

*Regulation & Integration of the Body*

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*Overlapping Functions of Nervous System*

- ▶ 1) sensory receptor utilization to monitor changes inside & outside the body
  - changes
    - called *stimuli*
  - gathered information
    - called *sensory input*

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*Overlapping Functions of Nervous System*

- ▶ 2) processing & interpretation of sensory input → decision of what to do
  - process called *integration*
- ▶ 3) response via activation of effector organs (muscles or glands)
  - response is called *motor output*

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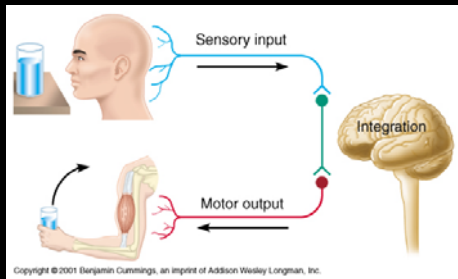
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## Functions of Nervous System (fig 11.1)



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## Organization of Nervous System

- ▶ two principal parts
  - central nervous system
    - CNS
  - peripheral nervous system
    - PNS

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## CNS

- ▶ consists of brain & spinal cord
- ▶ occupies the dorsal body cavity
- ▶ integrative & command center
- ▶ interprets
  - incoming sensory information
- ▶ dictates
  - motor responses
    - based on past experience, reflexes & current conditions

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## *PNS*

- consists mainly of nerves that extend from brain & spinal cord
  - a) spinal nerves
    - carry impulses to & from the spinal cord
  - b) cranial nerves
    - carry impulses to & from the brain
- peripheral nerves serve as communication lines
  - link all parts of body to CNS

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## *PNS*

- two functional divisions
  - 1) sensory ~ afferent division
    - nerve fibers send impulses to CNS from sensory receptors in the body
      - inform CNS about internal & external body changes
    - a) somatic afferent fibers
      - sensory fibers
        - convey impulses from skin, skeletal muscles, joints
    - b) visceral efferent fibers
      - transmit impulses from visceral organs
        - w/in ventral body cavity

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## *PNS*

- two functional divisions
  - 2) motor ~ efferent division
    - transmits impulses from CNS to effector organs (muscles, glands)
      - effect (bring about) a motor response
      - impulses activate
        - muscles to contract
        - glands to secrete
    - consists of two main parts
      - somatic nervous system (SNS)
      - autonomic nervous system (ANS)

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## Motor Division of PNS

- ▶ 1) somatic nervous system (SNS)
  - voluntary nervous system
  - consists of somatic motor nerve fibers
    - conducts impulses from CNS to skeletal muscles
      - allows conscious control over skeletal muscles

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## Motor Division of PNS

- ▶ 2) autonomic nervous system (ANS)
  - involuntary nervous system
  - consists of visceral motor nerve fibers
    - regulate the activity of smooth muscles, cardiac cells & glands
  - two divisions
    - sympathetic
    - parasympathetic

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## ANS

- ▶ sympathetic division
  - handles emergency situations
- ▶ parasympathetic division
  - promotes nonemergency functions
- ▶ \* *what one subdivision stimulates the other inhibits*

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## Supporting Cells

- ▶ AKA neuroglia or glial cells
- ▶ unique functions
  - insulate neurons
  - produce chemical
  - promote health & growth
- ▶ six types
  - four within CNS
  - \*two within PNS

• \*know one

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## CNS Supporting Cells

- ▶ 1) astrocytes
  - most abundant & versatile
  - numerous radiating processes
  - functions
    - cling to neurons & cover nearby capillaries
    - support & brace neurons & anchor them to the blood capillaries
    - control the chemical environment
      - mop up leaked K ions
      - recapture & recycle released NTs
    - signal each other via IC Ca pulses

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## CNS Supporting Cells

- ▶ 2) microglia
  - small ovoid cells w/ long “thorny” processes
    - branches touch nearby neurons to monitor their health
  - serve a protective role
    - become macrophages
      - when microorganisms or dead neurons are present

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## Supporting Cells (fig 11.3)

(a) Astrocyte  
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(b) Microglial cell

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## CNS Supporting Cells

- 3) ependymal cells
  - range in shape from squamous to columnar
  - many are ciliated
    - cilia beating helps to circulate CSF
      - cushions the brain & spinal cord
  - line the central cavities of brain & spinal cord
    - form a permeable barrier
      - between CSF (fills the cavities) and tissue fluid (bathes the CNS cells)

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## CNS Supporting Cells

- 4) oligodendrocytes
  - branch
    - have few branches than astrocytes
  - line up along the thicker neuron fibers in CNS
    - wrap their cytoplasmic extensions tightly around the fibers
  - produce insulating coverings
    - myelin sheaths

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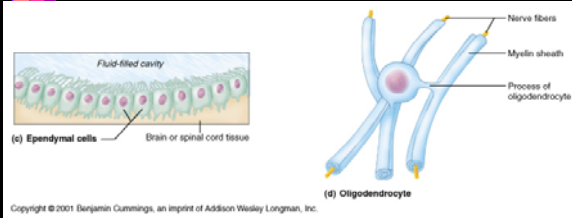
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## Supporting Cells (fig 11.3)



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## PNS Supporting Cells

- Schwann cells
  - AKA neurolemmocytes
  - surround & form myelin sheaths around the large nerve fibers in PNS
  - similar to oligodendrocytes functionally
  - important in peripheral nerve fiber regeneration

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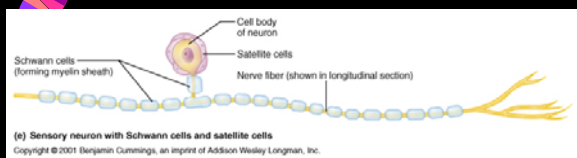
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## Supporting Cells (fig 11.3)



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## *Neurons*

- ▶ AKA nerve cells
- ▶ structural units of the nervous system
- ▶ highly specialized cells
- ▶ conduct messages in the form of nerve impulses
- ▶ typically large
- ▶ vary in structure

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## *Characteristics of Neurons*

- ▶ 1) extreme longevity
  - live & function optimally for a lifetime
    - with good nutrition
- ▶ 2) amitotic
  - lose their ability to divide
    - cannot replace themselves
    - exceptions
      - olfactory neurons
      - some hippocampal neurons (memory)
        - retain ability to reproduce throughout life

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## *Characteristics of Neurons*

- ▶ 3) high metabolic rate
  - require continuous & abundant supplies of glucose and oxygen

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### Structure of the Neuron

- ▶ three functional components
  - receptive or input region
  - conducting component
  - secretory or output component
- ▶ functional components are associated with a particular region of neuron's anatomy

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### Cell Body

- ▶ consists of spherical nucleus surrounded by cytoplasm
- ▶ major biosynthetic center of neuron
- ▶ focal point for outgrowth of neuron processes
- ▶ PM also acts as part of the receptive surface
  - receives information from other neurons

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### Cell Body

- ▶ contains usual organelles
  - no centrioles
  - protein- and membrane-making organelle
    - consists of clustered free ribosomes and RER
      - RER known as *Nissl bodies*

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## Cell Body

- ▶ most are located within CNS
  - protected by bones of skull and vertebral column
- ▶ clusters of cell bodies in CNS
  - called nuclei
- ▶ fewer clusters of cell bodies in PNS
  - lie along the nerves
  - called ganglia

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## Processes

- ▶ extend from the cell body of all neurons
- ▶ brain & spinal cord (CNS)
  - contain neuron cell bodies & their processes
- ▶ PNS
  - contains mainly neuron processes
- ▶ bundles of neuron processes
  - CNS
    - known as tracts
  - PNS
    - known as nerves

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## Processes

- ▶ two types
  - dendrites
    - main receptive or input region
    - neurons have hundreds clustered close to cell body
    - have short, branching extensions
    - provide an enormous surface area for receiving signals from other neurons
    - convey incoming messages *toward* the cell body

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## Processes

### two types

- axon
  - each neuron has a single axon
  - slender process
    - arises from axon hillock
      - cone shaped area
    - short or long
      - any long axon called a nerve fiber
  - conducting compartment of neuron
    - generates nerve impulses and transmits them away from the cell body

\*nerve impulse is generated at the junction of axon hillock and axon & conducted along the axon to axonal terminal (secretory component)

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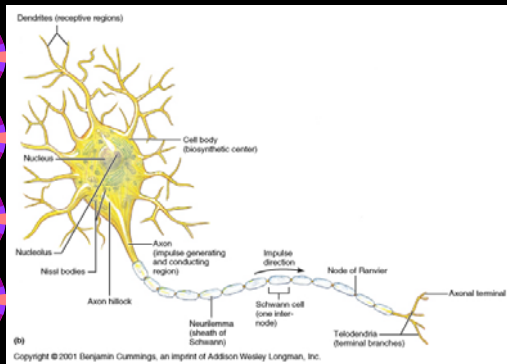
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## Structure of Motor Neuron (fig 11.4)



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## Myelin Sheath

- whitish, fatty (protein-lipoid) segmented covering
- covers nerve fibers
  - long or large in diameter
- protects and electrically insulates fibers from one another
- increases the speed of transmission of nerve impulses

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## Myelin Sheath

- ▶ axons bearing a myelin sheath
  - myelinated fibers
    - conduct nerve impulses rapidly
      - associated *only* with axons
- ▶ axons with no myelin sheath
  - unmyelinated fibers
    - conduct nerve impulses slowly
      - dendrites are *always* unmyelinated

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## Schwann Cells

- ▶ supporting cells of PNS
- ▶ form myelin sheaths
- ▶ indent to receive axon and wrap themselves like a jelly roll around the axon
- ▶ adjacent Schwann cells along an axon do not touch one another
  - create gaps in the sheath
    - called nodes of Ranvier or neurofibril nodes
      - occur at regular intervals along the axon

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## Schwann Cells

- ▶ regions of brain spinal cord containing dense collections of myelinated fibers
  - white matter
    - primary fiber tracts
- ▶ regions of dense collections of unmyelinated fibers
  - most nerve cell bodies
    - gray matter

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### Functional Classification of Neurons

- ▶ classifies neurons according to the direction in which the nerve impulse travels
  - relative to CNS
- ▶ three types of neurons
  - sensory (afferent)
  - motor (efferent)
  - interneurons (association)

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### Sensory Neurons

- ▶ transmit impulses from sensory receptors (skin or internal organs) *toward* the CNS
- ▶ ~ all are unipolar
  - have a single, short process that emerges from cell body
- ▶ cell bodies are located in sensory ganglia *outside* the CNS

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### Motor Neurons

- ▶ carry impulses *away* from CNS to effector organs (muscles, glands)
- ▶ most are multipolar
  - three or more processes
    - most common type of neuron
    - major type in CNS
    - most have numerous branching dendrites
- ▶ cell bodies are located in CNS
  - exception
    - some neurons of ANS

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## Association Neurons

- ▶ located between motor and sensory neurons
  - shuttle signals
- ▶ most are found entirely in CNS
- ▶ constitute 99% of neurons in the body
- ▶ ~ all are multipolar
- ▶ vary in size and fiber-branching patterns

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TABLE 11.1 Comparison of Structural Classes of Neurons

Neuron Type		
Multipolar	Bipolar	Unipolar (pseudounipolar)
<p><b>Functional Class: Neuron Type According to Direction of Impulse Conduction</b></p> <p>1. Some multipolar neurons are <b>motor neurons</b> that conduct impulses along the efferent pathways from the CNS to an effector (muscle/gland).</p> <p>2. Some multipolar neurons are higher level sensory neurons that convey sensory input from the first-order sensory neurons to higher CNS levels.</p>	<p>3. Most multipolar neurons are <b>interneurons (association neurons)</b> that conduct impulses within the CNS; may be one of a chain of CNS neurons, or single neuron connecting sensory and motor neurons.</p> <p>Essentially all bipolar neurons are <b>sensory neurons</b> that are located in some special sense organs. For example, bipolar cells of</p>	<p>the retina are involved with the transmission of visual inputs from eye to the brain (via an intermediate chain of neurons).</p> <p>Most unipolar neurons are <b>sensory neurons</b> that conduct impulses along afferent pathways to the CNS for interpretation. (These sensory neurons are primary or first-order sensory neurons.)</p>

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## Definitions

- ▶ **voltage**
  - measure of potential energy generated by separated charge
  - measured in mV or V
  - always measured between two points
    - called **potential difference** or **potential**
    - the greater the difference
      - the higher the voltage

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*Definitions*

- ▶ **current**
  - flow of electrical charge from one point to another
  - directly proportional to voltage
  - the greater the voltage (pot'l difference), the greater the current

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*Definitions*

- ▶ **chemical gradient**
  - movement pattern of ions as they diffuse passively from an area of higher concentration to an area of lower concentration
- ▶ **electrical gradient**
  - movement pattern of ions as they move toward an area of opposite electrical charge

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*Definitions*

- ▶ **electrochemical gradient**
  - combination of electrical and chemical gradients to allow the flow of ions toward an area of lower concentration and an area of opposite electrical charge

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## Definitions

- ▶ **resting membrane potential (RMP)**
  - potential difference or voltage in a resting neuron
  - (negative - inside; positive - outside)
  - membrane is **polarized**
  - value
    - -40 mV to -90 mV

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## Definitions

- ▶ **depolarization**
  - describes membrane potential change relative to resting membrane potential
  - reduction in membrane potential
  - inside of membrane is less negative (more positive)
    - closer to zero
  - example
    - from resting pot'l of -70 mV to -65 mV

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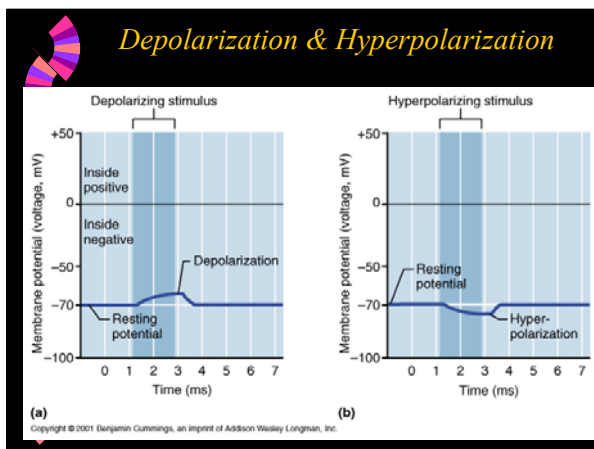
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*Definitions*

▶ **hyperpolarization**

- describes membrane potential change relative to resting membrane potential
- increase in membrane potential
- inside of membrane is more negative
- example
  - from resting pot'l of -70 mV to -75 mV

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*Definitions*

▶ **action potential**

- a large transient depolarization event
- includes polarity reversal conducted along the membrane of a muscle cell or nerve fiber
- only generated by excitable membranes
  - muscle and neuron cells
- principal way neurons communicate

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*Definitions*

▶ **nerve impulse**

- occurs in neurons
- self-propagating wave of depolarization
- also known as an action potential
  - transmitted action potential

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## *Electrochemical Basis of RMP*

- ▶ ionic differences in ICF and ECF
  - ICF
    - higher [K], lower [Na]
    - negatively charged anions to balance K
  - ECF
    - higher [Na], lower [K]
    - negatively charged anions, primarily Cl to balance Na
  - ICF & ECF
    - other solutes
      - glucose, urea, other ions

▶ *\*Na & K are most important ions in membrane pot'l*

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## *Ionic Differences*

- ▶ 1) differential permeability of PM
  - Na & K
- ▶ 2) operation of Na-K pump

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## *Differential Permeability*

- ▶ resting PM is polarized
  - outside of cell is positive
    - predominant EC ion is Na
  - inside of cell is negative
    - predominant IC ion is K
  - PM is ~ impermeable to both ions
    - slightly impermeable to K
    - nearly impermeable to Na

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## Differential Permeability

- K diffuses out along its [ ] gradient
- Na is attracted to interior by its [ ] gradient
  - but membrane is less permeable to Na
    - Na influx does not equal K efflux
    - unequal diffusion of Na and K across membrane
      - deficit of positive ions w/in cell
      - establishes resting membrane pot'l

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## Sodium-Potassium Pump

- ATP-driven Na-K pump
- ejects 3 Na ions from cell
- transports 2 K ions into the cell
- stabilizes the resting membrane pot'l
- maintains diffusion gradients for Na & K

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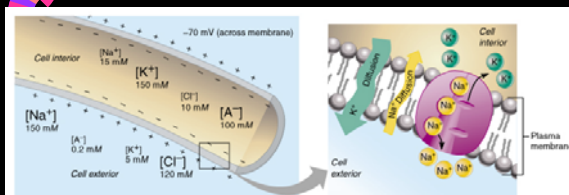
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## Resting Membrane Potential (RMP) (fig 11.8)



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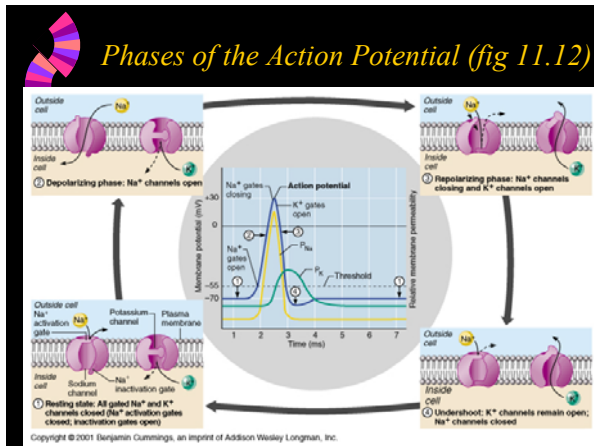
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### Generation of an Action Potential

- ▶ three consecutive, overlapping changes in membrane permeability
  - due to opening & closing of ion channels
  - induced by depolarization of axonal membrane

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### Generation of an Action Potential

- ▶ \*1) transient increase in Na permeability
- ▶ \*2) restoration of Na impermeability
- ▶ \*\*3) short lived increase in K permeability

- ▶ \* occur during depolarization
  - upward rising part of AP curve
- ▶ \*\* responsible for repolarization
  - downward part of AP curve

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## *Action Potential Phases*

- ▶ 1) resting state
  - channels are closed
- ▶ 2) depolarizing phase
  - increase in Na permeability
  - reversal of membrane pot'l
  - threshold
    - critical level need for depolarization to be self-generating
    - –55 and -50 mV

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## *Action Potential Phases*

- ▶ 3) repolarization
  - decrease in Na permeability
  - membrane pot'l passes 0 mV
  - AP spike stops rising & reverses direction
  - increase in K permeability
  - restoration of internal negativity of resting neuron

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## *Action Potential Phases*

- ▶ 4) undershoot
  - continuation of K permeability
    - K gates are slow to respond
  - after-hyperpolarization
    - AKA undershoot
    - due to excessive K efflux

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*Resting Electrical Conditions*

- ▶ restored by repolarization
- ▶ does not restore original ionic state distributions

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*Original Ionic State*

- ▶ restored by “reeving up” of Na-K pump after repolarization
  - pump ejects 3 Na from the cell for each 2 K transported in

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*Propagation of an Action Potential (Nerve Impulse)*

- ▶ AP is sent or transmitted along the axon’s entire length
- ▶ AP is generated by influx of Na ions
  - local patch of axonal membrane undergoes polarity reversal
    - inside become positive
    - outside becomes negative
  - patch moves laterally from the area of polarity reversal

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*Propagation of an Action Potential  
(Nerve Impulse)*

- ▶ impulse propagates from point of origin
  - initiated at one end of axon
  - conducted away from that point toward the axon's terminals
- ▶ each AP provides the depolarizing stimulus for triggering an AP in the next membrane patch

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*Propagation of an Action Potential  
(Nerve Impulse)*

- ▶ once initiated, AP is self-propagating
  - continues along the axon
    - driven by Na influx
      - domino effect
- ▶ regions that have just generated APs
  - refractory
    - unresponsive to threshold stimulus
      - nerve impulse is propagated in one direction only

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*Propagation of an Action Potential  
(Nerve Impulse)*

- ▶ post-depolarization
  - each segment of axonal membrane repolarizes
    - restoration of RMP
- ▶ process occurs in unmyelinated axons

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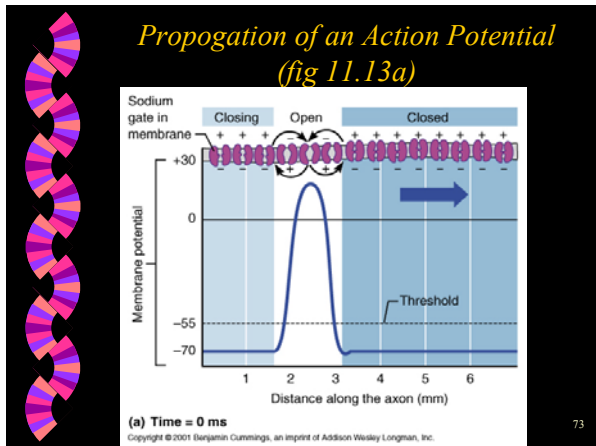
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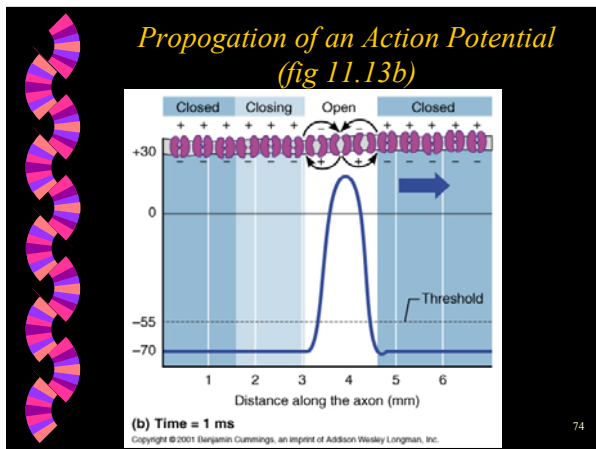
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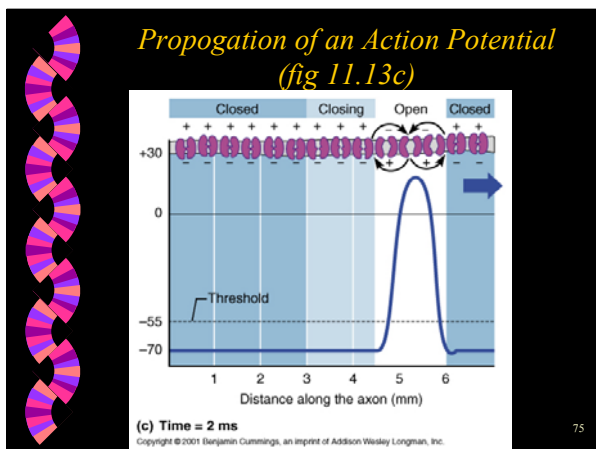
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### *Threshold Stimulus*

- ▶ stimulus strong enough to open sodium channels
- ▶ raises the membrane pot'l to +30 mV
  - generates an AP

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### *Subthreshold Stimulus*

- ▶ stimulus too weak to open sodium channels
- ▶ membrane pot'l remains at RMP of -70 mV
- ▶ neuron does not respond

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### *All-or-None Phenomenon*

- ▶ AP will either occur or not occur
- ▶ membrane pot'l changes to +30 mV or stays at -70 mV (RMP)
- ▶ all APs along a neuron are the same strength of +30 mV
- ▶ all APs travel at the same speed

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## *All-or-None Phenomenon*

- ▶ example
  - lighting a match under a dry twig
  - when the twig becomes hot enough
    - when enough sodium ions have entered
  - the critical flash point
    - threshold
  - is reached and the flame will consume the entire twig
    - AP is generated and propagated
  - match is extinguished before the critical T ignition does not occur
    - if too few sodium ions enter to achieve threshold, no AP occurring

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## *Coding for Stimulus Intensity*

- ▶ all APs
  - independent of stimulus strength
  - alike
- ▶ CNS determines an intense or weak stimulus
  - strong stimuli generate nerve impulses more frequently in a given time period

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## *Coding for Stimulus Intensity*

- ▶ stimulus intensity is coded by # of impulses generated per second
  - frequency of impulse transmission
  - not increases in strength of individual APs

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## Refractory Period

- ▶ absolute refractory period
  - period in which a neuron cannot respond to another stimulus
    - because it is already generating an AP
  - period from the opening of Na activation channels to closing of inactivation channels
  - ensures each AP is all-or-none
  - enforces one-way transmission of AP

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## Refractory Period

- ▶ relative refractory period
  - period after absolute refractory period
  - neuron's threshold is elevated
  - Na gates are closed, K gates are open
  - repolarization is occurring
  - exceptionally strong stimulus can reopen Na gates and allow another impulse to be generated

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## Refractory Period (fig 11.15)

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### *Rate of Impulse Propagation*

- ▶ dependent on two factors
  - axon diameter
  - degree of myelination

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### *Axon Diameter*

- ▶ varies
- ▶ the larger the diameter, the faster the impulse conduction
- ▶ larger axons have less resistance to flow of local current

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### *Degree of Myelination*

- ▶ unmyelinated axons
  - APs are generated
    - sites immediately next to each other
      - conduction is slow
  - AP propagation
    - continuous conduction

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## *Degree of Myelination*

- ▶ myelinated axons
  - APs are generated
    - only at nodes of Ranvier
      - conduction is fast
  - AP propagation
    - saltatory conduction
      - electrical signal jumps from node to node along the axon

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## *Saltatory Conduction (fig 11.16)*

The diagram illustrates the process of saltatory conduction. It shows a neuron with a cell body on the left and a distal axon on the right. The axon is covered by a myelin sheath, with gaps between the segments called nodes of Ranvier. An action potential (AP) is shown as a wave of depolarization moving along the axon. At each node of Ranvier, the AP 'jumps' from one node to the next, bypassing the myelin segments. The diagram labels the 'Cell body', 'Area of polarity reversal (node of Ranvier)', 'Myelin sheath', and 'Distal axon'. Small arrows indicate the direction of AP propagation. A copyright notice at the bottom reads: 'Copyright © 2011 Benjamin Cummings, an imprint of Addison Wesley Longman, Inc.'

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## *Multiple Sclerosis (MS)*

- ▶ autoimmune ds
- ▶ affects mostly young adults
- ▶ symptoms
  - visual disturbances
  - muscle weakness, paralysis
  - urinary incontinence

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### *Multiple Sclerosis (MS)*

- ▶ nerve fibers are severed
- ▶ CNS myelin sheaths are destroyed
  - reduced to scleroses
    - nonfunctional hardened lesions
- ▶ loss of myelin
  - immune system attacks myelin proteins
- ▶ affects impulse conduction
- ▶ axons are not damaged

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### *Numbness*

- ▶ caused by cold or continuous pressure
- ▶ interrupts blood circulation
  - delivery of oxygen and nutrients to neuronal processes
    - impair ability to conduct impulses

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### *Synapse*

- ▶ functional junction between neurons
- ▶ presynaptic neuron
  - conducts the impulse toward the synapse
  - information sender
- ▶ postsynaptic neuron
  - neuron beyond the synapse
  - transmits the impulse away from the synapse
  - information receiver

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## *Synapse*

- ▶ two types
  - electrical
  - \*chemical

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## *Chemical Synapse*

- ▶ site of NT release and binding
- ▶ consists of two parts
  - 1) axonal terminal of presynaptic neuron
    - contain synaptic vesicles w/ NT
  - 2) receptor region of postsynaptic neuron
    - contain NT receptors

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## *Events at a Chemical Synapse*

- ▶ 1) Arrival of depolarization wave (nerve impulse)
  - influx of Ca into axonal terminal
- ▶ 2) Ca ions cause fusion of synaptic vesicles w/ presynaptic membrane and exocytosis of NT
- ▶ 3) Diffusion of NT across synaptic cleft & attachment to receptors on postsynaptic membrane

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## Events at a Chemical Synapse

- ▶ 4) Binding of NT opens ionic channels on postsynaptic membrane
- ▶ 5) Destruction of NT by enzymes
  - subsequent closing of ion channels
  - termination of the synaptic response

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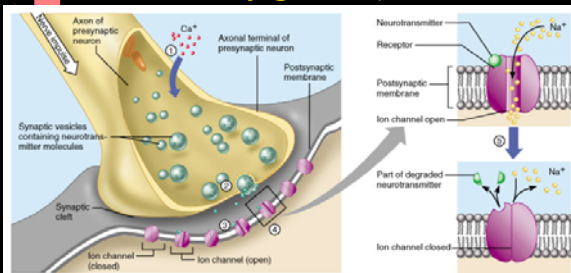
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## Events at a Chemical Synapse (fig 11.18)



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## Chemical Synapses

- ▶ two types
- ▶ classified according to how they affect the membrane potential of postsynaptic membrane
  - excitatory postsynaptic potential
    - EPSP
  - inhibitory postsynaptic potential
    - IPSP

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### *EPSP*

- ▶ local graded depolarizations
  - binding of NT at excitatory chemical synapse
- ▶ opening of channels
  - allow Na and K entry

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### *IPSP*

- ▶ hyperpolarization
  - binding of NT at inhibitory chemical synapse
- ▶ opening of channels
  - allow Cl or K entry
- ▶ drive the membrane pot'l farther from threshold
  - more negative

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### *Action Potentials*

- ▶ generated by axons
- ▶ not postsynaptic membranes

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### *Neurotransmitter (NT)*

- molecule that chemically connects neurons
- ACh
  - affects
    - excitatory to skeletal muscle
    - excitatory or inhibitory to visceral receptors
  - released by all neurons that stimulate skeletal muscles

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### *Neurotransmitter (NT)*

- endorphins/enkephalins
  - affects are generally inhibitory
  - neuropeptides that act as natural opiates
  - reduce our perception of pain under certain stressful conditions

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### *Neurotransmitter (NT)*

- endorphins
  - responsible for “runner’s high”
    - second wind
- enkephalins
  - activity increases in pregnant women during labor

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