University of Anbar
College of science
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Lectures of human physiology

Lec. 2

The Nervous System

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The Nervous System

The nervous system is composed of neurons, which produce and conduct electrochemical impulses, and supporting cells, which assist the functions of neurons. Neurons are classified functionally and structurally; the various types of supporting cells perform specialized functions.

The nervous system is divided into the **central nervous system (CNS),** which includes the brain and spinal cord, and the **peripheral nervous system (PNS),** which includes the *cranial nerves* arising from the brain and the *spinal nerves* arising from the spinal cord. The nervous system is composed of only two principal types of cells—neurons and supporting cells. **Neurons** are the basic structural and functional units of the nervous system. They are specialized to respond to physical and chemical stimuli, conduct electrochemical impulses, and release chemical regulators. Through these activities, neurons enable the perception of sensory stimuli, learning, memory, and the control of muscles and glands. Most neurons cannot divide by mitosis, although many can regenerate a severed portion or sprout small new branches under certain conditions. *Supporting cells* aid the functions of neurons and are about five times more abundant than neurons. In common usage, supporting cells are collectively called **neuroglia,** or simply **glial cells** Unlike neurons, which do not divide mitotically, glial cells are able to divide by mitosis. This helps to explain why brain tumors in adults are usually composed of glial cells rather than of neurons.

Neurons

Although neurons vary considerably in size and shape, they generally have three principal regions: (1) a cell body, (2) dendrites, and (3) an axon (fig. 2.1). Dendrites and axons can be referred to generically as *processes,* or extensions from the cell

body. The **cell body** is the enlarged portion of the neuron that contains the nucleus. It is the "nutritional center" of the neuron where macromolecules are produced. The cell body and larger dendrites (but not axons) contain *Nissl bodies*, which are seen as dark-staining granules under the microscope. Nissl bodies are composed of large stacks of rough endoplasmic reticulum that are needed for the synthesis of membrane proteins. The cell bodies within the CNS are frequently clustered into groups called *nuclei* (not to be confused with the nucleus of a cell). Cell bodies in the PNS usually occur in clusters called *ganglia*.

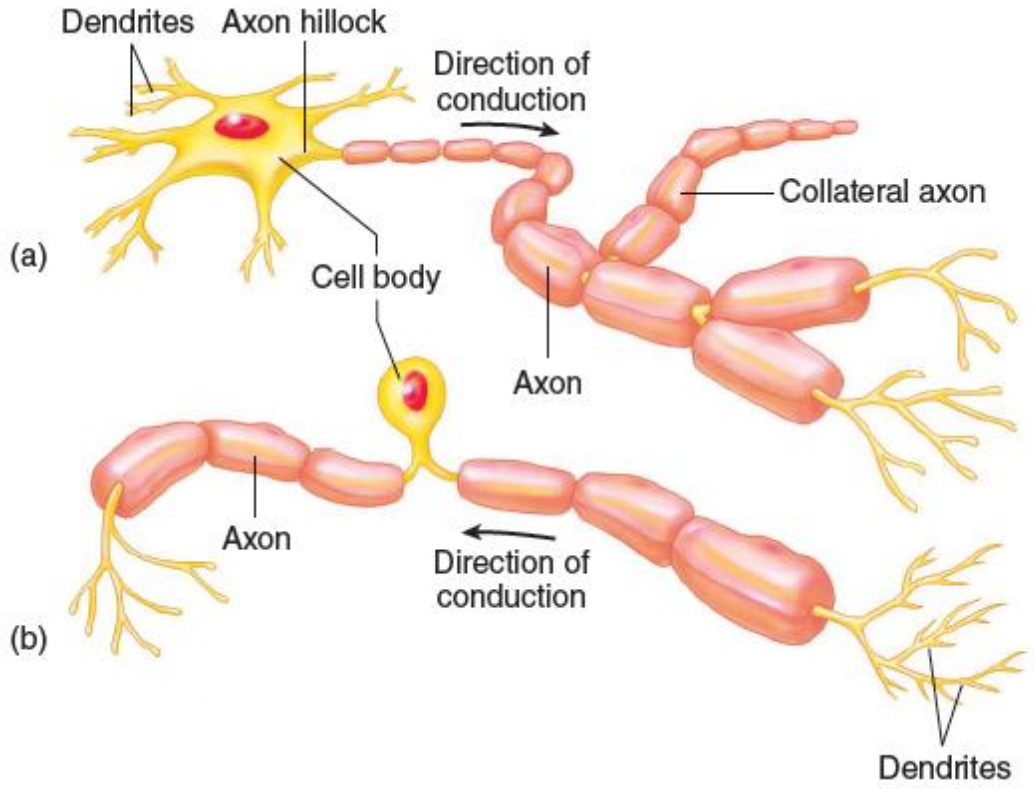


Figure 2.1 The structure of two kinds of neurons. A motor neuron (*a*) and a sensory neuron (*b*) .

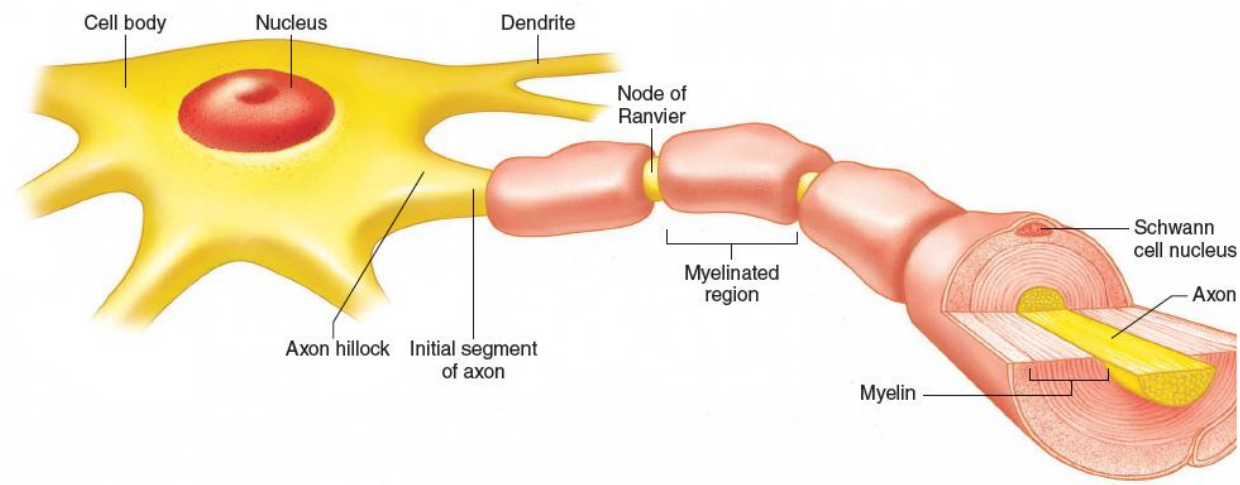


Fig 2.2 Parts of a neuron. The axon of this neuron is wrapped by Schwann cells, which form a myelin sheath

Dendrites are thin, branched processes that extend from the cytoplasm of the cell body. Dendrites provide a receptive area that transmits graded electrochemical impulses to the cell body. The **axon** is a longer process that conducts impulses, called *action potentials*, away from the cell body. The origin of the axon near the cell body is an expanded region called the *axon hillock.*

Axons vary in length from only a millimeter long to over a meter or more in length (for axons that extend from the CNS to the foot). Toward their ends, axons can produce up to 200 or more branches called **axon collaterals,** and each of these can divide to synapse with many other neurons. In this way, a single CNS axon may synapse with as many as 30,000 to 60,000 other neurons.

Axonal transport may occur from the cell body to the axon and dendrites. This direction is called **anterograde transport**.

By contrast, axonal transport in the opposite direction— that is, along the axon and dendrites toward the cell body—is known as **retrograde transport**.

Neurons may be classified according to their function or structure. The functional classification is based on the direction in which they conduct impulses, as indicated in figure 2.3. **Sensory,** or **afferent, neurons** conduct impulses from sensory receptors *into* the CNS. **Motor,** or **efferent, neurons** conduct

impulses *out* of the CNS to effector organs (muscles and glands). **Association neurons,** or **interneurons,** are located entirely within the CNS and serve the associative, or integrative, functions of the nervous system. There are two types of motor neurons: somatic and autonomic. **Somatic motor neurons** are responsible for both reflex and voluntary control of skeletal muscles. **Autonomic motor neurons** innervate (send axons to) the involuntary effectors—smooth muscle, cardiac muscle, and glands. The cell bodies of the autonomic neurons that innervate these organs are located outside the CNS in autonomic ganglia (fig. 2.3). There are two subdivisions of autonomic neurons: *sympathetic* and *parasympathetic.* Autonomic motor neurons, together with their central control centers, constitute the *autonomic nervous system.*

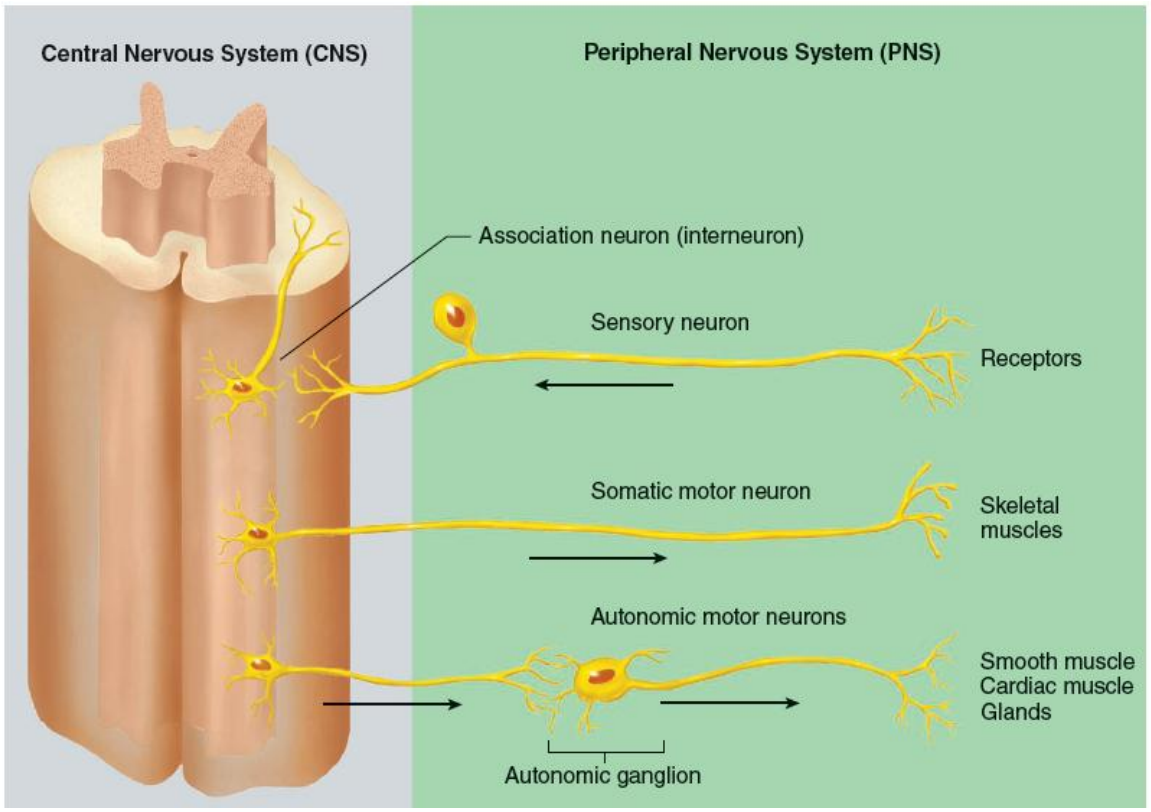


Fig 2.3The relationship between CNS and PNS. Sensory and motor neurons of the peripheral nervous system carry information into and out of, respectively, the central nervous system (brain and spinal cord).

The structural classification of neurons is based on the number of processes that extend from the cell body of the neuron (fig. 2.3). **Pseudounipolar neurons** have a single short process that branches like a T to form a pair of longer processes. They are called pseudounipolar (from the Late Latin *pseudo* 5 false) because, although they originate with two processes, during early embryonic development their two processes converge and partially fuse. **Bipolar neurons** have two processes, one at either end; this type is found in the retina of the eye. **Multipolar neurons,** the most common type, have several dendrites and one axon extending from the cell body; motor neurons are good examples of this type. A **nerve** is a bundle of axons located outside the CNS. Most nerves are composed of both motor and sensory fibers and are thus called *mixed nerves***.**

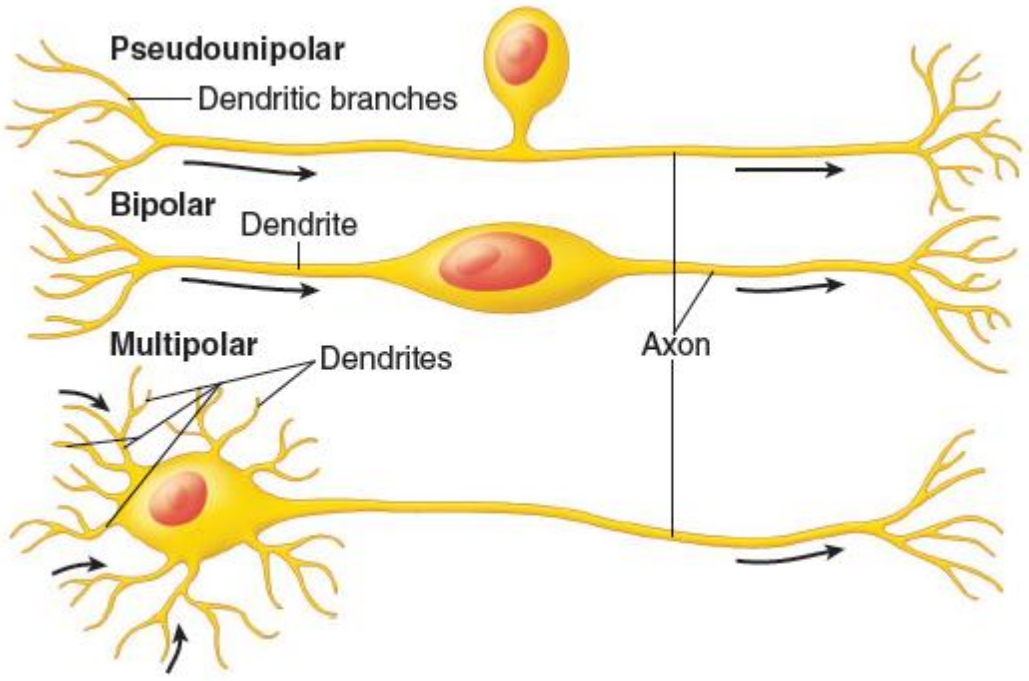


Fig 2.4 **Three different types of neurons**

Neuroglial Cells

Unlike other organs that are "packaged" in connective tissue derived from mesoderm (the middle layer of embryonic tissue), most of the supporting cells of the nervous system are derived from the same embryonic tissue layer (ectoderm) that produces neurons. The term *neuroglia* (or *glia*) traditionally refers to the supporting cells of the CNS, but in current usage the supporting cells of the PNS are often also called glial cells. There are two types of neuroglial cells in the peripheral nervous system:

1. Schwann cells (also called *neurolemmocytes*), which form myelin sheaths around peripheral axons; and

2. satellite cells, or **ganglionic gliocytes,** which support neuron cell bodies within the ganglia of the PNS.

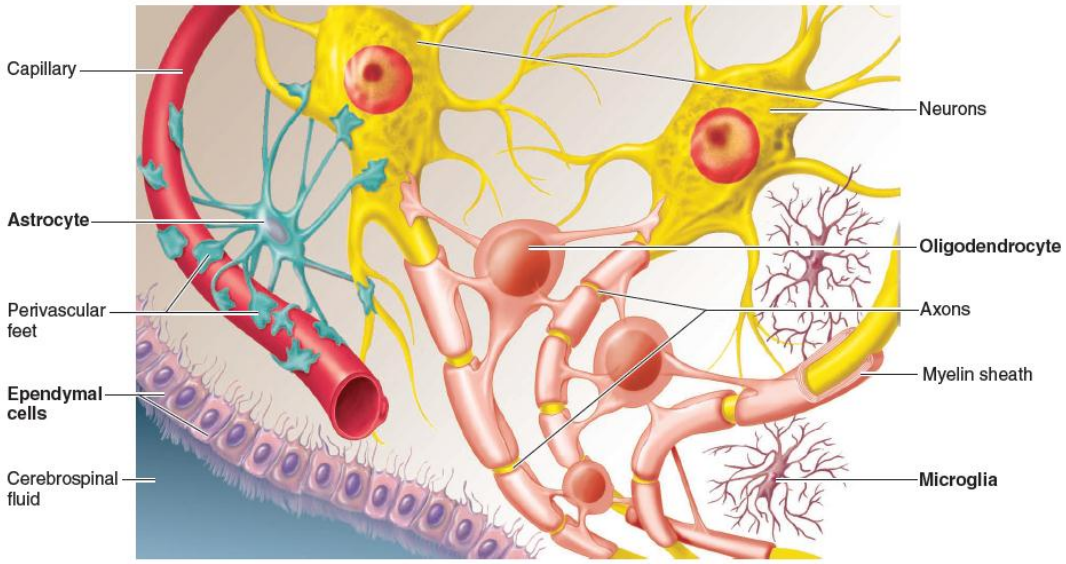
There are four types of neuroglial cells in the central nervous system (fig.):

1. oligodendrocytes, which form myelin sheaths around axons of the CNS;

2. microglia, which migrate through the CNS and phagocytose foreign and degenerated material;

3. astrocytes, which help to regulate the external environment of neurons in the CNS; and

4. ependymal cells, which are epithelial cells that line the ventricles (cavities) of the brain and the central canal of the spinal cord.



The different types of neuroglial cells

Production of nerve impulse

The permeability of the axon membrane to Na^+ and K^+ depends on gated channels that open in response to stimulation. Net diffusion of these ions occurs in two stages: first Na^+ moves into the axon, then K^+ moves out. This flow of ions, and the changes in the membrane potential that result, constitute an event called an **action potential**.

The nerve impulse is generated as a result of a change in the degree of polarization of the nerve fiber membrane, which is intended to change the electrical potential difference on both sides of the membrane. The plasma membrane of all cells, including neurons, carries a difference in electrical potential on its sides called the **resting potential**, and the potential difference ranges between 20-100 millivolts, as the inner surface of the membrane is negatively charged in relation to the positively charged outer surface.

Factors that lead to the formation of resting potential:

The difference in the degree of permeability of the living cell membrane to some important ions is highly exudative for potassium ions K^+ and little to sodium ions Na^+.

The difference in the concentration of potassium ions K^+ inside and outside the cell, as its concentration inside is ten times more than its concentration outside. Ions such as Na^+, K^+, and others pass through ion channels in the plasma membrane that are said to be *gated channels.* The "gates" are part of the proteins that compose the channels, and can open or close the ion channels in response to particular stimuli. When ion channels are closed, the plasma membrane is less permeable, and when the channels are open, the membrane is more permeable to an ion.

The ion channels for Na^+ and K^+ are specific for each ion. There are two types of channels for K^+. One type is gated, and the gates are closed at the resting membrane potential. The other type is not gated; these K^+ channels are thus always open and are often called *leakage channels.* Channels for Na^+, by contrast, are all gated and the gates are closed at the resting membrane potential, However, the gates of closed Na^+ channels appear to flicker open (and quickly close) occasionally, allowing some Na^+ to leak into the resting cell. As a result of these ion channel characteristics, the neuron at the resting membrane potential is much more permeable to K^+ than to Na^+.

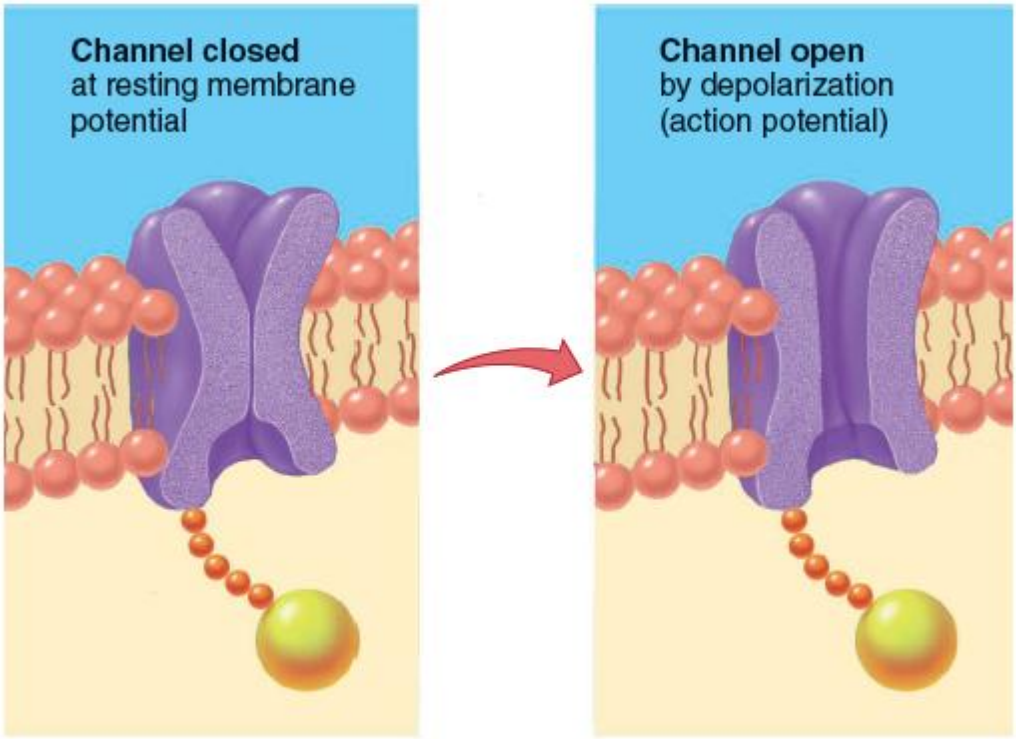


Fig. 2.5 voltage-gated ion

When the nerve fiber is stimulated, the membrane's perfusion changes and becomes highly perfuse for sodium ions and low for potassium ions this process is called depolarization. This process continues until the electric potential difference on both sides of the membrane becomes zero, and the process continues until the outer surface becomes negative in relation to the inner surface, which becomes positive, and this means the inversion of the electric potential difference , the process of inversion of potential difference on both sides of the membrane of the nerve fiber is called **action potential** , this change is not limited to the stimulus region, but the action potential flows from one point to another along the membrane of the nerve fiber, just as fire flows through a thread saturated with gunpowder and this flow of action is called a **nervous impulse** , in order to generate an action potential and apply it in the nerve fiber, the resting potential in the stimulus region must be reduced by one third.

The change in the perfusion of the membrane that precedes the nerve impulse does not exceed in a region of the membrane more than a few fractions of a second after which the membrane returns to its previous perfusion properties, meaning it becomes more perfuse for potassium ions and less for sodium ions.

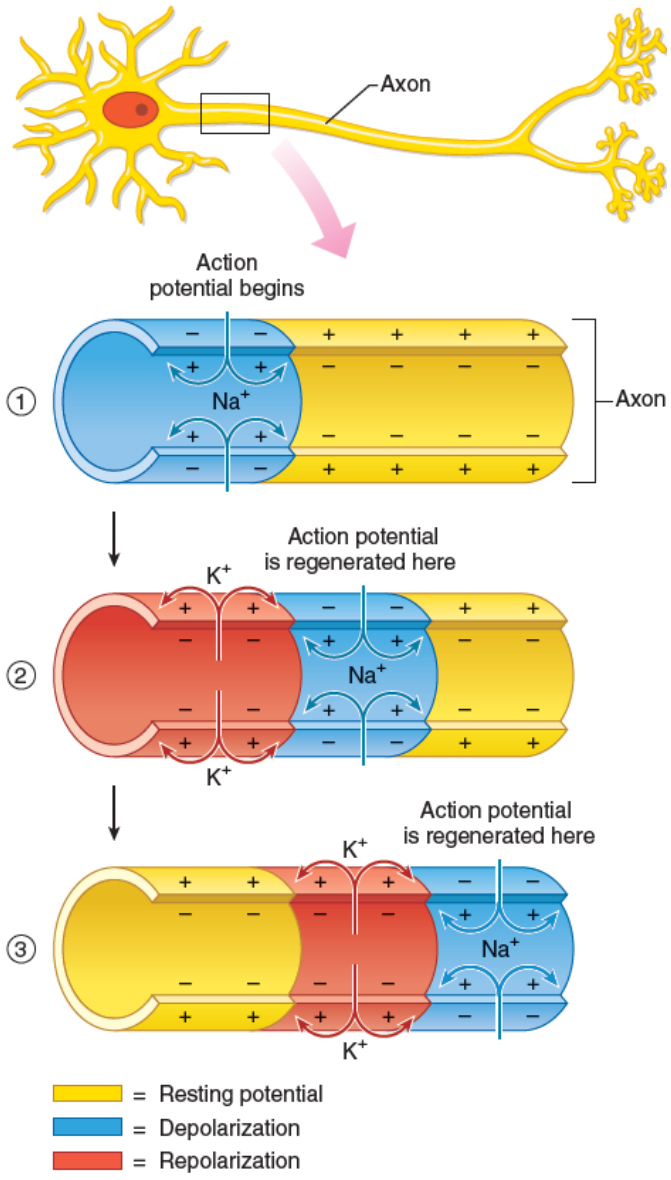


Fig 2.6 The conduction of action potentials in an unmyelinated axon.

Nervous impulse properties:

1- It follows an all-or-nothing law, which means that when a nerve fiber is stimulated, either a nerve impulse is generated or not.

2- The minimum strength of the stimulus necessary to cause a nerve impulse to flow in the fiber is called the threshold, where when the stimulus is below the threshold, the stimulus is not generated.

3- Nervous impulse does not depend on the strength of the stimulus, but on other factors such as the difference in the concentration of sodium and potassium ions between inside and outside the nerve fiber.

THE SYNAPSE:

Axons end close to, or in some cases in contact with, another cell. In specialized cases, action potentials can directly pass from one cell to another. In most cases, however, the action potentials stop at the axon terminal, where they stimulate the release of a chemical neurotransmitter that affects the next cell. A **synapse** is the functional connection between a neuron and a second cell. In the CNS, this other cell is also a neuron. In the PNS, the other cell may be either a neuron or an *effector cell* within a muscle or gland. Although the physiology of neuron-neuron synapses and neuron-muscle synapses is similar, the latter synapses are often called **myoneural,** or **neuromuscular, junctions.** Neuron-neuron synapses usually involve a connection between the axon of one neuron and the dendrites, cell body, or axon of a second neuron

Transmission of nerve impulse:

1- Transmission along of nerve fiber:

The most widely accepted theory among scientists is the membrane theory, which claims that nerve impulses are transmitted in the form of depolarizing waves that pass through the outer sheath of the nerve fiber.

2- Transmission across synapse:

A- Gap Junctions

Adjacent cells that are electrically coupled are joined together by **gap junctions.** In gap junctions, the membranes of the two cells are separated by only 2 nanometers (1 nanometer = 10^{-9} meter). In the plasma membrane of each apposed cell, six proteins called *connexins* come together to form a transmembrane structure with an aqueous core. Each of these composes half of the gap junction, called a *hemichannel.* When the hemichannels of two plasma membranes dock together, they form a complete gap junction (fig. 2.7) that spans both membranes and allows ions and molecules to pass from one cell to the other. Gap junctions are present in cardiac muscle, where they allow action potentials to spread from cell to cell so that the myocardium can contract as a unit. Similarly, gap junctions in most smooth muscles allow many cells to be stimulated and contract together, producing a stronger contraction (as in the uterus during labor).

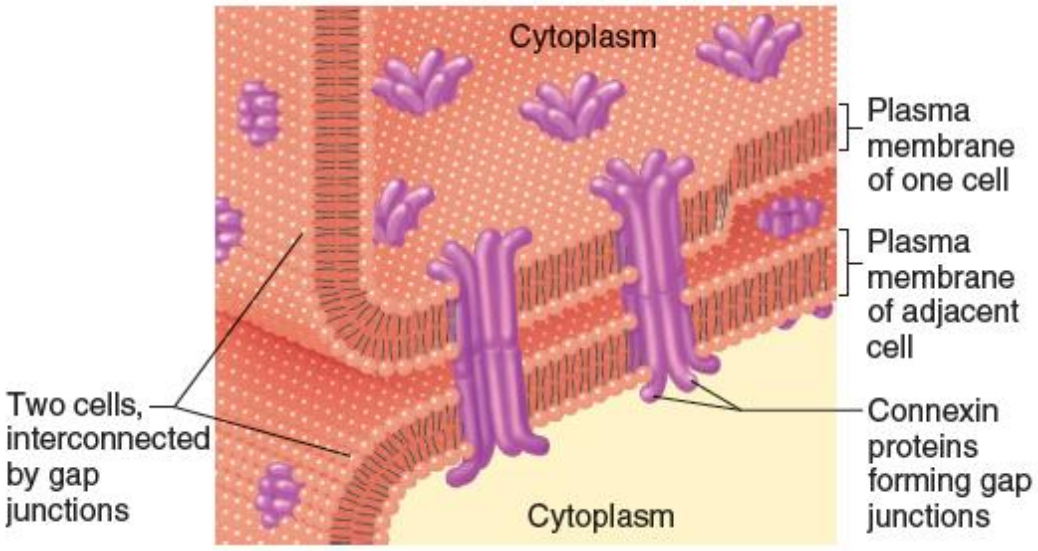


Fig 2.7 **The structure of gap junctions**

B- Chemical Synapses

Transmission across the majority of synapses in the nervous system is one-way and occurs through the release of chemical neurotransmitters from presynaptic axon endings. These presynaptic endings, called **terminal boutons** (from the Middle French *bouton* 5 button) because of their swollen appearance, are separated from the postsynaptic cell by a **synaptic cleft** so narrow (about 10 nm) that it can be seen clearly only with an electron microscope.

Chemical transmission requires that the synaptic cleft stay very narrow and that neurotransmitter molecules are released near their receptor proteins in the postsynaptic membrane. The physical association of the pre- and postsynaptic membranes at the chemical synapse is stabilized by the action of particular membrane proteins.

Neurotransmitter molecules within the presynaptic neuron endings are contained within many small, membrane-enclosed synaptic vesicles. In order for the neuro-transmitter within these

vesicles to be released into the synaptic cleft, the vesicle membrane must fuse with the axon membrane in the process of exocytosis. Exocytosis of synaptic vesicles, and the consequent release of neuro-transmitter molecules into the synaptic cleft, is triggered by action potentials that stimulate the entry of Ca $^{2+}$ into the axon terminal through voltage-gated Ca^{2+} channels (fig. 2.8).

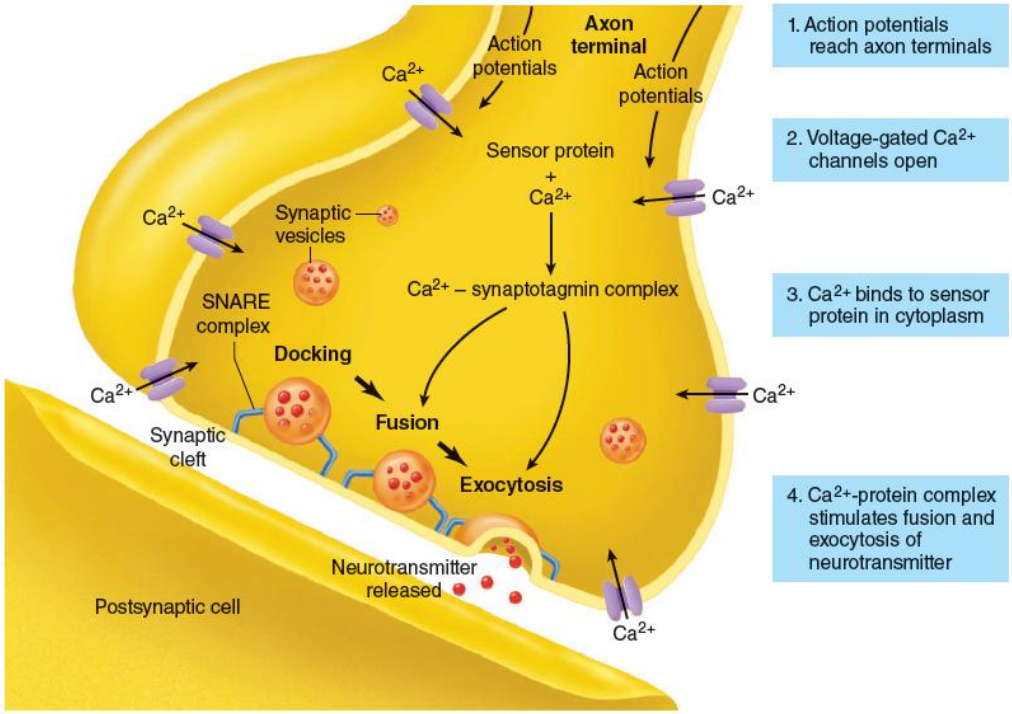


Fig 2.8The release of neurotransmitter

Steps 1–4 summarize how action potentials stimulate the exocytosis of synaptic vesicles. Action potentials open channels for Ca^{2+}, which enters the cytoplasm and binds to a sensor protein, believed to be synaptotagmin. Meanwhile, docked vesicles are held to the plasma membrane of the axon terminals by a complex of SNARE proteins. The Ca^{2+}-synaptotagmin complex interacts with the SNARE proteins and produces exocytosis of neurotransmitter in less than a millisecond after the action potential arrives.

Neurotransmitter

There are two transporters or local hormones that play a role in the process of transmitting nerve impulses through synapses:

1- **Sympathin:** It is a substance similar to noradrenaline in its chemical composition and physiological effect. It is secreted by the ends of nerve fiber axons located after the ganglia of the sympathetic nervous system and can be damaged by oxidative processes.

2- **Acetylcholine**: It is a substance secreted by nerve fibers in the sympathetic and parasympathetic nervous system. And perhaps also the nerve fibers of the central nervous system.

Reflex arc

A reflex arc is a neural pathway that controls a reflex. In vertebrates, most sensory neurons do not pass directly into the brain, but synapse in the spinal cord. This allows for faster reflex actions to occur by activating spinal motor neurons without the delay of routing signals through the brain. The brain will receive the sensory input while the reflex is being carried out and the analysis of the signal takes place after the reflex action.

There are two types: autonomic reflex arc (affecting inner organs) and somatic reflex arc (affecting muscles). Autonomic reflexes sometimes involve the spinal cord and some somatic reflexes are mediated more by the brain than the spinal cord.

-Reference

Fox, S. I. (2014). Fox Human Physiology.