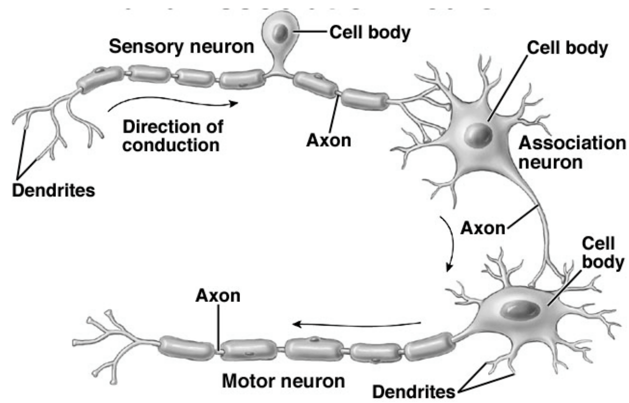
The Nervous System

Nervous system links sensory receptors and motor effectors

Sensory (afferent) neurons carry impulses from receptors

Motor (efferent) neurons carry impulses to effectors - muscles and glands

Association neurons (interneurons) are present in most nervous systems - found in brain and spinal cord (CNS)



Association neurons allow for integration of information, reflexes and associative functions (decision making)

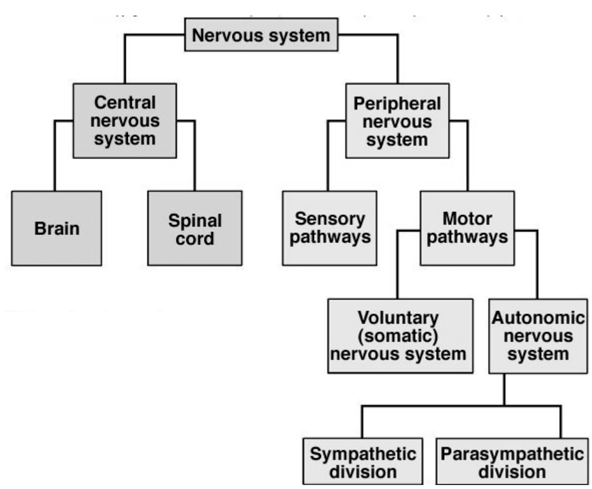
Peripheral nervous system (PNS) is composed of sensory and motor neurons

Somatic motor neurons stimulate skeletal muscle contraction

Autonomic motor neurons regulate smooth and cardiac muscle, glands

Autonomic system has sympathetic and parasympathetic divisions

Act antagonistically.

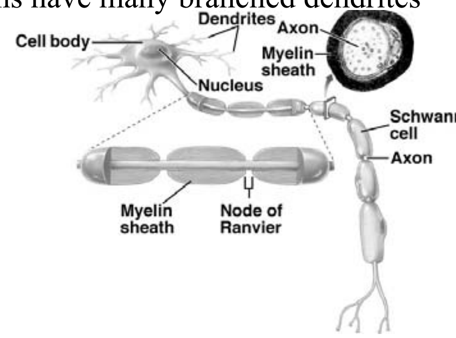


Neuron Structure and Function

Cell body - an enlarged region containing nucleus

Dendrites extend from cell body -
- branched cytoplasmic extensions
- Motor and association neurons have many branched dendrites

Axon - a long
- extension of the cell for signal transmission
- usually only one per cell



Cell can receive input from many sources

Surface of cell body integrates information from dendrites

If input is sufficient an nerve impulse is sent along axon

Wave of depolarization travels outward from cell body

Neurons have supporting cells
- called neuroglia in CNS
- include Schwann cells and oligodendrocytes
- Either cell can envelop axon, forming myelin sheath
- Nodes of Ranvier - gaps between cells

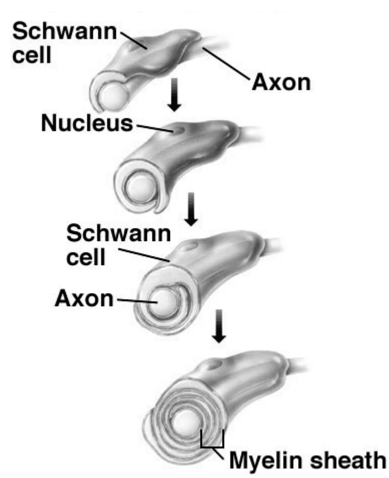
Schwann cells produce myelin in PNS

Oligodendrocytes produce myelin in CNS

Myelin sheath insulates neuron in layers of neuroglial cell membranes

Myelination increases speed of nerve impulse

In brain -
- white matter is myelinated
- gray matter is not myelinated



Nerve impulses are produced on the axon membrane

There is a charge difference across the plasma membrane in all cells called the "membrane potential"

Interior of cell is negative relative to extracellular side

Resting membrane potential - the charge difference in a cell at rest about 70 millivolts (-70 mV)

Membrane potential due to three factors

- sodium-potassium pumps ($3\ Na^+$ out for $2\ K^+$ in)
- different permeability for different ions
- most important is the presence of fixed anions (-) proteins and organic phosphates

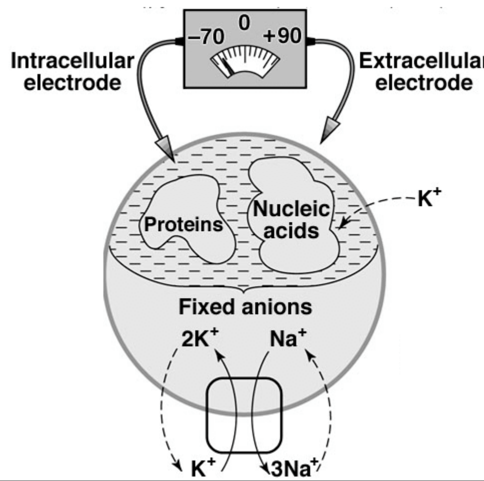


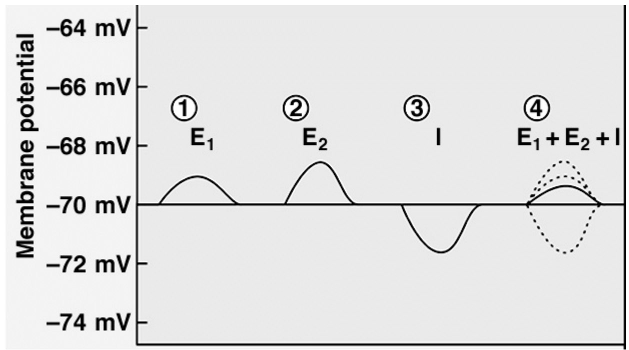
Table 54.1 The Ionic Composition of Cytoplasm and Extracellular Fluid (ECF)				
Ion	Concentration in Cytoplasm (mM)	Concentration in ECF (mM)	Ratio	Equilibrium Potential (mV)
Na^+	15	150	10:1	+60
K^+	150	5	1:30	–90
Cl^-	7	110	15:1	–70

Each ion has its own equilibrium potential - influenced by concentration and charge differences

For K^+ - there is 30x more inside cell than outside - K^+ will diffuse out due to a concentration difference - but it is also attracted to the negative charges inside the cell - if not held by negative charges it would move (out) until the membrane potential was -90 mV

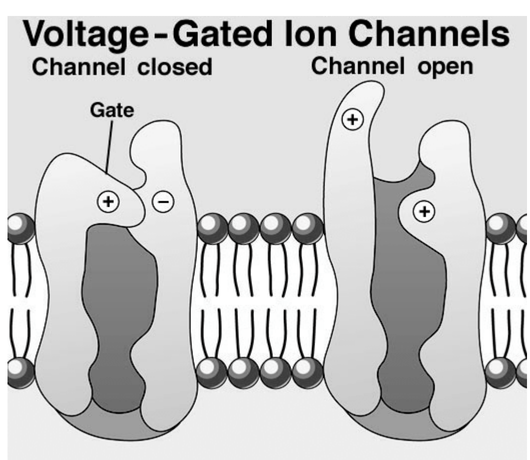
At rest, the concentration differences of all ions across the cell membrane, and differences in membrane permeability, result in an overall charge difference of -70 mV

Cell membrane potential can change in response to stimulation
Depolarization - becomes less negative (-70 mV to -50 mV)
Hyperpolarization - becomes more negative (-70mV to -85 mV)



Nerve and muscle cells have Na^+ and K^+ channels that are sensitive to change in the membrane potential - “voltage-gated channels”
Protein pore opens or closes with change in membrane potential
At rest, all Na^+ gates are closed, some K^+ gates are open

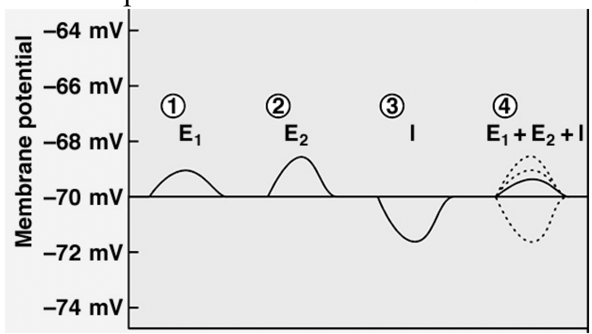
Different types of stimulation can cause a channel to open or close



Excitatory stimulation causes depolarization (less negative) - due to some Na^+ gates opening

Inhibitory stimulation causes hyperpolarization (more negative) - due to some K^+ gates closing, or Cl^- gates opening

The effects of multiple simultaneous stimuli are summed



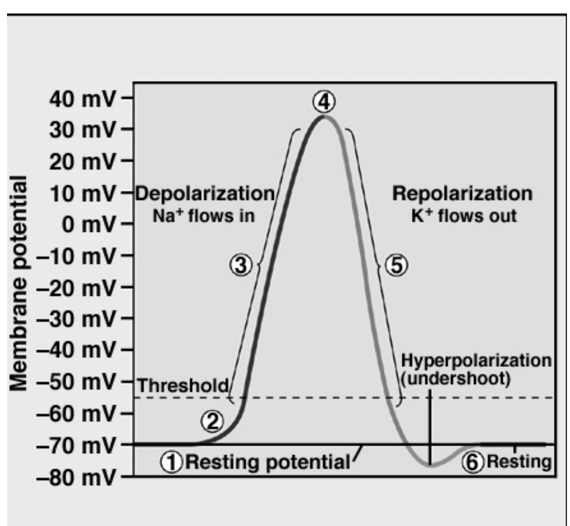
Small scale stimulation - causing a slight change in membrane permeability and membrane potential is called a "graded potential" - followed by a return to the resting membrane potential

If a graded potential reaches the "threshold potential" then a sequences of changes in membrane permeability and membrane potential begin - called an "action potential"

The threshold potential is usually about -55 mV

Action potential -
- large depolarization
- repolarization
- hyperpolarization
- return to resting

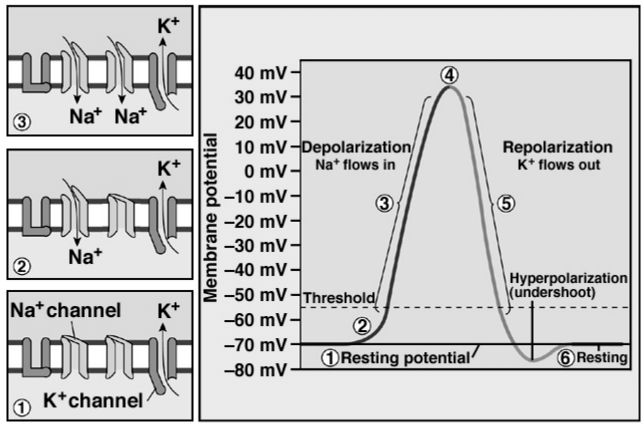
only seen in neurons, muscle cells, and sense organ cells



At rest (1) Na^+ channels are closed and some K^+ channels are open

When stimulated (2) some Na^+ channels open causing small depolarization

If threshold depolarization (3) is reached all Na^+ channels open causing large depolarization



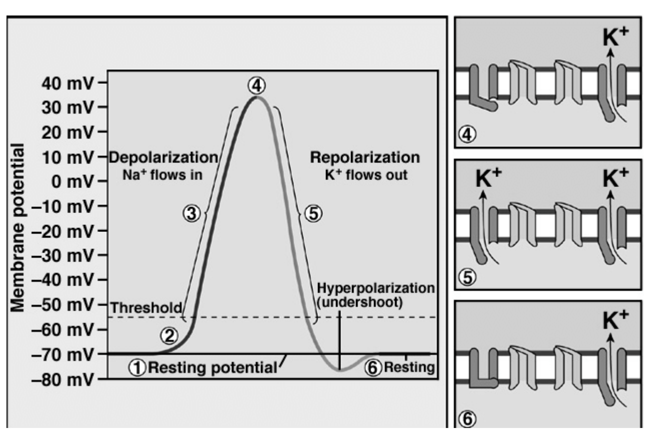
At maximum depolarization (4) Na^+ channels close

K^+ flowing out starts repolarization and opening of all K^+ channels causes complete repolarization (5) and then hyperpolarization

After hyperpolarization, some K channels close and cell returns to resting membrane potential (6)

The entire sequence of changes requires about 0.003 sec.

Following the action potential the Na^+/K^+pump restores the concentration gradients



Action potentials are always of the same intensity - “all or none”

Action potentials can’t be summed - each one is a separate sequence of events

Immediately following an action potential the cell enters a “refractory period” when Na^+ channels can’t be opened again - corresponds to the time in which the Na^+/K^+ pump reestablishes the original concentration gradients

Nerve impulses are action potentials that are propagated along the axon

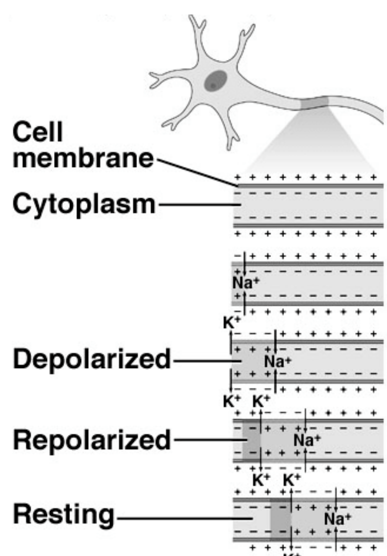
An action potential begins with threshold depolarization at the base of the axon

An action potential in one region causes threshold depolarization the next adjacent region of the axon

A uniform action potential wave travels along the axon - a nerve impulse

All nerve impulses are of the same intensity and magnitude - “all or none”

After a nerve impulse the axon enters a refractory period when it can’t transmit another impulse

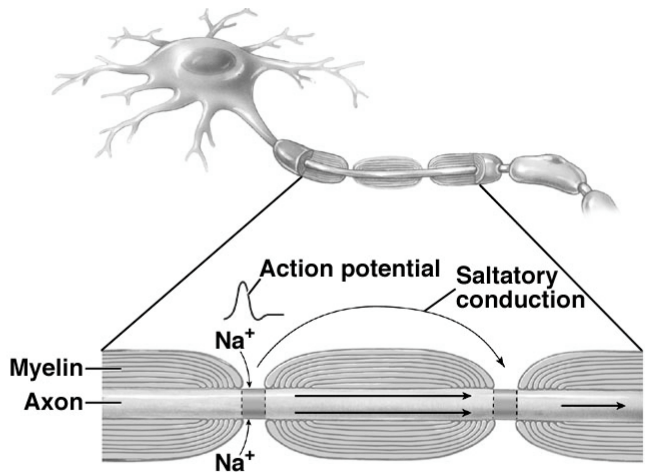


Myelinated neurons conduct action potentials more quickly

Action potentials at one “node of Ranvier” stimulate the next node - rather than the adjacent membrane

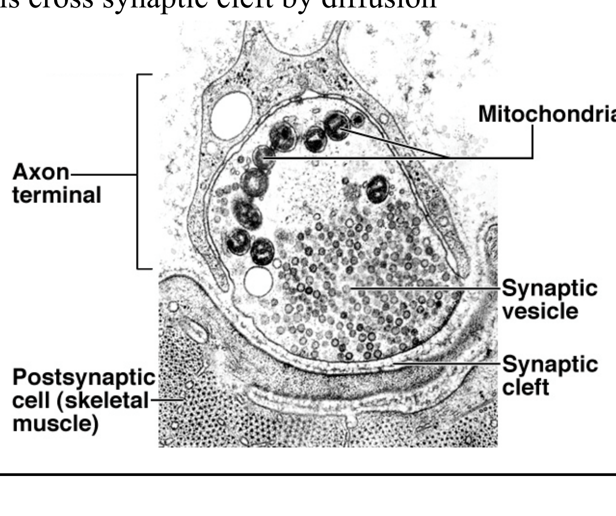
Saltatory conduction - the action potential “jumps” from node to node

Axons of large diameter also transmit action potentials faster



At the terminus of an axon is a synapse - an intercellular junction

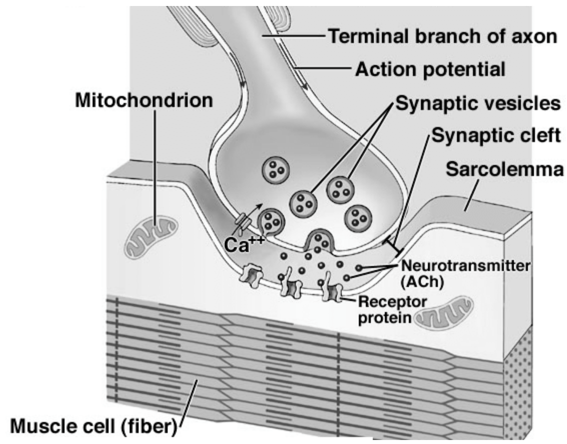
- synapses occur
  - between neurons - axon/dendrite junctions,
  - between neurons and muscles or gland cells
- Synaptic cleft - narrow gap between cells
- Chemical signals cross synaptic cleft by diffusion



Axon terminus has synaptic vesicles - contain neurotransmitters
When an action potential arrives at terminus - voltage-gated Ca^{++} channels opened
Stimulates fusion of synaptic vesicle membrane with plasma membrane - contents released via exocytosis
More action potentials cause more vesicles to release contents

Neurotransmitters diffuse across cleft, bind to receptor proteins - produce change in receiving cell

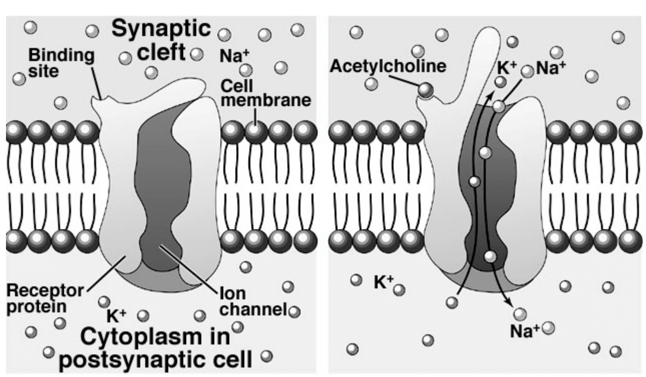
Neurotransmitters are then degraded by enzymes in the synaptic cleft and recycled into the axon



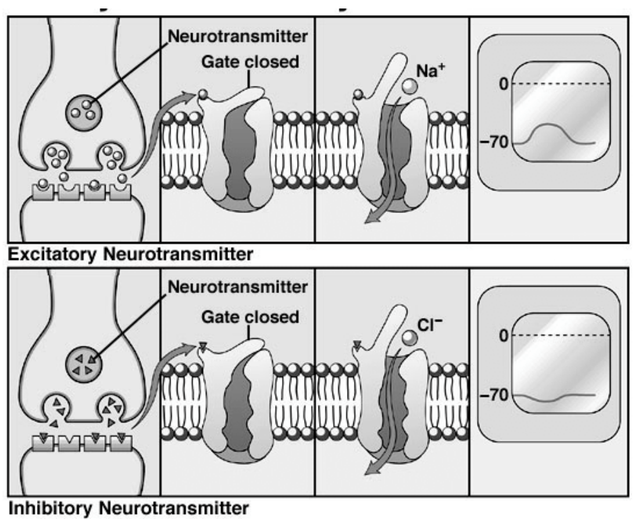
At neuromuscular junctions the neurotransmitter is acetylcholine (ACh)

ACh causes depolarization of muscle cell membrane through the opening of ion channels in the muscle cell membrane

Depolarization is transmitted via T-tubules to the sarcoplasmic reticulum and ultimately causes muscle contraction



Different neurotransmitters have different effects
Excitatory neurotransmitters cause depolarization of receiving cell
Inhibitory neurotransmitters cause hyperpolarization of receiver



Glutamate, Glycine and GABA

Glutamate - excitatory transmitter in vertebrate CNS
- Normal amounts produce physiological stimulation
- Excessive amounts cause neurodegradation

Glycine and GABA (gamma aminobutyric acid)
- Inhibitory neurotransmitters - Cause hyperpolarization
- Opens chemically-regulated gated Cl- channel
- Inward diffusion of Cl- makes inside more negative
- Important for control of body movements, brain functions
- Associated with sedation effects of Valium (diazepam)

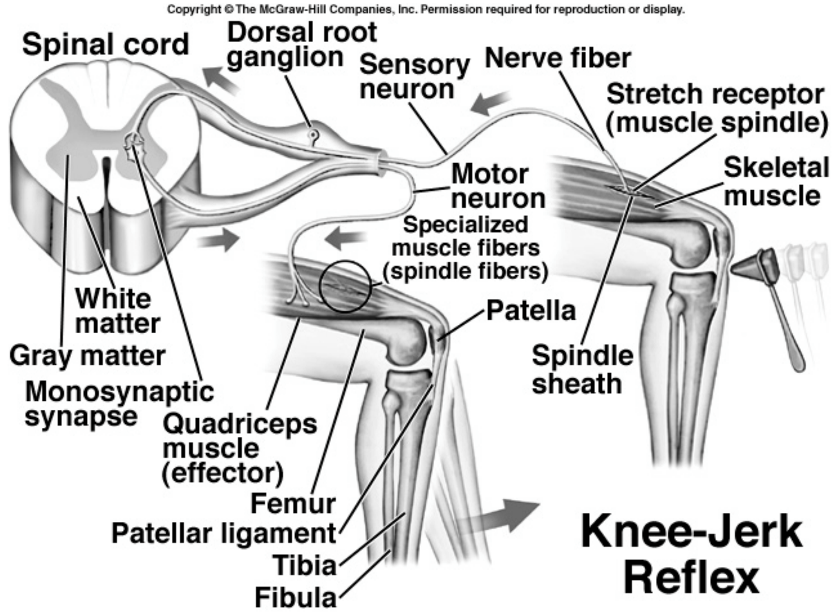
Biogenic Amines - chemicals derived from amino acids
- Epinephrine, dopamine, norepinephrine, serotonin

Epinephrine (adrenaline) is a hormone

Dopamine is a neurotransmitter found in the brain
- Controls body movement and other functions
- Degeneration of dopamine-releasing neurons causes Parkinson's disease
- Schizophrenia associated with excessive dopamine activity

Norepinephrine
- neurotransmitter in the brain and some autonomic neurons
- Complements actions of epinephrine hormone

Serotonin
- helps regulate sleep, implicated in various emotional states
- Insufficient activity of serotonin-producing neurons results in clinical depression
- Some antidepressant drugs block elimination of serotonin from synaptic cleft - e.g. Prozac, Paxil, Zoloft



Knee-Jerk Reflex

Cutaneous Spinal Reflex