THE NERVOUS SYSTEM: INTRODUCTION

NEURONS AND SYNAPSES

- 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.

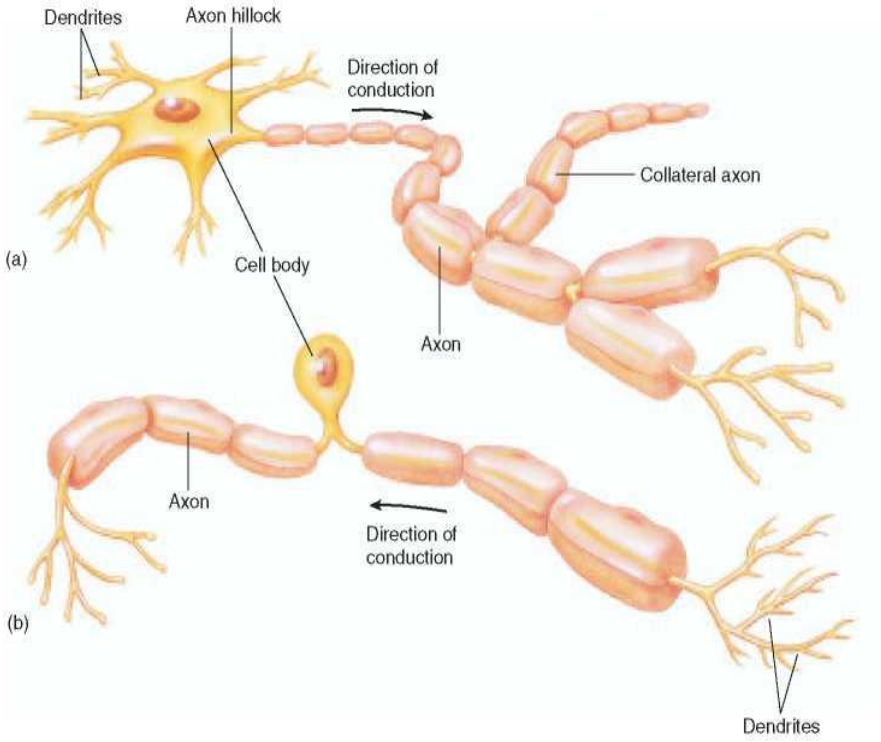
- The nervous system is composed of only two principal types of cells—neurons and supporting cells. **Neurons** are the basic structural and functional units of the nervous system. They are specialized to respond to physical and chemical stimuli, conduct electrochemical impulses, and release chemical 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 the CNS, supporting cells are collectively called **neuroglia,** or simply **glial cells** (*glia* = glue). Unlike neurons, which do not mostly 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.

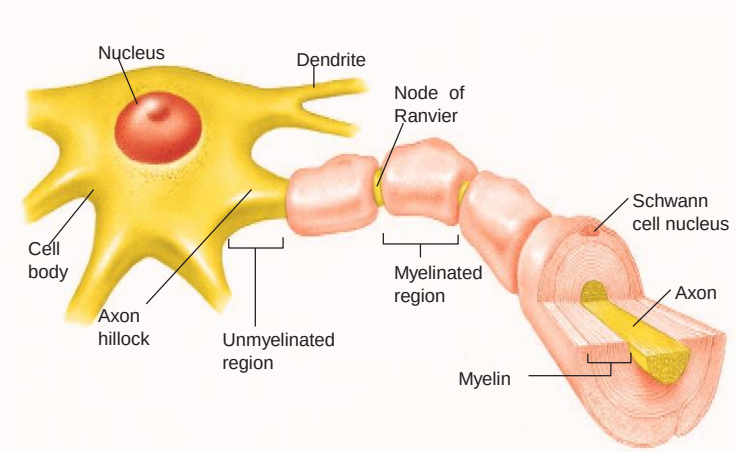
TERMINOLOGY AND NOMENCLATURE

Term	Definition
Central nervous system (CNS)	Brain and spinal cord
Peripheral nervous system (PNS)	Nerves, ganglia, and nerve plexuses (outside of the CNS)
Association neuron (interneuron)	Multipolar neuron located entirely within the CNS
Sensory neuron (afferent neuron)	Neuron that transmits impulses from a sensory receptor into the CNS
Motor neuron (efferent neuron)	Neuron that transmits impulses from the CNS to an effector organ, for example, a muscle
Nerve	Cablelike collection of many axons, may be "mixed" (contain both sensory and motor fibers)
Somatic motor nerve	Nerve that stimulates contraction of skeletal muscles
Autonomic motor nerve	Nerve that stimulates contraction (or inhibits contraction) of smooth muscle and cardiac muscle and that stimulates glandular secretion
Ganglion	Grouping of neuron cell bodies located outside the CNS
Nucleus	Grouping of neuron cell bodies within the CNS
Tract	Grouping of nerve fibers that interconnect regions of the CNS

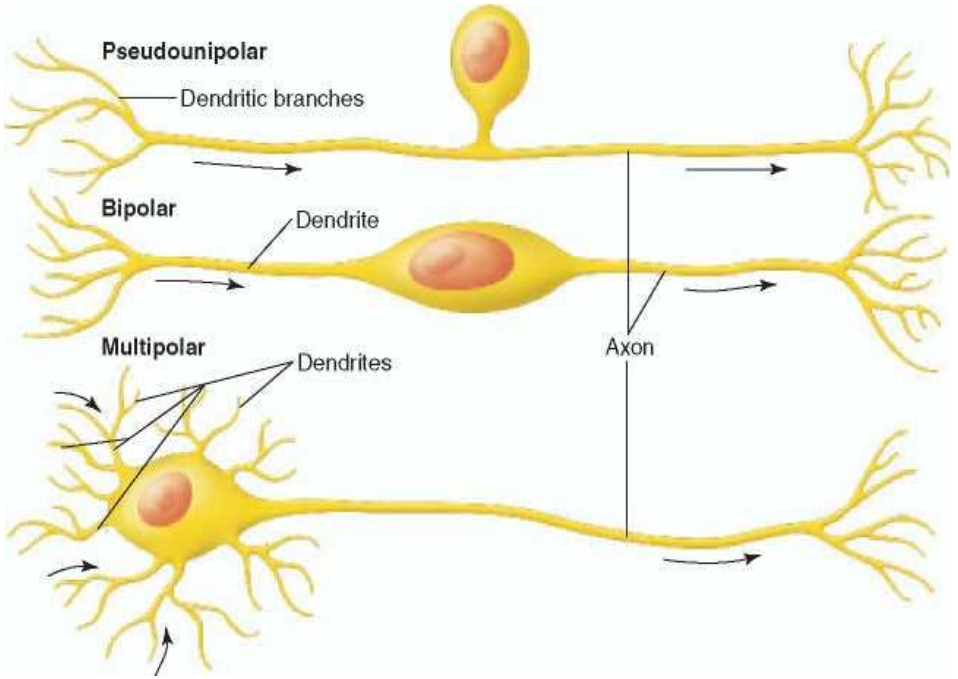
DIFFERENT KINDS OF NEURONS



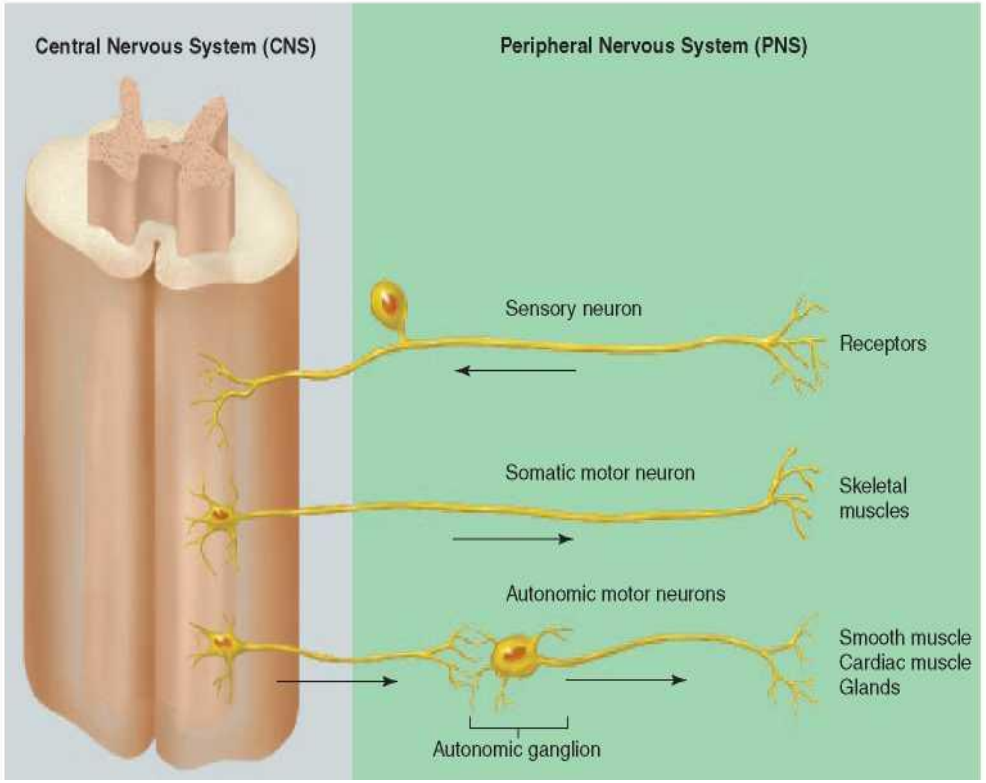
The structure of two kinds of neurons: *(a)* a motor neuron and *(b)* a sensory neuron.



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

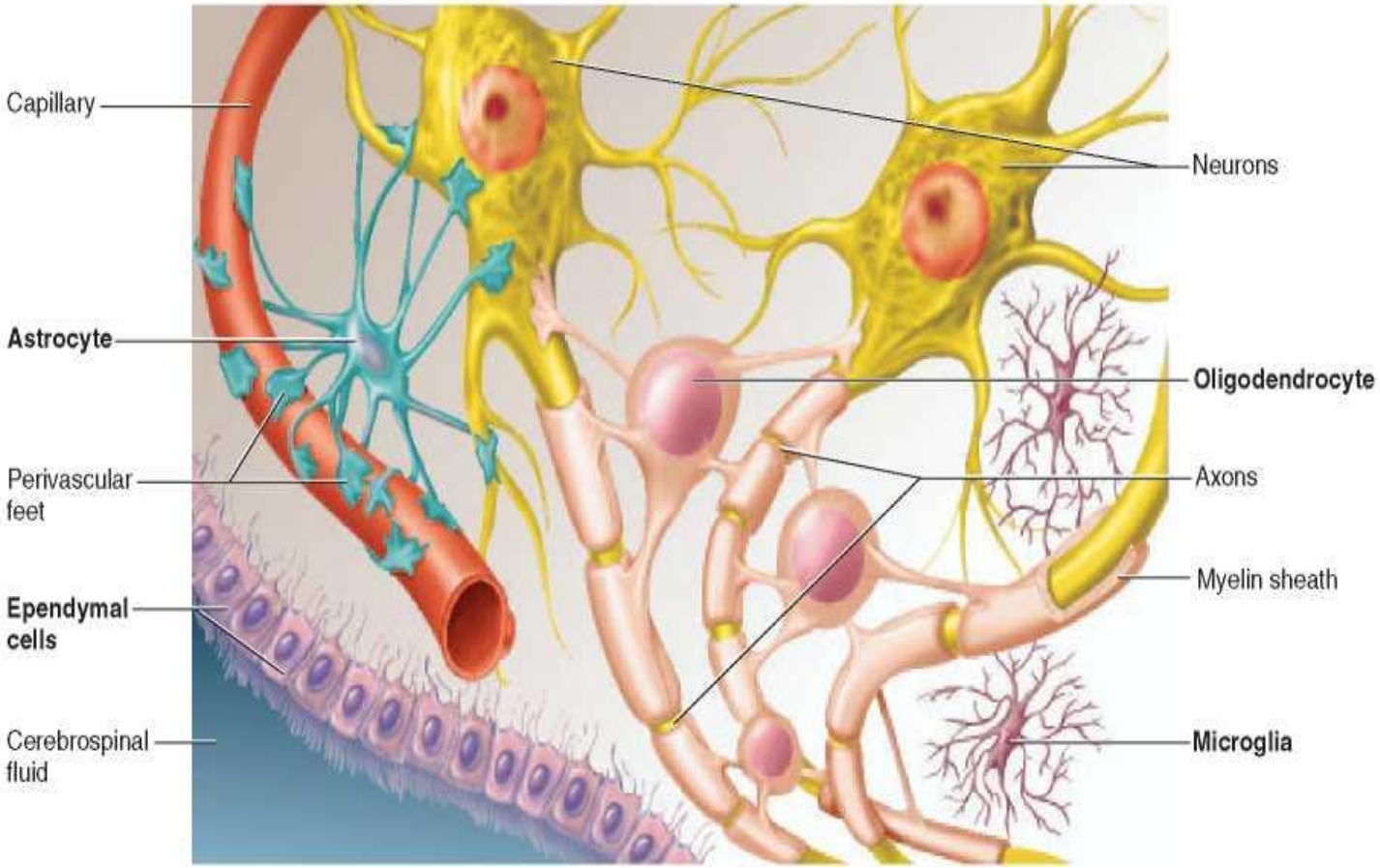


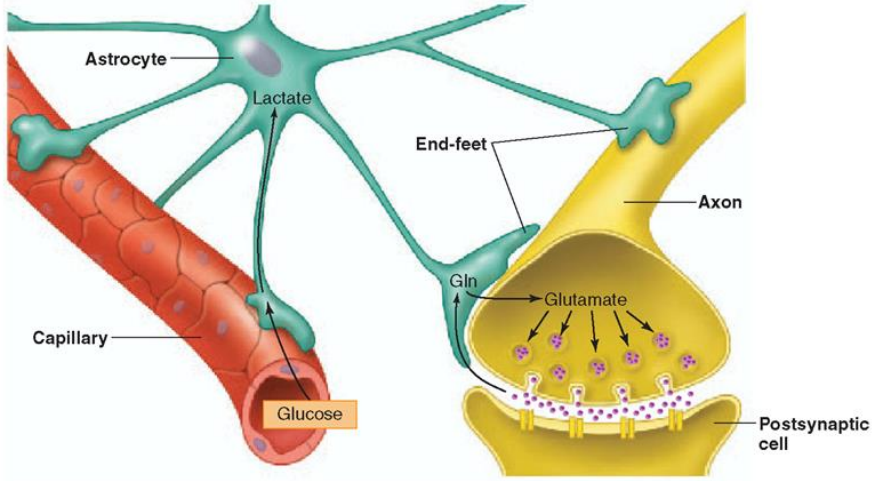
CLASSIFICATION OF NEURONS AND NERVES



- Neurons may be classified according to their function or structure.
- The functional classification is based on the direction in which they conduct impulses. Se**nsory, 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. There are two subdivisions of autonomic neurons: sympathetic and parasympathetic. autonomic motor neurons, together with their central control centers, constitute the autonomic nervous system.

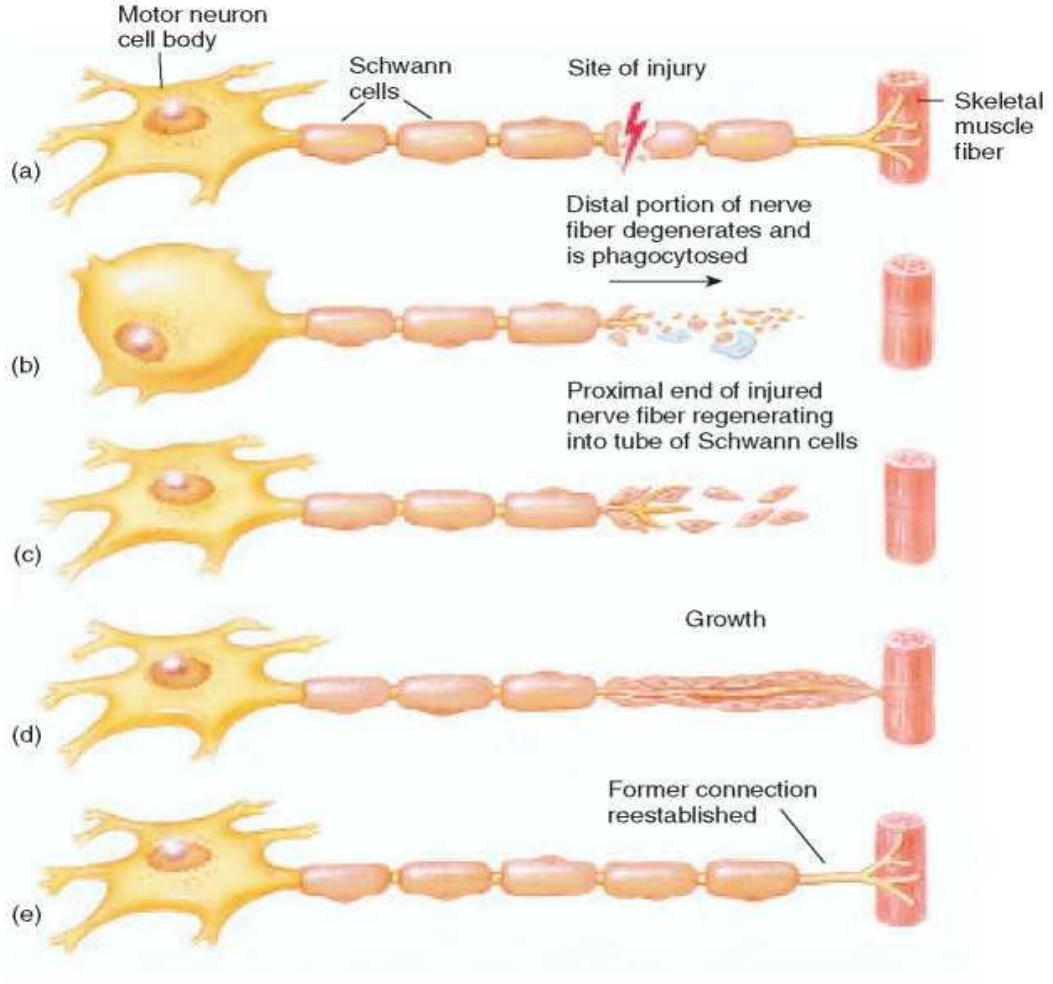
THE DIFFERENT TYPES OF NEUROGLIAL CELLS.





Myelin sheaths around axons are formed in the CNS by oligodendrocytes. Astrocytes have extensions that surround both blood capillaries and neurons. Microglia are phagocytic, and ependymal cells line the brain ventricles and central canal of the spinal cord.

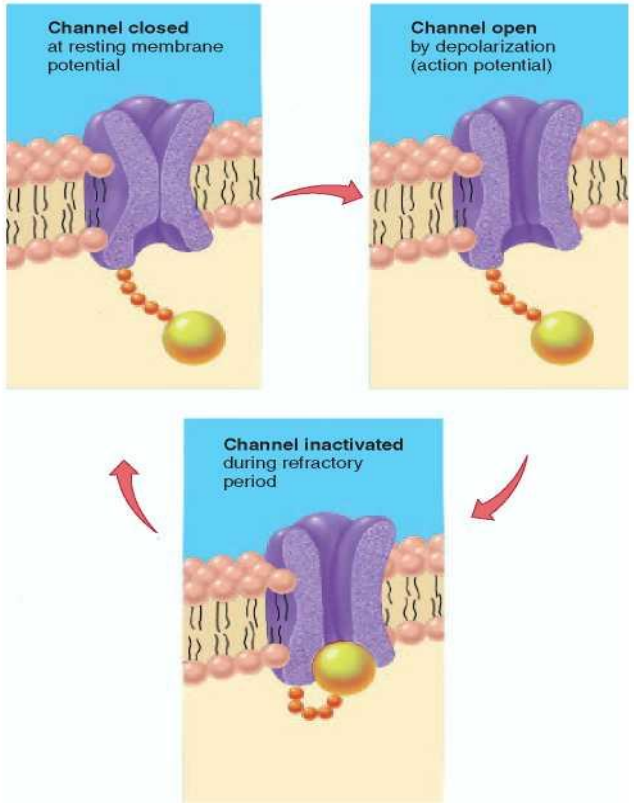
NEURONAL REGENERATION

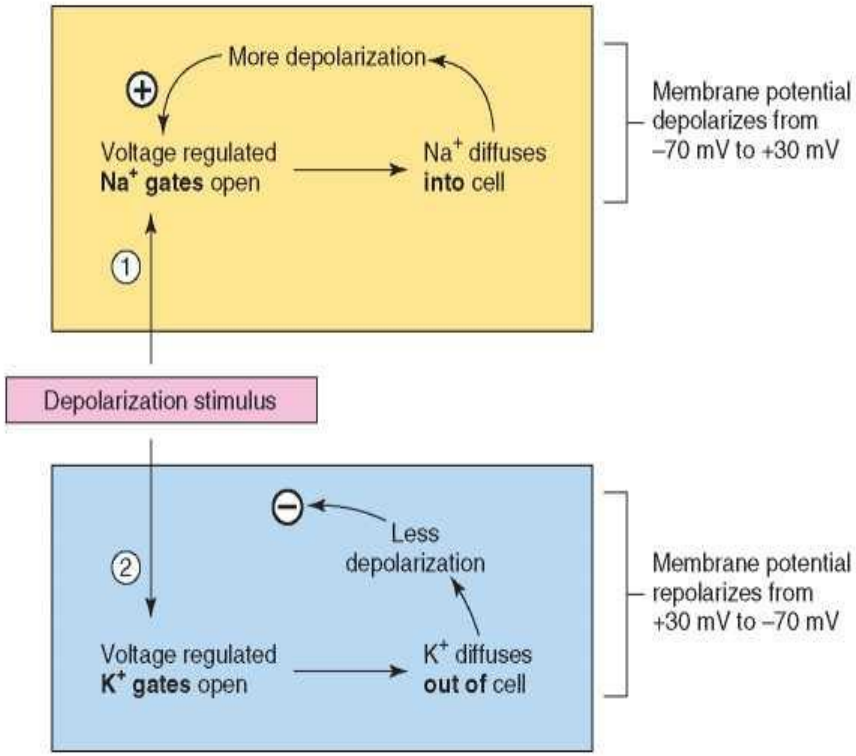


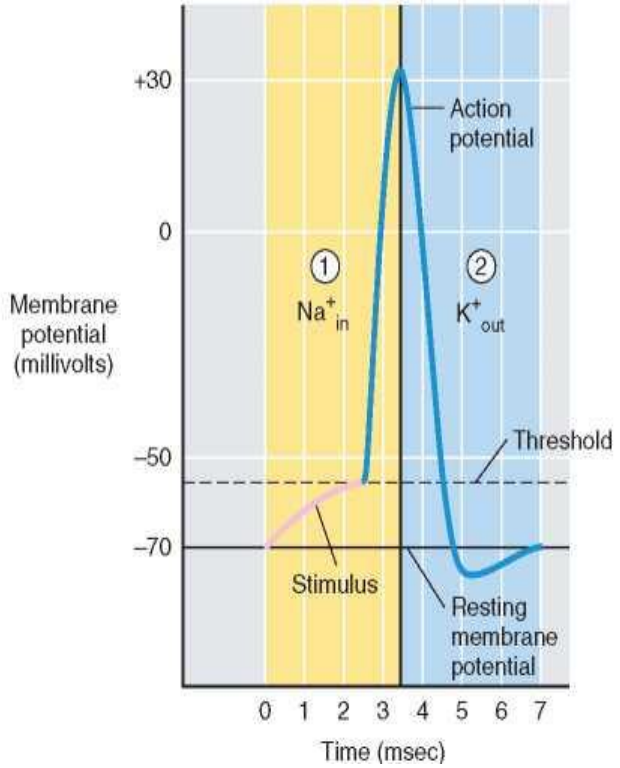
- Injury in the CNS stimulates growth of axon collaterals, but central axons have a much more limited ability to regenerate than peripheral axons. This may be due in part to the absence of a continuous neurilemma (as is present in the PNS), which precludes the formation of a regeneration tube, and to inhibitory molecules produced by oligodendrocytes and astrocytes in the injured CNS.
- In addition to the limited ability of CNS neurons to regenerate, injury to the spinal cord has recently been shown to actually evoke apoptosis in neurons that were not directly damaged by the injury.

The process of peripheral neuron regeneration. (a) If a neuron is severed through a myelinated axon, the proximal portion may survive, but (b) the distal portion will degenerate through phagocytosis. The myelin sheath provides a pathway (c) and (d) for the regeneration of an axon, and (e) innervation is restored.

ION GATING IN AXONS



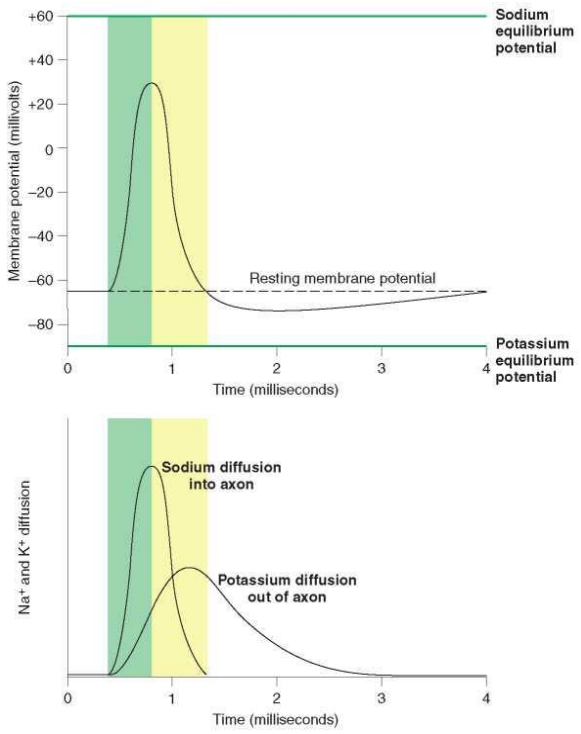




A model of a voltage-gated ion channel. The channel is closed at the resting membrane potential but opens in response to a threshold level of depolarization. This permits the diffusion of ions required for action potentials. After a brief period of time, the channel is inactivated by the "ball and chain" portion of a polypeptide chain.

Depolarization of an axon affects Na+ and K+ diffusion in sequence. (1) Na+ gates open and Na+ diffuses into the cell. (2) After a brief period, K+ gates open and K+ diffuses out of the cell. An inward diffusion of Na+ causes further depolarization, which in turn causes further opening of Na+ gates in a positive feedback (+) fashion. The opening of K+ gates and outward diffusion of K+ makes the inside of the cell more negative, and thus has a negative feedback effect (-) on the initial depolarization.

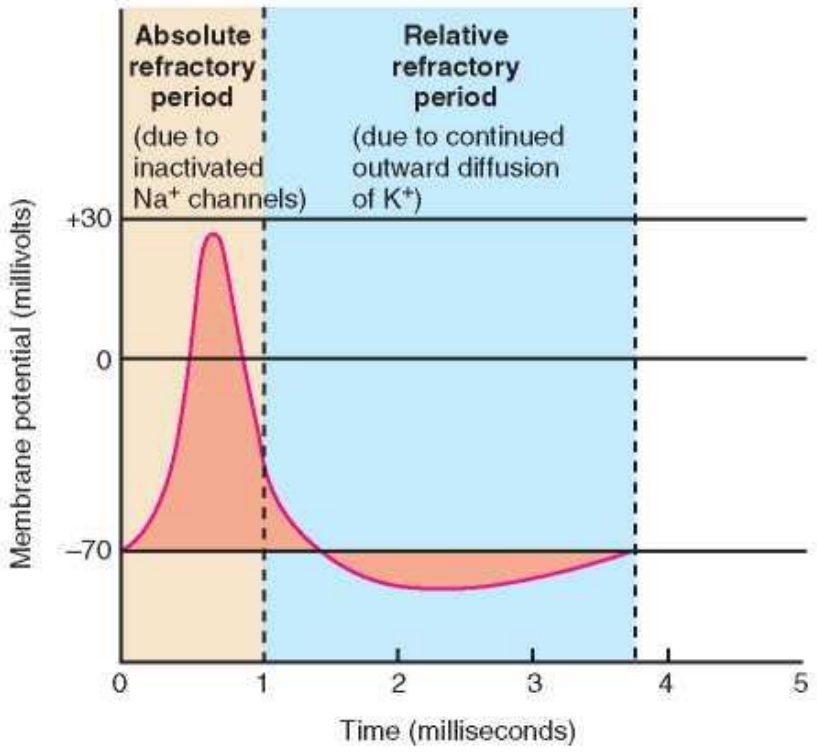
MEMBRANE POTENTIAL CHANGES AND ION MOVEMENTS DURING AN ACTION POTENTIAL



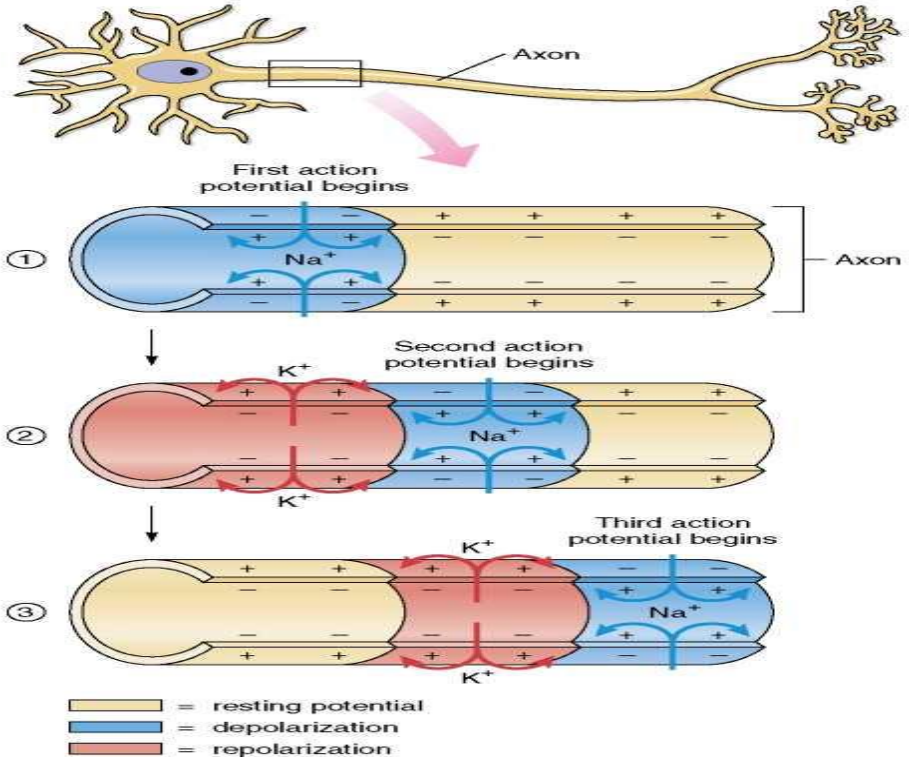
An action potential (top) is produced by an increase in sodium diffusion that is followed, after a short delay, by an increase in potassium diffusion (bottom).

- When the axon membrane has been depolarized to a threshold level, the Na+ gates open and the membrane becomes permeable to Na+. This permits Na+ to enter the axon by diffusion, which further depolarizes the membrane.
- Since the gates for the Na+ channels of the axon membrane are voltage regulated, this additional depolarization opens more Na+ channels and makes the membrane even more permeable to Na+. As a result, more Na+ can enter the cell and induce a depolarization that opens even more voltage-regulated Na+ gates. A positive feed-back loop is thus created, causing the rate of Na+ entry and depolarization to accelerate in an explosive fashion.
- The explosive increase in Na+ permeability results in a rapid reversal of the membrane potential in that region from -70 mV to +30 mV. At that point in time, the channels for Na+ close (they actually become inactivated), causing a rapid decrease in Na+ permeability. Also at this time, as a result of a time-delayed effect of the depolarization, voltage-gated K+ channels open and K+ diffuses rapidly out of the cell. Since K+ is positively charged, the diffusion of K+ out of the cell makes the inside of the cell less positive, or more negative, and acts to restore the original resting membrane potential of -70 mV.
- The last process is called repolarization and represents the completion of a negative feedback loop. These changes in Na+ and K+ diffusion and the resulting changes in the membrane potential they produce constitute an event called the **action potential, or nerve impulse**.

ACTION POTENTIALS IN AN UNMYELINATED AXON

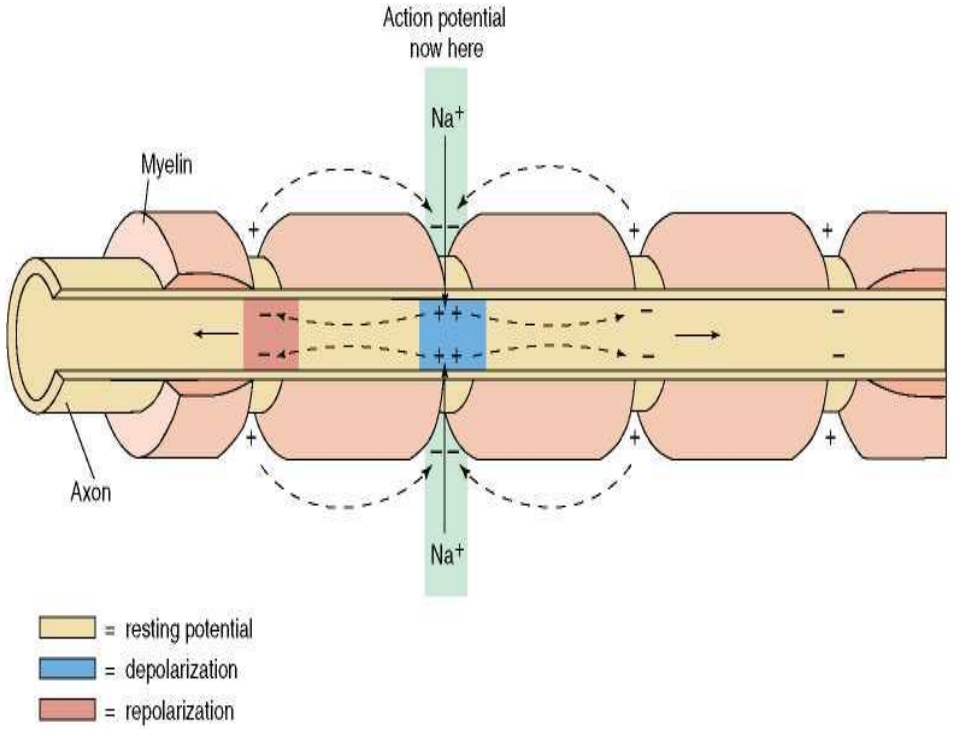


Absolute and relative refractory periods. While a segment of axon is producing an action potential, the membrane is absolutely or relatively resistant (refractory) to further stimulation.



Action potential "injects" positive charges that spread to adjacent regions. The region that has just produced an action potential is refractory. The next region, not having been stimulated previously, is partially depolarized. As a result, its voltage-regulated Na+ gates open and the process is repeated. Successive segments of the axon regenerate, or "conduct," the action potential.

THE CONDUCTION OF A NERVE IMPULSE IN A MYELINATED AXON

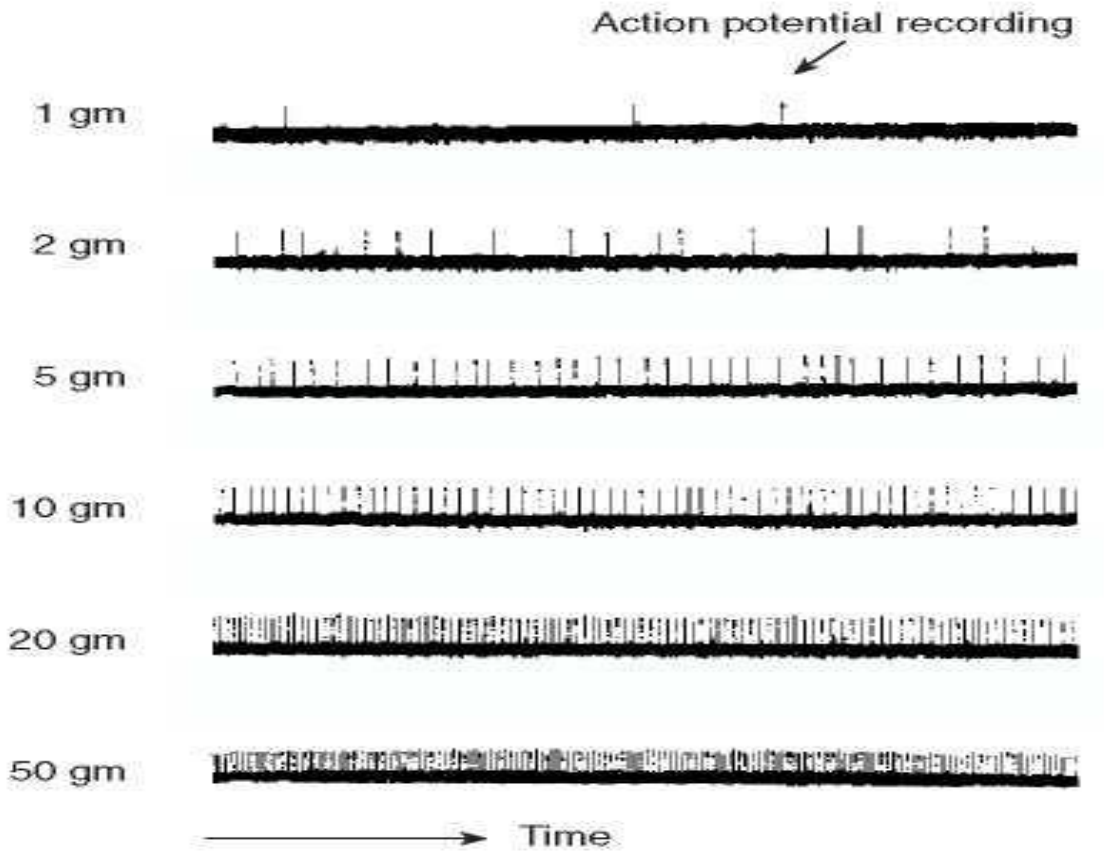


Since the myelin sheath prevents inward Na+ current, action potentials can be produced only at gaps in the myelin sheath called the nodes of Ranvier. This "leaping" of the action potential from node to node is known as salutatory conduction.

CONDUCTION VELOCITIES AND FUNCTIONS OF MAMMALIAN NERVES OF DIFFERENT DIAMETERS

Diameter (μm)	Conduction Velocity (m/sec)	Examples of Functions Served
12–22	70–120	Sensory: muscle position
5–13	30–90	Somatic motor fibers
3–8	15–40	Sensory: touch, pressure
1–5	12–30	Sensory: pain, temperature
1–3	3–15	Autonomic fibers to ganglia
0.3–1.3	0.7–2.2	Autonomic fibers to smooth and cardiac muscles

CODING FOR THE STIMULUS INTENSITY



The effect of stimulus strength on action potential frequency. These are recordings from a single sensory fiber of the sciatic nerve of a frog stimulated by varying degrees of stretch of the gastrocnemius muscle. Notice that increasing degrees of stretch (indicated by increasing weights attached to the muscle) result in a higher frequency of action potentials.

- Because action potentials are all-or-none events, a stronger stimulus cannot produce an action potential of greater amplitude.
- The code for stimulus strength in the nervous system is not amplitude modulated (AM). When a greater stimulus strength is applied to a neuron, identical action potentials are produced more frequently (more are produced per second). Therefore, the code for stimulus strength in the nervous system is frequency modulated (FM).
- When an entire collection of axons (in a nerve) is stimulated, different axons will be stimulated at different stimulus intensities. A weak stimulus will activate only those few axons with low thresholds, whereas stronger stimuli can activate axons with higher thresholds. As the intensity of stimulation increases, more and more axons will become activated. This process, called **recruitment**, represents another mechanism by which the nervous system can code for stimulus strength.

REVIEW QUESTIONS

1. Define the terms depolarization and repolarization, and illustrate these processes graphically.

2. Describe how the permeability of the axon membrane to Na+ and K+ is regulated and how changes in permeability to these ions affect the membrane potential.

3. Describe how gating of Na+ and K+ in the axon membrane results in the production of an action potential.

4. Explain the all-or-none law of action potentials and describe the effect of increased stimulus strength on action potential production. How do the refractory periods affect the frequency of action potential production?

5. Describe how action potentials are conducted by unmyelinated nerve fibers. Why is saltatory conduction in myelinated fibers more rapid?

6. What does it mean the term “apoptosis”?

7. Explain differences between afferent and efferent fibers.