Before we start neurons:

- Let go back to October...
What are the three stages of cell signaling?

- Reception
- Transduction
- Response
Explain Reception

- Reception-The target cell’s detection of a signal molecule coming from outside the cell.
Explain Transduction

Transduction: The conversion of the signal to a form that can bring about a specific cellular response. Often involving a signal transduction pathway within the cell.
Explain the response.

Response: The specific cellular response to the signal molecule.
What is a ligand and how do cells avoid sending the wrong signals

- A ligand is a signal molecule. Cell receptors are highly specific. The binding between a ligand and a receptor often causes a conformational change in the receptor to initiate transduction.
There are two types of receptors characterized by their locations. Which is found inside the cell?

- Intracellular receptors are found inside the plasma membrane in the cytoplasm or nucleus.

How could a signal reach these receptors?

- The signal molecule must cross the plasma membrane. Therefore it must be hydrophobic (such as the hormone testosterone) or very small (such as nitric oxide (NO)).
1. In which of the following ways do plant hormones differ from hormones in animals?

*Plant hormones may travel in air or through vascular systems*

2. In the formation of biofilms, such as those forming on unbrushed teeth, cell signaling serves which function?

*Aggregation (clumping together) of bacteria that can cause cavities*

3. What would be likely to happen to an animal's target cells that lacked receptors for local regulators, such as growth factors?

*They might not be able to respond to the stimuli, for instance, they might not be able to multiply in response to growth factors from nearby cells.*
Explain the G-protein coupled receptor.

- Ligand (signal molecule) binds to G-protein coupled receptor.
  - Causes conformational change allowing the receptor to bind to inactive G-protein.
    - This binding allows GTP to displace and replace GDP, activation the G-protein.
      - The active G-protein then binds to and activates a specific enzyme which will in turn trigger the next step in the pathway, ending in a cellular response.

  » These conformational changes are temporary, and so will reset itself.
Explain the tyrosine kinase receptor.

- Ligands (signal molecules) binds to Tyrosine Kinase Receptors, causing the formation of a dimer.
  - In the dimer configuration, each tyrosine kinase adds a phosphate from an ATP molecule.
    - Each phosphorylated tyrosine can now trigger a unique cellular response.

- THE ability to trigger MULTIPLE RESPONSES AT ONCE is the key difference between tyrosine kinase receptors, and the G-protein coupled receptor.
How do ligand-gated ion channels work?

• An ion channel is a protein embedded in a cell membrane through which specific enzymes may flow.

• A specific signal molecule can cause ligand-gated ion channels in a membrane to open or close, regulating the flow of specific ions.

• THIS WILL BECOME IMPORTANT VERY SOON!
1. Which type of cellular communication is characterized by a cell releasing a signal molecule into the environment, followed by a number of cells in the immediate vicinity responding?

   *paracrine signaling*

2. Explain how the nervous system illustrates both local and long-distance signaling.

   **Synaptic signaling** occurs when chemical messages (carried by neurotransmitters) are released in an area (known as the synapse) between the nerve cell and its target cell. These signals stimulate the target cell.

   The release of NTs are triggered by an electrical signal. That electrical signal travels the length of the nerve cell, is converted to the chemical signal, then stimulates the next nerve cell and is converted back to an electrical signal. Nerve cells can be quite long, allowing these signals to travel long distances very quickly.
Chapter 48

Neurons, Synapses, and Signaling
BioFlix
How Neurons Work

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Concept 48.1: Neuron organization and structure reflect function in information transfer

- The squid possesses extremely large nerve cells and has played a crucial role in the discovery of how neurons transmit signals.
Figure 48.2

Ganglia
Brain
Arm
Nerve
Eye
Mantle
Nerves with giant axons
Introduction to Information Processing

- Nervous systems process information in three stages: sensory input, integration, and motor output.
The Nervous System

- 2 main kinds of cells
  - Neurons
  - Glia
Glial cells

- 100 billion neurons
- 10x more glial cells

Glial cells
- Support neurons (literally, provide physical support, as well as nutrients)
- Cover neurons with myelin
- Clean up debris
Astrocytes

- Regulate external environment (ions, etc.)
- Most abundant glial cell
- Histocytes may contribute to blood-brain barrier and to synapses
Three main types of neurons

- Sensory Neurons
- Interneurons
- Motor Neurons
• Sensors detect external stimuli and internal conditions and transmit information along sensory neurons.

• Sensory information is sent to the brain or ganglia, where interneurons integrate the information.

• Motor output leaves the brain or ganglia via motor neurons, which trigger muscle or gland activity.
Sensory (Afferent) vs. Motor (Efferent)

sensory (afferent) nerve

Neurons that send signals from the senses, skin, muscles, and internal organs to the CNS

e.g., skin

motor (efferent) nerve

Neurons that transmit commands from the CNS to the muscles, glands, and organs

e.g., muscle

Gray’s Anatomy 38 1999
The Withdrawal Reflex

• Many animals have a complex nervous system that consists of
  - A **central nervous system (CNS)** where integration takes place; this includes the brain and a nerve cord
  - A **peripheral nervous system (PNS)**, which carries information into and out of the CNS
  - The neurons of the PNS, when bundled together, form **nerves**
Nervous System

- **Central nervous system (CNS):**
  - Brain
  - Spinal cord

- **Peripheral nervous system (PNS):**
  - Sensory neurons
  - Motor neurons (somatic and autonomic)
1. 2 main cells of the nervous system? Neurons & Glial cells

2. 3 type of neurons and their function? Sensory (take info in), Inter (interpret), Motor (act)

3. 2 major divisions of the nervous system? Central (brain and spinal cord) Peripheral (sensory, motor neurons)
The Nervous System

Central Nervous System (CNS)
- Brain
- Spinal Cord

Peripheral Nervous System (PNS)
- Motor Neurons
- Sensory Neurons

Somatic Nervous System
- voluntary movements via skeletal muscles

Autonomic Nervous System
- organs, smooth muscles
  - Sympathetic
    - “Fight-or-Flight” responses
  - Parasympathetic
    - maintenance
Which division of the autonomic nervous system would you expect to...

1. Eyes
   - Dilates pupil
   - Contracts pupil
Divisions of the autonomic nervous system

1. Eyes
   - Dilates pupil

2. Lungs
   - Relaxes bronchi

3. Heart
   - Accelerates, strengthens heartbeat

4. Stomach, intestines
   - Inhibits activity

5. Blood vessels of internal organs
   - Contracts vessels

Parasympathetic

- Contracts pupil
- Constricts bronchi
- Slows heartbeat
- Stimulates activity
- Dilates vessels

Sympathetic

- Accelerates heartbeat
- Inhibits activity
- Constricts vessels
- Dilates vessels
- Stimulates activity
Name the structures of the CNS.

Central Nervous System

Brain

Spinal cord
Figure 48.3

Sensor

Effector

Sensory input

Integration

Motor output

Peripheral nervous system (PNS)

Central nervous system (CNS)
Neuron Structure and Function

• Most of a neuron’s organelles are in the cell body
• Most neurons have dendrites, highly branched extensions that receive signals from other neurons
• The axon is typically a much longer extension that transmits signals to other cells at synapses
• The cone-shaped base of an axon is called the axon hillock
Neurons

- Dendrites
- Cell Body
- Myelin Sheath
- Axon Hillock
- Axon
- Dendrites of another neuron
- Axon of another neuron
In which part of a neuron would one find:

- The nucleus
- The majority of NT Receptors
- The long thin piece of the neuron that carries electrical signals
- The space between neurons where NTs are released and received.
Nervous System (NS) Review

1. Division of the NS that consists of the Brain and spinal cord. **CNS**

2. Division of the NS that consists of the nerves that communicate motor and sensory signals throughout the body. **PNS**

3. These collect information from external and internal stimuli. The rods & cones that detect light are an example. **Sensory receptors**

4. These transmit information from eyes and other sensors to the brain or spinal cord for processing. **Sensory neurons**

5. Connect sensory and motor neurons or make local connections in the brain and spinal cord. **Interneurons**

6. Transmit signals to effectors, such as muscle cells and glands. **Motor neurons**

7. Bundles of neurons. **Nerves**
8. 2 main cells of the nervous system? Neurons & Glial cells

9. 3 type of neurons and their function? Sensory (take info in), Inter (interpret), Motor (act)

10. 2 major divisions of the nervous system? Central (brain and spinal cord) & Peripheral (sensory, motor neurons)

11. 3 main parts of a neuron? Dendrite-cell body-axon

12. Fatty insulating substance that speeds up AP. Myelin sheath

13. Junction between 2 neurons (or a neuron and its target) synapse

14. Chemical messengers released from synaptic terminals (of a presynaptic cell) that bind to receptors on a second cell and cause a change in the second cell (a postsynaptic cell). Neurotransmitters (NTs)
Our Goals for today:

• Finish the overview of the nervous system
• To be able to describe, and diagram the action potential, how neurons send messages.
• You should have paper and be ready to draw.
The synaptic terminal of one axon passes information across the synapse in the form of chemical messengers called neurotransmitters.

A synapse is a junction between an axon and another cell.
Information is transmitted from a **presynaptic cell** (a neuron) to a **postsynaptic cell** (a neuron, muscle, or gland cell)
Figure 48.4

Dendrites
Stimulus

Axon hillock

Nucleus

Cell body

Presynaptic cell

Axon

Signal direction

Synapse

Neurotransmitter

Synaptic terminals

Postsynaptic cell

Synaptic terminals
Concept 48.2: Ion pumps and ion channels establish the resting potential of a neuron

- Every cell has a voltage (difference in electrical charge) across its plasma membrane called a membrane potential.
What is the resting potential of a neuron?

- **The resting potential** is the membrane potential of a neuron not sending signals.
  - Changes in membrane potential act as signals, transmitting and processing information.
Formation of the Resting Potential

In a mammalian neuron at resting potential, the concentration of $K^+$ is highest inside the cell, while the concentration of $Na^+$ is highest outside the cell.

What is the resting potential of a neuron?
What is the resting potential of a neuron?

- **Sodium-potassium** pumps use the energy of **ATP** to maintain these **K⁺** and **Na⁺** gradients across the plasma membrane.
  - These concentration gradients represent chemical potential energy.
3/3/16 Review

• What are the major differences between the Nervous System and the Endocrine System?
• What are the 3 main types of neurons? Explain their role in a reflex.
• What are the three main parts of the neuron?
• What is meant by membrane potential?
What did we just learn?

• In a mammalian neuron at resting potential, the concentration of **K⁺** is highest inside the cell, while the concentration of **Na⁺** is highest outside the cell.

What was the name of the transport system that maintains this gradient? Is it active or passive?

**Na⁺/K⁺ pump**
Active transport
• The opening of ion channels in the plasma membrane converts chemical potential to electrical potential
• A neuron at resting potential contains many open K⁺ channels and fewer open Na⁺ channels; K⁺ diffuses out of the cell
  - The resulting buildup of negative charge within the neuron is the major source of membrane potential.
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Animation: Resting Potential
Right-click slide / select “Play”
So, at rest, why is the inside of the neuron (intracellular) negative compared to the outside (extracellular)?

1. More open K+ Channels
2. Negatively charged proteins
3. 2:3 In to out Na/K pump.

Negative Net Charge within the Membrane
Concept 48.3: Action potentials are the signals conducted by axons

- Changes in membrane potential occur because neurons contain **gated ion channels** that open or close in response to stimuli
When gated $K^+$ channels open, $K^+$ diffuses out, making the inside of the cell more negative. This is hyperpolarization, an increase in magnitude of the membrane potential.
Figure 48.10

(a) Graded hyperpolarizations produced by two stimuli that increase membrane permeability to $K^+$

(b) Graded hyperpolarizations produced by two stimuli that increase membrane permeability to $Na^+$

(c) Action potential triggered by a depolarization that reaches the threshold
Graded hyperpolarizations produced by two stimuli that increase membrane permeability to K⁺
• Opening other types of ion channels triggers a **depolarization**, a reduction in the magnitude of the membrane potential.

• For example, depolarization occurs if gated Na\(^+\) channels open and Na\(^+\) diffuses into the cell.
(b) Graded depolarizations produced by two stimuli that increase membrane permeability to Na⁺
Graded Potentials and Action Potentials

- **Graded potentials** are changes in polarization where the magnitude of the change varies with the **strength** of the stimulus.
  - These are not the nerve signals that travel along axons, but they do have an effect on the generation of nerve signals.
Action potentials

- If a **depolarization** shifts the membrane potential sufficiently, it results in a massive change in membrane voltage called an **action potential**
  - Action potentials have a constant magnitude, are **all-or-none**, and transmit signals over long distances
  - They arise because some ion channels are **voltage-gated**, opening or closing when the membrane potential passes a certain level
Figure 48.10c
(c) Action potential triggered by a depolarization that reaches the threshold
Generation of Action Potentials: A Closer Look

- An action potential can be considered as a series of stages
- At resting potential
  1. Most voltage-gated sodium (Na\(^+\)) channels are closed; most of the voltage-gated potassium (K\(^+\)) channels are also closed
1. At **resting potential**: Most voltage-gated *sodium* (Na$^+$) channels are **closed**; most of the voltage-gated *potassium* (K$^+$) channels are also **closed**.

![Diagram of membrane potential and ion channels](image)
• When an action potential is generated

2. Voltage-gated Na⁺ channels open first
• Allows Na⁺ flows into the cell
3. During the **rising phase**, the **threshold** is crossed, and the membrane potential increases.
Figure 48.11-3

**Key**
- **Na⁺**
- **K⁺**

1. **Resting state**
2. **Depolarization**
3. **Rising phase of the action potential**

**Sodium channel**
**Potassium channel**

**Outside of cell**
**Inside of cell**

**Membrane potential (mV)**
- Resting potential
- Threshold
- Rising phase of the action potential

**Time**

---

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3. During the **falling phase**, voltage-gated $\text{Na}^+$ channels become **inactivated**; voltage-gated $\text{K}^+$ channels **open**, and $\text{K}^+$ flows out of the cell.
Figure 48.11-4

1. Resting state
2. Depolarization
3. Rising phase of the action potential
4. Falling phase of the action potential

**Key**
- **Na⁺**
- **K⁺**

**Graph**
- Membrane potential (mV): +50, 0, -50, -100
- Time
- Action potential
- Threshold
- Resting potential
5. During the **undershoot**, membrane permeability to $K^+$ is at first higher than at rest, then voltage-gated $K^+$ channels close and resting potential is restored.
Inactivation loop

Action potential

Sodium channel

Potassium channel

Key

Na\(^+\)

K\(^+\)

Resting state

Depolarization

Rising phase of the action potential

Falling phase of the action potential

Resting potential

Threshold

Membrane potential (mV)

Time

OUTSIDE OF CELL

INSIDE OF CELL

Inactivation loop

1 Resting state

2 Depolarization

3 Rising phase of the action potential

4 Falling phase of the action potential

5 Undershoot

Figure 48.11-5

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Figure 48.11a

<table>
<thead>
<tr>
<th>Membrane potential (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+50</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>-50</td>
</tr>
<tr>
<td>-100</td>
</tr>
</tbody>
</table>

- **Action potential**
- **Threshold**
- **Resting potential**

**Time**
During the **refractory period** after an action potential, a second action potential cannot be initiated.

- The refractory period is a result of a temporary inactivation of the Na\(^+\) channels.
Animation: Action Potential
Right-click slide / select “Play”
Conduction of Action Potentials

- At the site where the action potential is generated, usually the axon hillock, an electrical current depolarizes the neighboring region of the axon membrane.

- **Action potentials** travel in only one direction: toward the **synaptic terminals**.
  - What stops an action potential from running up and down the axon?

- **Refractory Period**
  - Inactivated Na⁺ channels behind the zone of depolarization prevent the action potential from traveling backwards.
Figure 48.12-2

Action potential

Axon

Plasma membrane

Cytosol

1

Na⁺

2

K⁺

Na⁺

K⁺
Evolutionary Adaptation of Axon Structure

- The speed of an action potential increases with the axon’s diameter.
- In vertebrates, axons are insulated by a myelin sheath, which causes an action potential’s speed to increase.
- Myelin sheaths are made by glia—
  - oligodendrocytes in the CNS and
  - Schwann cells in the PNS.
Figure 48.13

Axon
Myelin sheath
Schwann cell
Nodes of Ranvier

Node of Ranvier
Layers of myelin
Axon
Schwann cell
Nucleus of Schwann cell

0.1 µm
• Action potentials are formed only at nodes of Ranvier, gaps in the myelin sheath where voltage-gated Na\(^+\) channels are found
  - Action potentials in myelinated axons jump between the nodes of Ranvier in a process called **Saltatory Conduction**
  • **Saltatory Conduction** increases the speed of nerve impulse
Concept 48.4: Neurons communicate with other cells at synapses

- At electrical synapses, the electrical current flows from one neuron to another.
- At chemical synapses, a chemical neurotransmitter carries information across the gap junction.
- Most synapses are chemical synapses.
- The presynaptic neuron synthesizes and packages the neurotransmitter in synaptic vesicles located in the synaptic terminal.
- The action potential causes the release of the neurotransmitter.
- The neurotransmitter diffuses across the synaptic cleft and is received by the postsynaptic cell.
Axon of sending neuron

Receiving cell

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Animation: Synapse
Right-click slide / select “Play”
Figure 48.15

- Presynaptic cell
- Postsynaptic cell
- Axon
- Synaptic vesicle containing neurotransmitter
- Postsynaptic membrane
- Synaptic cleft
- Voltage-gated Ca\(^{2+}\) channel
- Ligand-gated ion channels
- K\(^+\)
- Na\(^+\)
Generation of Postsynaptic Potentials

• Direct synaptic transmission involves binding of neurotransmitters to ligand-gated ion channels in the postsynaptic cell
• Neurotransmitter binding causes ion channels to open, generating a postsynaptic potential
Postsynaptic potentials fall into two categories

- **Excitatory postsynaptic potentials (EPSPs)** are depolarizations that bring the membrane potential toward threshold

- **Inhibitory postsynaptic potentials (IPSPs)** are hyperpolarizations that move the membrane potential farther from threshold
• After release, the neurotransmitter
  - May diffuse out of the synaptic cleft
  - May be taken up by surrounding cells
  - May be degraded by enzymes
Summation of Postsynaptic Potentials

- Most neurons have many synapses on their dendrites and cell body
- A single EPSP is usually too small to trigger an action potential in a postsynaptic neuron
Figure 48.17

Terminal branch of presynaptic neuron

Postsynaptic neuron

Axon hillock

Membrane potential (mV)

Threshold of axon of postsynaptic neuron

Resting potential

(a) Subthreshold, no summation

(b) Temporal summation

(c) Spatial summation

(d) Spatial summation of EPSP and IPSP

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Neurotransmitters

- There are more than 100 neurotransmitters
- **Acetylcholine** is a common neurotransmitter in vertebrates and invertebrates
  - Can be excitatory or inhibitory
  - It is involved in muscle stimulation, memory formation, and learning
- Other common neurotransmitters include
  - Epinephrine
  - Norepinephrine
  - Dopamine
  - Serotonin
  - GABA
<table>
<thead>
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<th>Neurotransmitter</th>
<th>Structure</th>
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<tr>
<td>Acetylcholine</td>
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<td><strong>Amino Acids</strong></td>
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<tr>
<td>GABA (gamma-aminobutyric acid)</td>
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<tr>
<td>Glutamate</td>
<td><img src="image" alt="Glutamate Structure" /></td>
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<tr>
<td>Glycine</td>
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<tr>
<td><strong>Biogenic Amines</strong></td>
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<td>Norepinephrine</td>
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<tr>
<td>Dopamine</td>
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<tr>
<td>Serotonin</td>
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</tr>
<tr>
<td><strong>Neuropeptides</strong></td>
<td>(a very diverse group, only two of which are shown)</td>
</tr>
<tr>
<td>Substance P</td>
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</tr>
<tr>
<td>Met-enkephalin (an endorphin)</td>
<td><img src="image" alt="Met-enkephalin Structure" /></td>
</tr>
<tr>
<td><strong>Gases</strong></td>
<td></td>
</tr>
<tr>
<td>Nitric oxide</td>
<td><img src="image" alt="Nitric oxide Structure" /></td>
</tr>
</tbody>
</table>
Action potential

Membrane potential (mV)

Rising phase

Falling phase

Threshold (-55)

Depolarization

Undershoot

Resting potential

Time (msec)

-100 -70 0 1 2 3 4 5 6

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Figure 48.UN03

$E_{Na}(+62)$

$E_{K}(-90)$

Threshold

mV

+100

+50

-50

-100

Time →
Think about evolution:

WHERE DID OUR NERVOUS SYSTEM COME FROM?
• Cnidarians have a neural net.
What is cephalization?

- **Cephalization** is a trend toward clustering sensory neurons and interneurons at the anterior end.
Flatworms, or planarians, show cephalization, with a small brain and longitudinal nerve cord. They have the simplest, clearly defined Central Nervous System.
A. Hydra (cnidarian)  B. Sea star (echinoderm)

ORGANISMS WITHOUT A CNS

C. Flatworm  D. Leech  E. Insect

ORGANISMS WITH A CNS

©Addison Wesley Longman, Inc.
• Annelids & arthropods have *ventral nerve cords*.
Evolutionary relationships of vertebrates.

This cladogram represents one phylogenetic interpretation of vertebrate phylogeny. As new data are collected and considered, our understanding of these relationships is likely to change. The vertebrates plus the Myxini make up the craniate clade. The evolution of several major changes in body plan is indicated.

KEY CONCEPT: This cladogram showing relationships among vertebrates provides a framework for understanding the evolution of vertebrate diversity and adaptations to aquatic and terrestrial environments. As new data are collected and considered, details of the cladogram will likely change.
• Vertebrates have a **hollow dorsal nerve cord**
How does the nervous system work?

• Simplest examples are reflexes:
  
  • Reflex: A simple automatic nerve circuit in response to a stimulus.
Question:

• What happens when you touch something hot and why?
Neural Communication: An example

- A **sensory neuron's dendrites** are **stimulated** by a noxious (harmful) **stimulus** (such as contact with a hot object), it sends messages down the **axon** to the **synaptic terminal**, which are located in the **spinal cord**.

- The **synaptic terminal** of the **sensory neuron** release a **neurotransmitter** that **excites** the **interneuron**, causing it to send messages down its **axon**.

Read this and tell me which words we need to review.
Neural Communication: An Overview

• The synaptic terminal of the interneuron release a neurotransmitter that excites the motor neuron, which sends messages down its axon.

• The axon of the motor neuron joins a nerve and travels to a effector muscle.

• When the synaptic terminal of the motor neuron release their neurotransmitter, the muscle cells contract, causing the hand to move away from the hot object.
Figure 2.10  
**A Withdrawal Reflex.** The figure shows a simple example of a useful function of the nervous system. The painful stimulus causes the hand to pull away from the hot iron.
Knee-Jerk-Reflex

**Sensory Neurons - Afferent Neurons**
- Carry the message from the sense organs to the CNS

**Interneurons**
- Make up the CNS

**Motor Neurons - Efferent Neurons**
- Carry the message from the CNS to the muscles or glands

**Remember - SAME**
(sensory = afferent, motor = efferent)
Organization of the Nervous System

THE NERVOUS SYSTEM

Central Nervous System

1

Peripheral Nervous System

2

Autonomic Nervous System

3

Blood Vessels, Glands, Internal Organs

4

Skeletal Muscles
The Brain
The brain’s cushion: Cerebrospinal Fluid (SPF)

• The brain is very soft and jellylike.

• The weight of a human brain (approximately 1400 g (3Lbs)), along with its delicate construction, necessitates that it be protected from shock.
  - The brain is well protected because it floats in a bath of CSF contained within the subarachnoid space.
  - CSF can also be found within the brain in hollow structures known as ventricles.
FIGURE 3.4
The Ventricular System of the Brain. The figure shows (a) a lateral view of the left side of the brain and (b) a frontal view.
White & Gray Matter

- **Gray matter** - areas of the CNS with high concentrations of cell bodies; outer surface of cerebrum (cerebral cortex)

- **White matter** - areas of the CNS with mostly myelinated axons; inner part of cerebrum

- **Glial cells** - cells in the brain that nourish and protect neurons
Figure AB-7: Forebrain / Midbrain / Hindbrain
Hindbrain - Cerebellum

- Controls **balance** and **coordination**
- In the **rear of the head**, behind the brainstem
Hindbrain - Brain Stem

- **Medulla** - where spinal cord meets the skull; controls heartbeat and breathing
- **Pons** - above the medulla, this also controls involuntary functions.
- In general, the brain stem controls homeostatic function such as breathing rate, regulates sleep and arousal, and conducts sensory and motor signals between the brain and spinal cord.
What did you just learn?

1. Areas of the **CNS** with high concentrations of **cell bodies**; outer surface of cerebrum.
2. Areas of the **CNS** with mostly **myelinated axons**; inner part of cerebrum.
3. Where spinal cord meets the skull; controls heartbeat and breathing **Medulla**
4. Located about the medulla **pons**
5. The answers to 3 & 4, along with the reticular formation make up the **Brain stem**

Dorsal (above) to the brain stem is the **thalamus**
Arousal and Sleep

- The brainstem and cerebrum control arousal and sleep
  - The core of the brainstem has a diffuse network of neurons called the **reticular formation**
  - These neurons control the timing of sleep periods characterized by rapid eye movements (REMs) and by vivid dreams
  - Sleep is also regulated by the **biological clock** and regions of the forebrain that regulate intensity and duration
Figure 49.12

Eye

Reticular formation

Input from touch, pain, and temperature receptors

Input from nerves of ears
Arousal and Sleep

- Sleep is essential
  - may play a role in the consolidation of learning and memory
  - Dolphins sleep with one brain hemisphere at a time and are therefore able to swim while “asleep”

Key

- Low-frequency waves characteristic of sleep
- High-frequency waves characteristic of wakefulness

<table>
<thead>
<tr>
<th>Location</th>
<th>Time: 0 hours</th>
<th>Time: 1 hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left hemisphere</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right hemisphere</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Biological Clock Regulation

- Cycles of sleep and wakefulness are examples of **circadian rhythms**, daily cycles of biological activity
  - Such rhythms rely on a **biological clock**, a molecular mechanism that directs periodic gene expression and cellular activity
  - Biological clocks are typically synchronized to light and dark cycles
In mammals, circadian rhythms are coordinated by a group of neurons in the hypothalamus called the suprachiasmatic nucleus (SCN).

The SCN acts as a pacemaker, synchronizing the biological clock.
Emotions

- Generation and experience of emotions involve many brain structures, including the amygdala, hippocampus, and parts of the thalamus.
- These structures are grouped as the limbic system.
Thalamus

- **RELAY STATION**
- Pair of egg-shaped organs above the brainstem; receives information from the senses (EXCEPT FOR SMELL) and relays it to the rest of the brain.

What brain structure links the nervous system with the endocrine system? It is located below the thalamus.
Forebrain: Limbic System

- **Hypothalamus** - below the thalamus; regulates hunger, thirst, body temp, sex, fight-or-flight; triggers the **pituitary** (the “master gland”); reward center

- **Amygdala** -
  - storage of **emotion** in the memory
  - influences **fear** and **aggression**

- **Hippocampus** -
  - consolidation of long term **memory**
Forebrain: Cerebrum

Cerebrum - The largest division of the brain. It is divided into two hemispheres, each of which is divided into four lobes.

http://williamcalvin.com/BrainForAllSeasons/img/bonoboLH-humanLH-viaTWD.gif
Forebrain: Cerebrum

Cerebral Cortex - The outermost layer of gray matter making up the superficial aspect of the cerebrum.

Figure 49.16

- Motor cortex (control of skeletal muscles)
- Somatosensory cortex (sense of touch)
- Sensory association cortex (integration of sensory information)
- Frontal lobe
- Parietal lobe
- Prefrontal cortex (decision making, planning)
- Visual association cortex (combining images and object recognition)
- Occipital lobe
- Auditory cortex (hearing)
- Wernicke’s area (comprehending language)
- Cerebellum
- Visual cortex (processing visual stimuli and pattern recognition)

- Broca’s area (forming speech)
Which structure (bundle of nerves) links the 2 hemispheres of the brain?

- The corpus callosum
Review

- Made up of the medulla oblongata, pons, and midbrain. Controls homeostatic functions such as breathing rate, conducts sensory and motor signals between the spinal cord and higher brain centers, and regulates sleep and arousal.

**Brain stem**

- Helps to coordinate motor/balance, perceptual, and cognitive functions

**Cerebellum**

- Main center through which sensory and motor information passes to and from the cerebrum

**Thalamus**
Review

- Regulates homeostasis; basic survival behaviors such as the “4 F’s” feeding, fighting, fleeing, and reproducing; also works as a thermostat, appestat, thirst center, and circadian rhythms.

  **hypothalamus**

- Has two hemispheres, each with a covering of gray matter over white matter. Information processing is centered here. This region is greatly expanded in mammals.

  **Cerebrum**

- Controls voluntary movement and cognitive function.

  **Cerebral Cortex**

- A thick band of axons that enables communication between the right and left hemisphere.

  **Corpus Callosum**
The ion concentrations the researchers recorded for the squid giant axon are listed in the table below.

<table>
<thead>
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<th>Extracellular (mM)</th>
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<tbody>
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<td>Potassium (K(^+))</td>
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Some of these ion concentrations for the human are listed in the table below.

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Using the Nernst equation, your textbook calculates that in humans the equilibrium potential for potassium is $-90$ mV and that for sodium is $+62$ mV.

What are the equilibrium potentials for potassium and sodium for the squid?

The Nernst Equation $E_{\text{ion}} = \frac{62 \text{mV}}{z} \log \frac{[\text{ion}]_{\text{out}}}{[\text{ion}]_{\text{in}}}$ \hspace{1cm} z = \text{ion valance} \hspace{1cm} (e.g., Na = +1, Cl = −1)
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$E_K = \frac{62}{1} \times \log(20/400) = -80 \text{ mV}$

$E_{Na} = \frac{62}{1} \times \log(440/50) = +58 \text{ mV}$

Values in this range are typical for most neurons. The difference in actual concentrations of the ions (human system vs. squid) can be accounted for because the squid is a marine organism and the sodium and potassium concentrations in the ocean are approximately 469 mM and 10 mM, respectively.
4. In a typical neuron, which ion has the greatest influence on the membrane potential at rest? In other words, flux of which ion contributes the most to the resting membrane potential? Explain why this occurs.

At rest almost all sodium voltage-gated channels are closed. However, while most of the potassium voltage-gated channels are closed, some potassium channels are open. As a result, potassium can move down its chemical concentration gradient out of the axon. However, the resting potential is seldom equal to the equilibrium potential for potassium because the outward flow of potassium is counterbalanced by the electric potential difference set up that is the result not only of the potassium gradients but also of the anion and other cation gradients. In addition, some very small amount of sodium does leak across (out to in) down its concentration gradient.
5. In calculating the resting and action potentials of the axon, we generally don’t worry about the concentration differences of calcium or chloride ions. Explain.

The concentration differences are set up by active transport of the ions across the neuron membranes. The same is true for all such concentration differences. In general, we are not concerned with the concentration differences of calcium and chloride ions because the neuron membrane is essentially impermeable to these under normal conditions.

6. What effects would the following changes in extracellular $K^+$ concentration be likely to have on the resting membrane potential of neurons in a human?
   a. Change extracellular $K$ from 5 mM to 2 mM
      
      \[
      E_{K^+} = \frac{62}{1} \times \log(2/140) = -113 \text{ mV}
      \]
      This would hyperpolarize the cells, making it more difficult to generate an action potential.

   b. Change extracellular $K$ from 5 mM to 10 mM
      
      \[
      E_{K^+} = \frac{62}{1} \times \log(20/140) = -52 \text{ mV}
      \]
      The normal potassium equilibrium potential is $-90 \text{ mV}$. Changing the external potassium concentration to 20 mM would most likely change the equilibrium potential enough to bring it above threshold. As a result, all neurons in the body would fire and death would be the result. *(Note: Death by lethal injection often involves sedatives and muscle relaxers in combination with intravenous delivery of a high concentration of potassium.)*