Chapter Eight

Nerves

In the next four chapters we will be looking at the single most important system in our bodies that help to maintain homeostasis:

The Nervous System

The main functions of this vital system are to receive signals concerning what is going on inside and outside our bodies (**perception**); to sort and direct these signals to other areas of the body (**integration**); and, to manage the responses of the organ systems to these signals.

Think about how fast we can react to a stimulus such as a baseball being thrown at us. Much like the aquarium story we explored back in Chapter One, our bodies contain receivers (which we will learn about this week), which send signals to a control center (known as the **Central Nervous System** or **CNS**), so that the effectors (again, this is what you will explore this week) will respond to what the control center tells it to do. And all of these actions have to occur very fast or that baseball that is moving closer towards your head is going to hurt a lot!

In order to understand the functions of the nervous system, we need to look at its most basic structure:

The Nerve Cell

The nerve cell (neuron) is very similar to most of the 50-100 trillion cells in your body. They are surrounded by a cell membrane, contain DNA, and carry out many of the normal processes of regular cells.

However, there are two very important differences between neurons and the other cells within your body...

Structure and Signaling

In terms of structure, neurons are the longest cells in the human body. Some of these individual cells can reach over three feet in length! A typical neuron consists of a branched end known as the **soma** which contains the cell nucleus. Each of the branches spreading out from the soma are known as **dendrites** and are structures which receive an incoming stimulus. A long slender body known as the **axon** extends from the soma as well. Axons take information away from the soma and move them towards the central nervous system. In a little bit we will talk about how these "messages" are sent; however, we still need a little more information about the structure of a nerve cell.

First of all, the axons of nerve cells tend to be packed together like a cable into long strands which we call **nerves**. And...

Nerves are classified by the direction in which they send information:

Sensory (or **afferent**) **nerves**: Send information from sensory receivers (e.g., in skin, eyes, nose, tongue, ears) TOWARD the central nervous system.

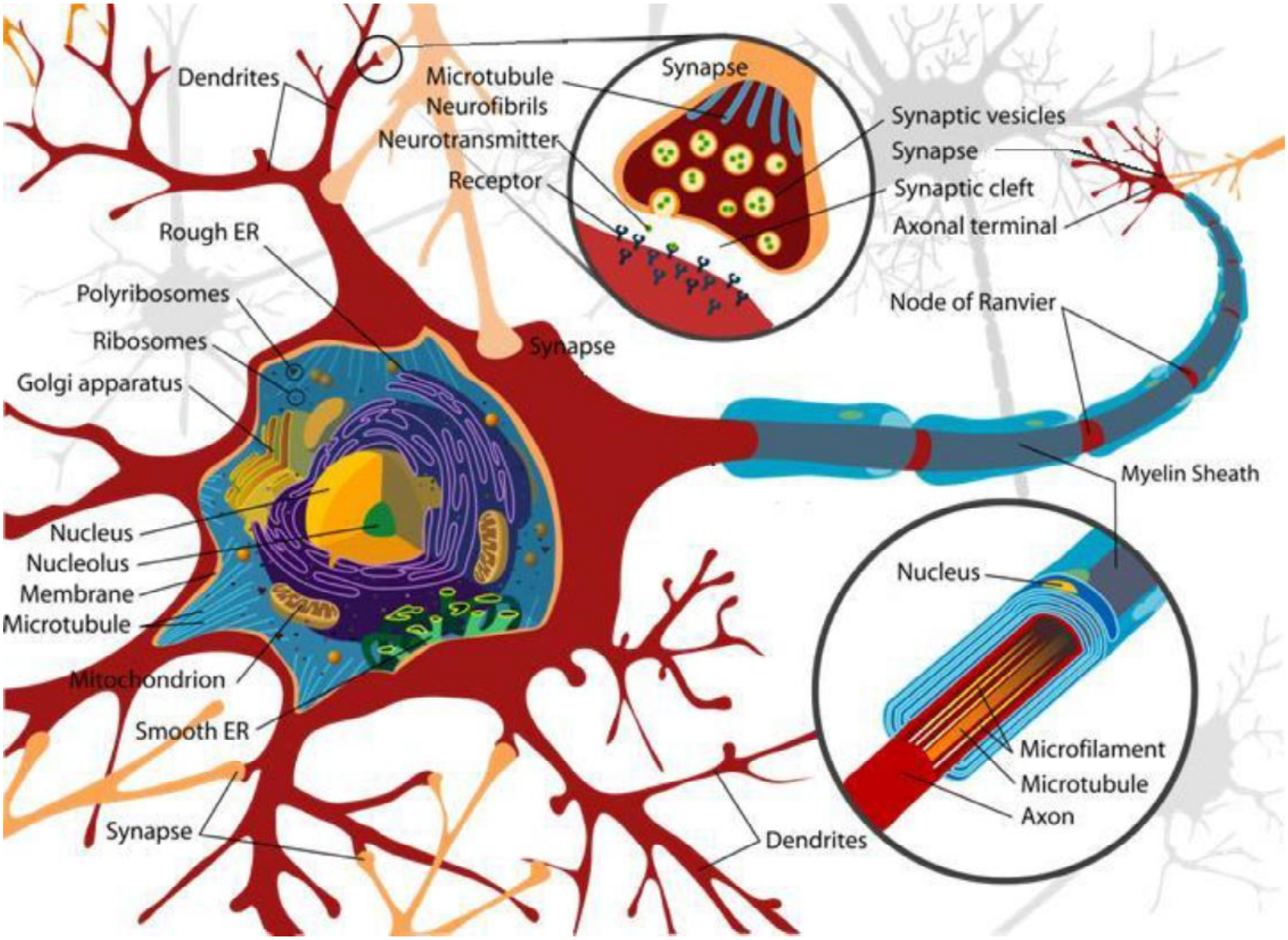
Motor (or **efferent**) **nerves**: Send information AWAY from the central nervous system to the effectors (e.g. muscles or glands.)

If you need a little help keeping all this in your memory, try this little device:

Afferent connections arrive, and efferent connections exit.

Dendrites deliver impulses while axons send them away.

The Anatomy of a Neuron



Now what about these "messages" sent by neurons?

This next section deals with how neurons differ from ordinary cells in the body in terms of how they signal other cells. Neurons communicate with each other through an **electrochemical process**. This means that chemicals cause an electrical signal to be sent through your nerve cells. How can this happen?

Well, to understand this you have to understand one basic thing about electricity…

The movement of electrons causes electricity to occur!

Nearly all objects we come into contact with in the world are electrically neutral at rest. This means the amount of positively-charged particles (**protons**) within an object is roughly identical to the amount of negatively-charged particles (**electrons**) as well. However, there is another fact within the universe which states that nothing every really stays at rest. This is true for the protons, but it is especially true for the electrons as they are over 1800 times smaller than protons and constantly in motion!

Here's what all this has to do with our neurons…

Two important elements in the human body (sodium and potassium) have the ability to lose one of their negatively-charged electrons spinning around their nuclei. When this happens, these elements become a little more positively-charged. Whenever an element loses or gains one or more electrons it is known as an **ion**. The symbol for a sodium ion is $\mathbf{Na}^{+}$ while the symbol for the potassium ion is $\mathbf{K}^{+}$. By moving a huge amount of these charged particles in and out of a neuron, the charge of the cell can be changed from being electrically neutral to electrically positive or negative. As a nerve cell becomes more negatively charged, it drives electrons along the axon of the nerve cell causing an electric current to flow!

Don't forget! Neurons are just like ordinary cells. As you learned in Chapter 2, the cell membrane around these cells are semipermeable which means they can control which substances (like ions) are allowed in and out of the cell.

You probably noticed the words "at rest" in the above few paragraphs were underlined. Here's why...

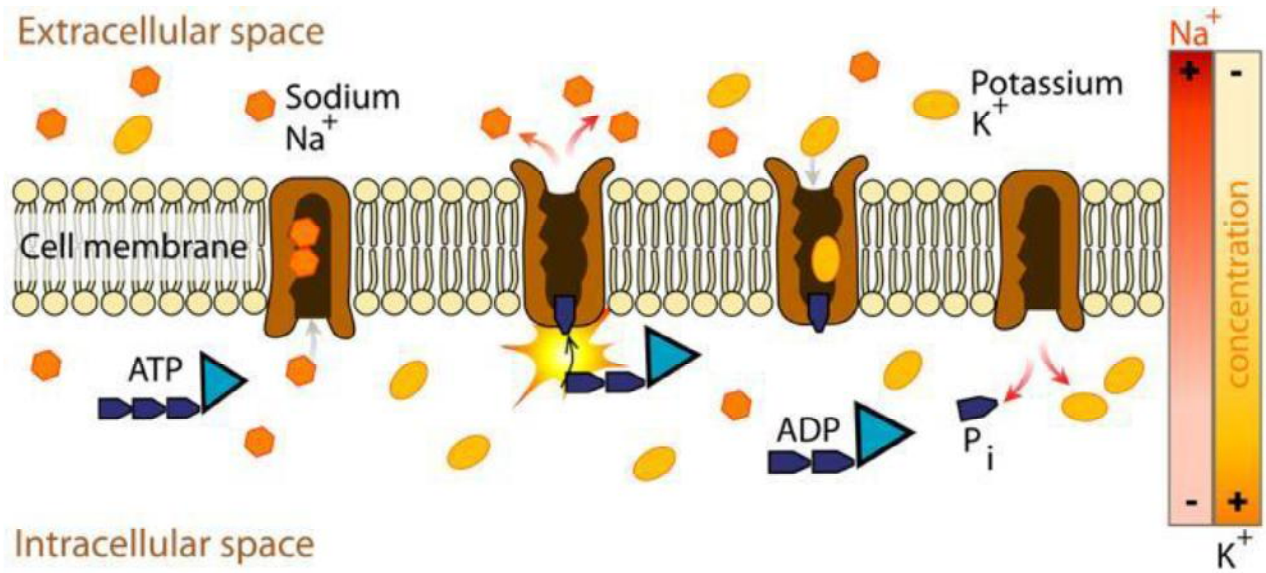
When a neuron is not sending a signal, it is "at rest" and contains a slightly negative charge as compared to its outside environment. This occurs because many of the particles within the neuron contain an abundance of electrons and maintain a negative charge. These particles cannot pass through the neuron's membrane because of its semipermeable nature.

A more thorough explanation of this would be...

At rest, there are relatively more sodium ions outside the neuron and more potassium ions inside a neuron. If you were to calculate all of the ion charges that exist on both sides of the cell membrane of a neuron, you would find that the internal environment of a neuron is more electrically negative than its surroundings. The semipermeable nature of the membrane is maintained by active transport, diffusion, and filtration systems (these later two are collectively referred to as *passive transport systems*). Diffusion and filtration systems allow ions to *passively* move through the cell membrane of the neuron through openings along the surface of the neuron. In contrast, *active* transport systems along each neuron (known as **sodium/potassium pumps)** use chemical energy (ATP) to move three sodium ions out of the neuron for every two potassium ions it allows in.

The bottom line is this... When you measure all of the charges within a neuron, it remains electrically negative at rest. This charge is known as the **resting potential**.

Sodium/Potassium Pump



Within the sodium/potassium pump, the chemical known as ATP (adenosine triphosphate) loses one of its three phosphate ions which allows for the release of energy to drive three sodium ions out of the cell for every two potassium ions it allows in. After losing one of its phosphates, ATP becomes the molecule known as ADP (adenosine diphosphate.)

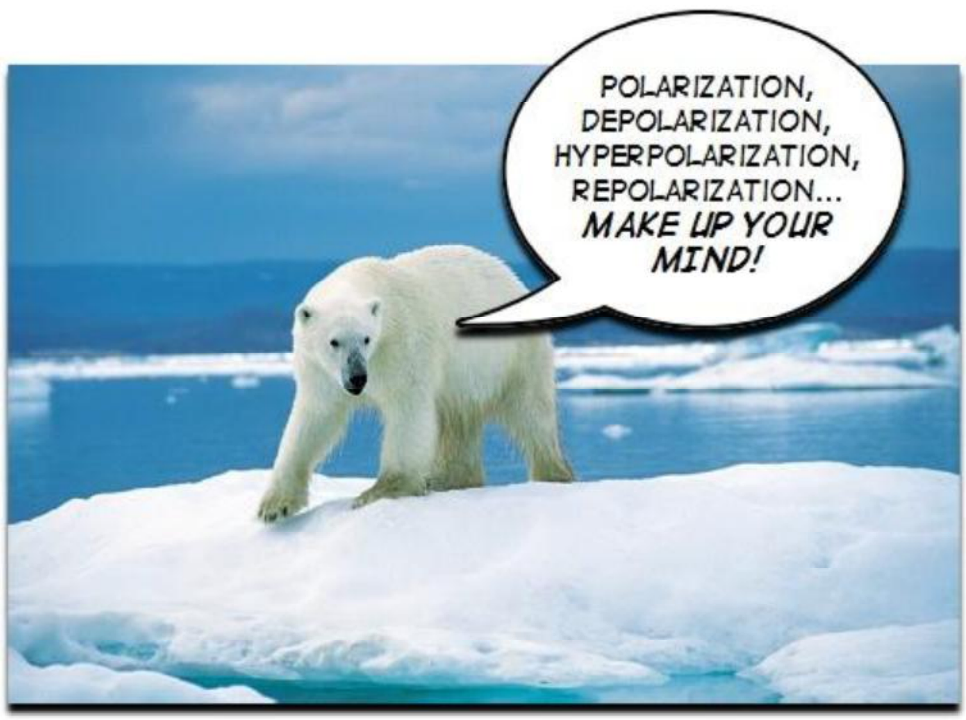
So what happens when a neuron is not "at rest"?

When a neuron is not at rest, a series of actions occur which result in a nerve impulse and is the "signal" or "message" we have been talking about throughout this chapter. A nerve impulse has five steps:

Polarization, Depolarization, Repolarization, Hyperpolarization, and the Refractory period

We've already discussed this first step. The **polarization** stage of a neuron exists when the electrical charge on the outside of the neuron is positive while the electrical charge on the inside of the membrane is negative. At this time, an abundance of sodium ions can be found outside the neuron as compared to the inside. The unbalanced negative charge of the neuron at rest is thereby known as its resting potential.

When the dendrites of a cell receive a stimulus, they allow a large amount of sodium ions to enter the cell. This begins a series of actions known collectively as an **action potential**. As a wave of positively-charged sodium ions enters the neuron, it ceases to be polarized (negatively charged) and begins to move more towards a positive charge (known as **depolarization**.)



Perhaps this visual will help:

Imagine a long hallway filled with doors of two different sizes - large and small. During the action potential, the smaller doors would continue to open, one-after-another, like a domino effect, allowing sodium ions to fill up the hallway.

This "hallway" symbolizes the axon of the nerve cell.

As each of these smaller doors open and sodium ions begin to enter the hallway at one end, the larger doors open and the larger potassium ions begin to leave the hallway (neuron) as well. Once the potassium ions pass through the doorway, the large doors close behind them along with the smaller doors nearby. This action triggers the opening of adjacent small and large doors farther down the hallway. This results in a wave-like effect of incoming sodium ions and departing potassium ions.

The movement of the larger positively-charged potassium ions from the inside of the cell begins to lower the now positively-charged cell back to a more negative charge. This process is known as **repolarization** and continues until too many potassium ions have escaped the cell, causing the internal charge of the neuron to be way too negative! At this stage, the neuron is said to be **hyperpolarized**.

With more potassium ions outside the cell rather than inside, the neuron is not even close to being at rest!

This is when the sodium/potassium pump gets to work! Through active transport, this pump drives three sodium ions out of the neuron for every two potassium ions it allows back in. During this time (known as the **refractory period**) a neuron can no longer send any more signals through its axon until it has reached its resting potential once again and the number of sodium ions outside the cell is in greater quantity than the number of potassium ions inside the cell. Once this is completed, the nerve cell can receive another stimulus and send another electrochemical signal down its axon.

How quickly do nerve impulses travel?

This question depends on a particular substance you first read about back in Chapter 2 – myelin. This lipid protects and insulates the axon much like the rubber/vinyl covering protects and insulates an electrical wire. This analogy is not entirely perfect as gaps exist within the myelin covering along the axon.

These gaps are very important as they regulate the speed of a nerve impulse!

As previously described, sodium and potassium ions move in and out of a neuron through a wave of doors opening and closing along the length of an axon. This occurs within nerve cells containing no myelin covering. However, the presence of myelin blocks many doors along its length. A few doors can open, then several are blocked by myelin, then another row of doors are allowed to open and so on. The few doors that are allowed to open, therefore, permit a faster rush of ions to be moved through the axon.

Imagine a crowd of people surrounding a stadium and attempting to get through one of many gates. What would happen if only a third of the gates were opened? People would crowd through the available openings at a much faster rate! This is very similar to the movement of sodium and potassium ions passing through the neuron's cell membrane along a myelinated axon.

Therefore, the speed in which the nerve impulse can perform is much greater! Here are some numbers for you...

The slowest nerve impulses travel at 1.7 miles per hour (2.7 km/hr) in small unmyelinated nerve cells.

Nerve impulses in large myelinated neurons can travel at 269 miles per hour (433 km/hr) or faster!

What happens when the nerve impulse reaches the end of the cell?

Much like reaching a dead end in a road, a nerve impulse would not travel very far at all if it could not find its way into other nerve cells. The location where two nerve cells meet and transmit signals to each other are known as **synapses.** Every synapse requires the action of two cells: the **presynaptic neuron** and the **postsynaptic neuron**. The presynaptic neuron is the cell that sends the message, while the postsynaptic neuron is the cell that receives the message. Some synapses allow the electrochemical signal to jump from one neuron to another in areas known as **gap junctions**. In other parts of the body, neurons communicate with other neurons or to muscle tissue by releasing chemicals called **neurotransmitters**. In short, presynaptic neurons release transmitters which influence receptors on the postsynaptic neurons or muscle tissue to create a response to a stimulus.

You have gathered a lot of information about how an individual nerve cell gathers information and sends a signal. Now you need to learn where this signal ends up! Next stop...

The Central Nervous System

Match the following vocabulary terms with their correct definition:

action potential	**integration**	**proton**
axons	**ion**	**refractory period**
Central Nervous System	**motor nerves**	**repolarization**
dendrites	**nerves**	**resting potential**
depolarization	**neurotransmitters**	**sensory nerves**
electrochemical process	**perception**	***sodium/potassium pumps***
electron	**polarization**	**soma**
gap junctions	**postsynaptic neuron**	**synapses**
hyperpolarized	**presynaptic neuron**	

1) ______________ a long cable-like bundle of nerve cell axons

2) ______________ a series of actions during a nerve impulse in which a large amount of sodium ions enter the cell after the dendrites receive a stimulus

3) ______________ active transport system which uses energy to move three sodium ions out of the neuron for every two potassium ions it allows in

4) ______________ an element which has lost or gained one or more electrons

5) ______________ areas between synapses in which an electrochemical system can jump from one neuron to another

6) ______________ cell body of a nerve cell

7) ______________ chemical which allow for neurons to communicate with other neurons

8) ______________ control center of the nervous system; consisting of the brain and spinal cord

9) ______________ electrically negative charge of all neurons

10)	____________	method of communication between neurons in which chemicals are released thereby triggering a nerve impulse
11)	____________	negatively-charged particle within an atom; 1800+ times smaller than a proton
12)	____________	period of time after repolarization when an excess of potassium ions have left the neuron causing it to become more negative
13)	____________	period of time during a nerve impulse in which a neuron can no longer send any more signals along its neuron before its resting potential is reached once again
14)	____________	period of time during a nerve impulse when waves of positively-charged sodium ions enters the neuron; this causes the neuron to become more positively charged
15)	____________	proton-charged particle within an atom
16)	____________	send information AWAY from the central nervous system to the effectors (e.g. muscles or glands)
17)	____________	send information from sensory receivers (e.g., in skin, eyes, nose, tongue, ears) TOWARD the central nervous system
18)	____________	special structures extending from the surface of nerve cells which receive a stimulus
19)	____________	special structures within a nerve cell which move nerve impulses towards the CNS
20)	____________	stage of a neuron in which the electrical charge on the outside of the neuron is positive while the electrical charge on the inside of the membrane is negative
21)	____________	stage within a nerve impulse when the movement of positively-charged ions from the inside of the cell begins to lower the positively-charged cell back to a more negative charge

22)	______________	the cell that receives the message from the presynaptic neuron
23)	______________	the cell which sends a message
24)	______________	the location where two nerve cells meet and transmit signals to each other
25)	______________	the receiving of signals concerning what is going on inside and outside the body
26)	______________	the sorting and directing of signals to other areas of the body

Choose the correct answer from the following questions:

1) **The areas of a neuron that typically receives incoming stimuli are called:**
   A) soma
   B) dendrites
   C) gap junctions
   D) synapses
   E) axons

2) **The diffusion of potassium ions out of a neuron causes it to experience:**
   A) repolarization
   B) an action potential
   C) a nerve impulse
   D) a depolarization

3) **The conduction of nerve impulses is fastest in neurons that are:**
   A) sensory
   B) unmyelinated
   C) cerebral
   D) motor
   E) myelinated

4) **A chemical that is released from presynaptic neurons to create a nerve impulse is called:**
   A) an ion
   B) an action potential
   C) the sodium-potassium pump
   D) a neurotransmitter

5) Afferent nerves are called __________, and motor nerves are called __________.

A) peripheral nerves; cranial nerves
B) sensory nerves; efferent nerves
C) cranial nerves; peripheral nerves
D) motor nerves; sensory nerves
E) mixed nerves; motor nerves

6) An action potential is caused by an influx of these ions into the cell:

A) both potassium and sodium
B) potassium
C) sodium
D) magnesium
E) calcium

Application Question:

Lithium ions reduce the ability of sodium ions (Na^+) to pass through the membrane of a cell. Predict the effect lithium ions in the extracellular fluid (fluid found outside of a neuron) would have on the response of a neuron to stimuli.