on the part of the clamp, which brings the centre of gravity into motion. But if the handle be simply held in the hand, the fork will not be sufficiently rigidly fixed and oscillations of the previous type cannot occur.

Thus the existence of two prongs makes it unnecessary to clamp the tuning-fork rigidly, i.e. it allows the instrument to be used when the handle is held in the hand.

Shaskol'Skaya & El'Tsin (1963)

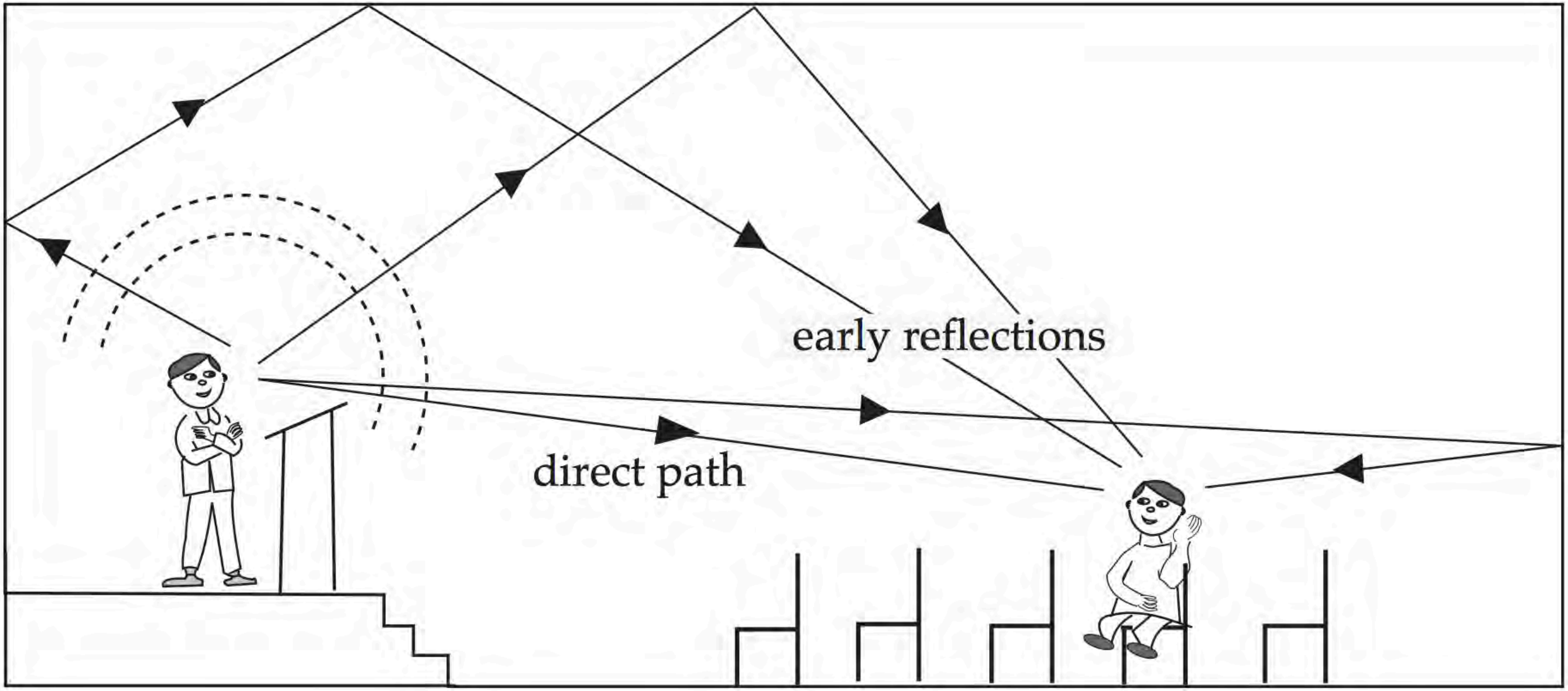
Ex.



Why does the sound in a hall filled with people sound deader than in the same hall empty?

Shaskol’Skaya & El’Tsin (1963)

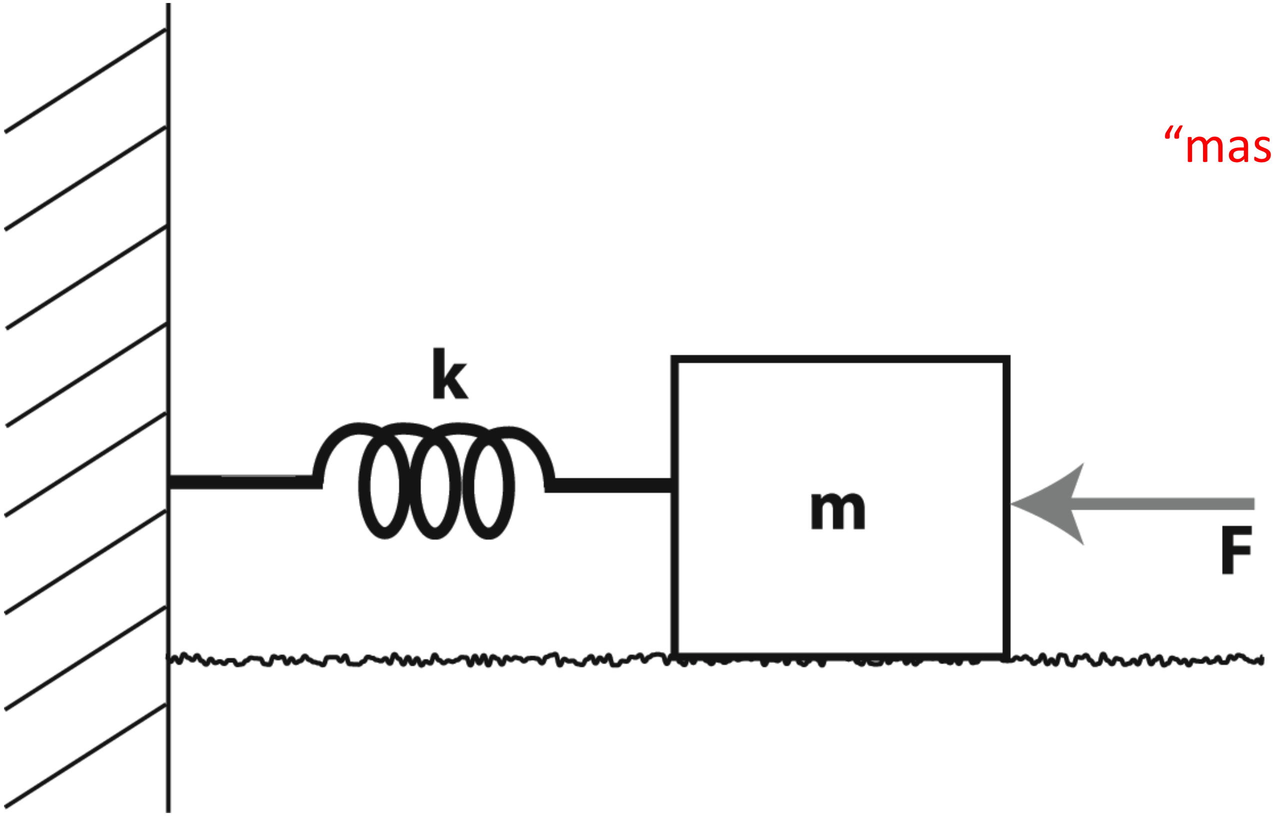
What is sound? (REVISITED)



→ The notion of acoustics deals not just with oscillations, but *waves* as well....

Pulkki & Karjalainen (2015)

Harmonic oscillator

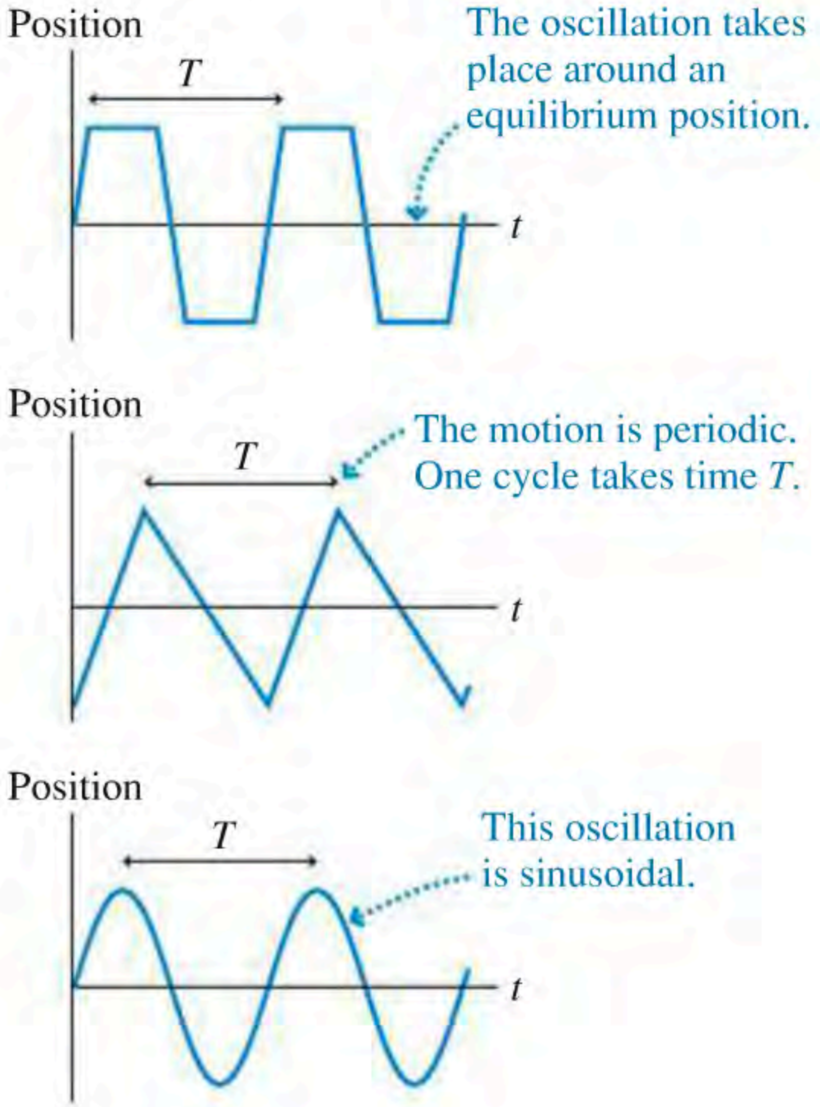


"mass-on-a-spring"

- One of the most fundamental/canonical problems in physics

Periodicity

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



The oscillation takes place around an equilibrium position.

The motion is periodic. One cycle takes time T.

This oscillation is sinusoidal.

Frequency & period

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

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

Units of frequency

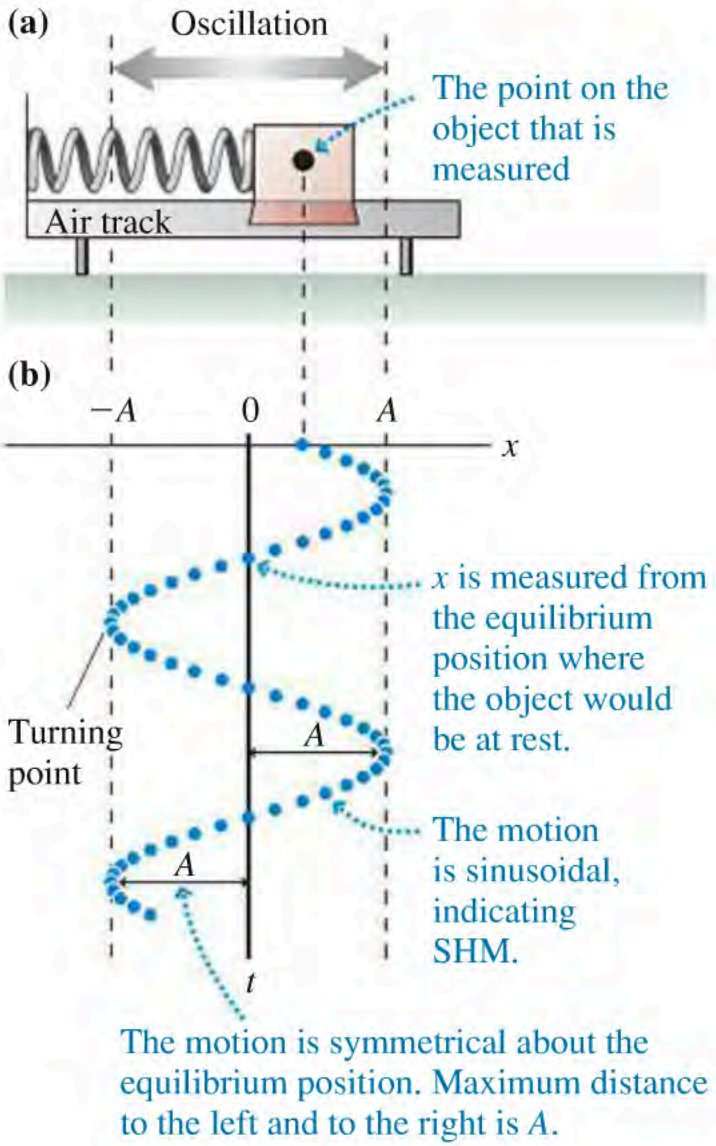
Frequency	**Period**
10^3 Hz = 1 kilohertz = 1 kHz	1 ms
10^6 Hz = 1 megahertz = 1 MHz	1 μs
10^9 Hz = 1 gigahertz = 1 GHz	1 ns

Angular frequency

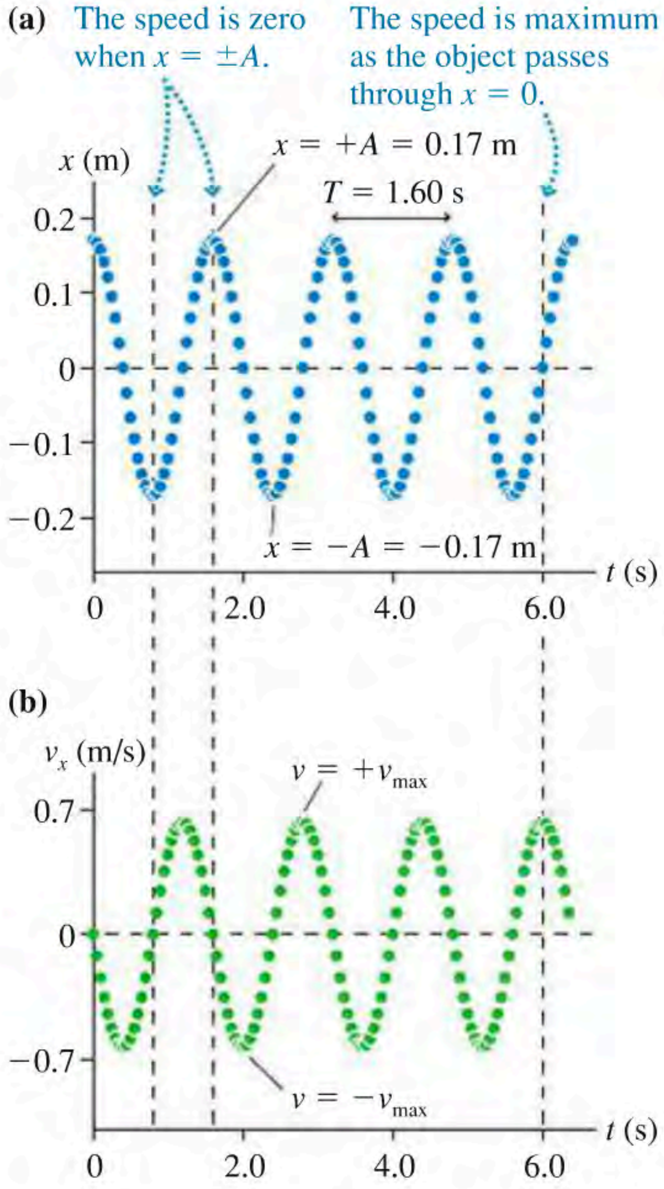
$$\omega\ (\text{in rad/s}) = \frac{2\pi}{T} = 2\pi f\ (\text{in Hz})$$

Knight

A prototype simple-harmonic-motion experiment.



Position and velocity graphs of the experimental data.



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

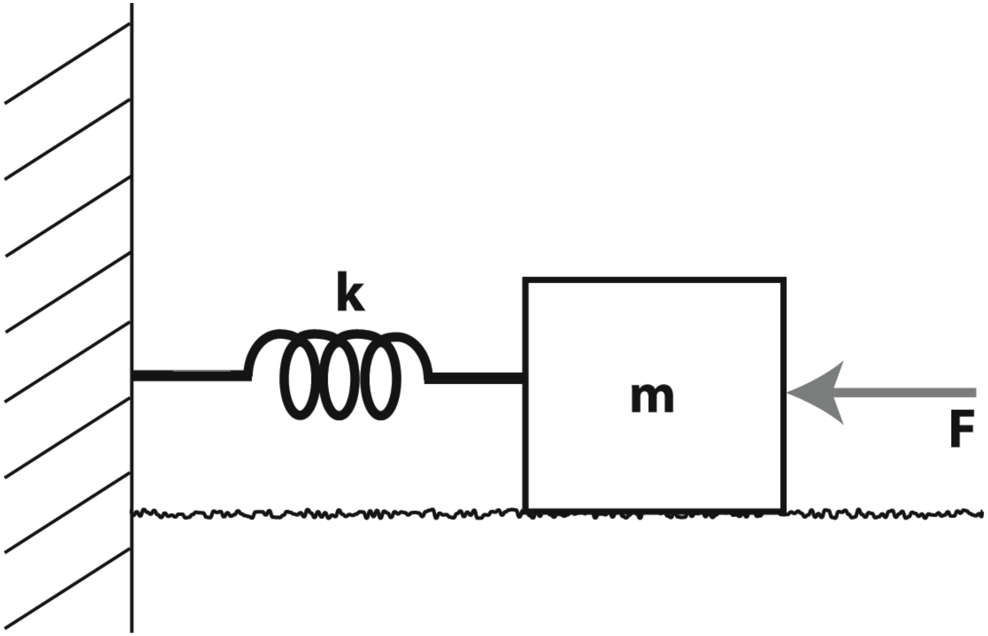
$$x(t) = A\cos\left(\omega_o t + \phi\right)$$

$\Rightarrow$ Solution is oscillatory!

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

System has a *natural* frequency

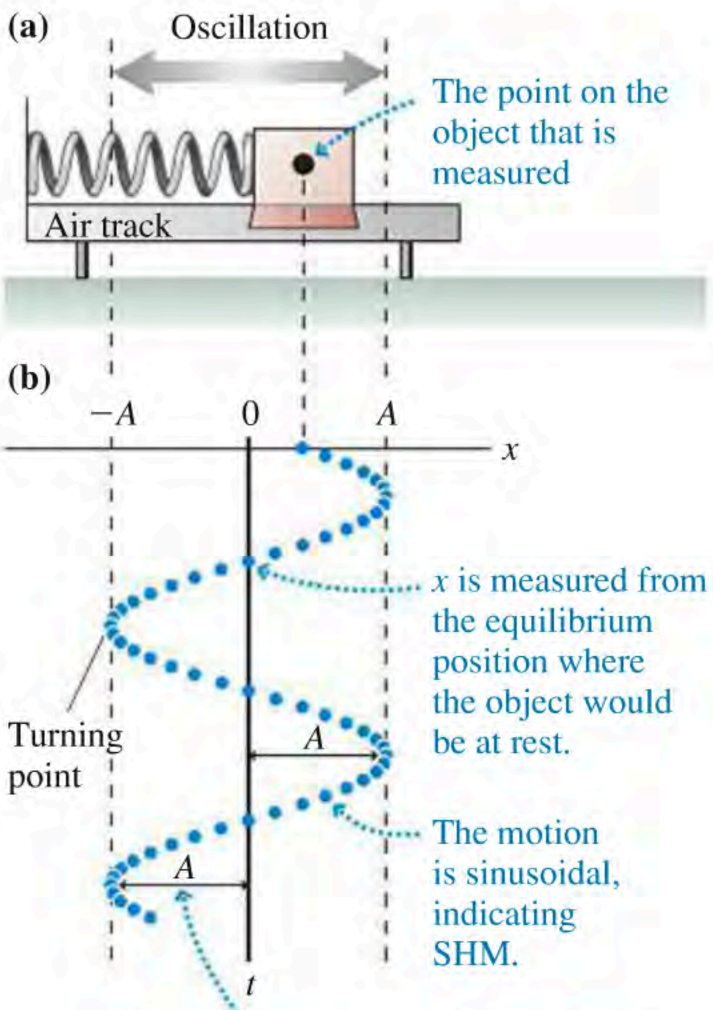
Harmonic oscillator



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

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

A prototype simple-harmonic-motion experiment.



The point on the object that is measured

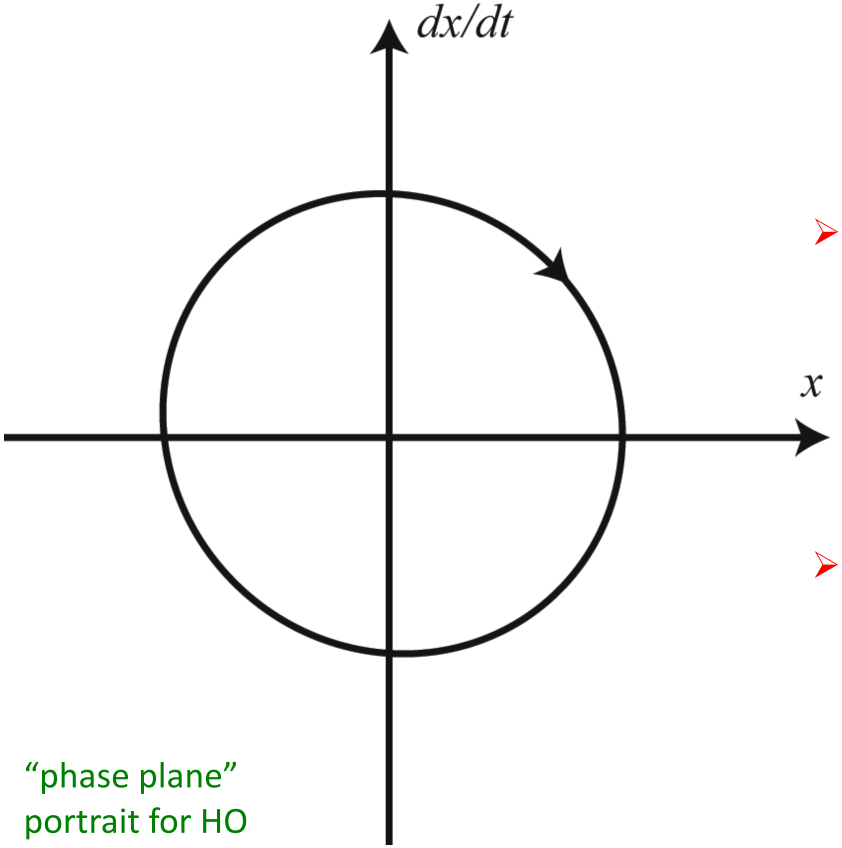
x is measured from the equilibrium position where the object would be at rest.

The motion is sinusoidal, indicating SHM.

The motion is symmetrical about the equilibrium position. Maximum distance to the left and to the right is *A*.

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)