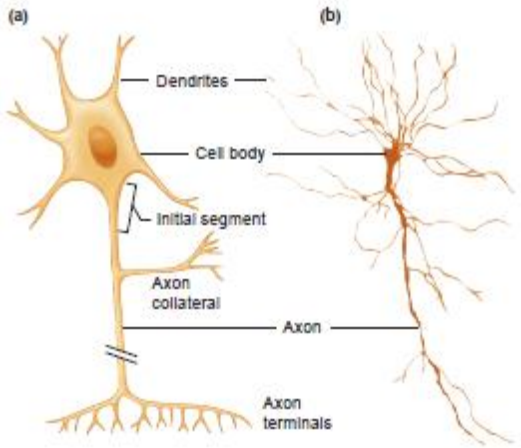
Nervous System: Neuronsand Action Potentials

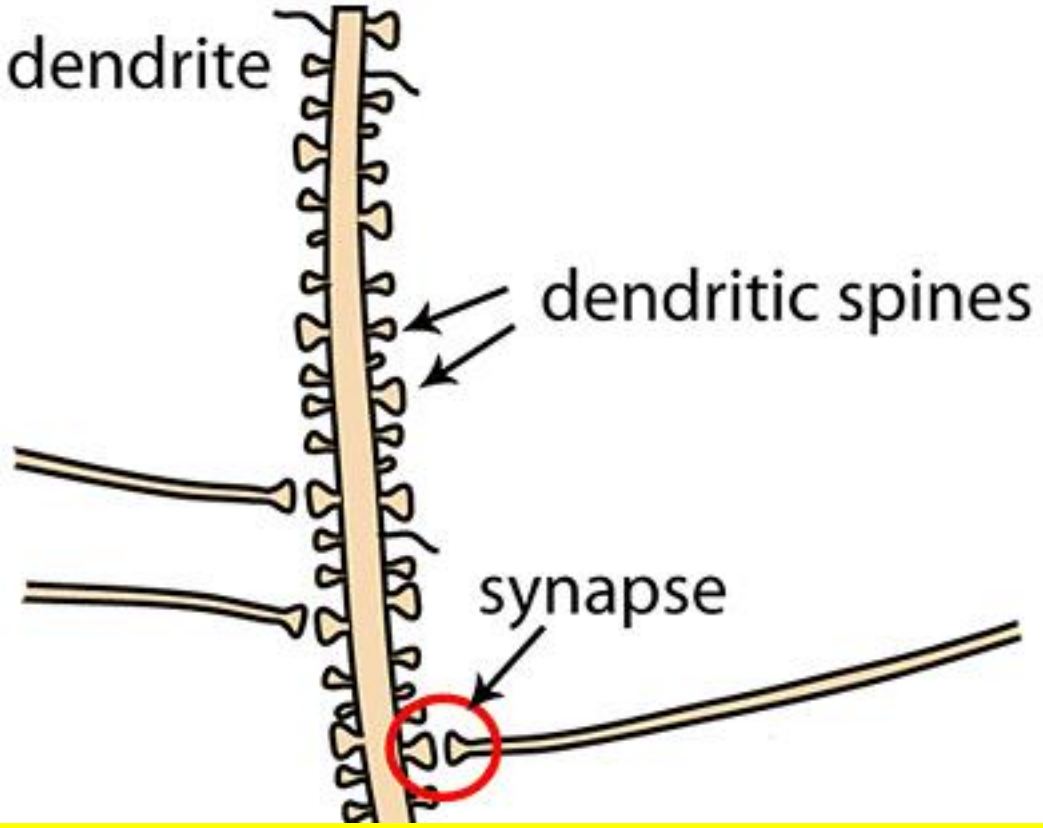
Physiology 2nd class

Structure and Maintenance of Neurons

Neurons occur in a wide variety of sizes and shapes, but all share features that allow cell-to-cell communication. Long extensions, or **processes,** connect neurons to each other and perform the neurons' input and output functions. Most neurons contain a cell body and two types of processes—dendrites and axons.

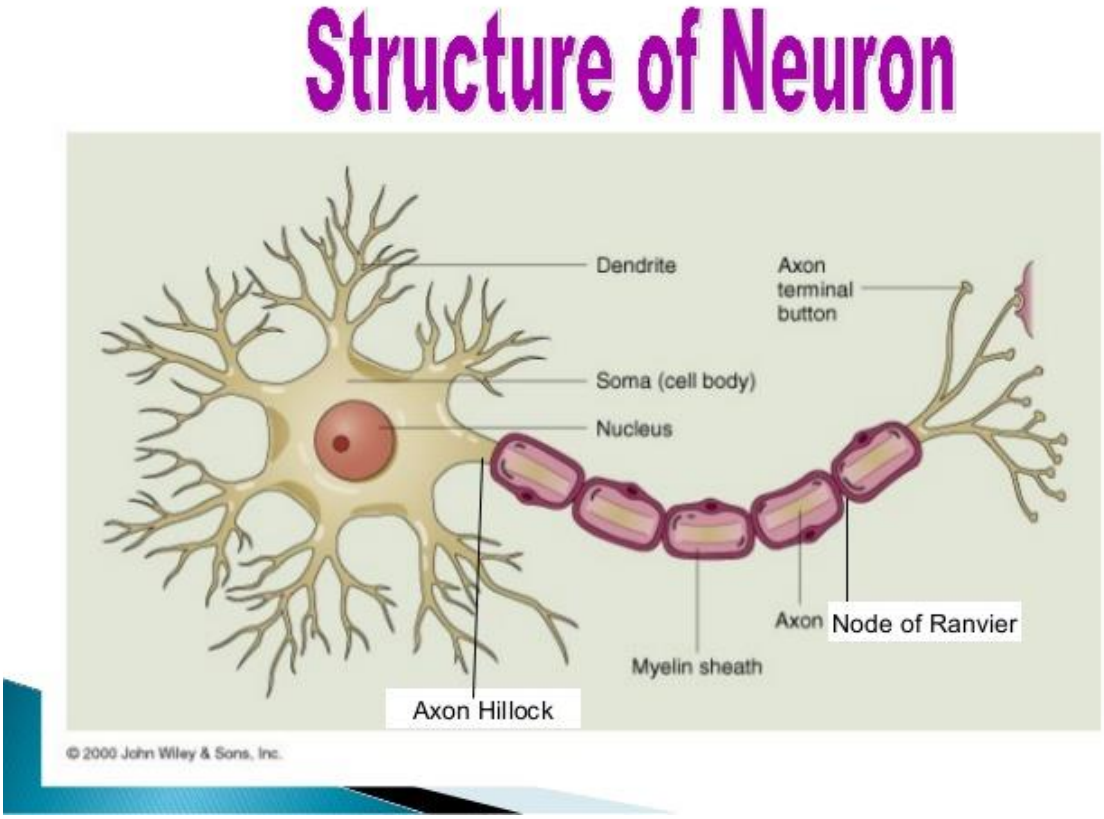


As in other types of cells, a neuron's **cell body** (or **soma**) contains the nucleus and ribosomes and thus has the genetic information and machinery necessary for protein synthesis. The **dendrites** are a series of highly branched outgrowths of the cell body. In the PNS, dendrites receive incoming sensory information and transfer it to integrating regions of sensory neurons. In the CNS, dendrites and the cell body receive most of the inputs from other neurons. Branching dendrites increase a cell's surface area—some neurons may have as many as 400,000 dendrites. There are outgrowths called **dendritic spines ((A dendritic spine** (or **spine**) is a small membranous protrusion from a neuron's **dendrite** that typically receives input from a single axon at the synapse.**Dendritic spines** serve as a storage site for synaptic strength and help transmit electrical signals to the neuron's cell body)).increase the surface area of dendrites still further, and there are often ribosomes present.

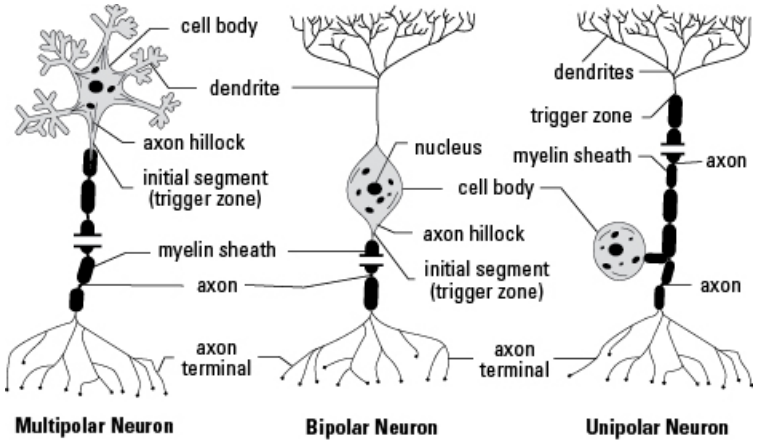


The presence of protein synthesis machinery allows dendritic spines to remodel their shape in response to variation in synaptic activity, which may Thus, the structure of dendrites in the CNS increases a cell'scapacity to receive signals from many other neurons.

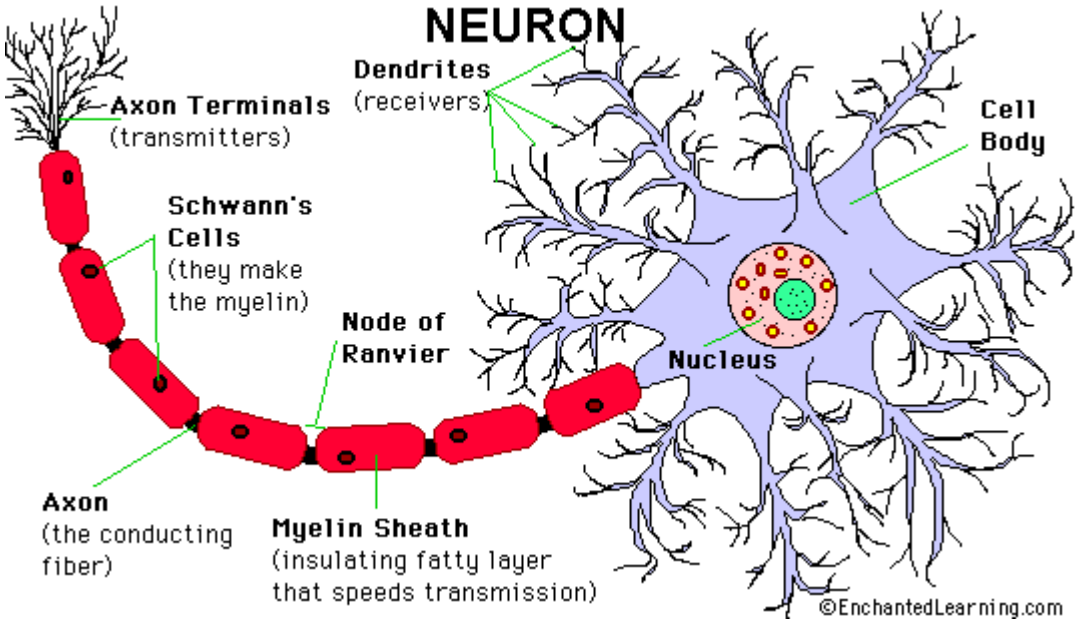
The **axon,** sometimes also called a **nerve fiber,** is a long process that extends from the cell body and carries outgoing signals to its target cells. In humans, axons range in length from a few microns to over a meter. The region of the axon that arises from the cell body is known as the **initial segment** (or **axon hillock**).



The initial segment is the "trigger zone" where, in most neurons, propagated electrical signals are generated. These signals then propagate away from the cell body along the axon or, sometimes, back along the dendrites.



Each branch ends in an **axon terminal,** which is responsible for releasing neurotransmitters from the axon. These chemical messengers diffuse across an extracellular gap to the cell opposite the terminal. The axons of many neurons are covered by sheaths of **myelin**, which usually consists of 20 to 200 layers of highly modified plasma membrane wrapped around the axon by a nearby supporting cell. In the brain and spinal cord, these myelin-forming cells are the **oligodendrocytes** **الخلايا المكونه لهذا الغلاف الدهني.**



Each oligodendrocyte may branch to form myelin on as many as 40 axons. In the PNS, cells called **Schwann cells** form individual myelin sheaths surrounding 1- to 1.5-mm-long segments at regular intervals along some axons. The spaces between adjacent sections of myelin where the axon's plasma membrane is exposed to extracellular fluid are called the **nodes of Ranvier.**

The myelin sheath speeds up conduction of the electrical signals along the axon and conserves energy. To maintain the structure and function of the

cell axon, various organelles and other materials must move as far as 1 meter between the cell body and the axon terminals. This movement, termed **axonal transport,** ((is a cellular process responsible for movement of mitochondria, lipids, synaptic vesicles, proteins, and other cell parts (i.e. organelles) to and from a neuron's cell body, through the cytoplasm of its **axon))** depends specialized types of motor proteins known as **kinesins** and **dyneins**.

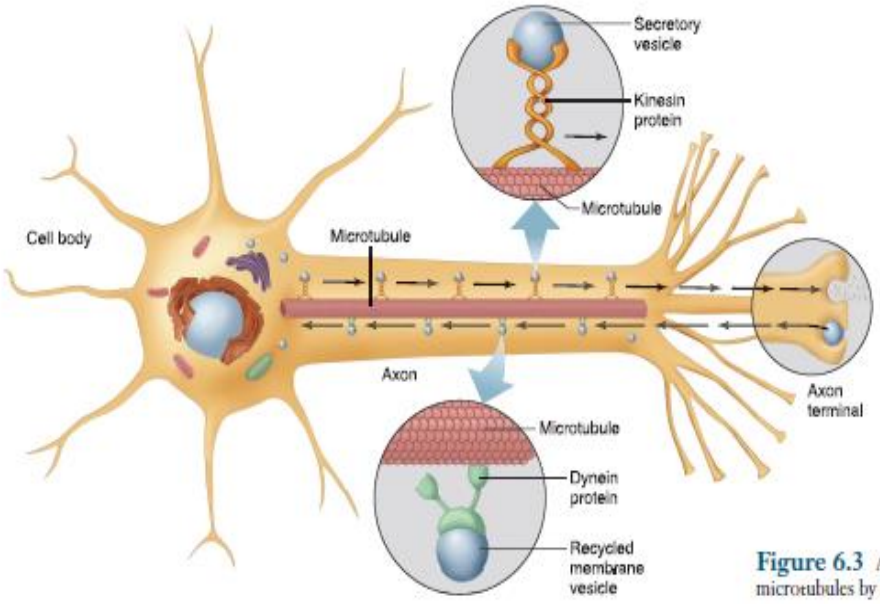
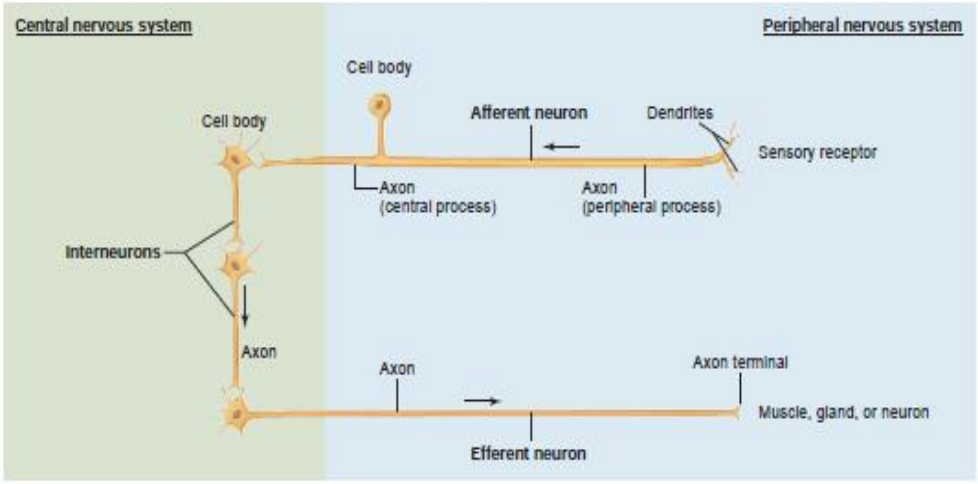


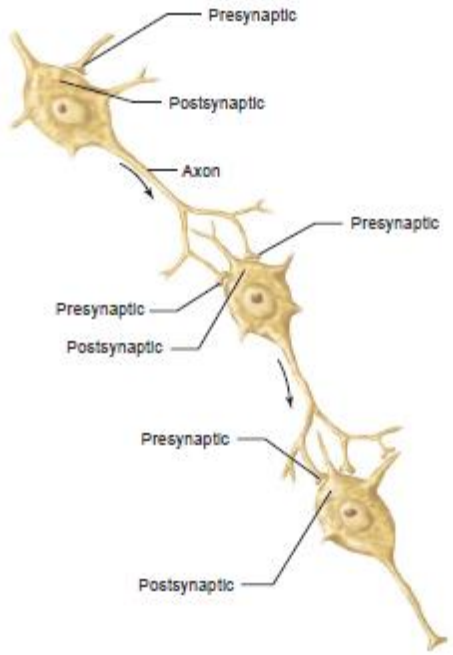
Figure 6.3 Axonal transport along microtubules by dynein and kinesin.



Kinesin transport mainly occurs from the cell body toward the axon terminals (**anterograde**) and is important in moving nutrient molecules, enzymes, mitochondria, neurotransmitter-filled vesicles, and other organelles. Dynein movement is in the other direction (**retrograde**), carrying growth factors, and other chemical signals that can affect the neuron's morphology, biochemistry, and connectivity. Retrograde transport is also the route by which some harmful agents invade the CNS, including tetanus toxin and the herpes simplex, rabies, and polio viruses.

Functional Classes of Neurons

Neurons can be divided into three functional classes: afferent neurons, efferent neurons, and interneurons.



Afferent neurons convey information from the tissues and organs of the body *toward* the CNS. **Efferent neurons** convey information *away from* the CNS to effector cells like muscle, gland, or other cell types. **Interneurons** connect neurons *within* the CNS. As a rough estimate, for each afferent

neuron entering the CNS, there are 10 efferent neurons and 200,000 interneurons. Thus, the great majority of neurons are interneurons.

At their peripheral ends (the ends farthest from the CNS), afferent neurons have **sensory receptors,** which respond to various physical or chemical changes in their environment by generating electrical signals in the neuron. The receptor region may be a specialized portion of the plasma membrane or a separate cell closely associated with the neuron ending.

The anatomically specialized junction between two neurons where one neuron alters the electrical and chemical activity of another is called a **synapse.** At most synapses, the signal is transmitted from one neuron to another by *neurotransmitters*, a term that also includes the chemicals efferent neurons use to communicate with effector cells (e.g., a muscle cell). The neurotransmitters released from one neuron alter the receiving neuron by binding with specific protein receptors on the membrane of the receiving neuron.

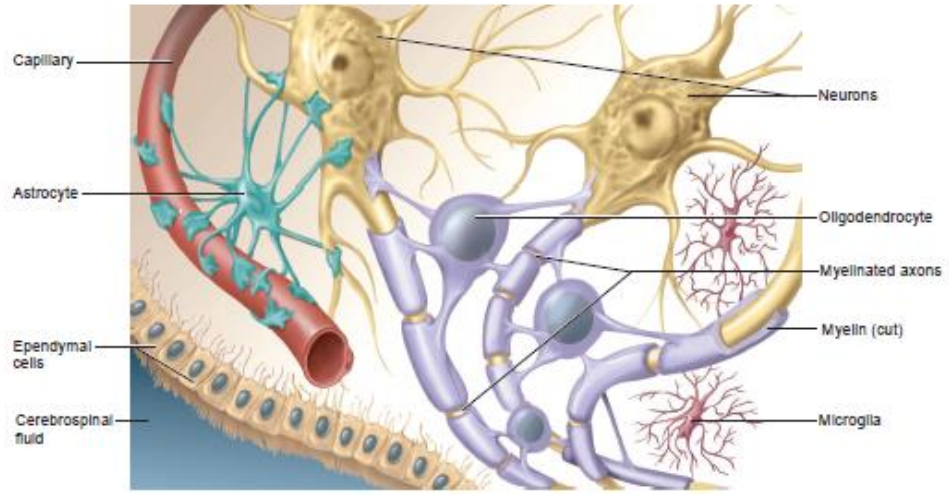
Most synapses occur between an axon terminal of one neuron and a dendrite or the cell body of a second neuron. Sometimes, however, synapses occur between two dendrites or between a dendrite and a cell body or between an axon terminal and a second axon terminal. A neuron that conducts a signal toward a synapse is called a **presynaptic neuron,** whereas a neuron conducting signals away from a synapse is a **postsynaptic neuron.**

Glial Cells

Neurons account for only about half of the cells in the human CNS. The remainder are **glialcells** (*glia*, "glue"). Glial cells surround the soma, axon, and dendrites of neurons and provide them with physical and metabolic

support. Unlike most neurons, glial cells retain the capacity to divide throughout life. Consequently, many CNS tumors actually originate from glial cells rather than from neurons.

There are several different types of glial cells found in the CNS.



One type is the oligodendrocyte, which forms the myelin sheath of CNS axons.

A second type of glial cell, the **astrocyte,** helps regulate the composition of the extracellular fluid in the CNS by removing potassium ions and neurotransmitters around synapses. Another important function of astrocytes is to stimulate the formation of tight junctions between the cells that make up the walls of capillaries found in the CNS. This forms the **blood–brain barrier,** which is a much more selective filter for exchanged substances than is present between the blood and most other tissues.

The **microglia,** a third type of glial cell, are specialized, macrophage-like cells that perform immune functions in the CNS. Lastly, **ependymal cells** line the fluid-filled cavities within the brain and spinal cord and regulate the production and flow of cerebrospinal fluid.

Schwann cells, the glial cells of the PNS, have most of the properties of the CNS glia. Schwann cells produce the myelin sheath of the axons of the peripheral neurons.

Neural Growth and Regeneration

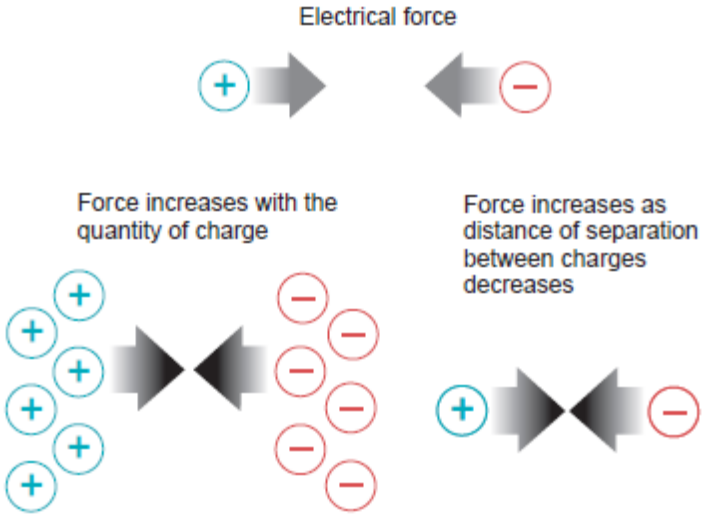
A surprising aspect of development of the nervous system occurs after growth and projection of the axons. Many of the newly formed neurons and synapses degenerate. In fact, as many as 50% to 70% of neurons undergo a programmed self-destruction called **apoptosis** in the developing CNS. Throughout the life span, our brain has an amazing ability to modify its structure and function in response to stimulation or injury, a characteristic known as **plasticity.** This involves both the generation of new neurons and remodeling of synaptic connections, and is stimulated by exercise and by engaging in cognitively challenging activities.

Basic Principles of Electricity

The predominant solutes in the extracellular fluid are sodium and chloride ions. The intracellular fluid contains high concentrations of potassium ions and ionized non-penetrating molecules, particularly phosphate compounds and proteins with negatively charged side chains. Electrical phenomena resulting from the distribution of these charged particles occur at the cell's plasma membrane and play a significant role in signal integration and cell-to-cell communication, the two major functions of the neuron.

A fundamental physical principle is that charges of the same type repel each other—positive charge repels positive charge, and negative charge repels

negative charge. In contrast, oppositely charged substances attract each other and will move toward each other if not separated by some barrier.

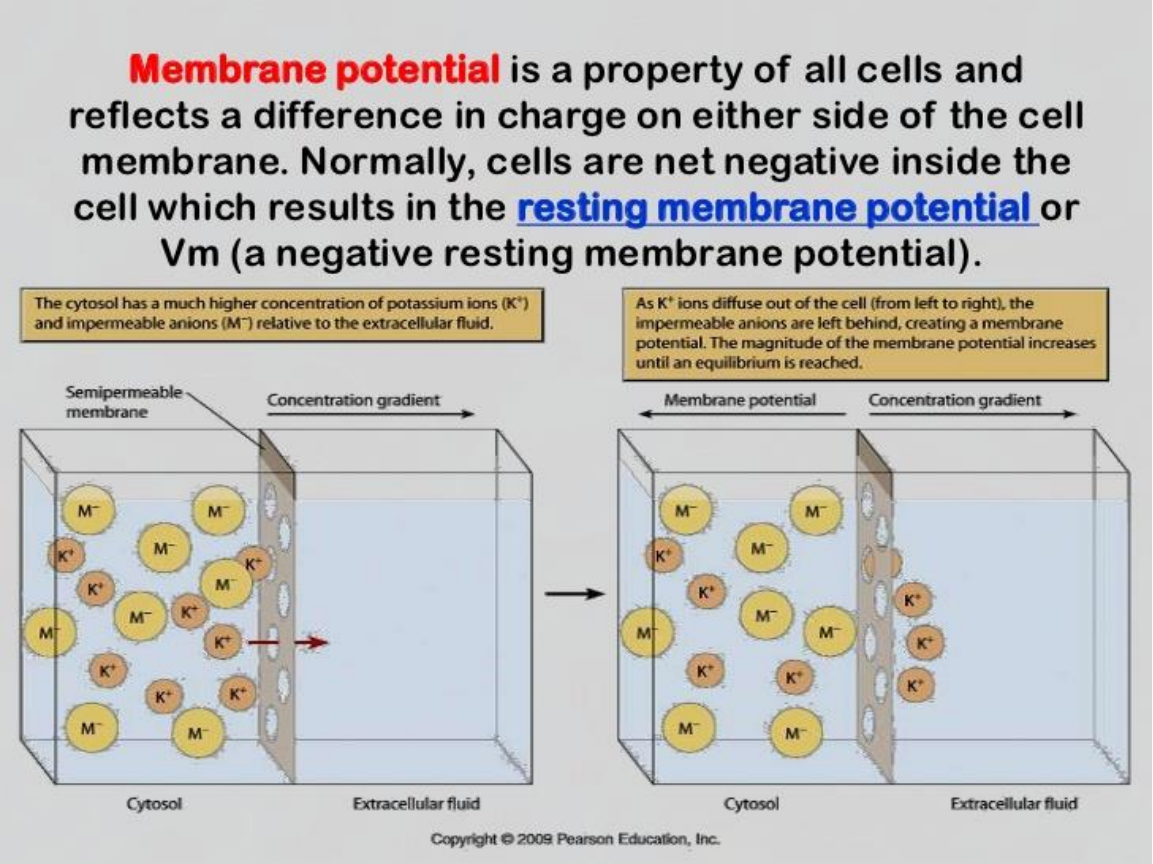


The intracellular and extracellular fluids contain many ions and can therefore carry current. Lipids, however, contain very few charged groups and cannot carry current. Therefore, the lipid layers of the plasma membrane are regions of high electrical resistance separating the intracellular fluid and the extracellular fluid, two low-resistance aqueous compartments.

The Resting Membrane Potential

All cells under resting conditions have a potential difference across their plasma membranes, with the inside of the cell negatively charged with respect to the outside.

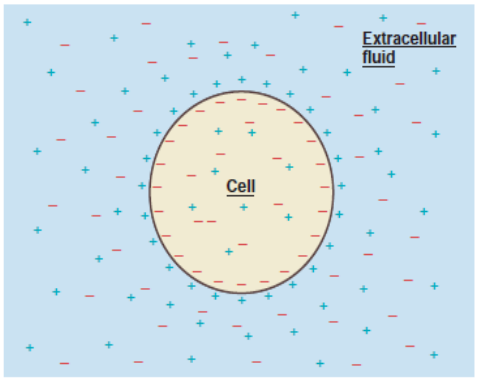
This potential is the **resting membrane potential.**



The **resting membrane potential** of a neuron is about -70 mV (mV=millivolt) - this means that the inside of the neuron is 70 mV less than the outside. The resting membrane potential holds steady unless changes in electrical current alter the potential.

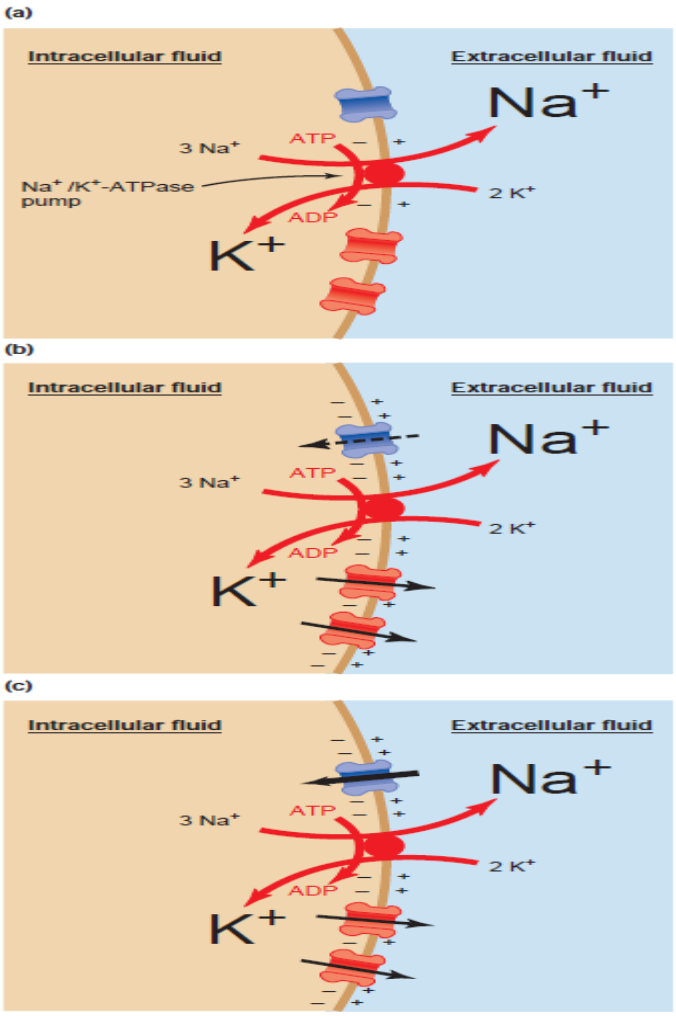
The resting membrane potential exists because of a tiny excess of negative ions inside the cell and an excess of positive ions outside. The excess

negative charges inside are electrically attracted to the excess positive charges outside the cell, and vice versa.



In a resting cell, ((**The resting potential is mostly determined by the concentrations of the ions in the fluids on both sides of the cell membrane and the ion transport proteins that are in the cell membrane))**, the number of ions the pump moves equal the number of ions that leak down their concentration and/or electrical gradients. As long as the concentration gradients remain stable and the ion permeability of the plasma membrane do not change, the electrical potential across the resting membrane will also remain constant.

Thus far, we have described the membrane potential as due purely and directly to the passive movement of ions down their electrochemical gradients, with the concentration gradients maintained by membrane pumps. However, the Na /K -ATPase pump not only maintains the concentration gradients for these ions but also helps to establish the membrane potential more directly. The Na /K -ATPase pumps actually move three sodium ions out of the cell for every two potassium ions that they bring in. This unequal transport of positive ions makes the inside of the cell more negative than it would be from ion diffusion alone. When a pump moves net charge across the membrane and contributes directly to the membrane potential, it is known as an **electrogenic pump.**



First, the action of the Na /K -ATPase pump sets up the concentration gradients for Na and K (**a**). These concentration gradients determine the equilibrium potentials for the two ions— that is, the value to which each ion would bring the membrane potential if it were the only permeating ion. Simultaneously, the pump has a small electrogenic effect on the membrane due to the fact that three sodium ions are pumped out for every two potassium ions pumped in. The next step shows that initially there is a greater flux of K out of the cell than Na into the cell (**b**). This is because in a resting membrane there is a greater permeability to K than there is to Na. Because there is greater net efflux than influx of positive ions during this

step, a significant negative membrane potential develops, with the value approaching that of the K equilibrium potential. In the steady state resting neuron, the flux of ions across the membrane reaches a dynamic balance (**c**). Because the membrane potential is not equal to the equilibrium potential for either ion, there is a small but steady leak of Na into the cell and K out of the cell.

The concentration gradients do not dissipate over time, however, because ion movement by the Na /K -ATPase pump exactly balances the rate at which the ions leak in the opposite direction. Now let's return to the behavior of chloride ions in excitable cells. The plasma membranes of many cells also have Cl channels but do not contain chloride ion pumps. Therefore, in these cells, Cl concentrations simply shift until the equilibrium potential for Cl is equal to the resting membrane potential. In other words, the negative membrane potential determined by Na and K moves Cl out of the cell, and the Cl concentration inside the cell becomes lower than that outside. This concentration gradient produces a diffusion of Cl back into the cell that exactly opposes the movement out because of the electrical potential.

In contrast, some cells have a non-electrogenic activetransport system that moves Cl out of the cell, generating a strong concentration gradient. In these cells, the Cl equilibrium potential is negative to the resting membrane potential, and net Cl diffusion into the cell contributes to the excess negative charge inside the cell; that is, net Cl diffusion makesthe membrane potential more negative than it would be if only Na and K were involved.

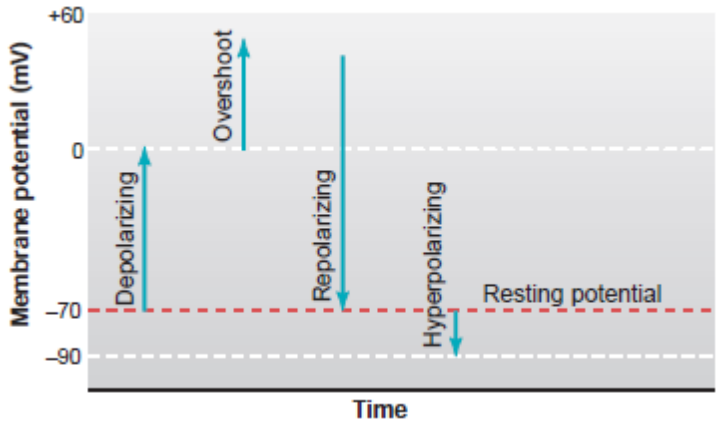
Action Potentials

You have just learned that all cells have a resting membrane potential due to the presence of ion pumps and leak channels in the cell membrane. In

addition, however, some cells have another group of ion channels that can be gated (opened or closed) under certain conditions. Such channels give a cell the ability to produce electrical signals that can transmit information between different regions of the membrane. This property is known as **excitability,** and such membranes are called **excitable membranes.**

Cells of this type include all neurons and muscle cells, as well as some endocrine, immune, and reproductive cells. The electrical signals occur in two forms: graded potentials and action potentials. Graded potentials are important in signaling over short distances, whereas action potentials are long-distance signals that are particularly important in neuronal and muscle cell membranes.

The terms *depolarize*, *repolarize*, and *hyperpolarize* are used to describe the direction of changes in the membrane potential relative to the resting potential.



The resting membrane potential is "polarized," simply meaning that the outside and inside of a cell have a different net charge. The membrane is **depolarized** when its potential becomes less negative (closer to zero) than the resting level. **Overshoot** refers to a reversal of the membrane potential polarity—that is, when the inside of a cell becomes positive relative to the

outside. When a membrane potential that has been depolarized is returning toward the resting value, it is **repolarizing.** The membrane is **hyperpolarized** when the potential is more negative than the resting level.

Membrane Potential

- Plasma membrane of all living cells has a membrane potential (polarized electrically)
- Separation of opposite charges across plasma membrane
- Due to differences in concentration and permeability of key ions

- Separated charges create the ability to do work (hydroelectric dam) millivolt- 1/1000 volt

The changes in membrane potential that the neuron uses as signals occur because of changes in the permeability of the cell membrane to ions. When a neuron receives a chemical signal from a neighboring neuron, for instance, some gated channels will open, allowing greater ionic current across the membrane. The greater movement of ions down their electrochemical gradient alters the membrane potential so that it is either depolarized or hyperpolarized relative to the resting state.

In addition to the movement of ions on the inside and the outside of the cell, charge is lost across the membrane because the membrane is permeable to ions through open membrane

channels.

Action potentials are very different from graded potentials. They are large alterations in the membrane potential; the membrane potential may change by as much as 100 mV. For example, a cell might depolarize from -70 to +30 mV, and then repolarize to its resting potential. Action potentials are generally very rapid (as brief as 1–4 milliseconds) and may repeat at frequencies of several hundred per second. The propagation of action potentials down the axon is the mechanism the nervous system uses to communicate over long distances.