Cognitive Construction of Space: Part I

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The Story of Epistemology So Far

- Euclid's geometry was the paradigm of science shared by Aristotle, Descartes, and many people in between.
- The scientific explanation of a general fact about the world consists in a valid deductive argument that has a description of that general fact as its conclusion and has true, fundamental claims as its premises.

The Story of Epistemology So Far

- Revolutionary developments in science were replacing the Aristotelian and Cartesian view of how knowledge is acquired with a quite different conception.
- There were no intuitions of general principles about lodestones or human physiology from which everything else in these subjects was deduced.
- Instead, examples of particular phenomena were observed, found to be repeatedly and regularly produced, and thus taken to hold generally.

The Story of Epistemology So Far

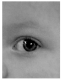
- The goal of the new science was to go beyond simple generalizations of observed regularities to find their **causes** and the **laws** governing those causes.
- Whether in Newton's "general induction" or in Bacon's simpler framework, inductive inference is subject to an important objection.
- The difficulty with inductive inference is that it can be unreliable.
- Even if we had all the observed data, human knowledge is still subject to metaphysical skepticism.

The Story of Epistemology So Far

- Kant claimed to had explained why arithmetic and geometry can be known *a priori* with certainty.
- He also claimed that he provided a refutation of Hume's skepticism about induction. Although the metaphysical skepticism is still there.
- Kant's idea is that the Euclidean space and time is the pure form of our intuition.
- But is that true? Can we learn about how we know where thing are using empirical methods?

The Construction of Space

How our senses and motor systems construct space?

Vision 

Hearing 

Touch 

Body position

Movement

Balance

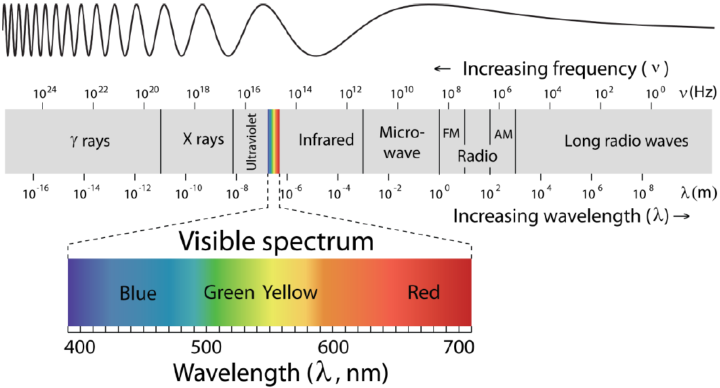
Outline

1. Visual Perception
2. Spacial Image Formation
3. Body Position Sensing
4. Neural Signals
5. Brain Maps
6. Sound and Brain Representations
7. Reference Frames and Navigation
8. Memory and Cognition

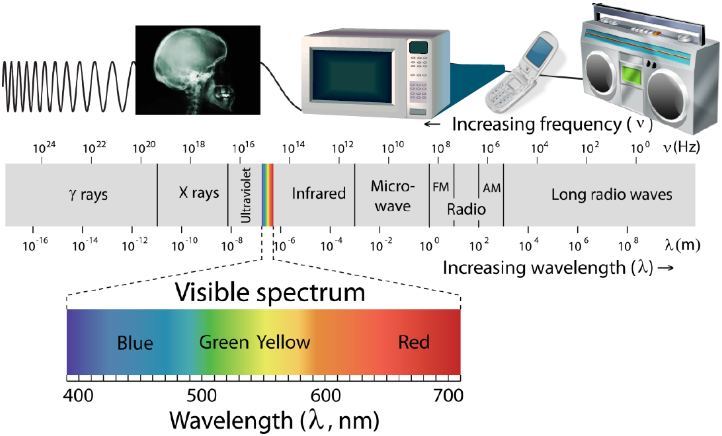
Early Notions of Vision

- Plato (428-348 BCE): Extramission
- Democritus (460-370 BCE): Intromission
- How do particles convey information such as size?
- Why can many observers see the same thing at once?

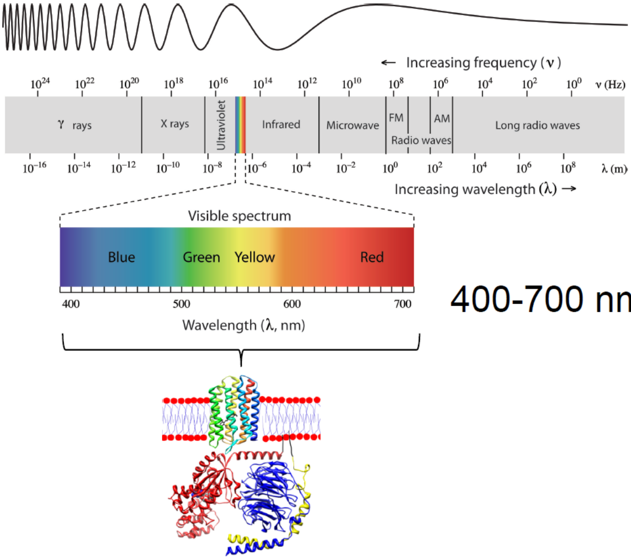
Light is Electromagnetic Radiation



Light is Electromagnetic Radiation

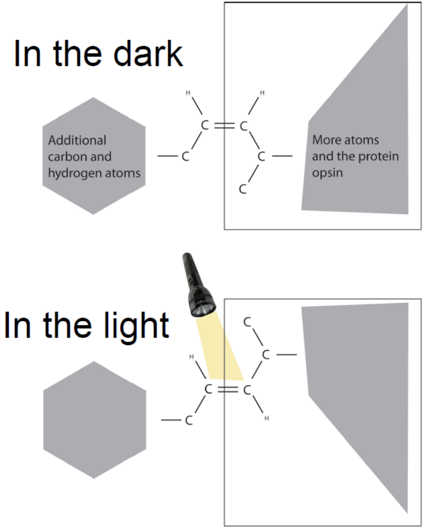


Biological Detection of Light

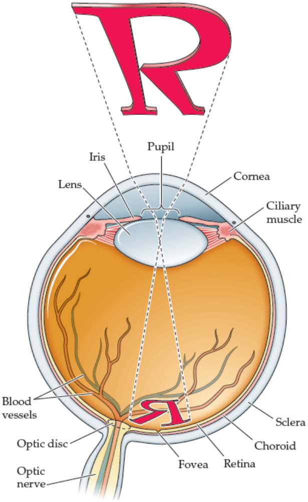


400-700 nm

Rhodopsin

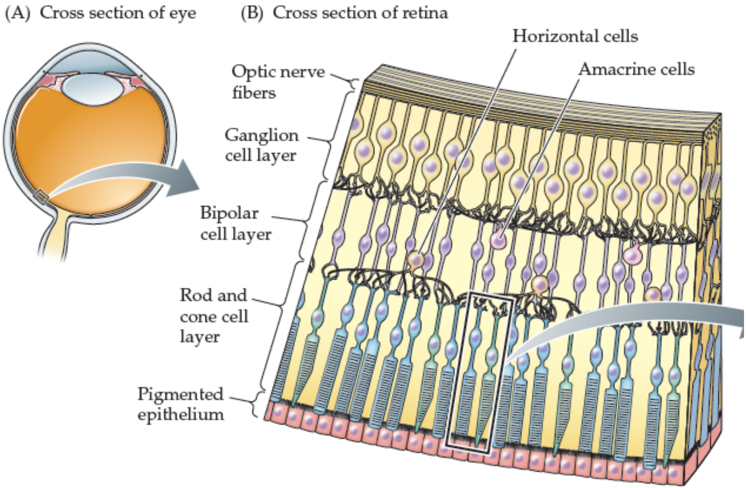

In the dark
Additional carbon and hydrogen atoms
More atoms and the protein opsin
In the light

Visual System



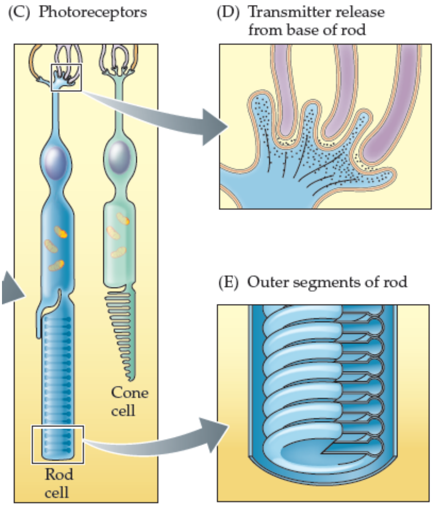
Behavioral Neuroscience, Figure 10.1

Anatomy of the Retina



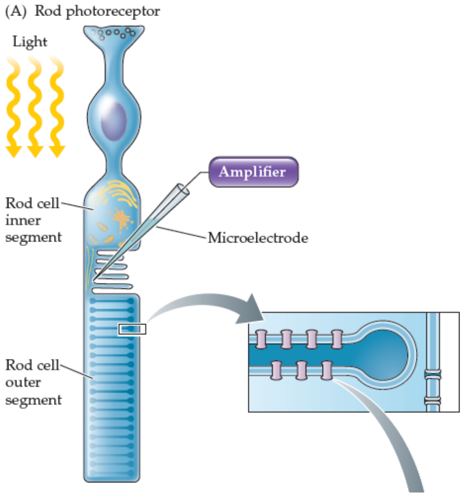
Behavioral Neuroscience, Figure 10.2

Anatomy of the Retina



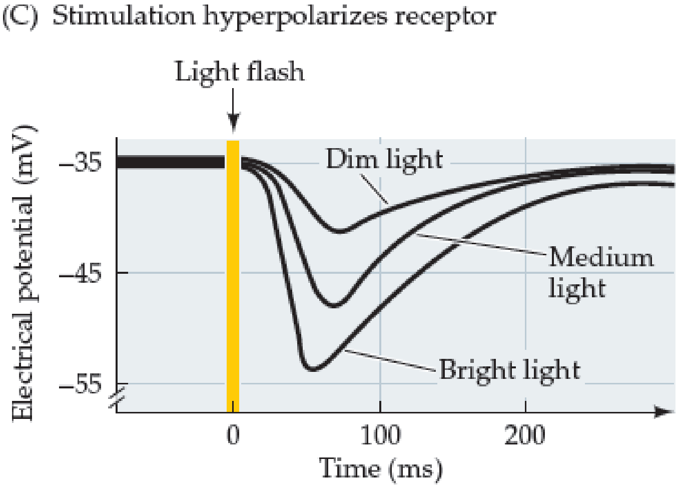
Behavioral Neuroscience, Figure 10.2

Hyperpolarization of Photoreceptors



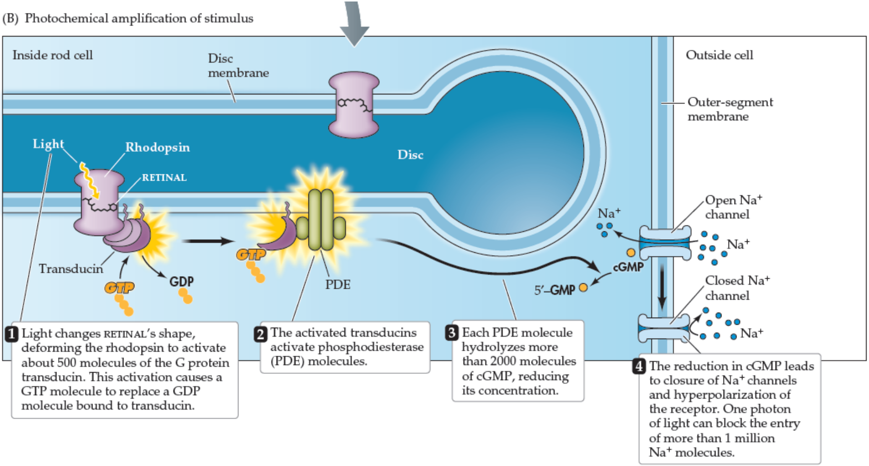
Behavioral Neuroscience, Figure 10.3

Hyperpolarization of Photoreceptors



Behavioral Neuroscience, Figure 10.3

Hyperpolarization of Photoreceptors



Behavioral Neuroscience, Figure 10.3

Outline

How Do We Form an Image?

First let's see how light travels in a scene:

- Light spreads outward from every point
- Light at every point arrives from every other point
- Light travels in straight lines

How Does Light Travel in a Scene

How Does Light Travel in a Scene

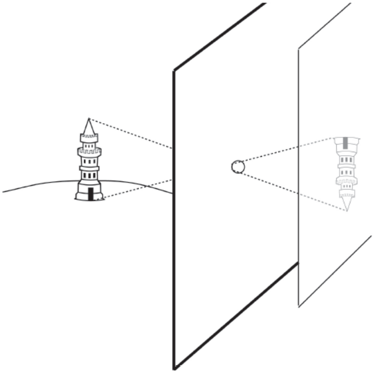
How Do We Form an Image?

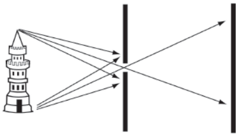
We need to:

- “Sort” light, keep it organized.
- Keep light from different objects/locations separate
- Create 1-to-1 correspondence between location of origin and location on the set of light sensors

Our visual system adopts two approaches: Pinhole and Lens

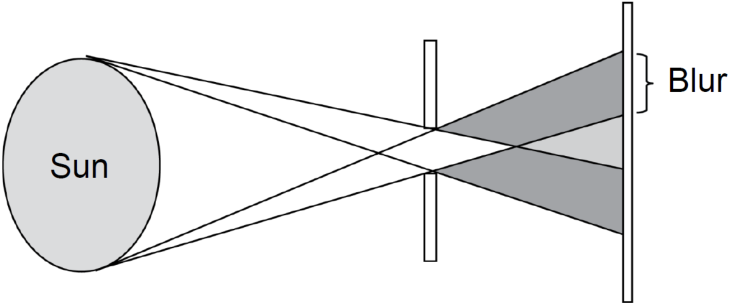
Pinhole



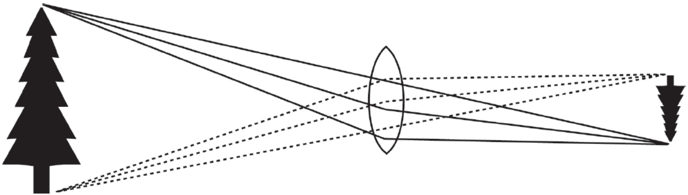


Pinhole in Our Eyes

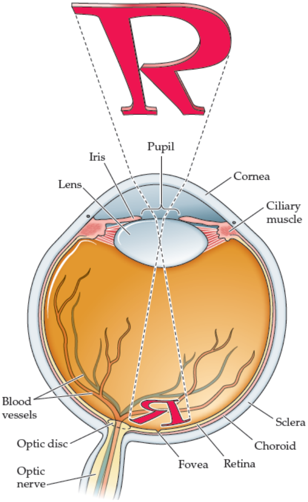
Pinhole and Blur



Solution: Lens



Visual System



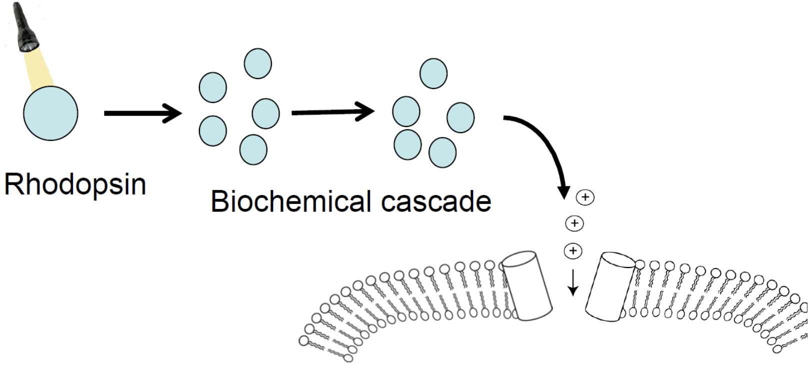
Behavioral Neuroscience, Figure 10.1

The Image is Upside Down

Observations from Inversion Prism Goggles:

- Vision guides the body
- Visual-body interactions are learned
- We perform better when the retinal image is what we are used to: correctly inverted once, rather than inverted a second time by goggles

Visual Sensation

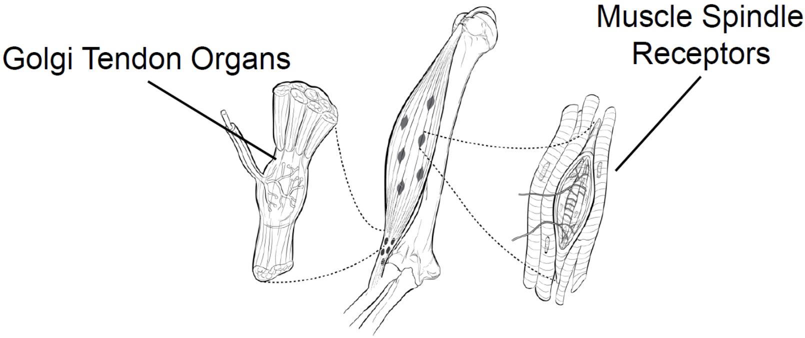


Outline

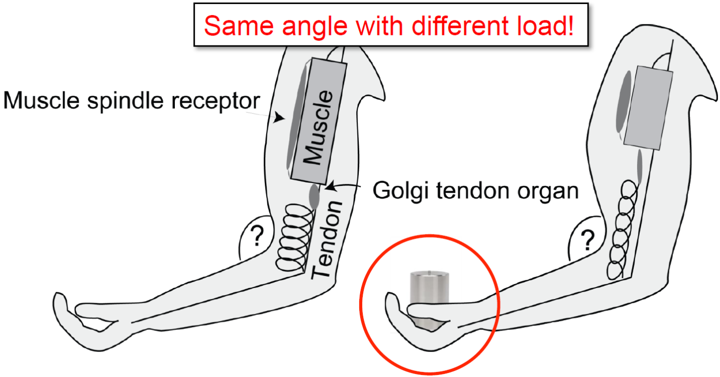
Body Sensing

Body Sensing

Body Sensing Neurons

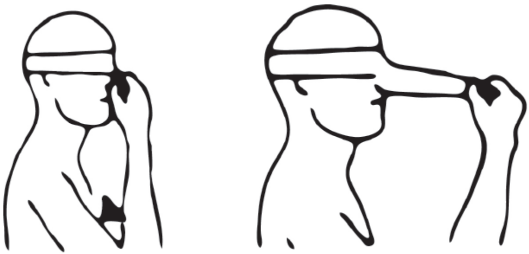


Body Sensing Neurons



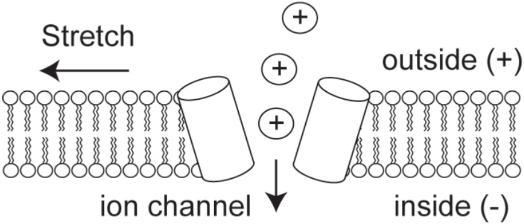
Vibratory Myesthetic Illusion

Lackner, J. R. (1988)



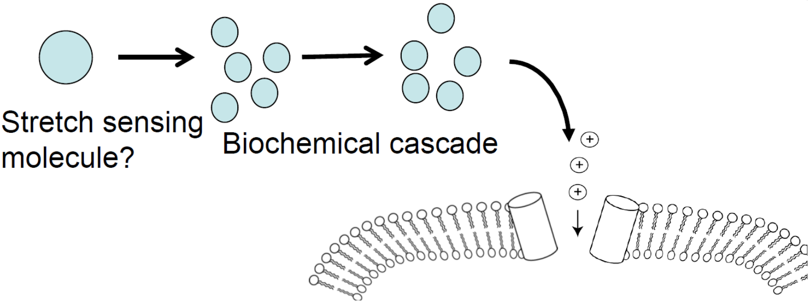
Possible mechanotransduction mechanism 1

Lackner, J. R. (1988)



Possible mechanotransduction mechanism 2

Lackner, J. R. (1988)



Outline

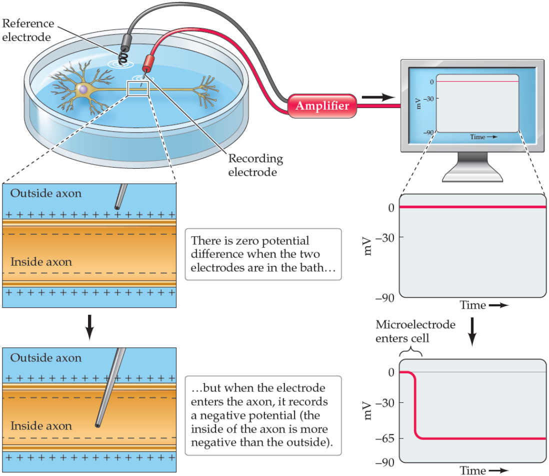
Neural Communication

- What makes neuron special? 1. communication 2. structrue, dentrite and axion.
- 2 types of communication: Electrical within the neurons, chemical between neurons
- Electrical signals are the vocabulary of the nervous system. A neuron at rest is a balance of electrochemical forces

The Resting Potential

- The resting membrane potential is -50 to -80 millivolts and shows the negative polarity of the cell's interior.
- So why is the resting membrane potential negative relative to the outside? 1. membrane; 2. several forces
- The cell membrane is a lipid bilayer, with two layers of lipid molecules.
- Ion Channels are proteins that span the membrane and allow ions to pass. Gated ion channels open and close in response to voltage changes, chemicals, or mechanical action.

The Resting Potential

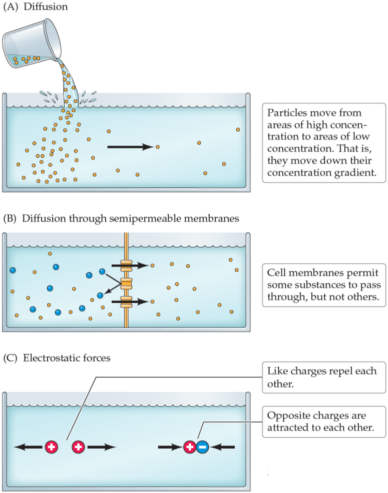


Biological Psychology, Figure 3.1

The Resting Potential

- Some channels are open all the time and only potassium ions (K+) to cross.
- The neuron shows selective permeability to (K+).
- Two opposing forces drive ion movements: Diffusion causes ions to flow from areas of high to low concentration, along their concentration gradient.
- Electrostatic pressure causes ions to flow toward oppositely charged areas.

The Resting Potential

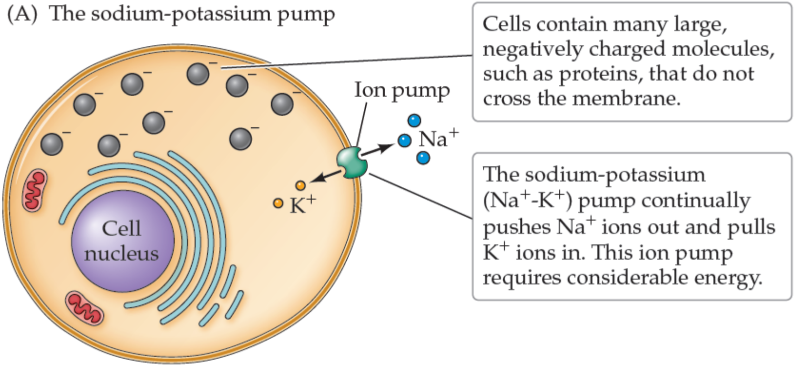


Biological Psychology, Figure 3.2

The Resting Potential

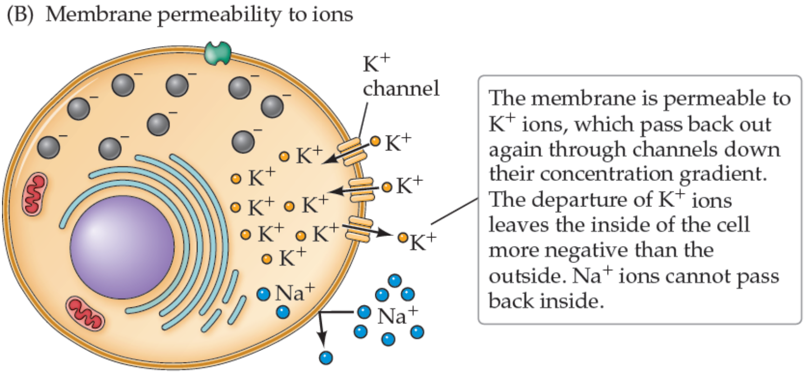
- There are lots of negatively charged proteins inside the cell that cannot get past the membrane, making the inside the cell negative.
- Neurons use a mechanism, the sodium potassium pump, to maintain resting potential. It pumps three sodium ions (Na+) out for every two K+ ions pumped in.
- At rest, K+ ions move into the negative interior of the cell because of electrostatic pressure. As K+ ions build up inside the cell, they also diffuse out through the membrane.
- K+ reaches equilibrium when the movement out is balanced by the movement in. This corresponds to the resting membrane potential of about -60 mV.

The Resting Potential



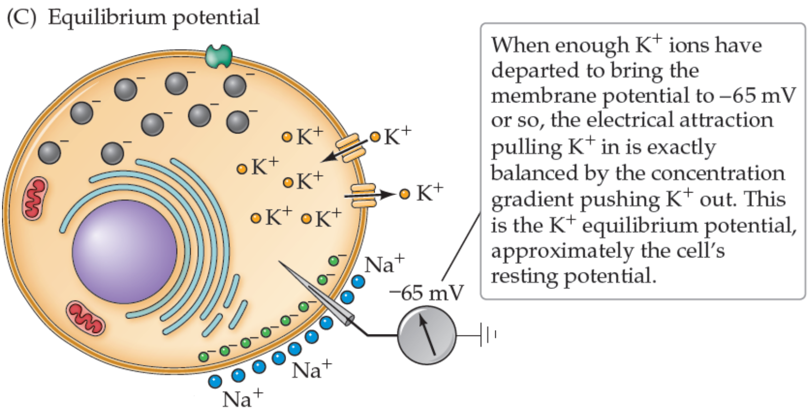
Biological Psychology, Figure 3.3

The Resting Potential



Biological Psychology, Figure 3.3

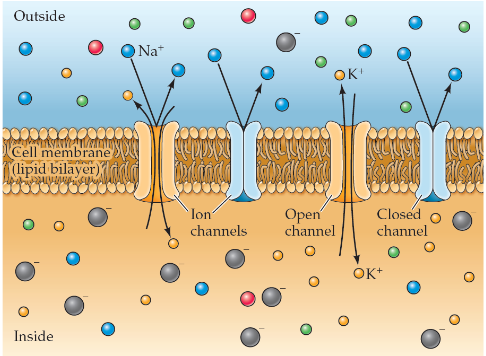
The Resting Potential



Biological Psychology, Figure 3.3

The Resting Potential

	Na^+	K^+	Cl^-	Ca^{2+}	Proteins
Concentration outside cell (m*M*)	145	5	110	1–2	few
Concentration inside cell (m*M*)	5–15	140	4–30	0.0001	many

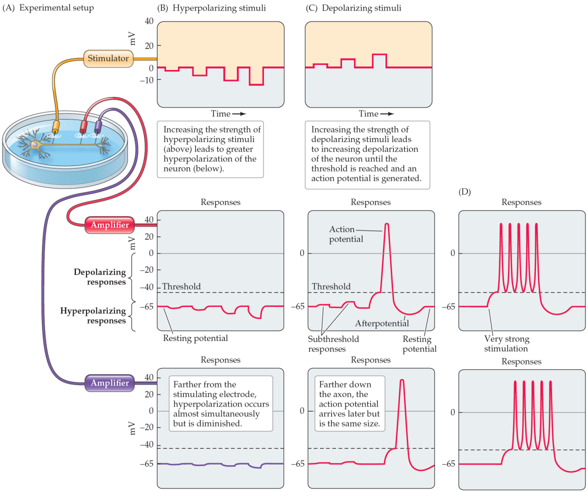


Biological Psychology, Figure 3.4

The Action Potential

- 2 types of changes: Hyperpolarization(even more negative), Depolarization(interior less negative)
- A hyperpolarizing stimulus produces a response that passively follows the stimulus.
- For a depolarizing stimulus, if the membrane reaches the threshold, about 40mV, it triggers an action potential. The membrane potential reverses and the inside of the cell becomes positive.
- Action potentials are brief but large changes in membrane potential.
- They originate in the axon hillock and are propagated along the axon.
- Patterns of action potentials carry information to postsynaptic targets.

The Action Potential

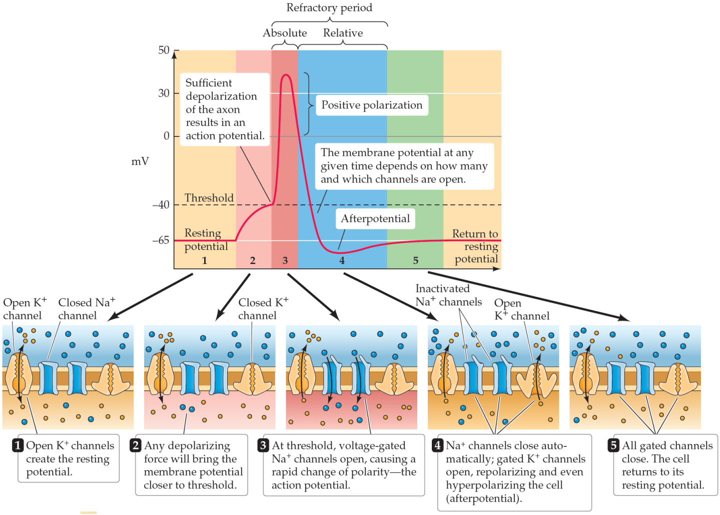


Biological Psychology, Figure 3.5

The Action Potential

- Voltage-gated Na+ channels open in response to the initial depolarization. More voltage-gated channels open and more Na+ ions enter.
- This continues until the membrane potential reaches the Na+ equilibrium potential of +40 mV.
- As the inside of the cell becomes more positive, voltage-gated K+ channels open, K+ moves out and the resting potential is restored.
- The sodium-potassium pump also helps enforce the concentrations of ions that maintain the resting potential.

The Action Potential



Biological Psychology, Figure 3.6

The Action Potential

- Voltage gated sodium channel is the key for action potential.
- Electrical Signals are the vocabulary of the nervous system.
- Action potentials are regenerated along the axon - each adjacent section is depolarized and a new action potential occurs.
- Action potentials travel in one direction because of the refractory state of the membrane after a depolarization. This is why the voltage gated potassium pump is important.

Reference

- Jennifer M. Groh. (2014) *Making Space: How the Brain Knows Where Things Are*, Harvard University Press.
- S. Marc Breedlove, Neil V. Watson. (2016) *Behavioral Neuroscience*, 8th edition. Sinauer Associates, Inc. Publishers.
- Wikimedia Commons https://commons.wikimedia.org/
- Jennifer M. Groh's Slides on "Brain and Space"