The Physics of the Nervous System

Dr. Dan Goldreich Dr. Deda Gillespie

(Some) Physics of the Nervous System

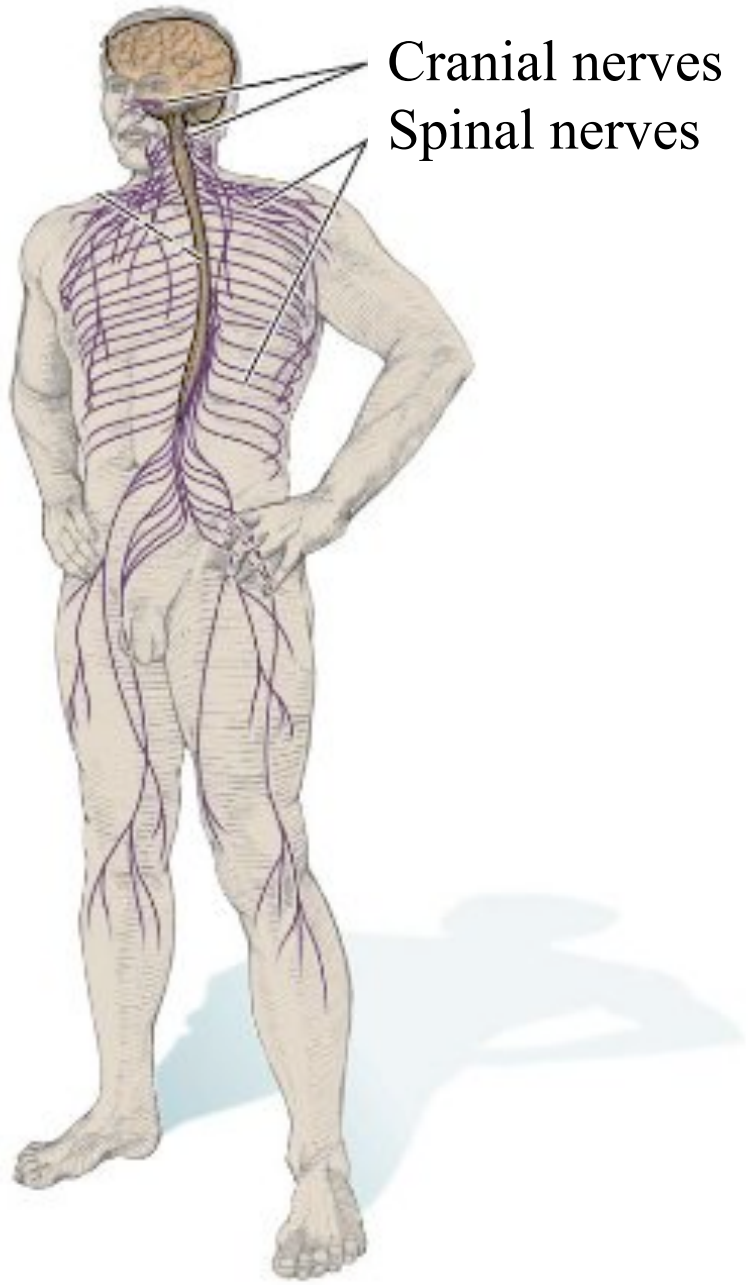
Intro

Touch

Hearing

Vision

Overview of the Nervous System



Neuro Facts

How many neurons in human brain?

100 billion

What is the size of a typical neuron?

10 μm (cell body diameter)

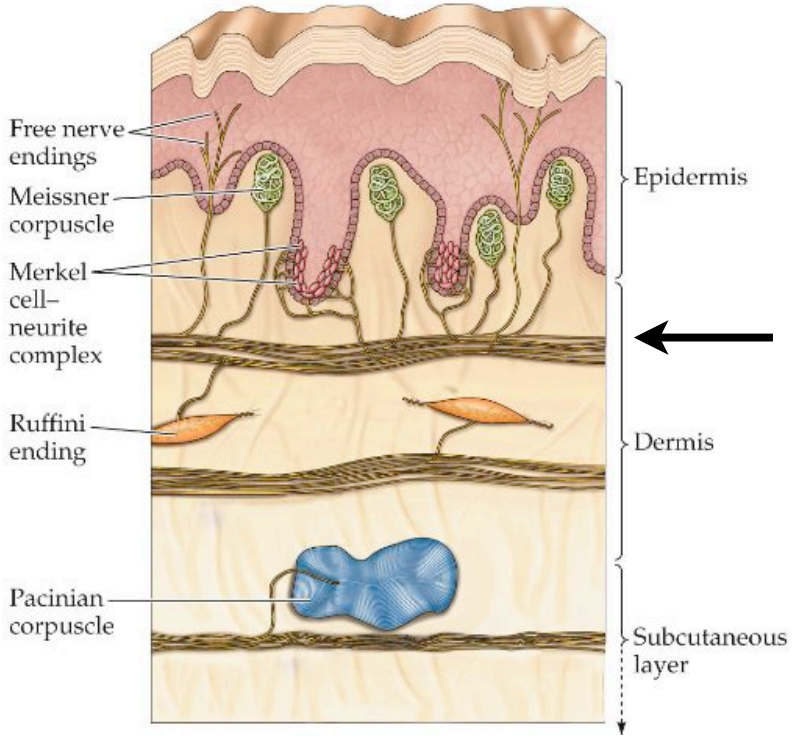
What % of the brain do we use?

100%

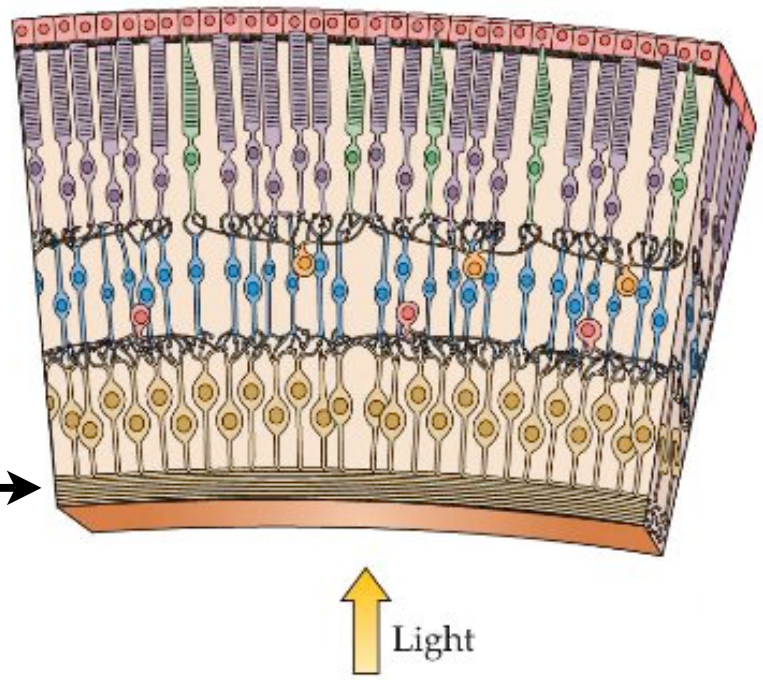
What is brain's power?

20 W (entire body power = 100 W)

Receptors (transduction)

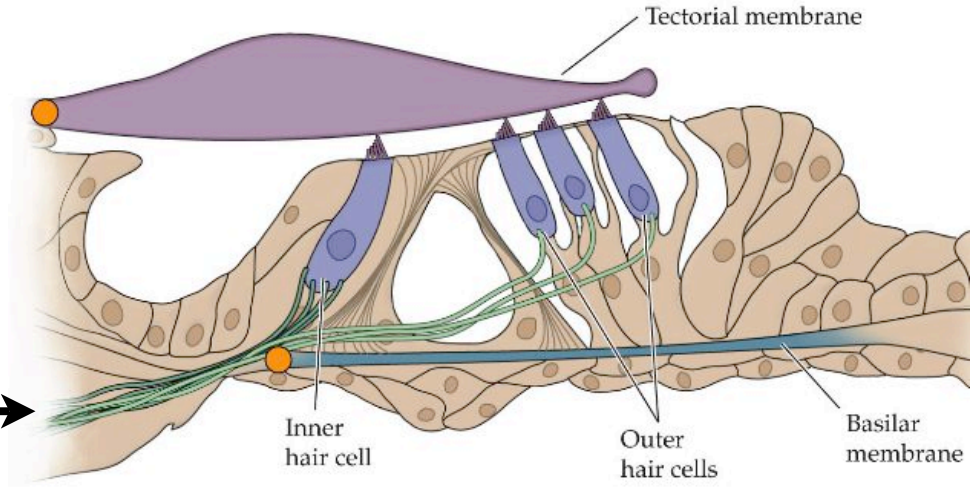


axons ←



axons →

Light



axons →

from Purves, D. et al. (2007) Neuroscience, 4th Ed. Sunderland, MA: Sinauer.

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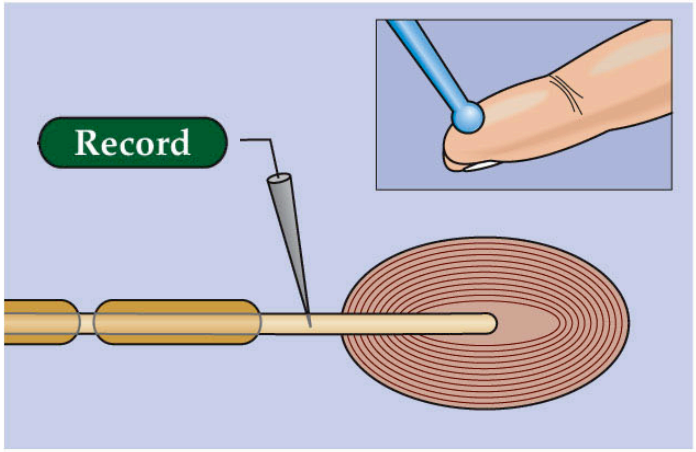
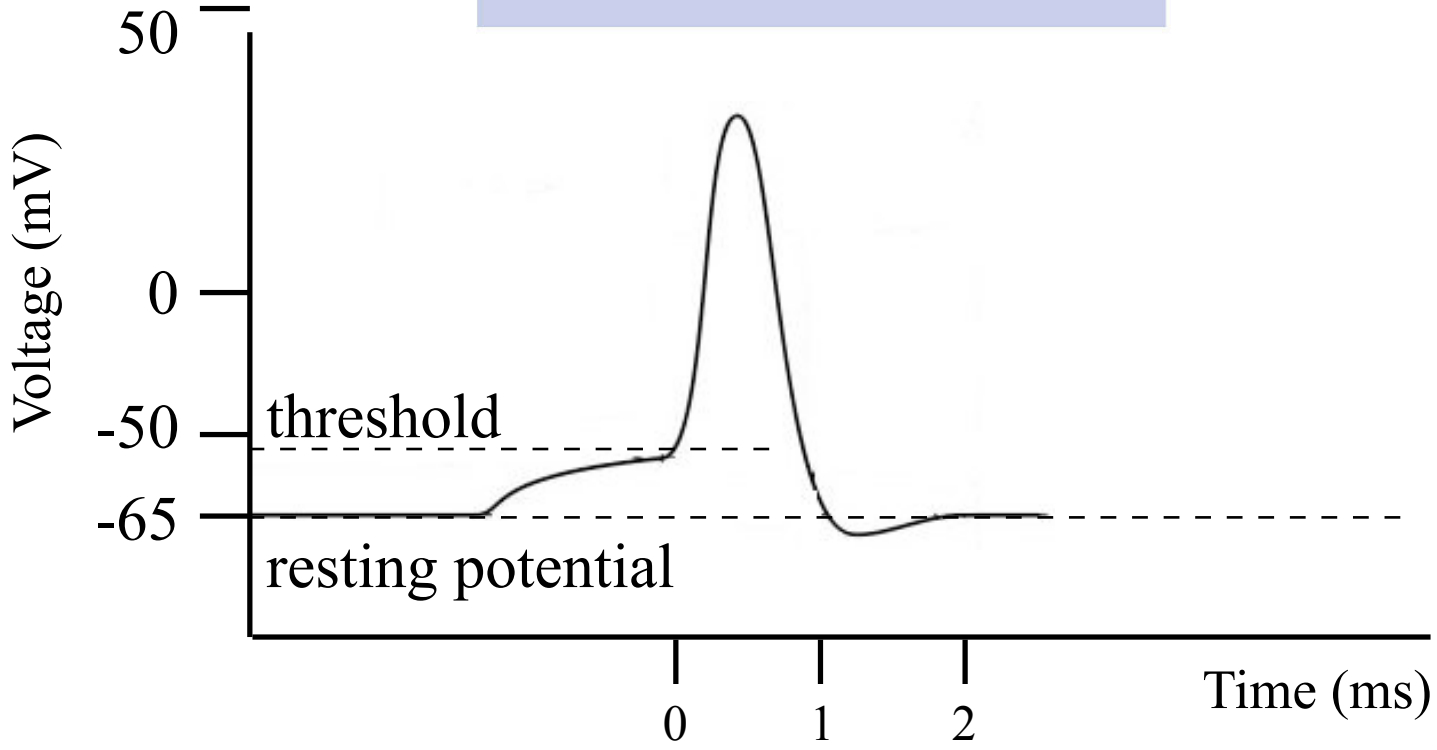
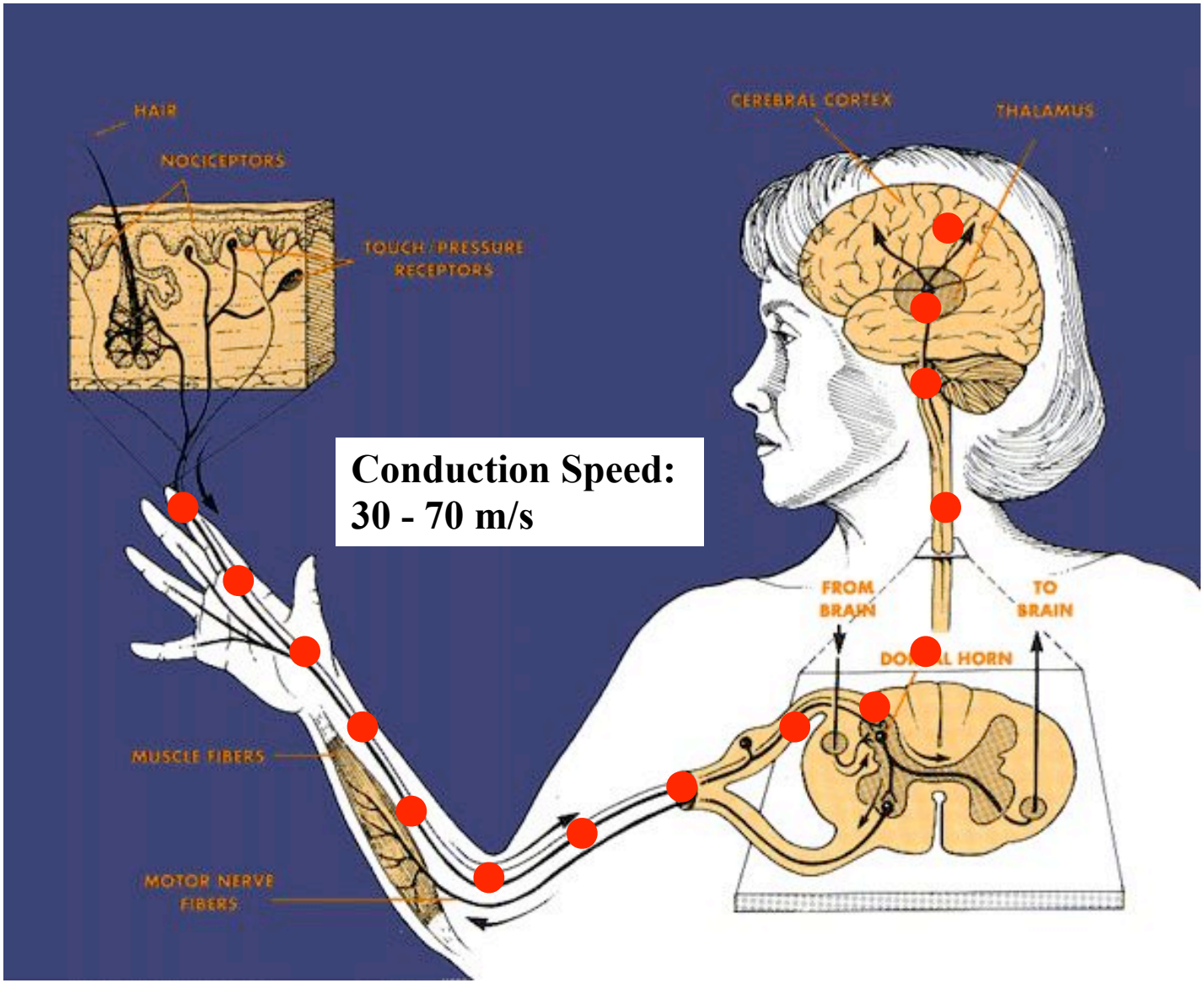
The Action Potential (electrical impulse)



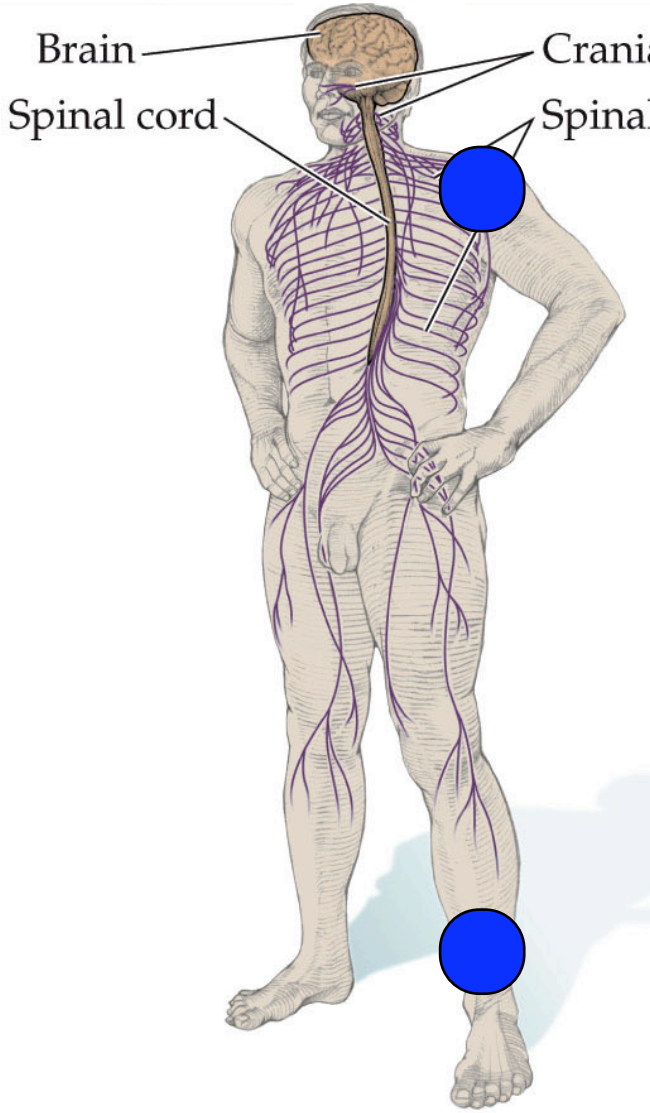


Touch Pathway



www.geocities.com/hotsprings/3468/9/dorsal-horn-large.gif

We sense the past!

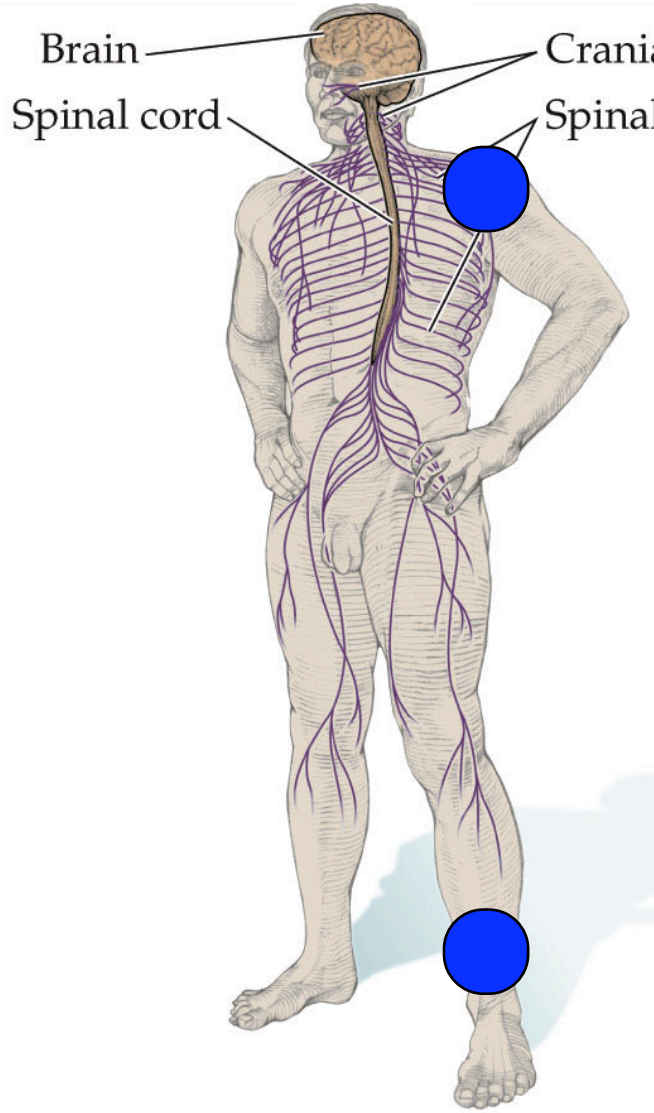


Close to brain (perception occurs with little delay)

Conduction Speed:
30 - 70 m/s

Farther from brain (perception occurs with longer delay)

Let's do it!



Close to brain (perception occurs with little delay)

Let's measure the conduction speed! **But how??**

Farther from brain (perception occurs with longer delay)

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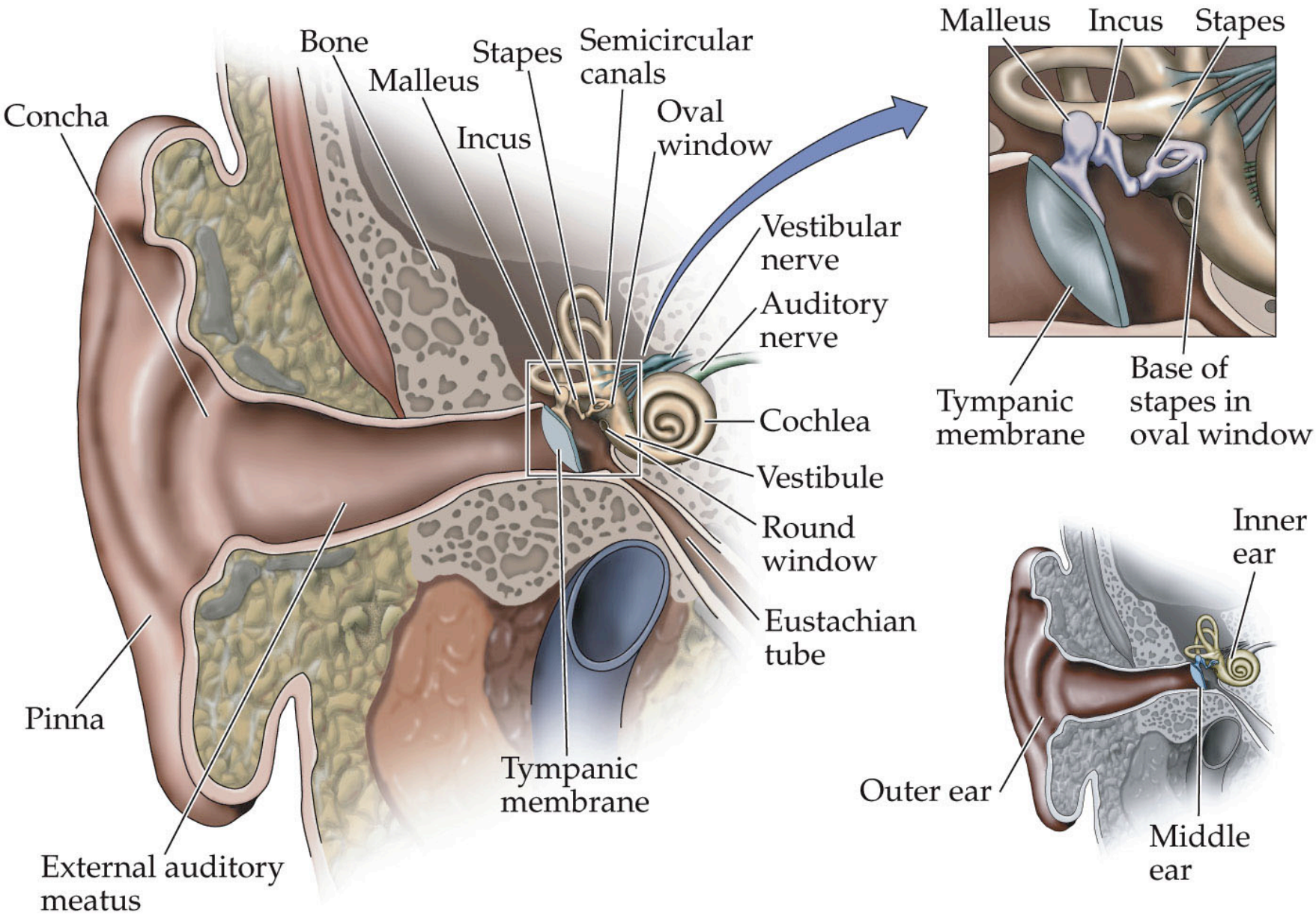
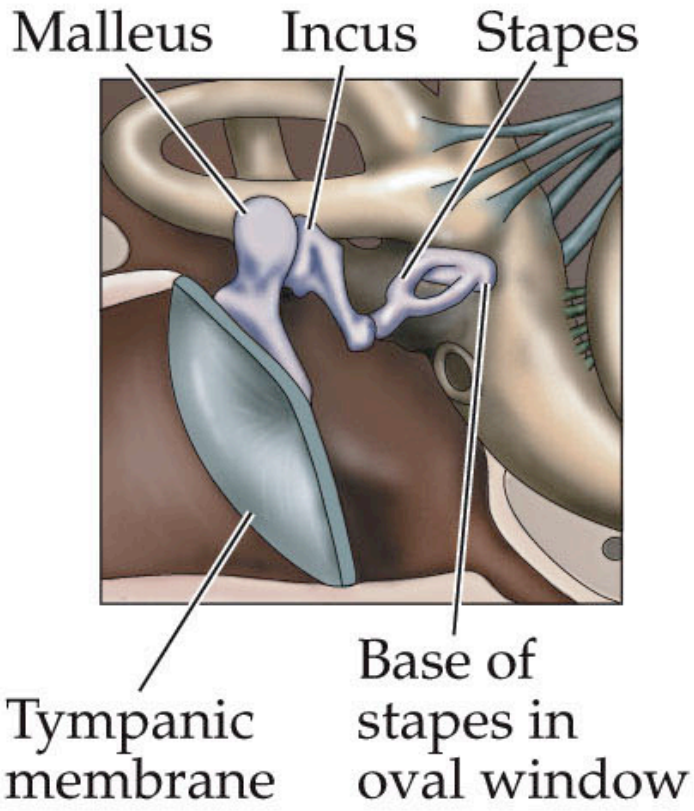
The human ear



***NEUROSCIENCE, Fourth Edition,* Figure 13.3**

Pressure amplification in the middle ear

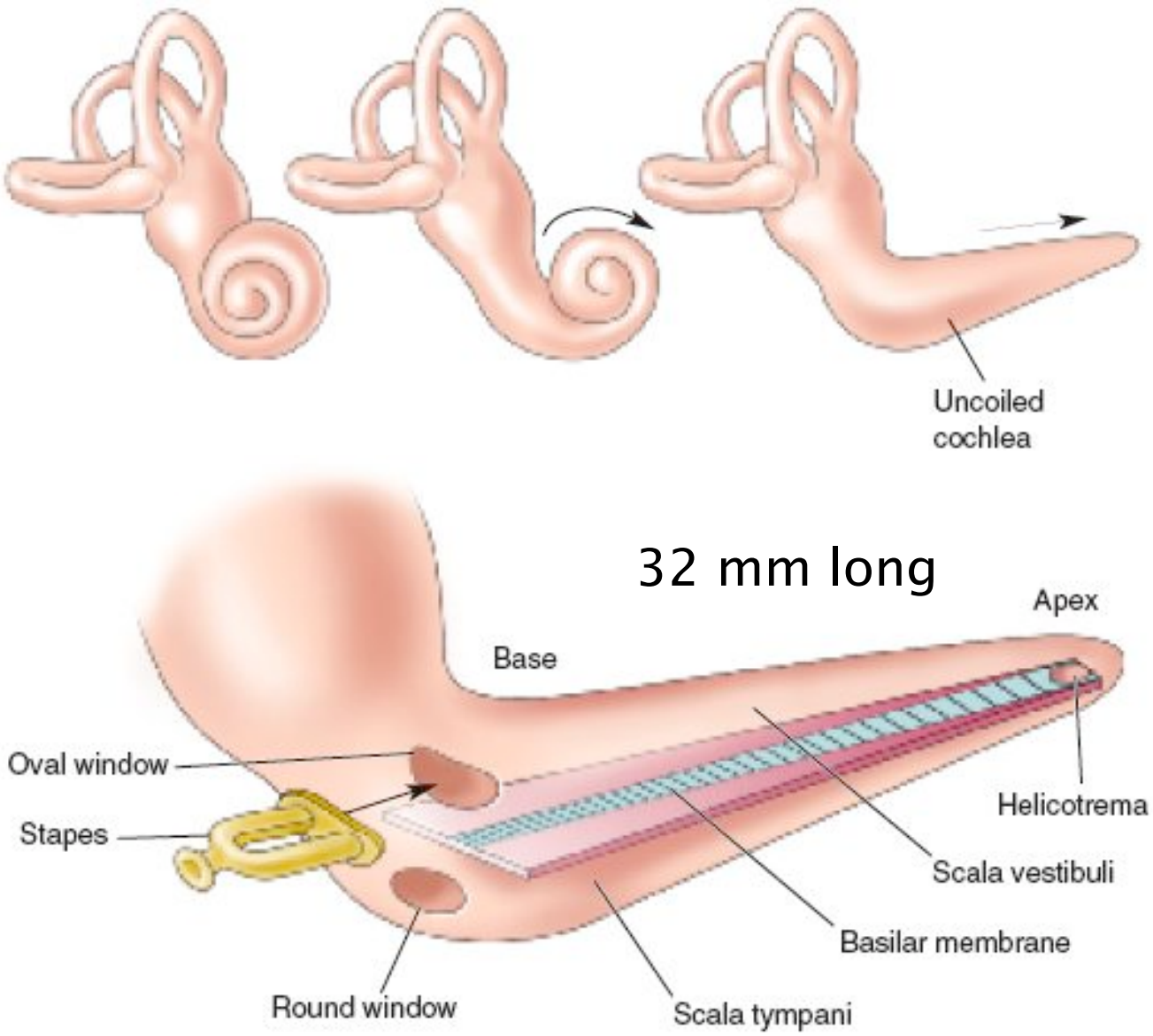


Pressure Amplification: 2 mechanisms

1) The oval window is much smaller than the tympanic membrane. Thus, force is **funnelled** to a smaller area, increasing pressure!

2) The stapes displaces the oval window with about 1/10 the displacement of the tympanic membrane, but with much greater force! The ossicles are a **lever** (mechanical advantage) **system**!

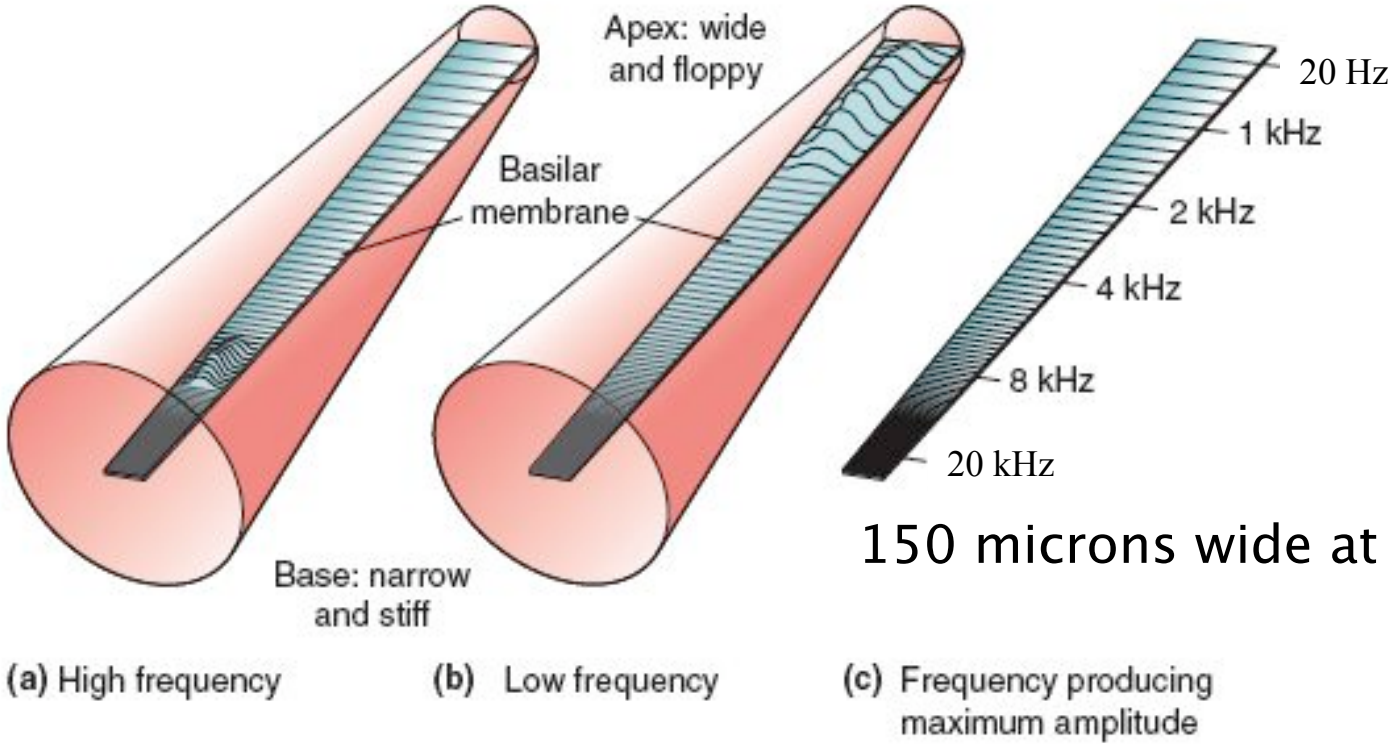
The Cochlea Uncoiled



Bear, Connors, & Paradiso. Neuroscience: Exploring the Brain, 3rd Ed. Ch. 11.

The Basilar Membrane: Resonant Frequency

500 microns wide at apex



150 microns wide at base

Bear, Connors, & Paradiso. Neuroscience: Exploring the Brain, 3rd Ed. Ch. 11.

Instruments - Resonant Frequency

xylophone

harp

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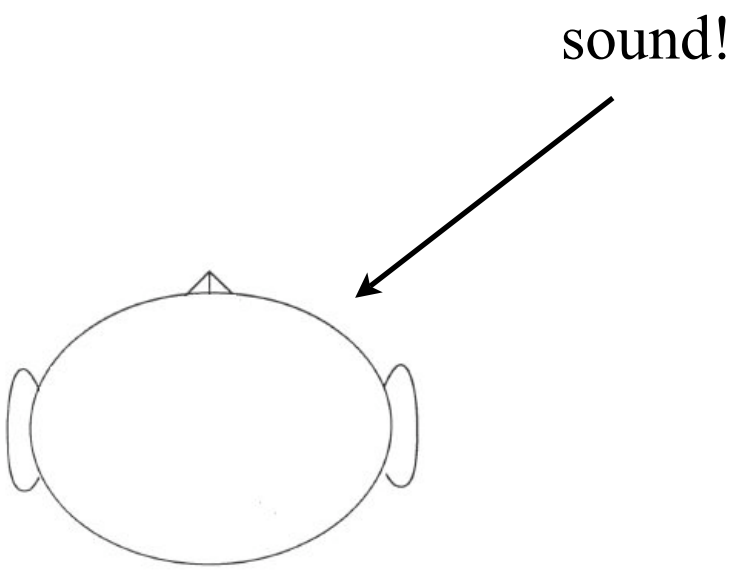
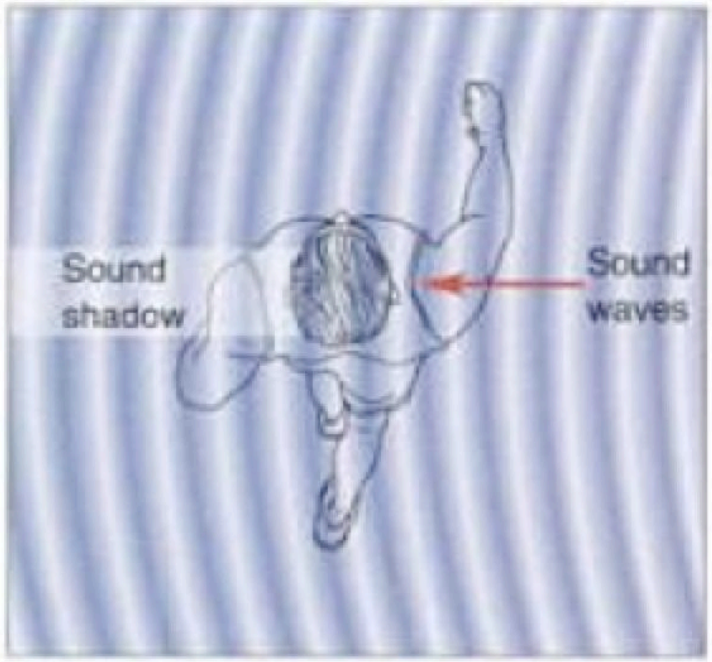
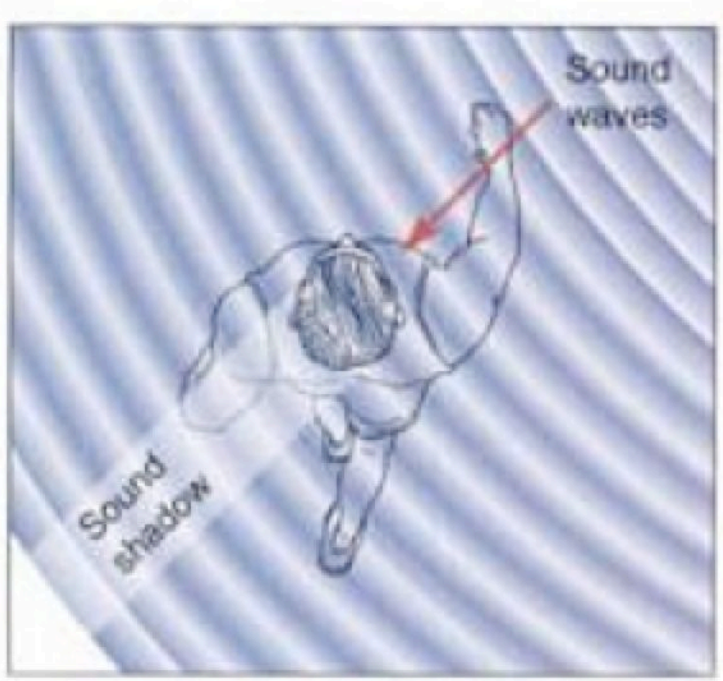
Localizing Sound: Demo!



Localizing Sound: interaural intensity difference

The nervous system monitors interaural intensity difference





High-frequency sounds are reflected by the head: **sound shadow!**

adapted from Neuroscience: exploring the brain. Fig. 11.23

Will the head create a sound shadow at all sound frequencies?

What is the lowest sound frequency that is blocked by the head?

The head reflects sound wavelengths of order head size or less

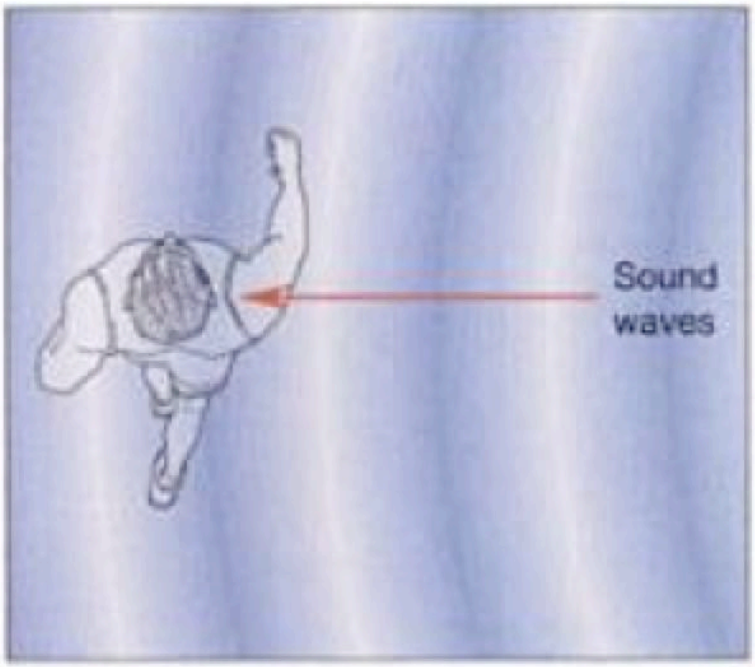
The speed of sound in air is 344 m / s

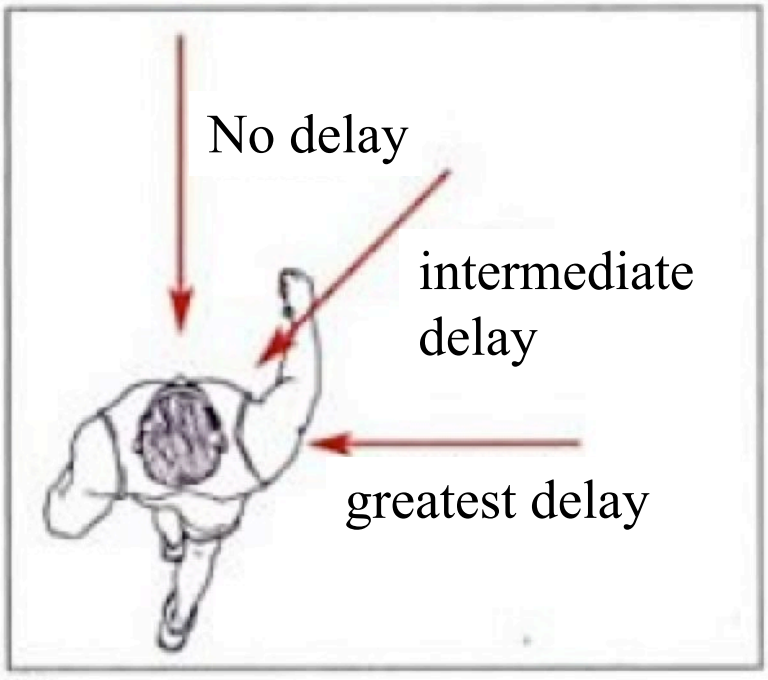
speed / head size = frequency

$$\frac{(344 \text{ m/s})}{(20 \text{ cm})} = \frac{(344 \text{ m/s})}{(0.2 \text{ m})} = 1720 \text{ Hz} \sim 2 \text{ KHz}$$

Localizing Sound: interaural time difference

The nervous system monitors interaural time difference





Low frequency sounds diffract around the head: no sound shadow!

20 Hz - 2,000 Hz

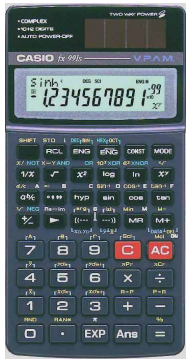
adapted from Neuroscience: exploring the brain. Fig. 11.22

Brain Teaser (10 min)!

Place all notes, books and other items below your desk.

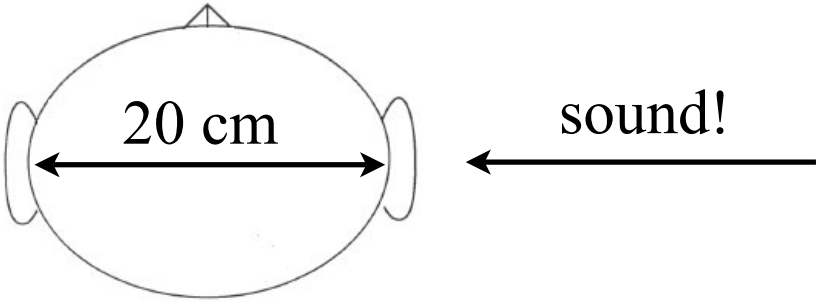
On your desk should be only:

- a piece of paper
- a pen/pencil
- your calculator



Brain Teaser!

a. (1 point)



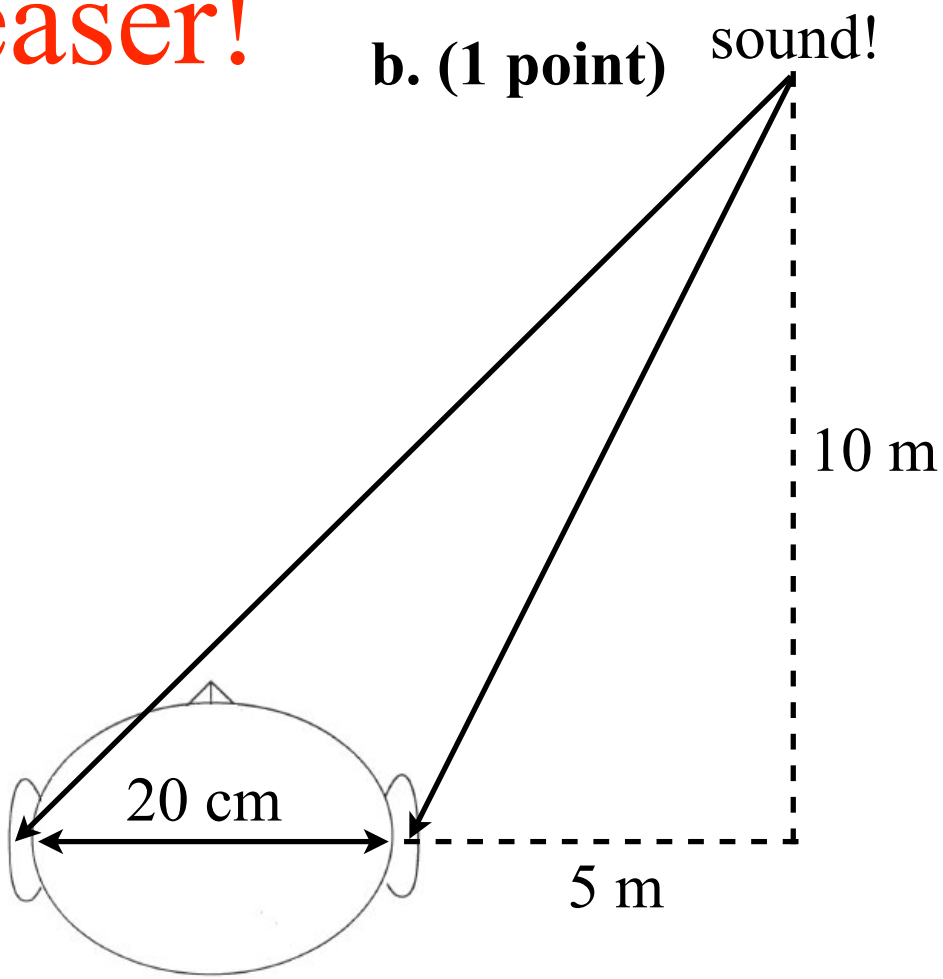
How much earlier does sound reach the right ear than the left?

Give your answer in milliseconds.

Note: the speed of sound in air is 344 m / s.

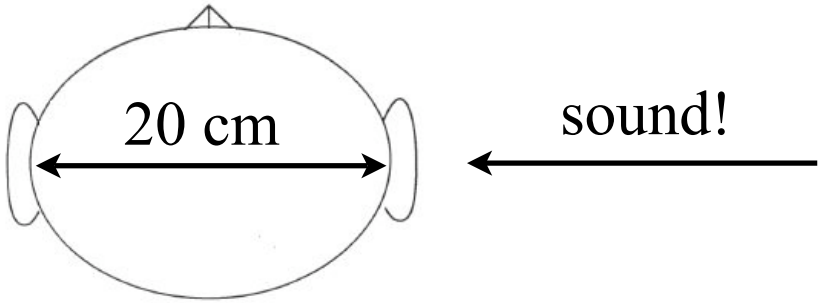
Show your work.

b. (1 point)



Brain Teaser Solution

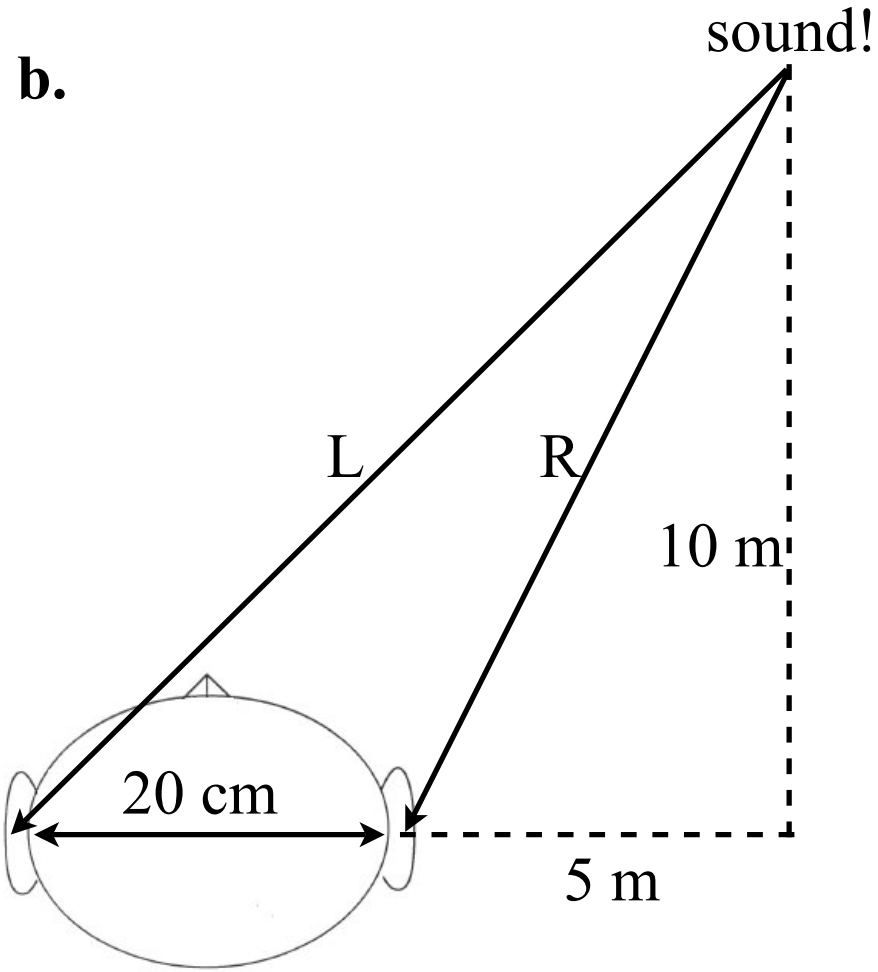
a.



$$(20cm)\left(\frac{1m}{100cm}\right)\left(\frac{1s}{344m}\right)\left(\frac{1000ms}{s}\right) = 0.6ms$$

Brain Teaser Solution

b.



$$R^2 = (5m)^2 + (10m)^2 = 125m^2$$

$$L^2 = (5.2m)^2 + (10m)^2 = 127.04m^2$$

$$R = \sqrt{125m^2} = 11.18m$$

$$L = \sqrt{127.04m^2} = 11.27m$$

$$L - R = 11.27m - 11.18m = 0.09m$$

$$(0.09m)\left(\frac{1s}{344m}\right)\left(\frac{1000ms}{s}\right) = 0.3ms$$

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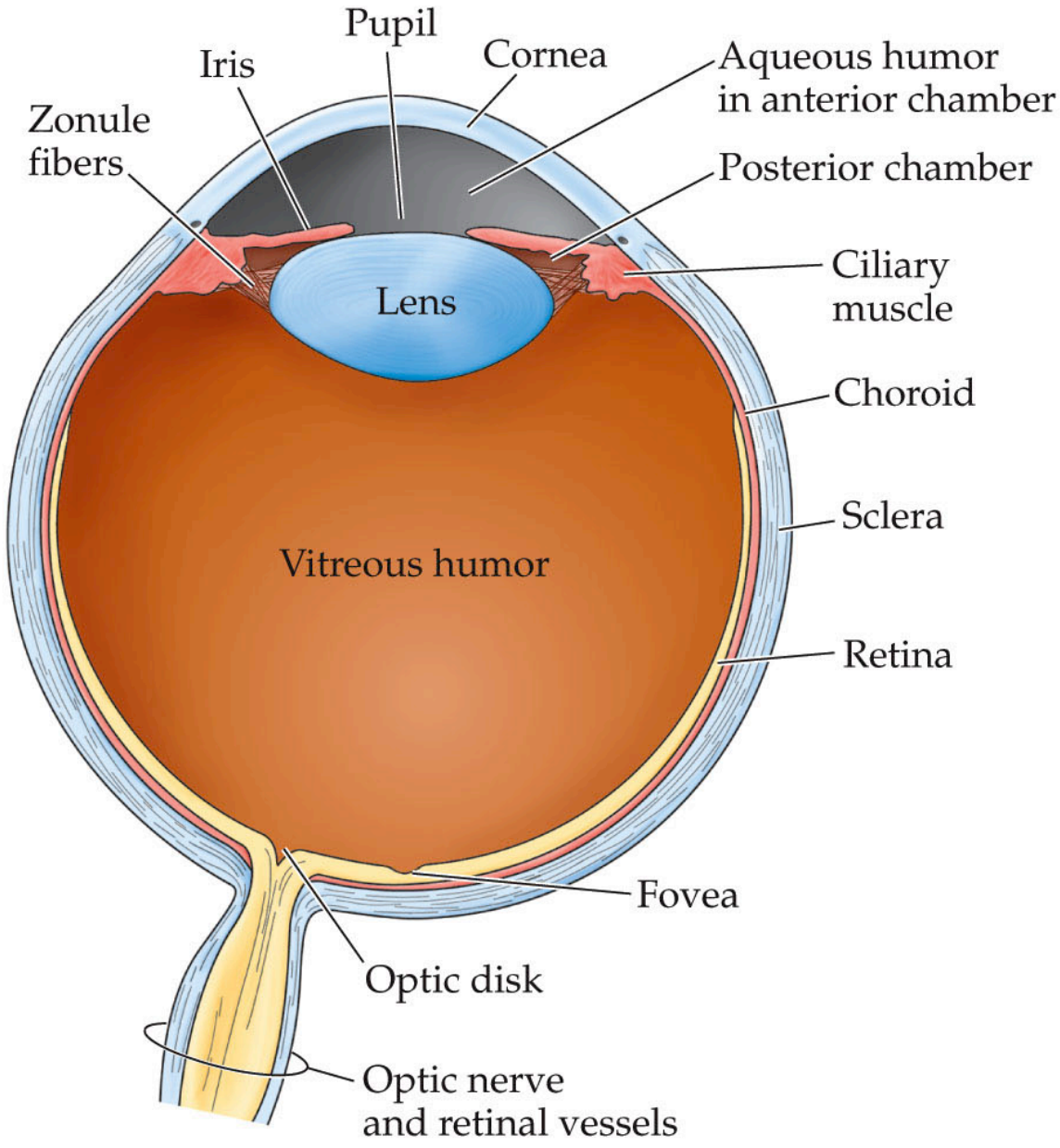
Anatomy of the human eye



***NEUROSCIENCE, Fourth Edition,* Figure 11.1**

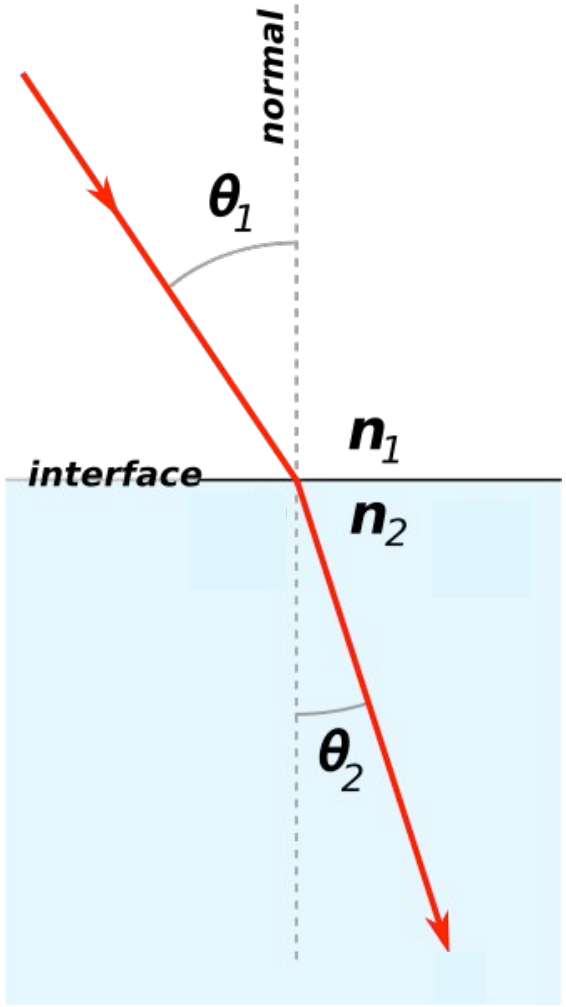
Which part of the eye provides the most refractive power?

Snell's Law gives the answer

Snell's Law

n = refractive index

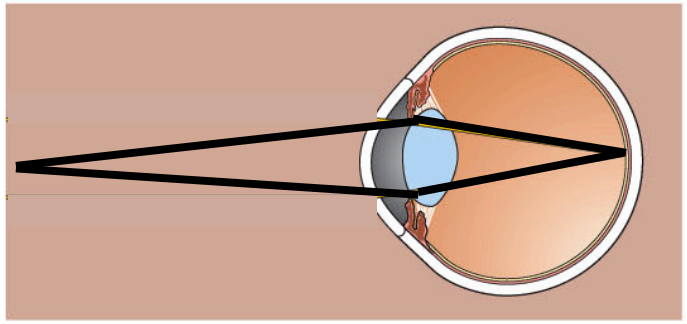
material	*n*
vacuum	1.000
air	1.003
water	1.33
cornea	1.38
lens	1.42
diamond	2.42



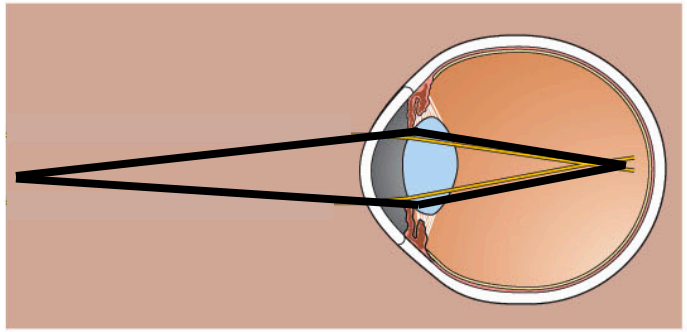
$$\frac{Sin\theta_1}{Sin\theta_2} = \frac{n_2}{n_1}$$

Refractive Errors

(A) Emmetropia (normal)

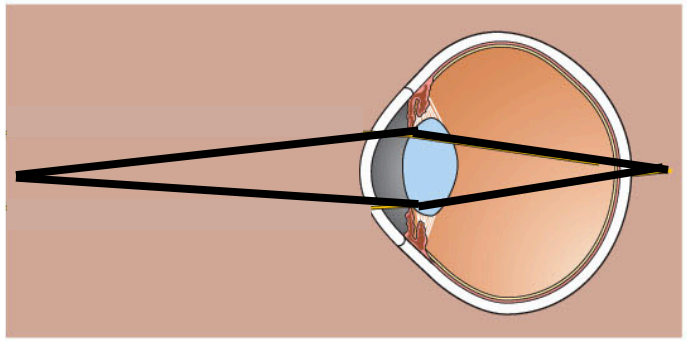


(B) Myopia (nearsighted)



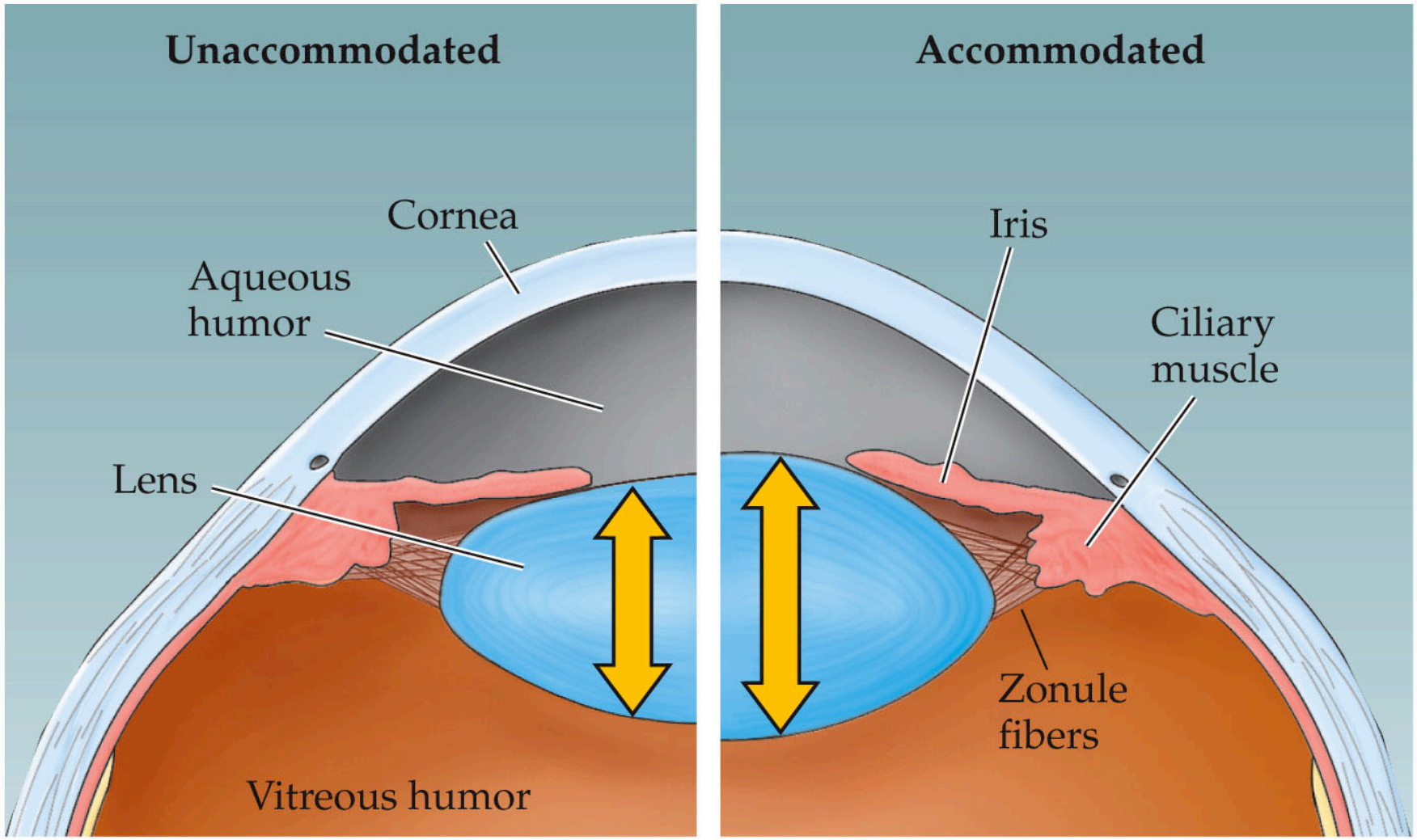
focal plane is in front of the retina, either because the eyeball is too long, or the cornea is too curved.

(C) Hyperopia (farsighted)



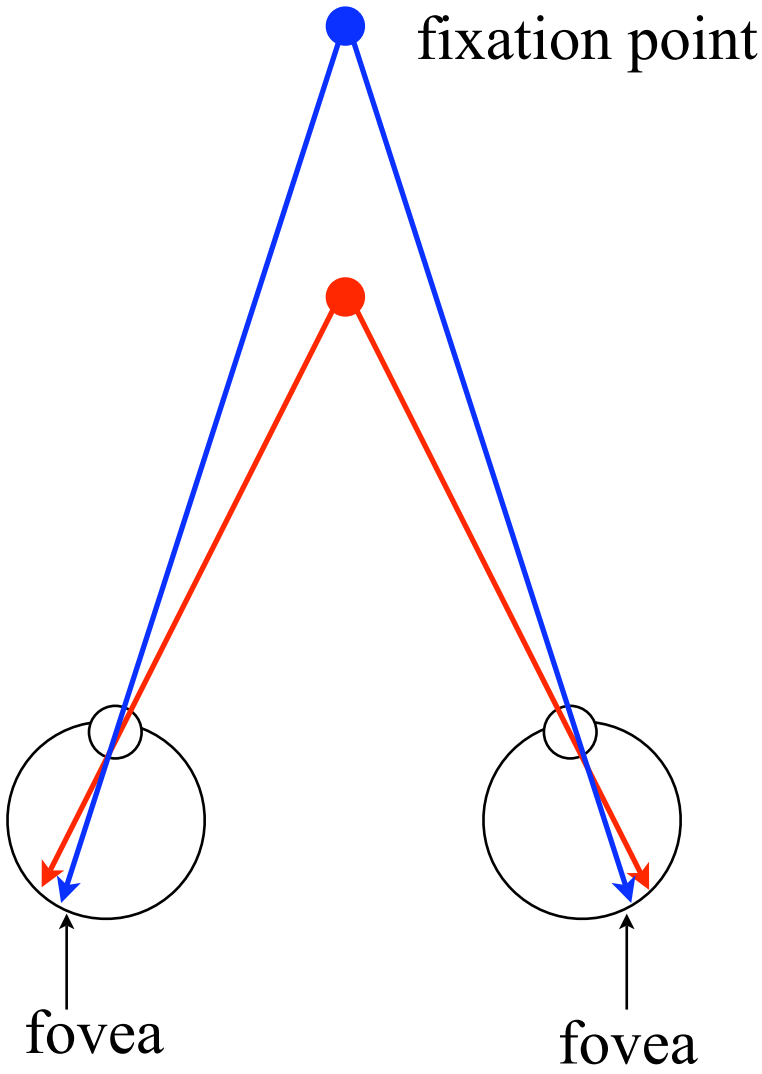
focal plane is behind the retina, either because the eyeball is too short, or the cornea is insufficiently curved.

Focusing Up Close

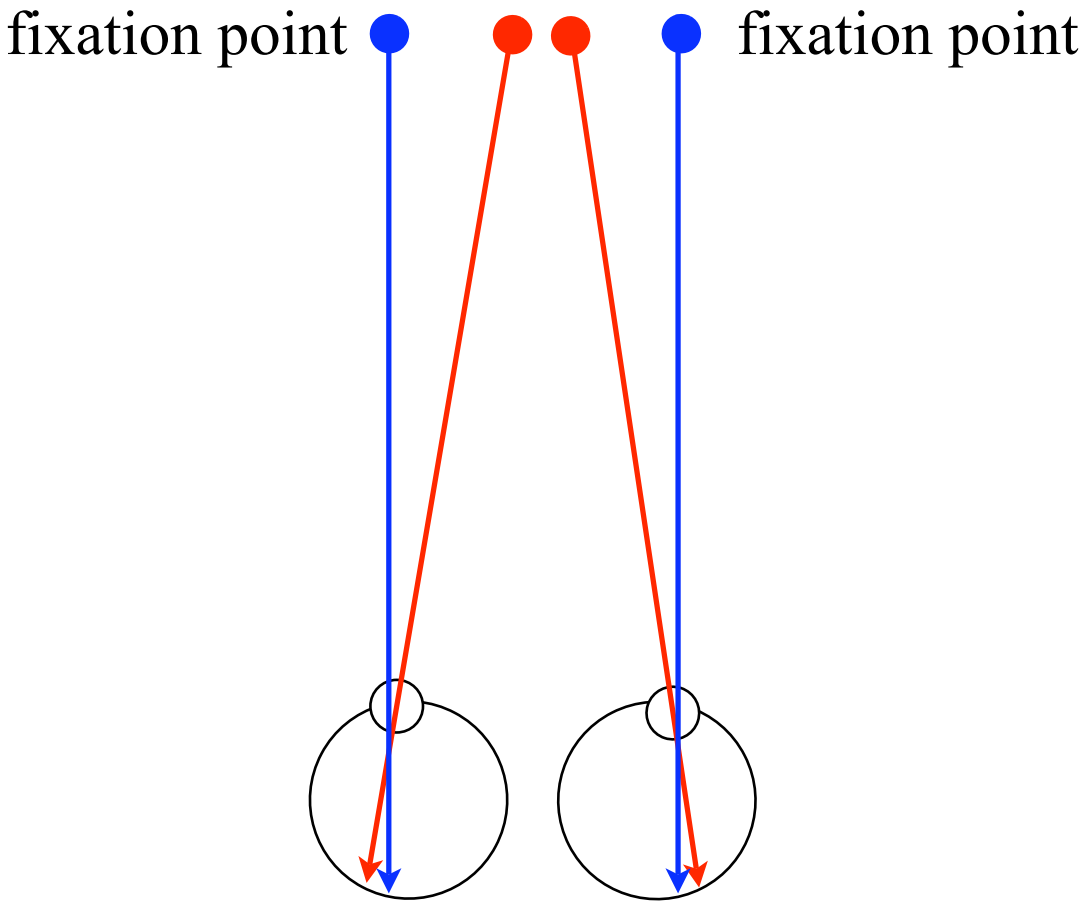


***NEUROSCIENCE, Fourth Edition,* Figure 11.2**

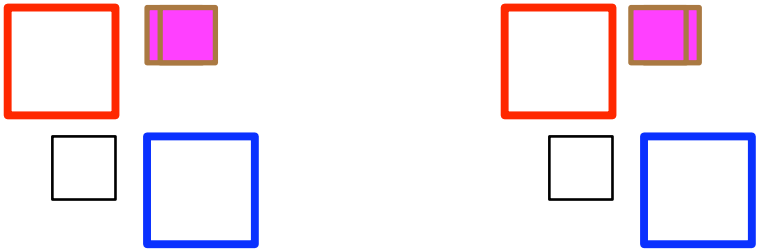
Stereopsis



Depth illusion: the two red objects hit the retina just as a single closer object would



How to Create a Stereogram!



Slides and other info

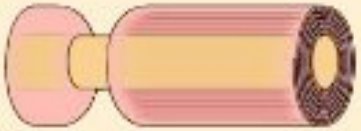
http://psych.mcmaster.ca/neuroclassics/OAPT.html

(Will be posted next Tuesday)

Extra

Somatosensory Axons

TABLE 9.1 Somatic Sensory Afferents that Link Receptors to the Central Nervous System

Sensory function	Receptor type	Afferent axon type[a]		Axon diameter	Conduction velocity
Touch	Merkel, Meissner, Pacinian, Ruffini		Aβ	6-12 μm	35-75 m/s
Pain/Temp	Free nerve endings		Aδ	1-5 μm	5-30 m/s
Pain/Temp/Itch	Free nerve endings		C	0.2-1.5 μm	0.5-2 m/s

About how long will it take a-beta, a-delta, and c-fiber APs to travel 1m?

A-beta: at ~50 m/s, time to travel 1 m = (1/50)s = **20 ms**
A-delta: at ~10 m/s, time to travel 1 m = (1/10)s = **100 ms**
C: at ~1 m/s, time to travel 1 m = **1 s**