Chapter 48.

Nervous System
Why do animals need a nervous system?

Remember to think about the bunny...
What characteristics do animals need in a nervous system?

- fast
- accurate
- reset quickly

Poor bunny!
Nervous system cells

- **Neuron**
  - a nerve cell

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

Dendrites → cell body → axon
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 1 millisecond response time
Transmission of a signal

- How is a signal transmitted down neuron?

Think Dominoes!
Transmission of a signal

- **Dominoes**
  - **start the signal**
    - knock down line of dominoes by tipping 1st one
      → send message
  - **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
  - channels are set up
  - once 1st is opened, the rest open in succession
    - all or nothing response
  - an 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 (negative ions)
    - more concentrated within the cell
    - Cl⁻, charged amino acids
  - cations (positive ions)
    - more concentrated in the extracellular fluid
    - K⁺, Na⁺

channel leaks K⁺
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 -70mV
How does a nerve impulse travel?

- **Stimulus**: nerve is stimulated
  - open Na\(^+\) channels in cell membrane
    - reached threshold potential
    - membrane becomes very permeable to Na\(^+\)
    - 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 other $\text{Na}^+$ gates in next section of cell
    - “voltage-gated” channels
  - $\text{Na}^+$ ions continue to move into cell
  - “wave” moves down neuron = action potential

The rest of the dominoes fall
How does a nerve impulse travel?

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

Set dominoes back up quickly

![Diagram of nerve impulse]

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

Ready for next time!
How does a nerve impulse travel?

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

In the blink of an eye!
Voltage-gated channels

- Ion channels open & close in response to changes in charge across membrane
  - $\text{Na}^+$ channels open **quickly** in response to depolarization & close slowly
  - $\text{K}^+$ channels open **slowly** in response to depolarization & close slowly

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**Diagram:**

- $\text{Na}^+$ channels and $\text{K}^+$ channels
- Depolarization wave

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AP E
2005-2006
How does the nerve re-set itself?

- After firing a neuron has to re-set itself
  - $\text{Na}^+$ needs to move back \textbf{out}
  - $\text{K}^+$ needs to move back \textbf{in}
  - both are moving \textbf{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-set charge across membrane

That's a lot of ATP! Feed me some sugar quick!
Neuron is ready to fire again

resting potential
Action potential graph

1. Resting potential
2. Stimulus reaches threshold potential
3. Na⁺ channels open; K⁺ channels closed
4. Na⁺ channels close; K⁺ channels open
5. Undershoot: K⁺ channels close slowly
**Myelin sheath**

- **made of Schwann cells**
  - cells coat axon
    - insulate axon
  - saltatory conduction
    - signal hops from node to node
  - 150m/sec vs. 5m/sec
    (330mph vs. 11mph)

myelin sheath
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

How does the wave jump the gap?
Synaptic terminal

- Chemicals stored in vesicles
  - release neurotransmitters
    - diffusion of chemical across synapse conducts the signal — chemical signal — across synapse
    - stimulus for receptors on dendrites of next neuron

We switched... from an electrical signal to a chemical signal
Chemical synapse: follow the path

- action depolarizes membrane
- triggers influx of Ca+
- vesicles fuse with membrane
- release neurotransmitter to cleft
- neurotransmitter bind with receptor
- neurotransmitter degraded / reabsorbed
Nerve impulse in next neuron

- Post-synaptic neuron
  - triggers nerve impulse in next nerve cell
    - chemical signal opens “ion-gated” channels
    - $\text{Na}^+$ diffuses into cell
    - $\text{K}^+$ diffuses out of cell

Here we go again!
<table>
<thead>
<tr>
<th>Neurotransmitter</th>
<th>Structure</th>
<th>Functional Class</th>
<th>Secretion Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetylcholine</td>
<td><img src="image1" alt="Structure" /></td>
<td>Excitatory to vertebrate skeletal muscles; excitatory or inhibitory at other sites</td>
<td>CNS; PNS; vertebrate neuromuscular junction</td>
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<tr>
<td><strong>Biogenic Amines</strong></td>
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<tr>
<td>Norepinephrine</td>
<td><img src="image2" alt="Structure" /></td>
<td>Excitatory or inhibitory</td>
<td>CNS; PNS</td>
</tr>
<tr>
<td>Dopamine</td>
<td><img src="image3" alt="Structure" /></td>
<td>Generally excitatory; may be inhibitory at some sites</td>
<td>CNS; PNS</td>
</tr>
<tr>
<td>Serotonin</td>
<td><img src="image4" alt="Structure" /></td>
<td>Generally inhibitory</td>
<td>CNS</td>
</tr>
<tr>
<td><strong>Amino Acids</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GABA (gamma aminobutyric acid)</td>
<td><img src="image5" alt="Structure" /></td>
<td>Inhibitory</td>
<td>CNS; invertebrate neuromuscular junction</td>
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<tr>
<td>Glycine</td>
<td><img src="image6" alt="Structure" /></td>
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<td>CNS</td>
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<tr>
<td>Glutamate</td>
<td><img src="image7" alt="Structure" /></td>
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<td>CNS; invertebrate neuromuscular junction</td>
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<td><strong>Neuropeptides</strong></td>
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<td>Substance P</td>
<td><img src="image9" alt="Structure" /></td>
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<td>CNS; PNS</td>
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<tr>
<td>Met-enkephalin (an endorphin)</td>
<td><img src="image10" alt="Structure" /></td>
<td>Generally inhibitory</td>
<td>CNS</td>
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</tbody>
</table>
Neurotransmitters

- **Acetylcholine**
  - transmit signal to skeletal muscle

- **Epinephrine (adrenaline) & norepinephrine**
  - fight-or-flight response

- **Dopamine**
  - widespread in brain
  - affects sleep, mood, attention & learning
  - lack of dopamine in brain associated with Parkinson’s disease
  - excessive dopamine linked to schizophrenia

- **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: nitric oxide, carbon monoxide
    - mood altering drugs:
      - stimulants
        - amphetamines, caffeine, nicotine
      - depressants
    - hallucinogenic drugs
    - Prozac
    - poisons
Acetylcholinesterase

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

- **Reflex**, or automatic response

  - rapid response
    - automated
  - signal only goes to spinal cord
  - adaptive value
    - essential actions
    - don’t need to think or make decisions about
      - blinking
      - balance
      - pupil dilation
      - startle
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?
Any Questions??
Human brain

Forebrain
- Cerebrum
- Thalamus
- Hypothalamus

Midbrain
- Pons
- Medulla oblongata
- Cerebellum

Hindbrain

Cerebral cortex
Pituitary gland
Spinal cord
Evolutionary older structures

- Evolutionary older structures of the brain regulate essential autonomic & integrative functions
  - brainstem
    - pons
    - medulla oblongata
    - midbrain
  - cerebellum
  - thalamus, hypothalamus, epithalamus
Brainstem

- The “lower brain”
  - medulla oblongata
  - pons
  - midbrain

- Functions
  - homeostasis
  - coordination of movement
  - conduction of impulses to higher brain centers
Medulla oblongata & Pons

- Controls autonomic homeostatic functions
  - breathing
  - heart & blood vessel activity
  - swallowing
  - vomiting
  - digestion

- Relays information to & from higher brain centers
Midbrain

- Involved in the integration of sensory information
  - regulation of visual reflexes
  - regulation of auditory reflexes
Reticular Formation

- Sleep & wakefulness produces patterns of electrical activity in the brain
  - recorded as an **electroencephalogram (EEG)**
  - most dreaming during **REM** (rapid eye movement) sleep
Cerebrum

- Most highly evolved structure of mammalian brain
- Cerebrum divided
  - hemispheres
  - left = right side of body
  - right = left side of body
- Corpus callosum
  - major connection between 2 hemispheres
Lateralization of Brain Function

- **Left hemisphere**
  - language, math, logic operations, processing of serial sequences of information, visual & auditory details
  - detailed activities required for motor control

- **Right hemisphere**
  - pattern recognition, spatial relationships, non-verbal ideation, emotional processing, parallel processing of information
Cerebrum specialization

- Regions of the cerebrum are specialized for different functions

- Lobes
  - frontal
  - temporal
  - occipital
  - parietal
Limbic system

Mediates basic emotions (fear, anger), involved in emotional bonding, establishes emotional memory

Amygdala involved in recognizing emotional content of facial expression
Any Questions??