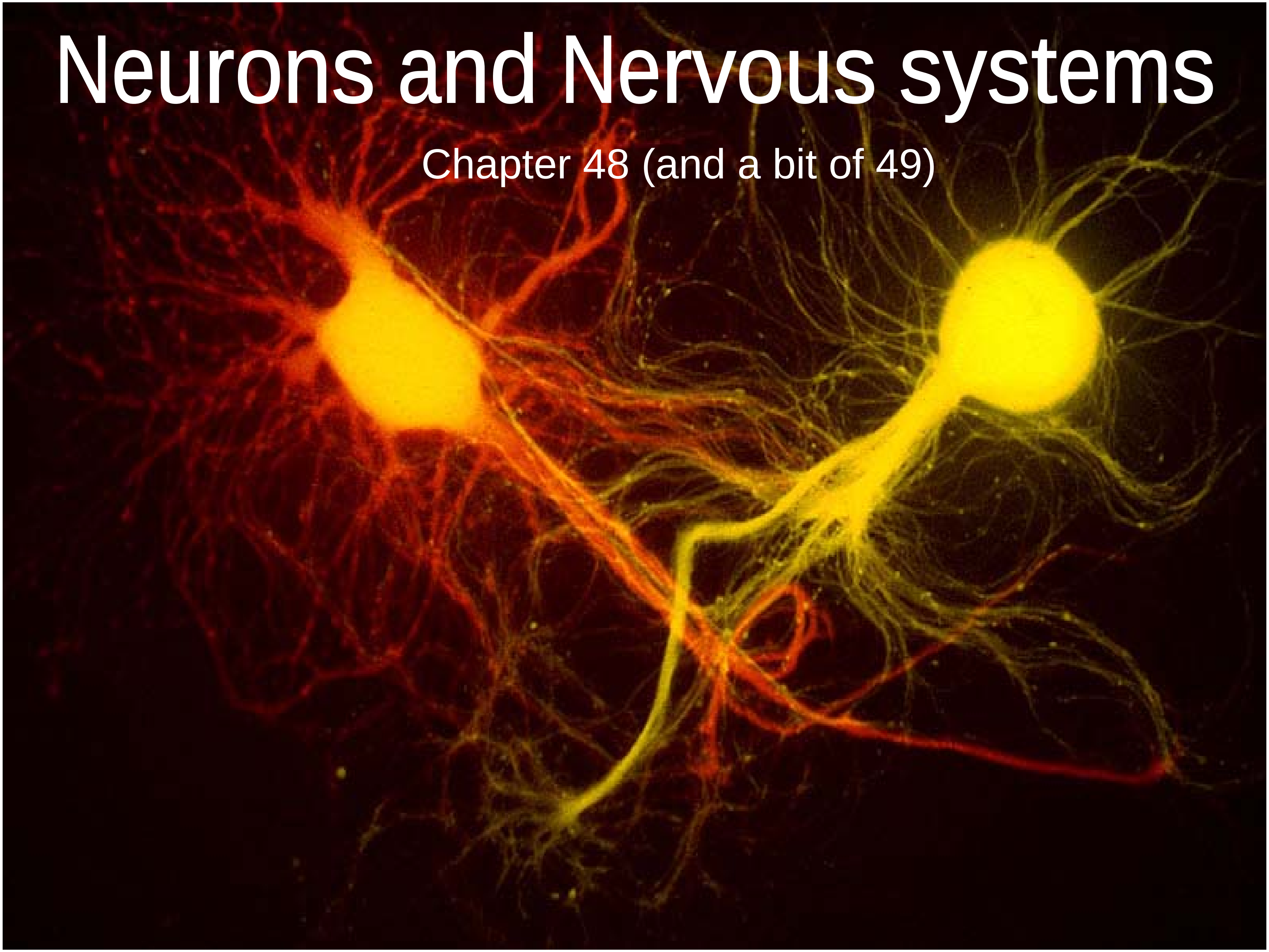
Neurons and Nervous systems

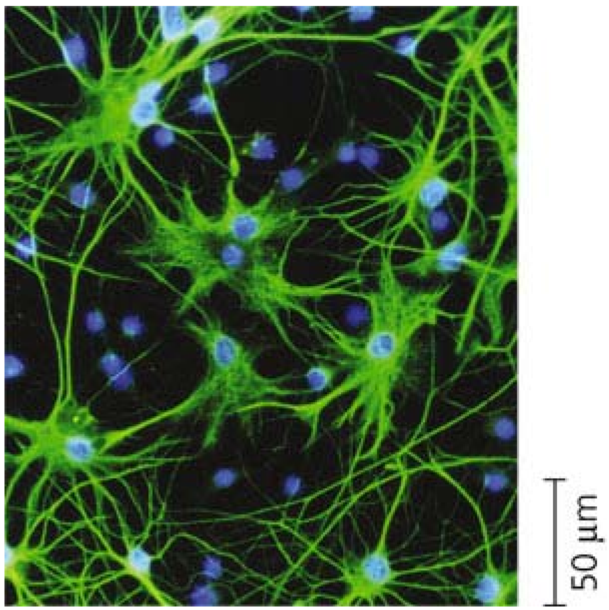
Chapter 48 (and a bit of 49)



2

What is a Nervous system?

The collection of organs, tissues and cells
that coordinates, records and distributes information
by electrical and chemical signals
between the brain and other parts of the body
allowing response to external stimuli
and control of other organ systems.



Animal Nervous systems

3

Most animals have a nervous system (except sponges).

Many are **cephalized** with neurons clustered on one end into a brain

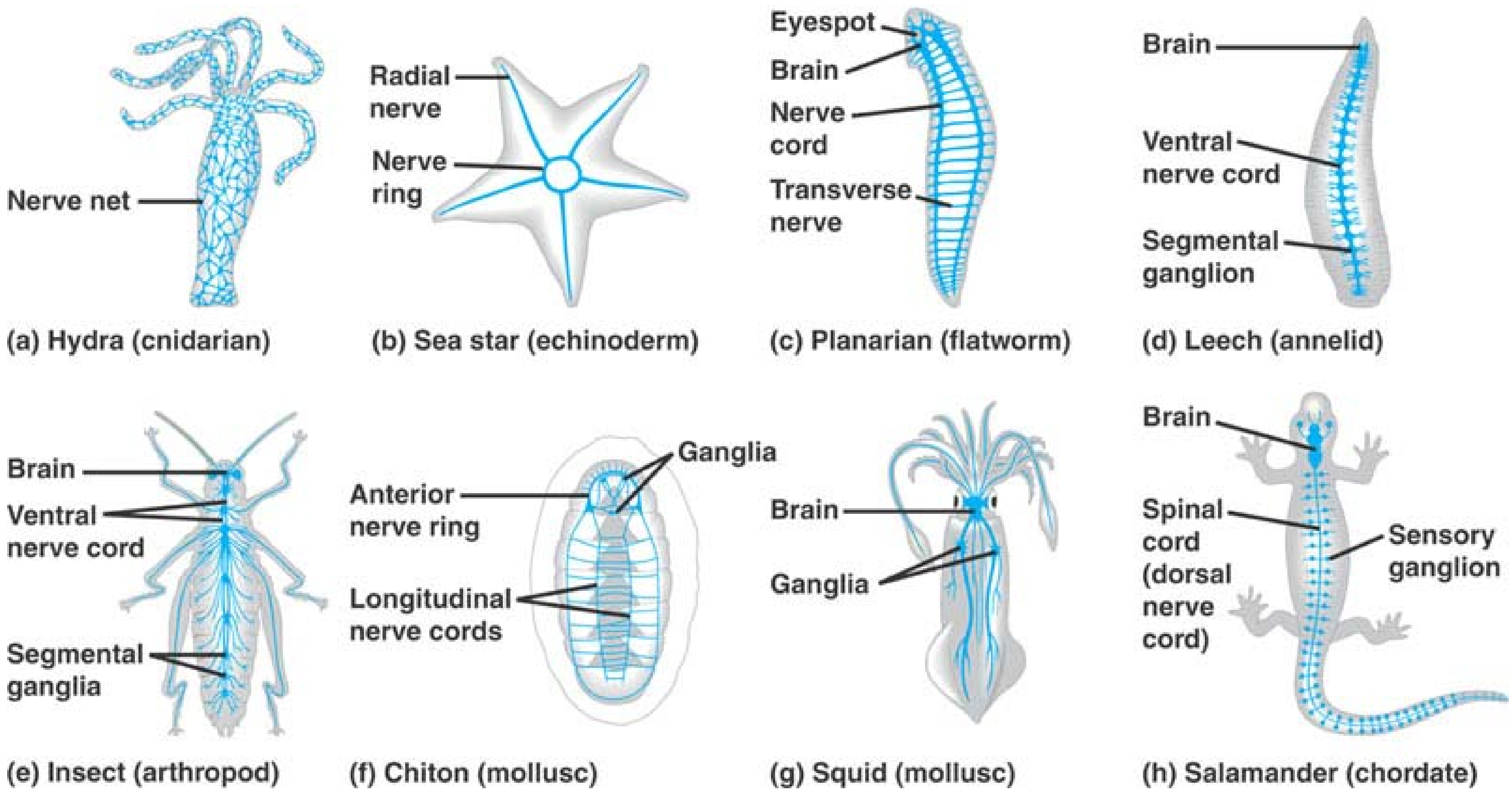


Figure 49.2 (Campbell 9th ed)

Nervous system comprised of 2 general cell types

4

Neurons

Transfer information via electrochemical energy

Glial Cells

Many functions which help support neurons and modulate action potentials

5

Neuron Structure

Most neurons have three main parts:

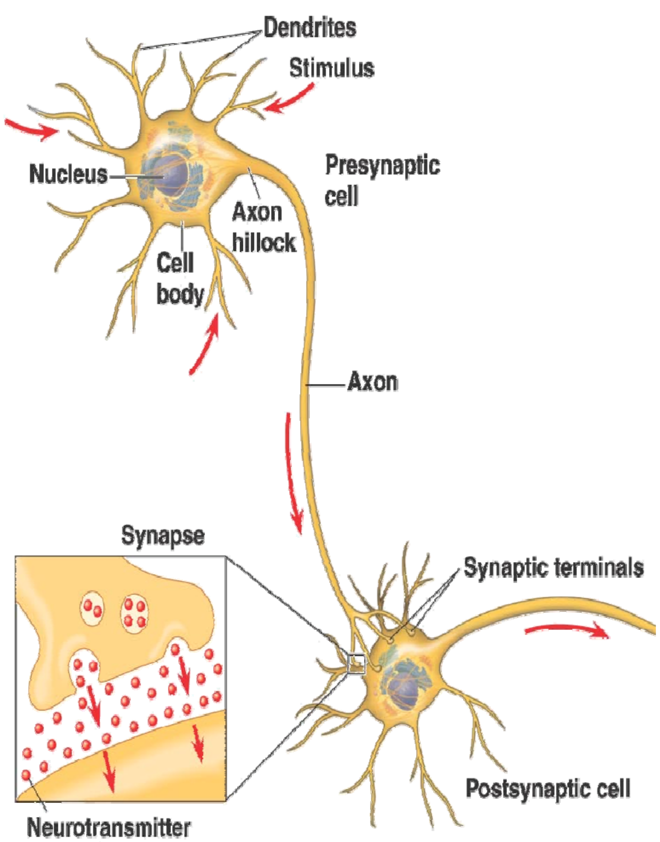


Figure 48.4 (Campbell 9th ed)

1. Dendrites
    - bring electrical stimuli from other neurons or sensory epithelial cells to the cell body.
    - several to many per neuron

2. Cell body
    - receives stimuli from dendrites or other neurons and propagates to axon
    - synthesizes some neurotransmitters (or neurohormones)
    - contains nucleus and other cell organelles

3. Axon
    - receives stimulus from cell body of neuron and propagates to synapse
    - only 1/ cell but distal end has several to many branches (thus each neuron can contact many other neurons)
    - synthesizes some neurotransmitters in synaptic terminals

Neuron Structure

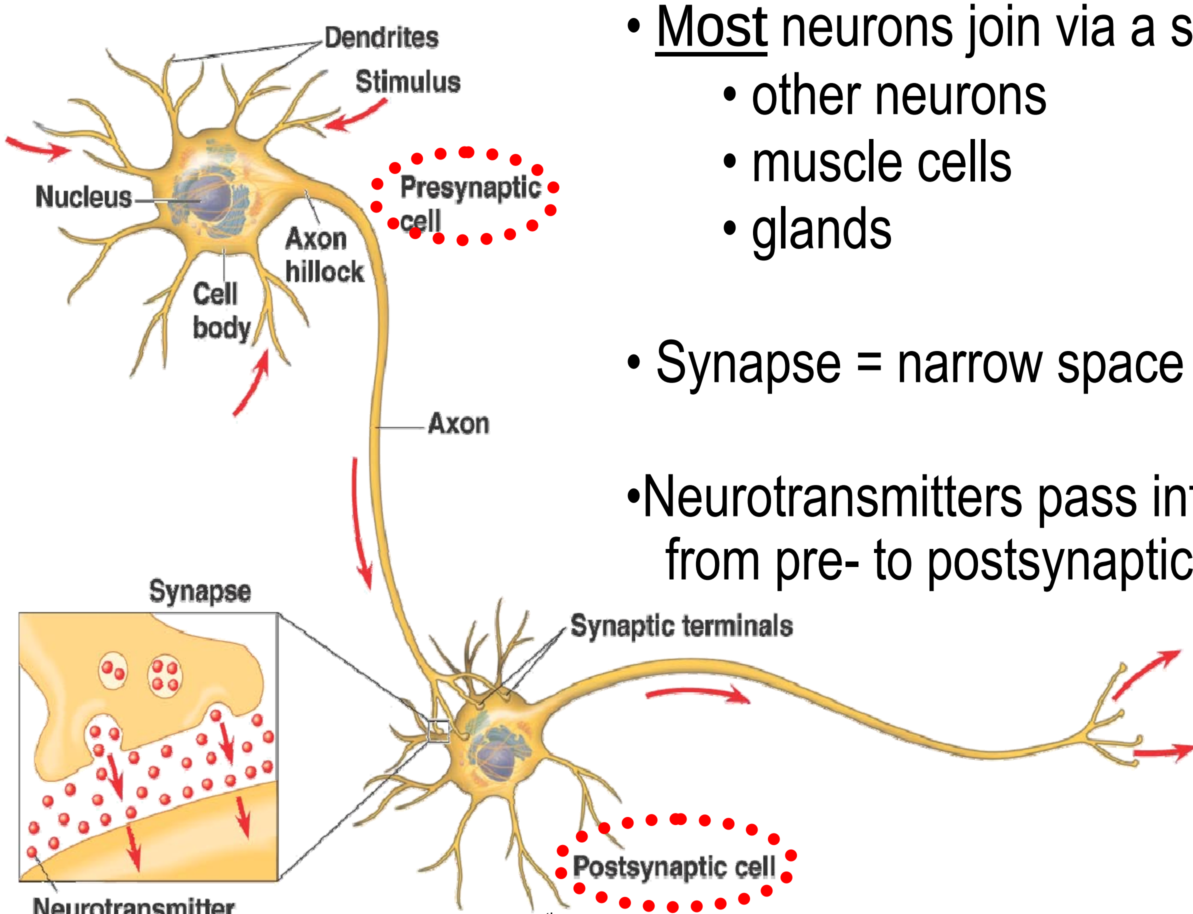
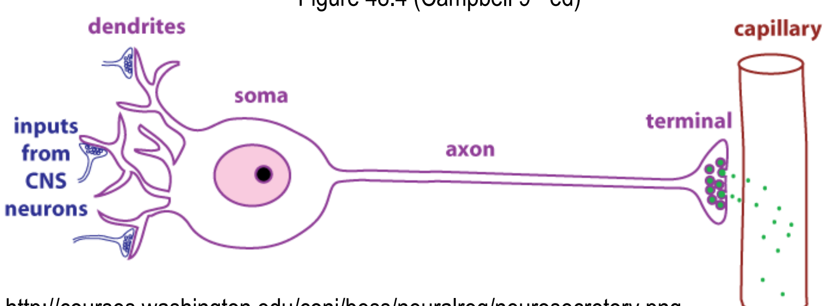


Figure 48.4 (Campbell 9th ed)

- Most neurons join via a synapse to:
  - other neurons
  - muscle cells
  - glands
- Synapse = narrow space between 2 cells
- Neurotransmitters pass info across synapse from pre- to postsynaptic cell (i.e. are a paracrine signal)



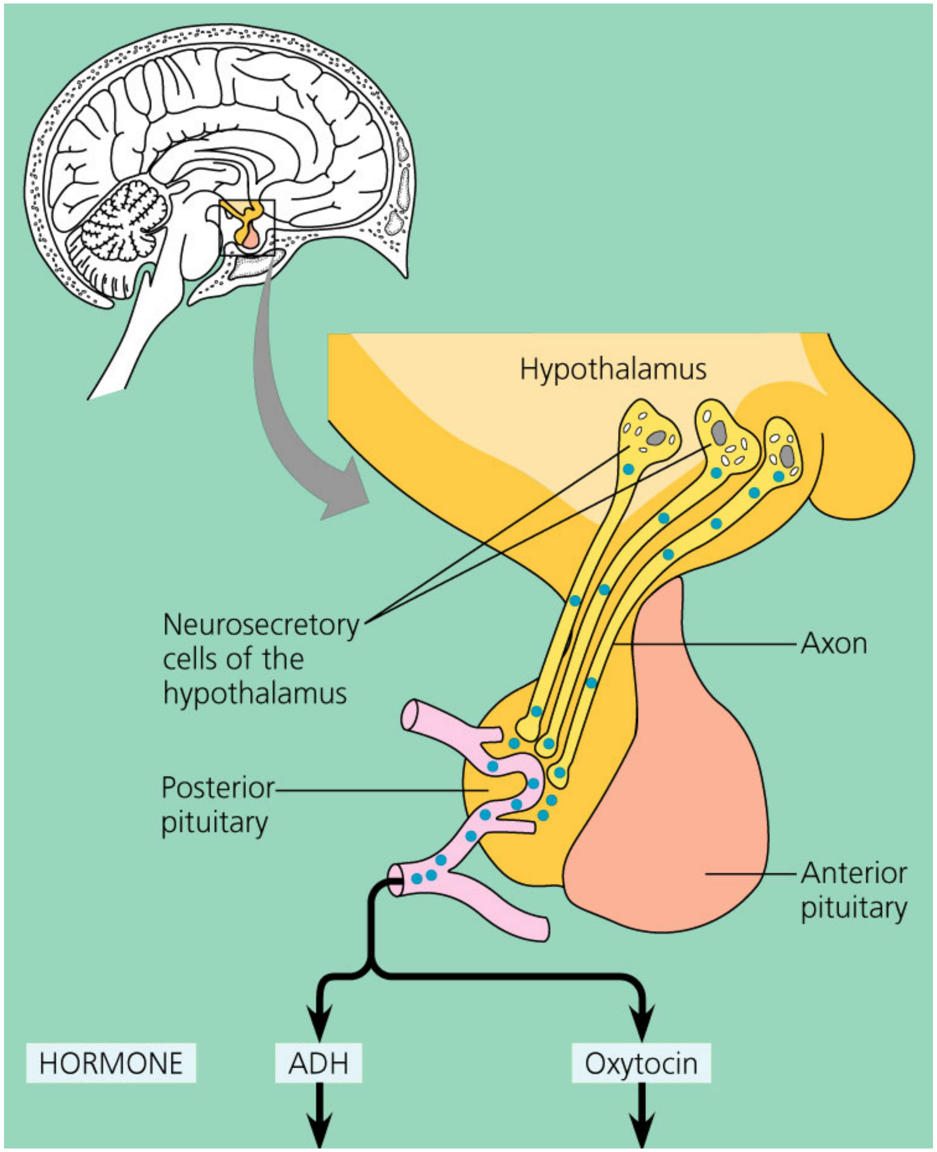
Some specialized neurons (neurosecretory cells) transmit chemicals (neurohormones) directly into the blood stream

http://courses.washington.edu/conj/bess/neuralreg/neurosecretory.png

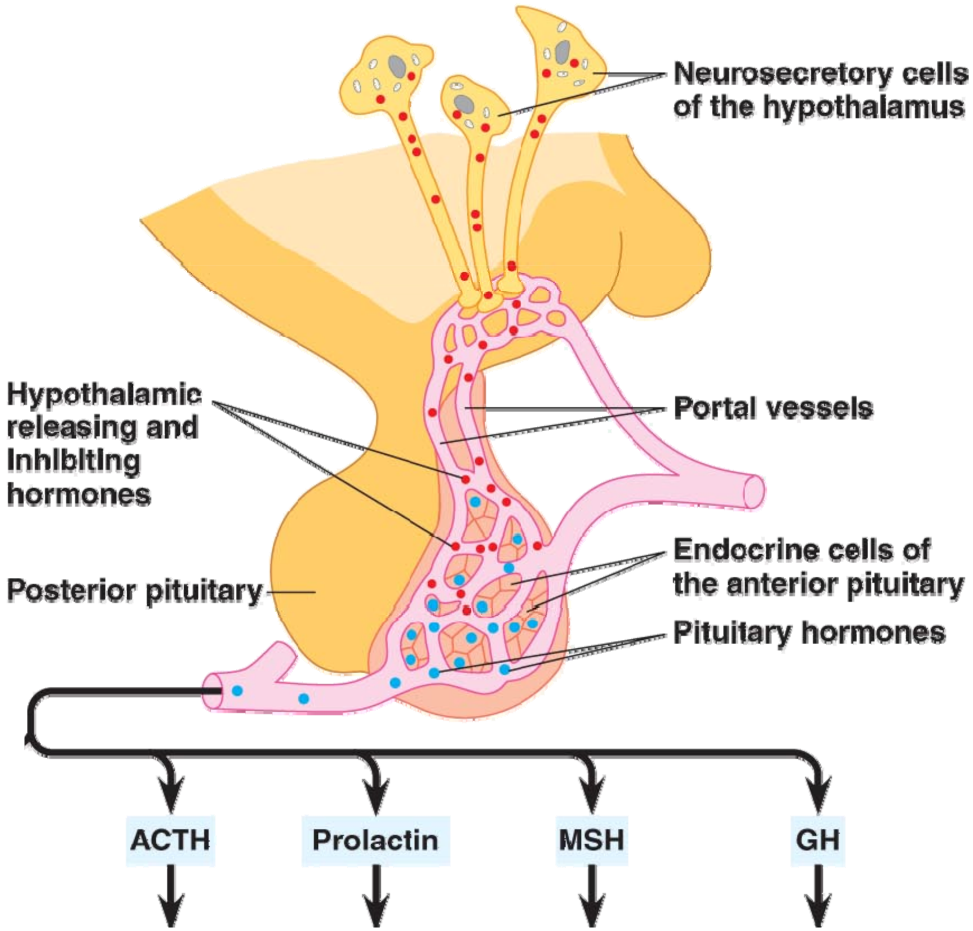
http://education.vetmed.vt.edu/Curriculum/VM8054/Labs/Lab10/IMAGES/NMJ1.jpg

8

Posterior pituitary



Anterior pituitary



9 4 Functional Types of Neurons

Sensory (afferent) – transmit info from external or internal sensors to the brain (or ganglia)
- e.g. light, odor, taste, temperature, pressure, pain, position, etc…

Interneurons – Analyze and interpret sensory input
- Found exclusively within the spinal cord and brain
- Stimulated by sensory neurons, other interneurons or both
- Hundreds or more types of interneurons that vary greatly in function
- Have many more dendrites than other neuron types (~100k)

Motor (efferent) – transmit signals to muscle and gland cells from the brain (or ganglia)
- primarily stimulated by interneurons

Neurosecretory – transmit chemicals into blood which act on distant targets

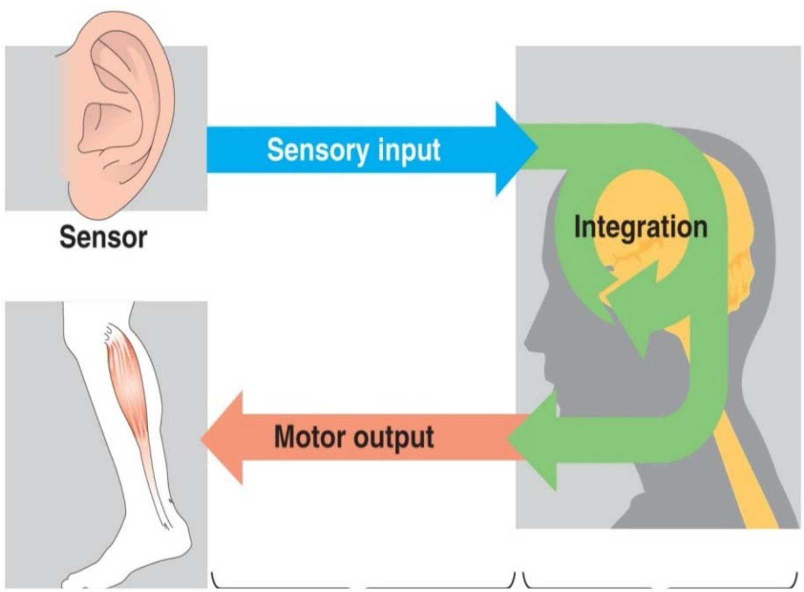


Figure 48.3 (Campbell 9th ed)

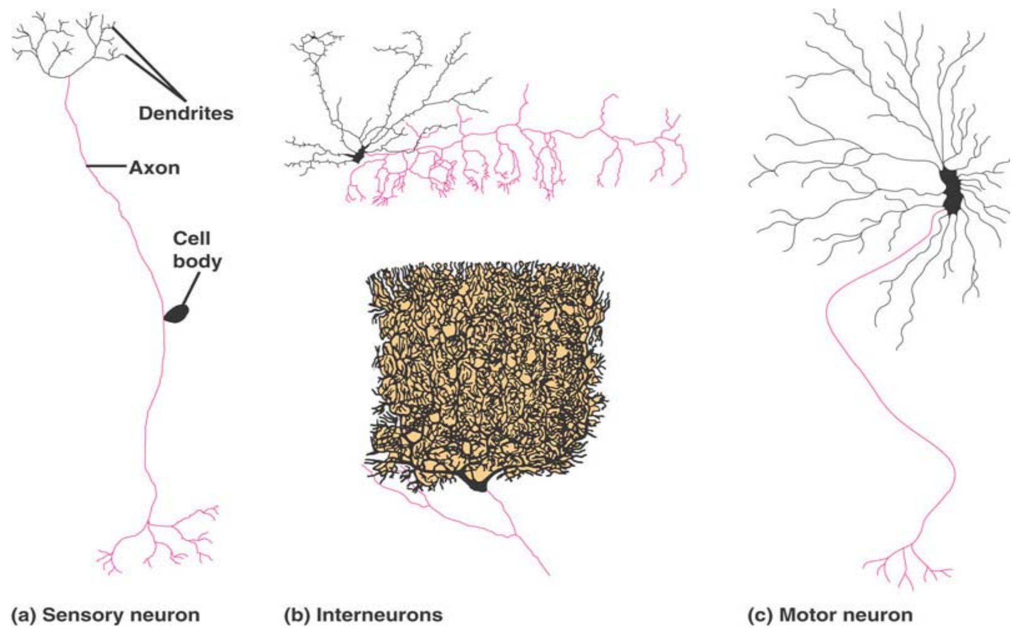


Figure 48.5 (Campbell 9th ed)

CNS vs. PNS

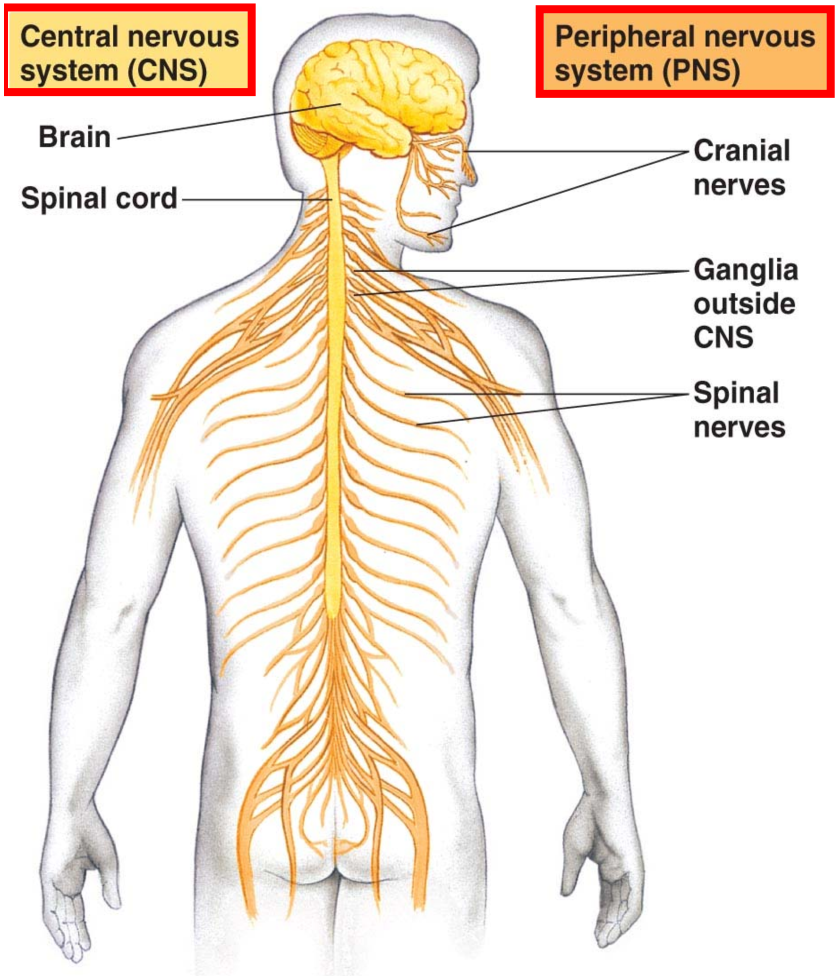
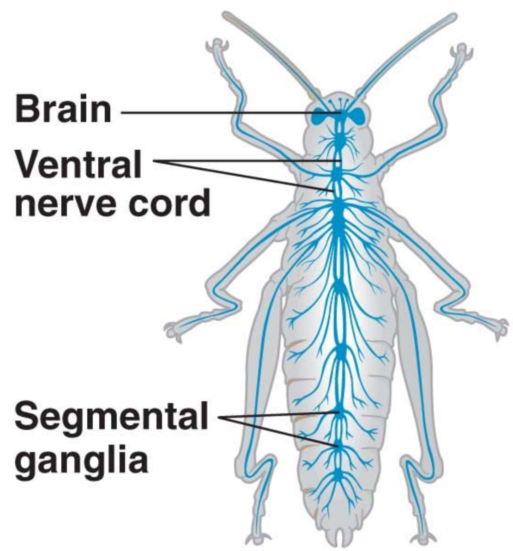


Figure 49.4 (Campbell 9th ed)

Ganglion

- A dense cluster of interconnected <u>neuron cell bodies</u> that, depending on the type, relay sensory (spinal ganglia) information to (afferent) or motor outputs from (efferent) the spinal cord.
- vs. brain
  - Smaller/ less complex than brain
  - Only contain neuron cell bodies not axons or dendrites
- In PNS in vertebrates but in CNS in invertebrates
  - Insect's brain is 6 fused ganglia in head each controlling different parts/ activities

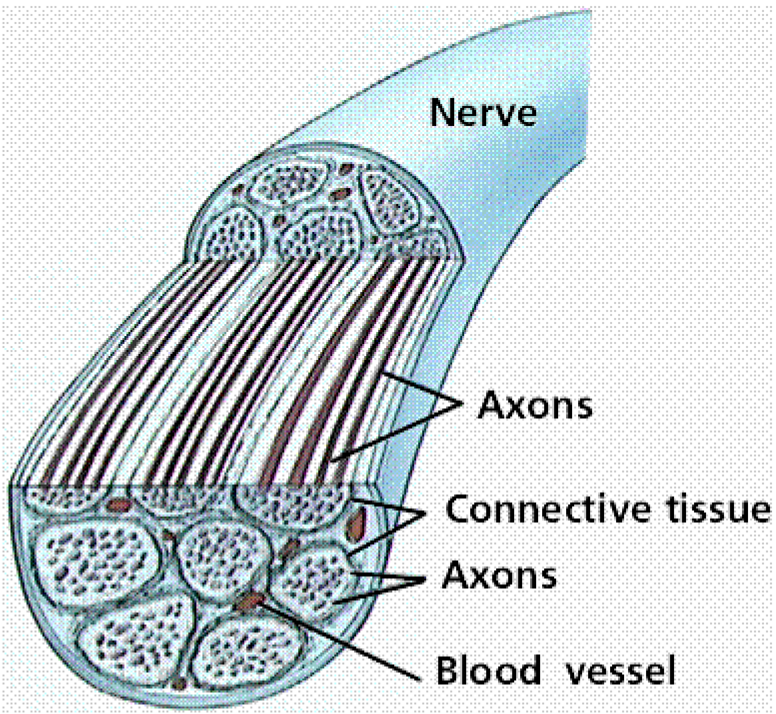


(e) Insect (arthropod)

Figure 49.2 (Campbell 9th ed)

11

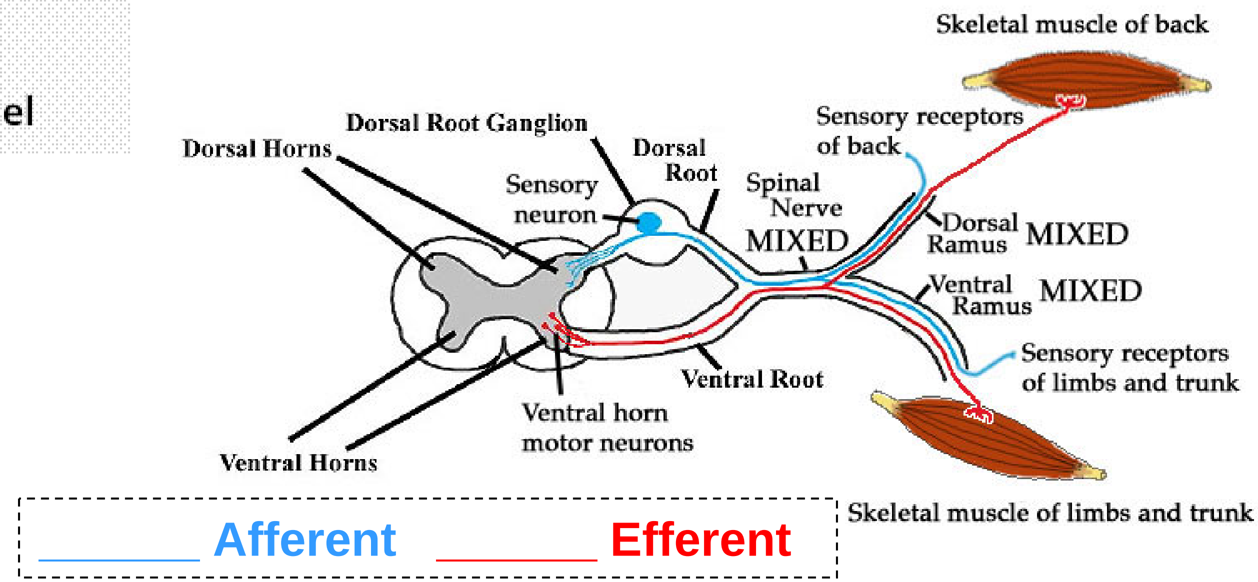
Nerves are Organs of the PNS made of bundles of AXONS, blood vessels & connective tissue



Nerves only occur in the PNS

Nerves may be:

- Afferent - Only sensory neuron axons
- Efferent - Only motor neuron axons
- Mixed - Both motor and sensory neuron axons



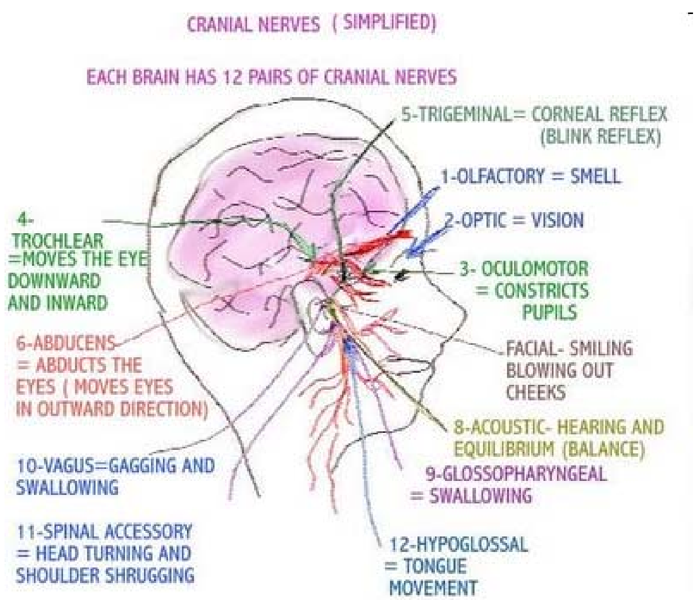
Cranial vs Spinal Nerves

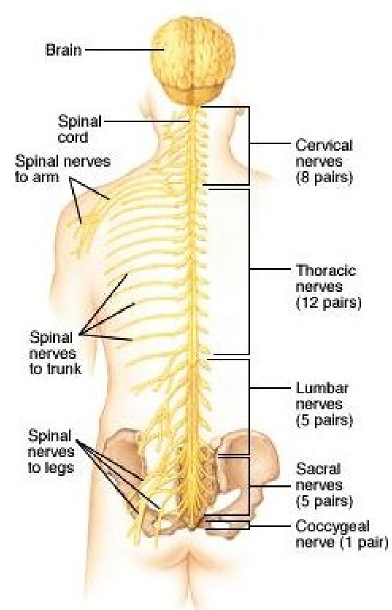
Cranial nerves

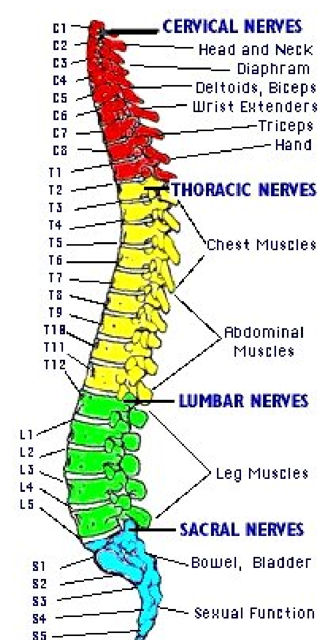
- originate in the brain and serve head and neck
- 12 pairs in humans and most vertebrates
- Some afferent, others efferent, others mixed

Spinal nerves

- originate in the spine and serve body below head
- 31 pairs in humans ~ corresponding to vertebral column segments
- All are mixed nerves (afferent and efferent)

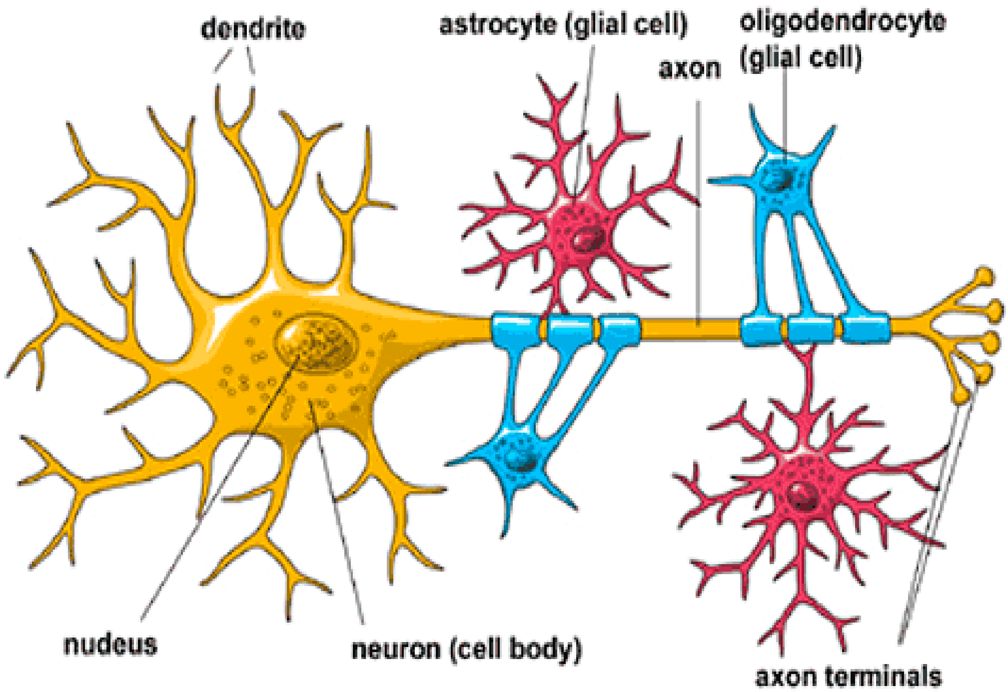






Do NOT need to know the names of specific cranial and spinal nerves

Glial Cells



- Support Cells for neurons
- 10-50x abundance of neurons

- Several types with different functions:
  - Facilitate info transfer at synapse
  - Anchor neurons
  - Improve nutrient deliver to neurons
  - Remove dead neurons
  - Form myelin sheath around axons
    - Schwann Cells (PNS)
    - Oligodendrocytes (CNS)
  - Circulate cerebrospinal fluid

Astrocytes = most abundant cell type in human brain:

- release neurotransmitters
- degrade or uptake neurotransmitters
- secrete K+ into extracellular area
- regulate blood/nutrient flow in brain
- direct growth of neurons
- direct location of synapses

Figure 49.6 (Campbell 9th ed)

14

How a neuron works

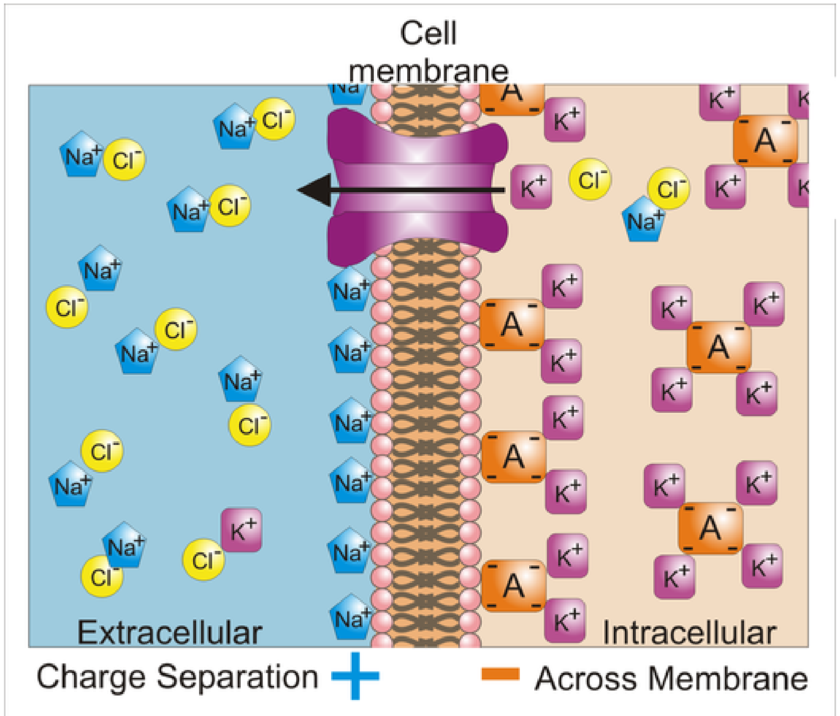
Membrane potential

Difference in electrical charge across a plasma membrane due to differential distribution of ions on each side of membrane.

- Determined by the possibility that ions could cross the membrane from [high] to [low]
  - e.g. More K^+ inside cell leads to potential for K^+ movement towards outside
- The potential for greater movement of ions in one direction is voltage.
  - Voltage causes ions to flow (like pressure causes H_2O to flow)

The size of a membrane potential depends on how different the [ion] is on each side of the membrane

- ↑ difs = ↑ membrane potential

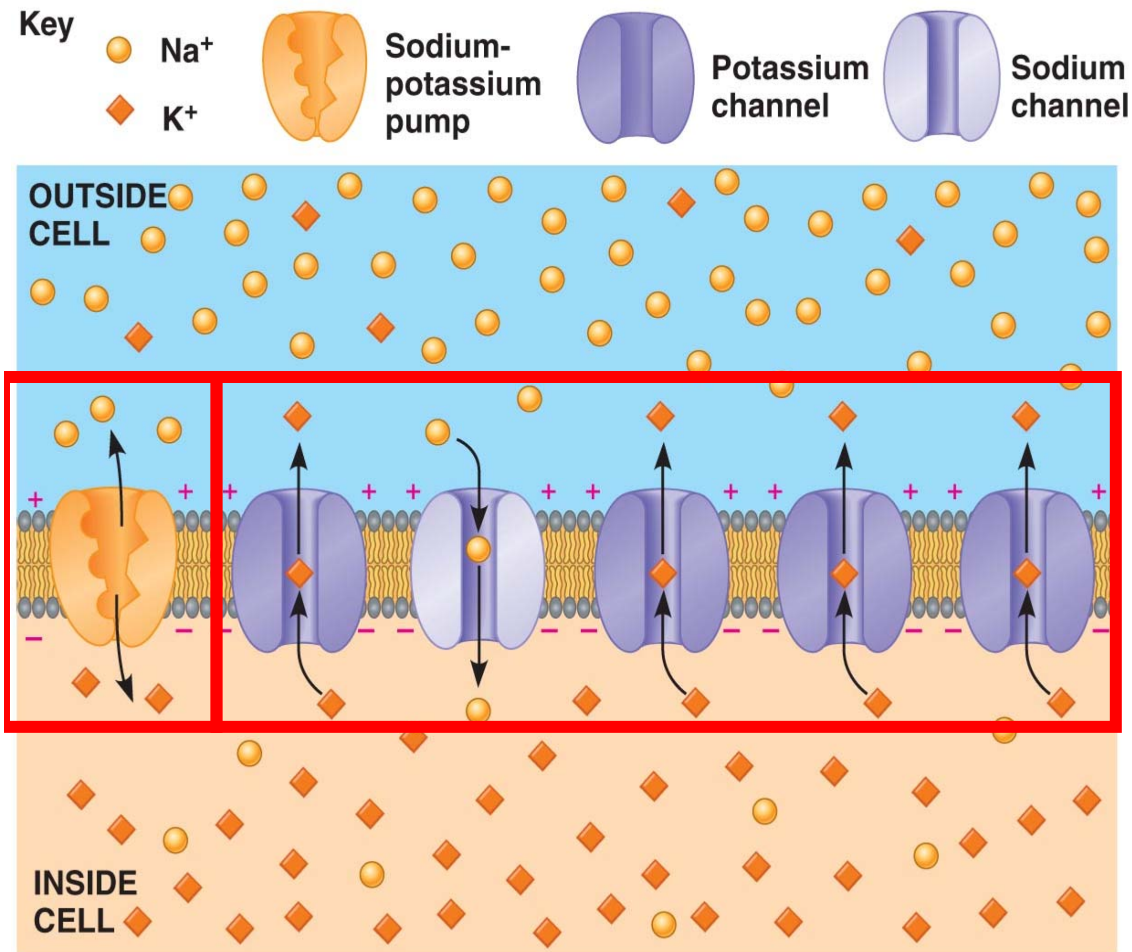


http://en.wikipedia.org/wiki/File:Basis_of_Membrane_Potential2.png

15

How a neuron works

Charge difference btwn inside/ outside established by selectively permeable ion channels.



Active: Requires ATP

Na^+/K^+ pump creates – charge inside cell since 3 Na^+ pumped out and only 2 K^+ pumped in (See Ch 7 (136-7) "How ion pumps maintain membrane potential")

Passive: Diffusion (no ATP)

More open K^+ than Na^+ channels so movement of K^+ out > Na^+ in adding to – charge inside

- If movement was equal in both directions there would be no membrane potential

Figure 48.7 (Campbell 9th ed)

16

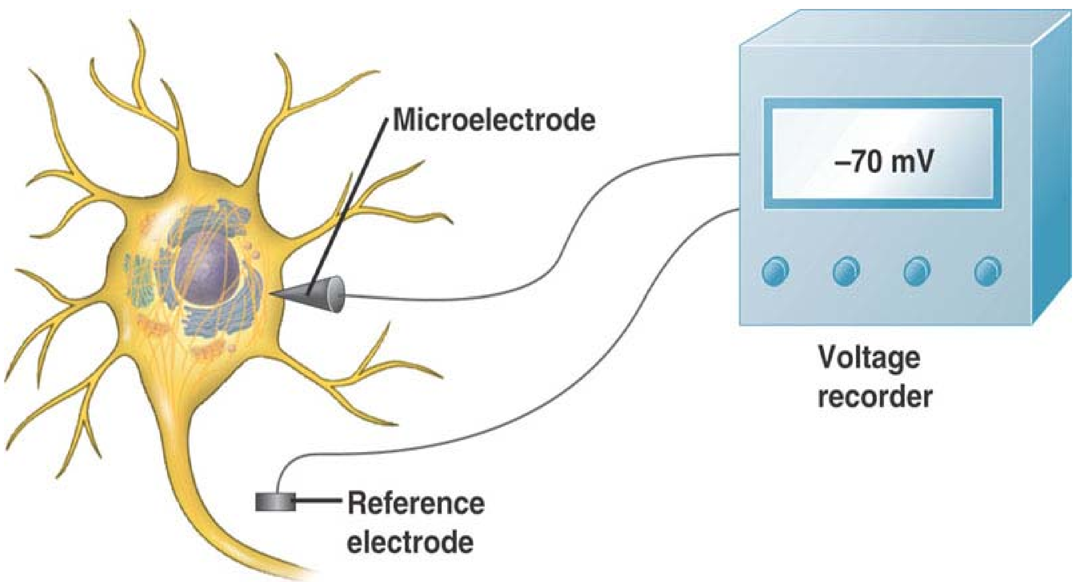
How a neuron works

Resting potential

Membrane potential of a nontransmitting neuron

= -60 to -80 mV (millivolts)

Slightly more K^+ leaving cell than Na^+ coming in



RESTING POTENTIAL MOVIE

Figure 48.8 and 48.9 (Campbell 9th ed)

17

How a neuron works

Resting neurons have high [K+] inside cell and high [Na+] outside cell

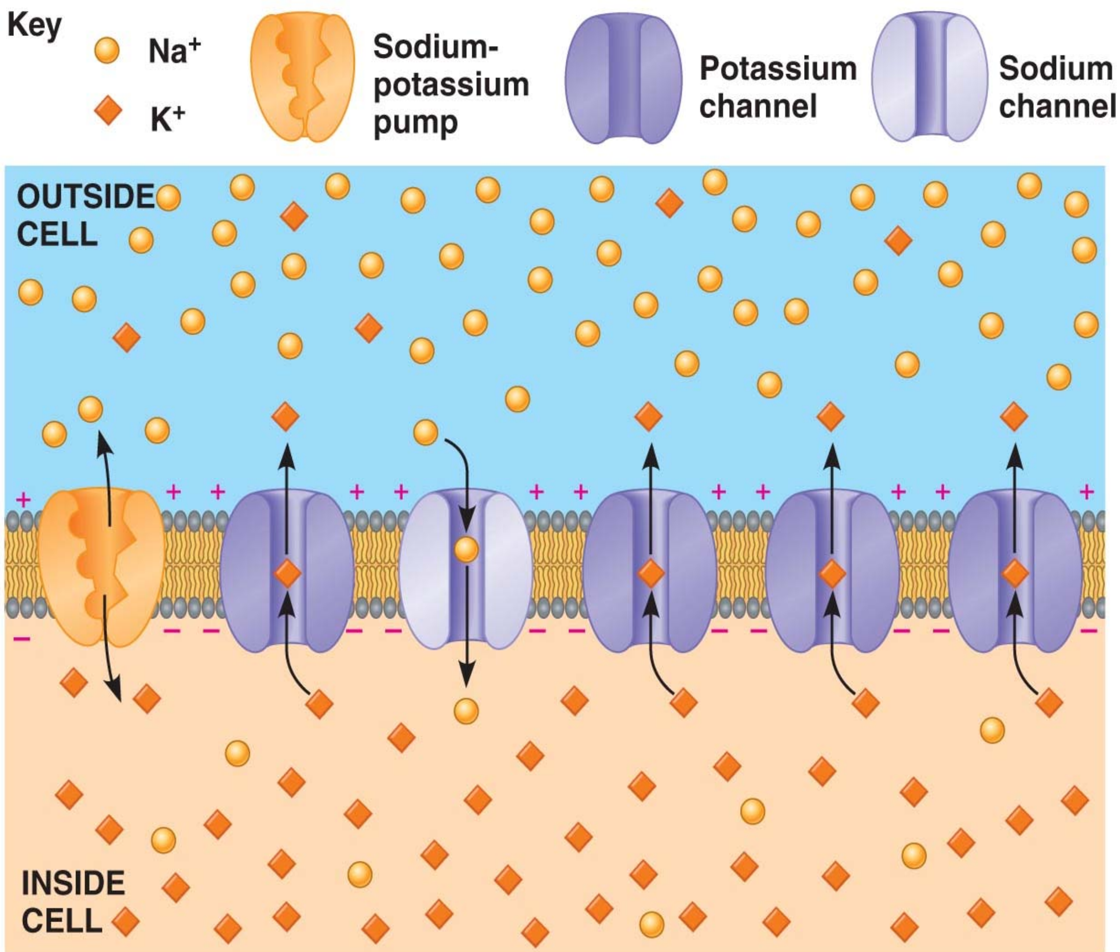


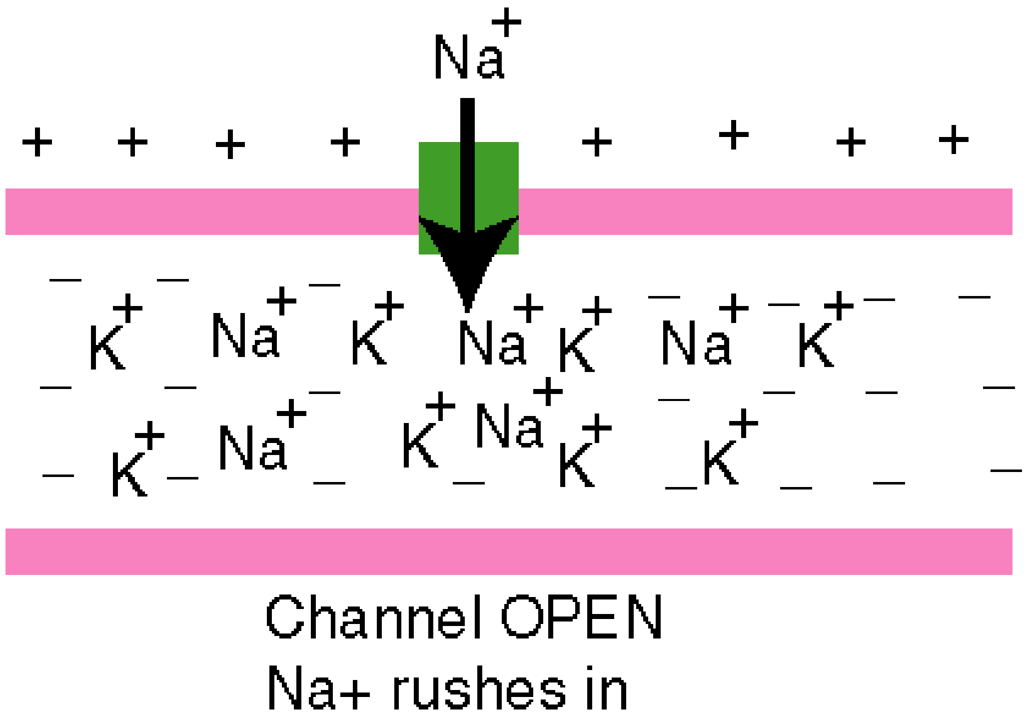
Figure 48.7 (Campbell 9th ed)

How a neuron works

<u>Depolarization</u>

A reduction in the magnitude of a cell's membrane potential.

Occurs when the inside of the cell becomes less negative due to Na^+ ions moving in



http://course1.winona.edu/sberg/ILLUST/Nerve4.gif

Neuron Ion Channels

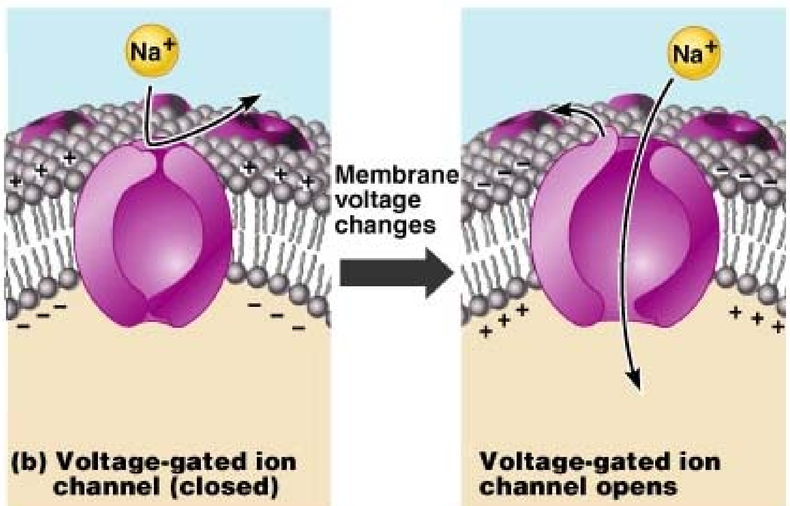
Un-gated

Always open;
passive ion diffusion

Gated

Open & close to stimuli

Voltage



Copyright © 2004 Pearson Education, Inc., publishing as Benjamin Cummings.

Voltage-gated ion channels (VGIC)
- Open/close due to change in membrane potential

1. Stimulus opens a few Na^+ channels and ions flow in making inside slightly less negative (depolarization)

2. VGICs open in response to depolarization causing more depolarization (more Na^+ flows in).

3. This further depolarization causes many more VGICs to open resulting in a rapid depolarization called an "<u>action potential</u>"

Neuron Ion Channels

Un-gated

Always open;
passive ion diffusion

Gated

Open & close to stimuli

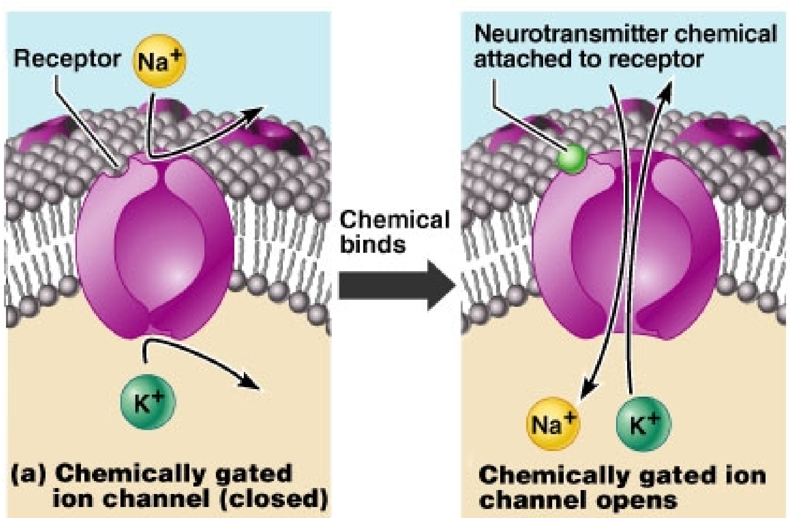
Pressure or Stretch

Light

Temp

Voltage

Ligand



B. Ligand-gated channels open due to binding of chemical to ion channel (e.g. neurotransmitter)

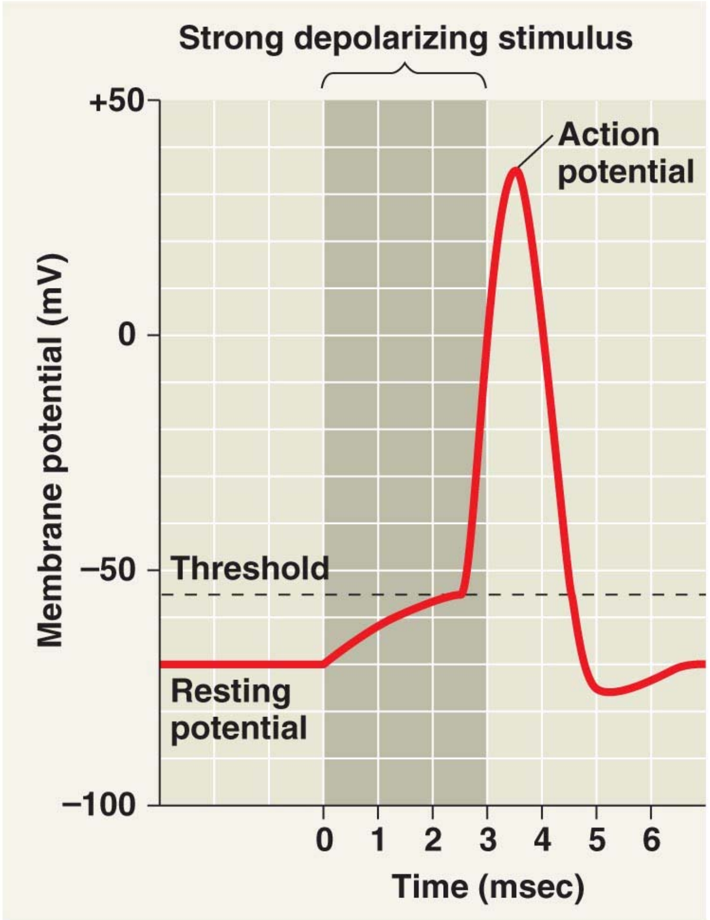
Other gated channels open due to changes in:

C. pressure (stretch)
D. temperature
E. light

Action Potential

Rapid change in membrane potential

Triggered when depolarization reduces the membrane potential (mV) to a particular "threshold" value (-55 mV in mammals)



(c) Action potential

Figure 48.10c (Campbell 9th ed)

23

Generation of Action Potential

1.Resting state:

- Gated Na^+ and K^+ channels closed
- Membrane potential -70 mV

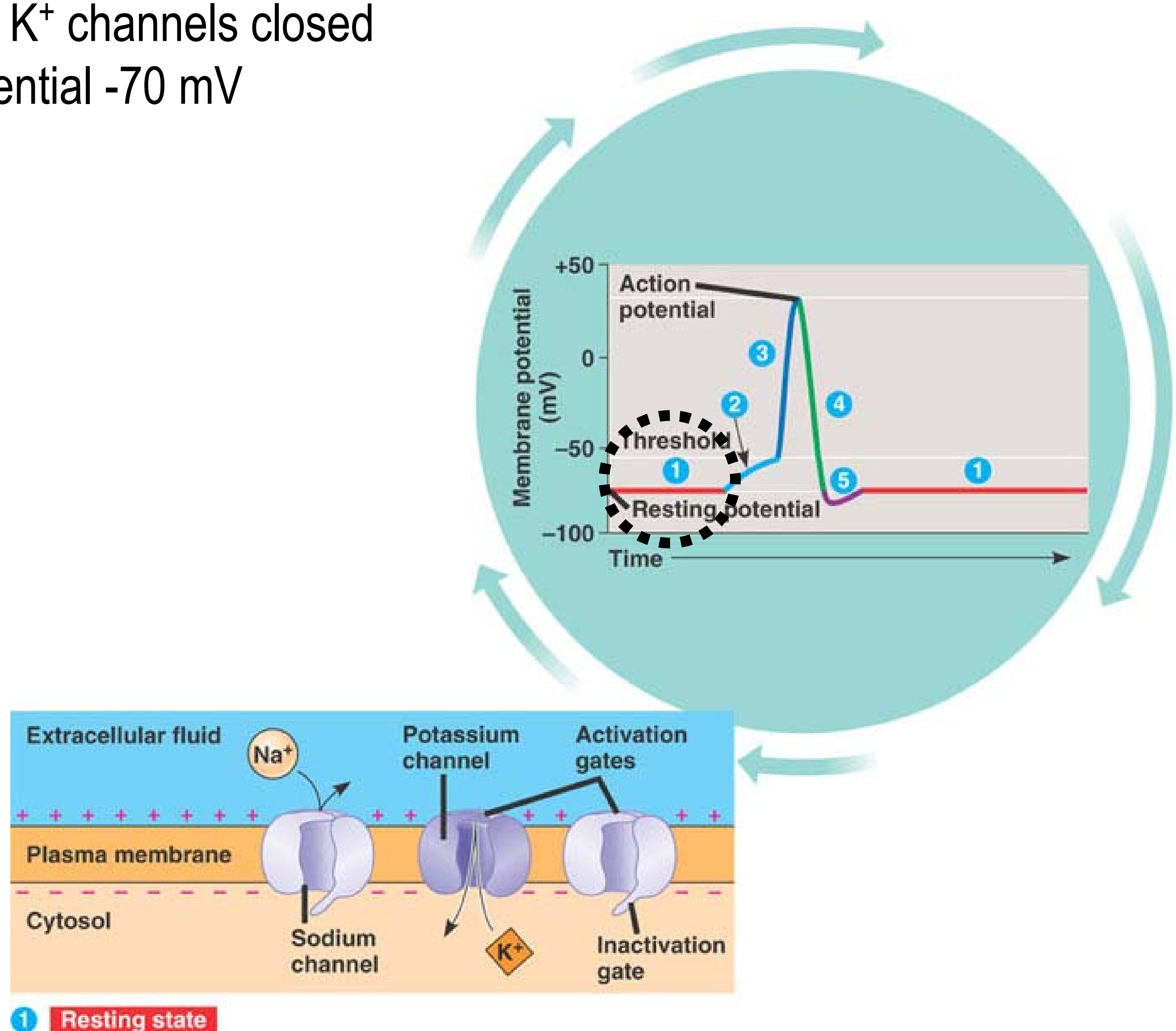


Figure 48.11 (Campbell 9th ed)

Generation of Action Potential

2. Depolarization:
   - Stimulus opens some gated Na^+ channels causing some VGICs to open
   - Membrane potential begins to increase (i.e. less negative) as Na^+ enters

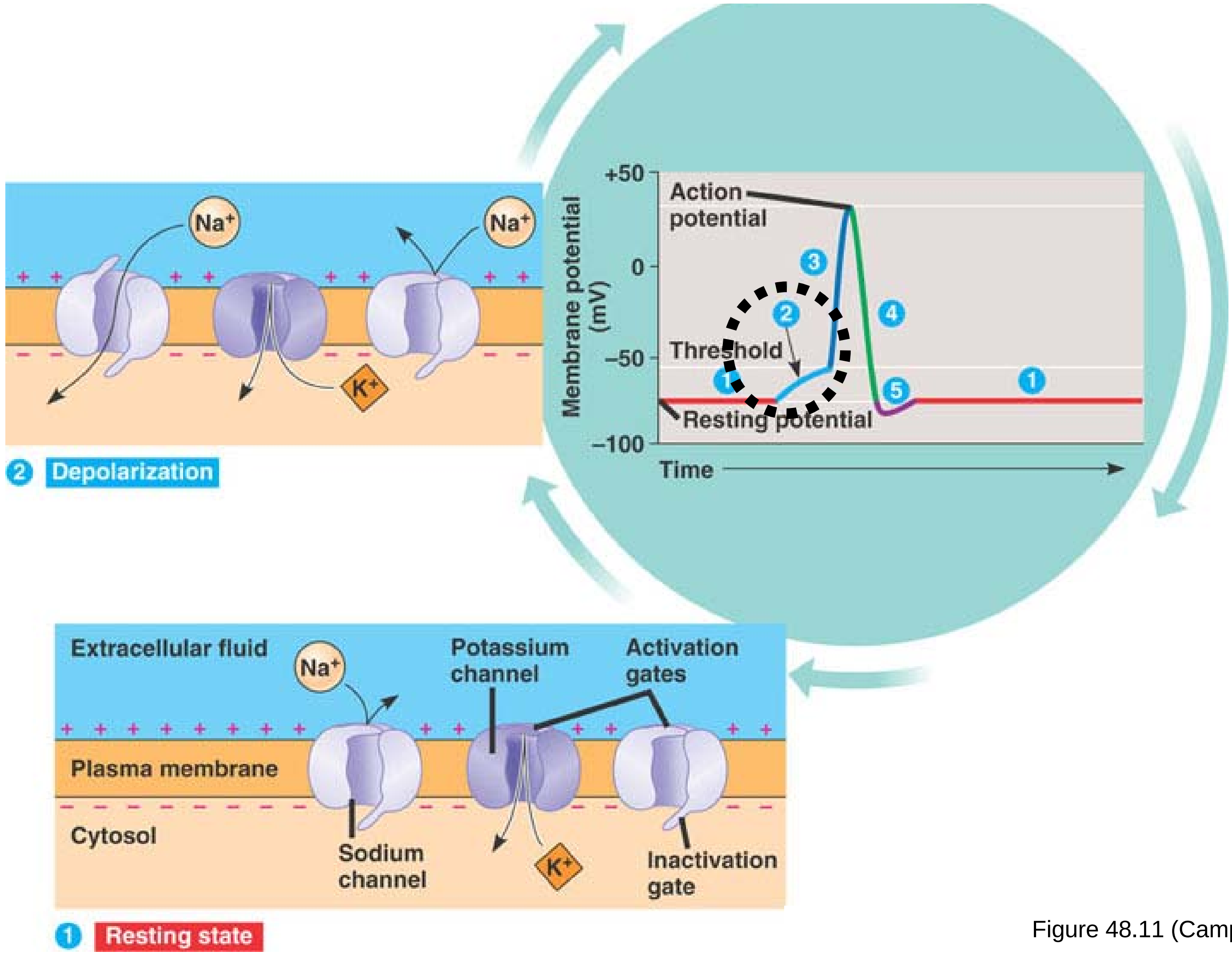
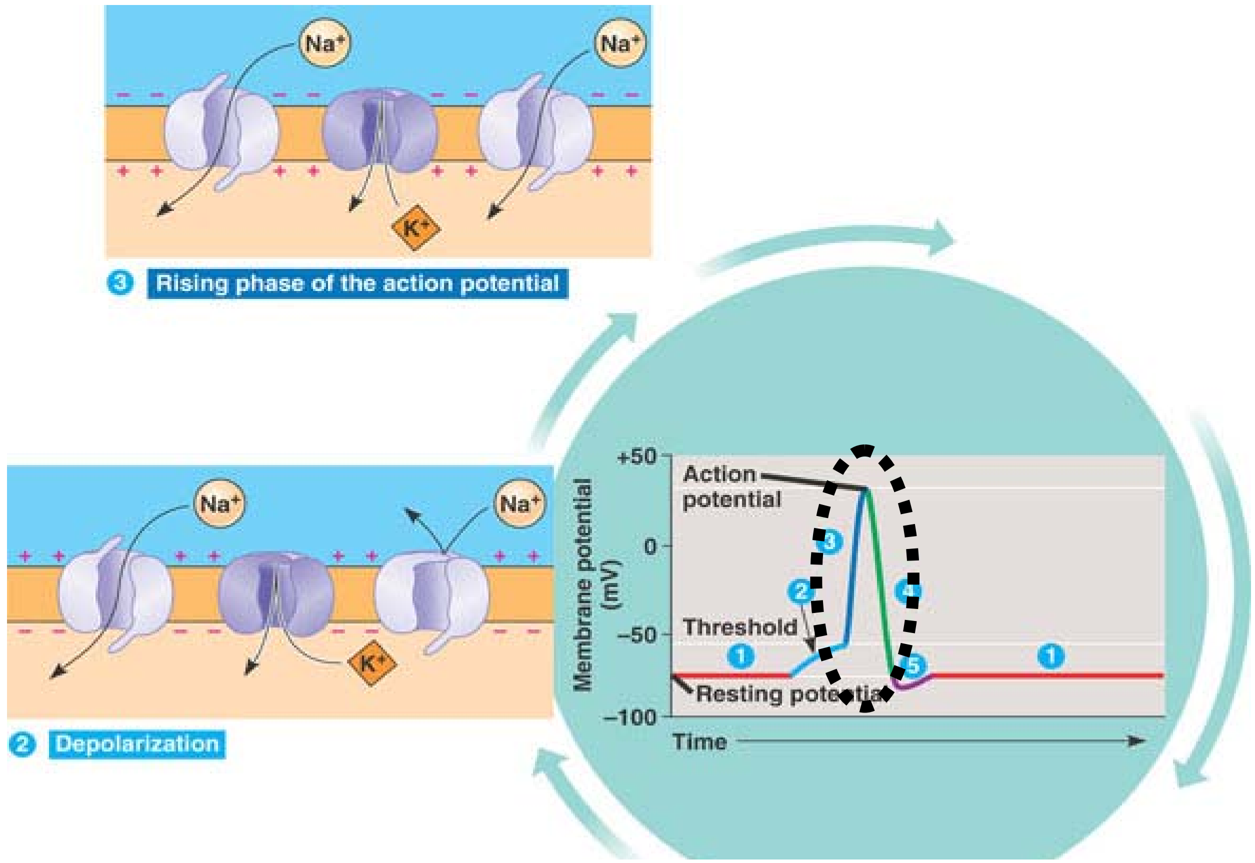


Figure 48.11 (Campbell 9th ed)

25

Generation of Action Potential

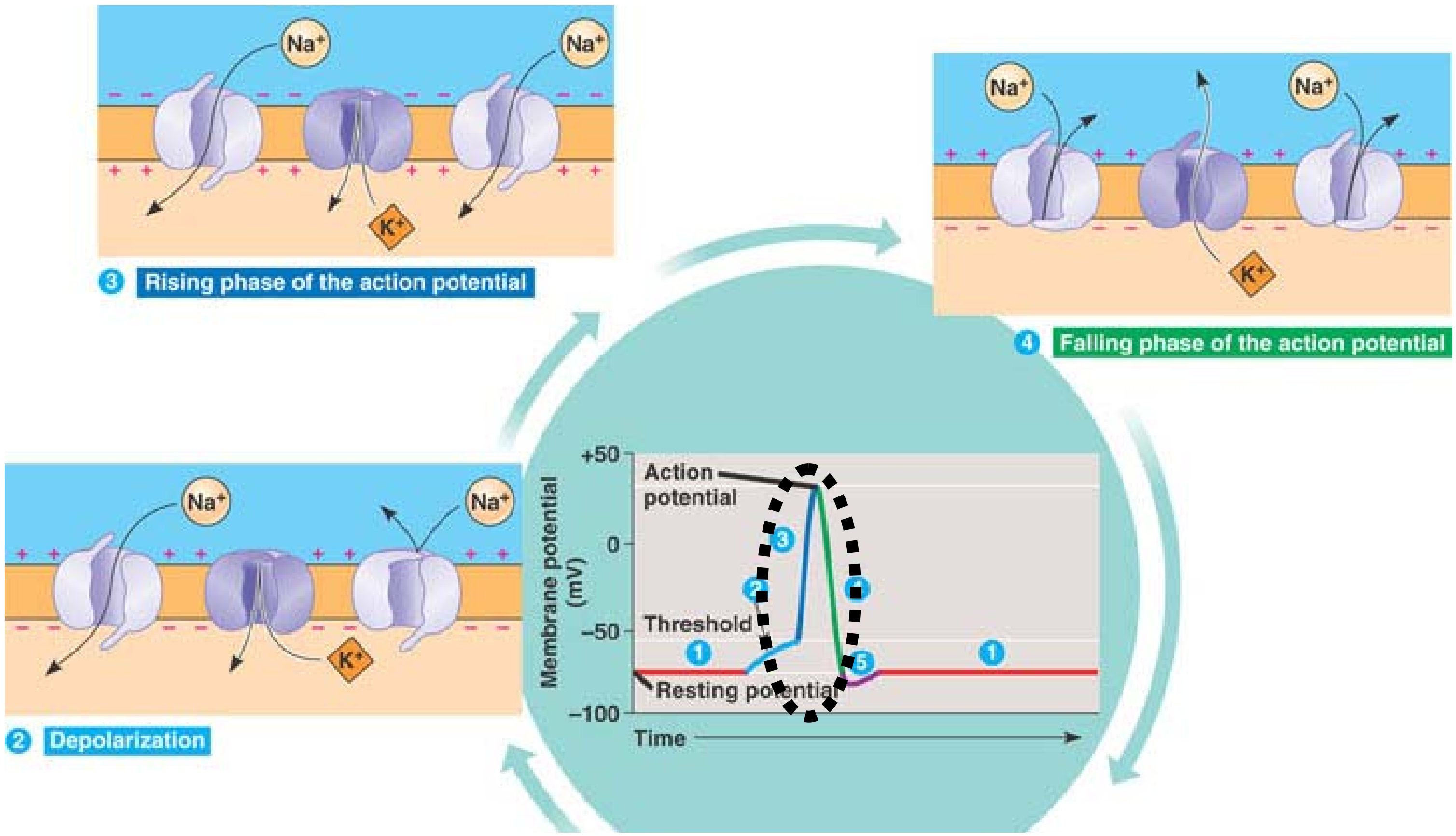


3. Rising phase of Action Potential
    - Threshold reached (-50mv) and most gated Na^+ channels open
        - Na+ rushes in
    - Causes inside of cell to become + with respect to outside of cell

Figure 48.11 (Campbell 9th ed)

26

Generation of Action Potential



4. Falling phase of action potential
   - Most Na^+ channels close and most K^+ channels open
   - K^+ flows out and membrane potential becomes negative again

Figure 48.11 (Campbell 9th ed)

Generation of Action Potential

5. Undershoot
   - All Na^+ channels closed but some K^+ channels still open
     - Membrane potential becomes more – than at rest (<-70mv)
   - As K^+ channels close, Na^+/ K^+ pump returns cell to resting potential

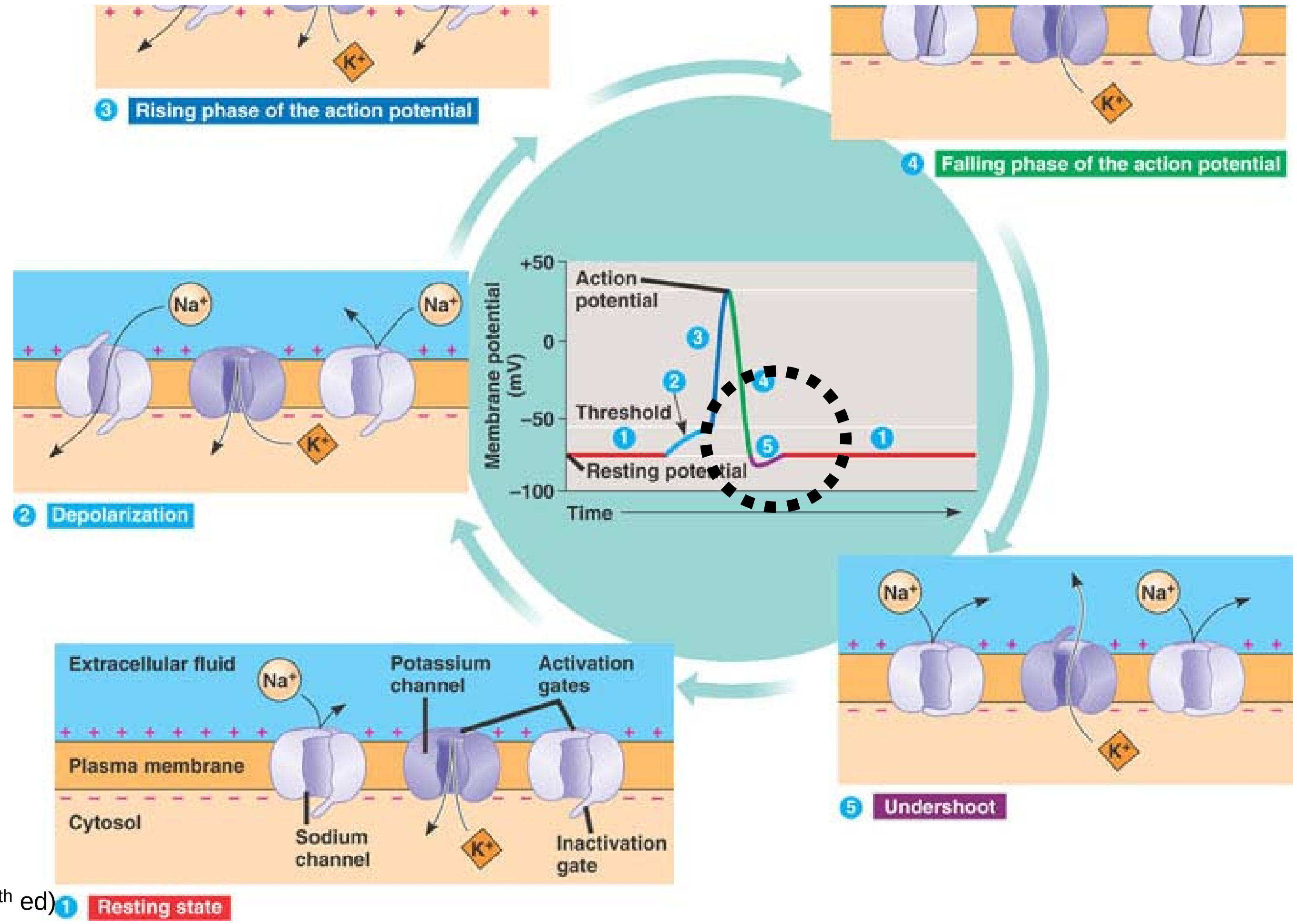


Figure 48.11 (Campbell 9th ed)

Conduction of Action Potential

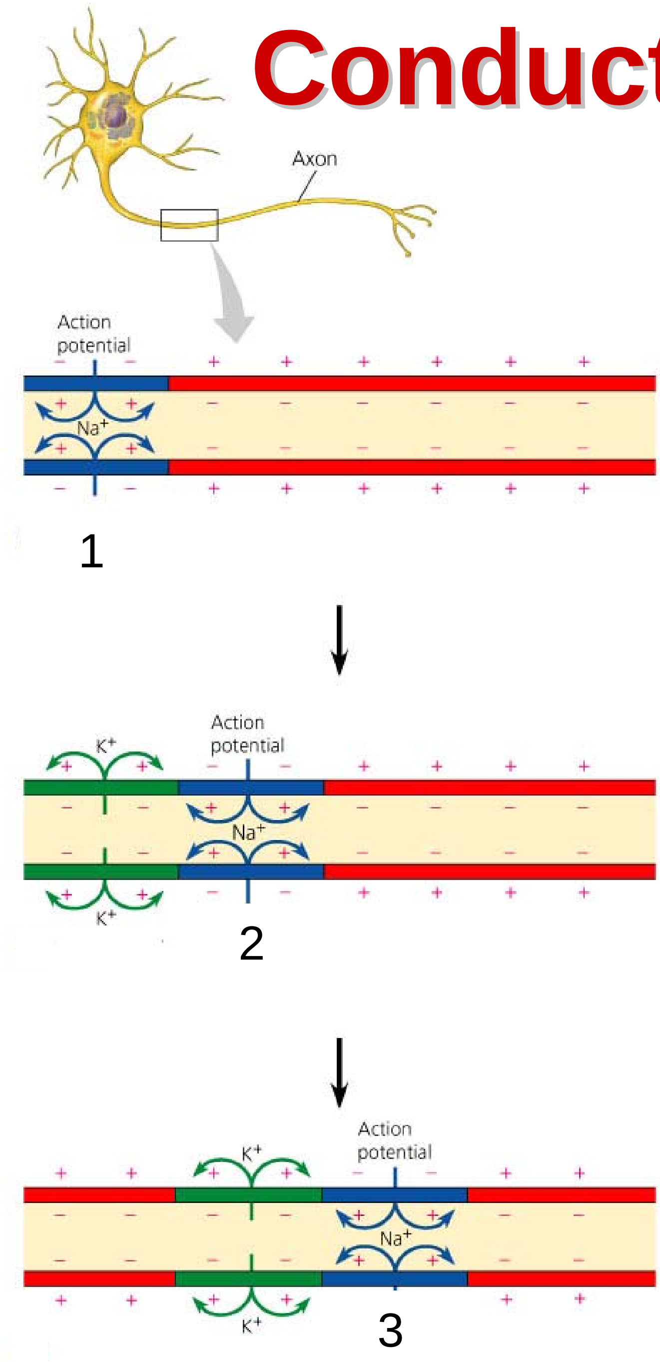


Figure 48.12 (Campbell 9th ed)

- Stimulus causes depolarization in region 1.
  As Na^+ channels open, Na^+ flows in
  and inside of cell in region 1 becomes (+)

- After depolarization Na^+ channels deactivate
  and K^+ channels activate so K^+ flows out
  making region 1 inside (-) again

- Meanwhile Na^+ inside region 1 diffuses to region 2
  making region 2 more (+) inside than out
  and causing depolarization in region 2.
  This continues down axon…

- Na^+ channels stay deactivated
  so depolarization cannot spread in reverse

ACTION POTENTIAL MOVIE

Conduction Speed

Affected by:

- Axon diameter
- Presence of insulation on axon
  - Myelin sheath (only in vertebrates)
    - Schwann Cells (PNS)
    - Oligodendrocytes (CNS)
  - Prevents loss of energy to surrounding tissue
    - Allows saltatory conduction
  - Permits thin yet fast axons

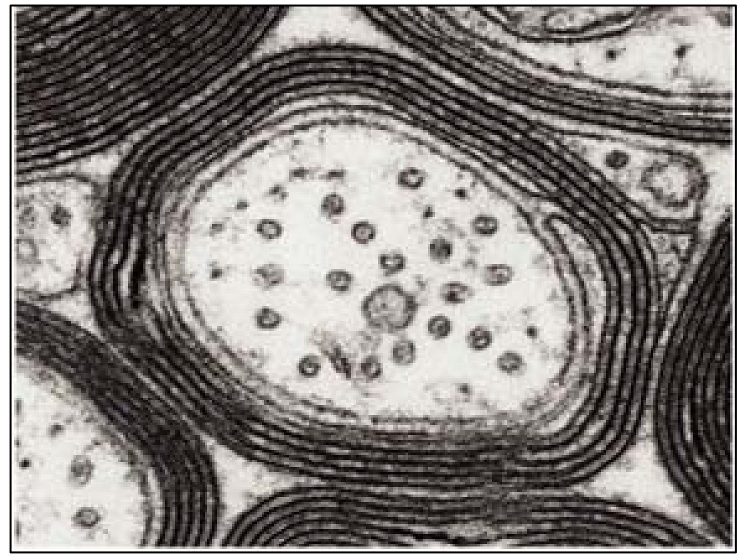
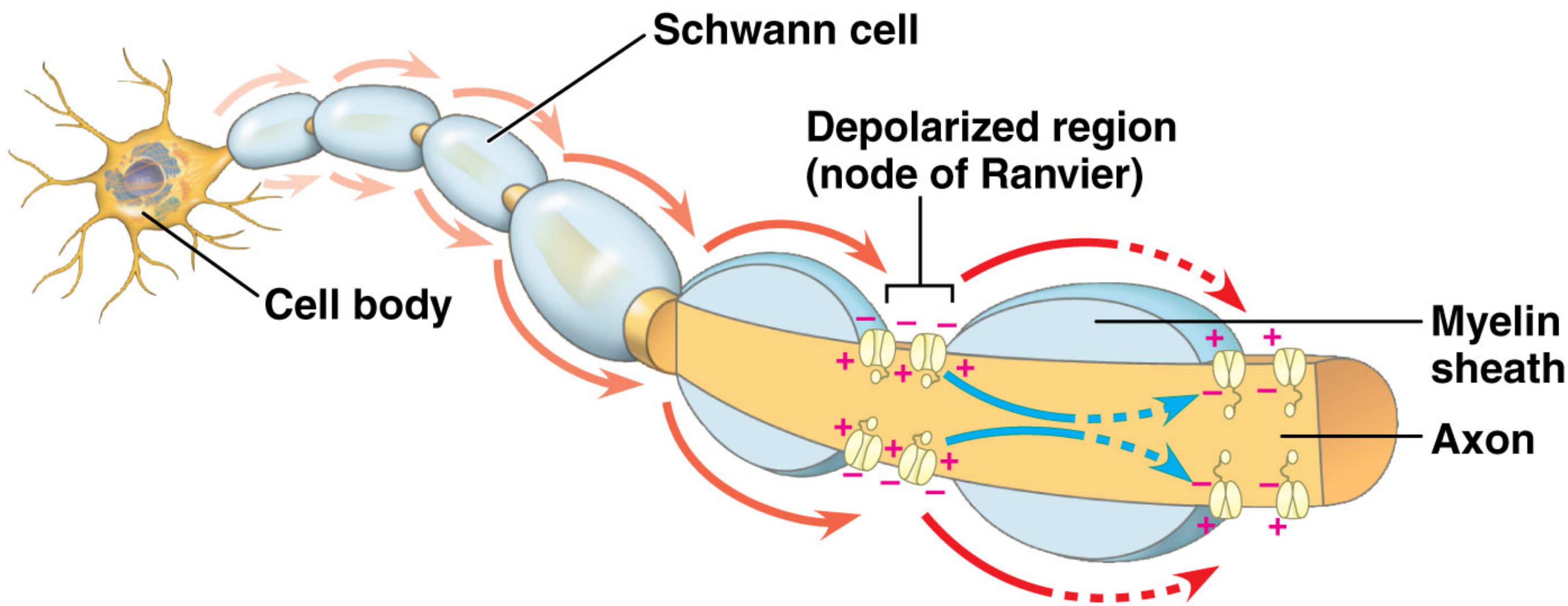


Figure 48.13 (Campbell 9th ed)

32

Myelinated axons conduct faster



© 2011 Pearson Education, Inc.

- Node of Ranvier w/ Voltage-gated Na+ channels = region of depolarization
- Cytoplasm conducts charge to next node which is depolarized
- Myelin reduces energy loss to surrounding tissues so charge is sufficient (i.e. threshold) to allow depolarization
- This discontinuous hopping of depolarization is called <u>saltatory conduction</u>

Figure 48.14 (Campbell 9th ed)

33

White vs. Grey Matter

- Only applies to CNS
- Location differs in brain vs spinal cord

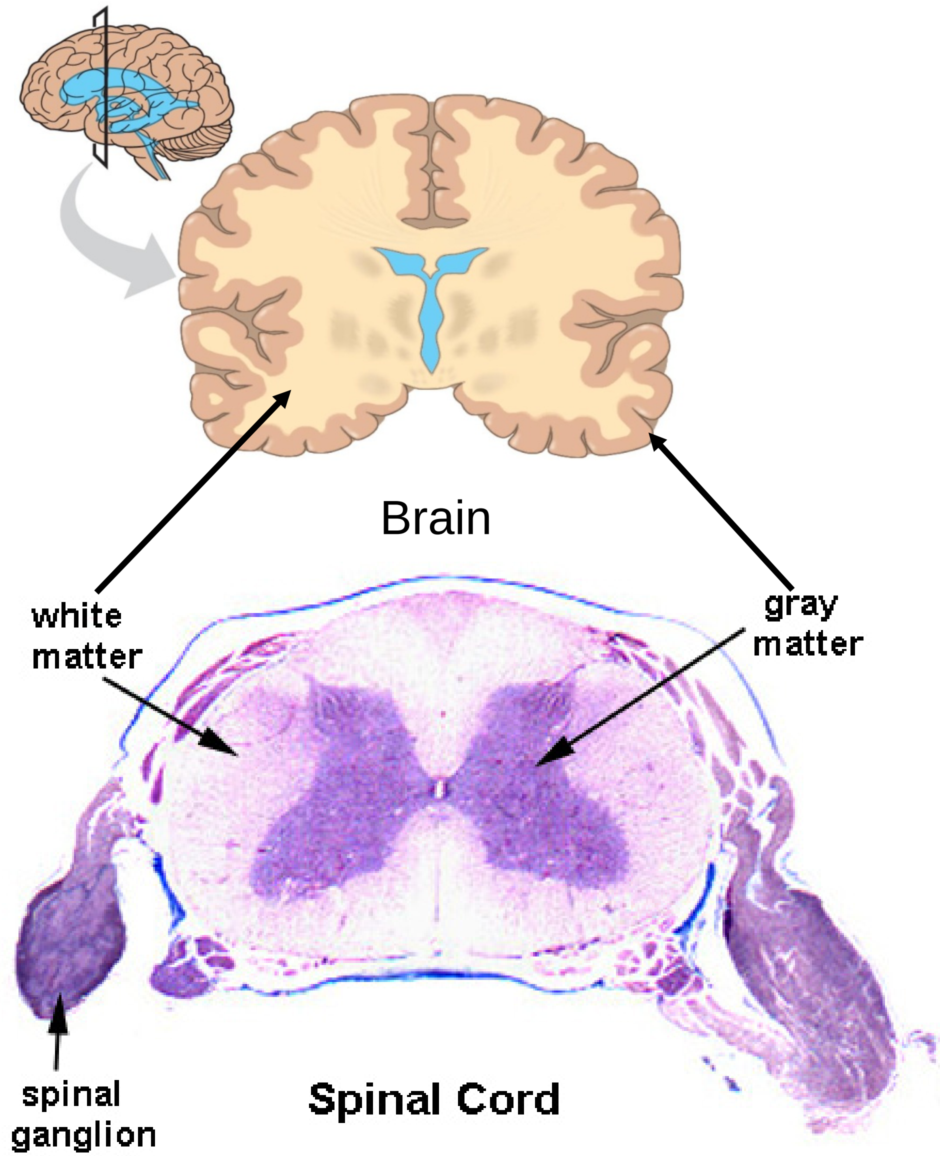


Figure 49.5 (Campbell 9th ed)

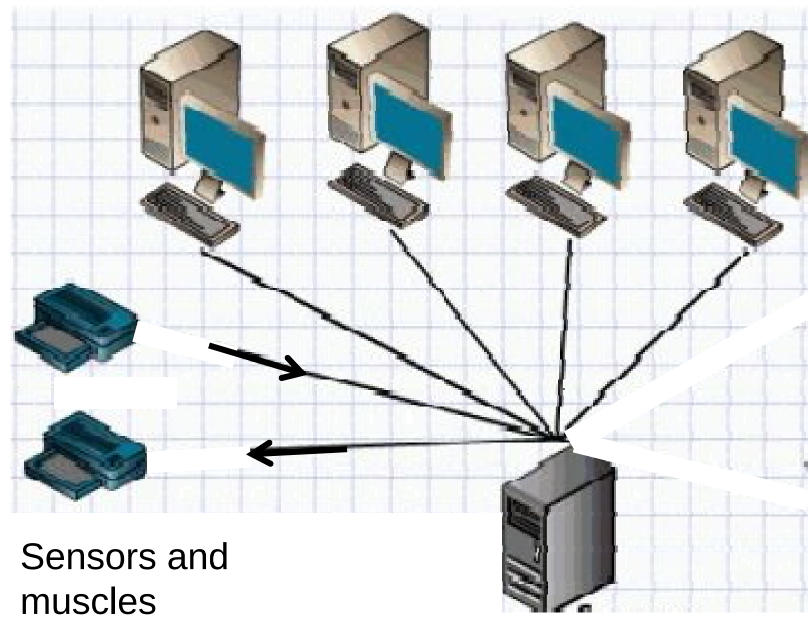
White vs. Grey Matter

White matter:

- ***Myelinated*** axons of motor and sensory neurons
- Communication btwn:
  - grey matter within CNS
  - CNS and PNS

Grey matter:

- Cell bodies, dendrites and *unmyelinated* axons of interneurons and motorneurons, capillaries and glial cells
- CNS processing of data from PNS



Sensors and muscles In PNS

Grey matter =
Cerebral and cerebellar cortex
thalamus; hypothalamus; basal nuclei; etc.

Figure 49.5 (Campbell 9th ed)

35

Communication between Neurons

Electrical synapses

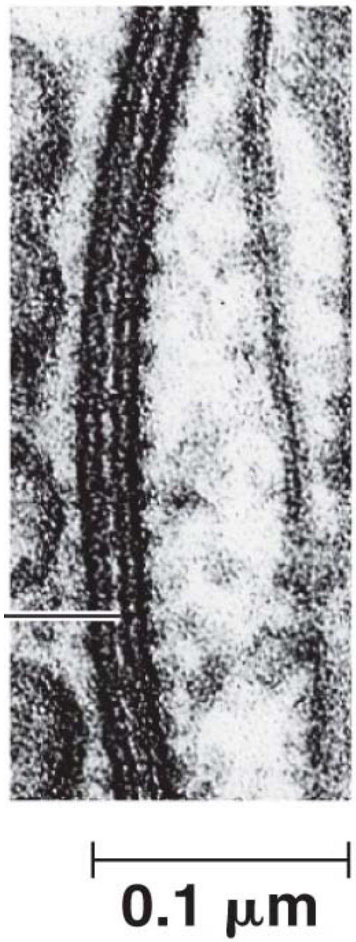


Figure 6.32 (Campbell 9th ed)

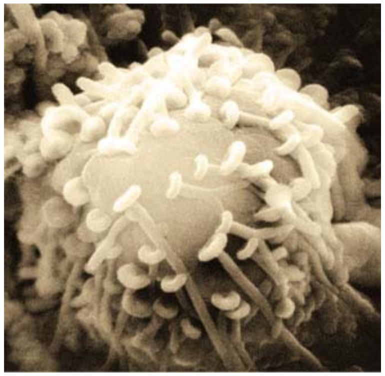
- Narrow (3.5 nm) space (gap junction) btwn cells
- Transmembrane channels join cell cytoplasms
- Action potential continuous btwn neurons (i.e. Na^+ moves from pre- to postsynaptic neuron)
- Bidirectional
- Involved in rapid unvarying behaviors (escape reflex)
- Much less common than chemical synapses

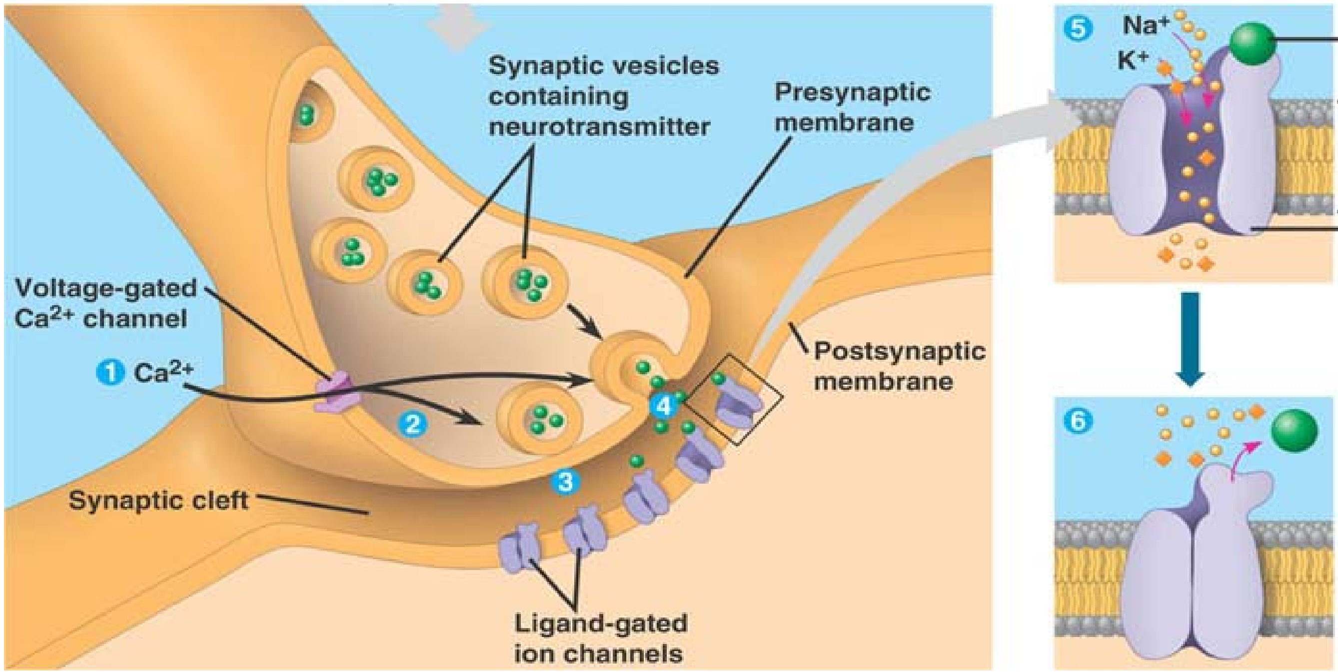
36

Communication between Neurons

Chemical synapses

- Action potential **stops** at axon terminals
- Depolarization of voltage-gated <u>Ca^{2+}</u> channels (vs Na^+ & K^+ in rest of axon)
- Ca^{2+} enters & causes synaptic vessel exocytosis of neurotransmitter (NT)
- NT crosses synapse and binds to **<u>ligand</u>**-gated ion channels on postsynaptic dendrite or cell body
- Na^+ ions flood in and depolarize postsynaptic neuron
- Action potential continues in postsynaptic neuron
- NT released and ion channels close
- NT diffuses away, taken up via pinocytosis or degraded by presynaptic neuron or glia





SHOW SYNAPSE MOVIE

Figure 48.15 (Campbell 9th ed)

37

Communication between Neurons

Electrical vs chemical synapse

	Electrical vs.	Chemical
Speed	Faster	Slower
Gap distance	Smaller	Wider
Postsynaptic Na^+ source	Presynaptic neuron via transmembrane channels	Extracellular inflow via ligand-gated ion channels
Directionality	Bidirectional	Unidirectional
Function	Rapid reactions	All other
Frequency in vertebrates	Less	Greater

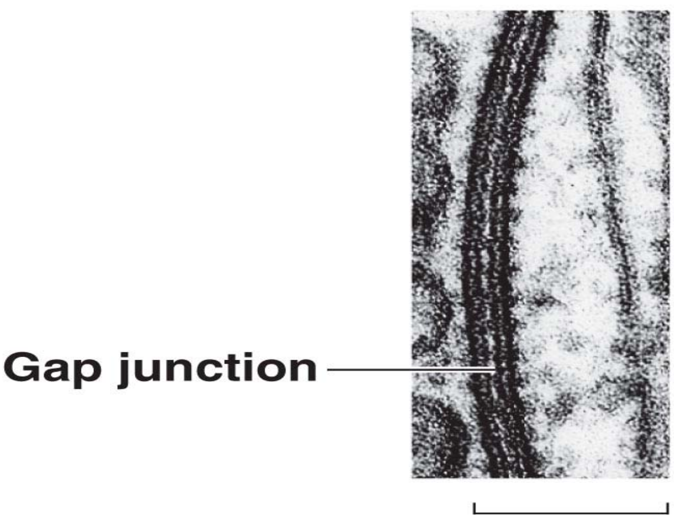


Figure 6.32 (Campbell 9th ed)

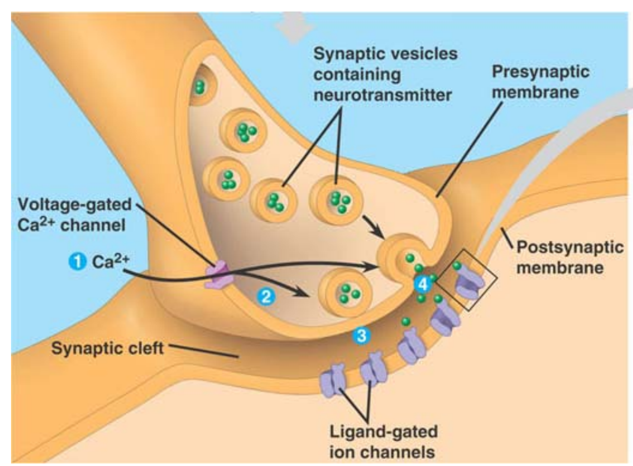


Figure 48.15 (Campbell 9th ed)

44

Ch 48/49 study guide

Chapter 48

- Skip: Modeling of the resting potential and Figure 48.8 (1049-1050)
- Skip: Figure 48.9 (1050)
- Skip: Generation…Summation…Modulated…and Figure 48.17 (1056-1057)
- Skip: Neurotransmitters, Table 48.2, and Figure 48.18 (1057-60)

Chapter 49

- Read: Nervous system consists of…and Figure 49.2 (1062-1063)
- Read: Organization of the vertebrate nervous system and Figures 49.4-49.5 (1063-1065)
- Skip: Figure 49.3 (1064)
- Read: Glia and Figure 49.6 (but do NOT need to know names of specific glial cells) (1065-1066)
- Read: 1st paragraph of The peripheral nervous system (1066)
- Skip: Rest of chapter (1066-1082)

NEXT

- Chapter 50 – Sensory and Motor Mechanisms