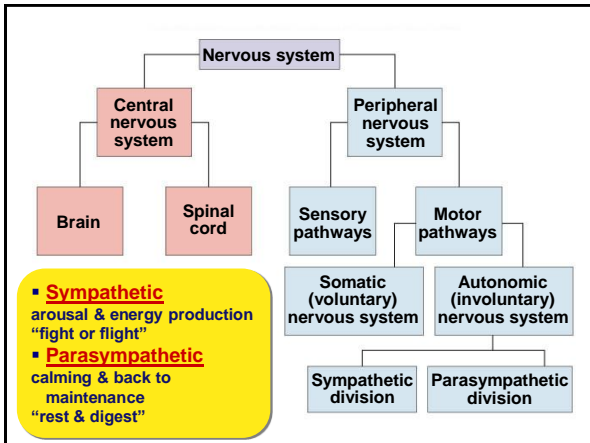


## Chapter 44

### Neurons and Nervous Systems

### Why do animals need a nervous system?

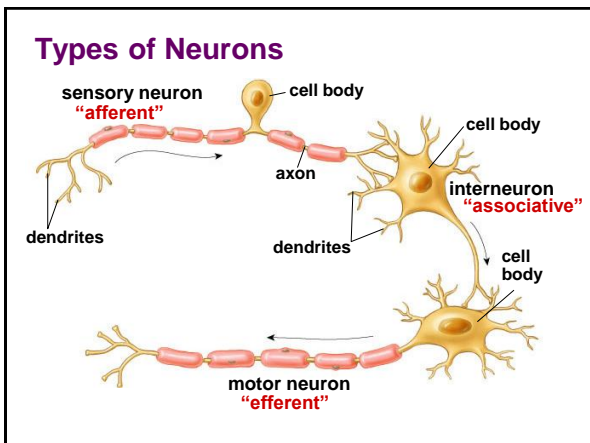
- What characteristics do animals need in a nervous system?
  - ◆ fast
  - ◆ accurate
  - ◆ reset quickly



### 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 →




### 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 1<sup>st</sup> 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

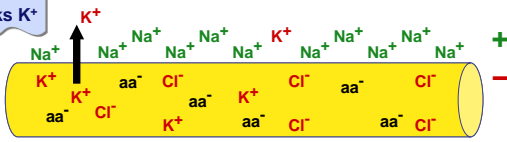
- Neuron has similar system
  - protein channels are set up
  - once first one is opened, the rest open in succession
    - all or nothing response**
  - a “wave” action travels along neuron
  - have to re-set channels so neuron can react again



### Cells: Surrounded by Charged Ions

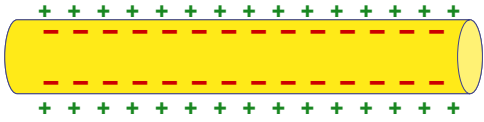
- Cells live in a sea of charged ions
  - anions**
    - more concentrated **within the cell**
    - Cl<sup>-</sup>, charged amino acids (aa<sup>-</sup>)
  - cations**
    - more concentrated in the **extracellular fluid**
    - K<sup>+</sup>, Na<sup>+</sup>

channel leaks K<sup>+</sup>

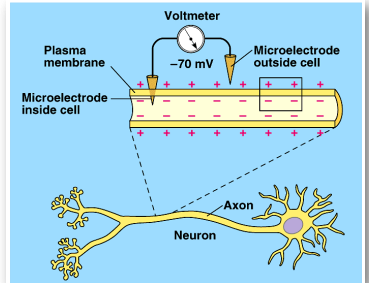


### Cells have voltage!

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



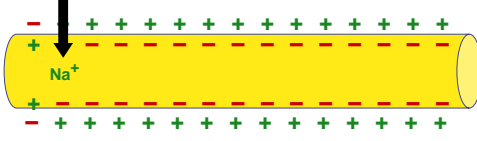
### Measuring Cell Voltage



unstimulated neuron = **resting potential** of **-60 mV**

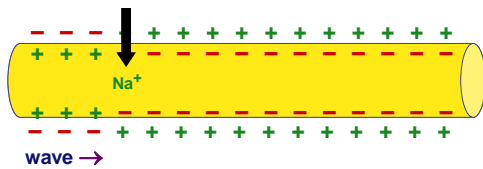
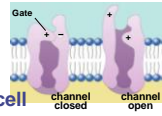
### How does a nerve impulse travel?

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



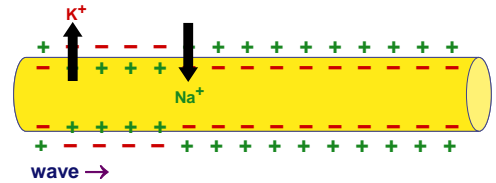
### How does a nerve impulse travel?

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



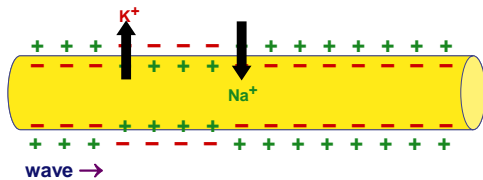
### How does a nerve impulse travel?

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



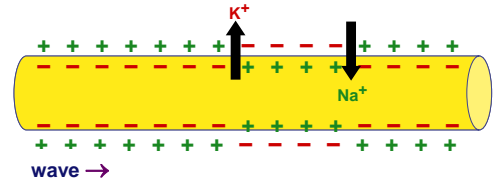
### How does a nerve impulse travel?

- **Combined waves** travel down neuron
  - ♦ wave of opening ion channels moves down neuron
  - ♦ signal moves in one direction → → → → →
    - flow of K<sup>+</sup> out of cell stops activation of Na<sup>+</sup> channels in wrong direction



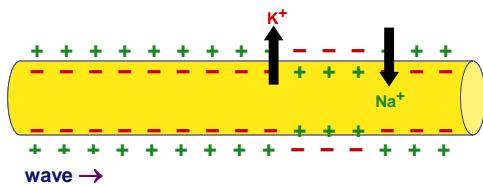
### How does a nerve impulse travel?

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



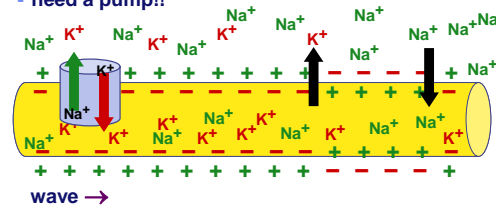
### Voltage-gated Channels

- Ion channels open & close in response to changes in charge across membrane
  - ♦ Na<sup>+</sup> channels **open quickly** in response to depolarization & close slowly
  - ♦ K<sup>+</sup> channels **open slowly** in response to depolarization & close slowly



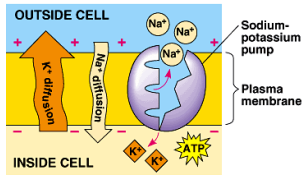
### How does the nerve re-set itself?

- After firing a neuron has to re-set itself
  - ♦ Na<sup>+</sup> needs to move back **out**
  - ♦ K<sup>+</sup> needs to move back **in**
  - ♦ both are moving **against** concentration gradients
    - need a pump!!

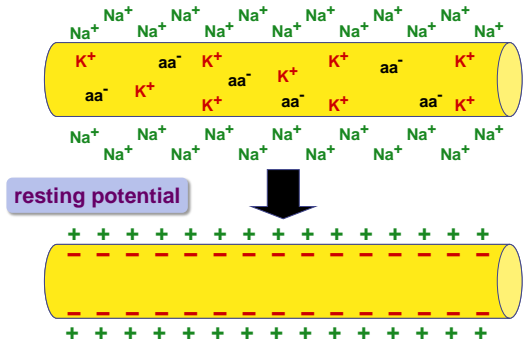


### How does the nerve re-set itself?

- **Na<sup>+</sup> / K<sup>+</sup> pump**
  - ◆ active transport protein in membrane
    - requires ATP
  - ◆ 3 Na<sup>+</sup> pumped out
  - ◆ 2 K<sup>+</sup> pumped in
  - ◆ re-sets charge across membrane

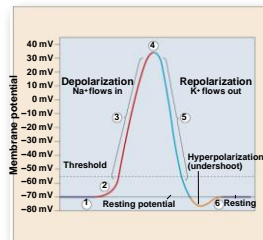


### Neuron is ready to fire again...



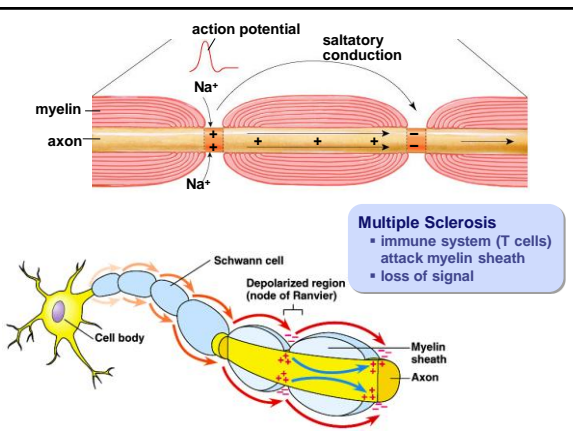
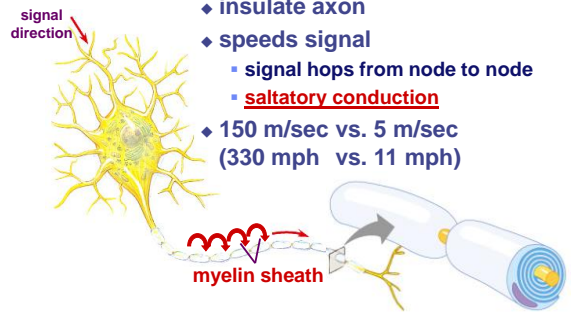
### Action Potential Graph

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



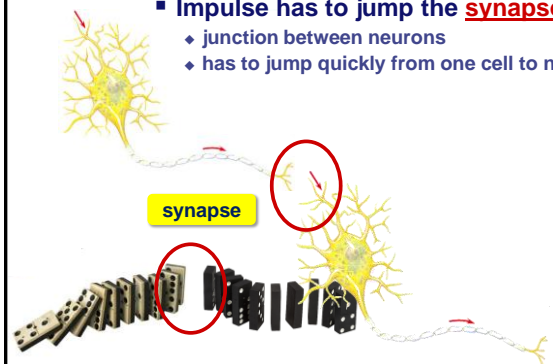
### Myelin Sheath

- 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)

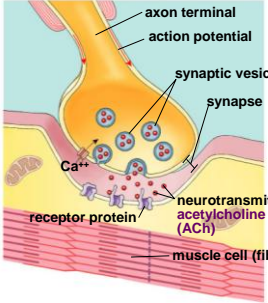


### What happens at the end of the axon?

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

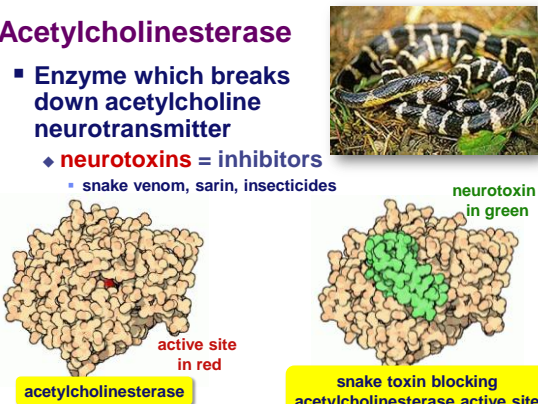


### The Synapse



- 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

active site in red

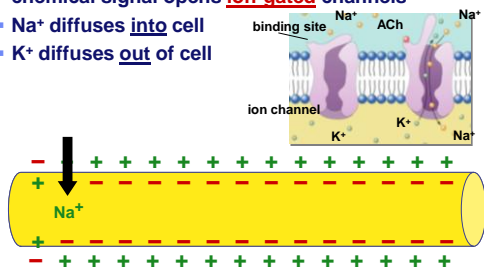
neurotoxin in green

acetylcholinesterase

snake toxin blocking acetylcholinesterase active site

### 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
- **Epinephrine (adrenaline) & norepinephrine**
  - ♦ fight-or-flight response
- **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 sleep, mood, attention & learning

### 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?

