CAMPBELL BIOLOGY: CONCEPTS & CONNECTIONS,
NINTH EDITION, GLOBAL EDITION
PowerPoint Lectures

# Chapter 29
## The Senses

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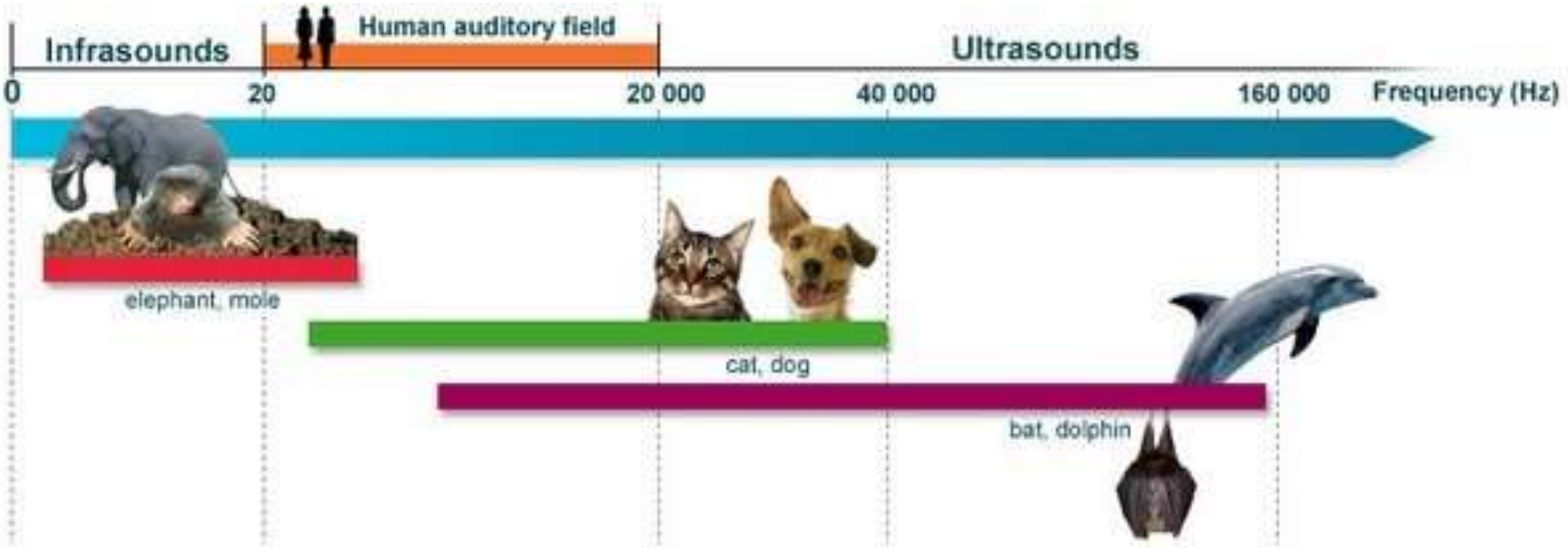
# Introduction

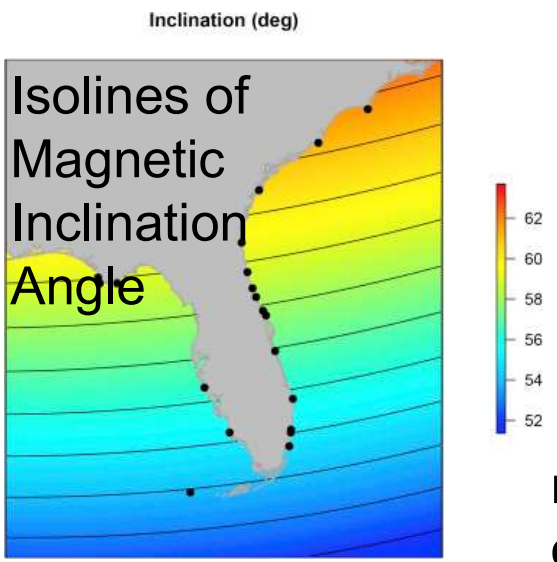
- Many animals have sensory abilities not found in humans.
  - Dogs can hear high-pitched sounds that are inaudible to your ears, while their noses detect subtle odors that you cannot perceive.
  - Bees can see ultraviolet patterns in flowers.
  - Sharks hunt by detecting changes in electric fields.
  - Migratory birds, fishes, and turtles are able to navigate by sensing Earth's magnetic field, a process called magnetoreception.

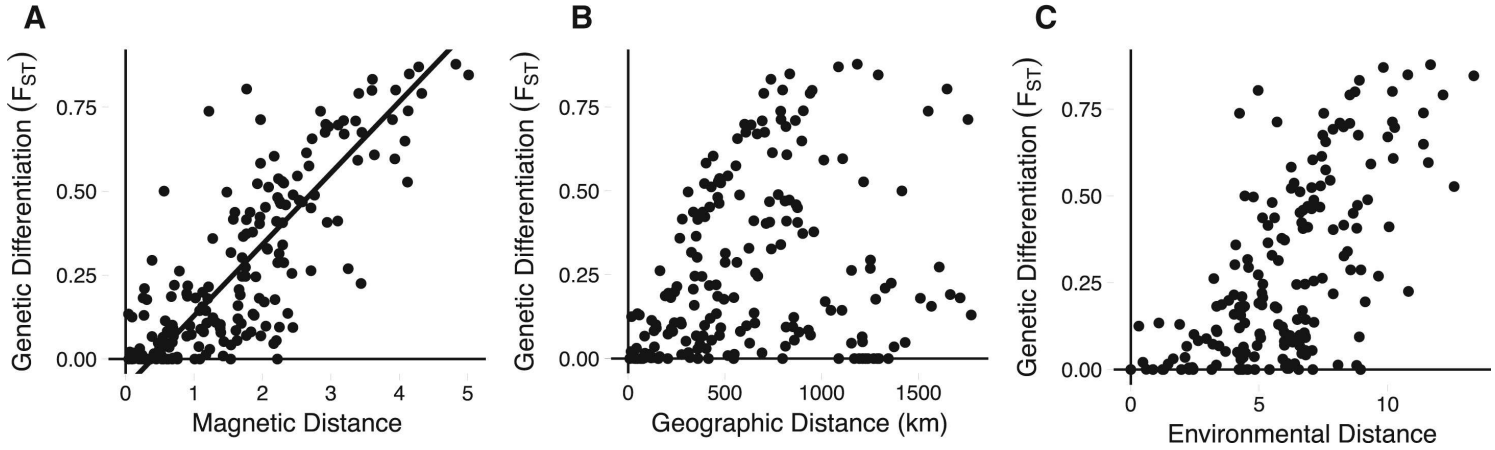



http://www.cochlea.org/en/hear/human-auditory-range

# A bees-eye view: How insects see flowers very differently to us

https://www.dailymail.co.uk/sciencetech/article-473897/A-bees-eye-view-How-insects-flowers-differently-us.html




nesting beaches with similar magnetic fields harbor populations of turtles that are genetically similar

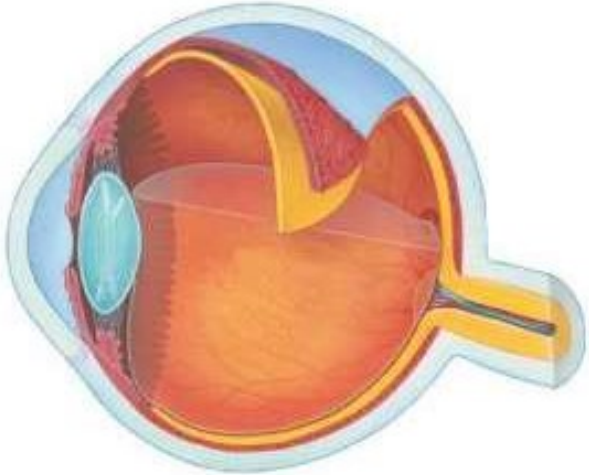
Evidence that Magnetic Navigation and Geomagnetic Imprinting Shape Spatial Genetic Variation in Sea Turtles (2018/4/23) Current Biology 28 (8), p1325–1329.e2.

Figure 29.0_1

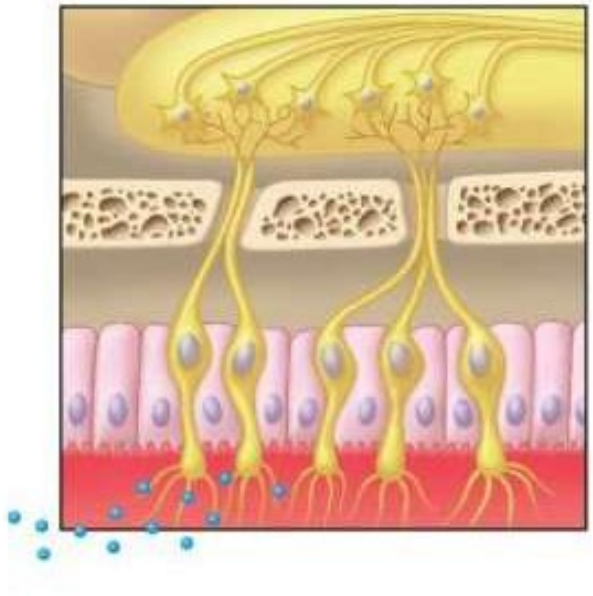
# Chapter 29: Big Ideas

**Sensory Reception**
**29.1-29.3**

**Hearing and Balance**
**29.4-29.6**



**Vision**
**29.7-29.10**



**Taste and Smell**
**29.11-29.13**

# SENSORY RECEPTION

# 29.1 Sensory receptors convert stimulus energy to action potentials

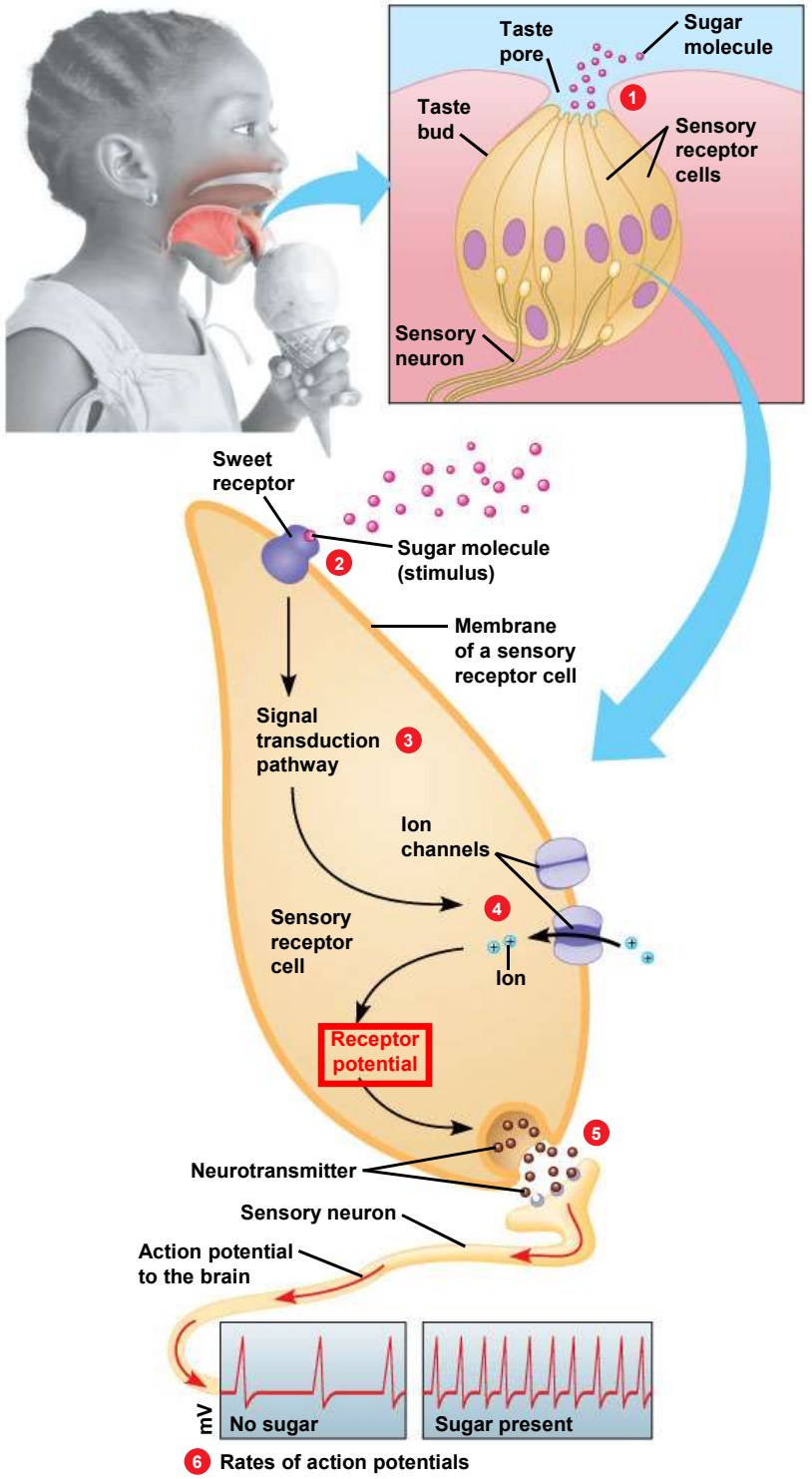
- All animal senses originate in **sensory receptors**, specialized cells or neurons that are tuned to the
  - conditions of the external world and the internal organs.
- **Sensory transduction** converts stimulus energy to **receptor potentials**, which trigger action potentials that are transmitted to the brain for processing by circuits of neurons.

感知與認知
Sensation & perception


electroreception

# 29.1 Sensory receptors convert stimulus energy to action potentials

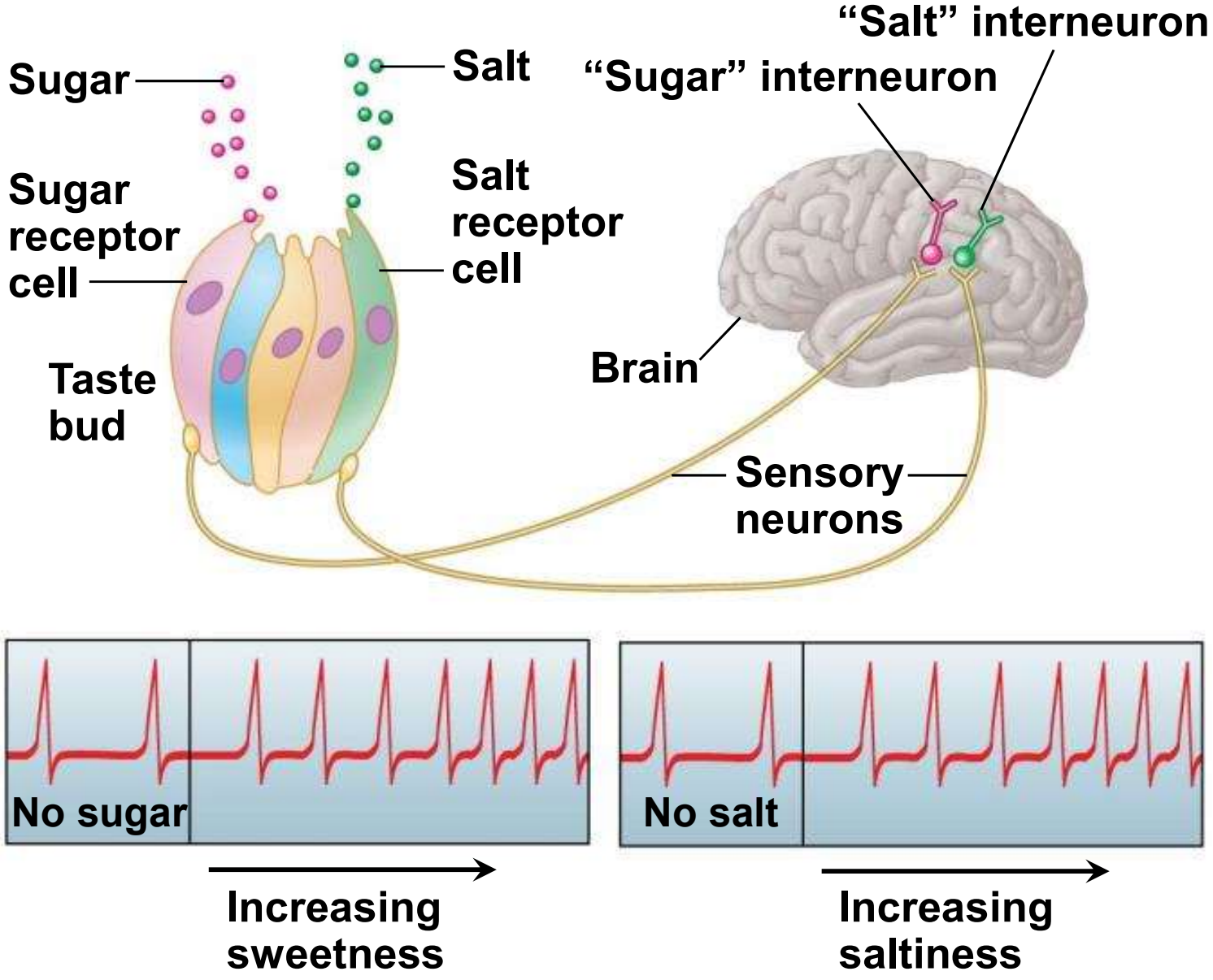
- In stimulus detection, the receptor cell converts one type of signal (the stimulus) to another type, an electrical signal.
- Action potential frequency reflects stimulus strength.
- This conversion is called **sensory transduction**; it produces a change in the cell's membrane potential.
- The tendency of some sensory receptors to become less sensitive when they are stimulated repeatedly is called **sensory adaptation**.



- When a sensory receptor cell in a taste bud detects sugar molecules,
  1. sugar molecules enter the taste bud,
  2. sugar molecules bind to sweet receptors, specific protein molecules embedded in a taste receptor cell membrane, and
  3. the binding triggers a signal transduction pathway that causes some ion channels in the membrane to close and others to open.
  4. These changes in the flow of ions create a graded change in membrane potential called a **receptor potential**.
  5. Once a stimulus is converted to a receptor potential, the receptor potential usually results in signals passing into the central nervous system.
  6. The graph shows the **rate** at which the sensory neuron sends action potentials when the taste receptor is and is not detecting any sugar.

## 29.1 Sensory receptors convert stimulus energy to action potentials

- Changes in the flow of ions create a graded change in membrane potential in sensory receptor cells called a **receptor potential**.
- Receptor potentials vary; the stronger the stimulus, the greater the receptor potential.
- The stronger the stimulus,
  - the more neurotransmitter released by the receptor cell and
  - the more frequently the sensory neuron transmits action potentials to the brain.
- Repeated stimuli may lead to **sensory adaptation**, the tendency of some sensory receptors to become less sensitive when they are stimulated repeatedly.

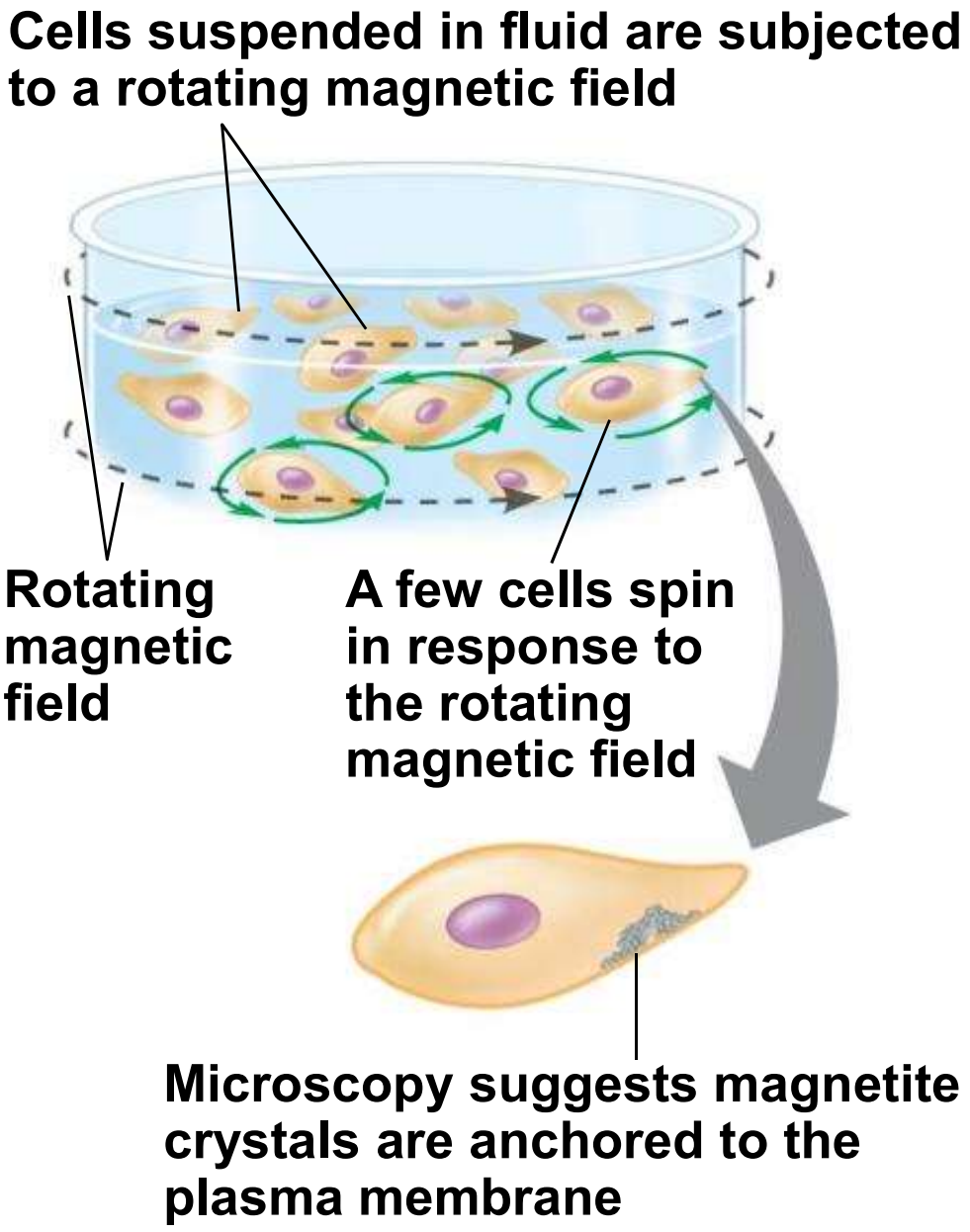

Sugar
Salt
"Salt" interneuron
"Sugar" interneuron
Sugar receptor cell
Salt receptor cell
Taste bud
Brain
Sensory neurons
No sugar
Increasing sweetness
No salt
Increasing saltiness

# 29.2 SCIENTIFIC THINKING: The model for magnetic sensory reception is incomplete

- Although steps in human sensory reception are clearly understood, those in other animals with unique senses are less clear.
- For sea turtles sensing Earth's magnetic field, the first step, detection, as it relates to magnetic sense (magnetoreception), is essentially unknown. Even the location of the magnetic sensory cells is obscure.
- Evidence suggests that there is not just one way animals detect the magnetic field to navigate. Three major hypotheses exist to explain the detection step in sensory reception as it relates to magnetoreception.
  - One hypothesis proposes that electrical fluctuations, influenced by Earth's magnetic field, are detected by sensory cells.

  - The other two hypotheses suggest that variations in the magnetic field affect biochemical reactions or the alignment of magnetic minerals inside sensory cells.
  - As is often the case in science, the different hypotheses need not be mutually exclusive.
- The strong magnetic mineral magnetite, which is used in compass needles, has been found in some animals with a magnetic sense, such as loggerhead sea turtles.
- Yet finding individual cells that contain magnetite has been challenging because a magnetite crystal is tiny (about 50 nm in diameter).
- In 2012, scientists dissociated cells from the nasal tissue of rainbow trout, suspended the cells in fluid, and subjected the cells to a rotating magnetic field.

- The spinning cells were separated and further examined by microscopy.
- Examination suggested that magnetite crystals anchor to the plasma membrane.
- Scientists hypothesize that mechanical pressure exerted by the magnetite crystals on the plasma membrane might cause ion channels to open, converting the pressure into a receptor potential capable of stimulating sensory neuron action potentials.



# **biogenic magnetite** $Fe_3O_4$ or iron (II, III) oxide

Octahedral crystals, 1.8 cm across
Wiki

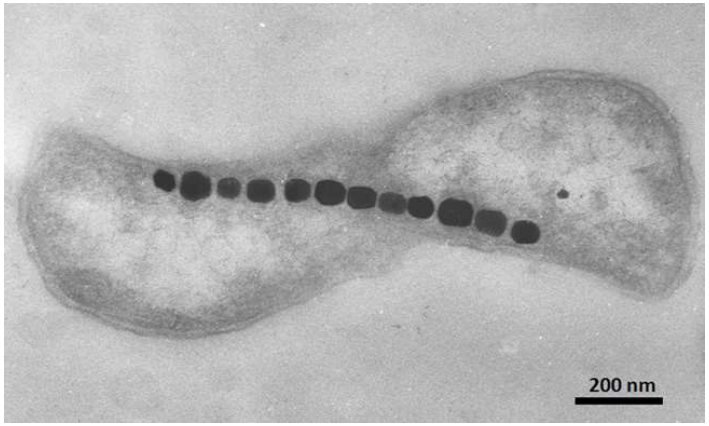
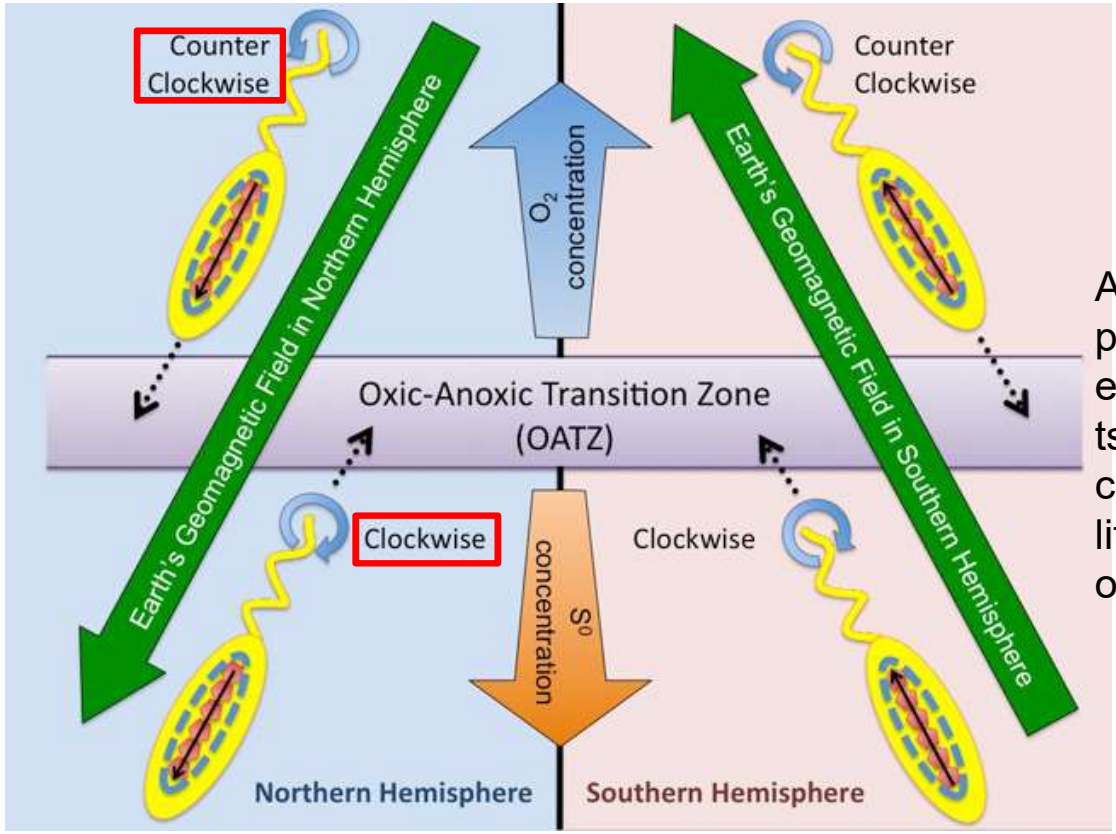



Figure 2: TEM image of a magnetotactic bacterium
Note the chain of twelve magnetite ($Fe_3O_4$) nanoparticles that are arranged along the long axis of the cell. The magnetic magnetite chain allows the organism to behave as a tiny motile compass needle

http://www.nature.com/scitable/knowledge/library/bacteria-that-synthesize-nano-sized-compasses-to-15669190




Anaerobes: prefer environments that contain little to no oxygen

These microbes prefer the oxic-anoxic transition zone (OATZ) where **oxygenated water** (or sediment) meets **oxygen-deficient** water (or sediment). The bacteria internally synthesize a chain of magnetic nanoparticles (shown as red pentagons in Figure 3), which act as a nano-sized magnet that allows the bacteria to passively align with Earth's geomagnetic field lines in both the Northern and Southern Hemispheres. Bacteria located in environments with higher than optimal oxygen concentration (top of the diagram) swim forward to the OATZ by rotating their flagella counter clockwise. Conversely, bacteria located in environments having lower than optimal oxygen concentration (bottom of diagram) rotate their flagella clockwise and swim backward to the OATZ

## 29.3 Specialized sensory receptors detect five categories of stimuli

- We can group animal sensory receptors into general categories, based on the type of signals to which they respond.
  1. **Pain receptors** detect dangerous stimuli including high heat and pressure.

     capsaicin (辣椒素)
  2. **Thermoreceptors** detect heat or cold.
  3. **Mechanoreceptors** respond to
     - mechanical energy, touch, pressure, and sound.
  4. **Chemoreceptors** include sensory receptors in our nose and taste buds and respond to chemicals.
  5. **Electromagnetic receptors** respond to
     - electricity,
     - magnetism, and
     - light (sensed by photoreceptors).

     Taste, smell, $O_2$, osmolarity, pheromone

Platypus bill: detect electric fields

Figure 29.3A

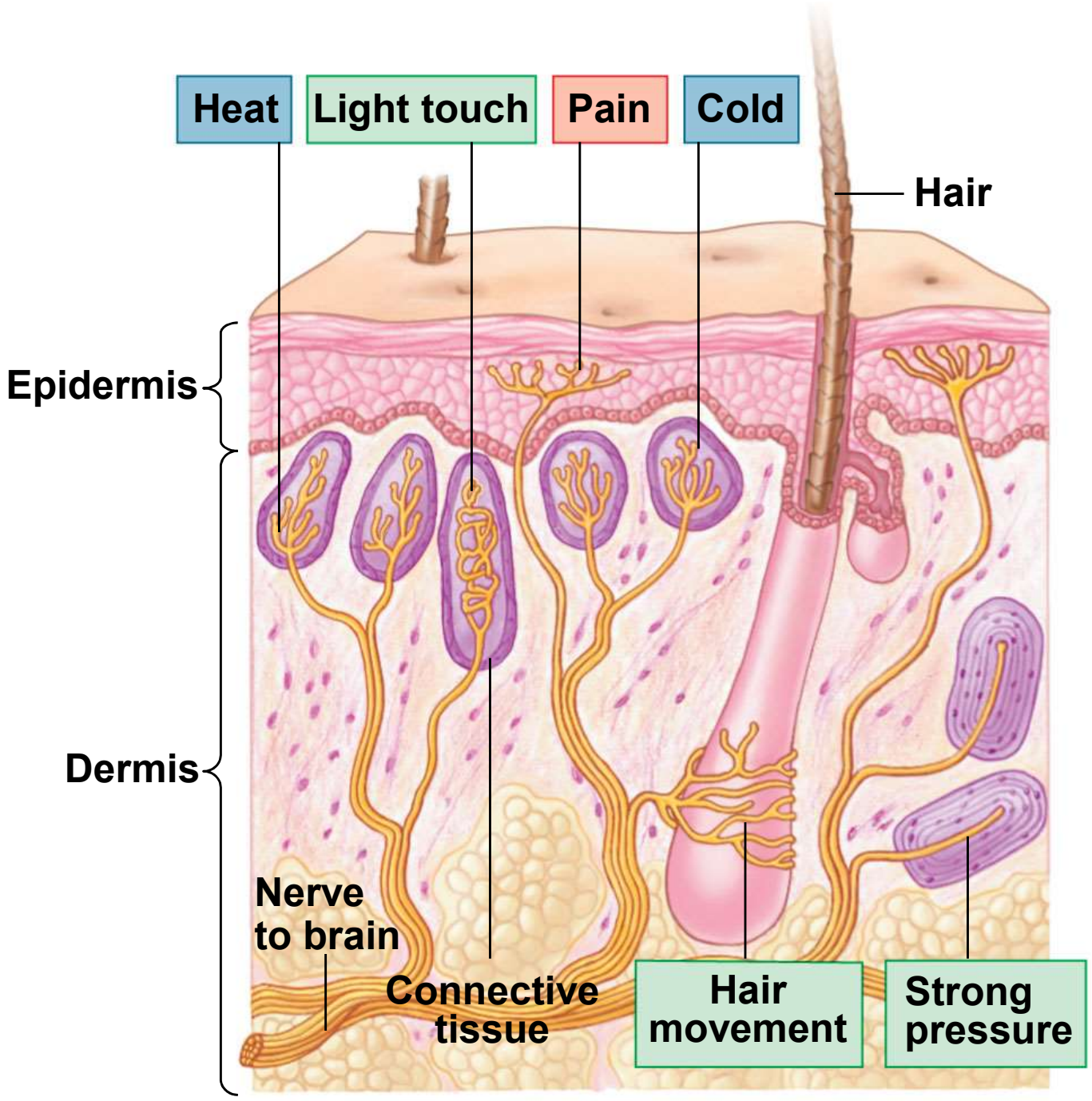
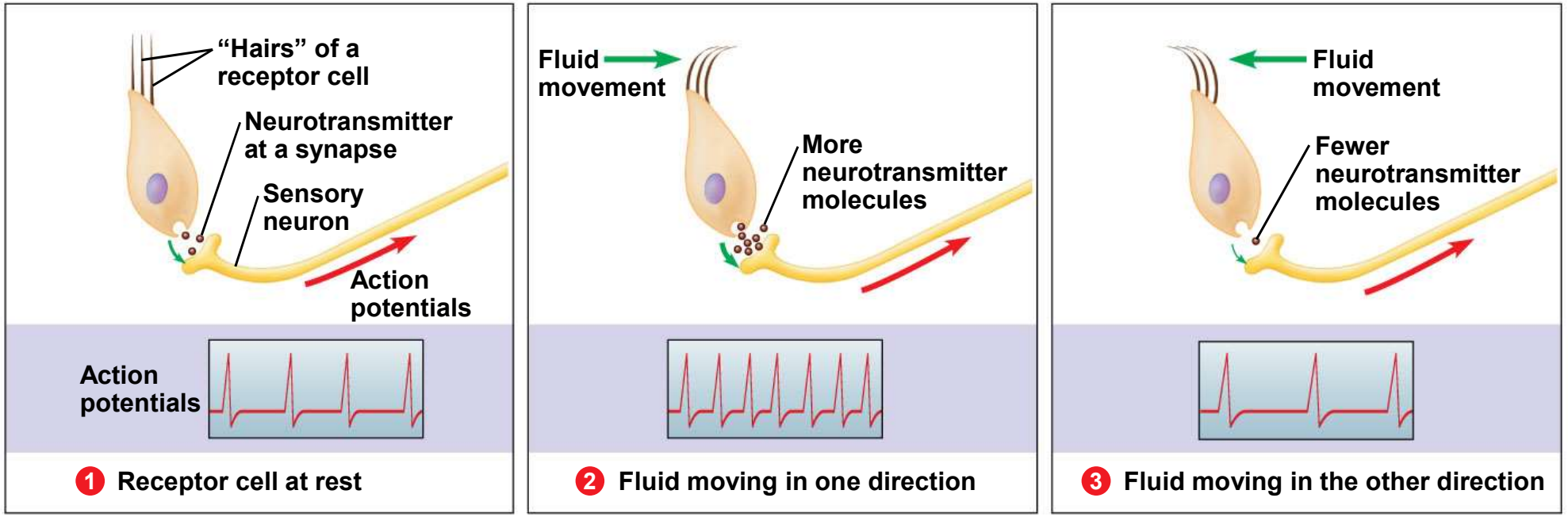
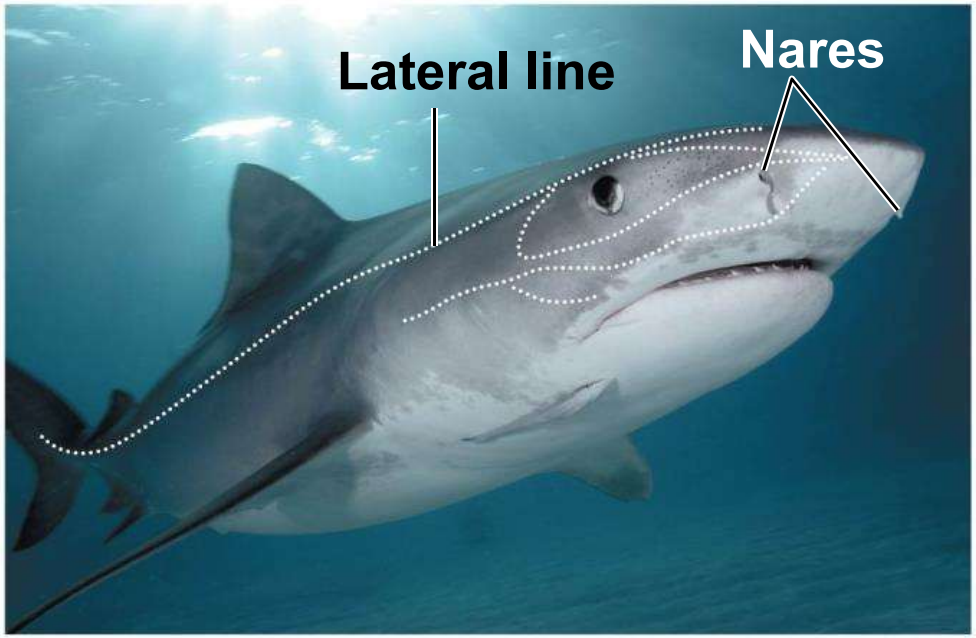
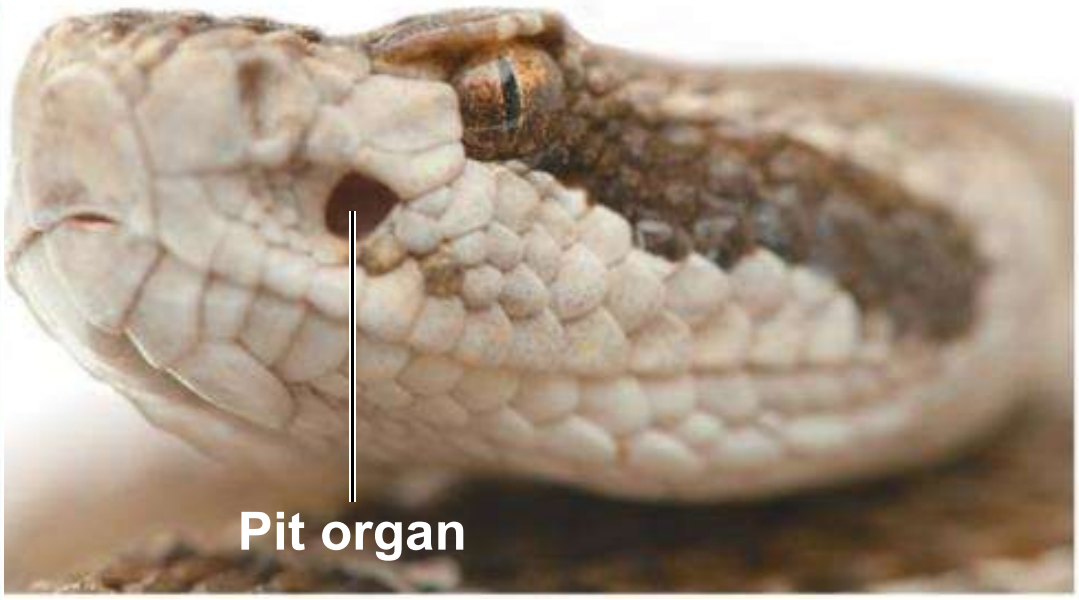


Figure 29.3B Mechanoreception





# HEARING AND BALANCE

第五條　娛樂場所、營業場所噪音管制標準值如下：

**Noise pollution and city life**

| 頻率 / 時段 / 音量 / 管制區 | 20 Hz 至 200 Hz | | | 20 Hz 至 20 kHz | | |
|---|---|---|---|---|---|---|
| | 日間 | 晚間 | 夜間 | 日間 | 晚間 | 夜間 |
| 第一類 | 32 | 32 | 27 | 55 | 50 | 40 |
| 第二類 | 37 | 32 | 27 | 57 | 52 | 47 |
| 第三類 | 37 | 37 | 32 | 67 | 57 | 52 |
| 第四類 | 40 | 40 | 35 | 80 | 70 | 65 |

You can ignore the noise but it still stimulates your nervous system

台北市環保局噪音管制標準
（各縣市稍有不同）

一類管制區：指環境亟需安寧之地區。
二類管制區：指供住宅使用為主且需要安寧之地區。
三類管制區：指供工業、商業及住宅使用且需維護其住宅安寧之地區。
四類管制區：指供工業使用為主且需防止嚴重噪音影響附近住宅安寧之地區。

Decibel (dB) 分貝

0~120, >130 can be painful

Frequency 20 ~ 20,000 Hz

Hair cells are never replaced!

人耳在1000 Hz這個頻率下能聽到的最小的聲音為0分貝，大致相當於3米外的一只蚊子在飛。每增加10分貝等於強度增加10倍，增加20 分貝增加100倍，30分貝則增加1000倍。

# 29.4 The ear converts air pressure waves to action potentials that are perceived as sound

- The human ear channels sound waves
  - from the **outer ear** with a flap-like **pinna**,
  - down the **auditory canal**,
  - to the **eardrum**, which separates the outer ear from the middle ear,
  - to a chain of bones in the **middle ear** (malleus, incus, and stapes), and
  - to the fluid in the coiled **cochlea** in the **inner ear**.
  - The **Eustachian tube** connects the pharynx to the middle ear, permitting pressure equalization.

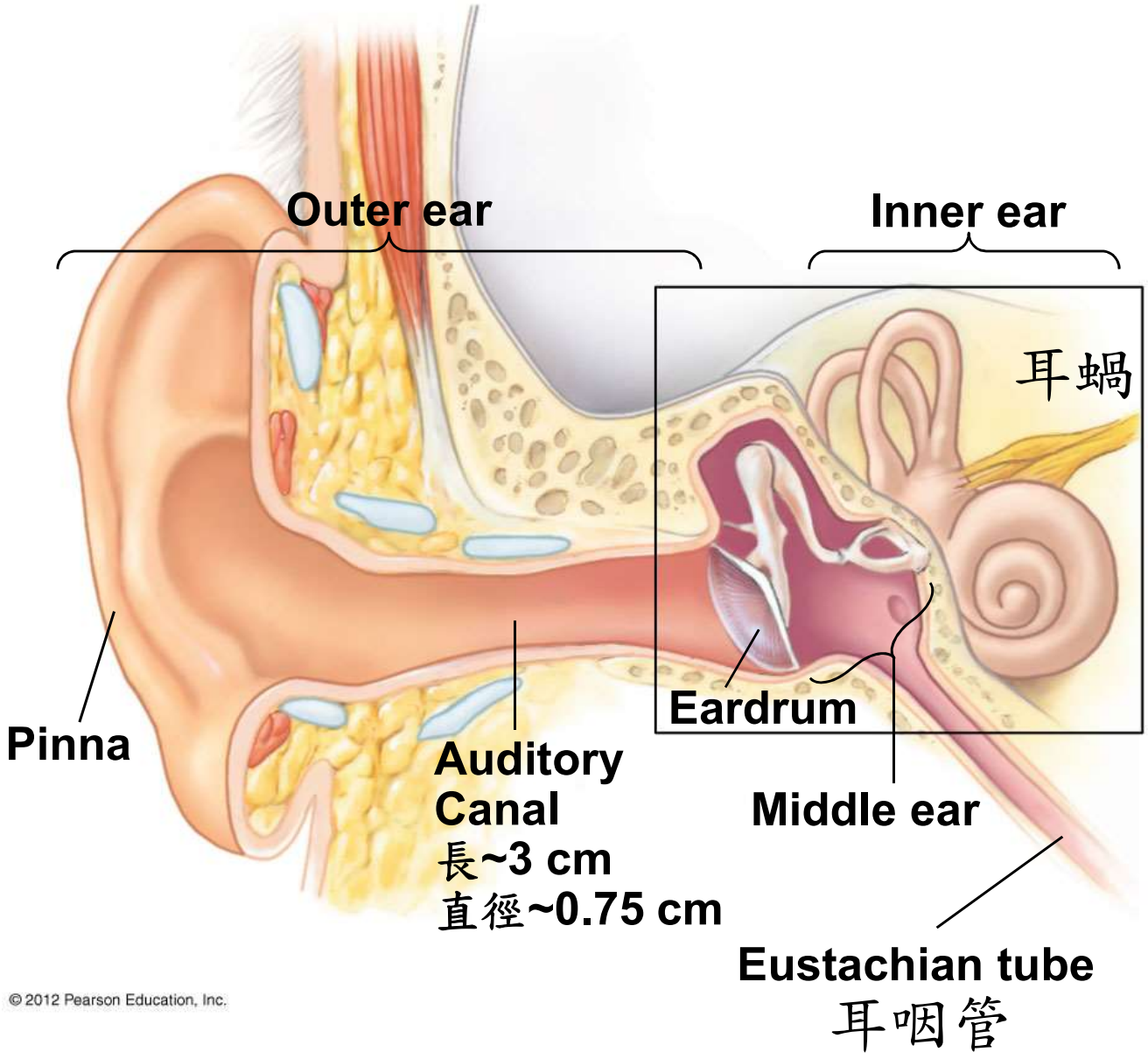
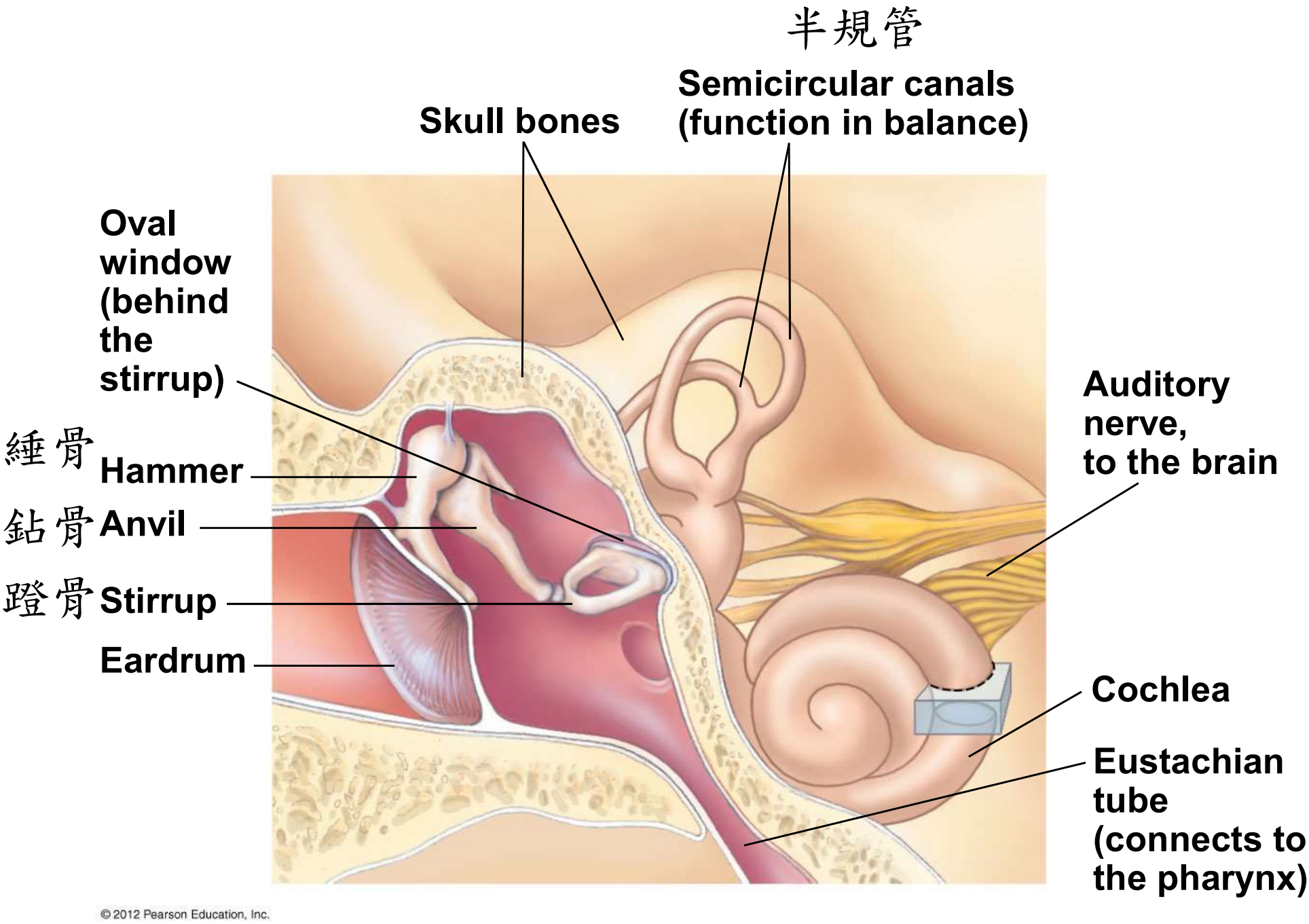
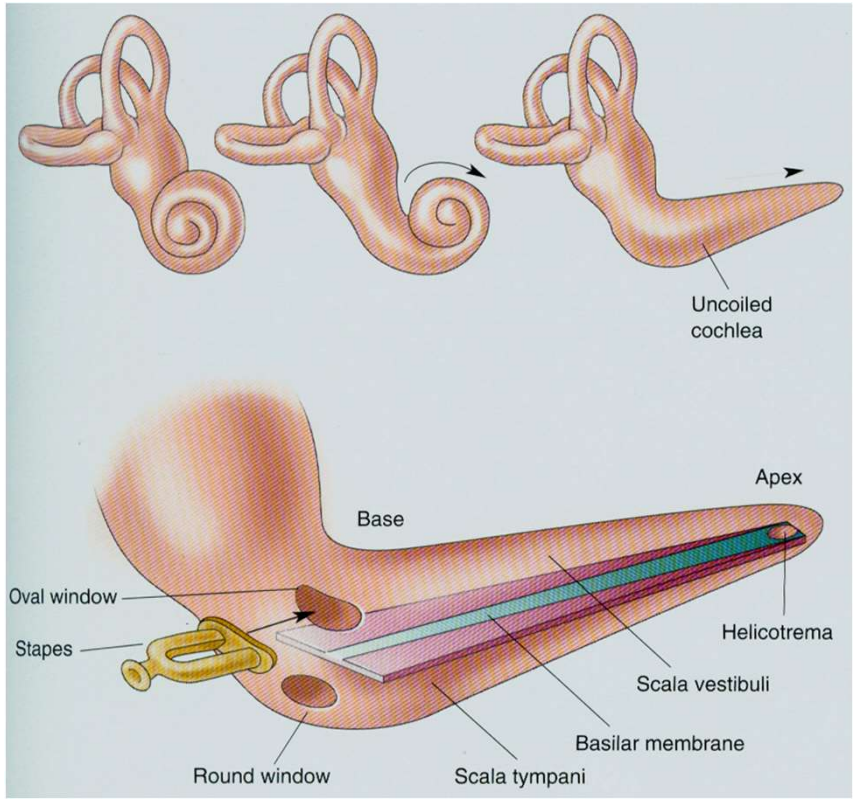


Figure 29.4B

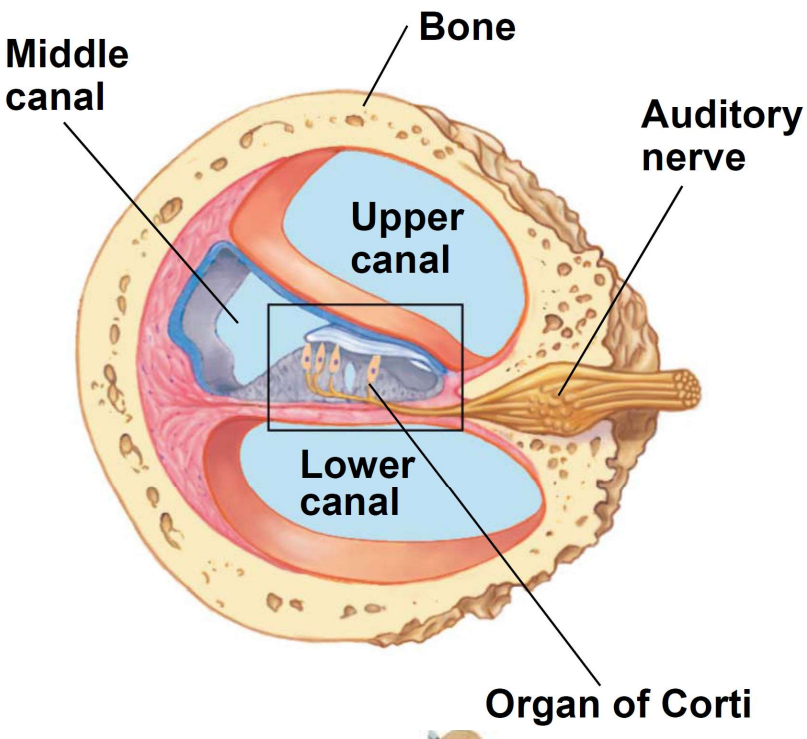


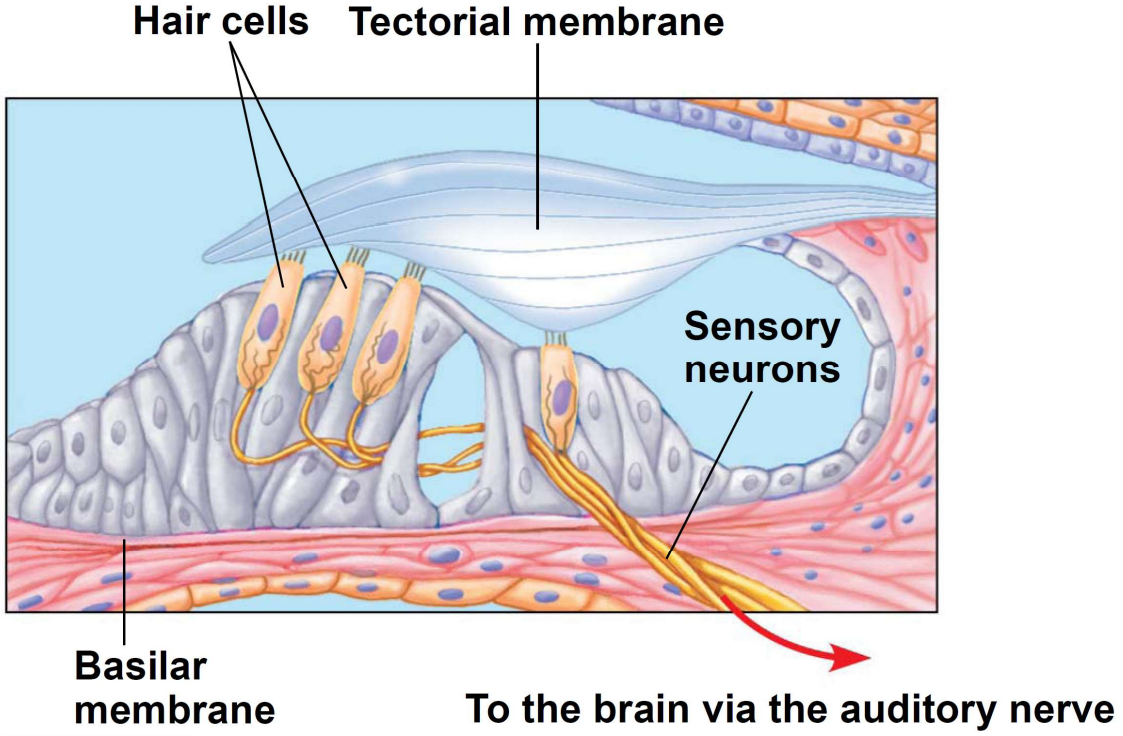
# 29.4 The ear converts air pressure waves to action potentials that are perceived as sound

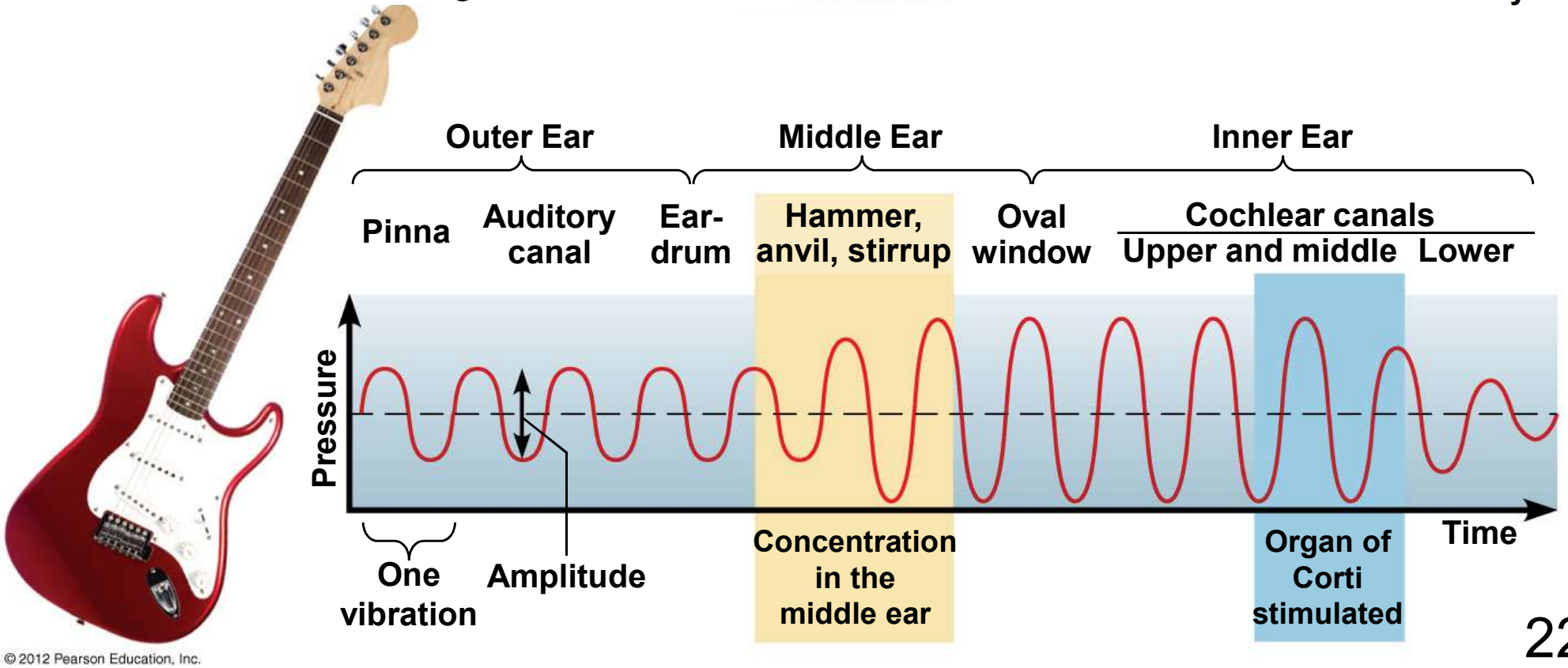
- Pressure waves transmitted to the fluid of the cochlea
  - bend hair cells in the **organ of Corti** against the **basilar membrane** and
  - trigger nerve signals to the brain.
- Louder sounds generate more action potentials.
- Various pitches stimulate different regions of the organ of Corti.




Neuroscience, Bear et al.



# 29.4 The ear converts air pressure waves to action potentials that are perceived as sound

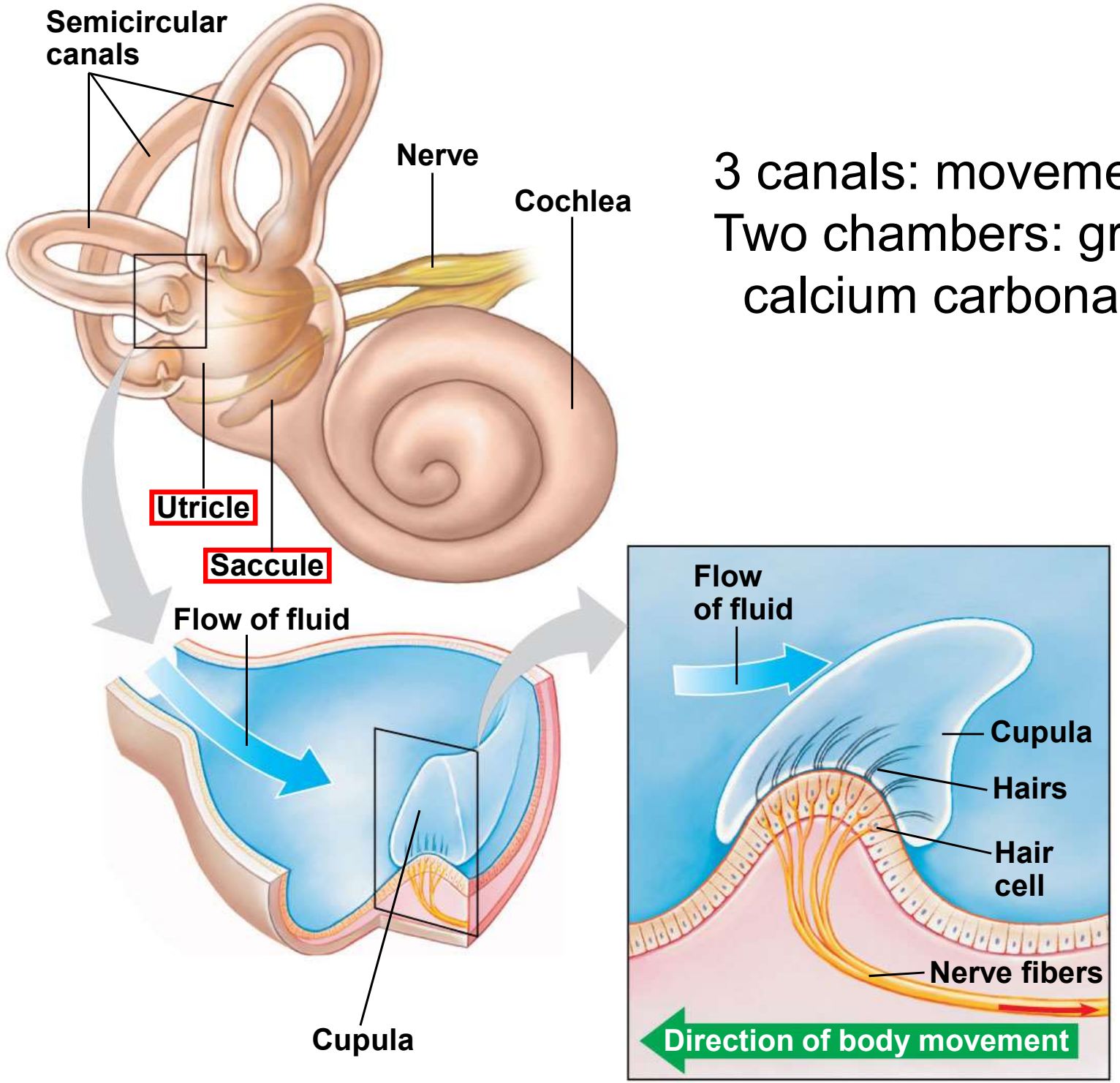
- Deafness is the loss of hearing.
- Deafness can be caused by the inability to detect sounds resulting from
  - middle-ear infections,
  - a ruptured eardrum, or
  - stiffening of the middle-ear bones.
- Deafness
  - can also result from damage to sensory receptors or neurons
  - is often progressive and permanent.

**1.1 billion people at risk of hearing loss: WHO highlights serious threat posed by exposure to recreational noise**
Press release *27 February 2015* | *Geneva* - Some 1.1 billion teenagers and young adults are at risk of hearing loss due to the unsafe use of personal audio devices, including smartphones, and exposure to damaging levels of sound at noisy entertainment venues such as nightclubs, bars and sporting events, according to WHO. Hearing loss has potentially devastating consequences for physical and mental health, education and employment.
http://www.who.int/mediacentre/news/releases/2015/ear-care/en/

# 29.5 The inner ear houses our organs of balance

- Three organs in the inner ear detect body position and movement. These include
  - three semicircular canals and
  - two chambers, the utricle and the saccule.
  - All three of these structures operate on the same principle: the bending of hairs on hair cells.
- The three **semicircular canals** detect changes in the head's rotation or angular movement.
- The utricle and saccule detect the position of the head with respect to gravity.

Figure 29.5




3 canals: movement
Two chambers: gravity, calcium carbonate

# 29.6 CONNECTION: What causes motion sickness?

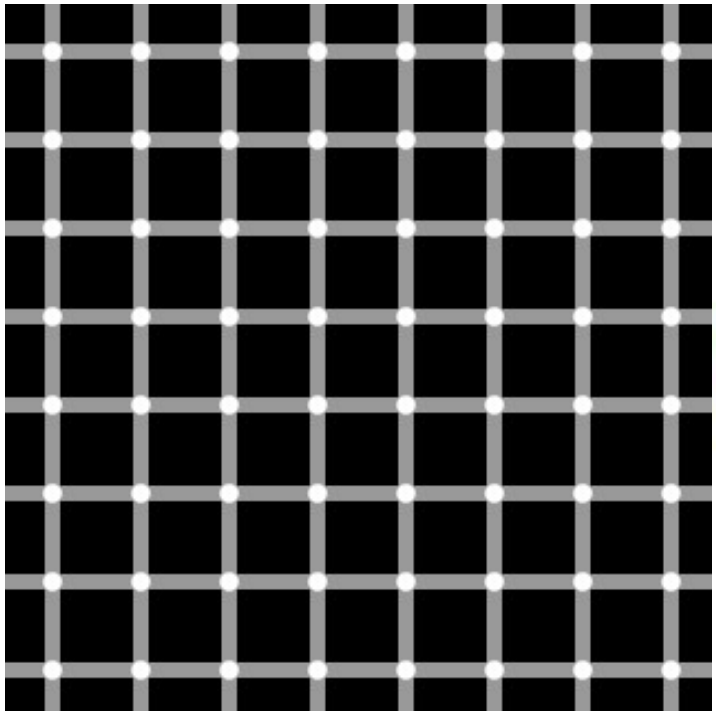
- Motion sickness may be caused by conflicting signals between the
  - inner ear and
  - eyes.

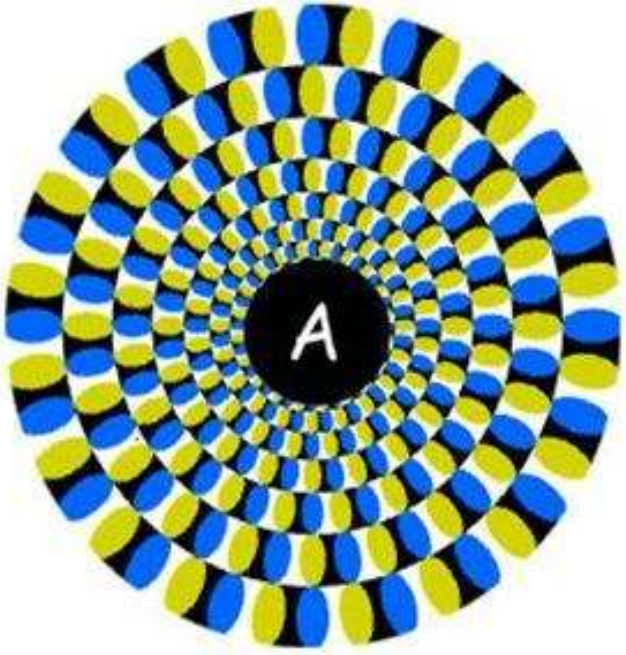
晕眩症

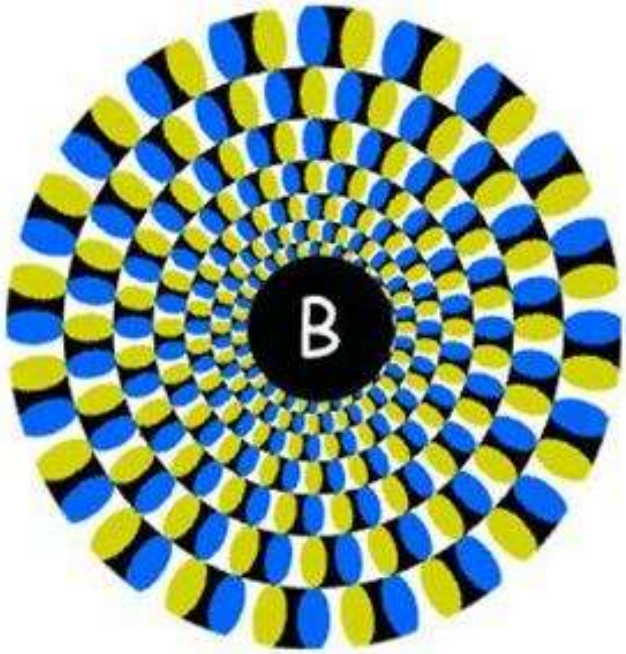
- Motion sickness can be a severe problem for astronauts.
  Mind over body: control vomiting reflex
- Motion sickness may be reduced by
  - closing the eyes,
  - limiting head movements,
  - focusing on a stable horizon,
  - sedatives such as dramamine or bonine, or
  - long-lasting, drug-containing skin patches.

# VISION

## Sensation and Perception





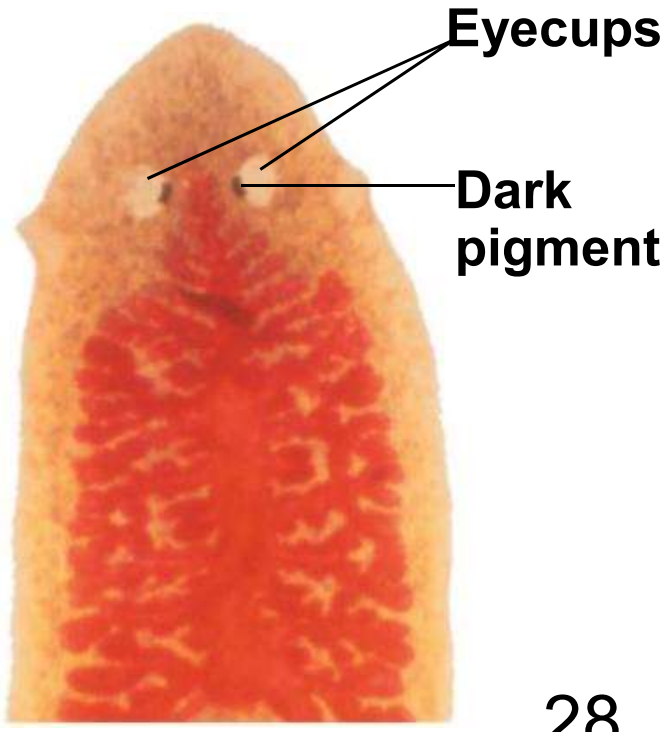

Which moves faster?

**Optical Illusions**
http://www.michaelbach.de/ot/

# 29.7 EVOLUTION CONNECTION: Several types of eyes have evolved independently among animals

- Evolution has resulted in a great diversity of organs that animals use to perceive light.
- All animal light detectors are based on cells called **photoreceptors** that contain pigment molecules that absorb light.
- Most invertebrate eyes include some kind of light-detecting organ.
- One of the simplest organs is the **eye cup**,
  - used by planarians,
  - which senses light intensity and direction

Planarian: not enough for an image, two cups face opposite directions



# 29.7 EVOLUTION CONNECTION: Several types of eyes have evolved independently among animals

- Two major types of image-forming eyes have evolved in the invertebrates.

1. **Compound eyes** of insects 複眼

   – consist of up to several thousand light detectors called ommatidia,

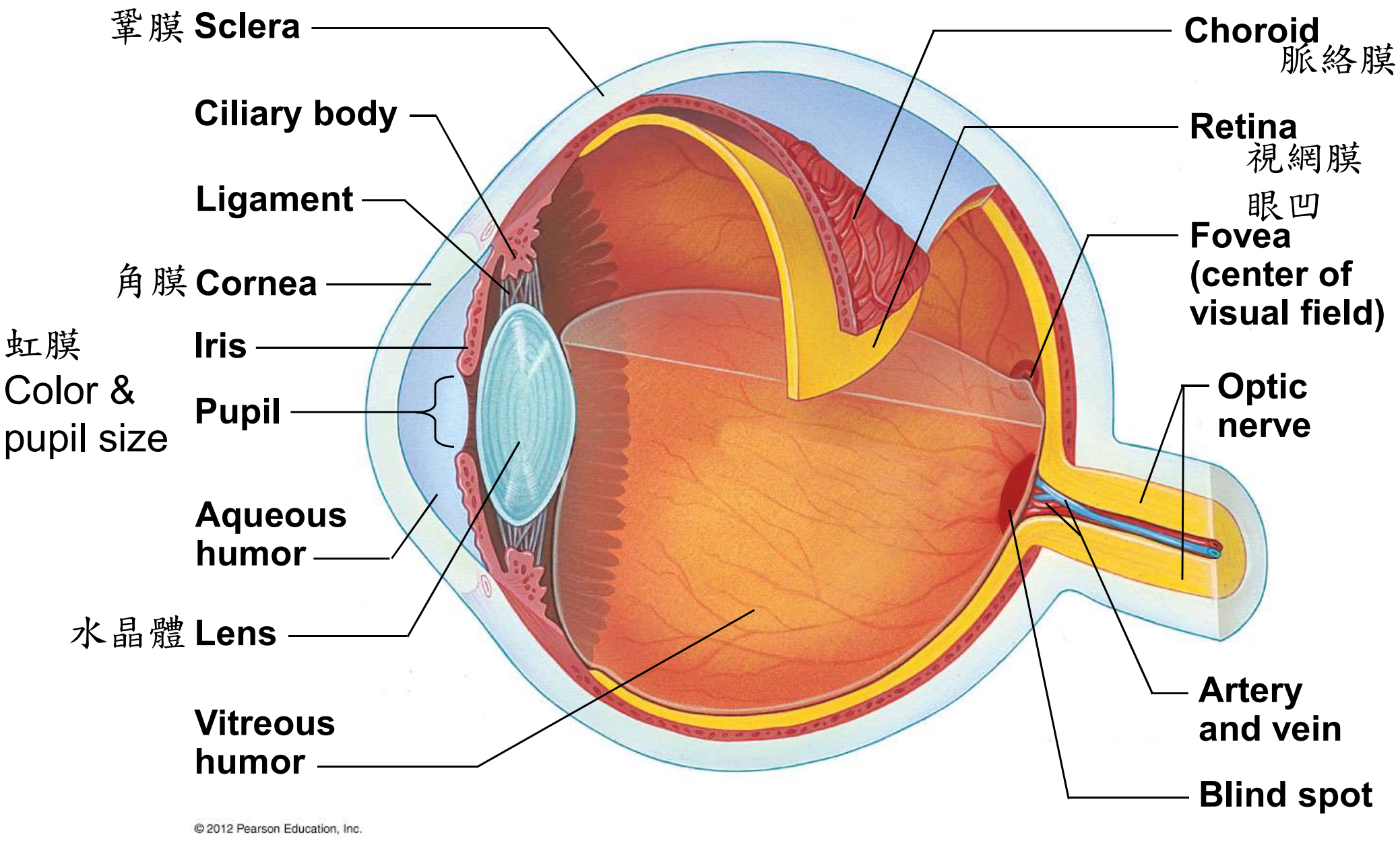
   – function as acute motion detectors, and

   – usually provide excellent color vision.

# 29.7 EVOLUTION CONNECTION: Several types of eyes have evolved independently among animals

2. In **single-lens eyes**
   - light enters the front center of the eye through a small opening, the **pupil**, controlled by an **iris**,
   - passes through a single disklike **lens**, and
   - is focused onto the **retina**, which consists of many photoreceptor cells.
   - The center of focus is the **fovea**, where photoreceptor cells are highly concentrated.
   - Single-lens eyes
     - evolved independently in the vertebrates but
     - are similar in structure.

Figure 29.7C

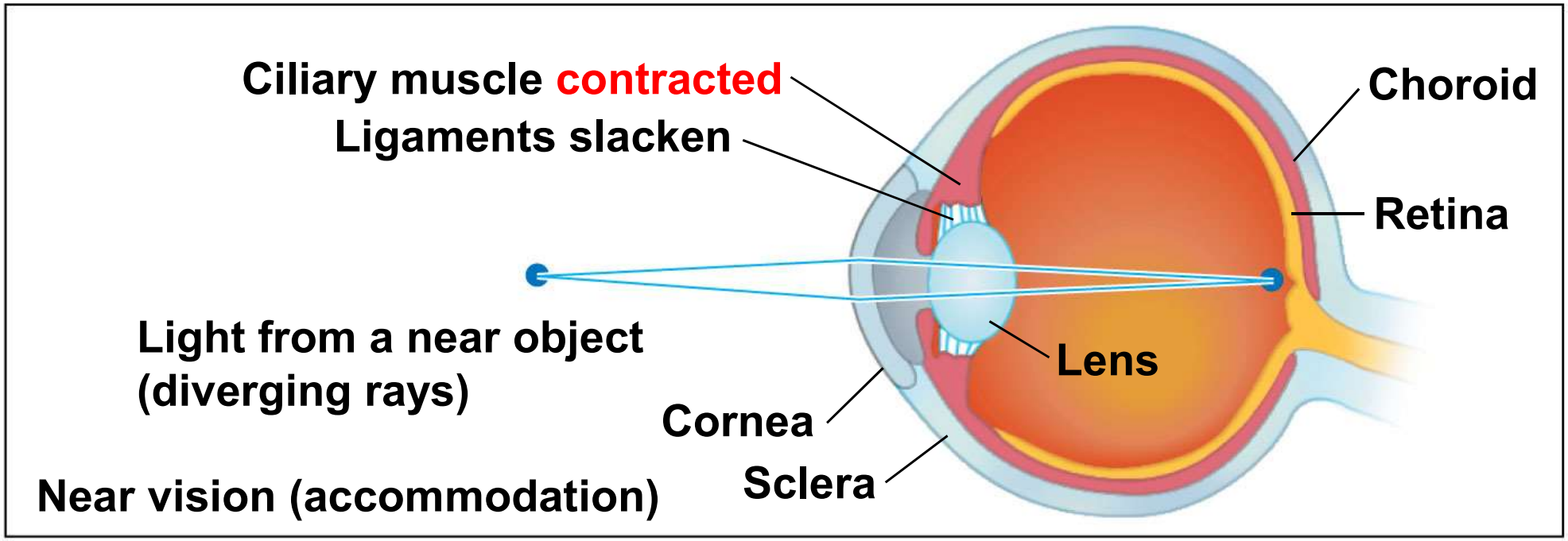


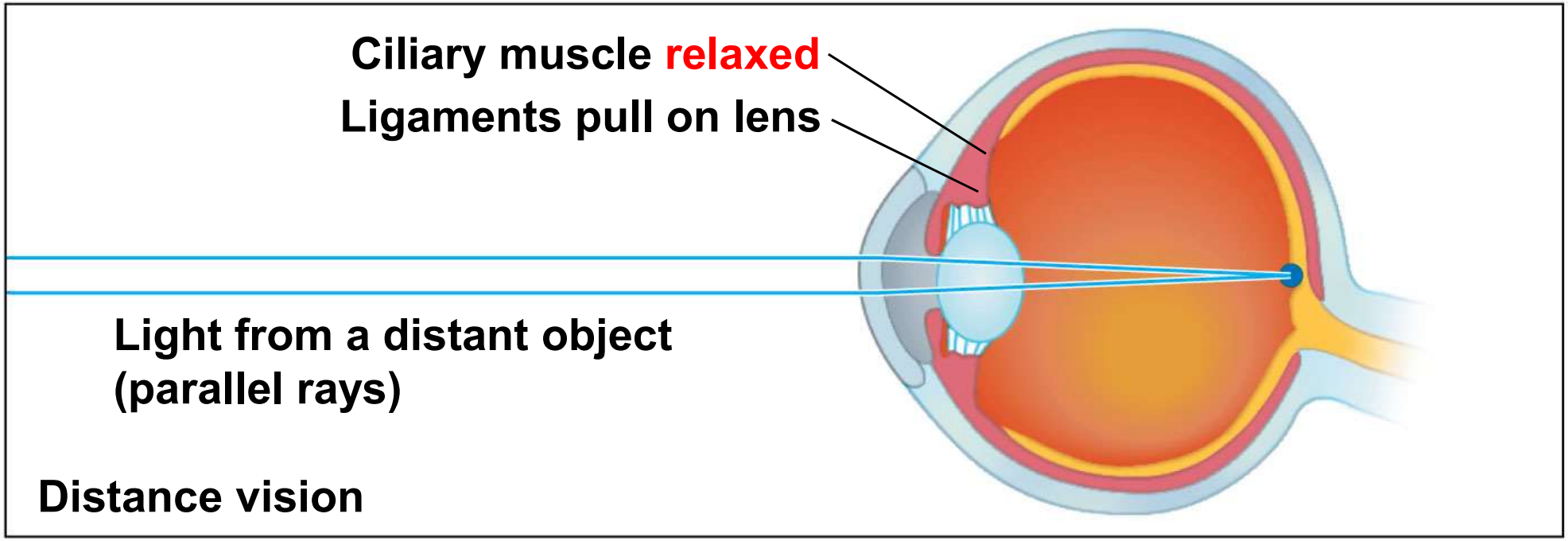

Glaucoma 青光眼、臺灣約有35萬病患
Humor circulation problem

# 29.8 Humans have single-lens eyes that focus by changing position or shape

- The outer surface of the human eyeball is a tough, whitish layer of connective tissue called the **sclera**.
  - At the front of the eye, the sclera becomes the transparent **cornea**,
    - lets light into the eye and
    - also helps focus light.
  - The sclera surrounds a pigmented layer called the **choroid**. The anterior choroid forms the iris, which gives the eye its color.
- The lens and ciliary body divide the eye into two fluid-filled chambers.
  1. The large chamber behind the lens is filled with a jellylike **vitreous humor**.
  2. The smaller chamber in front of the lens contains the thinner **aqueous humor**.
- These humors
  - help maintain the shape of the eyeball and
  - circulate nutrients and oxygen to the lens, iris, and cornea.

- The **conjunctiva** 結膜
  - lines the inner surface of the eyelids and folds back over the white of the eye (but not the cornea).
  - Conjunctivitis is an inflammation of the conjuctiva by bacteria or a virus.
- A gland above the eye secretes tears that
  - clean and
  - moisten the eye.
- The lens focuses light onto the retina by bending light rays. Focusing can occur in two ways.
  1. In squids and fishes, the lens focuses by moving back and forth.
  2. In mammals, the lens focuses by changing shape using
     - muscles attached to the choroid and
     - ligaments that suspend the lens.
     - depending on the distance to the object being viewed; the thicker the lens, the more sharply it bends light.



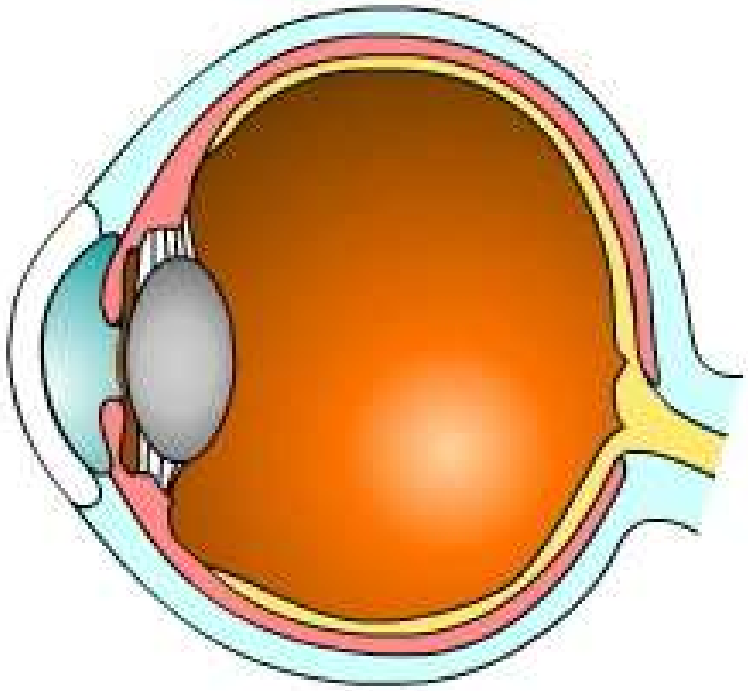



# 29.9 CONNECTION: Many vision problems can be corrected with artificial lenses or surgery

- **Visual acuity** is the ability of the eyes to distinguish fine detail.
  - Visual acuity is measured by reading standardized eye charts from a distance of 20 feet.
  - The ability to see normally at 20 feet is 20/20 vision.

Retinal display? 4K?

- Three vision problems are common.
  1. **Nearsightedness** is the inability to focus on distant objects, usually caused by an eyeball that is too long.
  2. **Farsightedness** is the inability to focus on close objects, usually caused by an eyeball that is too short.
  3. **Astigmatism** is blurred vision caused by a misshapen lens or cornea. 散光
- Corrective lenses can bend light rays to compensate for each of these problems.

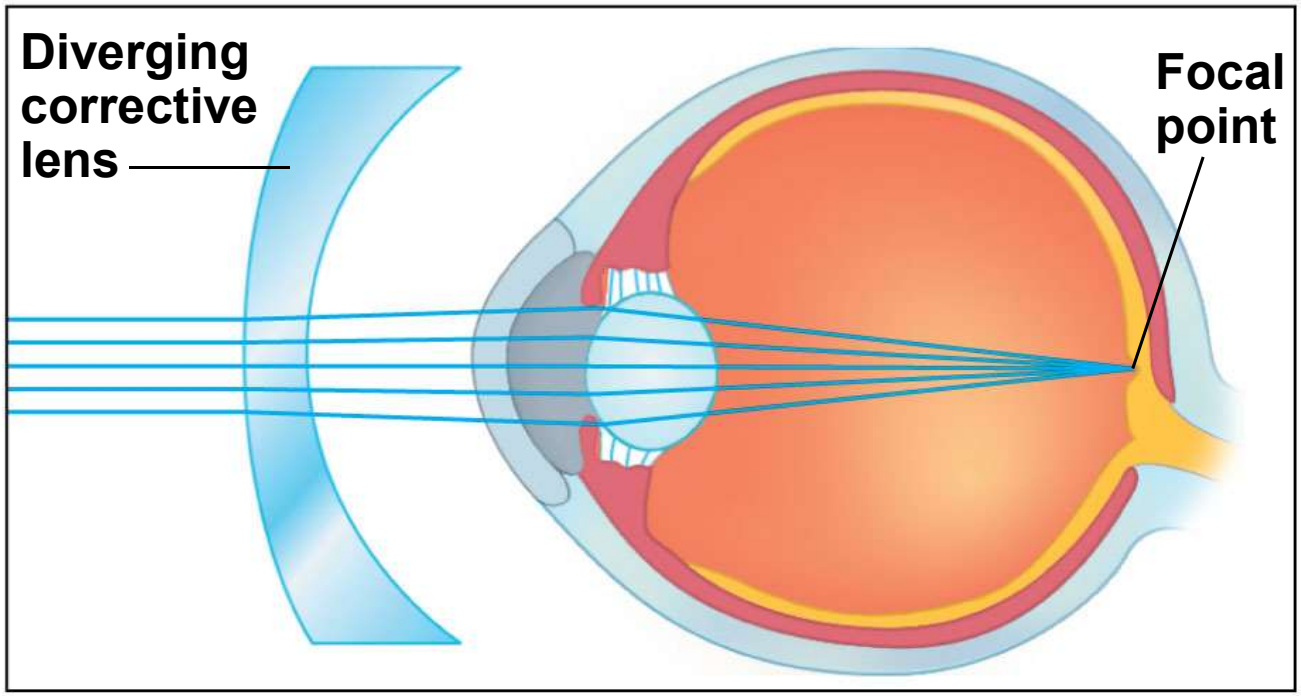




Animation: Near and Distant Vision

Right click on animation / Click play

Figure 29.9A



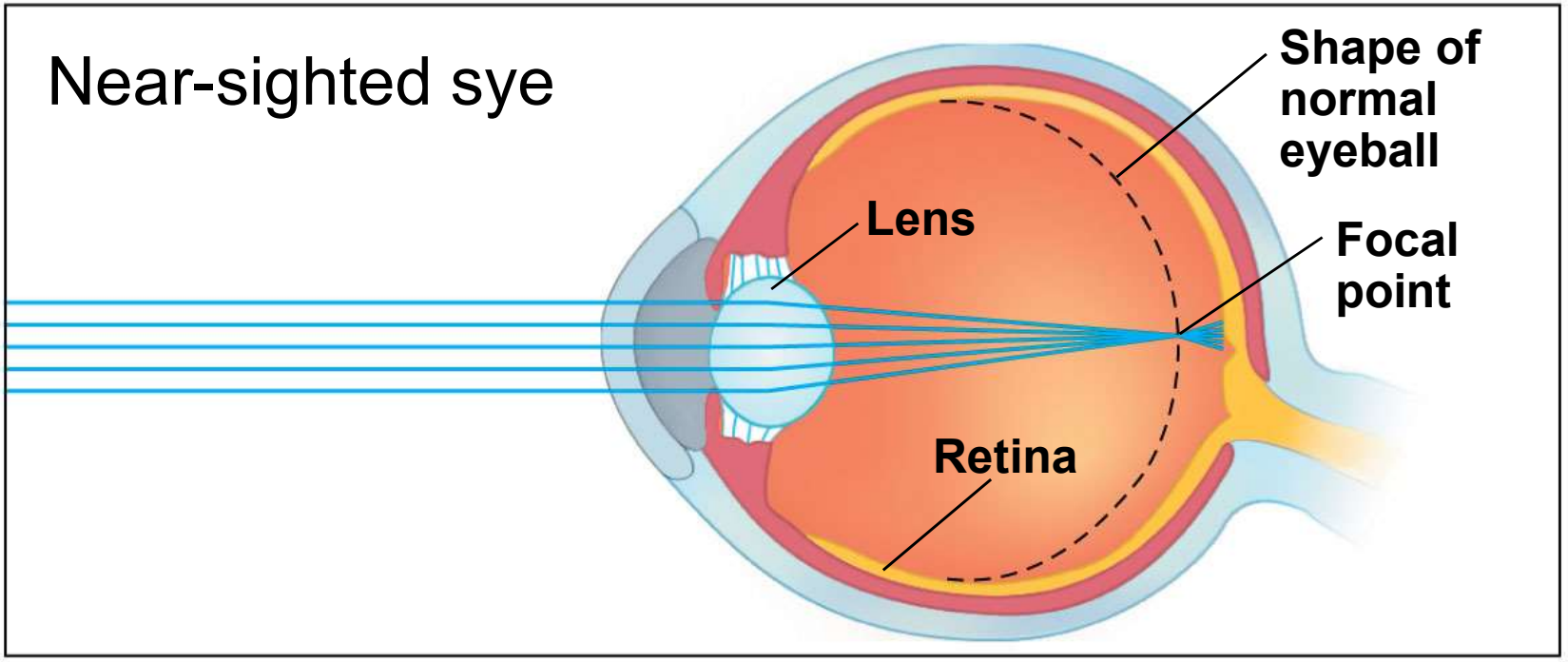
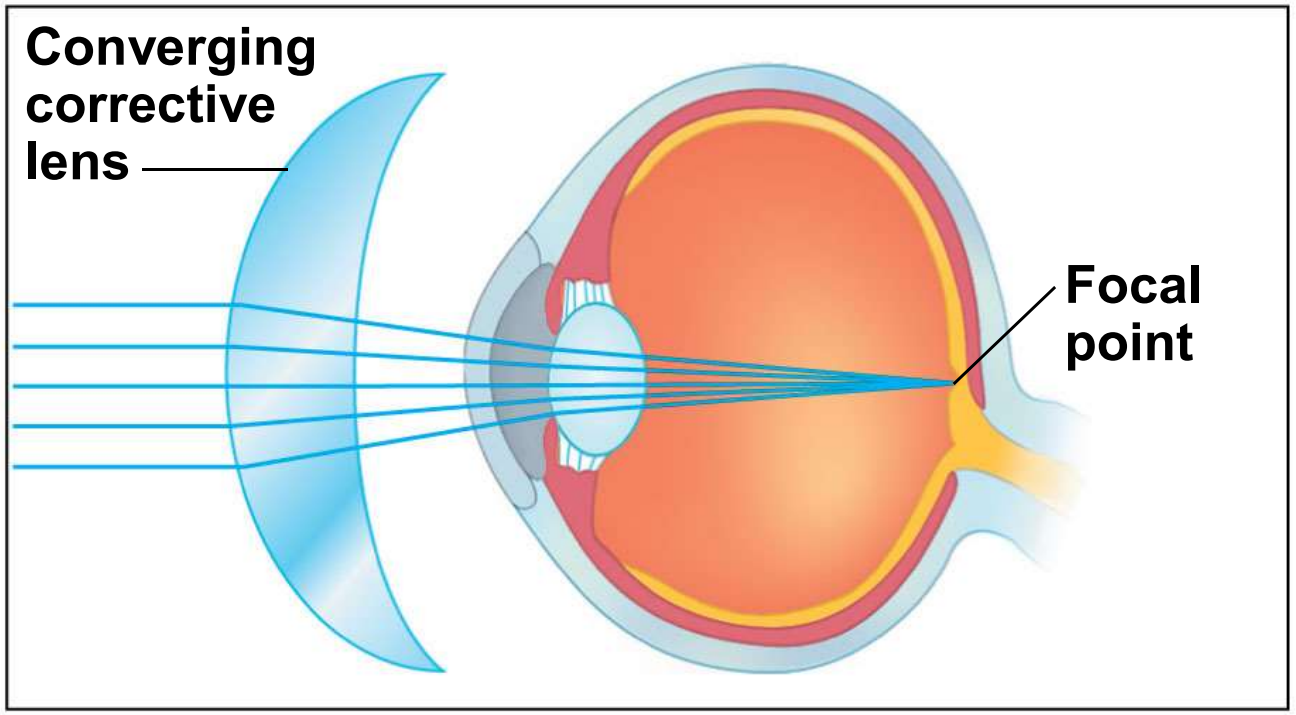
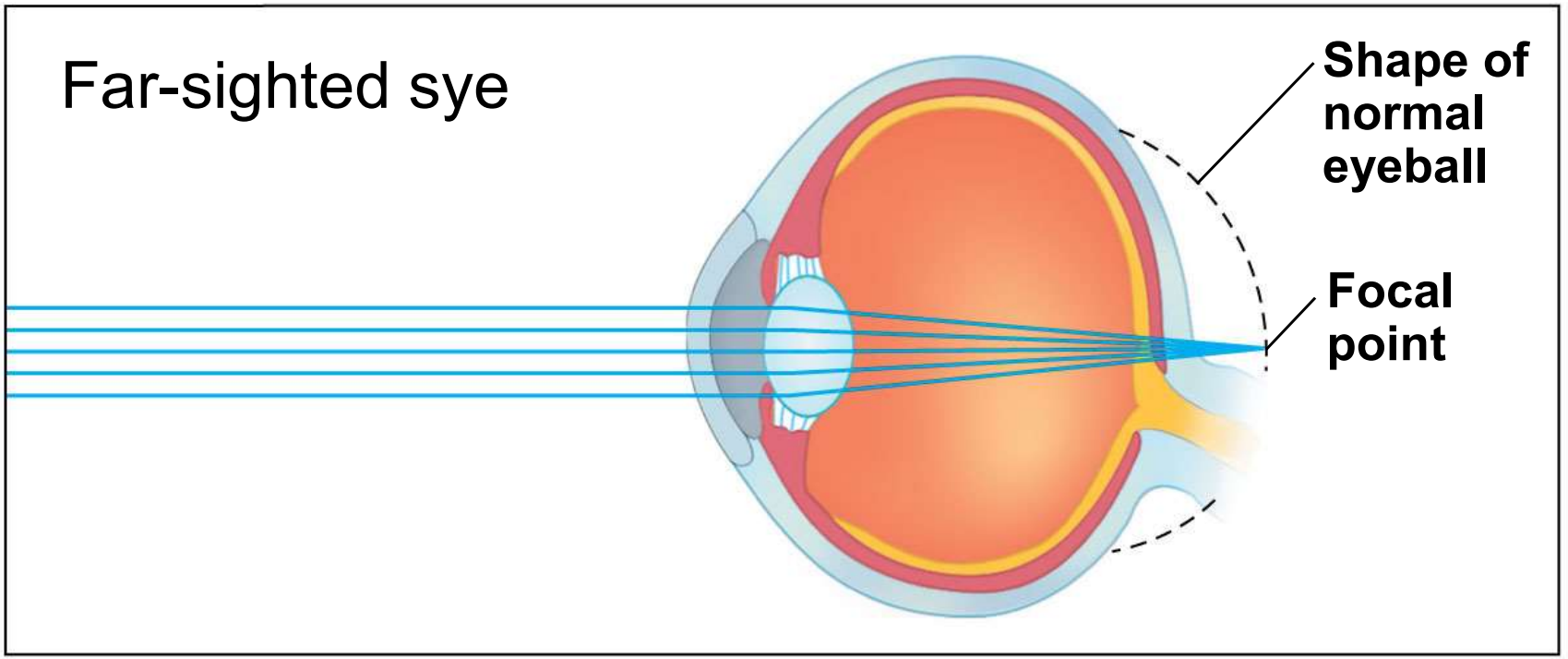



Figure 29.9B

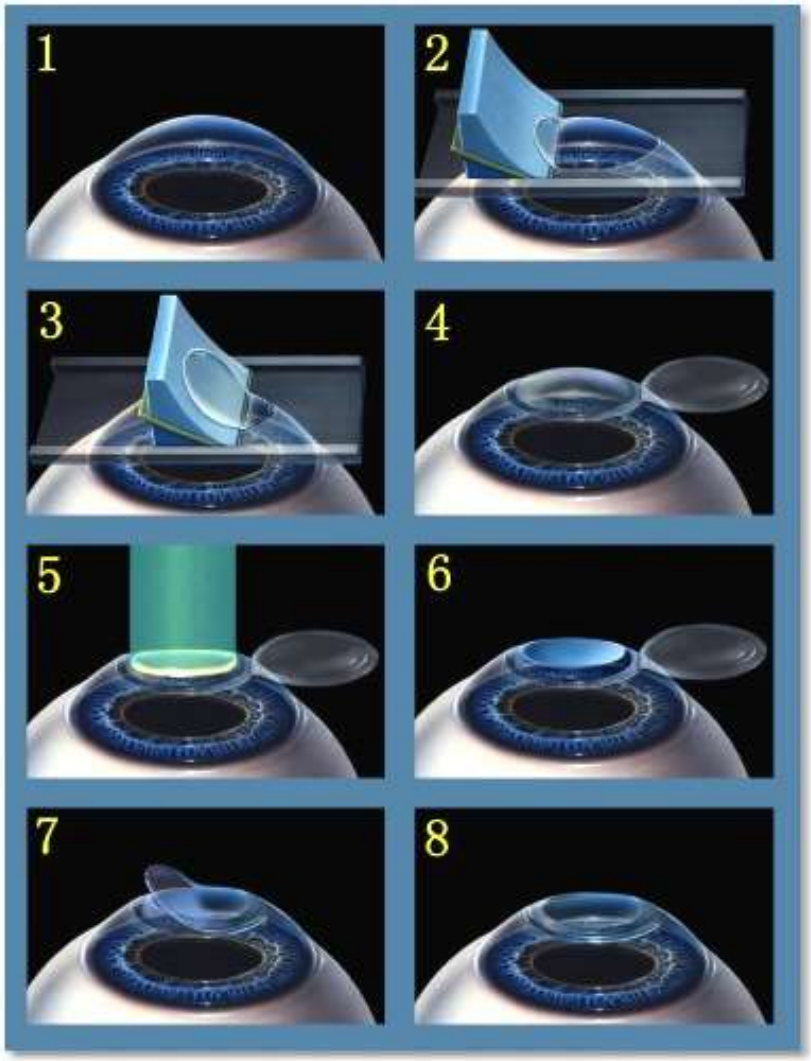


- **Presbyopia** 老花眼
  - Decreased flexibility of lens due to age
  - Decreased ability to focus closely

RK: radial keratotomy, cut cornea to change its shape

LASIK: laser-assisted in situ keratomileusis 雷射視力矯正




Several vision problems are age related.

A **cataract** is a clouding of the lens, which can occur in one or both eyes.

**Glaucoma** is a group of diseases that result in damage to the optic nerve. In most cases, glaucoma is caused by an excess of aqueous humor, leading to increased pressure in the eye.

iLASIK 全雷射手術

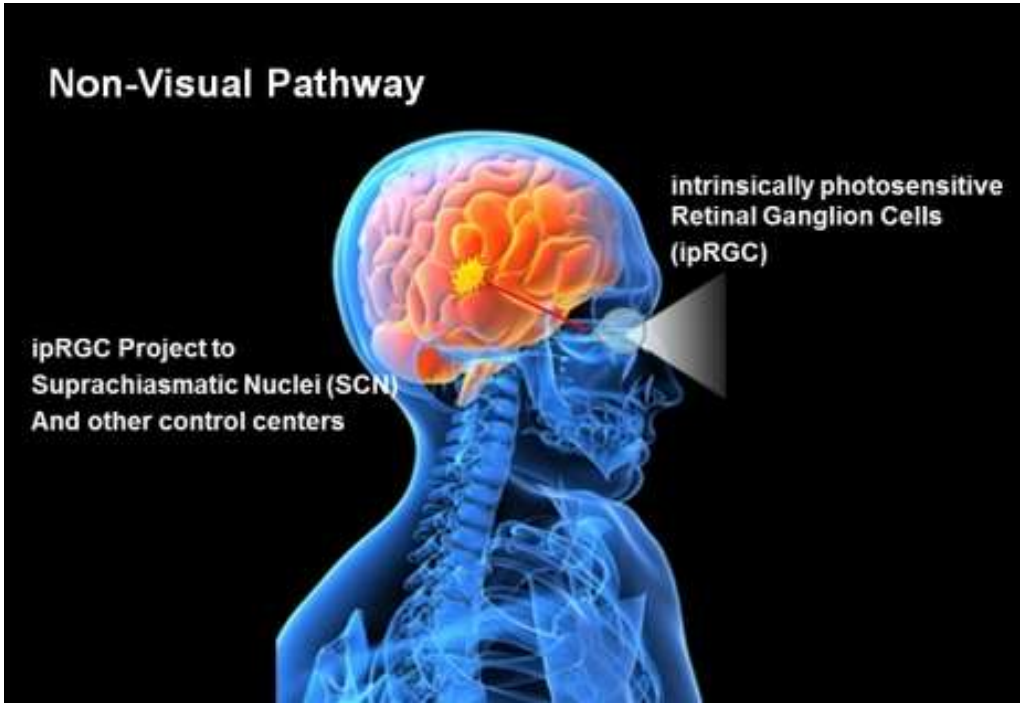
http://mulicia.pixnet.net/blog/post/27826245-%E8%AA%8D%E8%AD%98%E8%BF%91%E8%A6%96%E9%9B%B7%E5%B0%84%EF%BC%9A%E4%BD%95%E8%AC%82prk%E3%80%81lasek%E3%80%81lasik%E3%80%81epi-lasik

# 29.10 The human retina contains two types of photoreceptors: rods and cones

- The human retina contains two types of photoreceptors.
  1. **Rods**
     - contain the visual pigment rhodopsin, which can absorb dim light, and
     - can detect shades of gray in dim light.
  2. **Cones**
     - contain the visual pigment photopsin, which absorbs bright colored light, and
     - allow us to see color in bright light.
- When rhodopsin and photopsin absorb light,
  - they change chemically, and
  - the change alters the permeability of the cell's membrane.
  - The resulting receptor potential triggers a change in the release of neurotransmitter from the synaptic terminals.
  - This release initiates a complex integration process in the retina.

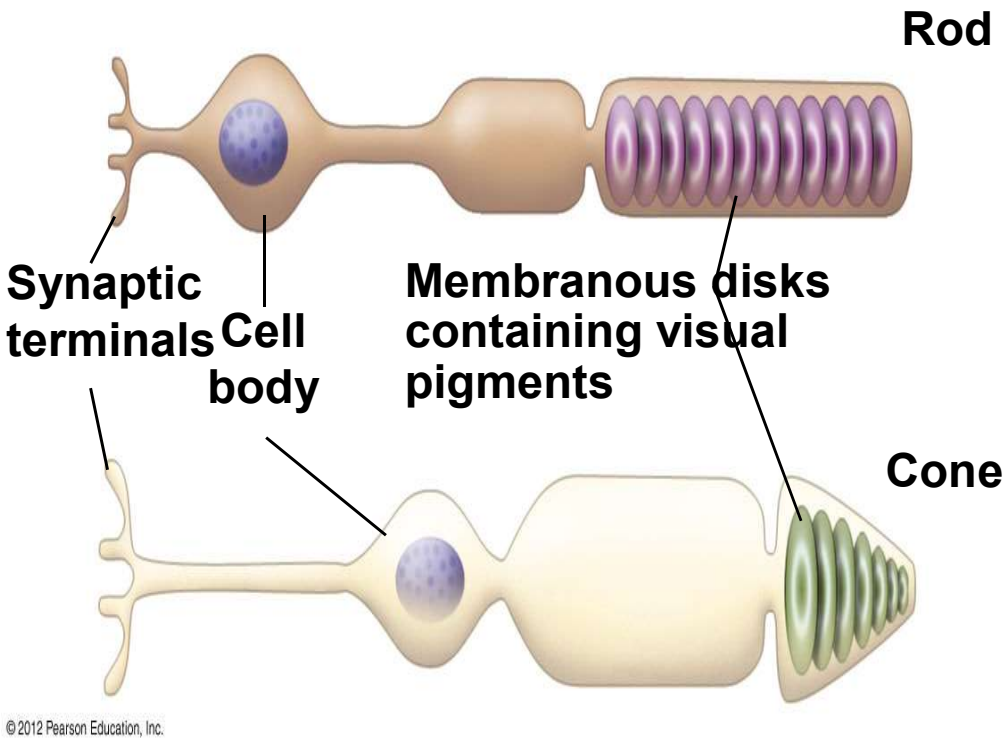
- When rhodopsin and photopsin absorb light, they change chemically, and the change alters the permeability of the cell's membrane.
- The resulting receptor potential triggers a change in the release of neurotransmitter from the synaptic terminals.
- This release initiates a complex integration process in the retina.

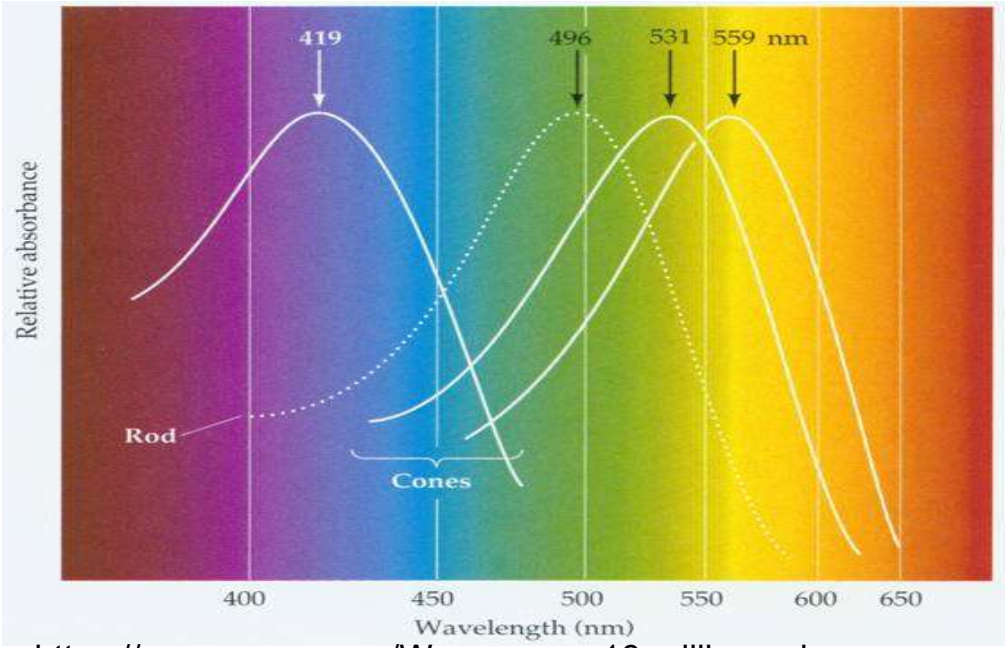
Circadian



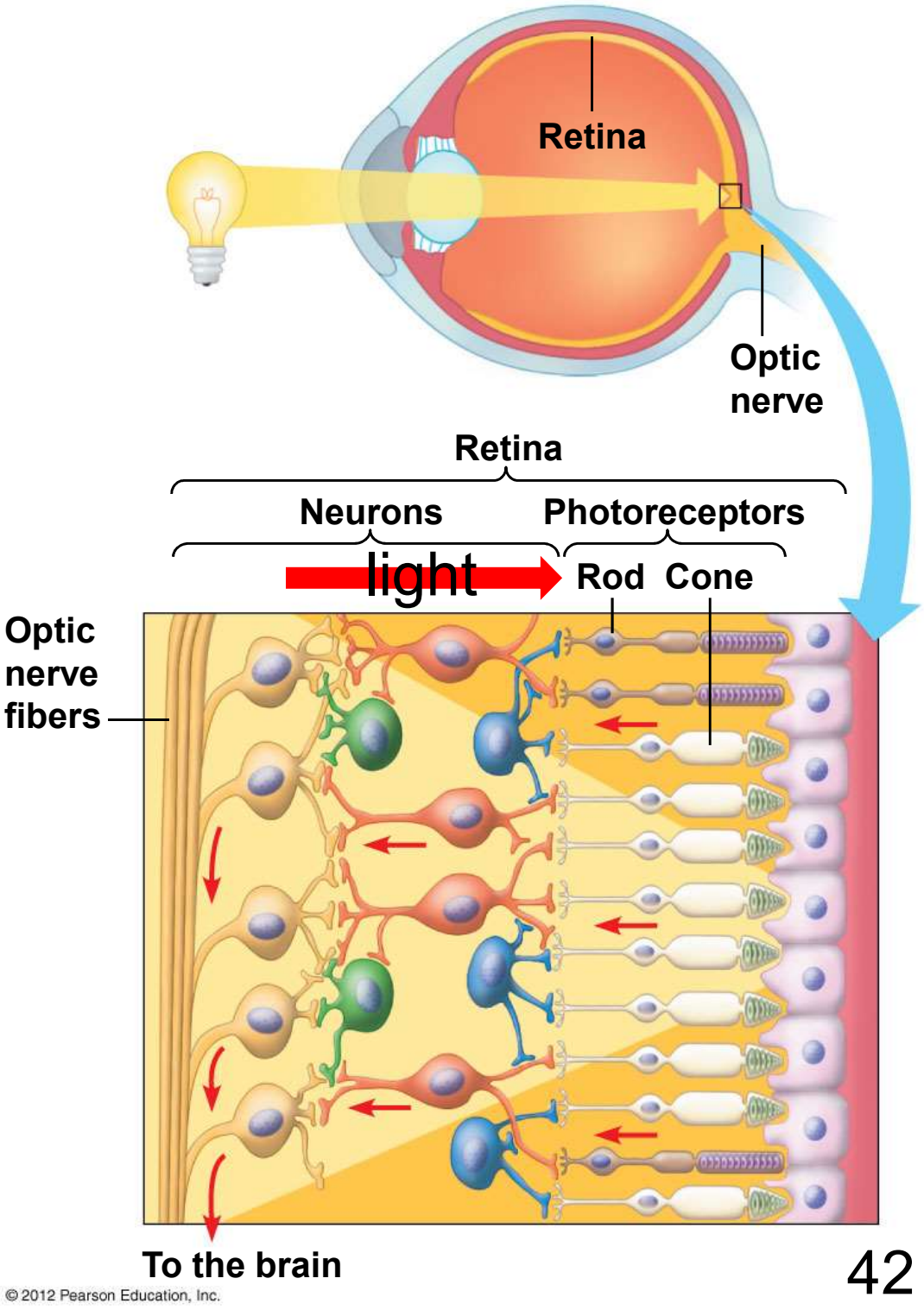

https://aiau.aia.org/sites/default/files/styles/large/public/TH101_Evidence-based%20lighting_0.jpg?itok=4Lzc5VZ2

Figure 29.10B




https://www.quora.com/We-can-see-16-million-colours-Does-this-mean-our-atoms-have-16-million-properties

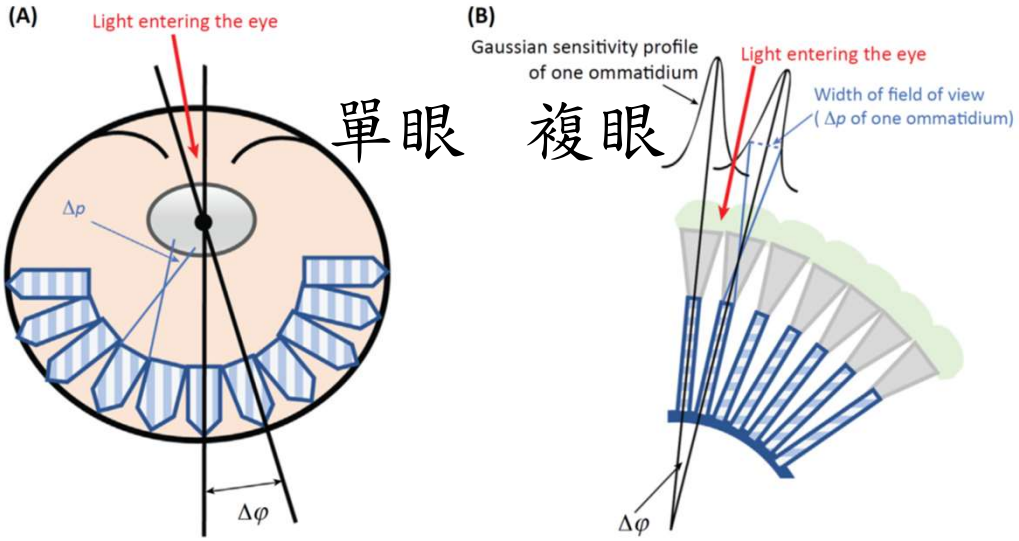


# 色盲有時不是「缺陷」，反而是「優勢」？

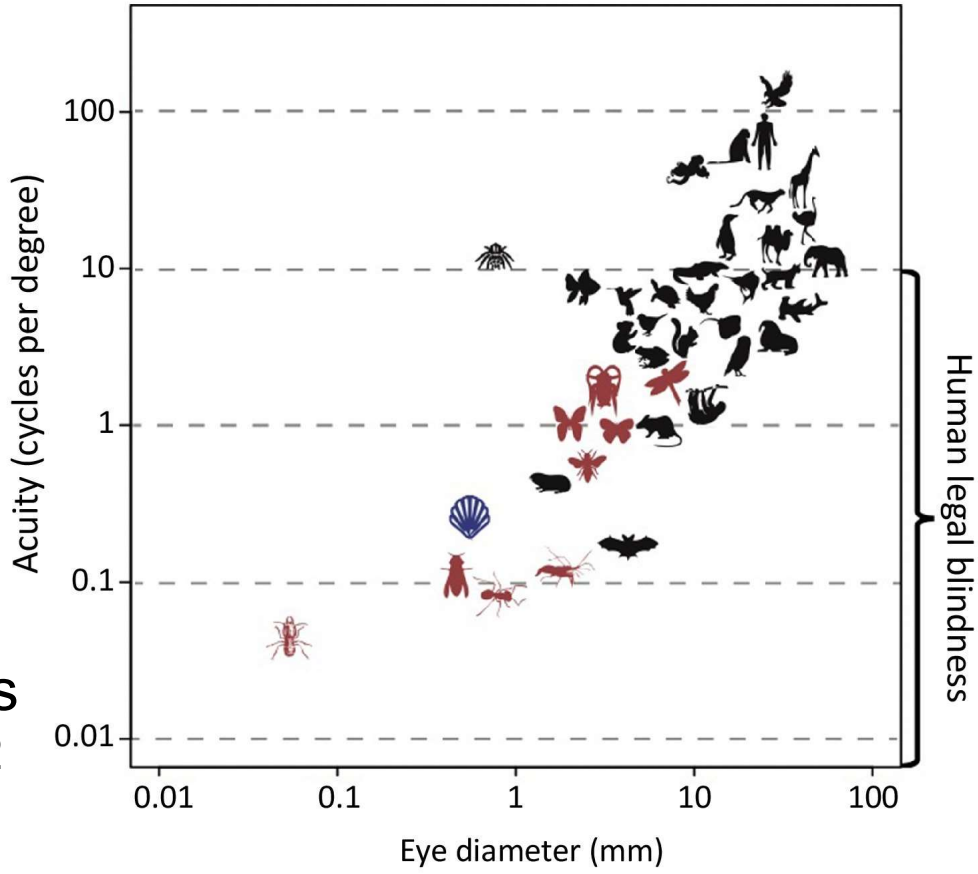
https://www.natgeomedia.com/environment/article/content-3236.html

除了夜猴和吼猴之外，剩下的約130種「新世界」猴都有一個共同點：多數雌性和全部雄性，都是色盲。「舊世界」（old world）的靈長類，包括我們智人在內，大多能看見人類看見的全部色彩。

Adaptation or defect？




單眼　複眼




Visual Acuity and the Evolution of Signals

Tends in Ecology and evolution (2018) 33, 358-372

動物眼中的世界 究竟是怎樣的？

https://kknews.cc/science/eybl854.amp

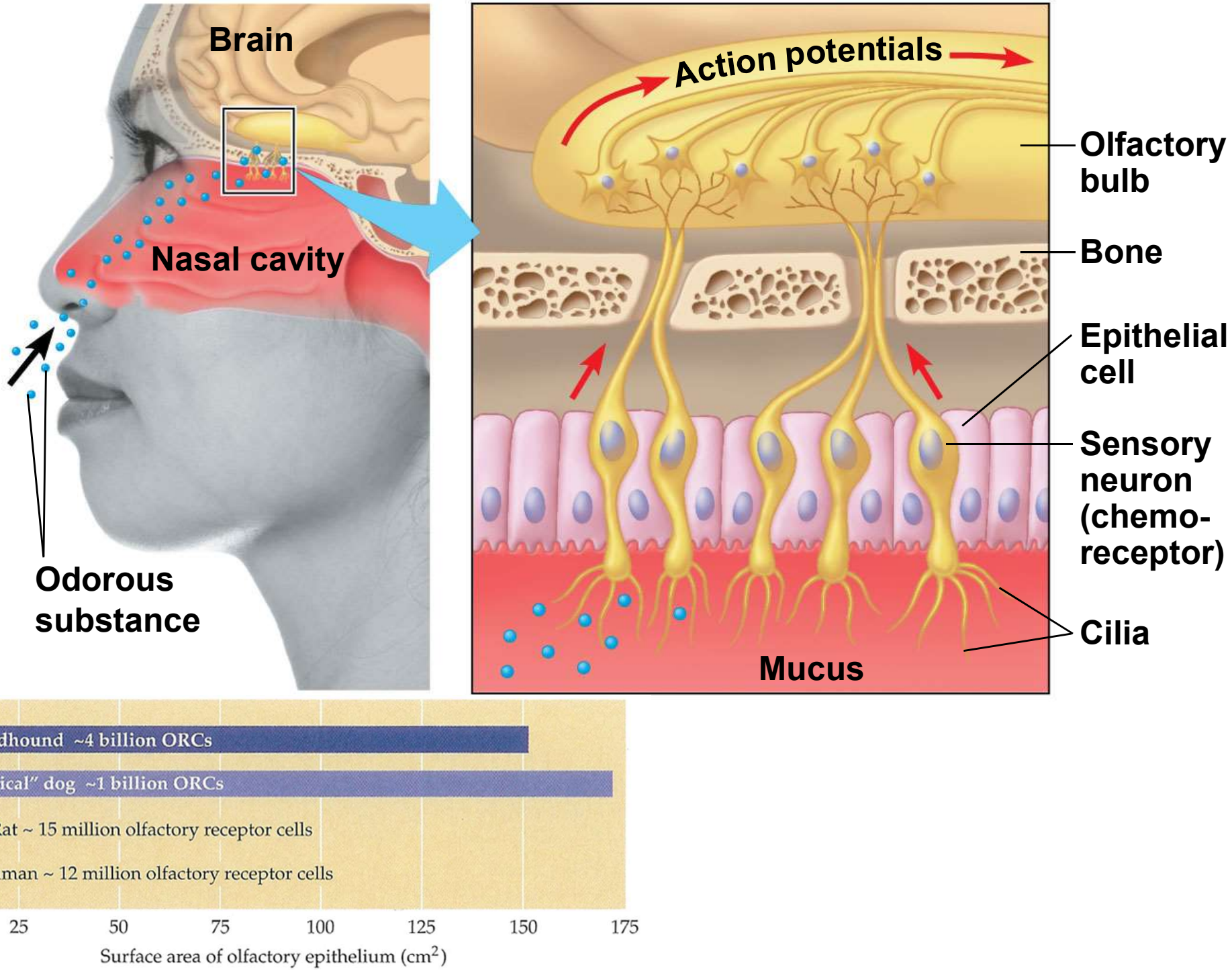
# TASTE AND SMELL

# 29.11 Taste and odor receptors detect chemicals present in solution or air

- Taste and smell depend on chemoreceptors that detect specific chemicals in the environment.
- Chemoreceptors
  - in taste buds detect molecules in solution and
  - lining the nasal cavity detect airborne molecules.
- Taste and smell interact. Much of what we taste is really smell. These two senses interact!
- Taste receptors
  - are located in taste buds on the tongue and
  - produce five taste sensations:
    1. sweet, salty, sour, bitter, and umami (the savory flavor of meats and cheeses).

Oleogustus, the 6th taste?
Reported at 2015.7

Figure 29.11

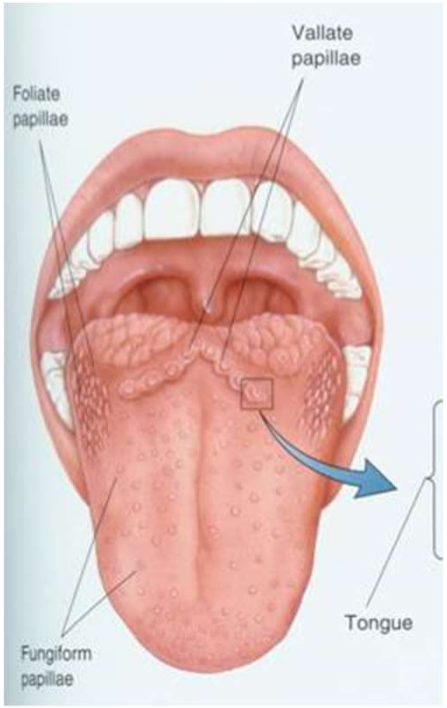

Brain
Nasal cavity
Odorous substance
Action potentials
Olfactory bulb
Bone
Epithelial cell
Sensory neuron (chemo-receptor)
Cilia
Mucus
Bloodhound ~4 billion ORCs
"Typical" dog ~1 billion ORCs
Rat ~ 15 million olfactory receptor cells
Human ~ 12 million olfactory receptor cells
25
50
75
100
125
150
175
Surface area of olfactory epithelium (cm²)

# 29.12 CONNECTION: Does cilantro taste like soap to you?

- The leaves of cilantro are a common ingredient in South Asian and Latin American cuisine.
- While many people love the taste of cilantro, those who do not are often vehement in their dislike.
- Scientists hypothesize that the strong aversion to this herb is genetically based.
- Studies comparing identical and fraternal twins provide clear evidence that there is a strong genetic component.


https://shop.lucifer.tw/products-detail.php?id=28

- About 25% of humans are "supertasters" with up to three times the sensitivity to bitter.
- Supertasters are more likely to
  - avoid spinach, broccoli, cabbage, coffee, and alcoholic beverages and
  - have a higher risk of colon cancer and some other serious health problems
  - Supertasters tend to find highly fatty and sugary foods less palatable than non-tasters.



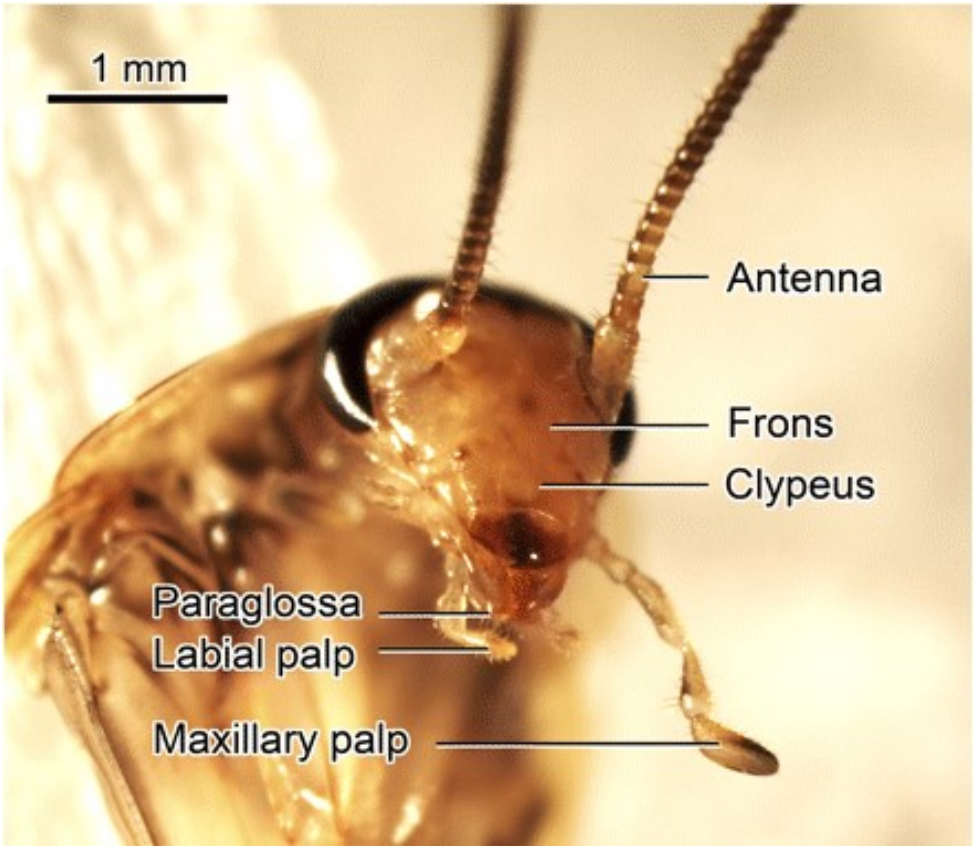



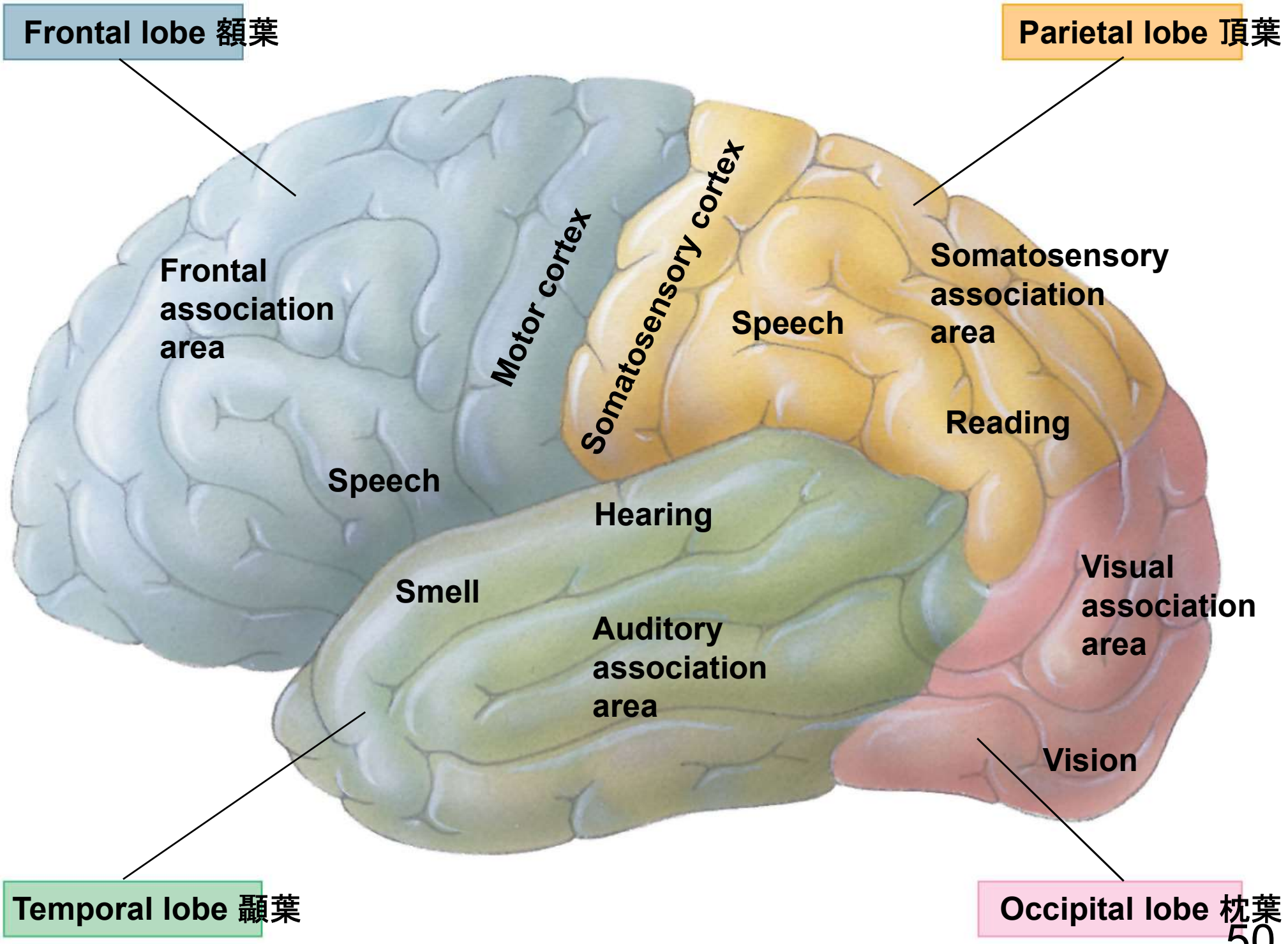

Figure 1 The 4 major external chemosensory paired appendages on the head of an adult male German cockroach. The translucent clypeus and frons are shown, through which ingested dyed solutions and agar could be observed.

## Differential Inputs from Chemosensory Appendages Mediate Feeding Responses to Glucose in Wild-Type and Glucose-Averse German Cockroaches, *Blattella germanica*

Chem Senses. 2011 Sep;36(7):589-600.

- The glucose-averse phenotype is apparently controlled by a single semidominant autosomal gene on chromosome 9
- It appears to be a recent adaptive response to the extensive use of pest control baits that pair glucose with insecticides. Thus, cockroaches with the glucose-aversion trait enjoy a selective advantage under these conditions.

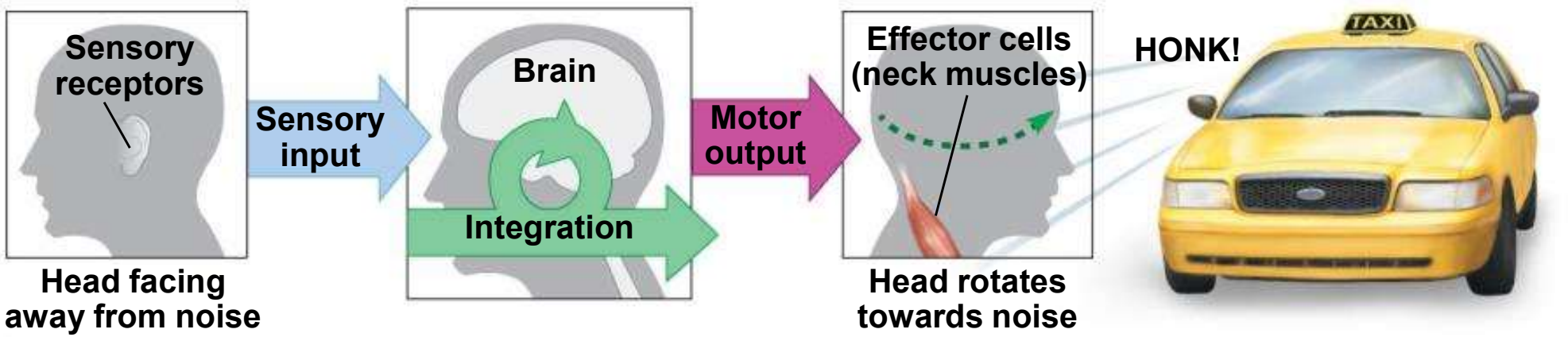
Figure 28.15



# 29.13 Review: The central nervous system couples stimulus with response

- The nervous system

1. receives sensory information,
2. integrates it, and
3. commands appropriate responses, either an action or no action.



## You should now be able to

1. Describe the essential roles of sensory receptors.
2. Explain how electromagnetic receptors help turtles and fish navigate.
3. Define sensory transduction, receptor potential, and sensory adaptation and provide examples of each.
4. Describe the five general categories of sensory receptors found in animals and provide examples of each.
5. List the structures of the ear in the sequence in which they participate in hearing.
6. Explain how body position and movement are sensed in the inner ear.
7. Explain what causes motion sickness and what can be done to prevent it.
8. Compare the structures and functions of the eyecups of planarians, the compound eyes of insects and crustaceans, and the single-lens eyes of humans.
9. Describe the parts of the human eye and their functions.
10. Explain the causes and symptoms of myopia, hyperopia, presbyopia, and astigmatism.
11. Compare the structures, functions, distributions, and densities of rods and cones.
12. Explain how odor and taste receptors function.
13. Describe the role of the central nervous system in sensory perception.