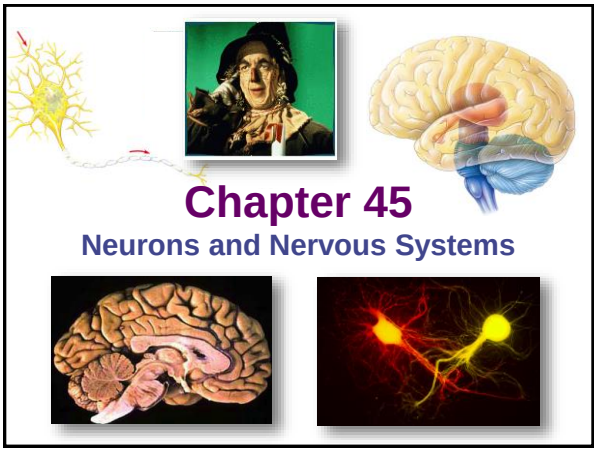
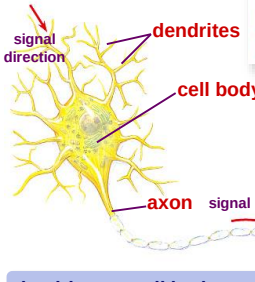


Chapter 45

Neurons and Nervous Systems

Nervous System Cells

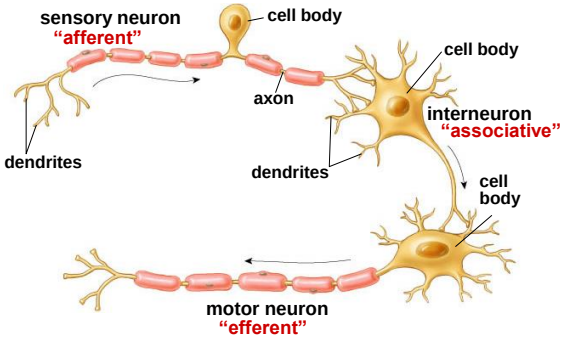
- Neuron
  - a nerve cell



- Structure fits function
  - many entry points for signal
  - one path out
  - transmits signal

dendrite → cell body → axon → terminal branches →

Types of Neurons



Fun Facts About Neurons

- Most specialized cell in animals
- Longest cell
  - blue whale neuron
    - 10-30 meters
  - giraffe axon
    - 5 meters
  - human neuron
    - 1-2 meters

Nervous system allows for ~ millisecond response times

Transmission of a Nerve Signal

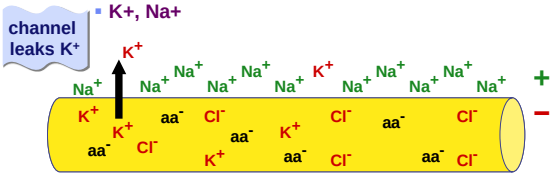
- Think dominoes!
  - start the signal
    - knock down line of dominoes by tipping 1st one → trigger the signal
  - propagate the signal
    - do dominoes move down the line? → no, just a wave through them!
  - re-set the system
    - before you can do it again, have to set up dominoes again → reset the axon

Transmission of a Nerve Signal

- Neuron has similar system
  - protein channels are set up
  - once first one is opened, the rest open in succession
    - all or nothing response
  - a "wave" action travels along neuron
  - have to re-set channels so neuron can react again

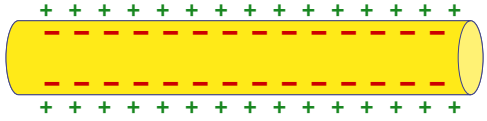
Cells: Surrounded by Charged Ions

- Cells live in a sea of charged ions
  - anions
    - more concentrated within the cell
    - Cl^-, charged amino acids (aa^-)
  - cations
    - more concentrated in the extracellular fluid
    - K+, Na+

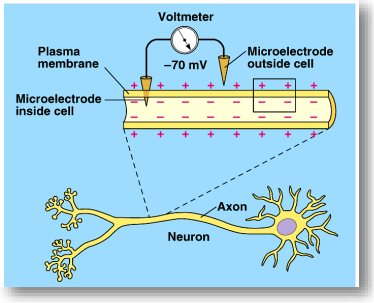


Cells have voltage!

- Opposite charges on opposite sides of cell membrane
  - membrane is polarized
    - negative inside; positive outside
    - charge gradient
    - stored energy (like a battery)



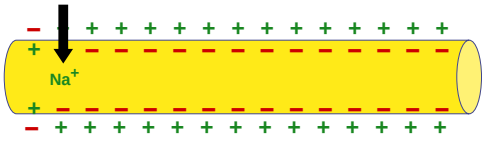
Measuring Cell Voltage



unstimulated neuron = resting potential of ~60 mV

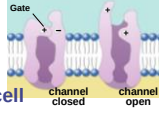
How does a nerve impulse travel?

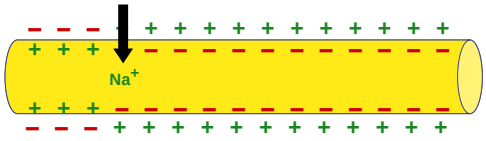
- Stimulus: nerve is stimulated
  - reaches threshold potential
    - open Na^+ channels in cell membrane
    - Na^+ ions diffuse into cell
  - charges reverse at that point on neuron
    - positive inside; negative outside
    - cell becomes depolarized



How does a nerve impulse travel?

- Wave: nerve impulse travels down neuron
  - change in charge opens next Na^+ gates down the line
    - "voltage-gated" channels
  - Na^+ ions continue to diffuse into cell
  - "wave" moves down neuron = action potential

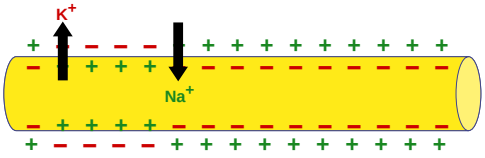




wave →

How does a nerve impulse travel?

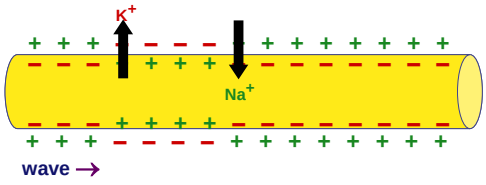
- Re-set: 2nd wave travels down neuron
  - K^+ channels open
    - K^+ channels up more slowly than Na^+ channels
  - K^+ ions diffuse out of cell
  - charges reverse back at that point
    - negative inside; positive outside



wave →

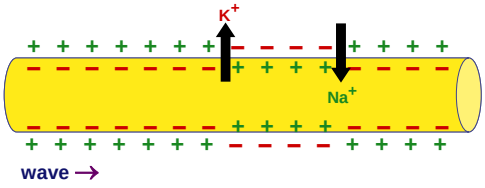
How does a nerve impulse travel?

- Combined waves travel down neuron
  - wave of opening ion channels moves down neuron
  - signal moves in one direction → → → → →
    - flow of K^+ out of cell stops activation of Na^+ channels in wrong direction



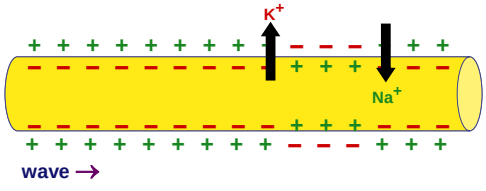
How does a nerve impulse travel?

- Action potential propagates
  - wave = nerve impulse, or action potential
  - brain → finger tips in milliseconds!



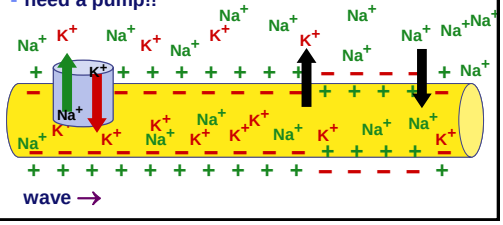
Voltage-gated Channels

- Ion channels open & close in response to changes in charge across membrane
  - Na^+ channels open quickly in response to depolarization & close slowly
  - K^+ channels open slowly in response to depolarization & close slowly



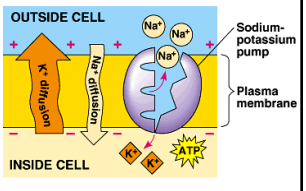
How does the nerve re-set itself?

- After firing a neuron has to re-set itself
  - Na^+ needs to move back out
  - K^+ needs to move back in
  - both are moving against concentration gradients
    - need a pump!!

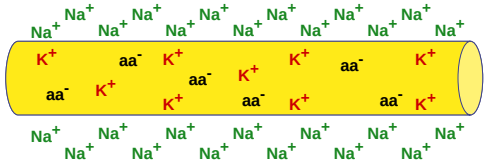


How does the nerve re-set itself?

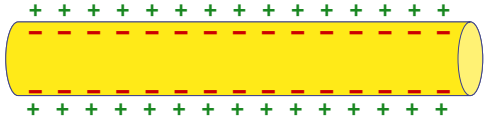
- Na^+ / K^+ pump
  - active transport protein in membrane
    - requires ATP
  - 3 Na^+ pumped out
  - 2 K^+ pumped in
  - re-sets charge across membrane



Neuron is ready to fire again…

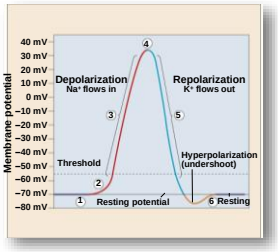


resting potential



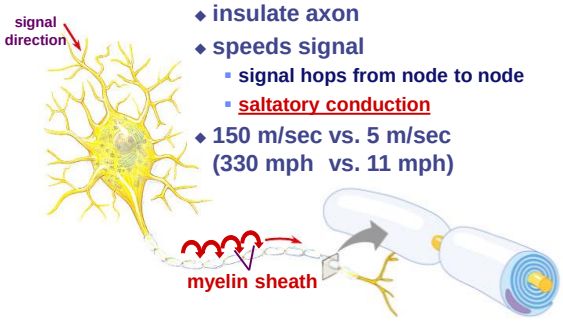
Action Potential Graph

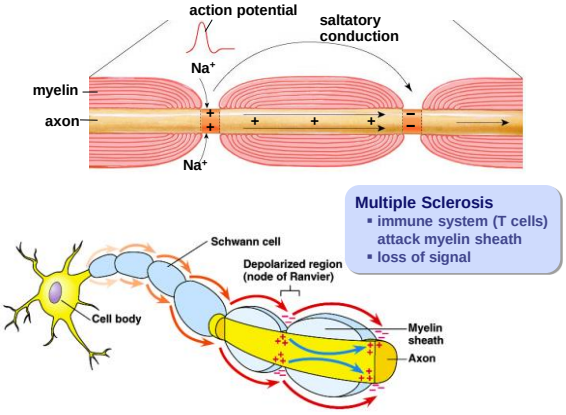
1. Resting potential
2. Stimulus reaches threshold potential
3. Depolarization
   Na^+ channels open;
   K^+ channels closed
4. K^+ channels open;
   Na^+ channels close;
5. Repolarization
   reset charge gradient
6. Undershoot: K^+ channels close slowly



Myelin Sheath

- Axon coated by Schwann cells
  - insulate axon
  - speeds signal
    - signal hops from node to node
    - saltatory conduction
  - 150 m/sec vs. 5 m/sec
    (330 mph vs. 11 mph)

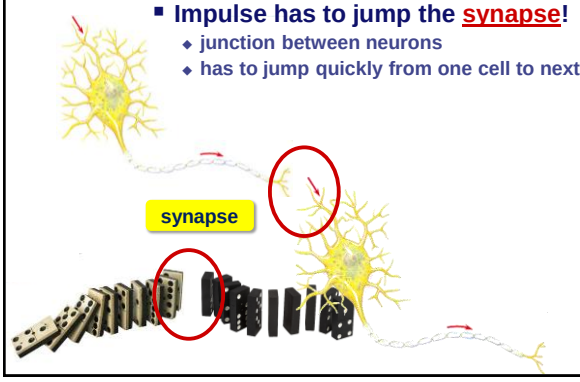




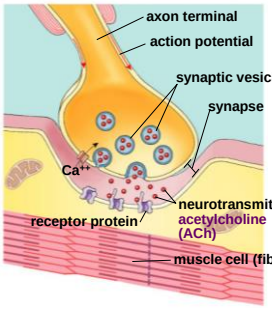
Multiple Sclerosis
- immune system (T cells) attack myelin sheath
- loss of signal

What happens at the end of the axon?

- Impulse has to jump the synapse!
  - junction between neurons
  - has to jump quickly from one cell to next



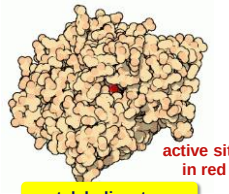
The Synapse

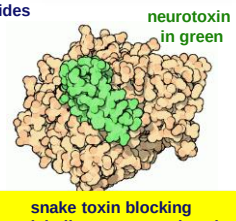


- Events at synapse
  - action potential depolarizes membrane
  - opens Ca^{++} channels
  - neurotransmitter vesicles fuse with membrane
  - release neurotransmitter to synaptic cleft
  - neurotransmitter binds with protein receptor
    - ion-gated channels open
  - neurotransmitter degraded or reabsorbed

Acetylcholinesterase

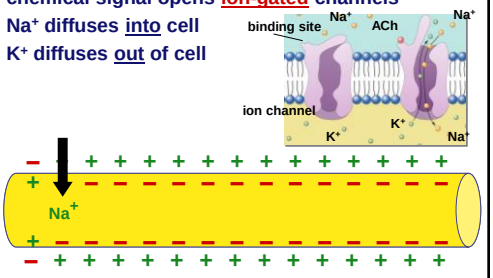
- Enzyme which breaks down acetylcholine neurotransmitter
  - neurotoxins = inhibitors
    - snake venom, sarin, insecticides





Nerve Impulse in Next Neuron

- Post-synaptic neuron
  - triggers nerve impulse in next nerve cell
    - chemical signal opens ion-gated channels
    - Na^+ diffuses into cell
    - K^+ diffuses out of cell



Neurotransmitters

- Acetylcholine
  - transmit signal to skeletal muscle
- Dopamine
  - widespread in brain
  - lack of dopamine in brain associated with Parkinson's disease
  - excessive dopamine linked to schizophrenia
  - pleasure & reward pathways
- Serotonin
  - widespread in brain
  - affects
- Glutamate
  - excites neurons into action
- GABA
  - inhibits passing of information

Neurotransmitters

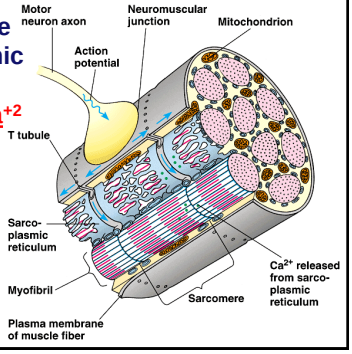
- Weak point of nervous system!
  - any substance that affects neurotransmitters or mimics them affects nerve function
    - gases: nitrous oxide, carbon monoxide
    - mood altering drugs:
      - stimulants
        - amphetamines, caffeine, nicotine
      - depressants
    - hallucinogenic drugs
    - Prozac
    - poisons

Questions to ponder…

- Why are axons so long?
- Why have synapses at all?
- How do "mind altering drugs" work?
  - caffeine, alcohol, nicotine, marijuana…
- Do plants have a nervous system?
  - Do they need one?

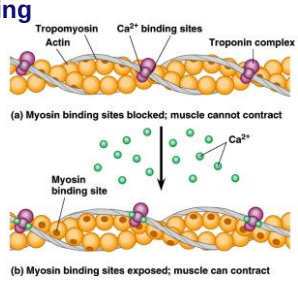
Muscle Contraction

- Nerve signal stimulates muscle cell's sarcoplasmic reticulum (SR) to release stored Ca^{+2}



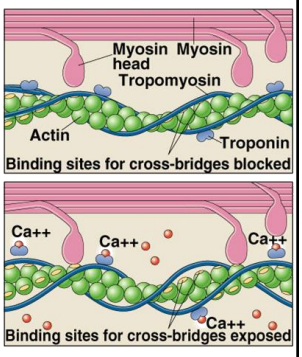
Ca^{+2} Triggers Muscle Action

- At rest, tropomyosin blocks myosin-binding sites on actin
- Ca^{+2} binds to troponin complex
  - shape change causes movement of tropomyosin-troponin complex
  - exposes myosin-binding sites on actin



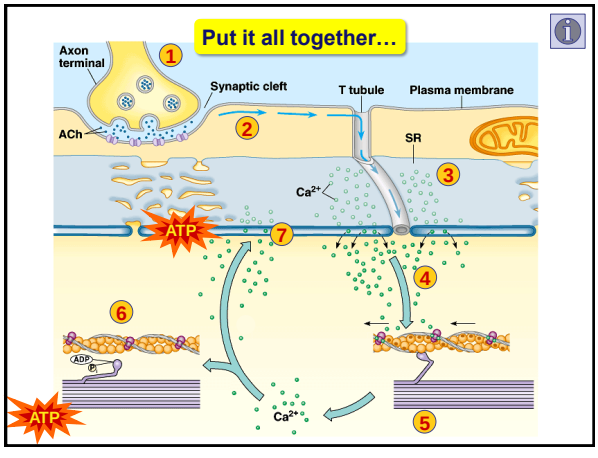
How Ca^{+2} Controls Muscle

- Sliding filament model
  - exposed actin binds to myosin
  - fibers slide past each other
    - ratchet system
  - shorten muscle cell
    - muscle contraction
  - muscle doesn't relax until Ca^{+2} is pumped back into SR
    - requires ATP



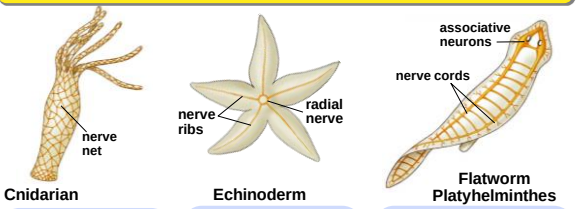
How it all works…

- Action potential causes Ca^{+2} release from SR
  - Ca^{+2} binds to troponin
- Troponin moves tropomyosin uncovering myosin binding site on actin
- Myosin binds actin
  - uses ATP to "ratchet" each time
  - releases, "unratchets" & binds to next actin
- Myosin pulls actin chain along
- Sarcomere shortens
  - Z lines move closer together
- Whole fiber shortens → contraction!
- Ca^{+2} pumps restore Ca^{+2} to SR → relaxation!
  - pumps use ATP



Cephalization = Brain Evolution

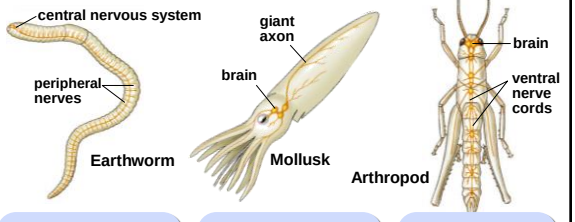
Cephalization = clustering of neurons in "brain" at front (anterior) end of bilaterally symmetrical animals →→ where sense organs are



Cnidarian	Echinoderm	Flatworm Platyhelminthes
Simplest nervous system: no control of complex actions	More organization but still based on nerve nets; supports more complex movement	Simplest, defined central nervous system: more complex muscle control

Cephalization = Brain Evolution

- increase in interneurons in brain region



Earthworm	Mollusk	Arthropod
More complex brains: connected to all other parts of body by peripheral nerves	More complex brains in predators: most sophisticated invertebrate nervous system	Further brain development: ganglia = neuron clusters along CNS

Evolution of Vertebrate Brain