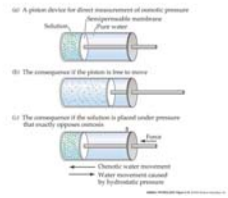
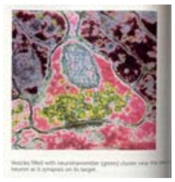
Lecture 5, 28 Jan 2008

Vertebrate Physiology
ECOL 437 (MCB/VetSci 437)
Univ. of Arizona, spring 2008

Kevin Bonine & Kevin Oh



1. Water, Solutes, Osmosis (Ch 3)
2. Intro Nervous System Fxn (Ch10)



http://eebweb.arizona.edu/eeb_course_websites.htm

Housekeeping, 28 January 2008

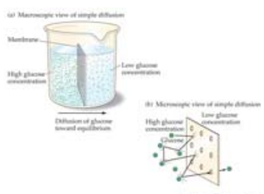
Upcoming Readings

today: Ch 3&10
Wed 30 Jan: Ch 10&11
LAB Wed 30 Jan: Bisbal & Specker, plus two optional papers
(see website for links to papers; "worksheet" via email)
Fri 01 Feb: Ch11

Lab discussion leaders: 30 Jan
1pm – Josh, Seth
3pm – Aaron, Adam

Lab discussion leaders: 06 Feb
1pm – Rittner, Whitney
3pm – Roxanne, Maria

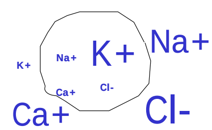
Vertebrate Physiology 437

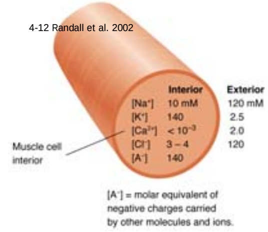


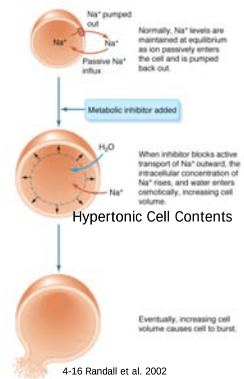
Chapter 3

Movement of Solutes and Water

Osmotic Properties of Cells and Relative Ion Concentrations

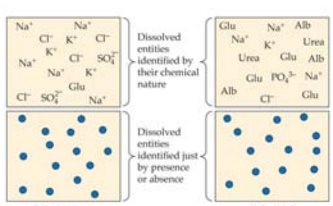




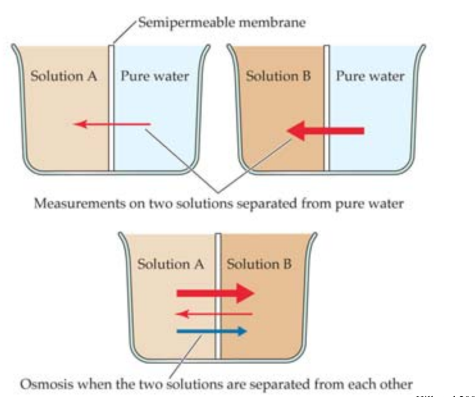


Colligative Properties

- Osmotic Pressure
- Freezing Point
- Water Vapor Pressure (boiling point; evaporation)



Hill et al 2004



Hill et al 2004

6 x 10^{23}

Osmolarity

1 osmolar solution (Osm)

has 1 Avogadro's number of dissolved particles/liter solvent

1 milliosmolar solution (mOsm)
has 0.001 Avogadro's number of dissolved particles/liter solvent

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What osmolarity do you get if you add 6 x 10^{23} molecules of glucose to a liter of water?

What osmolarity do you get if you add 6 x 10^{23} molecules of table salt to a liter of water?

NaCl (strong electrolyte)

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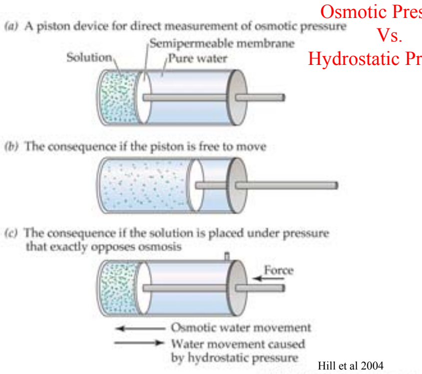
Osmotic Pressure
Vs.
Hydrostatic Pressure



Hill et al 2004

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Difference in osmotic potential

$$\text{Rate of Osmosis} = K \frac{\Pi_1 - \Pi_2}{X}$$

Proportionality Coefficient (~ permeability and temp)

Distance between solutions

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Electrochemical equilibrium

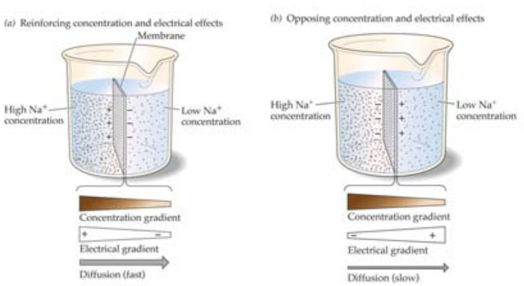

Fig 3.6, Hill et al 2004

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Movement Across Membranes

Electrochemical Gradient

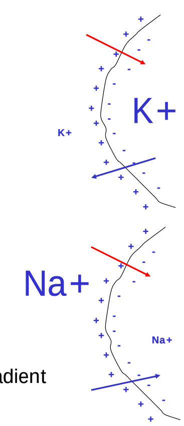
Electrical gradient

Concentration gradient

Electrochemical equilibrium

Equilibrium potential (E_x in mV)

when [X] gradient = electrical gradient



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<u>Equilibrium potential</u> (E_x in mV)

"Every ion's goal in life is to make the membrane potential equal its own equilibrium potential (E_x in mV)"

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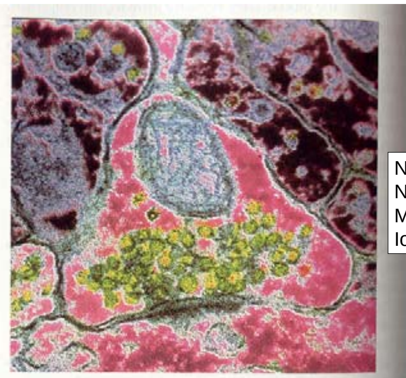

Vesicles filled with neurotransmitter (green) cluster near the end of neuron as it synapses on its target.

p. 214, Silverthorn 2001. 2[nd] ed. Human Physiology. Prentice Hall

Nervous System
Neurons
Membranes
Ions

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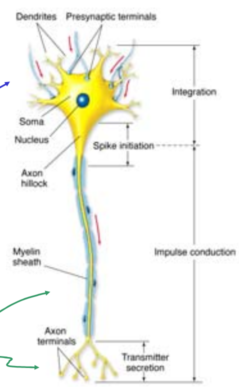
<u>Nervous System</u>

Comprises
- Neurons / Nerve Cells
- Glial Cells (support)

- Signalling via combination of Electrical and Chemical

- Integrate information
AFFERENT

- Coordinate Response
EFFERENT



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5-2 Randall et al. 2002

Organization of the Nervous System

Three main functions:
1. Sensory Reception (converts environmental stimulus to elect/chem)
2. Central Processing
3. Motor Output

Divided into CNS and PNS

A. CNS = Central Nervous System
- Brain and Spinal Cord
(and eyes and interneurons)

B. PNS = Peripheral Nervous System
- most sensory and motor axons

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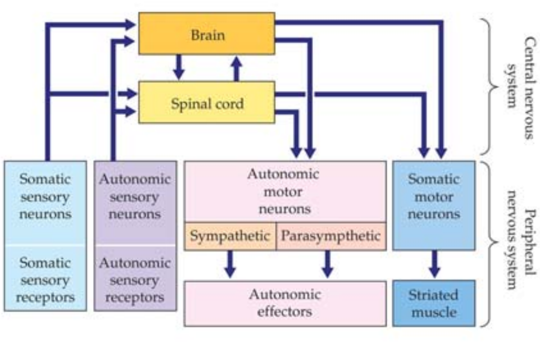
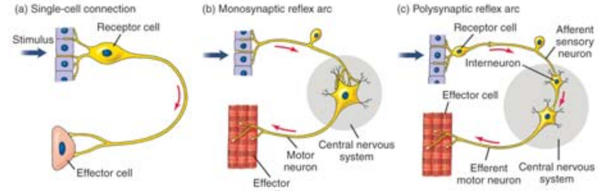


Hill et al. 2004, Fig 10.7

Flow of Information

Afferent Signal -> CNS -> Efferent Signal -> Response

Very Simple	Simple	Interneurons
e.g., Sensing Effectors	Monosynaptic	Polysynaptic

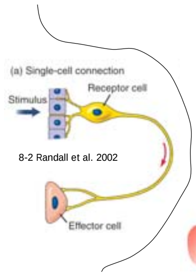


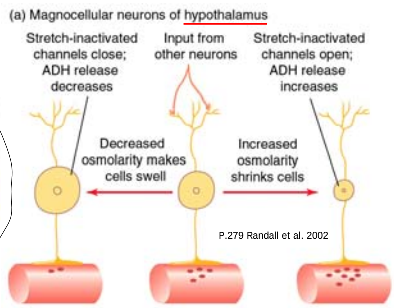
8-2 Randall et al. 2002

Sensing Effectors

Sensors with Afferent and Efferent Properties/Homeostasis

e.g., osmolarity and antidiuretic hormone (ADH)





Evolution of Nervous System:

- Based on the neuron
- Elaboration of Reflex Arc
- Group neurons into CNS
- More neurons in complex organisms
- New structures added on to old (not replaced)
- Size of CNS region correlated with importance
- Topological Maps

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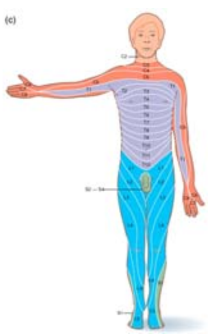
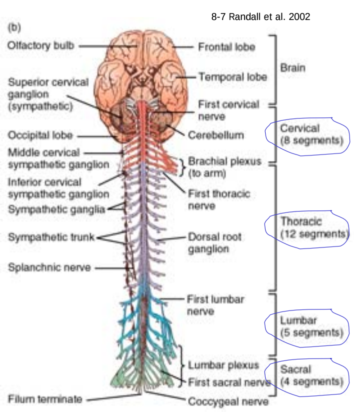
CNS - Spinal Cord

- Retains evidence of segmented ancestors





CNS - Spinal Cord

Functional Anatomy

White matter = myelin

Gray matter = somata and dendrites

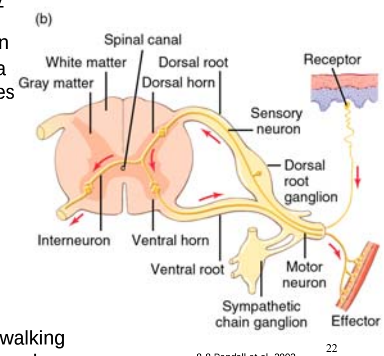
Cerebrospinal Fluid in spinal canal

Dorsal root, horn = ~afferent

Ventral root, horn = ~efferent

Spinal Reflexes:
- locomotion / walking
- chicken w/o head

Dorsal Root Ganglion (PNS)
- afferent sensory somata



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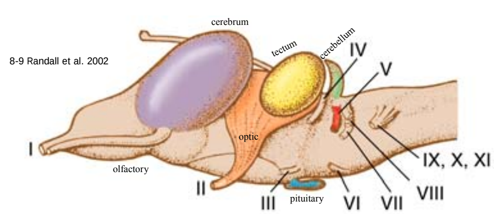
CNS - Brain

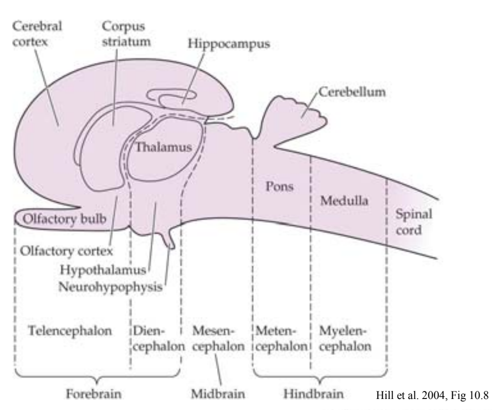
Vertebrate bilaterally paired nerve connections to periphery



Sensory
I Olfactory
II Optic
III Oculomotor
IV Trochlear

V Trigeminal ← Both
VI Abducens
VII Facial
VIII Vestibulocochlear

IX Glossopharyngeal
X Vagus
XI Spinal accessory
XII Hypoglossal
Motor



CNS - Brain Functional Anatomy

-Medulla oblongata
Respiration, autonomic funct, some sensory (hearing, equil.)

-Cerebellum
Coordinate motor output
Integrates info. from proprioceptors (stretch and joint)
visual, auditory
More convoluted (⇑ s.a.) in higher groups
Birds with large cerebellum to handle 3D flight

-Pons (and tectum)
Integrate and communicate
Visual, tactile, auditory maps
~ body movement coordination in some groups

-Cerebral Cortex
In higher groups takes over function of tectum

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CNS - Brain Functional Anatomy (con't)

-Thalamus
Sensory and motor coordination
Often communicates with cerebral cortex

-Amygdala
Processes info. and output related to emotions

-Hypothalamus
Also involved in emotions
Body temp, eating, drinking, sex
Water and electrolyte balance

-Olfactory Bulb
Key sense in many vertebrate groups
Anterior position

Olfaction straight to cerebrum w/o going through thalamus (in mammals)

-Cerebrum (covered by cerebral cortex)
More evolved in higher groups (size and folds)…

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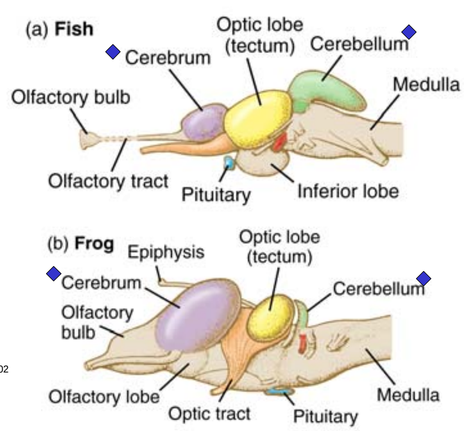
CNS - Brain

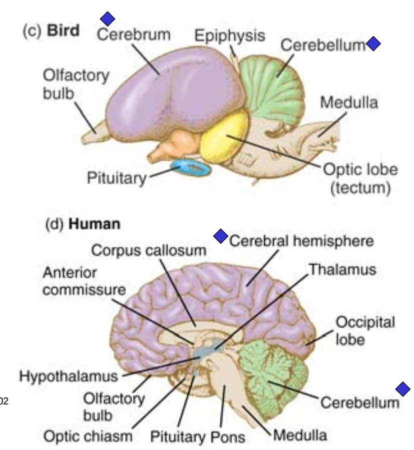
◆ Note change in size in difft. groups



8-10 Randall et al. 2002

CNS - Brain

◆ Note change in size in difft. groups



8-10 Randall et al. 2002

CNS - Brain

Cerebrum and Cerebral Cortex

- Folds increase surface area and # neurons
- Functional Regions
  1. Sensory cortex
     - somatosensory, auditory, visual
     - sensory homunculus ("little man")
  2. Motor cortex
     - often similar to sensory cortex map
  3. Association cortex
     - memory, future, thought, communication

Size of receptive fields?

Relative importance of each region changes among vertebrate groups

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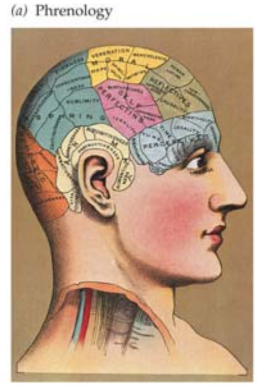
(a) Phrenology



Hill et al. 2004, Fig 10.9

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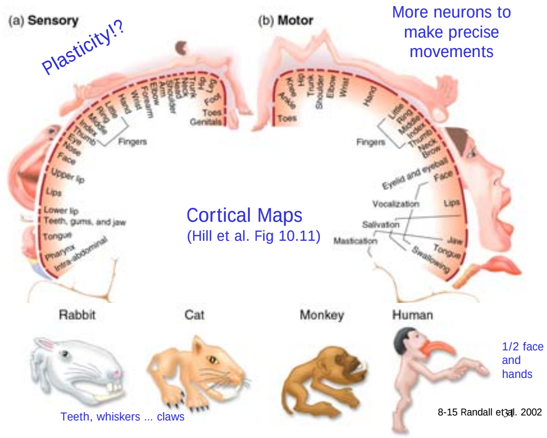

8-15 Randall et al. 2002

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Structural and Functional Regions

CNS

- Most neuronal somata
  incl. motor neurons
- Interneurons

Nuclei = collections of somata w/ similar function

Tracts = bundles of axons from nuclei

PNS

- Nervous system outside CNS

Nerve usually with both Afferent and Efferent axons

Nerves = axon bundles from sensory + motor neurons

Ganglia = somata of some autonomic neurons and most sensory neurons

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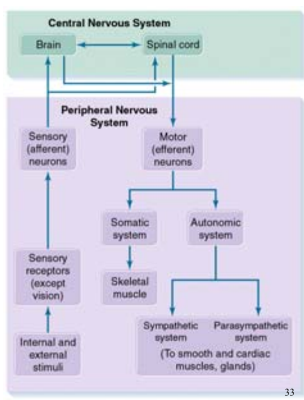
Structural and Functional Regions

8-6 Randall et al. 2002

- Efferent NS
  1. Somatic/Voluntary
     -skeletal muscle
  2. Autonomic
     - smooth muscle
     - cardiac muscle
     - glands
     - "housekeeping"
     A. Sympathetic
        ~ fight or flight
     B. Parasympathetic
        ~ rest and digest
     C. Enteric



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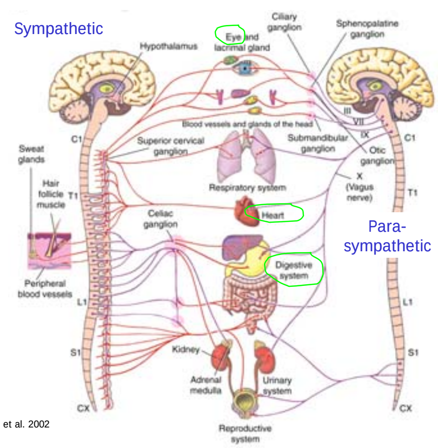

8-18 Randall et al. 2002

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Autonomic NS (vs Voluntary/Somatic)

Antagonistic Groups in Balance:

A. Sympathetic (f or f)
B. Parasympathetic (r + d)

Both function via reflex arcs, but often opposite effects

Efferent signal with two neurons:

1. Preganglionic (NT released is Acetylcholine [Ach])
2. Postganglionic (PNS, receptor is nicotinic ACh)

Difference between Symp. and Para. is in:
1. CNS origin
2. Location of postganglionic somata
3. Postganglionic NT
4. Receptors on target tissues

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Autonomic NS

Sympathetic	Parasympathetic
2-Postganglionic somata nearer CNS in chain ganglia	2-Postganglionic somata near effector, or in effector organ
3- Postganglionic NT is Norepinephrine	3- Postganglionic NT is ACh
4-Effector receptor is alpha or beta adrenergic	4-Effector receptor is muscarinic ACh

Difference between Symp. and Para. is in:
1. CNS origin
2. Location of postganglionic somata
3. Postganglionic NT
4. Receptors on target tissues

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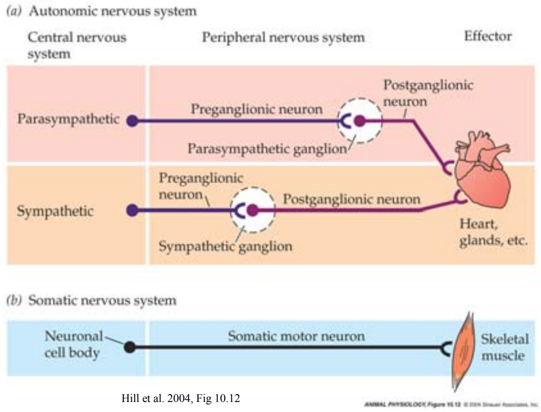
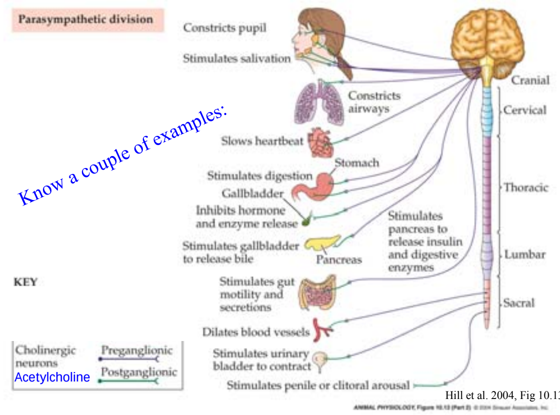
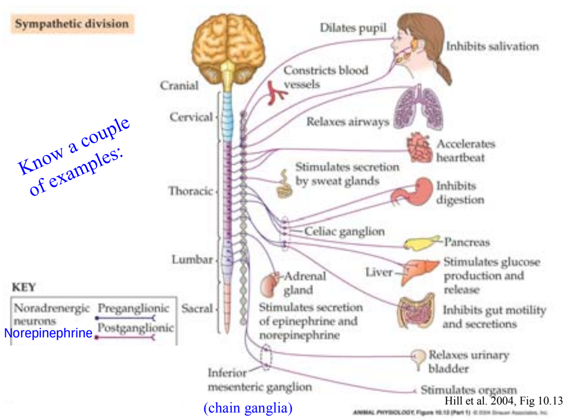


Hill et al. 2004, Fig 10.12



Hill et al. 2004, Fig 10.13



Hill et al. 2004, Fig 10.13

TABLE 10.2 Major actions of sympathetic and parasympathetic divisions in vertebrates

Process	Parasympathetic effect	Sympathetic effect
Digestion: gastrointestinal secretion and motility	Stimulates	Inhibits
Heartbeat	Slows	Increases rate and force
Blood vessels	Usually dilates	Constricts vessels to kidneys and gut; dilates vessels to skeletal muscles
Blood pressure	Decreases	Increases
Lung passages	Constricts	Dilates
Secretion of epinephrine and norepinephrine by adrenal medullary glands	—	Stimulates

Hill et al. 2004

"Squid axons are important to physiologists, and to the squid."
Hill et al. 2004, p.281

Sir Alan Hodgkin, Nobel Prize 1963

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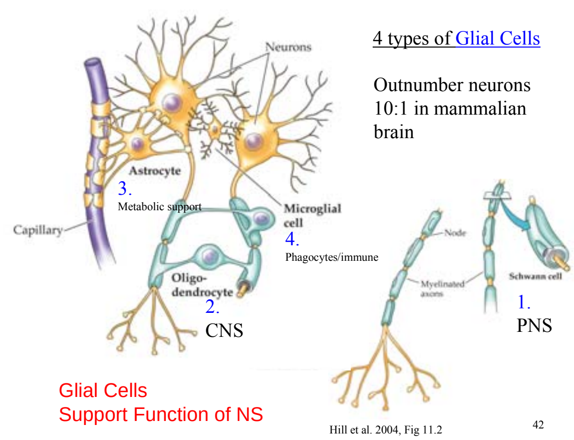

4 types of Glial Cells

Outnumber neurons 10:1 in mammalian brain

Glial Cells
Support Function of NS

Hill et al. 2004, Fig 11.2

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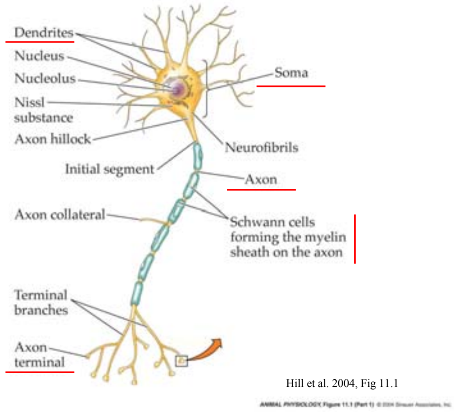
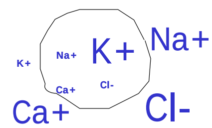
Neurons:

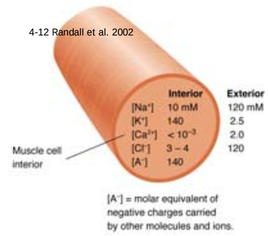


Hill et al. 2004, Fig 11.1

Osmotic Properties of Cells and Relative Ion Concentrations



4-12 Randall et al. 2002



To understand how the NS works we need to return to Membrane Details

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Movement Across Membranes

Electrochemical Gradient

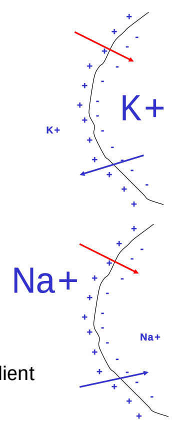
Electrical gradient

Concentration gradient

Electrochemical equilibrium

Equilibrium potential (E_x in mV)

when [X] gradient = electrical gradient



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Equilibrium potential (E_x in mV)

"Every ion's goal in life is to make the membrane potential equal its own equilibrium potential (E_x in mV)"

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Membrane Potential

1. To change Vm:
   A Small Number of Ions actually move relative to the number present both inside and outside the cell

2. Concentration gradients…
   (previously established by ATPase pumps) are not abolished when the channels for an ion species open

[Gradients allow for 'work' to be done, e.g., action potential sends signal along axon]

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Membrane Potential

3. Driven by ions that are permeable to the membrane (and have different $[\ ]_{in}$ as compared to $[\ ]_{out}$ a.k.a. gradient created with ATP)
   - K+ for example

4. Equilibrium Potential (E_x in mV):
   ~The equilibrium potentials of all the permeable ions (a function of their established gradients) will determine the membrane potential of a cell

5. emf determines which direction a given ion (X) will move when the membrane potential is known

$$emf_x = V_m - E_x$$

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Membrane Potential

6. Resting Membrane Potential driven by K+ efflux and, to a lesser extent, Na+ influx

7. Na+/K+ ATPase pump generates gradients that, for these permeable ions, determine membrane potential

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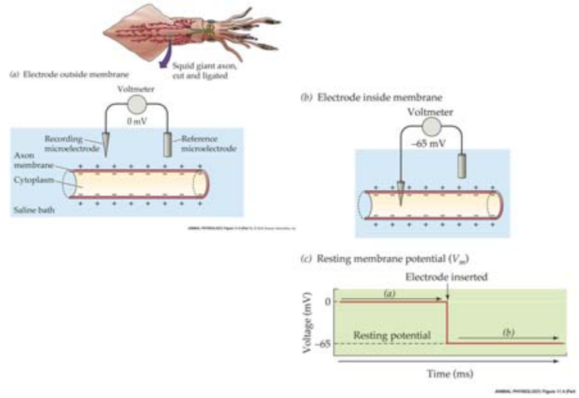

Hill et al. 2004, Fig 11.4

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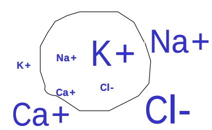
Table 5-1 Examples of ion channels found in axons

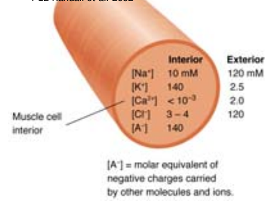
Randall et al. 2002

Channel	Current through channel	Characteristics	Selected blockers	Function
Leak channel (open in resting axon)	$I_{K\ (leak)}$	Produces relatively high P_K of resting cell	Partially blocked by tetraethylammonium (TEA)	Largely responsible for V_{rest}
Voltage-gated Na^+ channel	I_{Na}	Rapidly activated by depolarization; becomes inactivated even if V_m remains depolarized	Tetrodotoxin (TTX)	Produces rising phase of AP
Voltage-gated Ca^{2+} channel	I_{Ca}	Activated by depolarization but more slowly than Na^+ channel; inactivated as function of cytoplasmic $[Ca^{2+}]$ or V_m	Verapamil, D600, Co^{2+}, Cd^{2+}, Mn^{2+}, Ni^{2+}, La^{3+}	Produces slow depolarization; allows Ca^{2+} to enter cell, where it can act as second messenger
Voltage-gated K^+ channel ("delayed rectifier")	$I_{K(V)}$	Activated by depolarization but more slowly than Na^+ channel; inactivated slowly and not completely if V_m remains depolarized	Intra- and extracellular TEA, amino pyridines	Carries current that rapidly repolarizes the membrane to terminate an AP
Ca^{2+}-dependent K^+ channel	$I_{K(Ca)}$	Activated by depolarization plus elevated cytoplasmic $[Ca^{2+}]$; remains open as long as cytoplasmic $[Ca^{2+}]$ is higher than normal	Extracellular TEA	Carries current that repolarizes the cell following APs based on either Na^+ or Ca^{2+} and that balances I_{Ca}, thus limiting depolarization by I_{Ca}

Osmotic Properties of Cells and Relative Ion Concentrations



4-12 Randall et al. 2002



How do we calculate the value of an individual equilibrium potential, or the resting potential of a cell?

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Equilibrium potential (E_x in mV)

"Every ion's goal in life is to make the membrane potential equal its own equilibrium potential (E_x in mV)"

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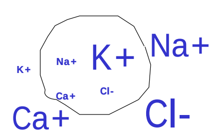
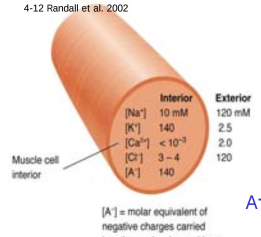
Osmotic Properties of Cells and Relative Ion Concentrations



4-12 Randall et al. 2002



Permeabilities

K+ >> Na+ ; Cl-

A^- (includes proteins, phosphate groups, etc.)

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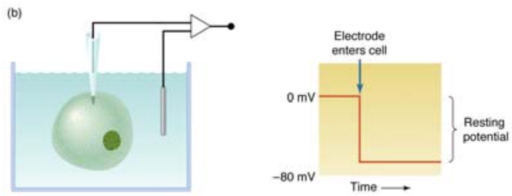
At Rest

Membrane Potential
(V_m in volts or mV)

- outside is zero by convention

- V_{rest} K^+, Na^+ about -60 mV



5-7 Randall et al. 2002

Nernst equation: $$E = \frac{RT}{zF} \ln \frac{C_{out}}{C_{in}}$$

where
E = equilibrium membrane potential
R = gas constant
T = absolute temperature
z = valence
F = Faraday's constant

(Mistake in Hill et al. text bottom of page 291; see if you can fix it)
Only in my book?

Equilibrium Potential

- Calculate for a given type of ion using the simplified Nernst Equation:

$$E_x = \frac{0.058}{z} \log \frac{[X]_{out}}{[X]_{in}}$$

$$E_{Na} = \frac{0.058}{z} \log \frac{[Na^+]_{out}}{[Na^+]_{in}}$$

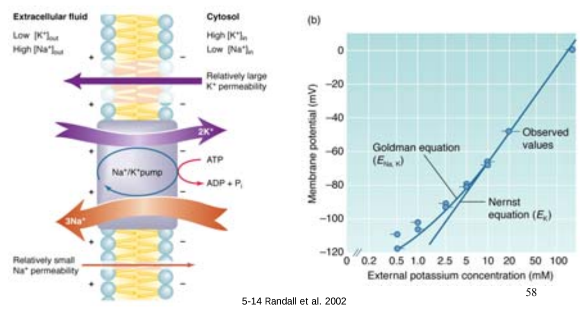
$$E_{Na} = \frac{0.058}{1} \log \frac{120 \text{ mM}}{10 \text{ mM}} = 63 \text{ mV } (0.063 \text{ V})$$

remember Equilibrium potential (E_x in mV)
when [X] gradient = electrical gradient

Membrane Potential
To calculate:

- Nernst for single ion
$V_m = E_x$ if only one ion 'driving'

- Goldman equation for multiple ions



5-14 Randall et al. 2002

Nernst Question

Calculate E_K if
$[K^+]_{inside}$ = 140 mM
$[K^+]_{outside}$ = 2.5 mM

-101 mV

If the resting membrane potential is –60 mV, which way will K+ 'want' to move (in or out of the cell)?

OUT

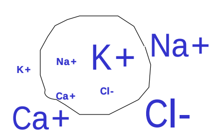
Which way will Na+ want to move?

IN

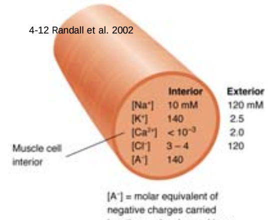
Which way will K+ want to move if membrane potential is -110 mV? 30 mV?

IN OUT

Osmotic Properties of Cells and Relative Ion Concentrations



4-12 Randall et al. 2002



Goldman Equation?

Donnan Equilibrium?