Membrane Potentials and Action Potentials

Electrical potentials exist across the membranes of virtually all cells of the body.

Membrane Potentials Caused by Ion Concentration Differences Across a Selectively Permeable Membrane

. potassium concentration is great inside a nerve fiber membrane but very low outside the membrane. There is a strong tendency for potassium ions to diffuse outward through the membrane, they carry positive electri-cal charges to the outside, thus creating electropositivity outside the membrane and electronegativity inside. The potential difference between the inside and outside,called the ***Diffusion Potential .***

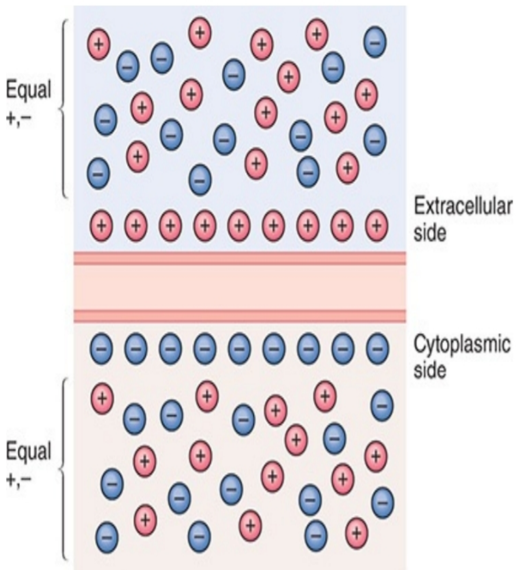


FIGURE 4–3 **A membrane potential results from separation of positive and negative charges across the cell membrane.** The excess of positive charges (red circles) outside the cell and negative charges (blue circles) inside the cell at rest represents a small fraction of the total number of ions present.

The **Nernst Equation** Describes the Relationship of Diffusion Potential to the Ion Concentration Difference Across a Membrane.Th e diffusion potential across a membrane that exactly opposes the net diffusion of a particular ion through the membrane is the called ***Nernst potential for that ion***

called the *Nernst equation*, can be used to calculate the Nernst potential for any univalent ion at the normal body temperature of 98.6°F (37°C):

$$\text{EMF (millivolts)} = \pm \frac{61}{z} \times \log \frac{\text{Concentration inside}}{\text{Concentration outside}}$$

where EMF is the electromotive force and z is the electrical charge of the ion (e.g., +1 for K^+).

When using this formula, it is usually assumed that the potential in the extracellular fl uid outside the mem-brane remains at zero potential, and the Nernst potential is the potential inside the membrane.

Resting Membrane Potential➡

represents an equilibrium situation at which the driving force for the membrane-permeant ions down their concentration gradients across the membrane is equal and opposite to the driving force for these ions down their electrical gradients.

Th e resting membrane potential of large nerve fi bers when they are not transmitting nerve signals is about −70 mil-livolts., Because there are more open K+ channels than Na+ channels at rest, the membrane permeability to K+ is greater. Consequently, ***the intracellular and extracellular K+ concentrations are the prime determinants of the resting membrane potential*** ,

▪cardiac pacemaker cells are never “resting"

▪In many other cells, even excitable cells, there is a quiescent period in which a resting membrane potential can be measured.The resting membrane potential is,only a brief transient state for many cells.

Goldman Equation ➡Is Used to Calculate the Dif-fusion Potential When the Membrane Is Permeable to Several Different Ions.

called the *Goldman equation* or the *Goldman-Hodgkin-Katz equation,* gives the calculated membrane potential on the *inside* of the membrane when two univalent positive ions, sodium (Na^+) and potassium (K^+), and one univalent negative ion, chloride (Cl^-), are involved:

$$\text{EMF (millivolts)} = -61 \times \log \frac{C_{Na_i^+} P_{Na^+} + C_{K_i^+} P_{K^+} + C_{Cl_o^-} P_{Cl^-}}{C_{Na_o^+} P_{Na^+} + C_{K_o^+} P_{K^+} + C_{Cl_i^-} P_{Cl^-}}$$

Active Transport of Sodium and Potassium Ions Through the Membrane—the Sodium- Potassium (Na+- K+) Pump➡

.all cell mem-branes of the body have a powerful Na+- K+ pump, it is an electrogenic pump➡three Na+ ions are pumped to the outside ⏪ for each two K+ ions to the inside, leaving a net deficit of positive ions on the inside and causing a negative potential inside the cell membrane.

Potassium [K+] "leak" channel➡ in the nerve membrane through which potassium ions can leak, even in a resting cell.These K+ leak channels may also leak sodium ions slightly.

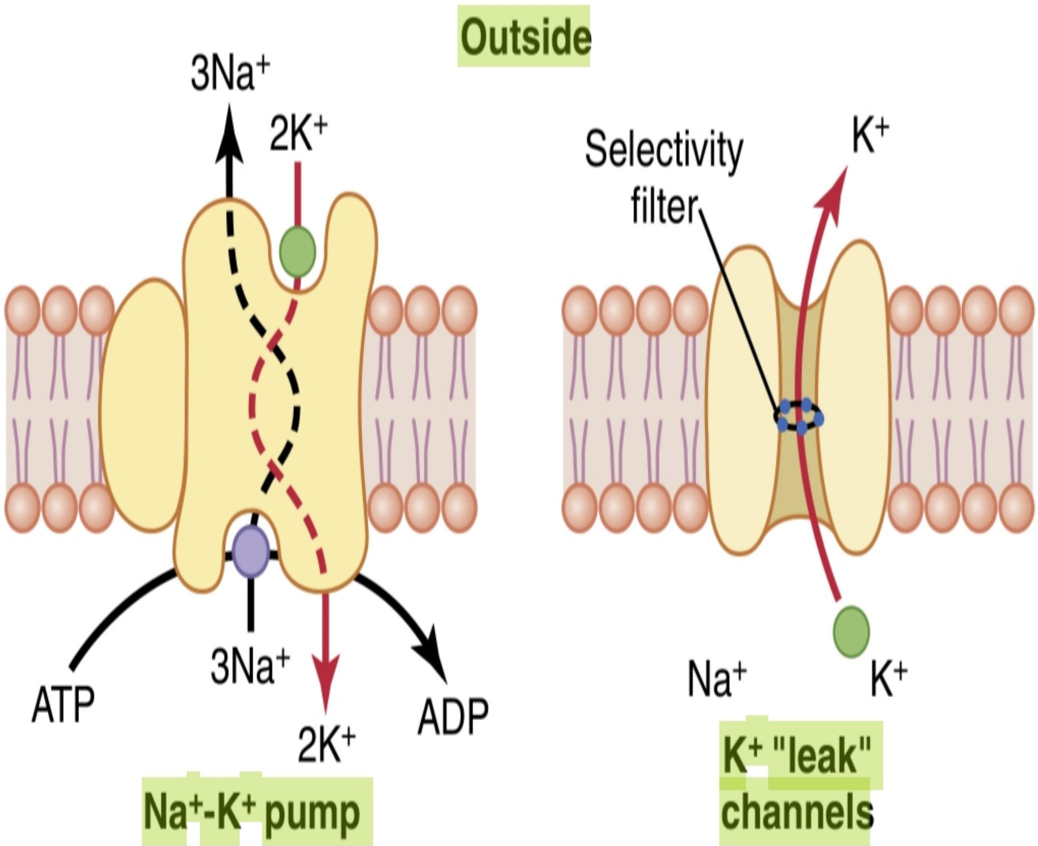


Figure 5-4 Functional characteristics of the Na^+-K^+ pump and the K^+ "leak" channels. The K^+ leak channels also leak Na^+ ions into the cell slightly but are much more permeable to K^+. ADP, Adenosine diphosphate; ATP, adenosine triphosphate.

NEURON ACTION POTENTIAL Nerve signals are transmitted by action potentials, which are rapid changes in the membrane potential that spread rapidly along the nerve fi ber membrane.

successive stages of the action potential are as follows...

Resting Stage. ➡The resting stage is the resting membrane potential before the action potential begins. ie - –70 mV.

.Depolarization Stage➡membrane sud-denly becomes permeable to sodiumrapid dif f usion of positively charged sodium ions to the interior of the axon.potential rising rapidly in the positive direction—a process called depolarization.

Repolarization Stage➡sodium channels begin to close, and the potassium channels open to a greater degreerapid dif f usion of potassium ions to the exterior re- establishes the normal negative resting membrane poten-tial, which is called repolarization of the membrane.

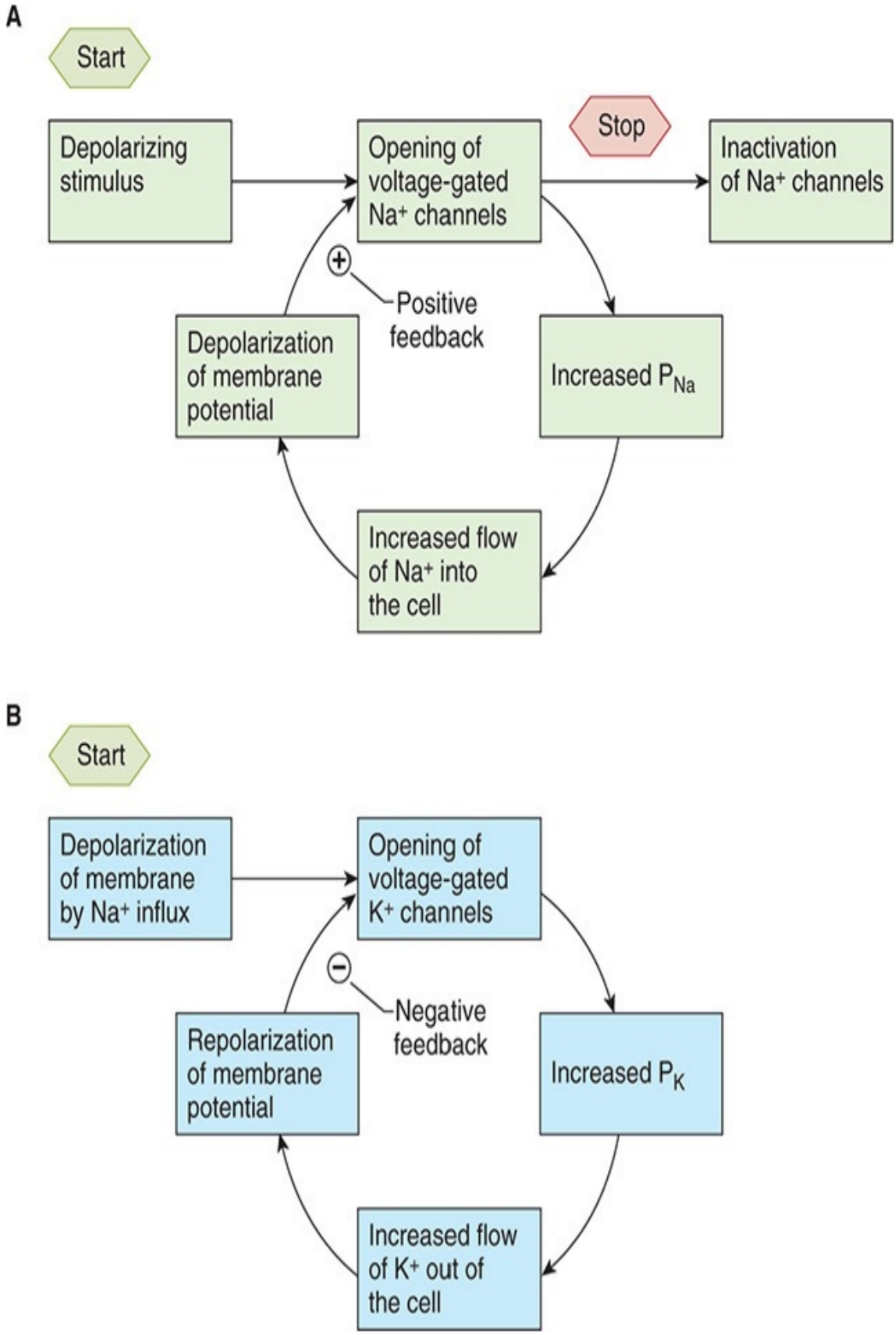


FIGURE 4–5 Feedback control in voltage-gated ion channels in the membrane. A) Na^+ channels exert positive feedback. **B)** K^+ channels exert negative feedback. P_{Na}, P_K is permeability to Na^+ and K^+, respectively.

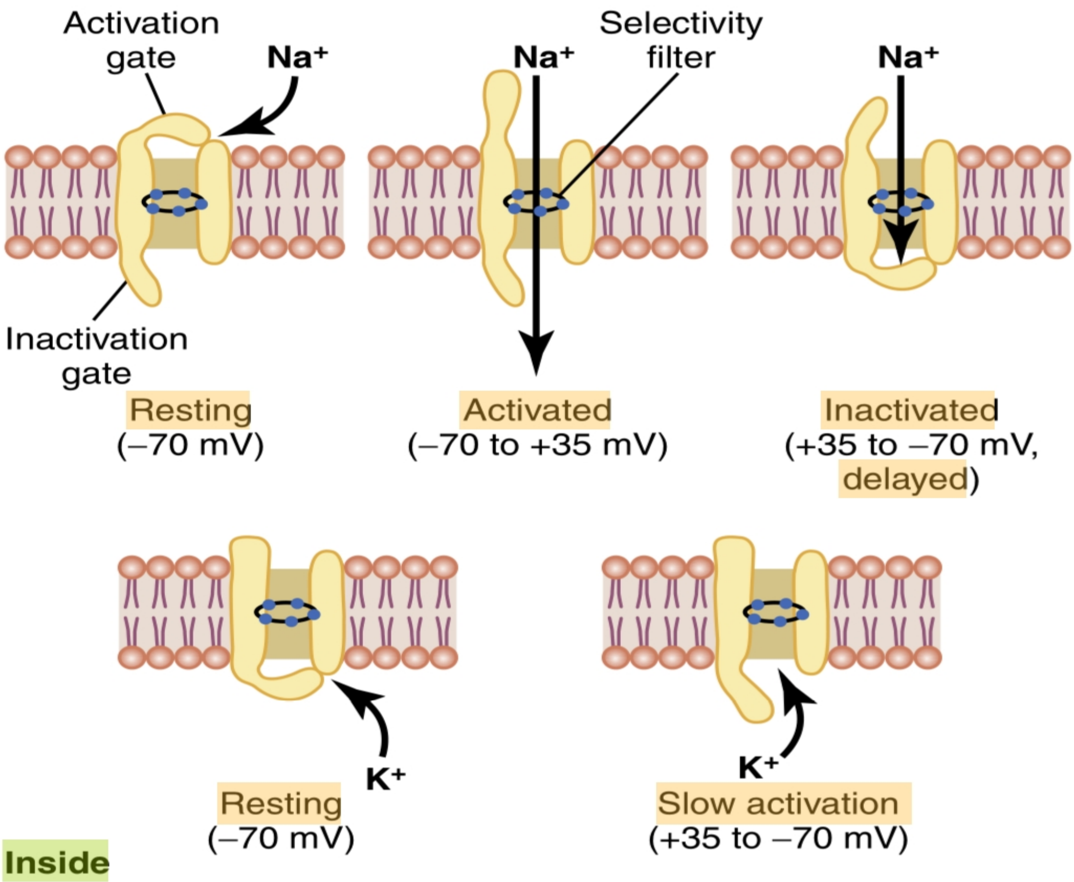


Figure 5-7 Characteristics of the voltage-gated sodium *(top)* and potassium *(bottom)* channels, showing successive activation and inactivation of the sodium channels and delayed activation of the potassium channels when the membrane potential is changed from the normal resting negative value to a positive value.

Roles of Other Ions During the Action Potential

Impermeant Negatively Charged Ions (Anions) are present Inside the Nerve Axon➡.Th ey include the anions of protein molecules and of many organic phosphate compounds and sulfate com-pounds, among others.

Because these ions cannot leave the interior of the axon➡,responsible for the negative charge inside the fi ber.

Body have a calcium pump similar to the sodium pump, ➡

calcium serves along with (or instead of) sodium in some cells to cause most of the action potential.

voltage- gated calcium channels➡

.major function of the voltage- gated calcium ion channels is to contribute to the depolarizing phase on the action potential in some cells.

gating relatively slow➡called slow channels,{in contrast to the sodium channels, which are called fast channels}.

When there is a def i cit of calcium ions,➡ the sodium channels become activated (opened) by a small increase of the membrane potential from its normal, very negative level. ➡Th erefore, the nerve fi ber becomes highly excitable, sometimes discharging repetitively without provocation often causing **muscle “tetany**.”

INITIATION OF THE ACTION POTENTIAL➡

- no action potential occurs in the normal nerve.
- .if any event causes enough initial rise in the membrane potential from −70 millivolts toward the zero level,➡voltage- gated sodium channels begin opening.➡rapid inf l ow of sodium ion➡rise in the membrane potential,➡opening still more voltage- gated sodium channels and allowing more stream-ing of sodium ions to the interior of the fi ber.➡Positive Feedback Cycle .
- A sudden rise in membrane potential of 15 to 30 millivolts is usually required for➡ Initiation of the Action Potential. Th is occurs when the number of sodium ions entering the fi ber is greater than the number of potassium ions leaving the fi ber.
- A sudden increase in the membrane potential in a large nerve fi ber, from −70 millivolts up to about −55 millivolts, usually causes the explosive devel-opment of an action potential. Th is level of −55 millivolts is said to be the threshold for stimulation.

PROPAGATION OF THE ACTION POTENTIAL

- an action potential elicited at any one point on an excitable membrane usually excites adjacent portions of the membrane, resulting in propagation of the action potential along the membrane transmission of the depolarization process along a nerve or muscle fi ber is called a nerve or muscle impulse.

Direction of Propagation➡.action potential travels in all directions away from the stimulus—even along all branches of a nerve fi ber—until the entire membrane has become depolarized.

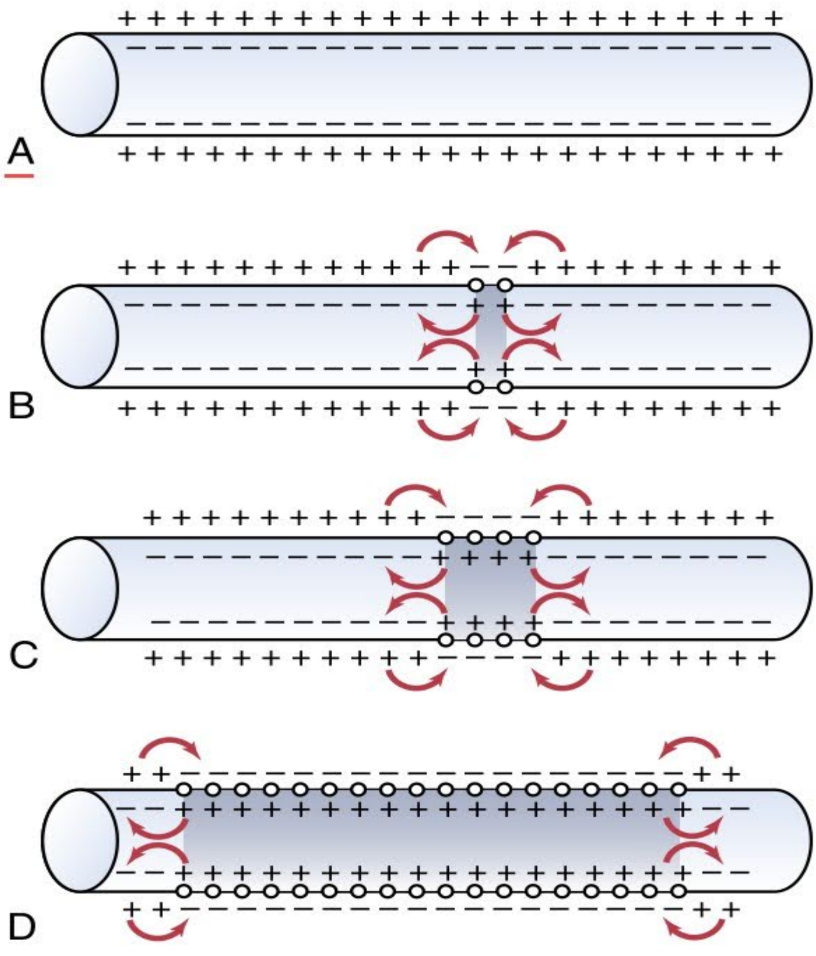


Figure 5-11 A–D, Propagation of action potentials in both directions along a conductive fiber.

All- or- Nothing Principle➡depolarization process travels over the entire membrane if conditions are right, but it does not travel at all if conditions are not right. Th is principle is called the all- or- nothing principle

ratio of action potential to threshold for excitation must at all times be greater than one. Th is “greater than 1” requirement is called the safety factor for propagation.

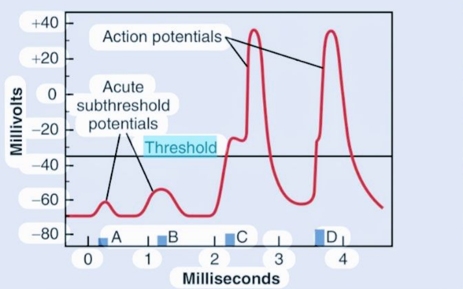


Figure 5-18 Effect of stimuli of increasing voltages to elicit an action potential. Note the development of acute subthreshold potentials when the stimuli are below the threshold value required for eliciting an action potential.

REFRACTORY PERIODS➡neuron is refractory to stimulation.

The refractory period is divided into

➡ an absolute refractory period, corresponding to the period from the time the firing level is reached until repolarization is about one-third complete, and ➡a relative refractory period, lasting from this point to the start of after-depolarization

During the **absolute refractory period**, no stimulus, no matter how strong, will excite the nerve

during the **relative refractory period**, stronger than normal stimuli can cause excitation.

Na+- K+ pump re-establishes the sodium and potassium membrane concentration differences (ie. recharging” of the nerve fiber)

,this pump requires energy for operation, derived from the adenosine tri-phosphate (ATP)➡Heat is produced.

In some cases, the excited membrane does not repolarize immediately after depolarization; instead, the potential remains on a plateau for many milliseconds before repolarization begin ,

plateau greatly prolongs the period of depolarization.

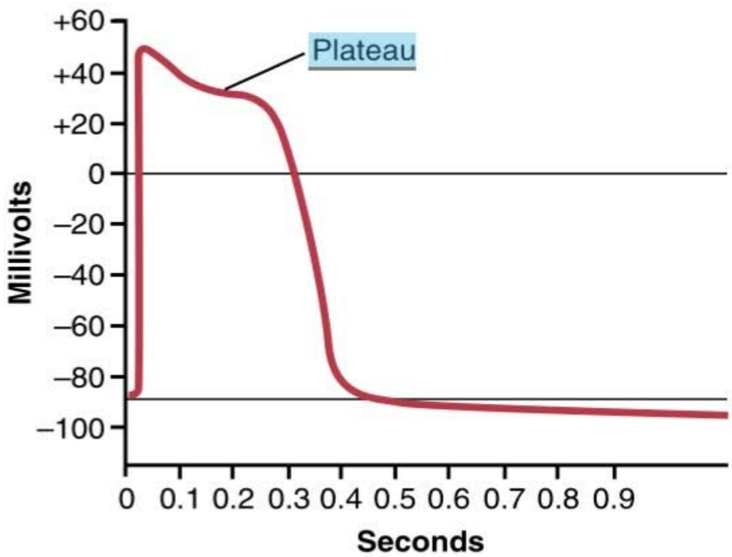


Figure 5-13 Action potential (in millivolts) from a Purkinje fiber of the heart, showing a plateau.

➡ ***This type of action potential occurs in heart muscle fibers*** .

In heart muscles two types of channels contribute to the depolarization process: (1)sodium channels,fast channels

(2) voltage-activated calcium- sodium channels(L- type calcium channels)slow channels.

Opening of fast channels causes the spike portion of the action potential, whereas the prolonged opening of the slow channels mainly allows calcium ions to enter the fiber, which is largely responsible for the plateau portion of the action potential.

RHYTHMICITY OF SOME EXCITABLE TISSUES—REPETITIVE DISCHARGE

Repetitive self- induced discharges occur normally in the heart, in most smooth muscle, and in many of the neurons of the central nervous system. Th ese rhythmi-cal discharges cause the following: (1) rhythmical beat of the heart; (2) rhythmical peristalsis of the intestines;

and (3) neuronal events such as the rhythmical control of breathing.

Key points

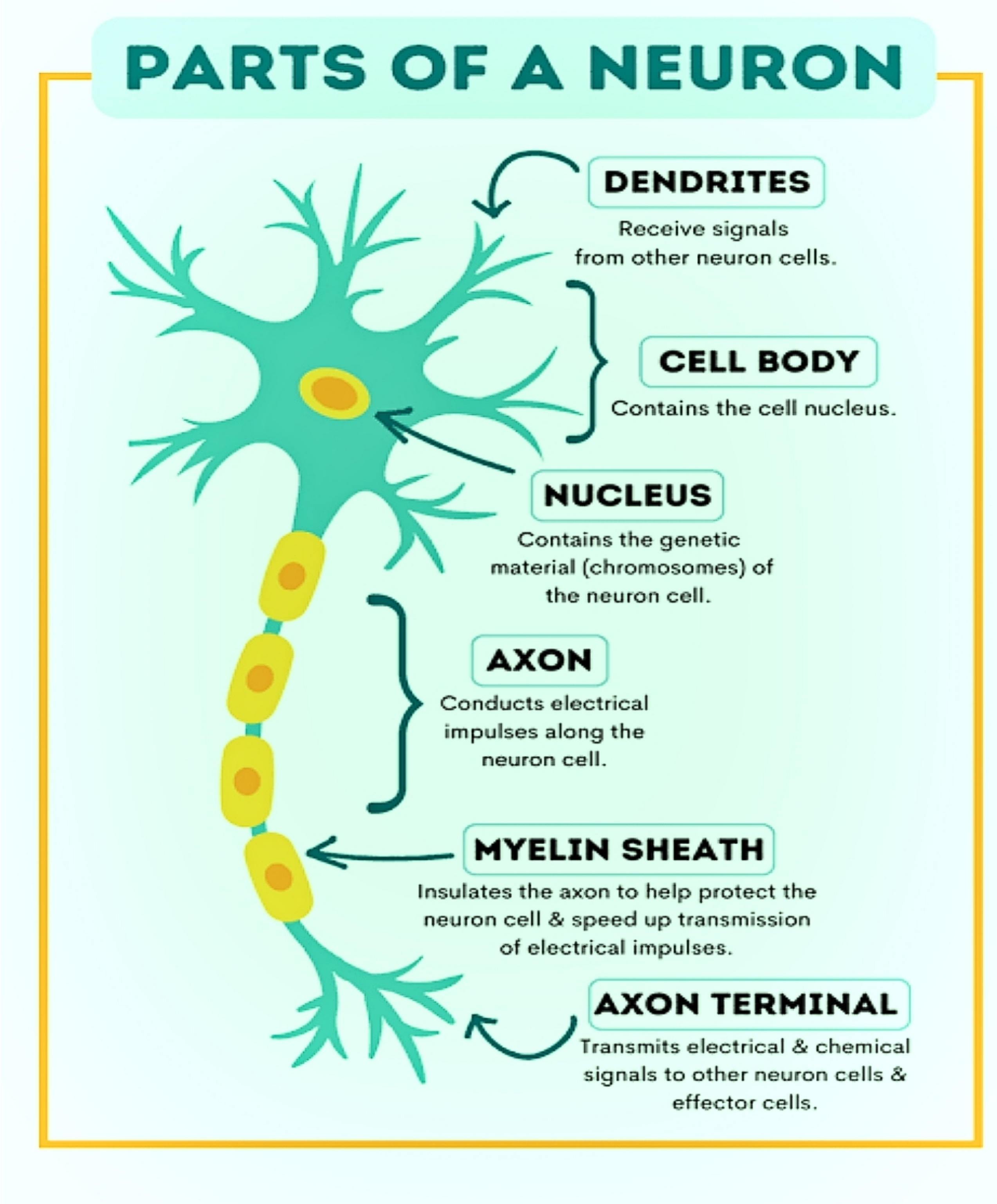
▲ In general, the greater the diameter of a given nerve fiber, the greater its speed of conduction.

▲ pressure on a nerve can cause loss of conduction in large-diameter motor, touch, and pressure fibers while pain sensation remains relatively intact.

Patterns of this type are sometimes seen in individuals who sleep with their arms under their heads for long periods, causing compression of the nerves in the arms ➡**Saturday night or Sunday morning paralysis.**

THE NEURON: BASIC WORKING UNIT OF THE NERVOUS SYSTEM

basic components of a neuron for the prototypical spinal motor neuron.➡



*The **cell body (soma)** contains the nucleus

*Neurons have several processes called **dendrites** that extend outward from the cell body and arborize extensively to aid their role in receiving incoming signals, processing the information, and then transmitting the information to the soma of the neuron.

*typical neuron also has a long fibrous **axon** that originates from a thickened area of the cell body (axon hillock).

The first portion of the axon is called the initial segment.The **axon terminal** divides into presynaptic knobs that are also called terminal buttons or boutons.

They contain granules or vesicles in which the synaptic transmitters released by the nerves are stored.

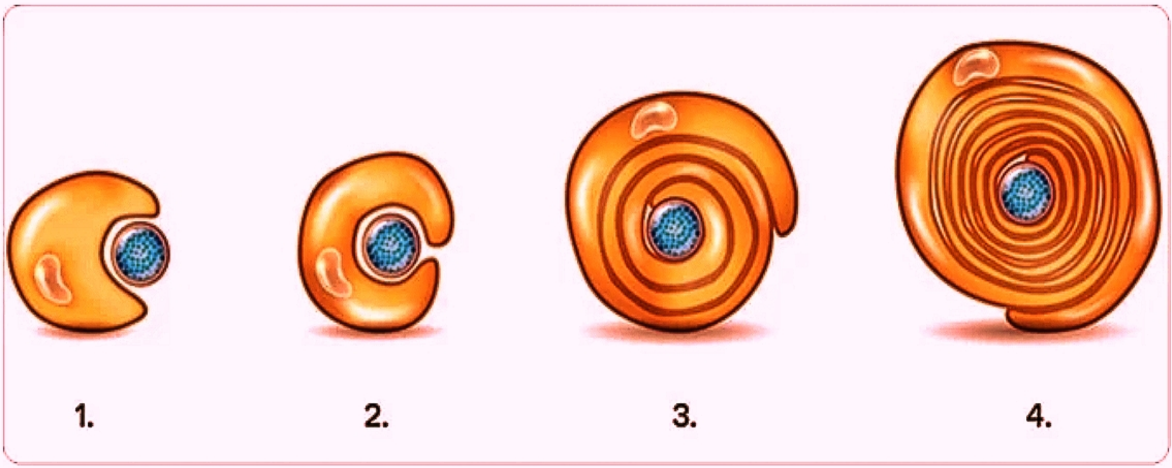
*Th e axon is filled in its center with axoplasm.

In myelinated nerves ➡Surrounding the axon is a myelin sheath.

myelin sheath is deposited around the axon by Schwann cells containing ➡the lipid substance sphingomyelin. This substance is an excellent **electrical insulator.**

At the juncture between each two successive Schwann cells along the axon, a small uninsulated area only 2 to 3 micrometers in length called the **node of Ranvier**.

The average nerve trunk contains about twice as many unmyelinated fibers as myelinated fibers.



Myelin sheath of the neuron. A schwann cell envelops and rotates around the axon forming myelin sheath, now axon is myelinated.

Saltatory Conduction in Myelinated Fibers from Node to Node.➡

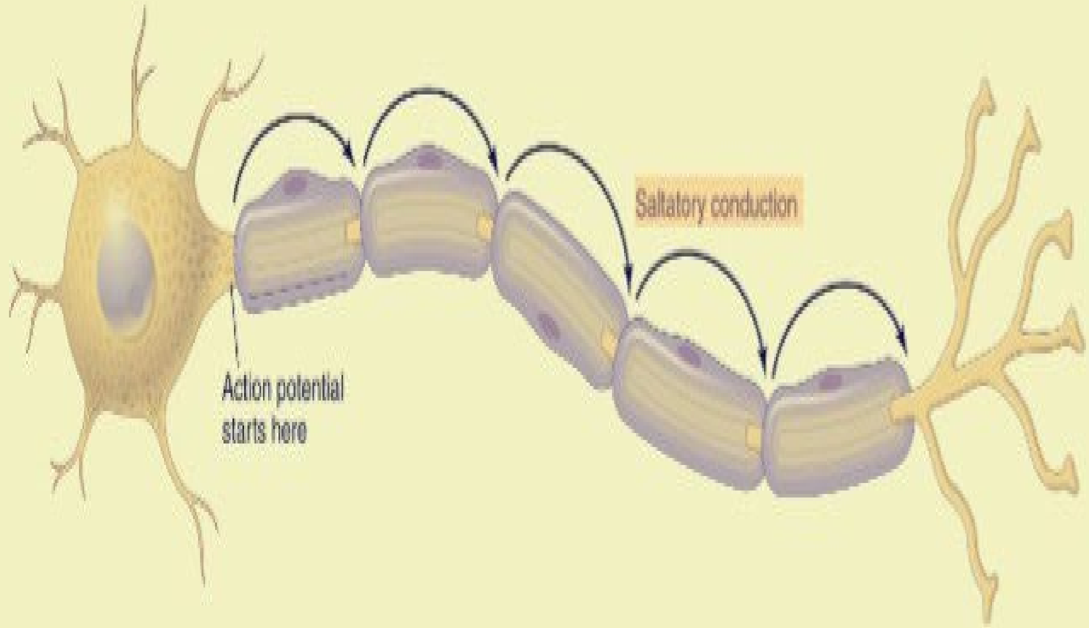
in Myelinated Fibers ,action potentials occur only at the nodes of Ranvier.

That is, electrical current fl ows through the surrounding extracellular fluid outside the myelin sheath, as well as through the axoplasm inside the axon from node to node, exciting successive nodes one after another. Th us, the nerve impulse jumps along the fiber, which is c/a saltatory conduction .

saltatory conduction ;is of value for two reasons:

(1).increases the velocity of nerve transmis-sion in myelinated fi bers as much as 5- to 50- fold.

(2).conserves energy



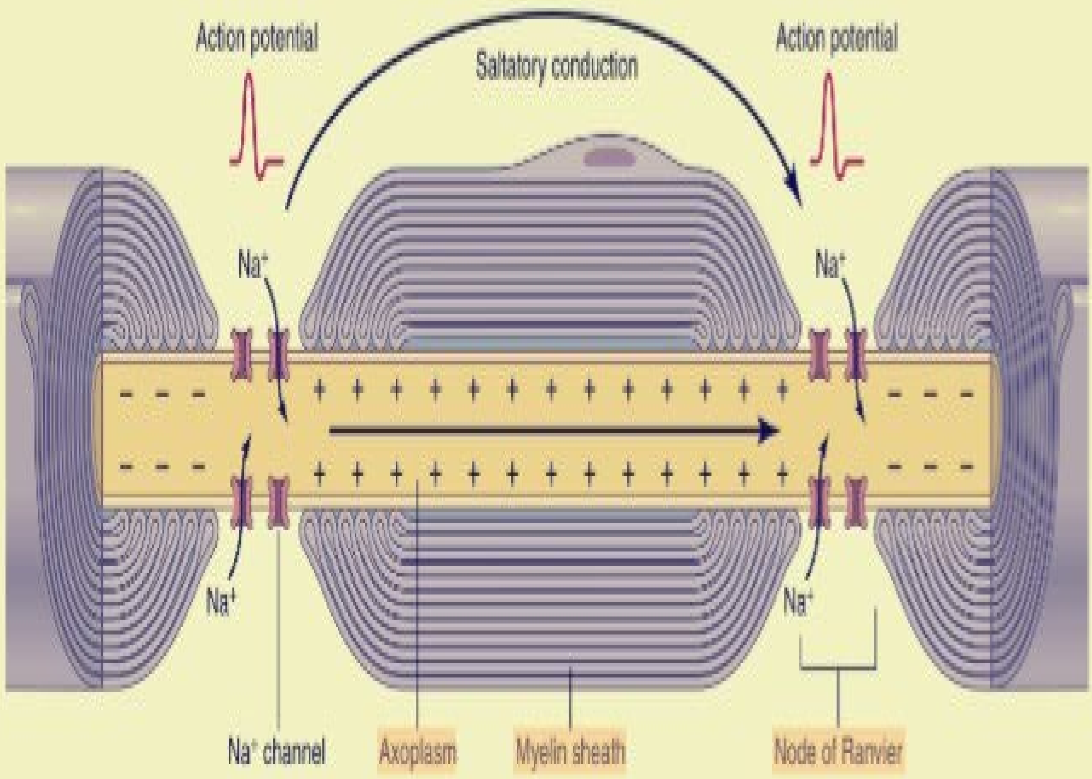


Figure 5-17 Saltatory conduction along a myelinated axon. The flow of electrical current from node to node is illustrated by the arrows.

Velocity of Conduction in Nerve Fibers

 * in small unmyelinated fibers

➡0.25 m/sec

*in large myelinated fibers

➡ up to 100 m/sec

Local anesthetics depress transmission in the unmyelinated fibres before they affect the myelinated fibres.

GLIA➡The word glia is Greek for glue.Glial cells are the “glue” of the nervous system, engaging in many activities to support typical brain function. They do this by facilitating communication between neurons, regulating inflammation and forming the blood-brain barrier.

Types➡

Demyelinating Diseases

defects in myelin can have major adverse neurologic consequences.One example is MS, an autoimmune diseaseIn MS, antibodies and white blood cells in the immune system attack myelin,Loss of myelin leads to failure to conduct action potentials. ➡Neurological problems .