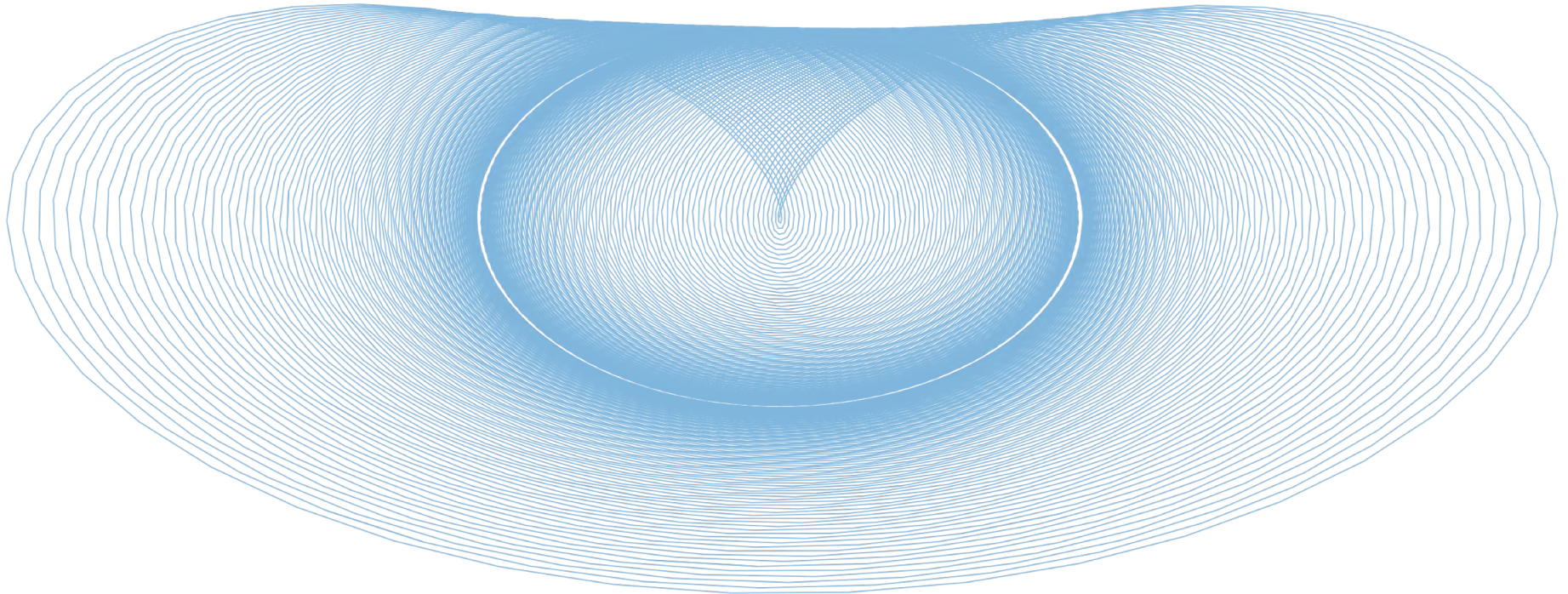# PHYS 1420 (F19)
Physics with Applications to Life Sciences

2019.xx.xx
<u>Relevant reading</u>:
Kesten & Tauck ch.xx

Christopher Bergevin
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<u>Ref.</u> (re images):
Wolfson (2007), Knight (2017)

What is the value of

$$\sqrt{.2^{-2}}$$

a) 5

b) 25

c) 10

d) .04

e) − .04

Announcements & Key Concepts (re Today)

→ Online HW #9: Posted and due

→ Lectures end a week from today!

Some relevant underlying concepts of the day…

➢ Imaginary #s revisited

➢ Resonance (and the wide variety of such)

➢ Speech as an example

<u>Ex.</u>

A load of mass m falls from height h on to a scale-pan suspended from a spring whose coefficient of elasticity is k; the load remains on the pan, i.e. its impact on the bottom of the scale-pan may be considered perfectly inelastic (Fig. 61). The pan begins to oscillate. Find the amplitude of the scale-pan's oscillation. (For the purposes of simplification consider first the case when the pan's weight may be neglected.)

Ex. (SOL)

→ Turns out this is kinda a hard problem…

When mass m reaches the scale-pan, it will have a kinetic energy of

$$\frac{mv^2}{2} = mgh. \tag{1}$$

After impact the load and the pan together will have the same momentum as the load had before impact, and (since we are ignoring the mass of the scale-pan) the same velocity and the same kinetic energy, viz., mgh. After impact the scale-pan plus load will move downwards and extend the spring. The extension of the spring will take place at the expense of the initial kinetic energy and the work done by the force of gravity. If the displacement downwards of the pan be considered positive, then the work done by the force of gravity is mgx, where x is the pan's displacement from its initial position. Therefore the greatest extension x_0

of the spring is determined by the fact that all the kinetic energy and the work done by the force of gravity go into the elastic deformation of the spring, i.e.

$$\frac{kx_0^2}{2} = mgh + mgx_0 \tag{2}$$

or

$$x_0^2 - \frac{2mg}{k} x_0 - \frac{2mgh}{k} = 0.$$

hence

$$x_0 = \frac{mg}{k} + \sqrt{\frac{m^2g^2}{k^2} + \frac{2mgh}{k}}.$$

Here the positive root of this equation corresponds with the lowest displacement downwards (since we agreed to consider downward displacement as positive). Since this greatest displacement is greater than mg/k (which corresponds with the scale-pan's position of equilibrium when the load is in it), it follows that the pan, having reached its lowest position will begin to rise, will pass through its original position and will rise farther, compressing the spring. When it comes to rest at its highest position the potential energy of the compressed spring will again equal the sum of the initial kinetic energy and the work done by the force of gravity, i.e. the greatest displacement upwards will also be determined by equation (2), but the second, negative root will correspond with this upward displacement. And so the scale-pan will make oscillations between the two extreme positions

$$x_{01} = \frac{mg}{k} + \sqrt{\frac{m^2g^2}{k^2} + \frac{2mgh}{k}}.$$

and

$$x_{02} = \frac{mg}{k} - \sqrt{\frac{m^2g^2}{k^2} + \frac{2mgh}{k}}.$$

Shaskol'Skaya & El'Tsin (1963)

Ex. (SOL)

And to the position of equilibrium of the scale-pan will correspond a displacement of

$$x_0 = \frac{mg}{k}.$$

Consequently the greatest displacements in either direction from the equilibrium position will be identical, and equal

$$\sqrt{\frac{m^2g^2}{k^2} + \frac{2mgh}{k}}. \qquad (3)$$

This is the amplitude of the scale-pan's oscillations.

If we are not allowed to neglect the mass of the scale-pan M, then the velocity with which the scale-pan will begin to move downwards will not equal the velocity with which the load reaches the scale-pan and which is determinable from equation (1). To find the velocity V with which the scale-pan begins to move downwards under the influence of the load's fall, we must make use of the law of conservation of momentum. In this case we shall have

$$mv = (M + m)V \text{ and } V = \frac{m}{M+m}v.$$

Substituting for v from equation (1), we shall get:

$$V = \frac{m}{M+m}\sqrt{2gh}.$$

Further it should be remembered that the moving mass will now be $M + m$. Besides this, at the initial moment the spring is extended a distance a as a result of the weight of the scale-pan, so that

$$ka = Mg \qquad (4)$$

Therefore the law of conservation of energy gives

$$\frac{kx^2}{2} - \frac{ka^2}{2} = \tfrac{1}{2}(M+m)\left[\frac{m\sqrt{2gh}}{M+m}\right]^2 + (M+m)g(x-a).$$

Substituting for a in this equation from equation (4) and taking all the terms over to the left-hand side, we shall obtain:

$$x^2 - \frac{2(M+m)g}{k}x - \frac{2m^2gh}{(M+m)k} + \frac{M(M+2m)g^2}{k^2} = 0.$$

Hence

$$x = \frac{M+m}{k}g \pm \sqrt{\frac{m^2g^2}{k^2} + \frac{2m^2gh}{(M+m)k}}.$$

The new equilibrium position will be

$$x_0 = \frac{M+m}{k}g.$$

Reasoning analogous to the previous case leads to this value for the amplitude

$$\sqrt{\frac{m^2g^2}{k^2} + \frac{2m^2gh}{(M+m)k}}. \qquad (5)$$

As we should expect, expression (5) becomes (3), if we put $M = 0$.

Shaskol'Skaya & El'Tsin (1963)

<u>Ex.</u>

A 500 g block on a spring is pulled a distance of 20 cm and released. The subsequent oscillations are measured to have a period of 0.80 s.

a. At what position or positions is the block's speed 1.0 m/s?
b. What is the spring constant?

MODEL The motion is SHM. Energy is conserved.

SOLVE a. The block starts from the point of maximum displacement, where $E = U = \frac{1}{2}kA^2$. At a later time, when the position is x and the speed is v, energy conservation requires

$$\frac{1}{2}mv^2 + \frac{1}{2}kx^2 = \frac{1}{2}kA^2$$

Solving for x, we find

$$x = \sqrt{A^2 - \frac{mv^2}{k}} = \sqrt{A^2 - \left(\frac{v}{\omega}\right)^2}$$

where we used $k/m = \omega^2$ from Equation 14.24. The angular frequency is easily found from the period: $\omega = 2\pi/T = 7.85$ rad/s. Thus

$$x = \sqrt{(0.20\ \text{m})^2 - \left(\frac{1.0\ \text{m/s}}{7.85\ \text{rad/s}}\right)^2} = \pm 0.15\ \text{m} = \pm 15\ \text{cm}$$

There are two positions because the block has this speed on either side of equilibrium.

b. Although part a did not require that we know the spring constant, it is straightforward to find from Equation 14.24:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

$$k = \frac{4\pi^2 m}{T^2} = \frac{4\pi^2\ (0.50\ \text{kg})}{(0.80\ \text{s})^2} = 31\ \text{N/m}$$

Knight

$$i^2 = -1, i = \sqrt{-1}$$

Euler's Formula

$$a + ib = Ae^{i\theta}$$

$$= A(\cos\theta + i\sin\theta)$$

Cartesian Form

$$a = A\cos(\theta)$$

$$b = A\sin(\theta)$$

$$\Longleftrightarrow$$

Polar Form

$$A = \sqrt{a^2 + b^2}$$

$$\theta = \tan^{-1}\left(\frac{b}{a}\right)$$
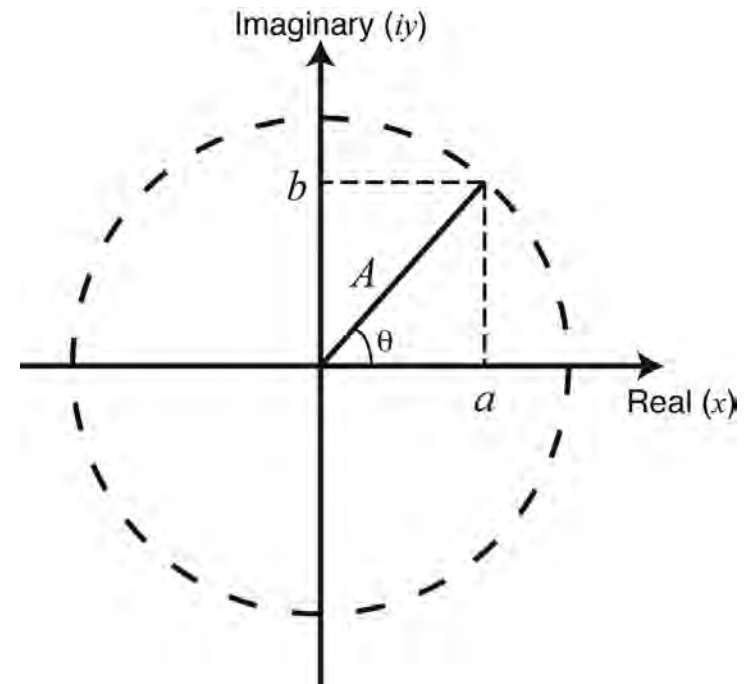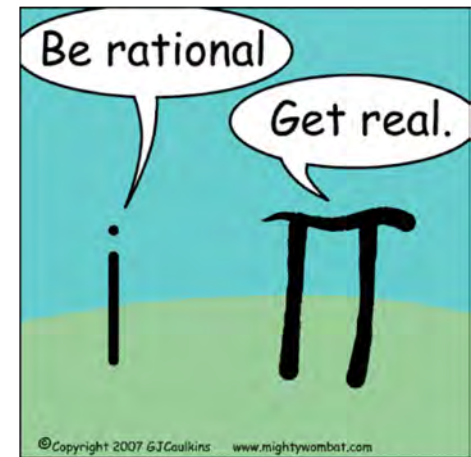
$\Rightarrow$ Complex solution contain both magnitude and phase information

Harmonic oscillator: Driven case (w/ damping)

$$\ddot{x} + \gamma\dot{x} + \omega_o^2 x = \frac{F_o}{m}e^{i\omega t}$$

Sinusoidal driving force at frequency ω

Assumption: Ignore onset behavior and that system oscillates at frequency ω

$$x(t) = Ae^{-i(\omega t+\delta)}$$

Assumed form of solution

$$A(\omega) = \frac{F_o/m}{[(\omega_o^2 - \omega^2)^2 + (\gamma\omega)^2]^{1/2}}$$

(magnitude)

$$\delta(\omega) = \arctan\left(\frac{\gamma\omega}{\omega^2 - \omega_o^2}\right)$$

(phase)

Harmonic oscillator: Driven case (w/ damping)

$$A(\omega) = \frac{F_o/m}{[(\omega_o^2 - \omega^2)^2 + (\gamma\omega)^2]^{1/2}}$$

$$\delta(\omega) = \arctan\left(\frac{\gamma\omega}{\omega^2 - \omega_o^2}\right)$$

Resonance

⇒ Second-order oscillator behaves as a "*band-pass filter*"

Amplitude

small γ

large γ

Phase

(cycles)

ω/ω_0
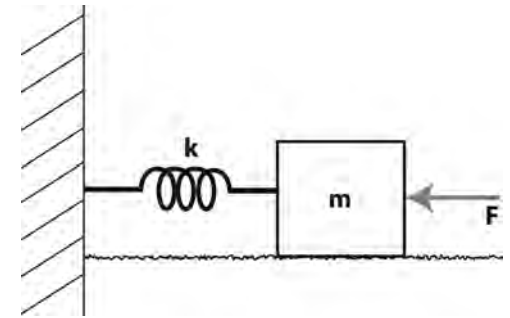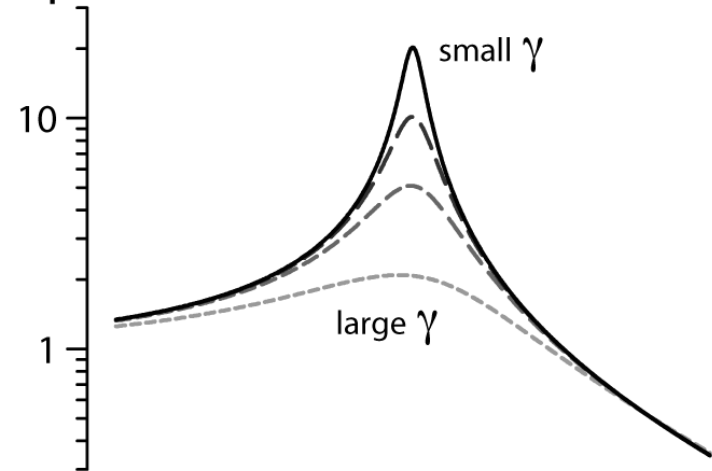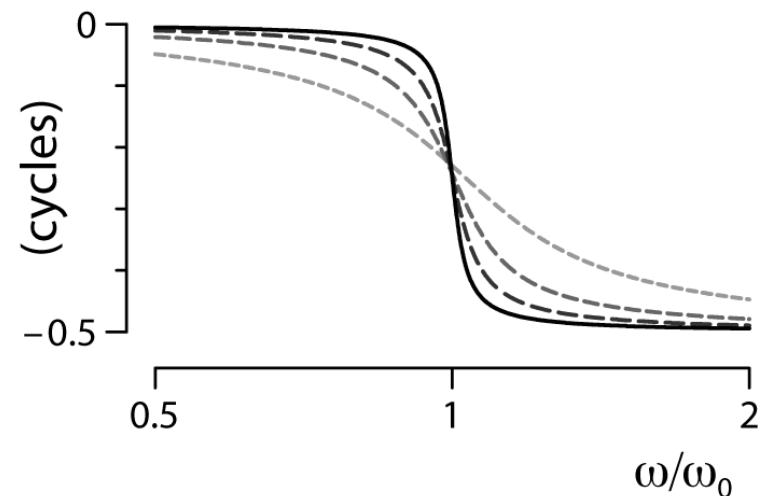
Resonance - Examples
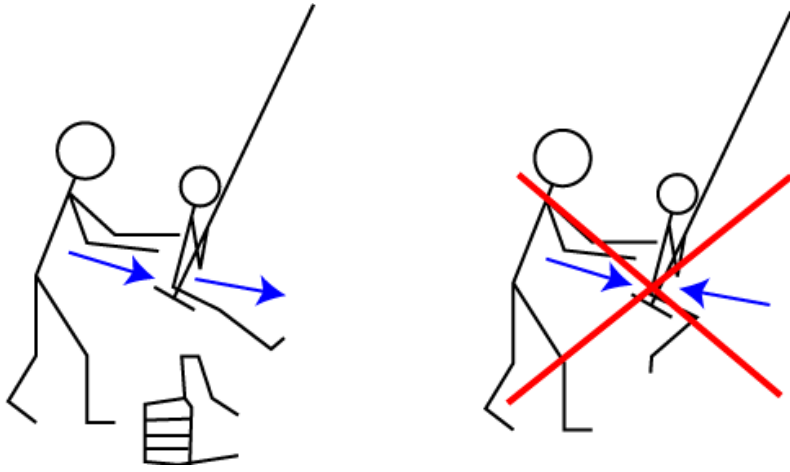
"Tonotopy" of the inner ear
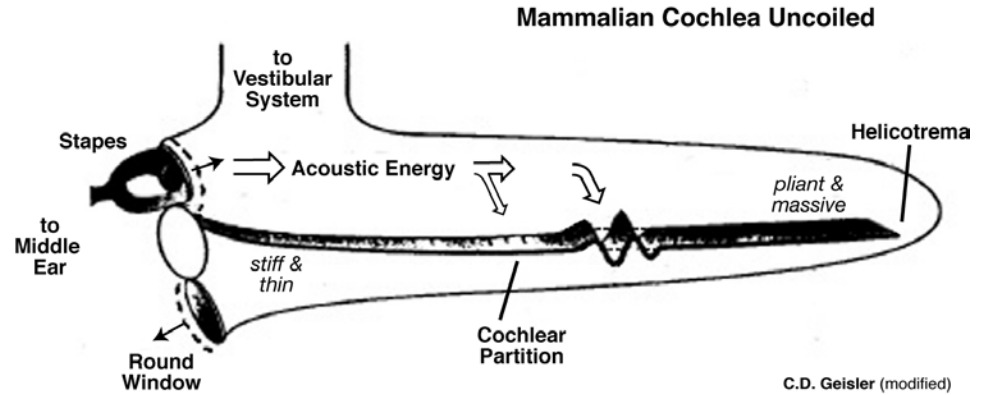
Slightly different type of "resonance"...

MRI
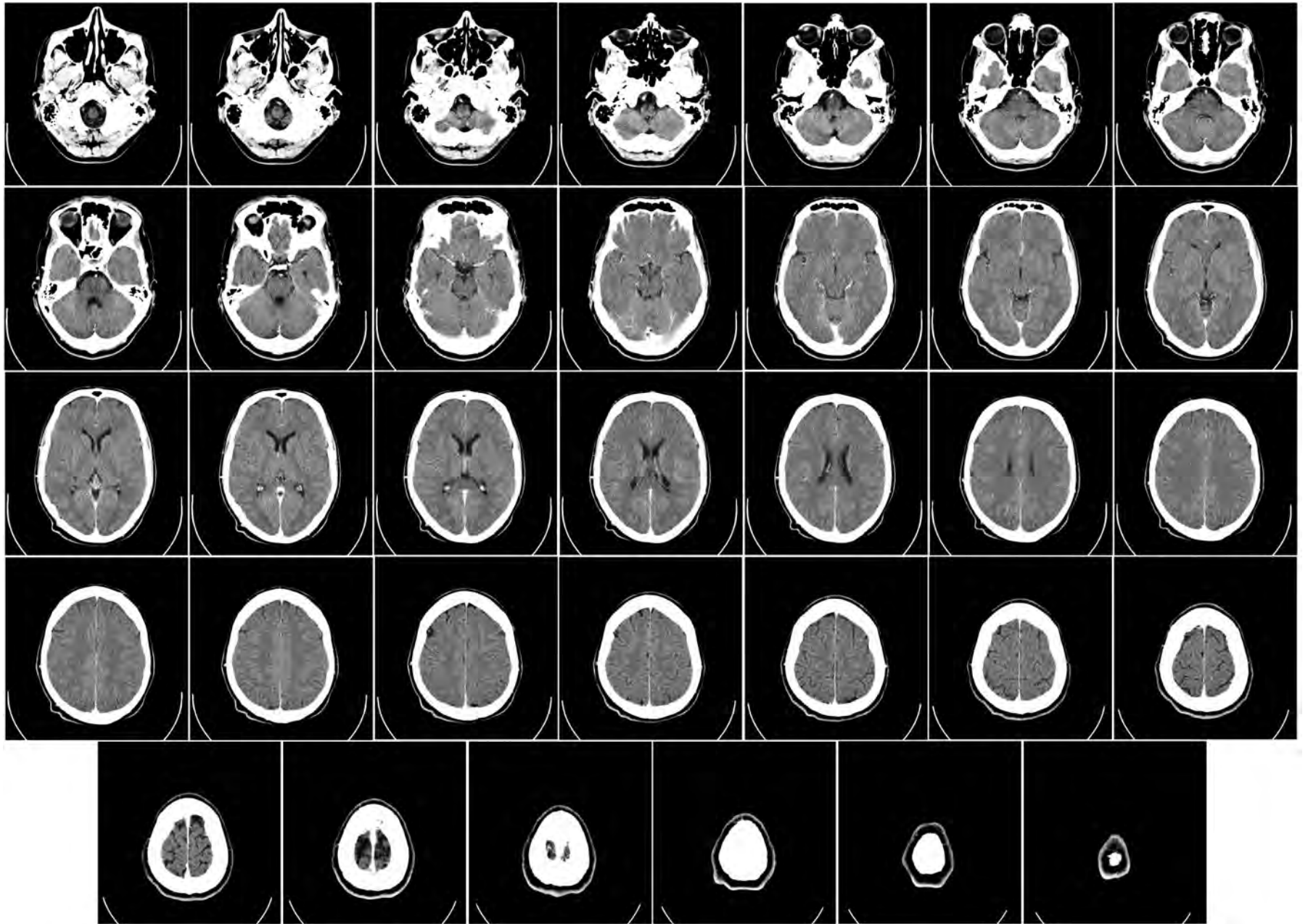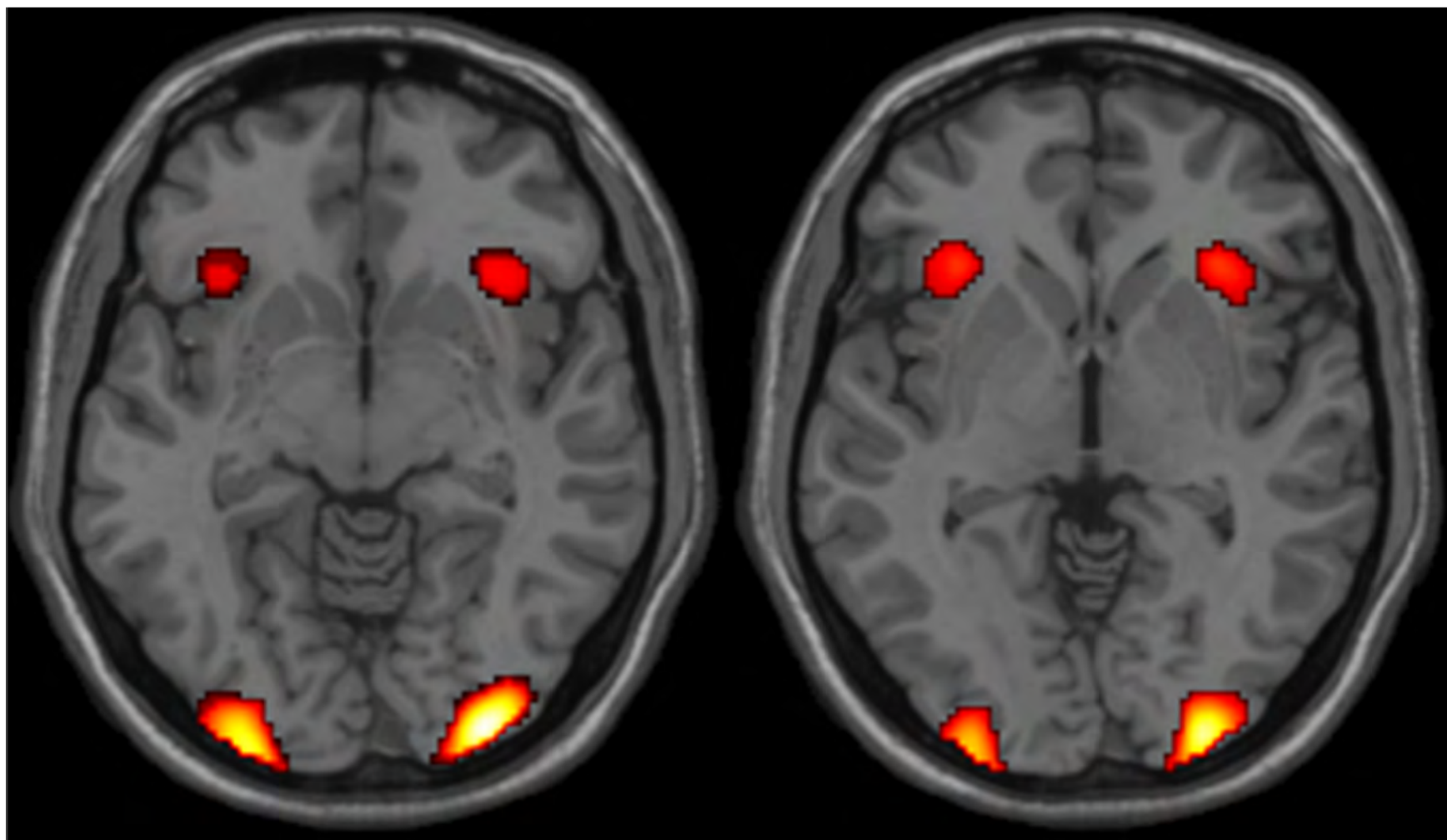
Aside: MRI/NMR Overview

➢ What are the basic ingredients for NMR/MRI?

- *static field*

- *particles (e.g., protons as spinning tops)*

- *coil to perturb particles from static field and measure resulting dynamics (via 'pulse sequences' of RF photons*)*

- *Fourier transforms*

MRI Scanner Cutaway

Radio Frequency Coil

Gradient Coils

Magnet

Scanner

Patient

Patient Table
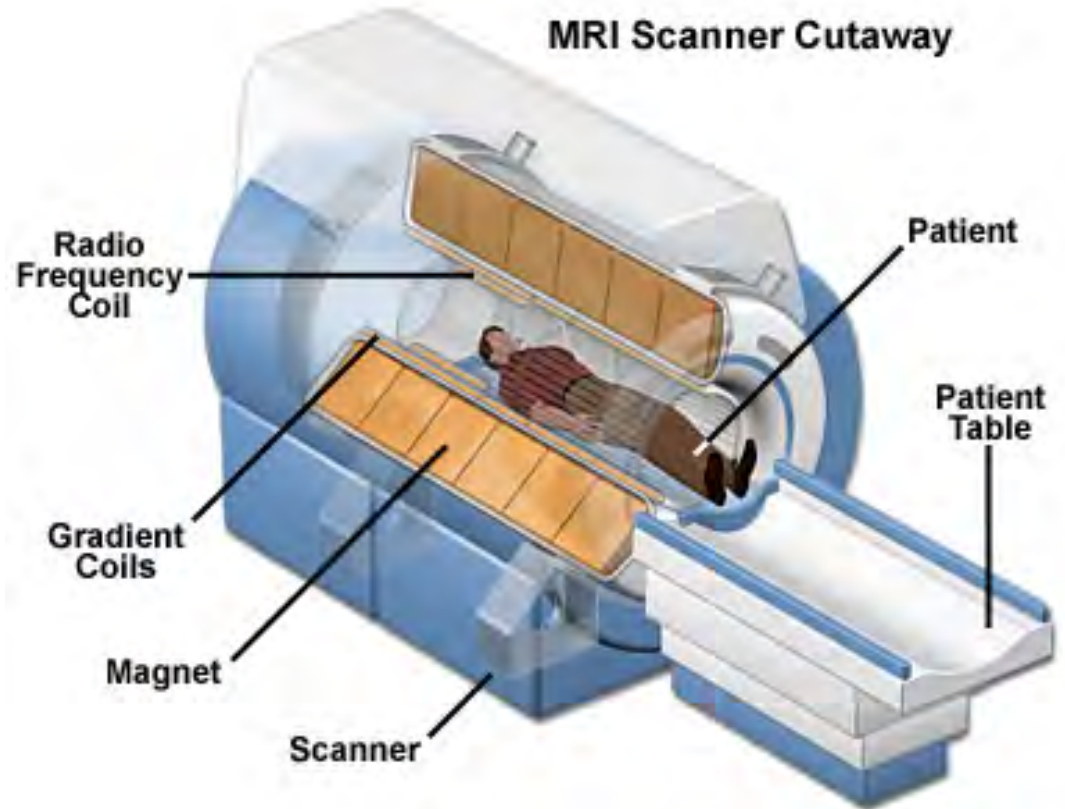
* RF – Radio Frequency

Interdisciplinary Connection: Physics & Biology

Coming back to "things that oscillate".....

Speech ("acoustic phonetics")
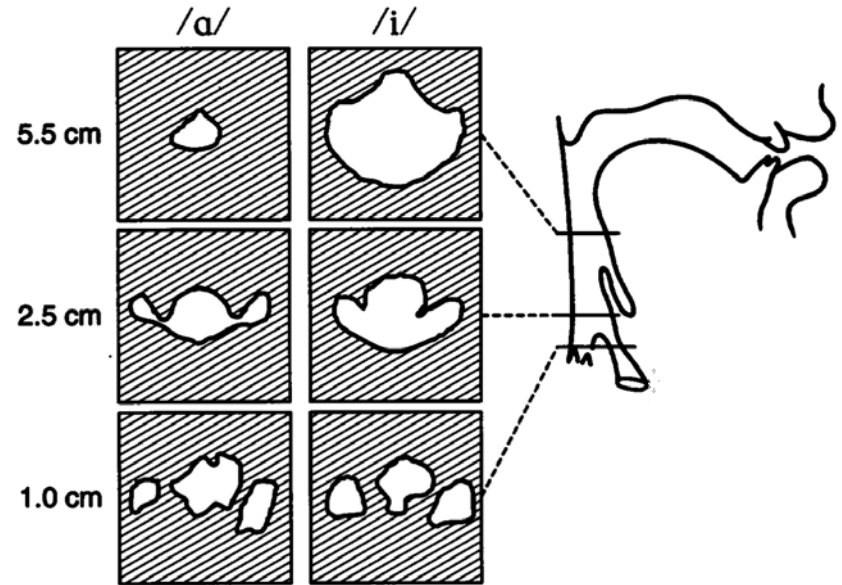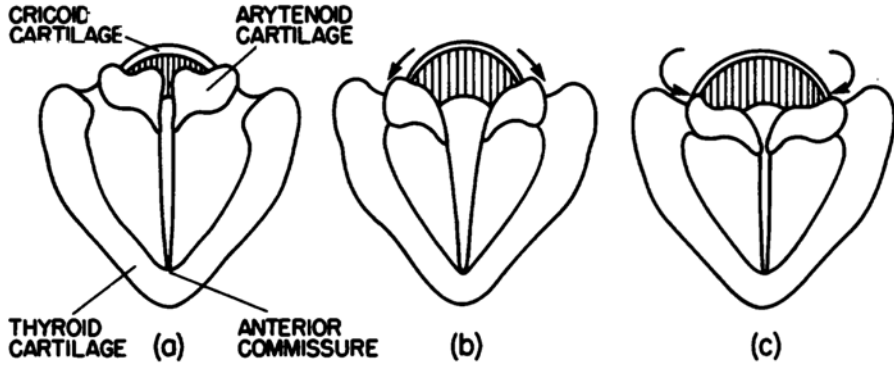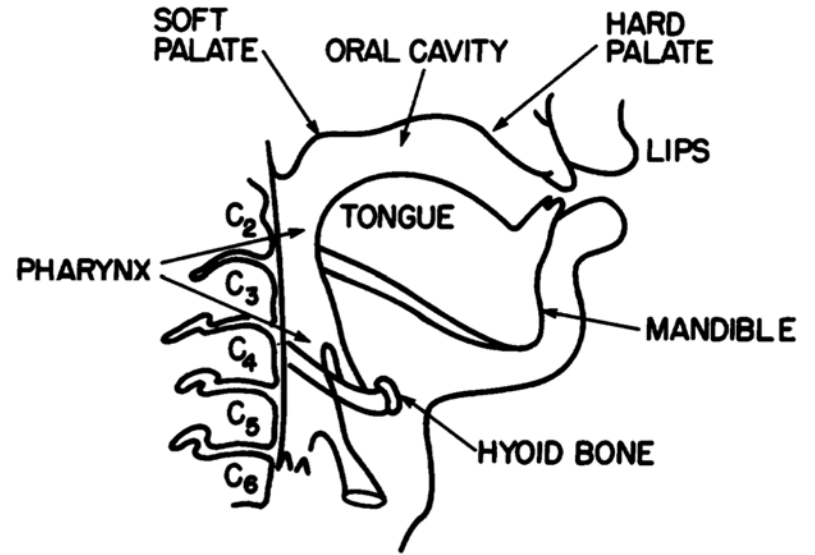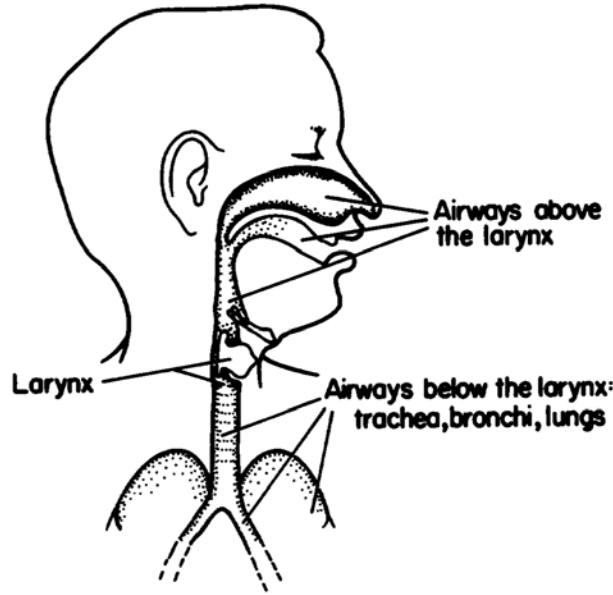
Speech

Snapshots of vibrating vocal folds
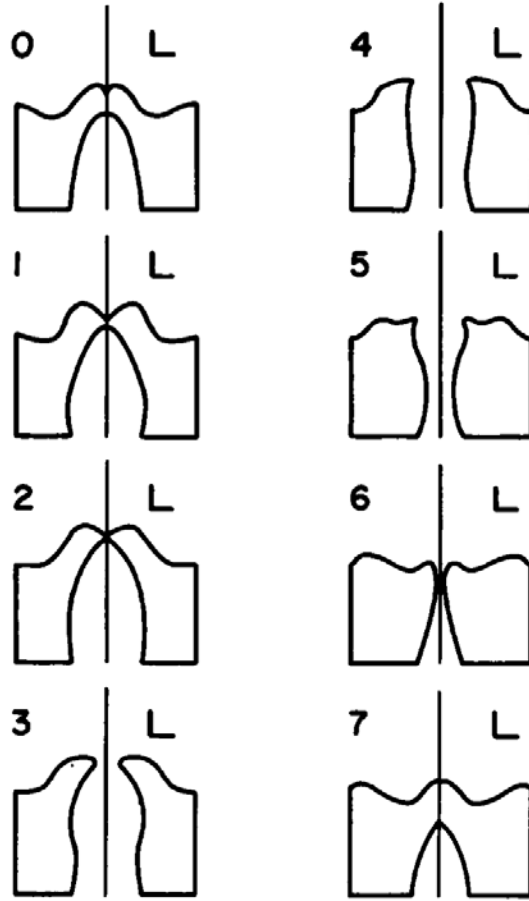
Simple two-mass model for the vocal folds
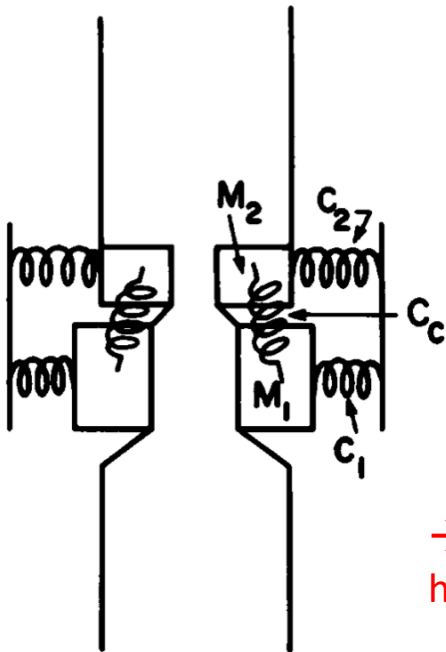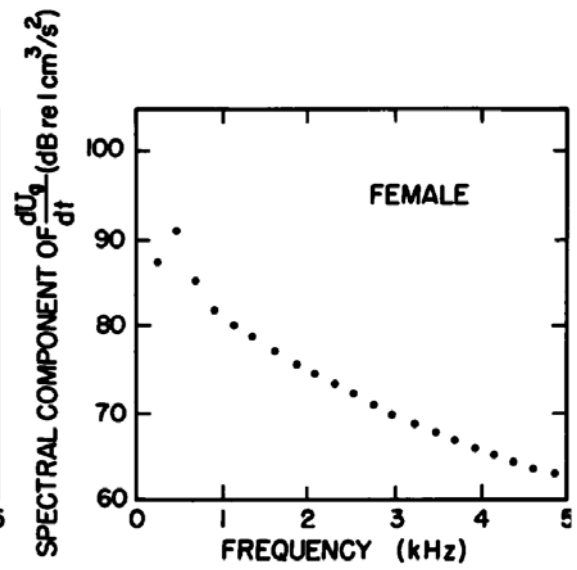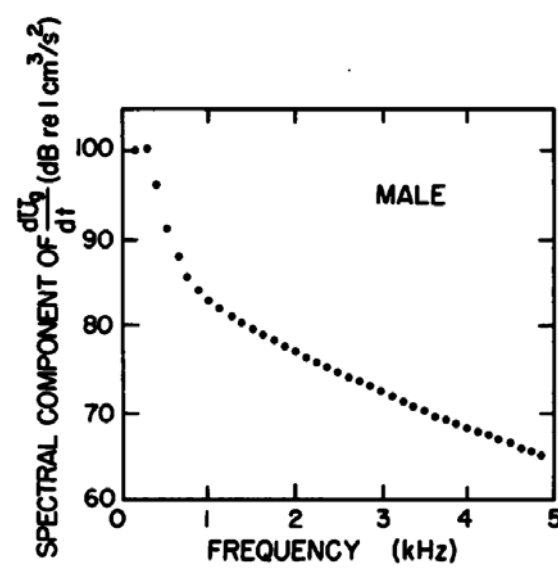

→ Vocal folds behaves like a harmonic oscillator (HO)!
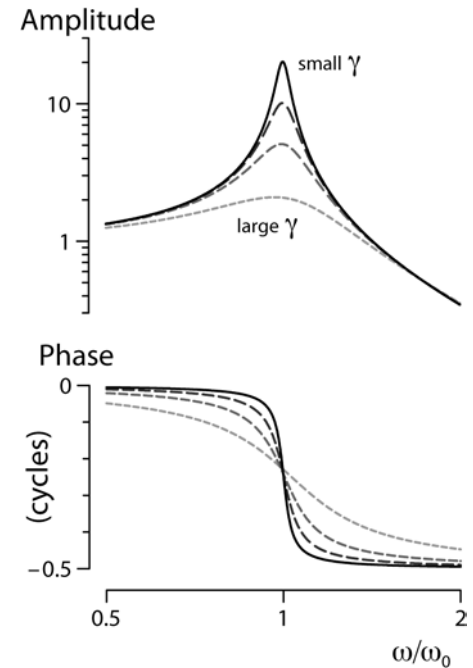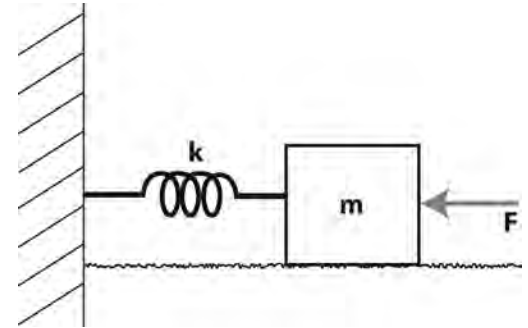
Reminder: We can describe HO in terms of 'spectral' response

Stevens (2000)
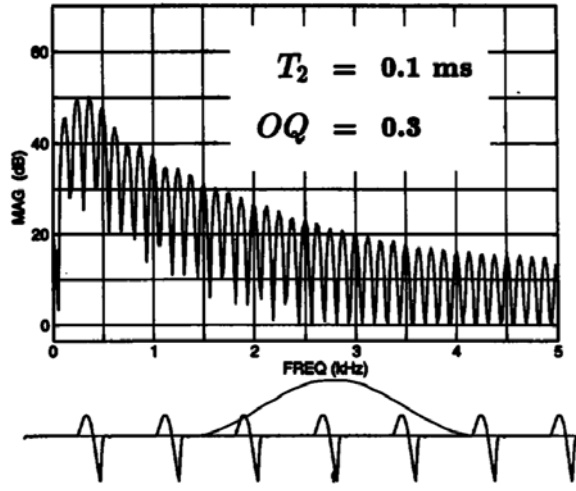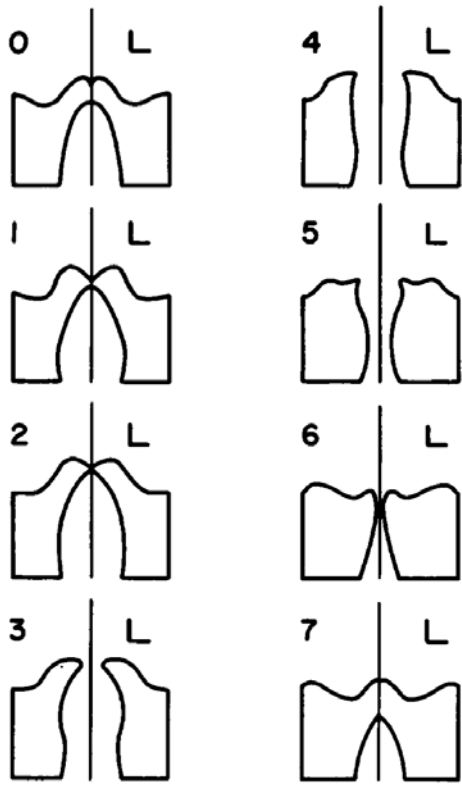
Speech

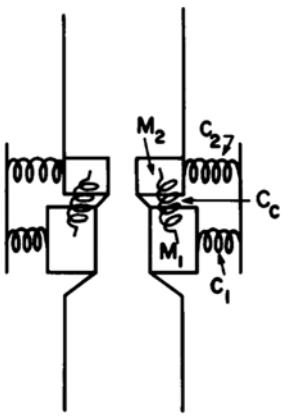
Key idea:
Spectrum
→ x-axis is frequency [Hz]

→ Vibrating vocal folds give off 'buzzy' sound due to harmonics

→ Males have lower 'fundamental' (due to more massive vocal folds)
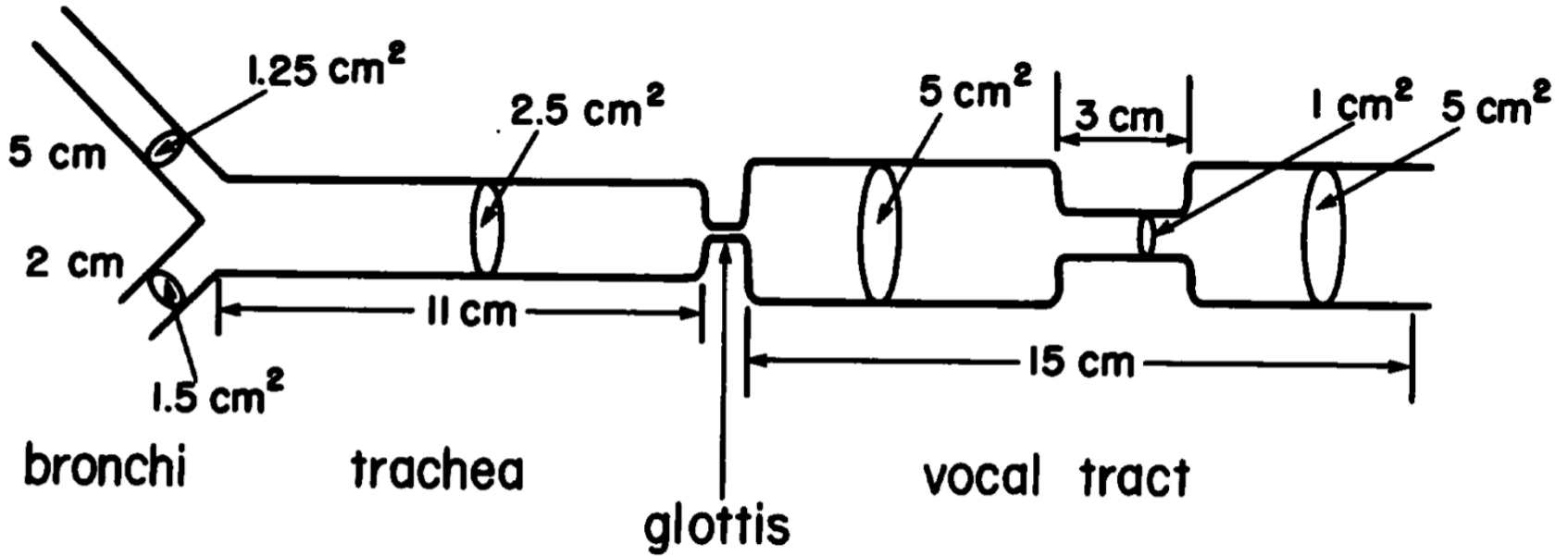
Stevens (2000)

Speech

Pressure source
(lungs)

Vibration source
(vocal folds)

Filter
(vocal tract)

Output
(mouth)

→ Complex acoustic process is boiled down to a relatively simple/tractable framework of 'sources' and tubes!
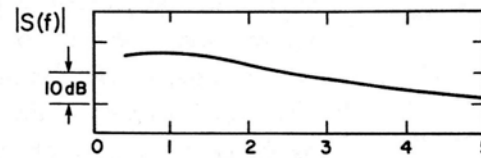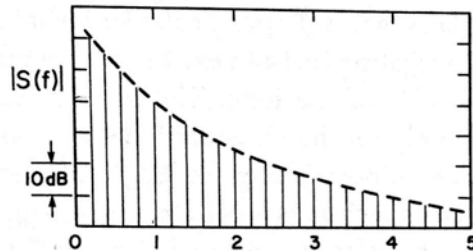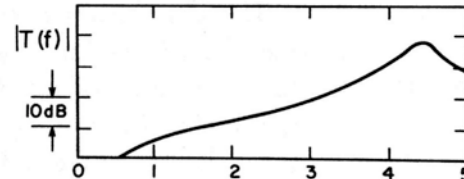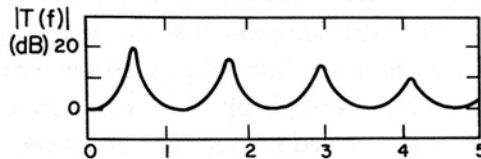
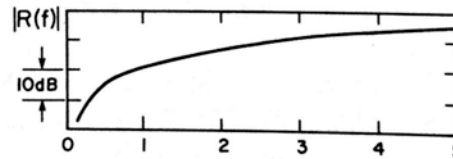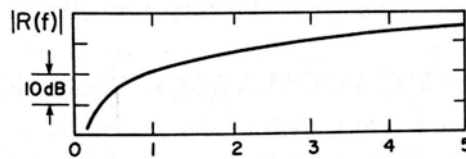Stevens (2000)

Speech

Vowel   Consonant ('sss')

Source (vocal folds)

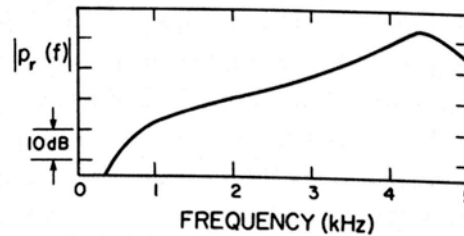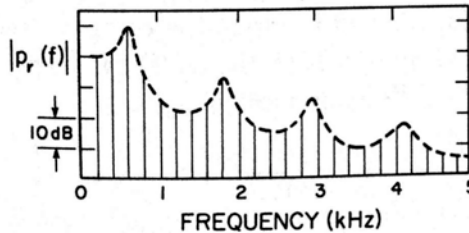Filter I (vocal tract)

Filter II (radiation)

Speech signal

Figure 3.1 Sketches indicating components of the output spectrum $|p_r(f)|$ for a vowel and a fricative consonant. The output spectrum is the product of a source spectrum $S(f)$, a transfer function $T(f)$, and a radiation characteristic $R(f)$. The source spectra are similar to those derived in figures 2.10 and 2.33 in chapter 2. For the periodic source, $S(f)$ represents the amplitudes of spectral components; for the noise source, $S(f)$ is amplitude in a specified bandwidth. See text.
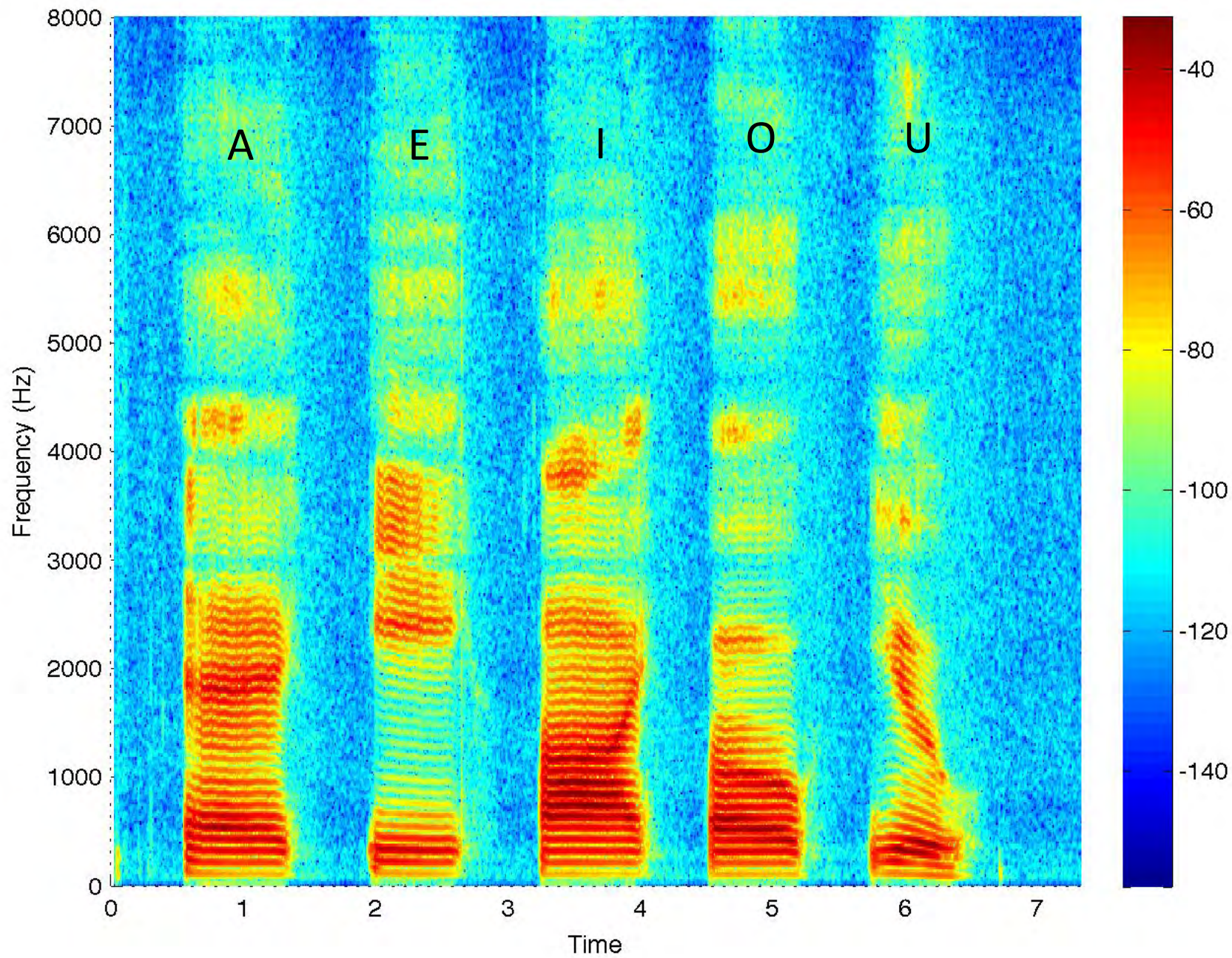
- Vibrating vocal folds make 'broadband' sound

- Vocal tract shapes that sound

- Resulting 'shape' emphasizes features which we then pick up with our ear (e.g., formants of vowels)

→ But what does it mean for everything to be a function of frequency?

Stevens (2000)

Figure 3.1 Sketches indicating components of the output spectrum $|p_r(f)|$ for a vowel and a fricative consonant. The output spectrum is the product of a source spectrum $S(f)$, a transfer function $T(f)$, and a radiation characteristic $R(f)$. The source spectra are similar to those derived in figures 2.10 and 2.33 in chapter 2. For the periodic source, $S(f)$ represents the amplitudes of spectral components; for the noise source, $S(f)$ is amplitude in a specified bandwidth. See text.
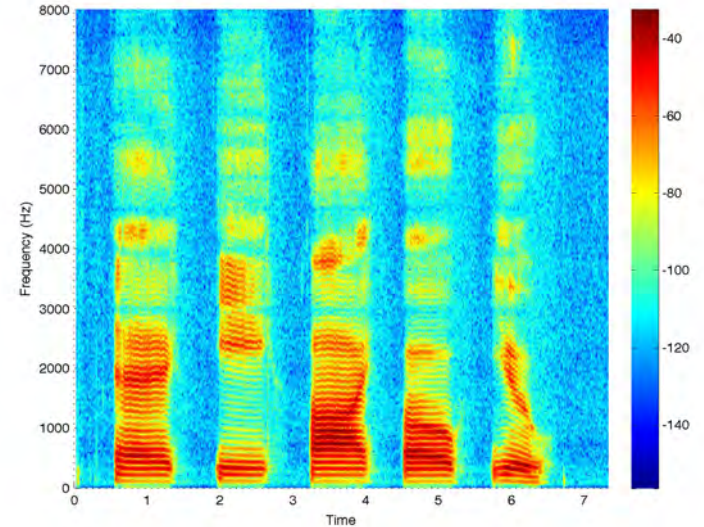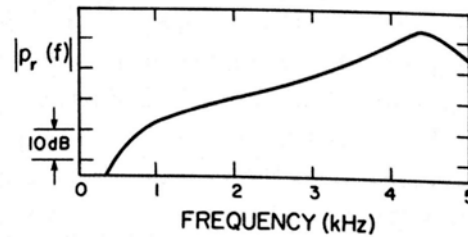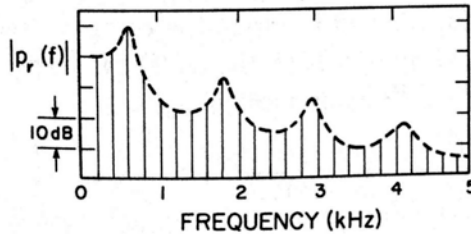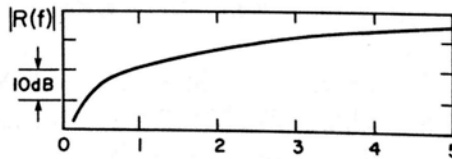
Stevens (2000)

"Physics 2030   Computational methods for physicists and engineers"

EXspectrogram.m

Mammalian Cochlea Uncoiled

C.D. Geisler (modified)

→ The ear's main job to to do this sort of spectral decomposition!

Waves....

Mammalian Cochlea Uncoiled

to Vestibular System

Stapes

Acoustic Energy

Helicotrema

pliant & massive

to Middle Ear

stiff & thin

Round Window

Cochlear Partition

C.D. Geisler (modified)

A

~16.5 mm

B
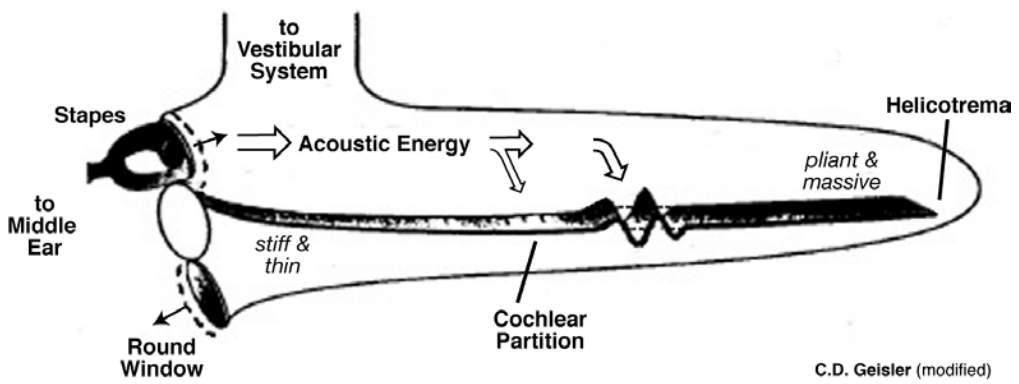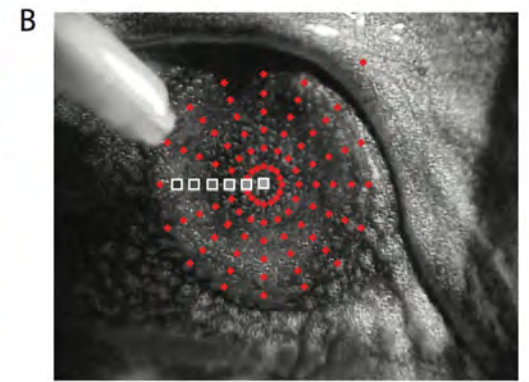
Light

➢ The notion of "light" is such an integral part of our daily lives....
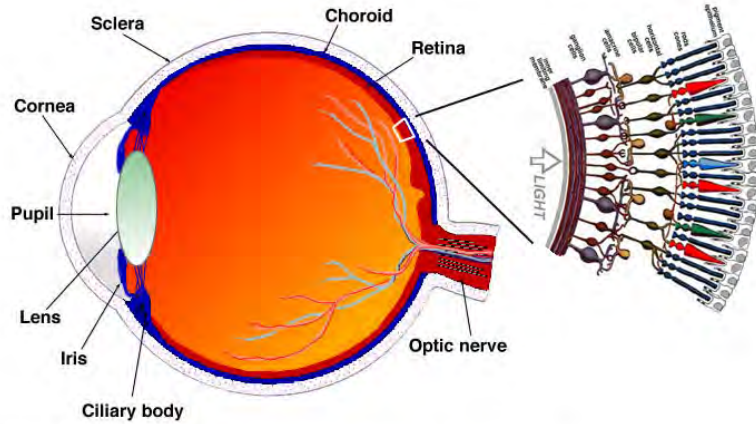
Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

WebVision (Utah)

Altai Mountains
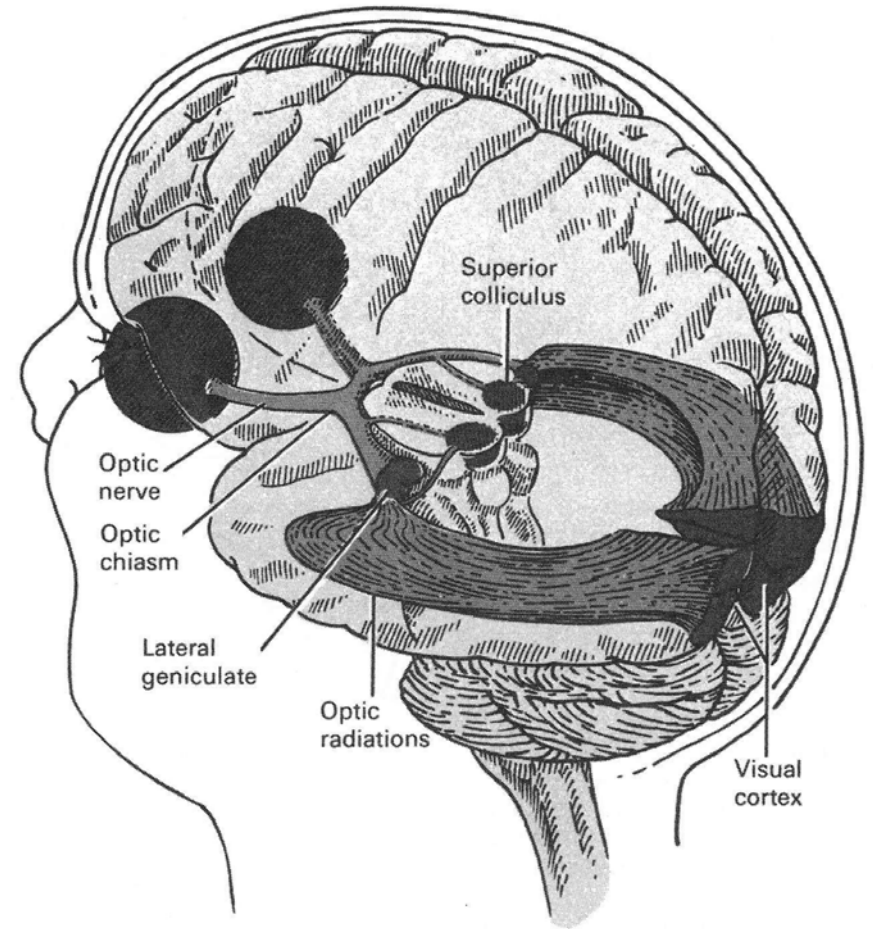
Palmer (1999)

Aside (re Light and the Brain)

Aside (re Light and the Brain)
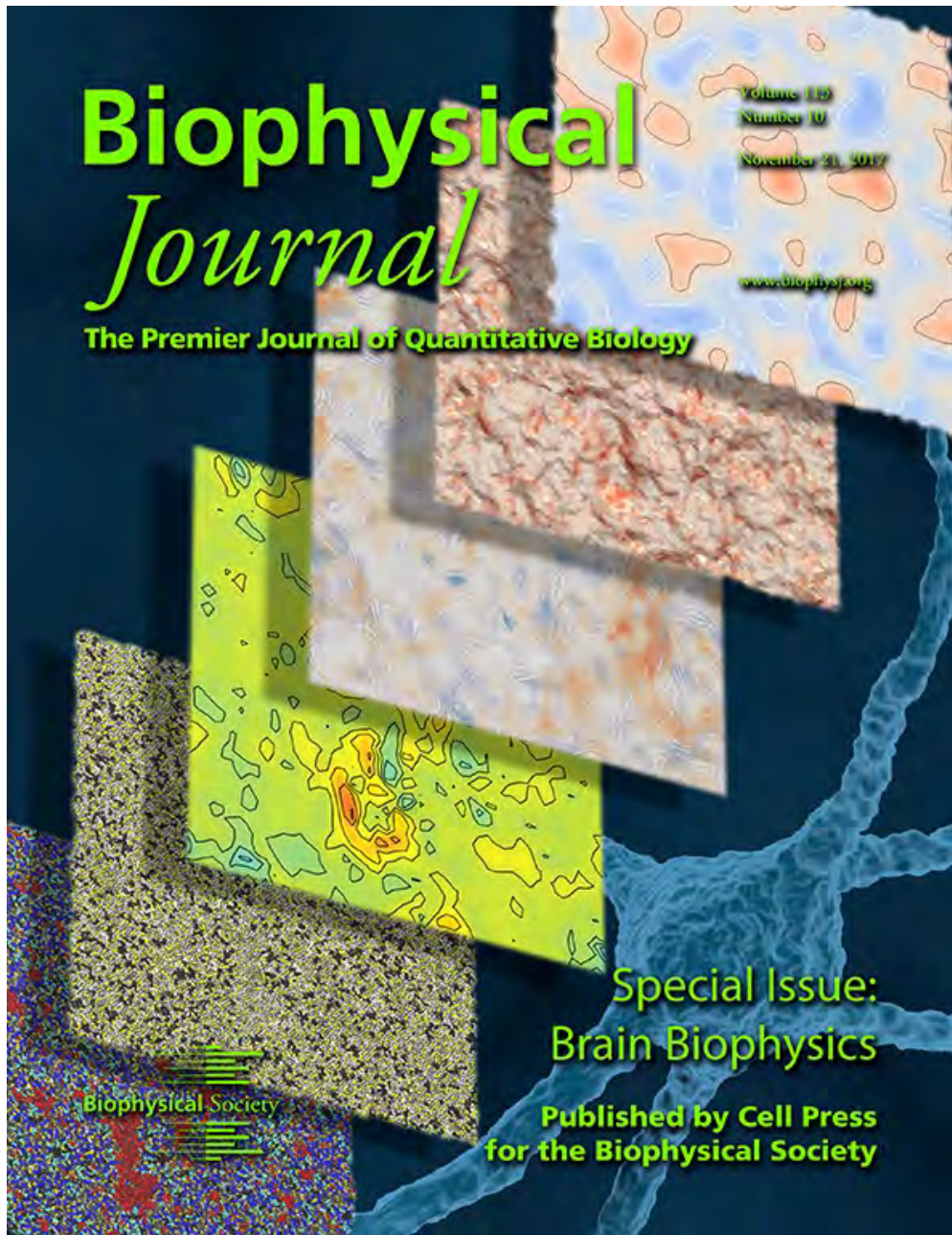
Biophysics of the Brain: From Molecules to Networks

Vasanthi Jayaraman[1]
[1]University of Texas-Houston Medical School, Houston, Texas

The brain, with billions of neurons making trillions of connections, still largely remains an enigma. The last decade has seen the development of new biophysical tools, including optical methods for mapping neuronal connections and high-resolution imaging. These new biophysical tools, along with electrophysiological, structural, and computational methods, have brought the understanding of the brain into better focus. This special issue of Biophysical Journal on brain biophysics highlights research in these areas.

Aside (re Light and the Brain)

One mechanism of communication between neurons is mediated by ionotropic glutamate receptors, the main excitatory neurotransmitter receptors in the central nervous system. In this issue, the Perspective by Mayer (1), as well as the manuscripts by Iacobucci et al. (2), Paramo et al. (3), and Zhang et al. (4), highlight how a combination of structural, functional, and computational methods complement each other and allow for an in depth understanding of the structure-dynamic control of the function in these proteins. Yasuda (5), in his Perspective, discusses the role of biochemical signaling at dendrites and its role in mediating synaptic plasticity, a process thought to underlie learning and memory.

Taking the question from the molecular level to a broader scale, the perspective by Nicholson et al. (6) discusses the use of biophysical methods in understanding the morphology of the brain extracellular space 6, while the article by Piatkevich et al. (7), provides new fluorescent tools from bacteria that can be used in neuroimaging 7.

Biophysical studies, such as those in this issue, have vastly expanded our understanding of the brain and we can expect that progress will continue to be rapid. One can speculate that in the near future these studies, together with newer techniques still to be fully implemented, could potentially provide an atlas of the brain at a cellular and molecular resolution that will lead to a better understanding of how the brain functions. This in turn could shed light on the underlying causes of neurological and psychiatric conditions, with the ultimate goal of developing effective treatments.

Aside (re Light and the Brain)

BIOPHYSICAL PERSPECTIVES

Brain Extracellular Space: The Final Frontier of Neuroscience

Charles Nicholson, Sabina Hrabětová

In Brief | Full-Text HTML | PDF
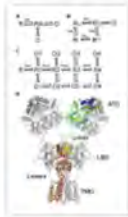
The Challenge of Interpreting Glutamate-Receptor Ion-Channel Structures

Mark L. Mayer

In Brief | Full-Text HTML | PDF
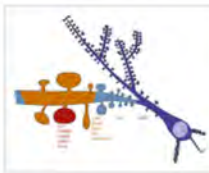
Biophysics of Biochemical Signaling in Dendritic Spines: Implications in Synaptic Plasticity

Ryohei Yasuda

In Brief | Full-Text HTML | PDF

Voltage and Calcium Imaging of Brain Activity

Masoud Sepehri Rad, Yunsook Choi, Lawrence B. Cohen, Bradley J. Baker, Sheng Zhong, Douglas A. Storace, Oliver R. Braubach

In Brief | Full-Text HTML | PDF

Aside (re Light and the Brain)

Modification of C Terminus Provides New Insights into the Mechanism of α-Synuclein Aggregation
Kseniia Afitska, Anna Fucikova, Volodymyr V. Shvadchak, Dmytro A. Yushchenko
In Brief | Full-Text HTML | PDF

Molecular Mechanisms of the R61T Mutation in Apolipoprotein E4: A Dynamic Rescue
Benfeard Williams II, Marino Convertino, Jhuma Das, Nikolay V. Dokholyan
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A Negative Slope Conductance of the Persistent Sodium Current Prolongs Subthreshold Depolarizations
Cesar C. Ceballos, Antonio C. Roque, Ricardo M. Leão
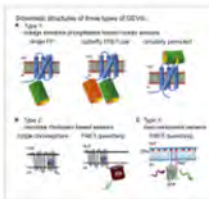In Brief | Full-Text HTML | PDF

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Disruption of Ankyrin B and Caveolin-1 Interaction Sites Alters Na^+,K^+-ATPase Membrane Diffusion
Cornelia Junghans, Vladana Vukojević, Neslihan N. Tavraz, Eugene G. Maksimov, Werner Zuschratter, Franz-Josef Schmitt, Thomas Friedrich
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Probing the Interplay between Dendritic Spine Morphology and Membrane-Bound Diffusion
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Probing the Interplay between Dendritic Spine Morphology and Membrane-Bound Diffusion

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ABSTRACT Dendritic spines are protrusions along neuronal dendrites that harbor the majority of excitatory postsynapses. Their distinct morphology, often featuring a bulbous head and small neck that connects to the dendritic shaft, has been shown to facilitate compartmentalization of electrical and cytoplasmic signaling stimuli elicited at the synapse. The extent to which spine morphology also forms a barrier for membrane-bound diffusion has remained unclear. Recent simulations suggested that especially the diameter of the spine neck plays a limiting role in this process. Here, we examine the connection between spine morphology and membrane-bound diffusion through a combination of photoconversion, live-cell superresolution experiments, and numerical simulations. Local photoconversion was used to obtain the timescale of diffusive equilibration in spines and followed by global sparse photoconversion to determine spine morphologies with nanoscopic resolution. These morphologies were subsequently used to assess the role of morphology on the diffusive equilibration. From the simulations, we could determine a robust relation between the equilibration timescale and a generalized shape factor calculated using both spine neck width and neck length, as well as spine head size. Experimentally, we found that diffusive equilibration was often slower, but rarely faster than predicted from the simulations, indicating that other biological confounders further reduce membrane-bound diffusion in these spines. This shape-dependent membrane-bound diffusion in mature spines may contribute to spine-specific compartmentalization of neurotransmitter receptors and signaling molecules and thereby support long-term plasticity of synaptic contacts.
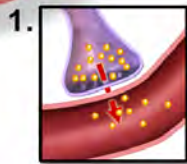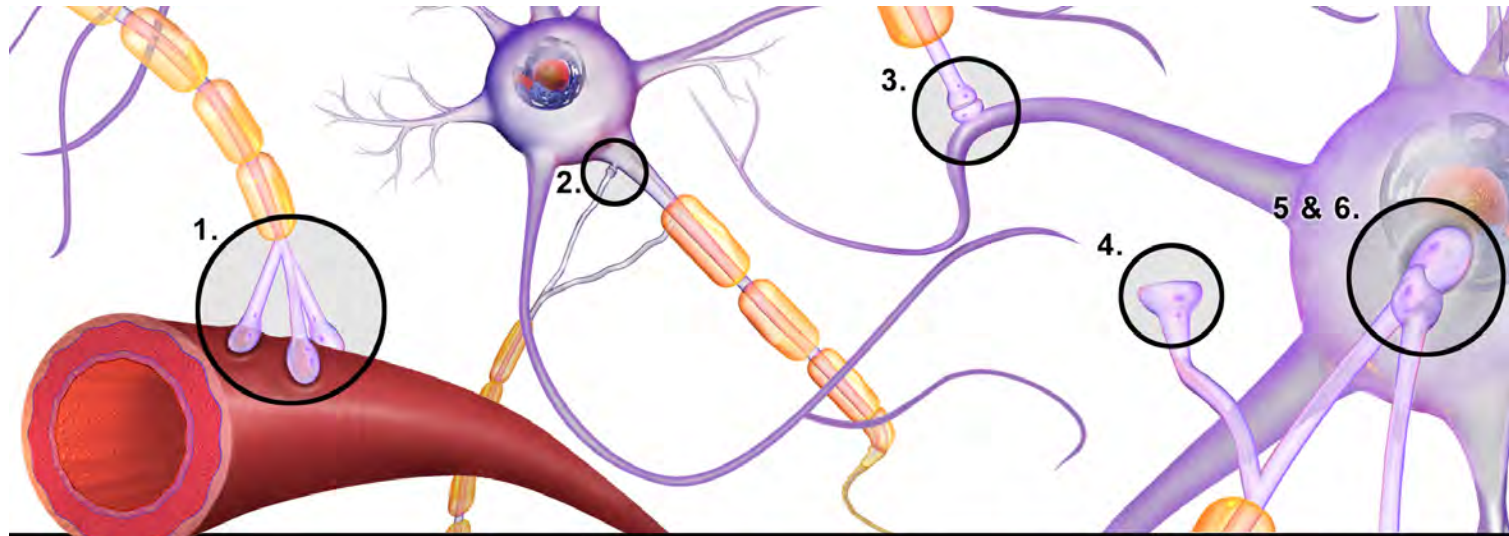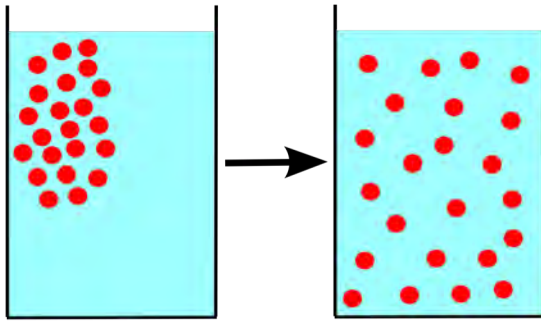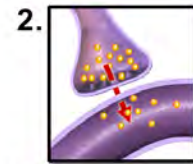
A DEEP LOOK AT SYNAPTIC DYNAMICS

The processes behind neuronal communication have not yet been resolved in detail, but dyes, microscopy and protein analysis are beginning to fill in the gaps.
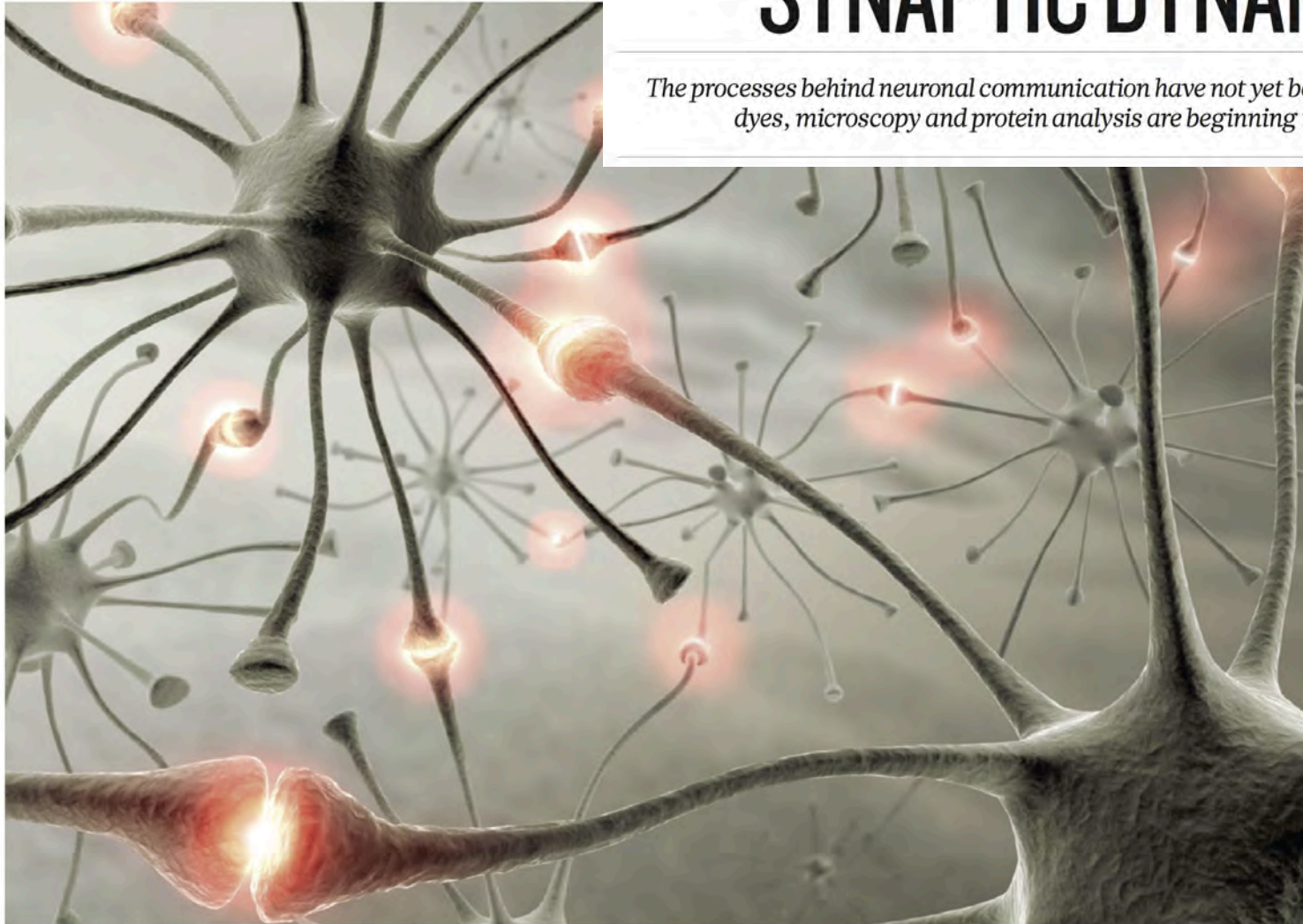
Synapses are crucial to the communication between neurons, but the events that happen there have been difficult to capture.

1.	2.	3.	4.	5 & 6.
Axosecretory	**Axoaxonic**	**Axodendritic**	**Axoextracellular**	**Axosomatic**
Axon terminal secretes directly into bloodstream	Axon terminal secretes into another axon	Axon terminal ends on a dendrite spine	Axon with no connection seccretes into extracellular fluid	Axon terminal ends on soma
				Axosynaptic Axon terminal ends on another axon terminal
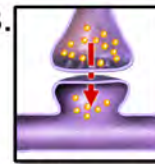
Wikipedia

What is a "wave"?

Vibrations and Waves

A.P. FRENCH

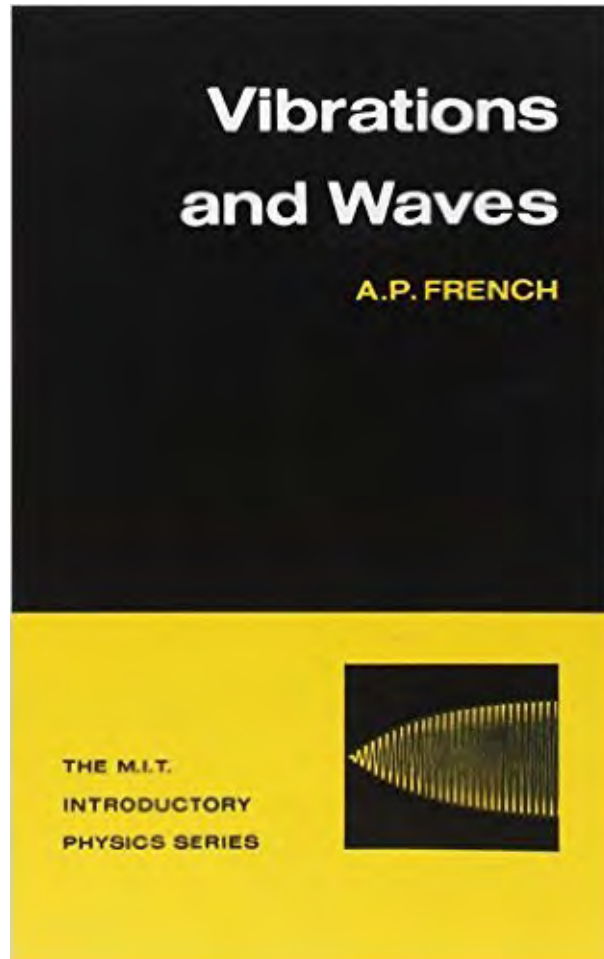THE M.I.T. INTRODUCTORY PHYSICS SERIES

FOR MANY PEOPLE—perhaps for most—the word "wave" conjures up a picture of an ocean, with the rollers sweeping onto the beach from the open sea. If you have stood and watched this phenomenon, you may have felt that for all its grandeur it contains an element of anticlimax. You see the crests racing in, you get a sense of the massive assault by the water on the land—and indeed the waves *can* do great damage, which means that they are carriers of energy—but yet when it is all over, when the wave has reared and broken, the water is scarcely any farther up the beach than it was before. That onward rush was not to any significant extent a bodily motion of the water. The long waves of the open sea (known as the swell) travel fast and far. Waves reaching the California coast have been traced to origins in South Pacific storms more than 7000 miles away, and have traversed this distance at a speed of 40 mph or more. Clearly the sea itself has not traveled in this spectacular way; it has simply played the role of the agent by which a certain effect is transmitted. And here we see the essential feature of what is called wave motion. A condition of some kind is transmitted from one place to another by means of a medium, but the medium itself is not transported. A local effect can be linked to a distant cause, and there is a time lag between cause and effect that depends on the properties of the medium and finds its expression in the velocity of the wave. All material media—solids, liquids, and gases—can carry energy and information by means of waves, and our study of coupled oscillators and normal modes has paved the way for an understanding of this important phenomenon.

Although waves on water are the most familiar type of wave, they are also among the most complicated to analyze in terms of underlying physical processes. We shall, therefore, not have very much to say about them. Instead, we shall turn to our old standby—the stretched string—about which we have learned a good deal that can now be applied to the present discussion.

A traveling wave is a broad term, but in a general sense can be defined as occurring when a "condition of some kind is transmitted from one place to another by means of a medium, but the medium itself is not transported"