# CHAPTER 17:
# The Nervous System

Pg. 320 - 345

# 17.1 - 2 MAJOR DIVISIONS:

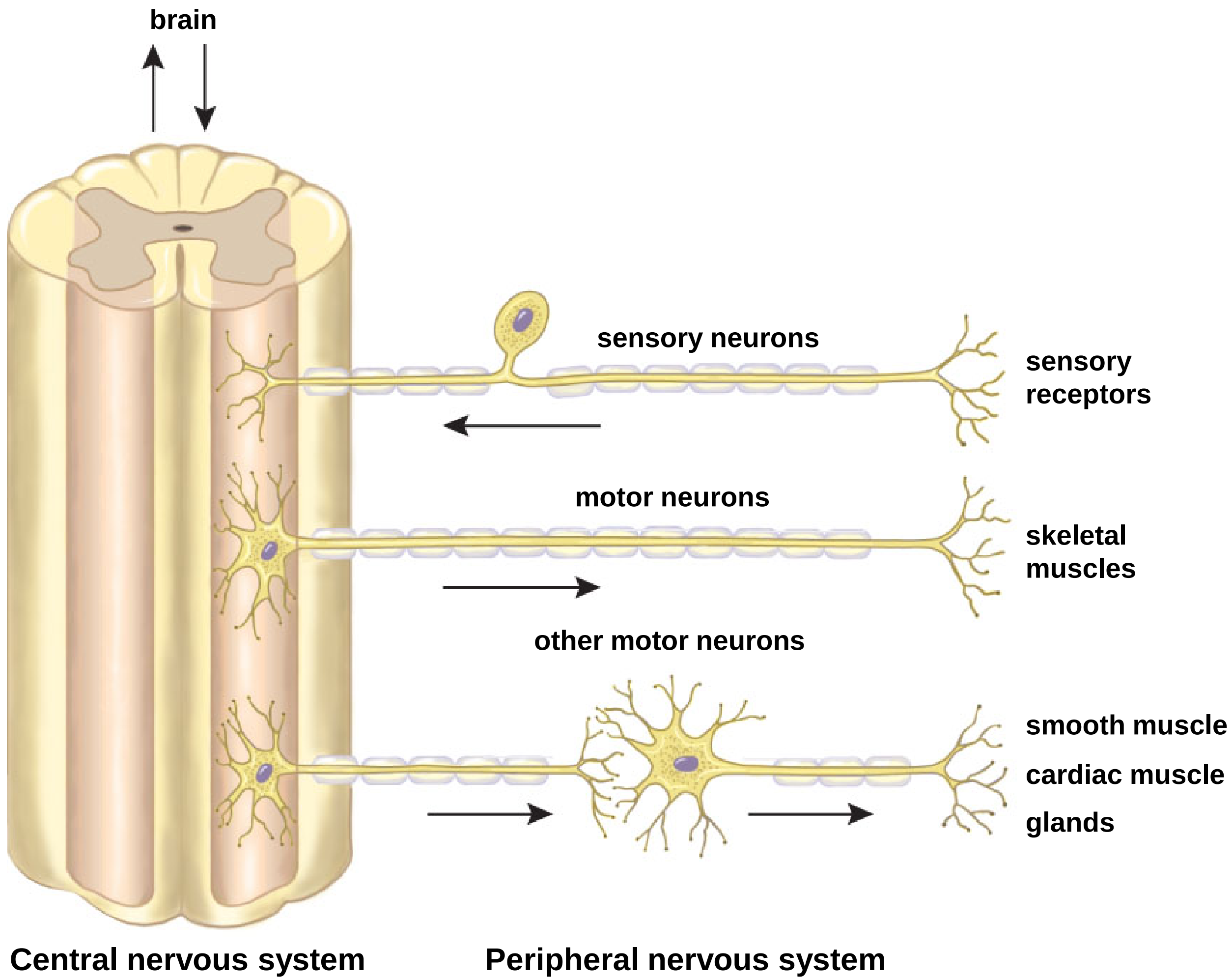
<u>Central nervous system (**CNS**)</u>

- Consists of brain and spinal cord (midline of body)

<u>Peripheral nervous system (**PNS**)</u>

- Everything else (periphery of body)
- Consists of nerves that carry sensory messages <u>**to**</u> CNS and motor commands <u>**from**</u> CNS to muscles and glands

The two divisions are interconnected and work together


brain
sensory neurons
sensory
receptors
motor neurons
skeletal
muscles
other motor neurons
smooth muscle
cardiac muscle
glands
Central nervous system
Peripheral nervous system

b.

# 2 DIVISIONS OF PNS:

1. ***Somatic Nervous System:***
   - Nerves that serve the musculoskeletal system (voluntary)
   - Nerves that serve the exterior sense organs- gives you information about the external environment and allows you to respond to it
   - Includes the **reflex arc** (talk later)

2. ***Autonomic Nervous System:***
   - Nerves that serve heart muscle, smooth, involuntary muscle
   - Controls the internal organs automatically and without "awareness"

# 2 TYPES OF CELLS IN THE N.S.

## NEURONS

- Transmit impulses

## NEUROGLIA

- Support and nourish neurons
- Maintain homeostasis
- Form myelin
- May aid in signal transmission

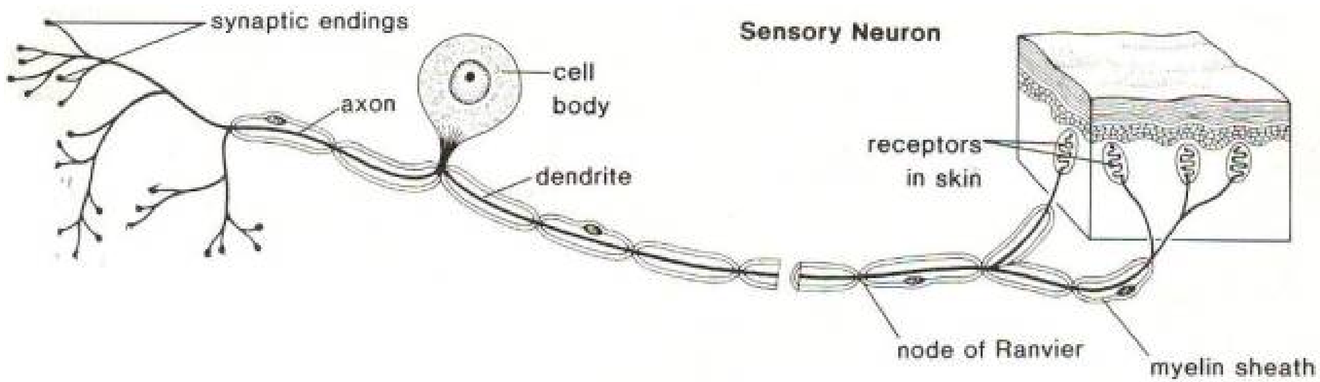
# 3 TYPES OF NEURONS

1. Sensory (afferent) neurons
2. Interneurons
3. Motor (efferent) neurons

# 1. SENSORY NEURONS:

- Part of the PNS
- Take messages **to** the CNS
- Long dendrite, short axon
- Usually equipped with **sensory receptors** that detect changes in environment

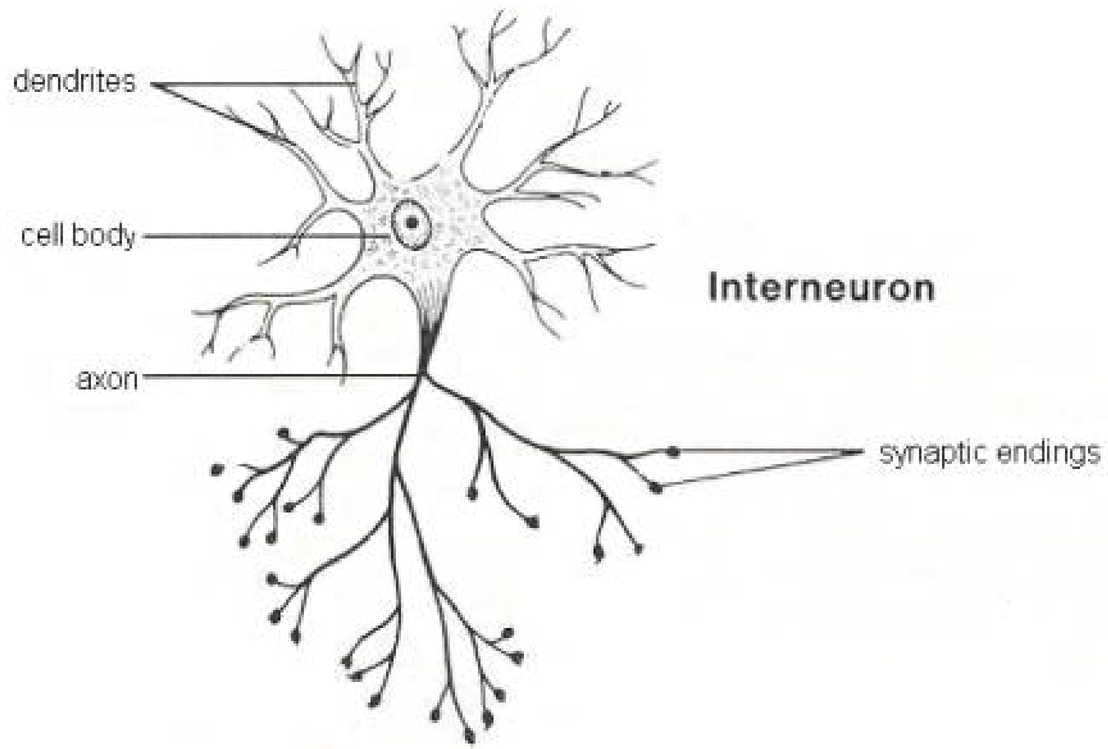
# SENSORY NEURON



# INTERNEURONS

- Lie within the CNS
- Short dendrites and short/long axons
- Receive messages **from** sensory neurons and other interneurons
- They sum up all the messages they receive before they communicate with motor neurons

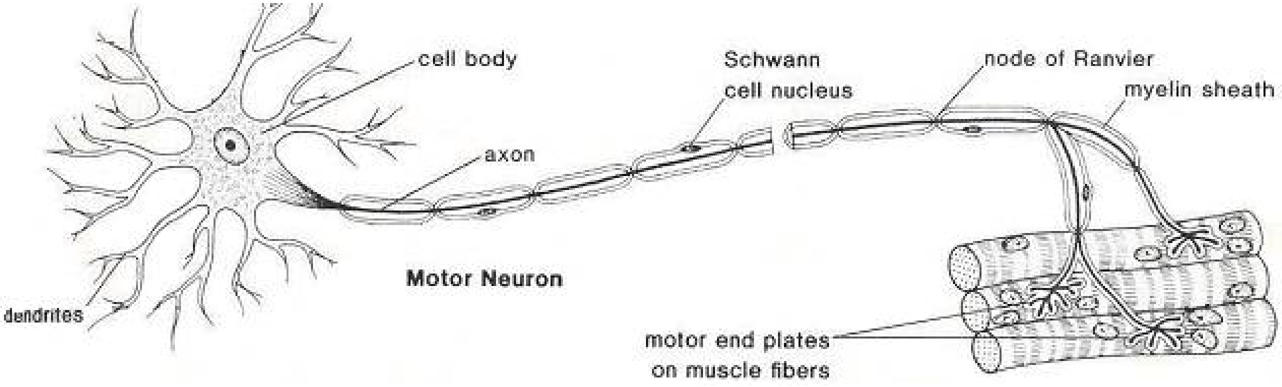
INTERNEURONS



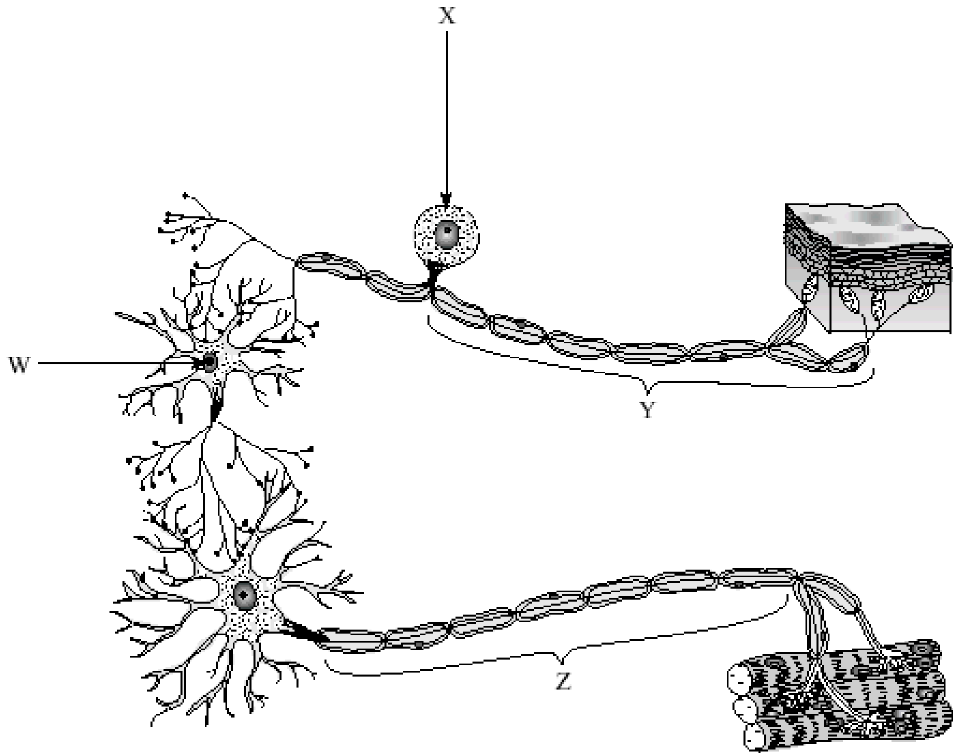
# 3. MOTOR NEURONS:

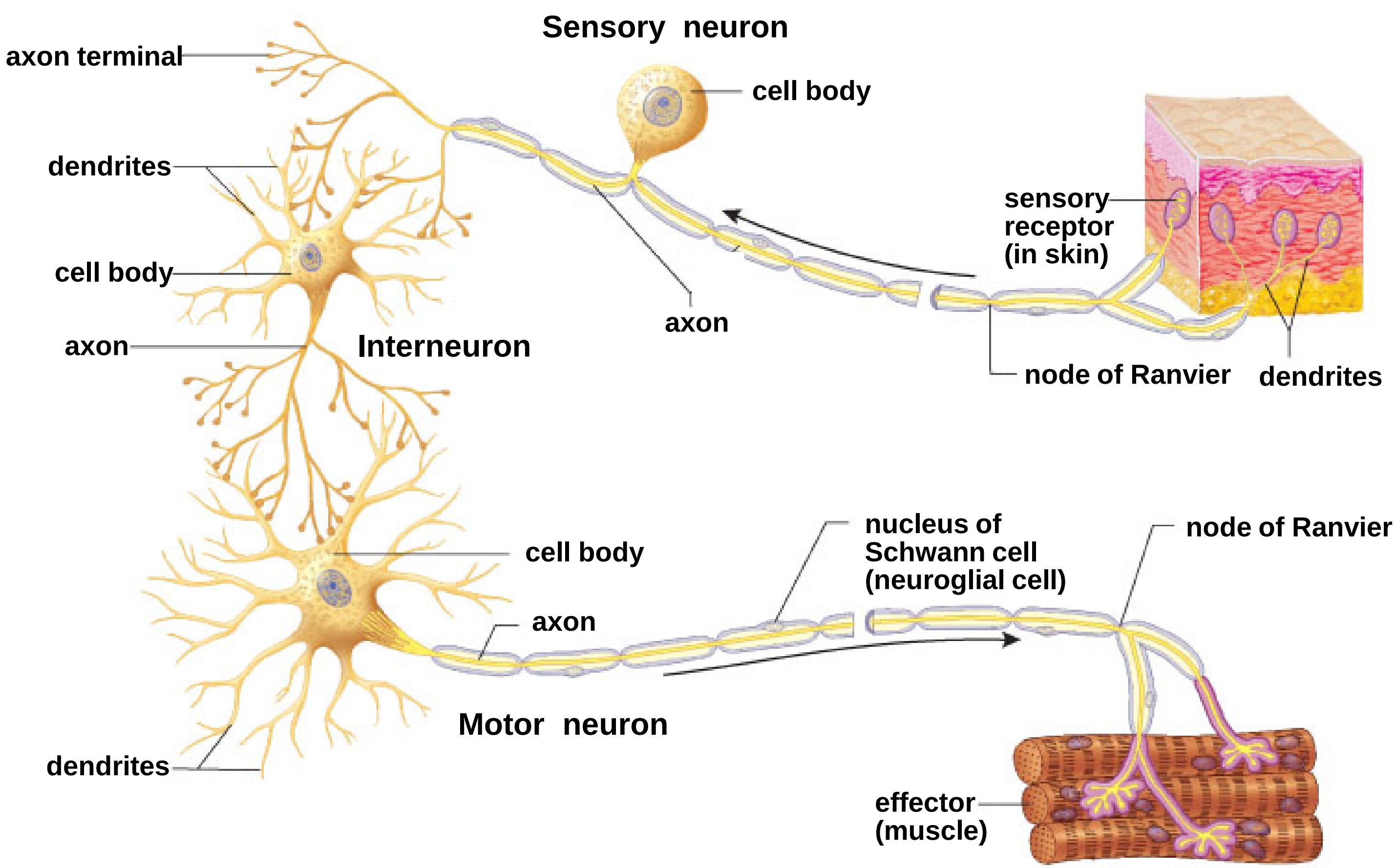
- Part of PNS
- Short dendrites, long axon
- Take messages away from CNS to an **effector**
  - *An effector is a muscle, organ or gland that carries out our response to environmental changes*

# MOTOR NEURON



# SENSORY, INTER-, AND MOTOR NEURONS

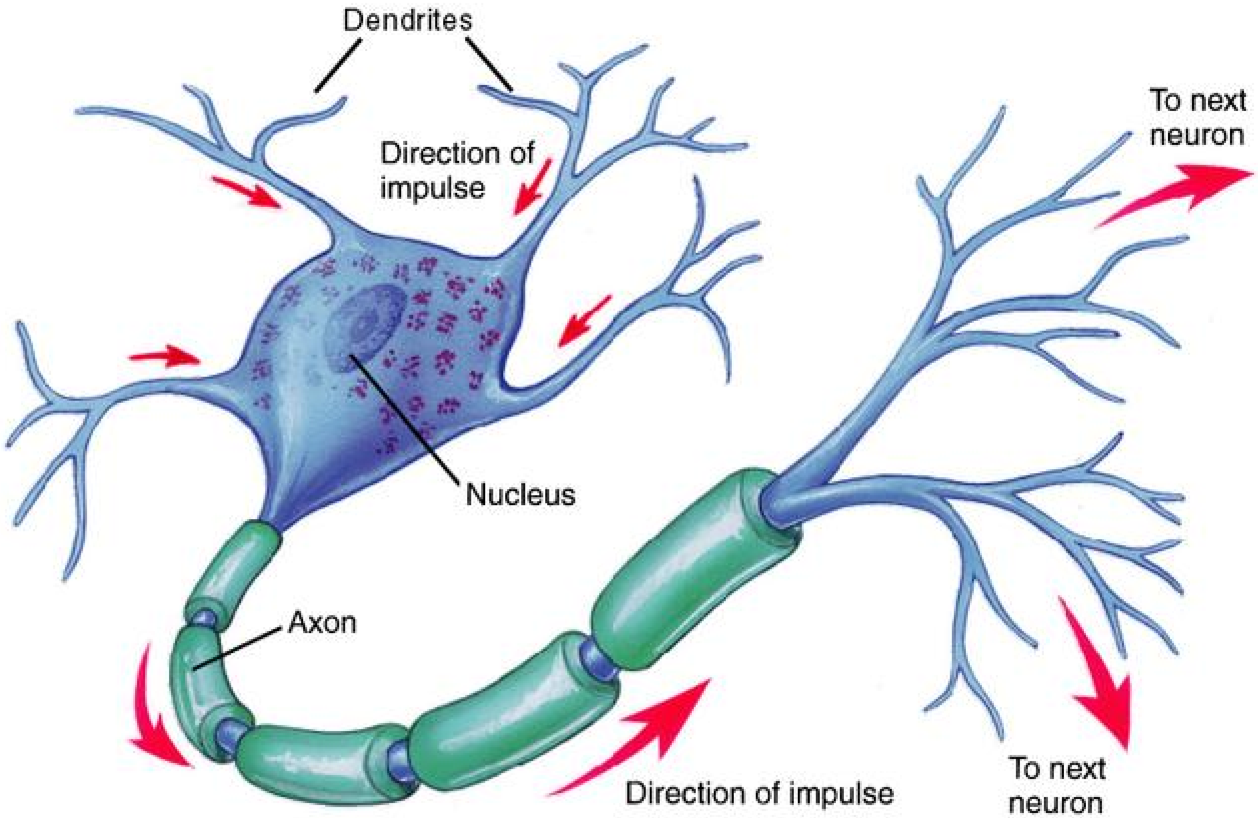



Sensory neuron
axon terminal
cell body
dendrites
sensory
receptor
(in skin)
cell body
axon
axon
Interneuron
node of Ranvier
dendrites
nucleus of
Schwann cell
(neuroglial cell)
node of Ranvier
cell body
axon
Motor neuron
dendrites
effector
(muscle)

# NEURON STRUCTURE:

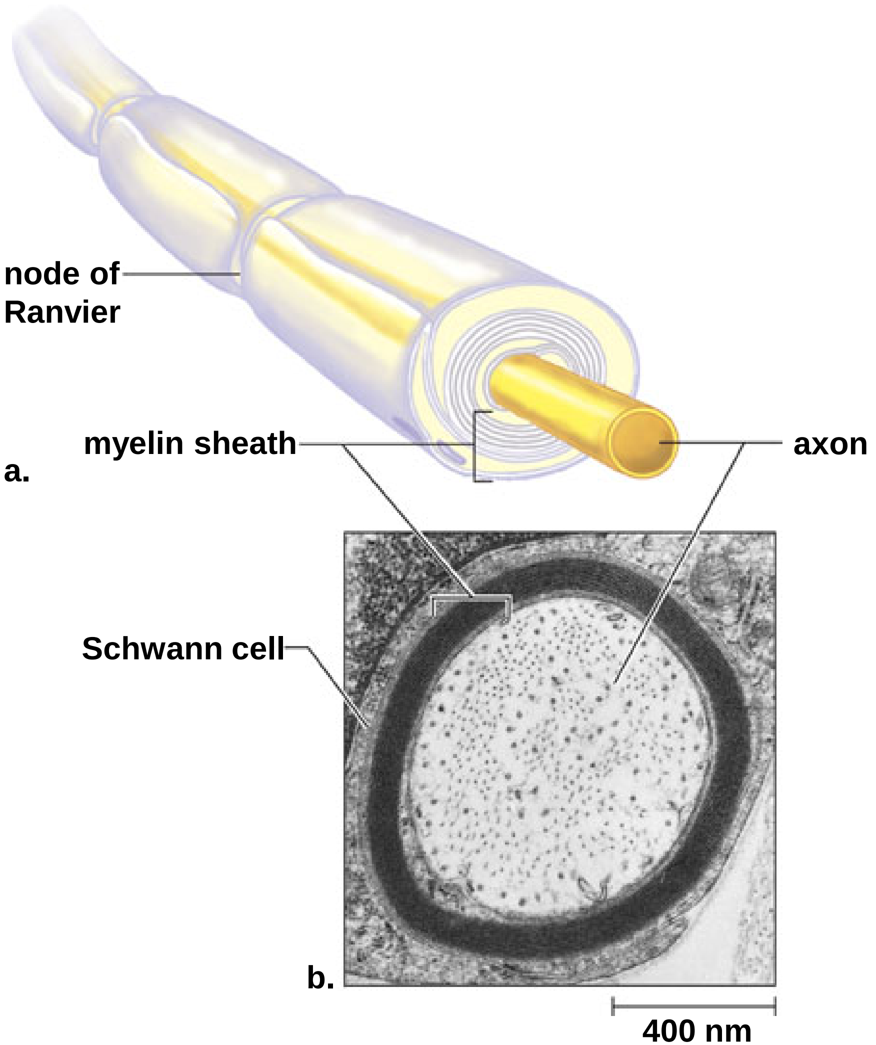
*Although there are different types, all neurons have 3 parts:*

1. **<u>Cell body</u>**
   - Contains nucleus and organelles
   - Carries out normal cell functions
2. **<u>Dendrites</u>**
   - Extensions leading towards cell body
   - Receive signals from other neurons and direct them toward cell body
3. **<u>Axon</u>**
   - Extension leading away from cell body
   - Conducts nerve impulses away from cell body towards other neurons or effectors


Dendrites
Direction of impulse
Nucleus
Axon
Direction of impulse
To next neuron
To next neuron

# MYELIN SHEATH

- Some axons are covered with a protective lipid layer called **<u>myelin</u>**
- *Myelin sheath* is formed by types of neuroglia called **<u>Schwann cells</u>** (PNS) and **oligodendroglial cells** (CNS)
- Schwann cells wrap themselves up to 100 times around an axon, laying down multiple layers of plasma membrane
  - Each cell myelinates only a small portion of an axon (~1mm) so there are gaps between each segment
  - These gaps are called the **<u>Nodes of Ranvier</u>**


node of
Ranvier
myelin sheath
axon
a.
Schwann cell
b.
400 nm

# WHY MYELINATE?

- In the PNS, myelin sheath gives neurons a white appearance

- Myelin serves as an **insulator**
  - Nerve impulses travel faster in myelinated cells:
    - **Ie. Non-myelinated = 5 m/s**
      **Myelinated = 100-200 m/s**

- Can **protect** nerve cells in the PNS to help them to regenerate if they are damaged

# NODES OF RANVIER

- Really important when it comes to impulse transmission

→ **<u>Saltatory conduction:</u>**

- Nervous impulses travel faster along myelinated axons because they jump from node to node…

# THE NERVE IMPULSE:

- It is an electrochemical change that moves in one direction along the length of a nerve fiber
  - It is electrochemical because it involves changes in voltage and concentrations of ions

- It has been studied using excised axons and an oscilloscope (voltmeter)

- ***Remember:*** voltage (expressed in mV) is a measure of the **electrical potential difference** between two points

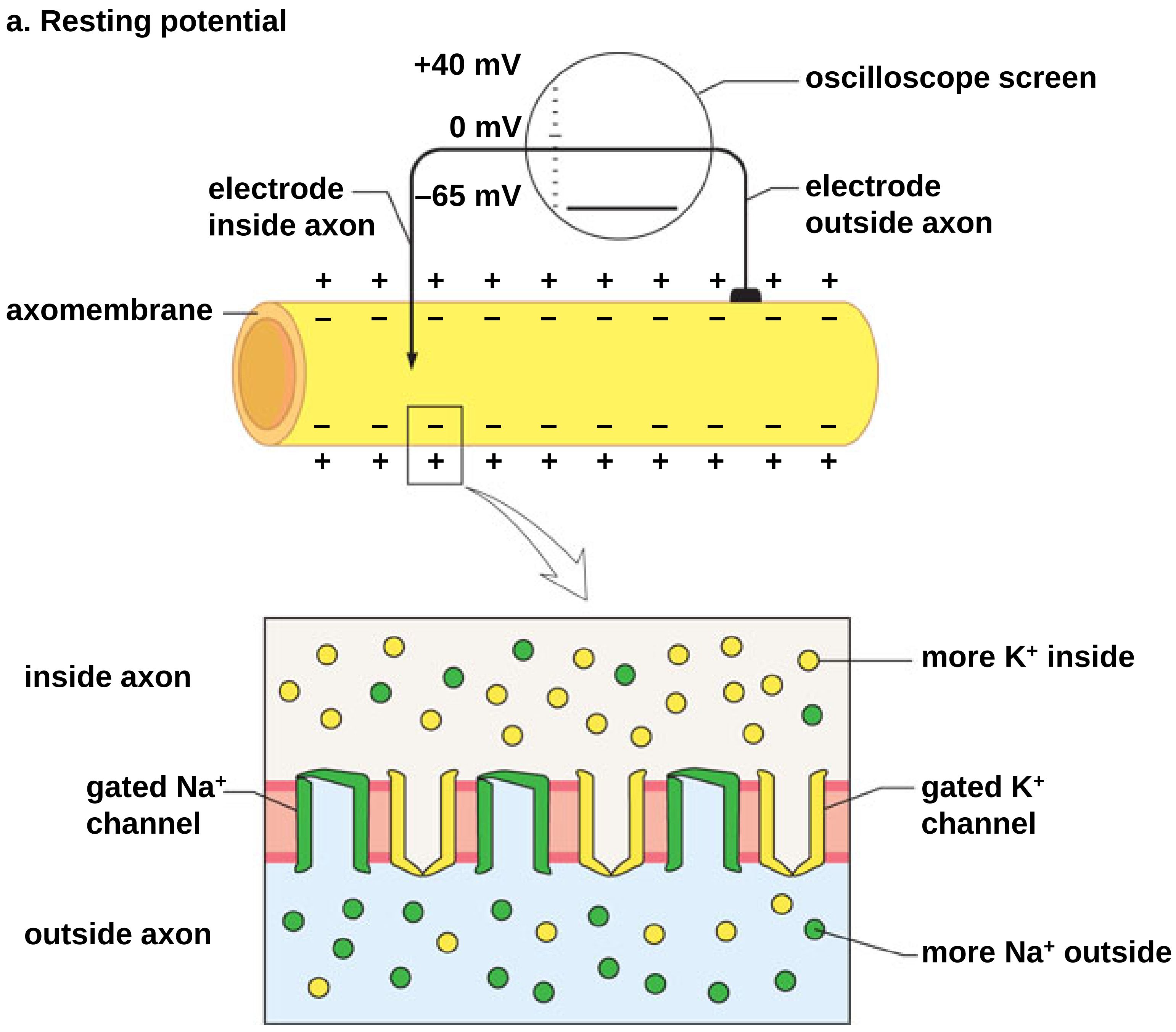
- In this case, the potential difference is between the outside and inside of an axomembrane

# 3 DISTINCT PHASES OF NERVE IMPULSE ALONG AN AXON:

- ***<u>RESTING POTENTIAL</u>***
  - *Na+/K+ pump at work*
- ***<u>ACTION POTENTIAL</u>***
  - *Depolarization: Na+ gates open*
  - *Repolarization: K+ gates open*
  - *Refractory Period: Na+ gates unable to open*
- ***<u>RECOVERY PHASE (simultaneous w/ refractory period)</u>***
  - *Na+/K+ pump at work*

# RESTING POTENTIAL:

- An axon is basically a membranous tube filled with axoplasm
- When an axon is at rest (not conducting an impulse) a voltmeter records a potential difference of **-65mV**
  - This indicates that the inside of the axon is negative compared to the outside
- It is due to the ***ion distribution*** on either side:
  - **<u>INSIDE:</u>** there are many large negatively charged ions and more K+
  - **<u>OUTSIDE:</u>** there is more Na+


a. Resting potential
+40 mV
0 mV
–65 mV
oscilloscope screen
electrode inside axon
electrode outside axon
axomembrane
inside axon
outside axon
gated Na+ channel
gated K+ channel
more K+ inside
more Na+ outside

# SODIUM & POTASSIUM

- The unequal distribution of $K^+$ and $Na^+$ inside and outside the axon is maintained by the **<u>$Na^+$/$K^+$ pump</u>**

- The $Na^+$/$K^+$ pump is **always working** because these ions tend to diffuse back across the membrane down their [ ] gradient

- The membrane is more permeable to $K^+$ than it is to $Na^+$
  - **.:** there are often **more positive charges outside the membrane**

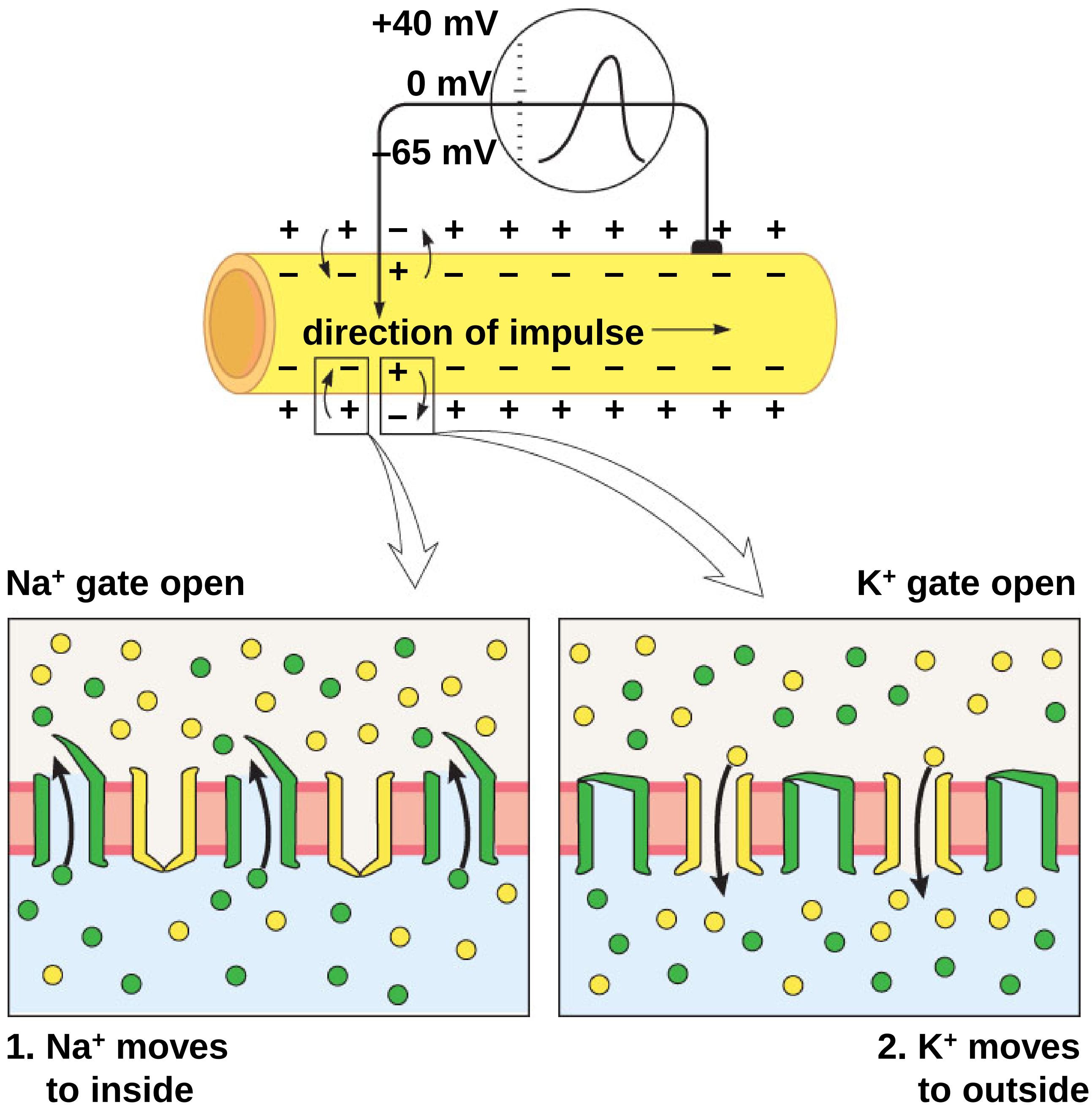
# ACTION POTENTIAL:

- Is a rapid change in polarity across the membrane as the nerve impulse occurs

- Begins with **depolarization**
  - **AKA:** Upswing (-65mV to +40mV)

- Depolarization of the membrane occurs when **sodium voltage-gated channels open**
  - Due to some stimulus (pH, electric shock, mechanical stimulation)
  - $Na^+$ diffuses into the axon causing the local region **inside to become positively charged**
  - As $Na^+$ leaves, the outside of the axon is left with a slight negative charge
  - The action potential is now at **+40mV**

## c. Action potential



# AP - REPOLARIZATION:

- The next thing to happen is the **<u>gates of the potassium channels open</u>**

- **$K^+$** diffuses **<u>out</u>** of the axon

- The charge inside the axon then changes from **<u>positive to negative</u>**

- The action potential is now **<u>back at -65mV</u>** but the ion distribution is not the same as it was before…

# AP - RECOVERY PHASE:

- After repolarization the $Na^{+}/K^{+}$ pumps start to work again
- This causes $K^{+}$ to be pumped back into the axon, and $Na^{+}$ back out
- Back to resting potential!

# REFRACTORY PERIOD

- The change in voltage during an action potential causes adjacent $Na^{+}$ VGCs to open too
  - This allows the impulse to travel the length of the axon

- However, the region from which the impulse originated is in a **refractory period**
  - When the $Na^{+}$ VGCs cannot open
  - This ensures that the impulse only travels in one direction down the axon towards the terminals

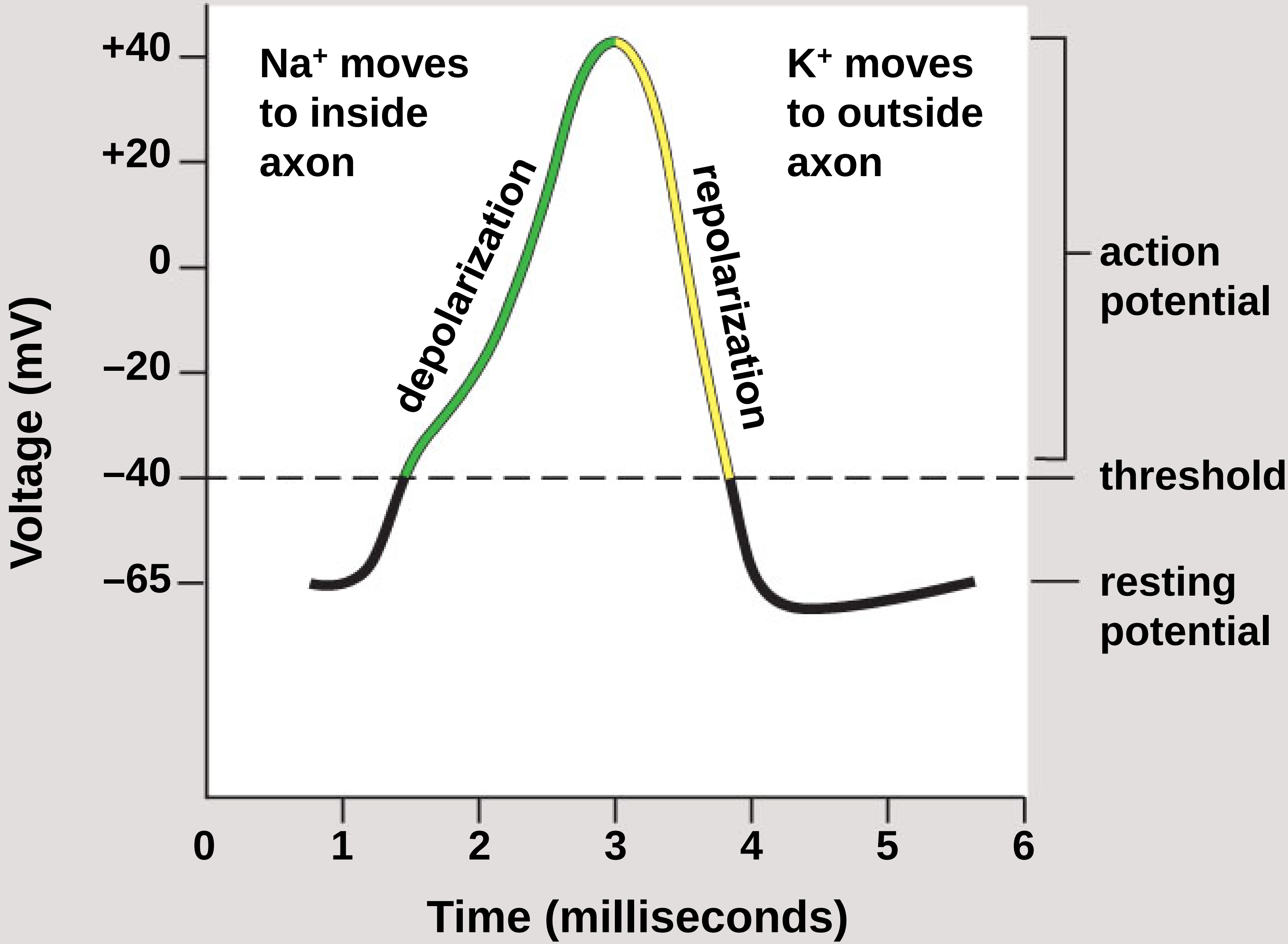
# THE "ALL-OR-NONE" RESPONSE

- An action potential (AP) is considered to be an **all-or-none** phenomena
- If a stimulus causes depolarization of the axonal membrane to a certain level (**threshold**) an AP occurs
  - Usually around -40mV is all it takes to start an AP
- That is, **the strength of an AP never changes**
  - *There is either an AP, or there isn't*
- The only variable that may change is frequency of APs
  - *The stronger a stimulus, the more frequent the APs*

# AN OVERVIEW:

1. **Resting potential (-65mV)**
   - $Na^+/K^+$ pump at work
2. **Depolarization (-65mV to +40mV)**
   - $Na^+$ VGCs open
   - $Na^+$ moves into axon
3. **Repolarization (+40mV to -65mV)**
   - $K^+$ VGCs open
   - $K^+$ moves out of axon
4. **Recovery Period**
   - $Na^+/K^+$ pump at work
   - Original ion distribution established
5. **Refractory Period**
   - $Na^+$ VGCs unable to open

# d. Enlargement of action potential



# SALTATORY CONDUCTION:

- In a myelinated nerve fiber, the only location that ion exchange across the axomembrane can occur is at the nodes of Ranvier
- Axoplasm is electrically conductive, so depolarization at one node is sufficient to elevate the voltage at a neighboring node to threshold
- This means that an action potentials propagate by "hopping" along the axon from node to node
- This is way faster than impulse transmission in unmyelinated neurons!

# AT THE END OF THE AXON...?

- Once a nervous impulse reaches the axon terminals it must cross a gap to the dendrites or cell body of the next neuron
- This is where the electrochemical nerve impulse turns chemical…
- Transmission across a synapse is next…

# VIDEO CLIPS:

Action potential

- http://www.youtube.com/watch?v=90cj4NX87Yk

Discovery Channel: Neurons and how they work

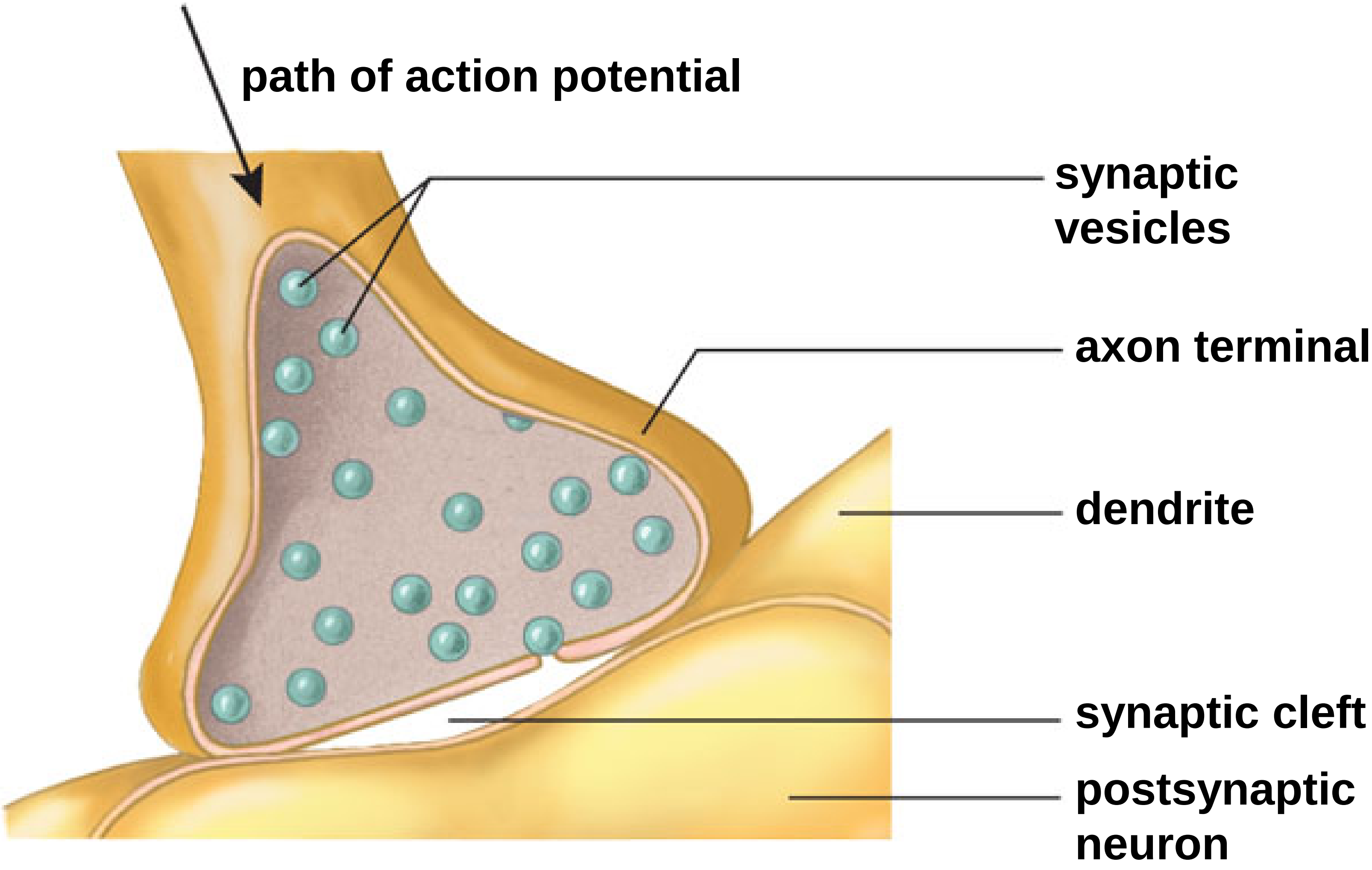
- http://www.youtube.com/watch?v=ysDGX6bOgAw

# YOUR ASSIGNMENT:

- Read ahead on “Transmission Across a Synapse”
- Reading assignment No. 3
- Complete PLOs we’ve covered so far
- Ch17 package

# TRANSMISSION ACROSS A SYNAPSE:

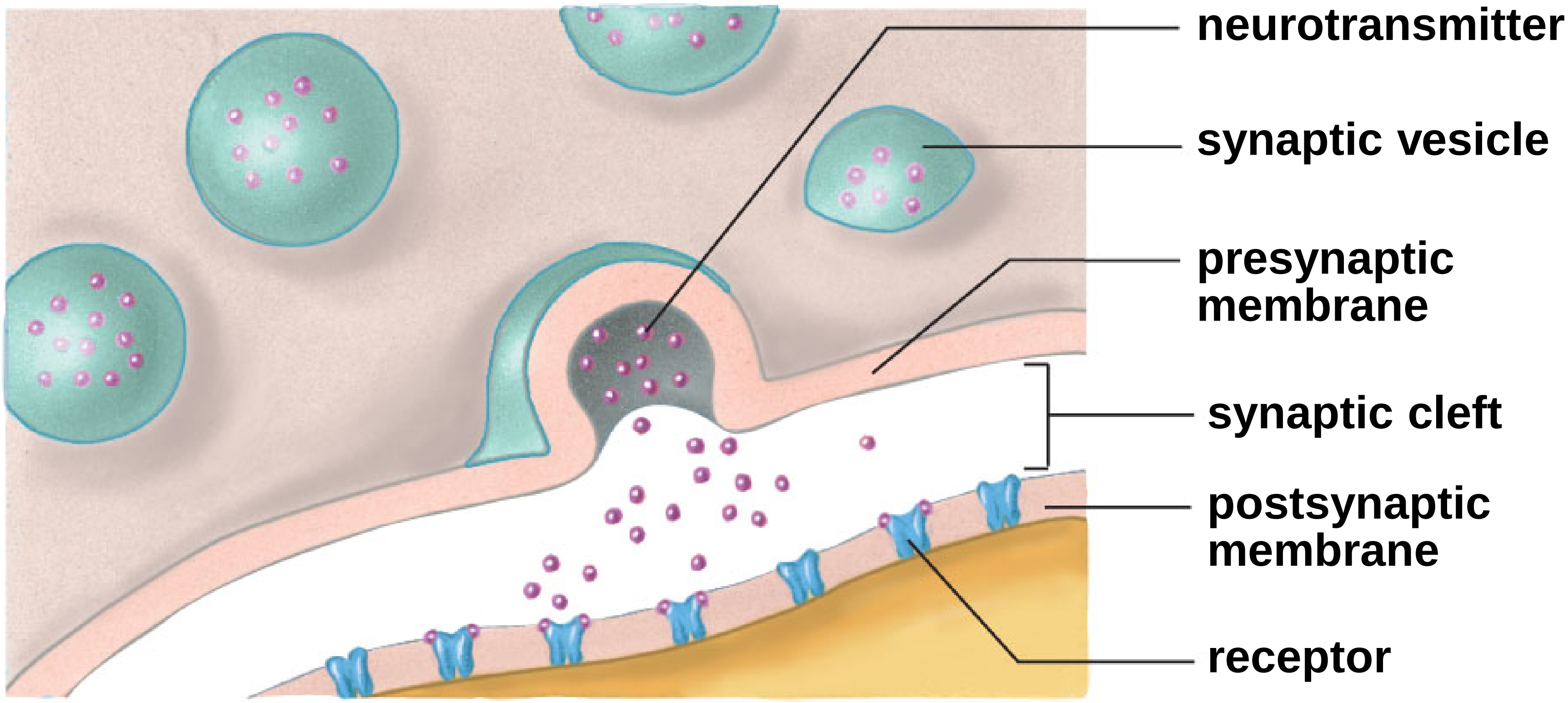
- All axons branch into fine-tipped endings called axon terminals or **synaptic endings**
- The region between the end of an axon and the cell body or dendrite with which it is associated is called a **synapse**
- The space between the **pre-synaptic membrane** (of axon) and the **post-synaptic membrane** (of next neuron) is called the **synaptic cleft**
- Communication between 2 neurons at a synapse is carried out by molecules called **neurotransmitters** which are stored in **synaptic vesicles** in the axon terminals




After an action potential arrives at an axon terminal, synaptic vesicles fuse with the presynaptic membrane.

# CONTINUED…

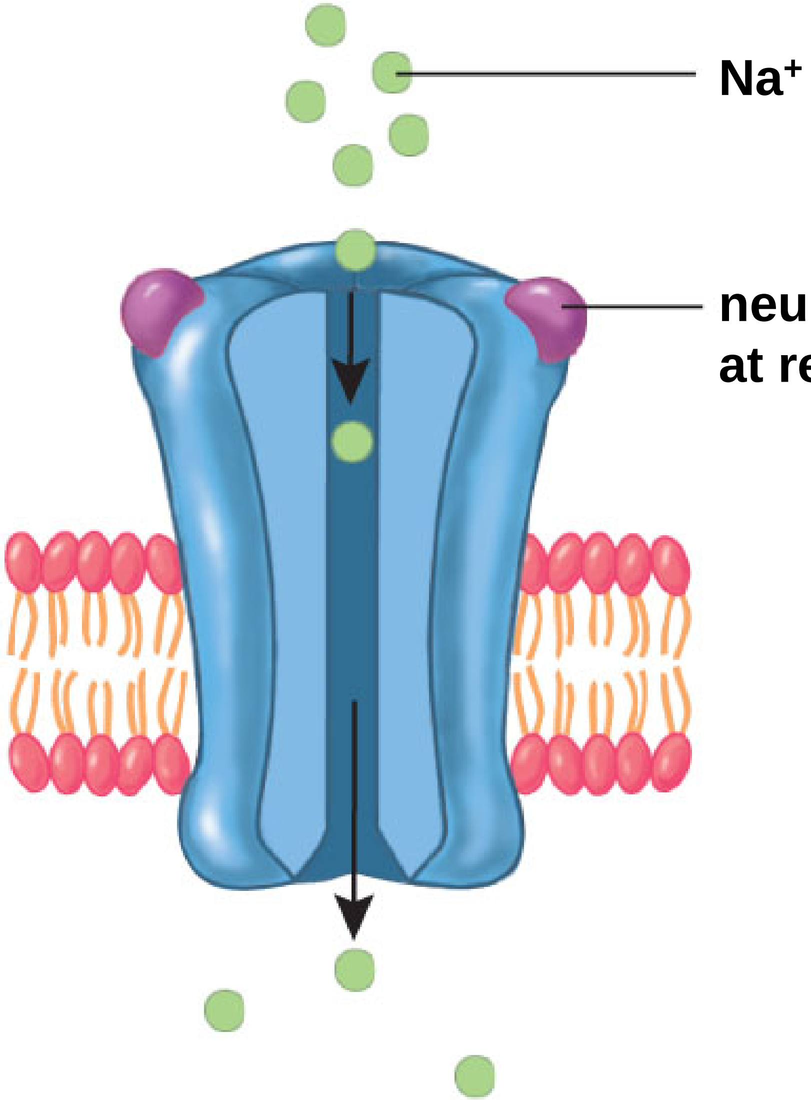
- The arrival of a nerve impulse at the axon terminal stimulates **gated calcium channels** to open allowing $Ca^{2+}$ to enter the terminal
- This rise in $Ca^{2+}$ causes **contractile proteins** (microfilaments) in the axon to initiate the movement of the synaptic vesicles to the pre-synaptic membrane
- Once there, the vesicles fuse with the membrane and their contents (*the neurotransmitters*) are released into the synaptic cleft
- At the post-synaptic membrane, the neurotransmitters bind to receptors and send either an **excitatory** or **inhibitory** message




Neurotransmitter molecules are released and bind to receptors on the postsynaptic membrane.

# NEUROTRANSMITTERS:

- **Can be single amino acids, chains a.a.'s, or protein derivatives**
- **Excitatory neurotransmitters** *cause an AP to occur at the next neuron*
  - *Eg. Norepinephrine (NE), adrenalin, acetylcholine (Ach)*
- **Inhibitory neurotransmitters** *prevent an AP from occurring at the next neuron*
  - *Eg. Serotonin, GABA*




When a stimulatory neurotransmitter binds to a receptor, $Na^+$ diffuses into the postsynaptic neuron.

# NT DEGRADATION

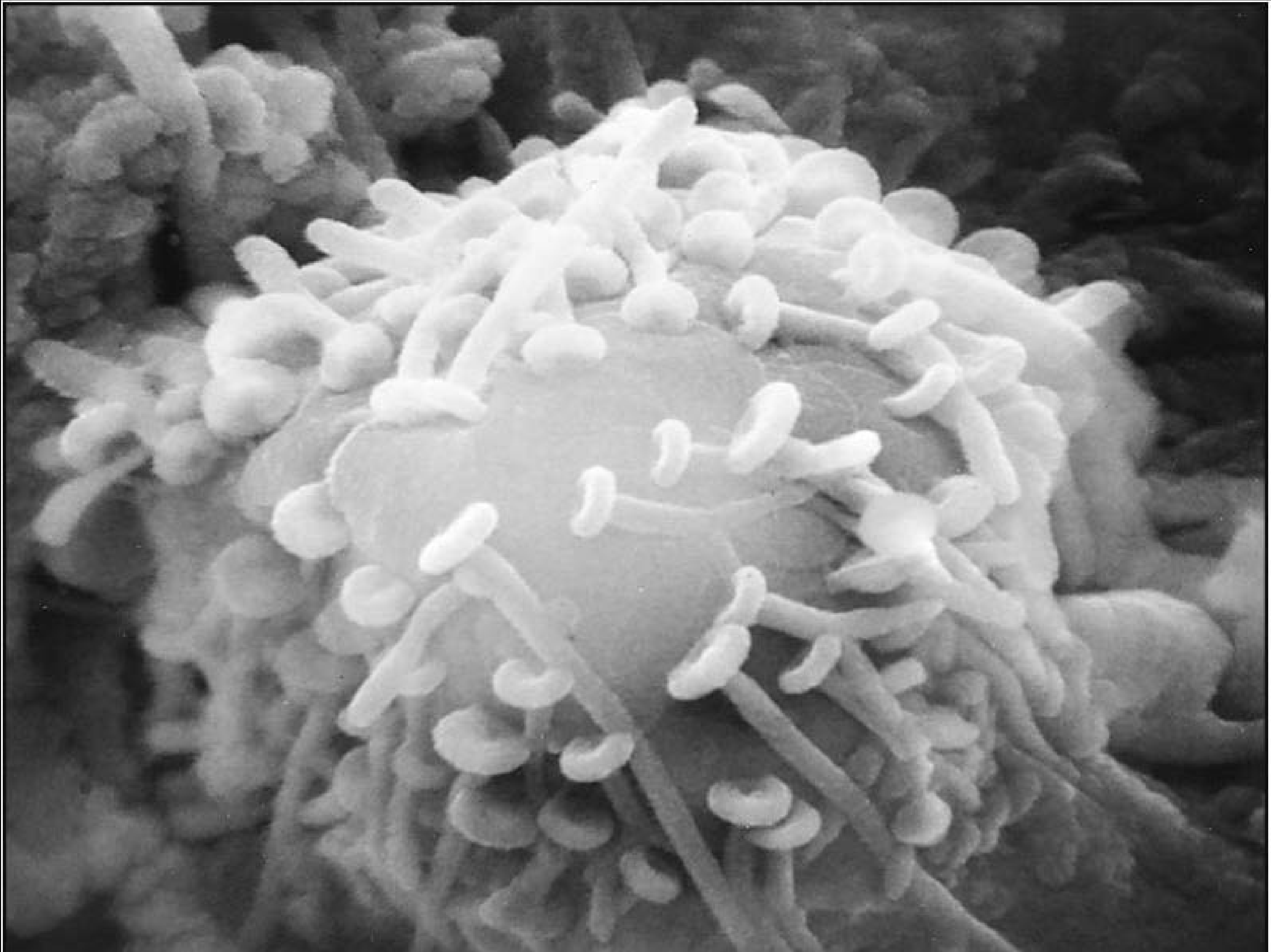
- NTs are quickly ***degraded by enzymes*** on the post-synaptic membrane or ***reabsorbed*** into the pre-synaptic axon terminal

- This prevents continual binding at the post-synaptic receptors
  - *Which would lead to continual stimulation or inhibition of the next neuron*

- **Ach** is degraded by <u>**acetylcholinesterase**</u>
- **NE** is degraded by <u>**monoamine oxidase**</u>
- **Serotonin** is reabsorbed

# SUMMATION OF SIGNALS…

- A single neuron may receive info from **thousands** of neighboring neurons
  - That is, there may be thousands of synapses around a neuron
- A neuron will **sum up** the excitatory inhibitory signals it receives
  - If a neuron receives significantly more excitatory signals than inhibitory ones, it will **“fire”**



# DRUGS ACTION AT A SYNAPSE:

***At a synapse drugs can:***

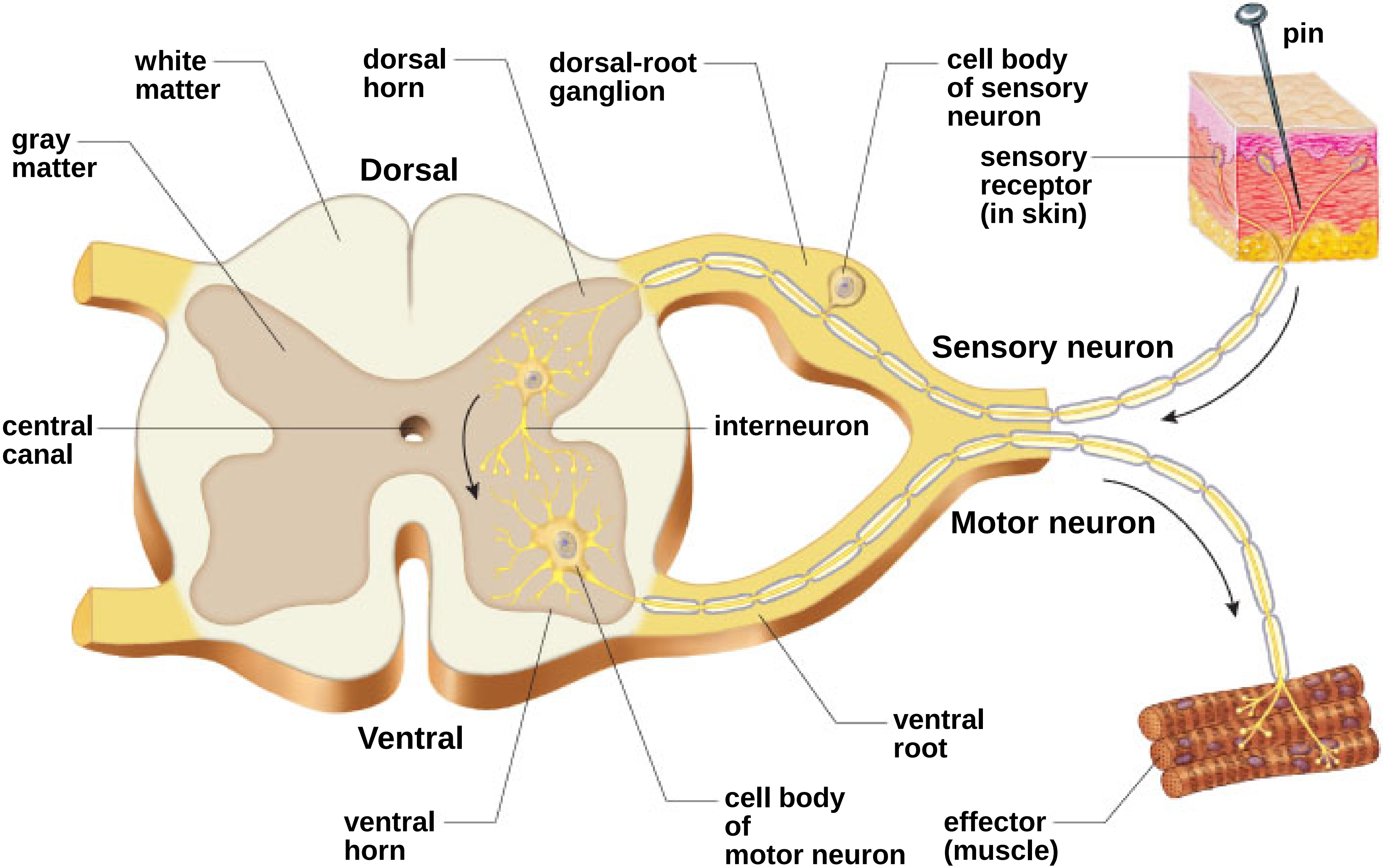
1. Cause NTs to leak out of a synaptic vesicle into the axon terminal
2. Prevent release of NTs into the synaptic cleft
3. Promote release of NTs into the synaptic cleft
4. Prevent reuptake of NTs by the presynaptic membrane
5. Block the enzyme that causes breakdown of the NT
6. Bind to a receptor, mimicking the action of an NT

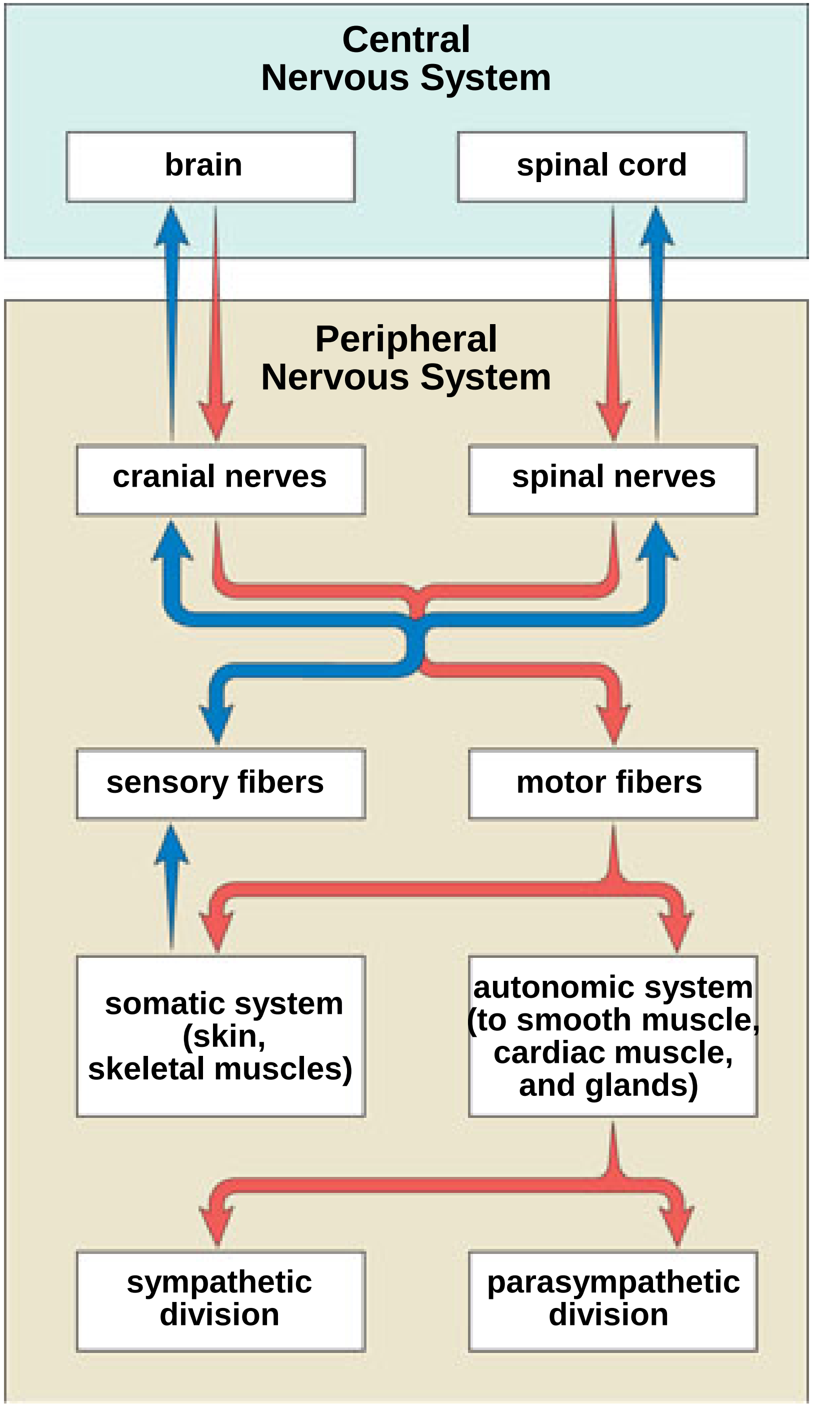
# THE REFLEX ARC:

- Reflexes are <u>**automatic**</u> and <u>**involuntary**</u>
  - They are responses to changes that occur either inside or outside of the body
  - Can involve the brain (blinking) or not (removing hand from something hot)
- The <u>**Reflex arc**</u> is the main functional unit of the <u>*somatic nervous system*</u>
  - It bypasses the brain so that we can react more quickly to external stimuli..

# PATH OF A REFLEX ARC:

1. Sensory receptor
2. Sensory neuron
3. Interneuron
4. Motor neuron
5. Effector


pin
white matter
dorsal horn
dorsal-root ganglion
cell body of sensory neuron
gray matter
sensory receptor (in skin)
Dorsal
Sensory neuron
central canal
interneuron
Motor neuron
ventral root
Ventral
cell body of motor neuron
ventral horn
effector (muscle)

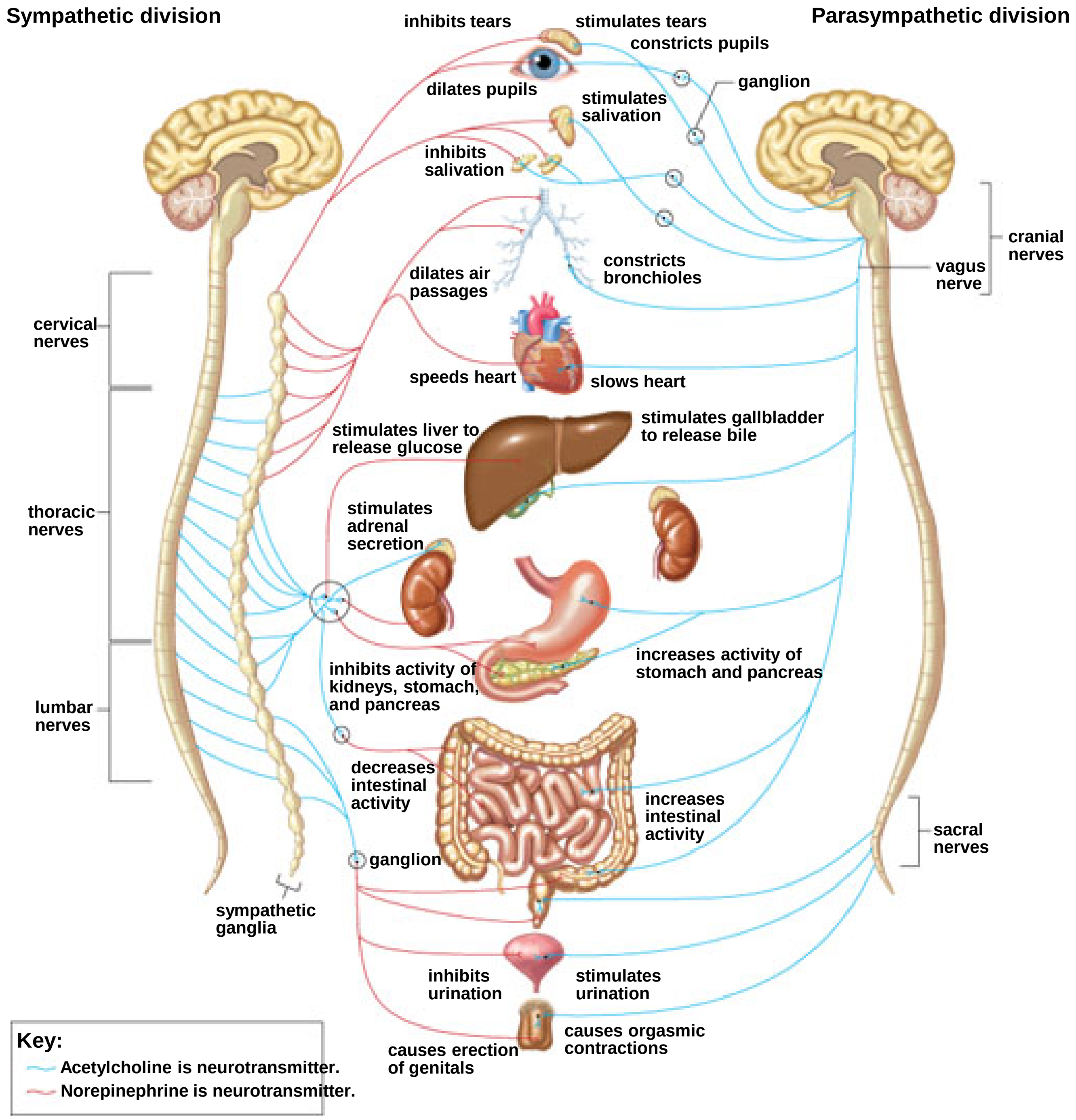

Central
Nervous System
brain
spinal cord
Peripheral
Nervous System
cranial nerves
spinal nerves
sensory fibers
motor fibers
somatic system
(skin,
skeletal muscles)
autonomic system
(to smooth muscle,
cardiac muscle,
and glands)
sympathetic
division
parasympathetic
division

# THE AUTONOMIC NERVOUS SYSTEM:

- Part of the PNS; involuntary; internal organs…

- Is divided into two divisions:
  - **SYMPATHETIC**
  - **PARASYMPATHETIC**

- These two systems connect to the same organs but have opposite effects


Sympathetic division
Parasympathetic division
inhibits tears
stimulates tears
constricts pupils
dilates pupils
ganglion
stimulates salivation
inhibits salivation
cranial nerves
vagus nerve
constricts bronchioles
dilates air passages
cervical nerves
speeds heart
slows heart
stimulates liver to release glucose
stimulates gallbladder to release bile
thoracic nerves
stimulates adrenal secretion
increases activity of stomach and pancreas
inhibits activity of kidneys, stomach, and pancreas
lumbar nerves
decreases intestinal activity
increases intestinal activity
sacral nerves
ganglion
sympathetic ganglia
inhibits urination
stimulates urination
causes orgasmic contractions
causes erection of genitals
Key:
Acetylcholine is neurotransmitter.
Norepinephrine is neurotransmitter.

# SYMPATHETIC DIVISION:

- Important during emergency situations
- Assoc. with **“FIGHT OR FLIGHT”** reaction
  - *Energy directed away from digestion and pee-making*
  - *Pupils dilate*
  - *Heart rate increases*
  - *Perspiration increases*
  - *Breathing rate increases*
  - *Salivation decreases*
- The neurotransmitter for this system is **NOREPINEPHRINE / NORADRENALIN**

# PARASYMPATHETIC DIVISION:

- Promotes all internal responses associated with a **<u>“REST & DIGEST”</u>** (relaxed) state
  - *Pupils constrict*
  - *Energy put into digestion of food and urine formation*
  - *Heart rate slows*

  ***(Think turkey-dinner!)***

- Neurotransmitter for this system is **<u>ACETYLCHOLINE</u>**

# *THE BRAIN:*

- ***You'll need to be able to identify and give functions for the following:***
  1. Medulla oblongata
  2. Cerebrum
  3. Thalamus
  4. Cerebellum
  5. Hypothalamus
  6. Pituitary gland
  7. Corpus callosum
  8. Meninges

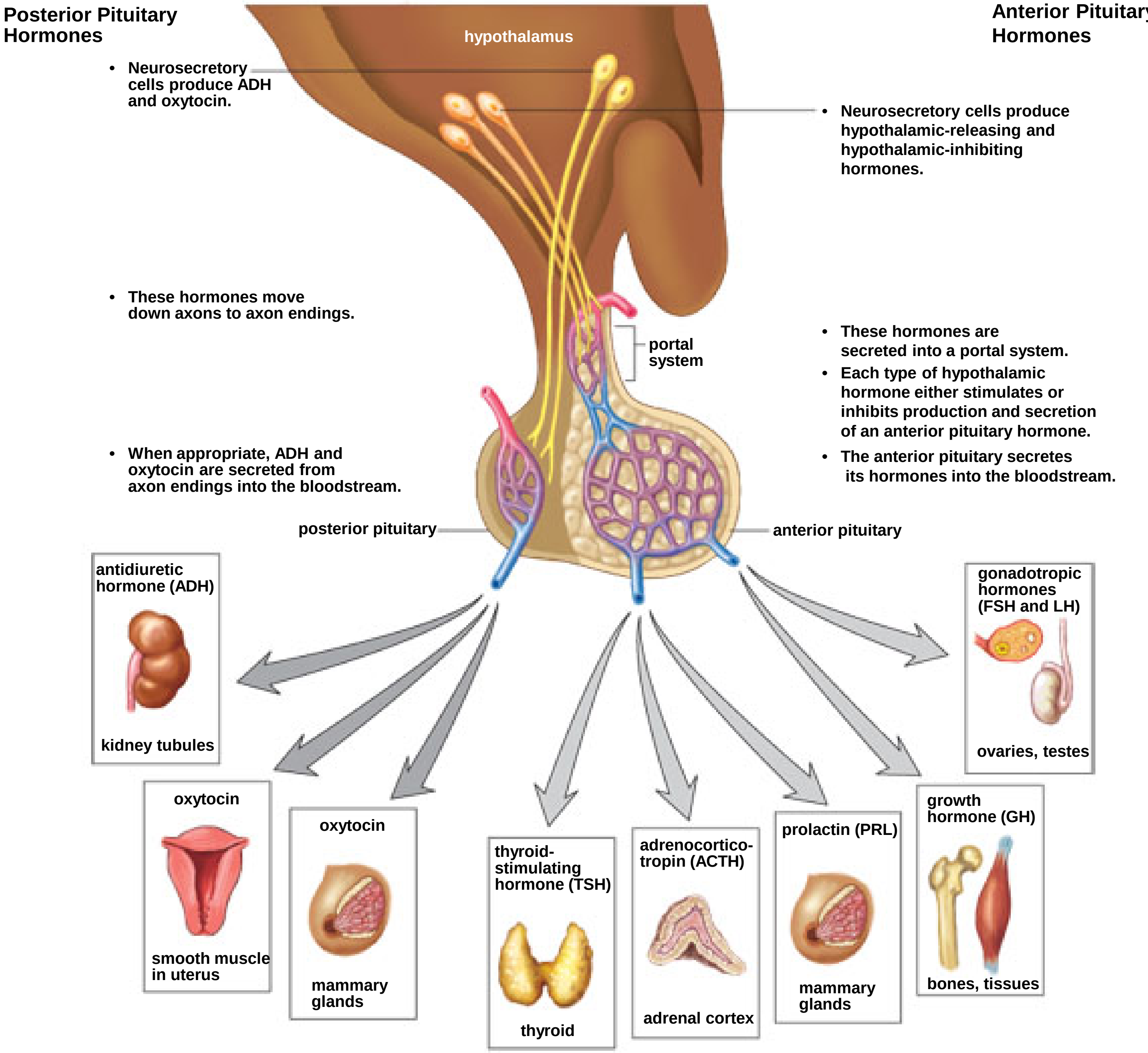
# PARTS OF THE BRAIN:

- **MEDULLA OBLONGATA:** reflex/regulatory centre
- **CEREBRUM:** conscious thought; problem solving
- **THALAMUS:** “gate-keeper” controls which sensory messages get directed to other parts of the brain
- **CEREBELLUM:** motor control; smooth/coordinated movement
- **HYPOTHALAMUS:** Maintenance of internal conditions (homeostasis)
- **PITUITARY GLAND:** secretion of various hormones that control other glands throughout the body
- **CORPUS CALLOSUM:** communication link between the left and right hemispheres of the brain
- **MENINGES:** protective membranes surrounding spinal cord and brain

# HYPOTHALAMUS

- Regulates internal environment in 2 ways:

1. Through the autonomic NS it regulates heartbeat, blood pressure, thirst, hunger, body temperature and water balance
2. It also controls the glandular secretions of the **pituitary gland**


Posterior Pituitary Hormones
• Neurosecretory cells produce ADH and oxytocin.
• These hormones move down axons to axon endings.
• When appropriate, ADH and oxytocin are secreted from axon endings into the bloodstream.
Anterior Pituitary Hormones
• Neurosecretory cells produce hypothalamic-releasing and hypothalamic-inhibiting hormones.
• These hormones are secreted into a portal system.
• Each type of hypothalamic hormone either stimulates or inhibits production and secretion of an anterior pituitary hormone.
• The anterior pituitary secretes its hormones into the bloodstream.
hypothalamus
portal system
posterior pituitary
anterior pituitary
antidiuretic hormone (ADH)
kidney tubules
oxytocin
smooth muscle in uterus
oxytocin
mammary glands
thyroid-stimulating hormone (TSH)
thyroid
adrenocortico-tropin (ACTH)
adrenal cortex
prolactin (PRL)
mammary glands
growth hormone (GH)
bones, tissues
gonadotropic hormones (FSH and LH)
ovaries, testes

# PITUITARY GLAND

- Has 2 portions:
  - The **posterior pituitary** and
  - The **anterior pituitary**

# POSTERIOR PITUITARY:

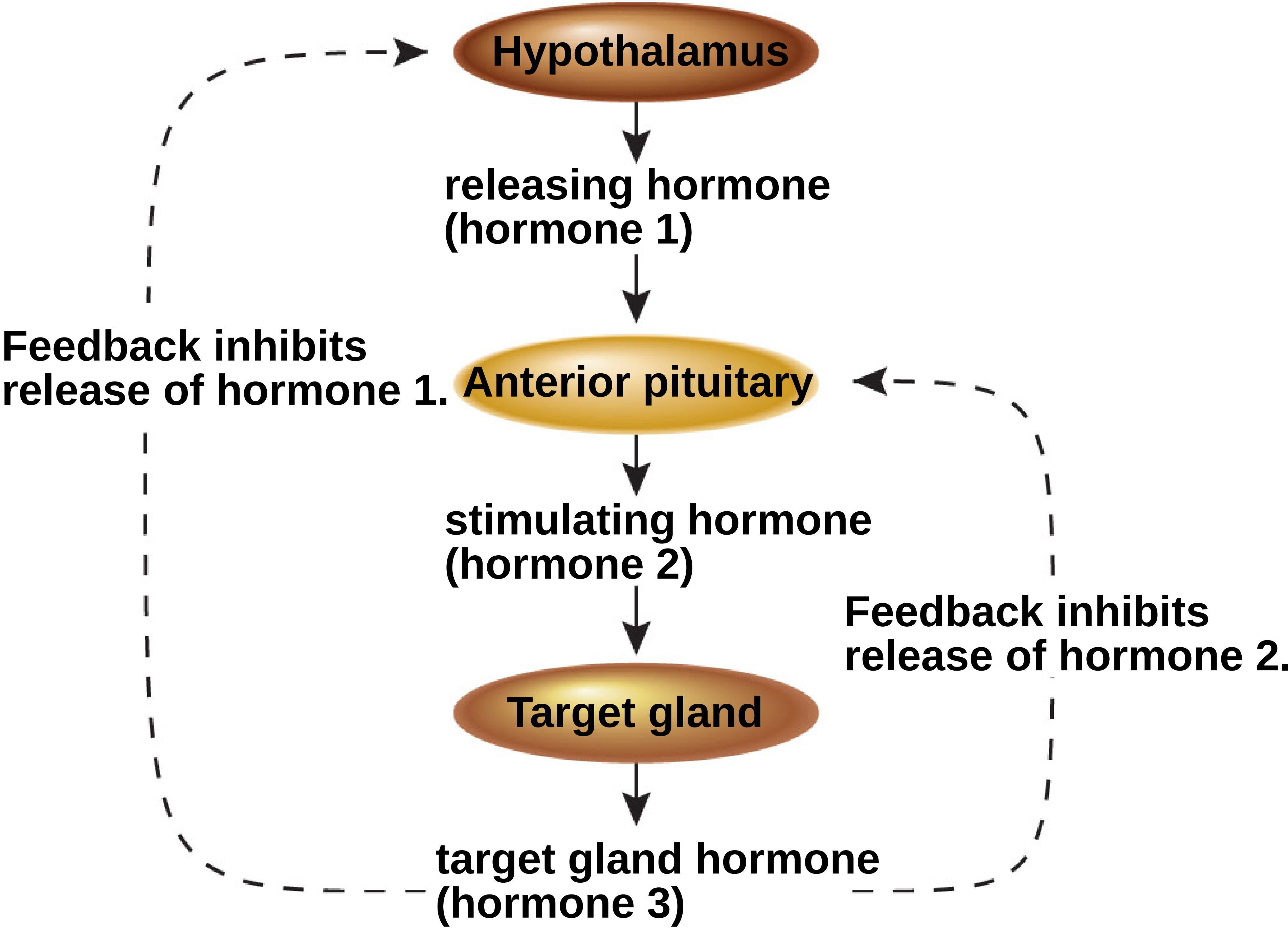
- Specialized neurons called ***neurosecretory cells*** in the hypothalamus produce the hormones **ADH** and **oxytocin**
- These hormones pass through axons into the post. pit. where they are stored in the axon terminals
- **ADH** (antidiuretic hormone) is released when the concentration of salts in the blood is too high → "anti-pee" hormone
- **Oxytocin** causes uterine contraction during childbirth and milk letdown when a baby is nursing

# OXYTOCIN & POSITIVE FEEDBACK

- When the uterus contracts during childbirth, nerve impulses are sent to the hypothalamus
- This stimulates the release of ***more*** oxytocin from the post. pit.
- This is an example of **positive feedback**, as the stimulus continues to bring about an effect that ever increases in intensity

# ANTERIOR PITUITARY:

- The hypothalamus controls the ant. pit. by producing **hypothalamic-releasing** (or inhibiting) **hormones**
- A **portal system** consisting of 2 capillary networks connected by a vein lies between the two
- The hormones either stimulate or inhibit production and secretion of an ant. pit. hormone
- The ant. pit. hormones are then released into the bloodstream

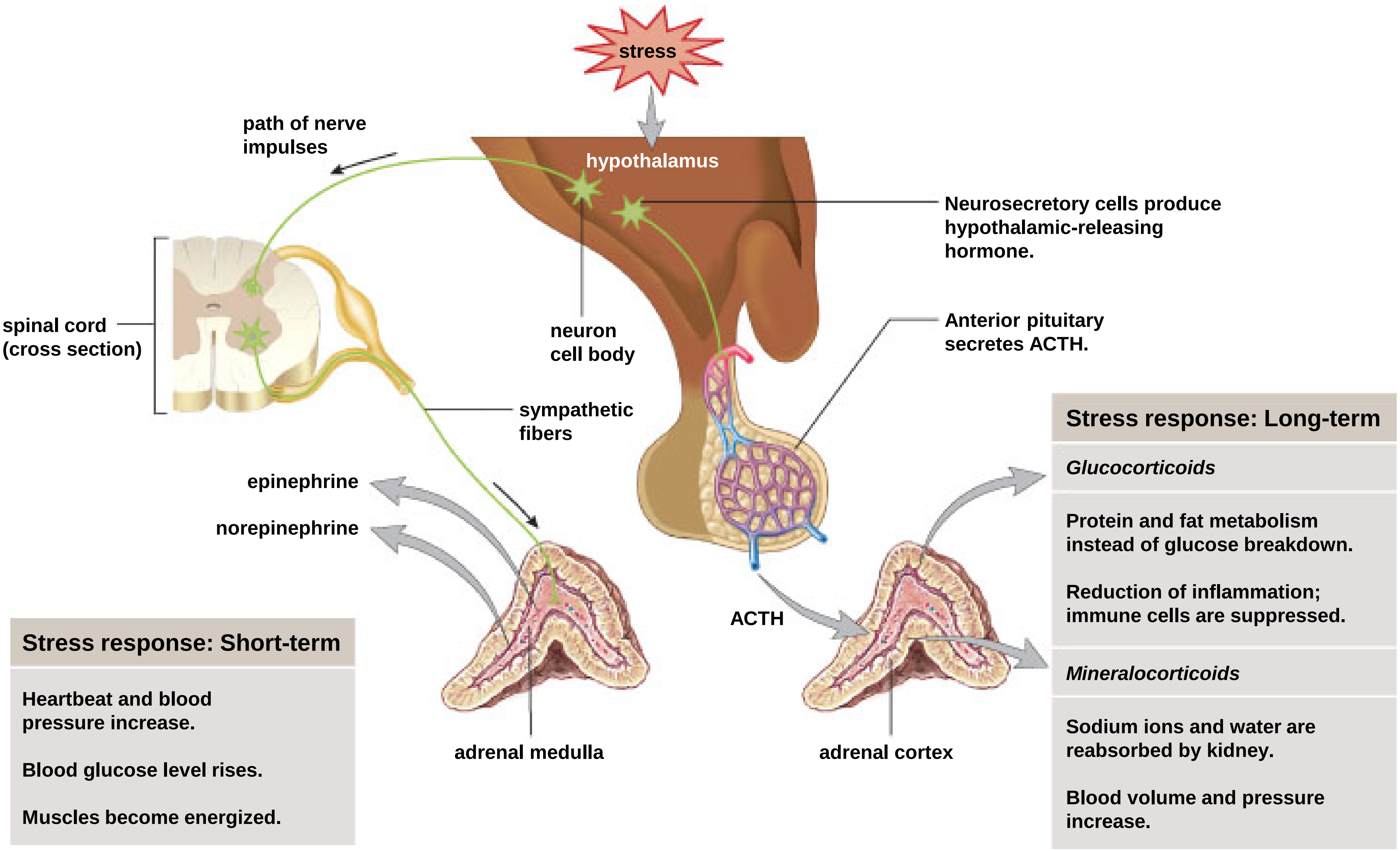

Hypothalamus
releasing hormone (hormone 1)
Feedback inhibits release of hormone 1.
Anterior pituitary
stimulating hormone (hormone 2)
Feedback inhibits release of hormone 2.
Target gland
target gland hormone (hormone 3)

# ANT. PIT. HORMONES:

- **TSH:** Thyroid Stimulating Hormone
- **ACTH:** Adrenocorticotropic hormone
- **GH:** Growth hormone
- **FSH:** Follicle-stimulating hormone
- **LH:** Leutenizing hormone
- **PRL:** Prolactin

# *EPINEPHRINE & NOREPINEPHRINE:*

- Both are secreted by the adrenal medulla, the inner portion of the adrenal gland
  - The adrenal gland sits atop the kidneys


stress
hypothalamus
path of nerve impulses
Neurosecretory cells produce hypothalamic-releasing hormone.
spinal cord (cross section)
neuron cell body
Anterior pituitary secretes ACTH.
sympathetic fibers
epinephrine
norepinephrine
ACTH
adrenal medulla
adrenal cortex
Stress response: Short-term
Heartbeat and blood pressure increase.
Blood glucose level rises.
Muscles become energized.
Stress response: Long-term
Glucocorticoids
Protein and fat metabolism instead of glucose breakdown.
Reduction of inflammation; immune cells are suppressed.
Mineralocorticoids
Sodium ions and water are reabsorbed by kidney.
Blood volume and pressure increase.

# YOUR ASSIGNMENT:

- Complete cue cards for each of the parts of the brain
- Complete all other PLO's
- Exam ________________!