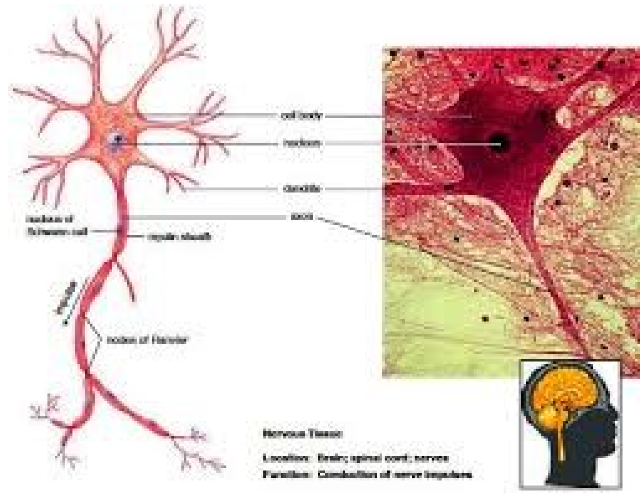
NERVOUS TISSUE



Course Name: Anatomy and Physiology 1
Course Code: 0521122
Lecturer: Ms. Asma El-Shara'. MPH
Faculty Of Pharmacy,
Philadelphia University-Jordan

Overview of the Nervous System

- ✓ The nervous system keeps controlled conditions within limits that maintain life.
- ✓ The nervous system regulates body activities by responding rapidly using nerve impulses.
- ✓ The nervous system is also responsible for our perceptions, behaviors, and memories, and it initiates all voluntary movements.
- ✓ With a mass of only 2 kg (4.5 lb), about 3% of the total body weight, the **nervous system** is one of the smallest and yet the most complex of the 11 body systems. This intricate network of billions of neurons and even more neuroglia is organized into two main subdivisions: ***the central nervous system and the peripheral nervous system.***

Neurology deals with normal functioning and disorders of the nervous system. A **neurologist** (noo-ROL-o¯-jist) is a physician who diagnoses and treats disorders of the nervous system.

Overview of the Nervous System

A- *Central Nervous System*

- The **central nervous system (CNS)** consists of the brain and spinal cord.
- The brain is the part of the CNS that is located in the skull and contains about 85 billion neurons.
- The spinal cord is connected to the brain through the foramen magnum of the occipital bone and is encircled by the bones of the vertebral column. The spinal cord contains about 100 million neurons.

→ The CNS processes many different kinds of incoming sensory information.

→ It is also the source of thoughts, emotions, and memories. Most signals that stimulate muscles to contract and glands to secrete originate in the CNS.

Overview of the Nervous System
B- *Peripheral Nervous System*

- The **peripheral nervous system (PNS)** consists of all nervous tissue ***outside*** the CNS.
- Components of the PNS include *nerves, ganglia, enteric plexuses, and sensory receptors.*

A- A nerve is a **bundle** of hundreds to thousands of axons plus associated connective tissue and blood vessels that lies outside the brain and spinal cord.

→ Twelve pairs of **cranial nerves** emerge from the brain and thirty-one pairs of **spinal nerves** emerge from the spinal cord. Each nerve follows a defined path and serves a specific region of the body.

B- Ganglia (GANG-gle»-a swelling or knot; singular is *ganglion*) are small masses of nervous tissue, consisting primarily of **neuron cell bodies**, that are located **outside** of the brain and spinal cord. Ganglia are closely associated with cranial and spinal nerves.

C- Enteric plexuses (PLEK-sus-ez) are extensive **networks** of neurons located in the walls of organs of the gastrointestinal tract. The neurons of these plexuses help regulate the digestive system.

D- The sensory receptor refers to a structure of the nervous system that **monitors changes** in the external or internal environment. Examples of sensory receptors include touch receptors in the skin, photoreceptors in the eye, and olfactory receptors in the nose.

Peripheral Nervous System → 1- Somatic Nervous System (SNS)

The PNS is divided into:

1- A **somatic nervous system (SNS)** (sō- MAT-ik; *soma* body),

2- An **autonomic nervous system (ANS)** (aw-tō-NOM-ik; *auto-* self; *-nomic* law),

3- An **enteric nervous system (ENS)** (en-TER-ik; *enteron* intestines).

***The* somatic nervous system (*SNS*)** consists of:

(1) sensory neurons that convey information to the CNS from somatic receptors in the head, body wall, and limbs and from receptors for the special senses of vision, hearing, taste, and smell,

(2) motor neurons that conduct impulses from the CNS to *skeletal muscles* only. Because these motor responses can be consciously controlled, the action of this part of the PNS is ***voluntary***.

Peripheral Nervous System → 2- Autonomic Nervous System (ANS)

The ANS consists of:

(1) sensory neurons that convey information to the CNS from autonomic sensory receptors, located primarily in visceral organs such as the stomach and lungs

(2) motor neurons that conduct nerve impulses from the CNS to *smooth muscle, cardiac muscle,* and *glands*. Because its motor responses are ***NOT*** normally under conscious control, the action of the ANS is involuntary.

→The motor part of the ANS consists of two branches, the **sympathetic division** and the **parasympathetic division.**

With a few exceptions, effectors receive nerves from both divisions, and usually the two divisions have opposing actions. For example, sympathetic neurons increase heart rate, and parasympathetic neurons slow it down.

→ In general, the *sympathetic* division helps support exercise or emergency actions, the "fight-or-flight" responses, and the *parasympathetic* division takes care of "rest-and-digest" activities.

Overview of the Nervous System

Peripheral Nervous System → 3- Enteric Nervous System (ENS)

- The operation of the ENS, the "brain of the gut," is involuntary.
- Once considered part of the ANS, the ENS consists of over 100 million neurons in enteric plexuses that extend most of the length of the gastrointestinal (GI) tract.
- Many of the neurons of the enteric plexuses function independently of the ANS and CNS to some extent, although they also **communicate** with the CNS via sympathetic and parasympathetic neurons.
- **Enteric Sensory neurons** of the ENS monitor chemical changes within the GI tract as well as the stretching of its walls.
- **Enteric motor neurons** govern contractions of GI tract smooth muscle to propel food through the GI tract, secretions of GI tract organs (such as acid from the stomach), and activities of GI tract endocrine cells, which secrete hormones.

The two main subdivisions of the nervous system are (1) the central nervous system (CNS), which consists of the brain and spinal cord, and (2) the peripheral nervous system (PNS), which consists of all nervous tissue outside the CNS.

Image Reference: https://slideplayer.com/slide/6000449/20/images/3/Organization+of+nervous+system.jpg

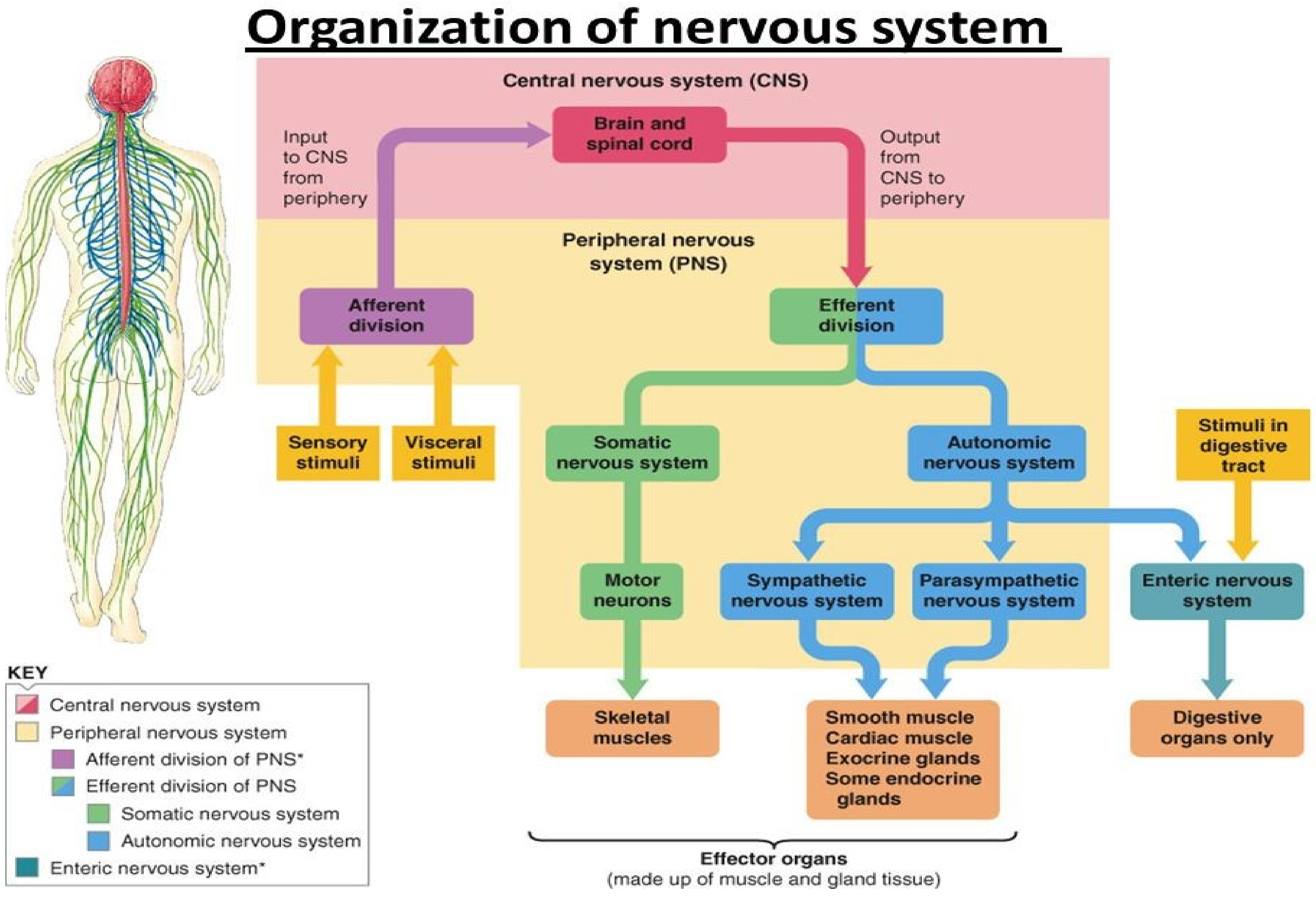
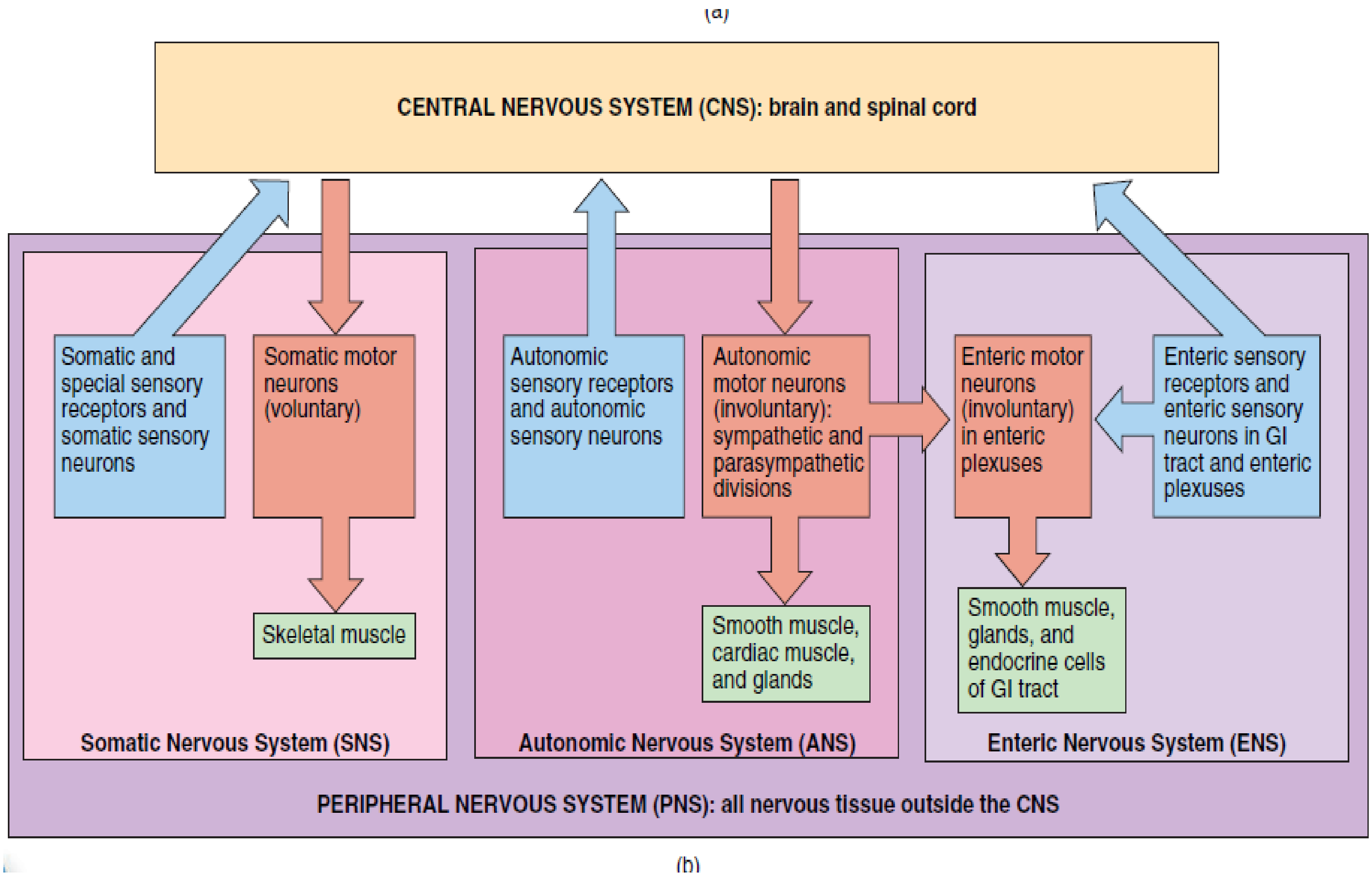


Figure 12.1 Organization of the nervous system. (a) Subdivisions of the nervous system. (b) Nervous system organizational chart; blue boxes represent sensory components of the peripheral nervous system, red boxes represent motor components of the PNS, and green boxes represent effectors (muscles and glands).



Histology of Nervous Tissue

- Nervous tissue comprises two types of cells—*NEURONS* AND *NEUROGLIA*.

- ***NEURONS*** are HIGHLY SPECIALIZED CELLS ***capable of reaching great lengths and making extremely intricate connections with other cells***, neurons provide most of the unique functions of the nervous system, such as sensing, thinking, remembering, controlling muscle activity, and regulating glandular secretions.

→**As a result of their specialization, most neurons have lost the ability to undergo mitotic divisions.**

- ***NEUROGLIA*** are smaller cells but they greatly outnumber neurons, perhaps by as much as 25 times. Neuroglia support, nourish, and protect neurons, and maintain the interstitial fluid that bathes them. Unlike neurons, neuroglia continue to divide throughout an individual's lifetime.

- Both neurons and neuroglia **differ structurally** depending on whether they are located in the central nervous system or the peripheral nervous system. These differences in structure correlate with the differences in function of the central nervous system and the peripheral nervous system.

Histology of Nervous Tissue
A- Neurons

- **NEURONS (nerve cells)** posses **electrical excitability;** the ability to respond to a stimulus and convert it into an action potential.
- A **stimulus** is any change in the environment that is strong enough to initiate an action potential.
- An **action potential (nerve impulse)** is an electrical signal that propagates (travels) along the surface of the membrane of a neuron.

→ It begins and travels due to the movement of ions (such as sodium and potassium) between interstitial fluid and the inside of a neuron through specific ion channels in its plasma membrane.

→ Once begun, a nerve impulse travels rapidly and at a constant strength.

- Some neurons are tiny and propagate impulses over a short **distance** (less than 1 mm) within the CNS. Others are the longest cells in the body.
- Nerve impulses travel these great distances at **speeds** ranging from 0.5 to 130 meters per second (1 to 290 mi/hr).

Parts of a Neuron: 1- Cell body

Most neurons have three parts:

(1) a cell body

(2) dendrites,

(3) an axon (Figure 12.2).

1- The **cell body,** also known as the *perikaryon* (per-i-KAR-e»-on) or *soma,* contains a **nucleus** surrounded by **cytoplasm** that includes typical cellular organelles such as lysosomes, mitochondria, and a Golgi complex.

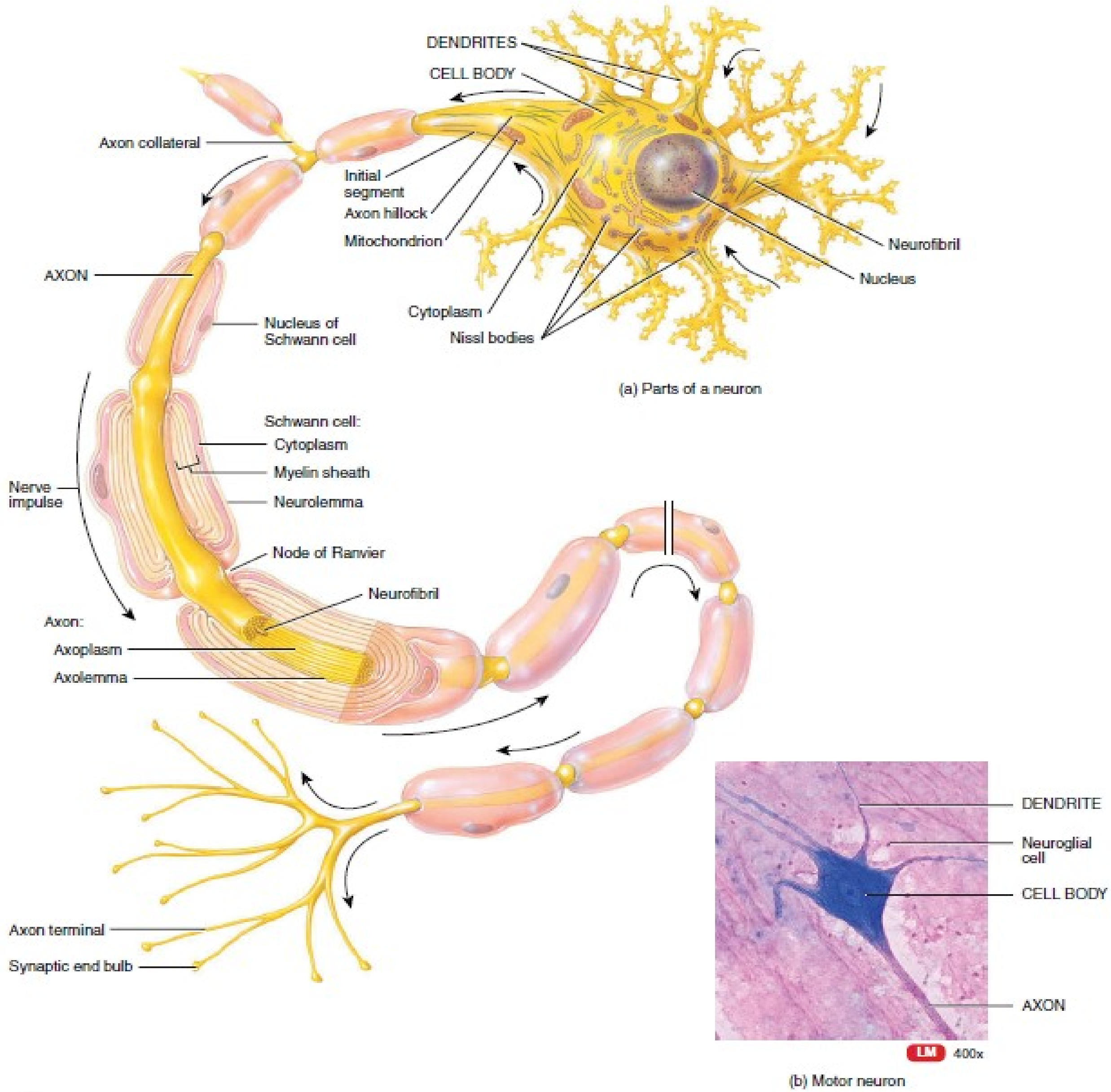
- Neuronal cell bodies also contain free ribosomes and prominent clusters of rough endoplasmic reticulum, termed **Nissl bodies** (NIS-el). The ribosomes are the sites of protein synthesis. Newly synthesized proteins produced by Nissl bodies are used to ***replace cellular components***, as material for growth of neurons, and to regenerate damaged axons in the PNS.
- A **nerve fiber** is a general term for any neuronal process (extension) that emerges from the cell body of a neuron. Most neurons have two kinds of processes: multiple dendrites and a single axon.

Figure 12.2

Structure of a multipolar neuron. A multipolar neuron has a cell body, several short dendrites, and a single long axon.

Arrows indicate the direction of information flow: dendrites → cell body → axon → axon terminals.

→ The basic parts of a neuron are dendrites, a cell body, and an axon.



Parts of a Neuron : 2- Dendrites

2- Dendrites are the receiving or input portions of a neuron.

- The plasma membranes of dendrites (and cell bodies) contain numerous receptor sites for binding chemical messengers from other cells.

- Dendrites usually are short, tapering, and highly branched.

- In many neurons the dendrites form a tree-shaped array of processes extending from the cell body.

Parts of a Neuron: 3- Axons

3- The single **axon** (axis) of a neuron propagates nerve impulses toward another neuron, a muscle fiber, or a gland cell.

- An axon is a long, thin, cylindrical projection that often joins to the cell body at a cone-shaped elevation called the **axon hillock**.
- The part of the axon closest to the axon hillock is the **initial segment.**
- In **most** neurons, NERVE IMPULSES arise at the junction of *the axon hillock and the initial segment,* an area called the **trigger zone,** from which they travel along the axon to their destination.

- Along the length of an axon, side branches called **axon collaterals** may branch off, typically at a **right** angle to the axon.
- The axon and its collaterals end by dividing into many fine processes called **axon terminals** or *axon telodendria* (te»l-o¯-DEN-dre»-a).

Parts of a Neuron - Synapse

- ***The site of communication between two neurons or between a neuron and an effector cell*** is called a **synapse.**

The tips of some axon terminals swell into:

A- bulb-shaped structures called **synaptic end bulbs**;

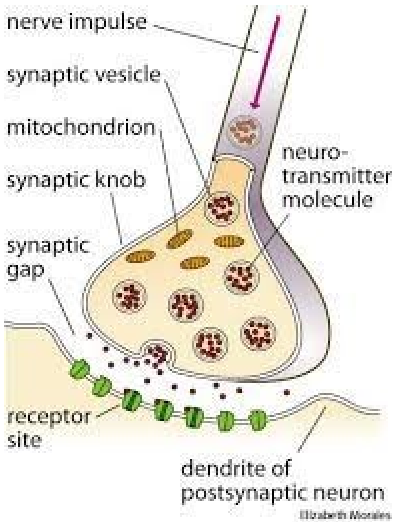
B- A string of swollen bumps called **varicosities**.

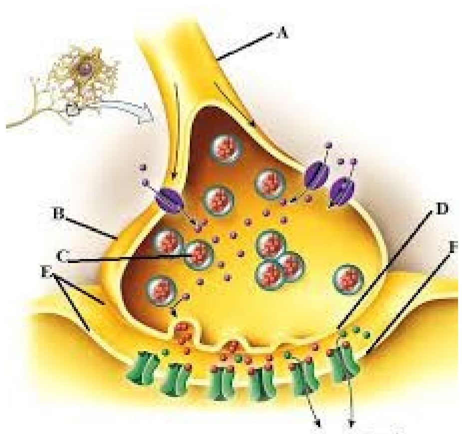
- Both synaptic end bulbs and varicosities contain many tiny membrane-enclosed sacs called **synaptic vesicles** that store a chemical called a **neurotransmitter**.

- A **neurotransmitter** is a molecule released from a synaptic vesicle that excites or inhibits another neuron, muscle fiber, or gland cell.

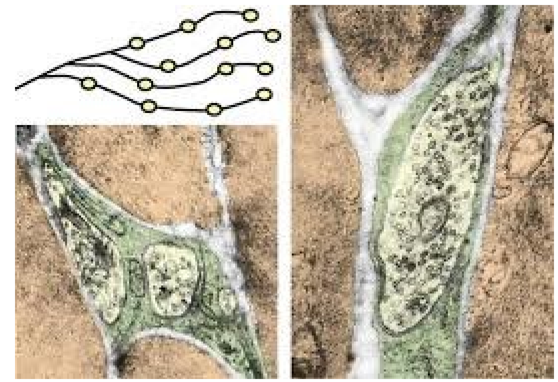
→ Many neurons contain two or even three types of neurotransmitters, each with different effects on the postsynaptic cell.

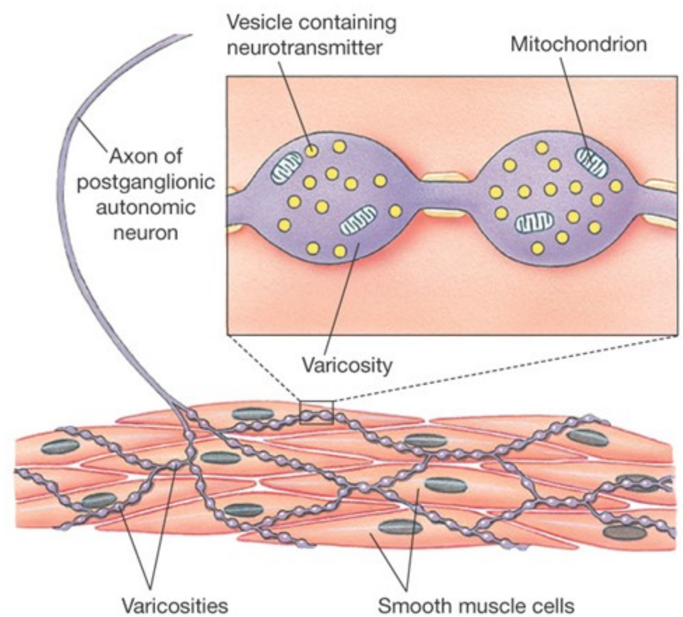
Synaptic End Bulbs





Varicosities





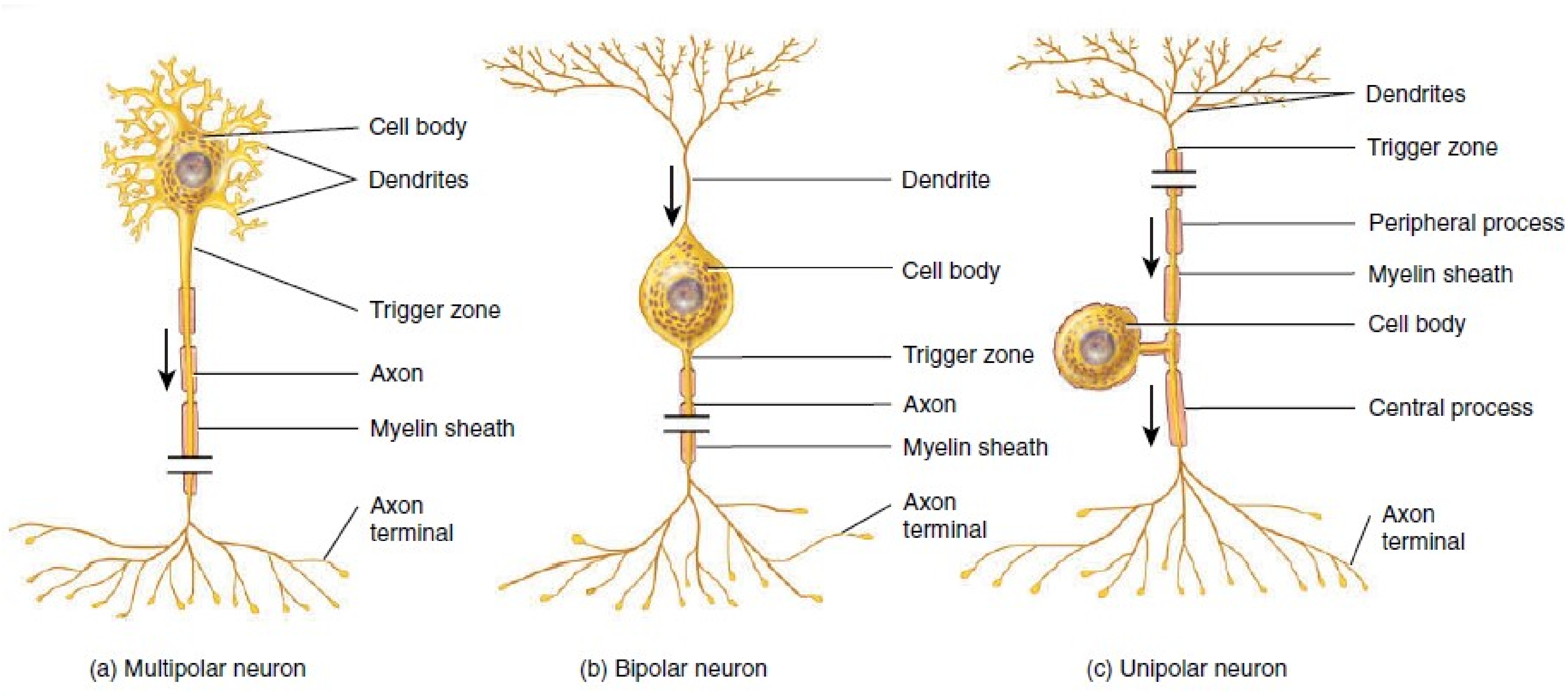
Classification of Neurons → Structural And Functional
1- STRUTURAL

Structural Classification Structurally, neurons are classified according to the number of processes extending from the cell body (Figure 12.3):

1. **Multipolar neurons** usually have **several dendrites and one axon** (Figure 12.3a). **Most** neurons in the brain and spinal cord are of this type, as well as **all motor neurons** (described shortly).
2. **Bipolar neurons** have **one main dendrite and one axon** (Figure 12.3b). They are found in the retina of the eye, the inner ear, and the olfactory area of the brain.
3. **Unipolar neurons (*pseudounipolar*)** have **dendrites and one axon that are fused together** to form a continuous process that emerges from the cell body (Figure 12.3c).
   - ✓ The dendrites of most unipolar neurons function as **sensory receptors** that detect a sensory stimulus such as touch, pressure, pain, or thermal stimuli (see Figure 12.10).
   - ✓ THE TRIGGER ZONE for nerve impulses in a unipolar neuron is at the junction of the dendrites and axon (Figure 12.3c). The impulses then propagate toward the synaptic end bulbs. The cell bodies of most unipolar neurons are located in the **ganglia** of spinal and cranial nerves.

Figure 12.3 Structural classification of neurons. Breaks indicate that axons are longer than shown.

→ A multipolar neuron has many processes extending from the cell body, a bipolar neuron has two, and a unipolar neuron has one.



Classification of Neurons → Structural And Functional
2- FUNCTIONAL

Functional Classification Functionally, neurons are classified according to the direction in which the nerve impulse (action potential) is conveyed with respect to the CNS.

1. **Sensory** or *afferent neurons* either contain sensory receptors at their distal ends (dendrites) (see Figure 12.10) OR are located just after sensory receptors that are separate cells.

   → Once an appropriate stimulus activates a sensory receptor, the sensory neuron forms an action potential in its axon and the action potential is conveyed *INTO* the CNS through cranial or spinal nerves. Most sensory neurons are unipolar in structure.

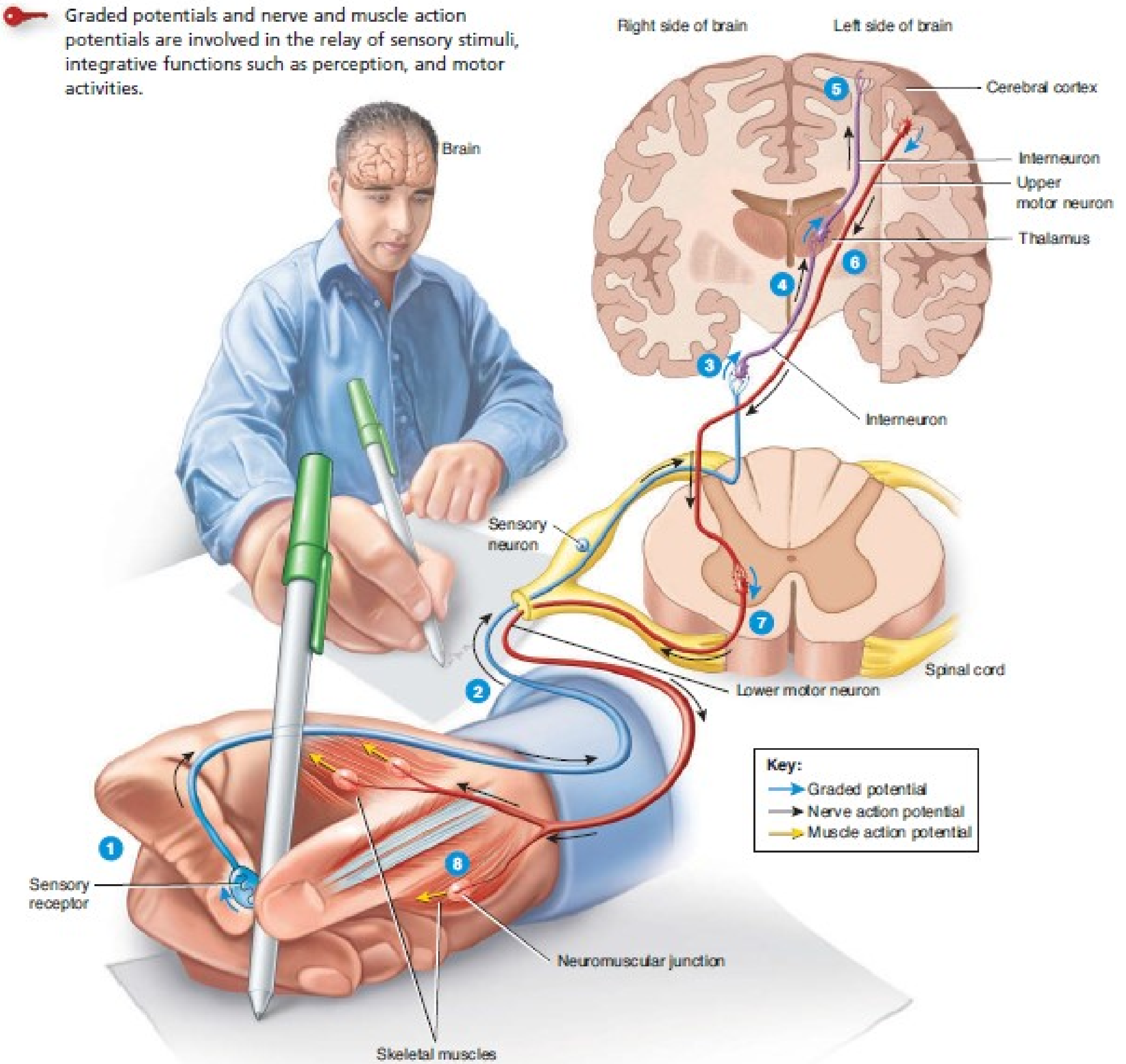
2. **Motor** or *efferent neurons* convey action potentials *AWAY* from the CNS to **effectors** (muscles and glands) in the periphery (PNS) through cranial or spinal nerves (see Figure 12.10). Motor neurons are multipolar in structure.

3. **Interneurons** or *association neurons* are mainly located within the CNS BETWEEN sensory and motor neurons (see Figure 12.10).

✓ Interneurons integrate (process) incoming sensory information from sensory neurons and then elicit a motor response by activating the appropriate motor neurons. Most interneurons are multipolar in structure.

Figure 12.10 Overview of nervous system functions.

Graded potentials and nerve and muscle action potentials are involved in the relay of sensory stimuli, integrative functions such as perception, and motor activities.



Histology of Nervous Tissue
B- **Neuroglia (introduction)**

❖**NEUROGLIA** or *glia* make up about half the volume of the CNS.

- Their name derives from the idea of early histologists that they were the "glue" that held nervous tissue together.
- Generally, neuroglia are smaller than neurons, and they are 5 to 25 times more numerous.
- In contrast to neurons, glia do not generate or propagate action potentials, and they can multiply and divide in the mature nervous system.
- In cases of injury or disease, neuroglia **multiply** to fill in the spaces formerly occupied by neurons.

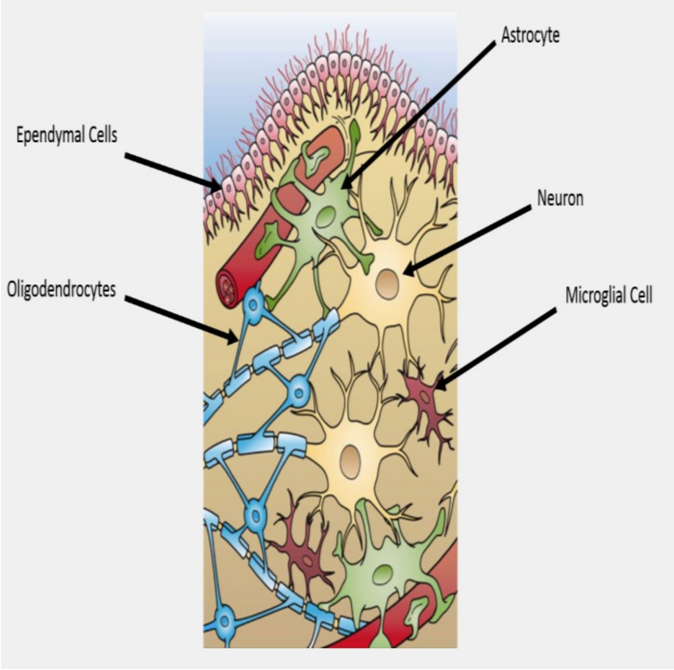
→ *Brain tumors derived from glia, called **gliomas**, tend to be highly malignant and to grow rapidly.*

- Of the six types of neuroglia, four—**astrocytes, oligodendrocytes, microglia, and ependymal cells**—**are found only in the CNS**.
- The remaining two types—**Schwann cells and satellite cells**—**are present in the PNS.**

Histology of Nervous Tissue
B- **Neuroglia**
1- Neuroglia of the CNS

- Neuroglia of the CNS can be classified on the basis of size, cytoplasmic processes, and intracellular organization into four types:

→ Astrocytes
→ Oligodendrocytes
→ Microglial cells
→ Ependymal cells (Figure 12.6).



Histology of Nervous Tissue

B- **Neuroglia**

1- Neuroglia of the CNS – **ASTROCYTES**

Astrocytes These star-shaped cells have many processes and are the largest and most numerous of the neuroglia.

The functions of astrocytes include the following:

1. Astrocytes contain microfilaments that give them considerable strength, which enables them to **support** neurons.

2. Processes of astrocytes **wrapped around blood capillaries isolate neurons** of the CNS from various potentially harmful substances in blood by secreting chemicals that maintain the unique selective permeability characteristics of the endothelial cells of the capillaries. In effect, the endothelial cells create a ***blood–brain barrier,*** which restricts the movement of substances between the blood and interstitial fluid of the CNS.

3. In the embryo, astrocytes secrete chemicals that appear to **regulate** the growth, migration, and interconnection among neurons in the brain.

4. Astrocytes help to **maintain the appropriate chemical environment** for the generation of nerve impulses. For example, they regulate the concentration of important ions such as K; take up excess neurotransmitters; and serve as a conduit for the passage of nutrients and other substances between blood capillaries and neurons.

5. Astrocytes may also play a role in **learning and memory** by influencing the formation of neural synapses (see Section 16.5).

Histology of Nervous Tissue
B- **Neuroglia**
***2- Neuroglia of the CNS* – OLIGODENDROCYTES**

- ✓**Oligodendrocytes** These resemble astrocytes but are smaller and contain fewer processes.

- ✓Processes of **oligodendrocytes** are responsible for forming and maintaining the myelin sheath around CNS axons.

- ✓The **myelin sheath** is a multilayered lipid and protein covering around some axons that insulates them and increases the speed of nerve impulse conduction.

- ✓Such axons are said to be *myelinated* (mı»-e-li-NA¯ -ted).

Histology of Nervous Tissue
B- **Neuroglia**
3- Neuroglia of the CNS – **MICROGLIA**

- ✓ **Microglial cells or Microglia** These neuroglia are small cells with slender processes that give off numerous ***spinelike*** projections.

- ✓ **Microglial cells** or *microglia* function as phagocytes.

- ✓ Like tissue macrophages, they remove cellular debris formed during normal development of the nervous system and phagocytize microbes and damaged nervous tissue.

Histology of Nervous Tissue

B- **Neuroglia**

4- Neuroglia of the CNS – **EPENDYMAL CELLS**

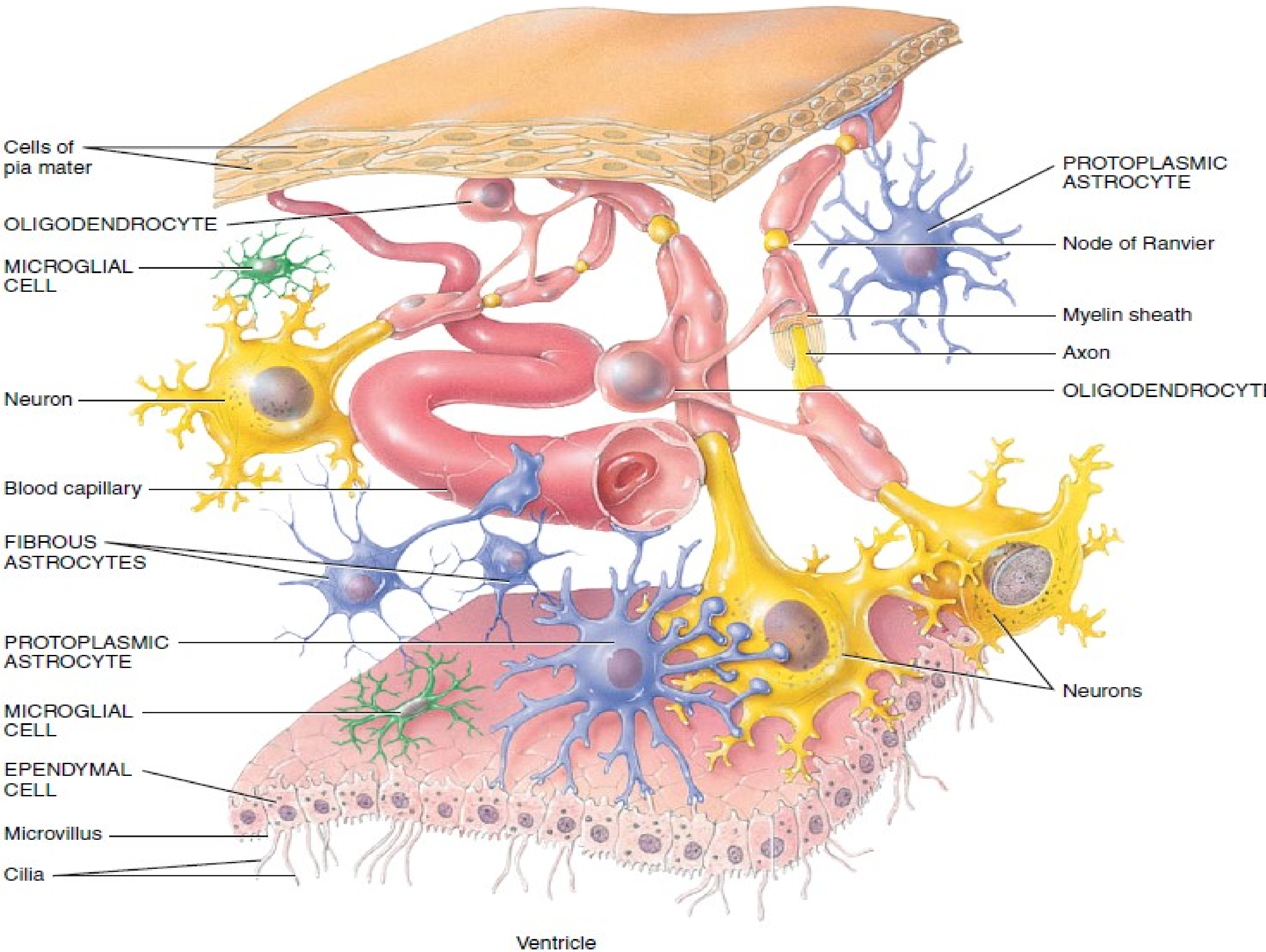
✓**Ependymal cells** are cuboidal to columnar cells arranged in a single layer that possess microvilli and cilia.

✓These cells line the ventricles of the brain and central canal of the spinal cord (spaces filled with cerebrospinal fluid, which protects and nourishes the brain and spinal cord).

✓Functionally, ependymal cells produce, possibly monitor, and assist in the circulation of cerebrospinal fluid.

✓They also form the blood–cerebrospinal fluid barrier.

Figure 12.6 Neuroglia of the central nervous system.
Neuroglia of the CNS are distinguished on the basis of size, cytoplasmic processes, and intracellular organization.



Histology of Nervous Tissue
B- **Neuroglia --- *2- Neuroglia of the PNS***

- Neuroglia of the PNS ***completely SURROUND axons and cell bodies***.
- The two types of glial cells in the PNS are **Schwann cells and satellite cells** (Figure 12.7).

SCHWANN CELLS

- These cells encircle PNS axons. Like oligodendrocytes, they form the myelin sheath around axons.
- A single oligodendrocyte myelinates several axons, but each **Schwann cell** (SCHVON or SCHWON) myelinates a **single axon** (Figure 12.7a; see also Figure 12.8a, c).
- A single Schwann cell can also enclose as many as 20 or more unmyelinated axons (axons that lack a myelin sheath) (Figure 12.7b).
- Schwann cells participate in axon regeneration, which is more easily accomplished in the PNS than in the CNS.

SATELLITE CELLS

- These **flat** cells surround the cell bodies of neurons of PNS ganglia (Figure 12.7c).
- Besides providing structural support, **satellite cells** (SAT-i-lı»t) regulate the exchanges of materials between neuronal cell bodies and interstitial fluid.

Figure 12.7 Neuroglia of the peripheral nervous system. Neuroglia of the PNS completely surround axons and cell bodies of neurons.

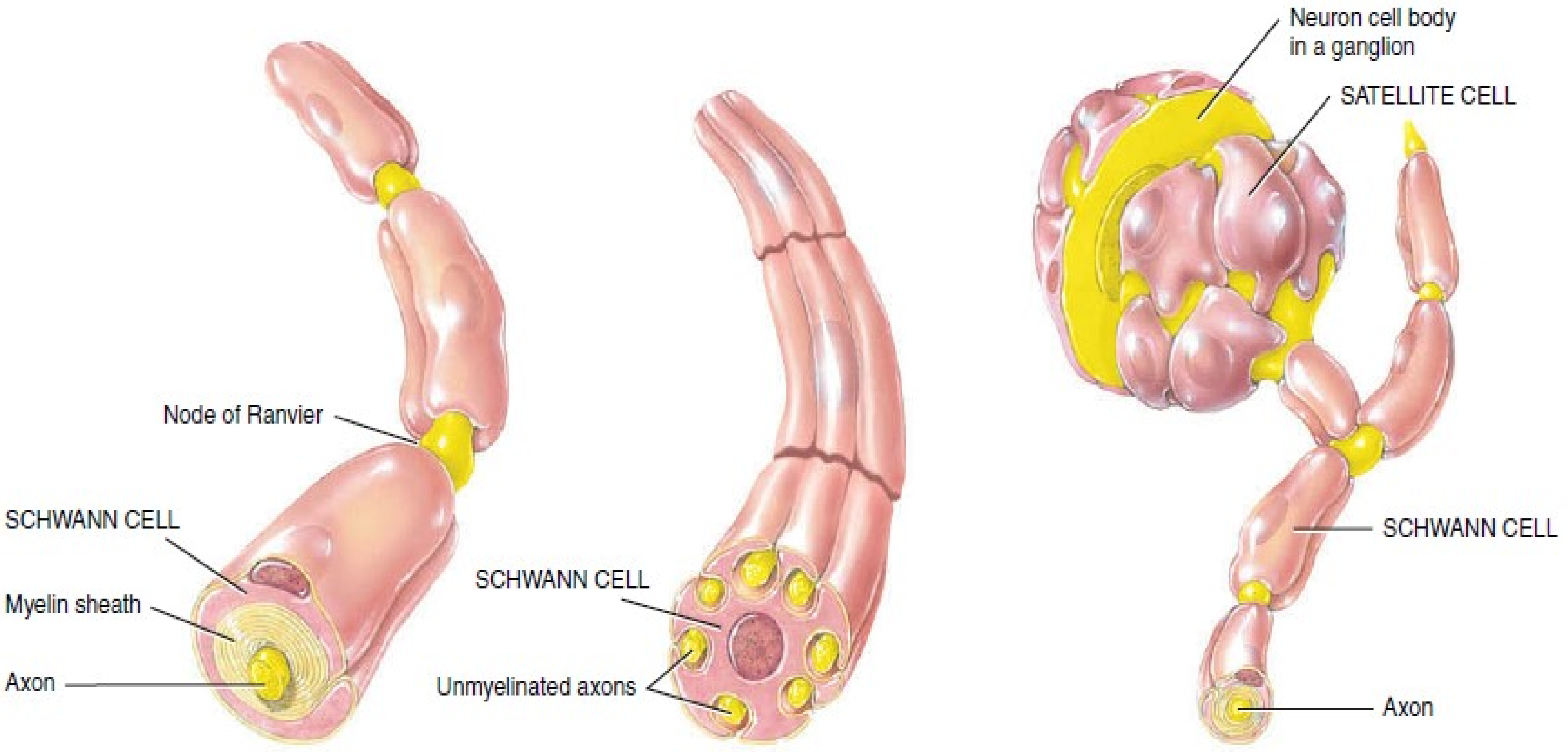
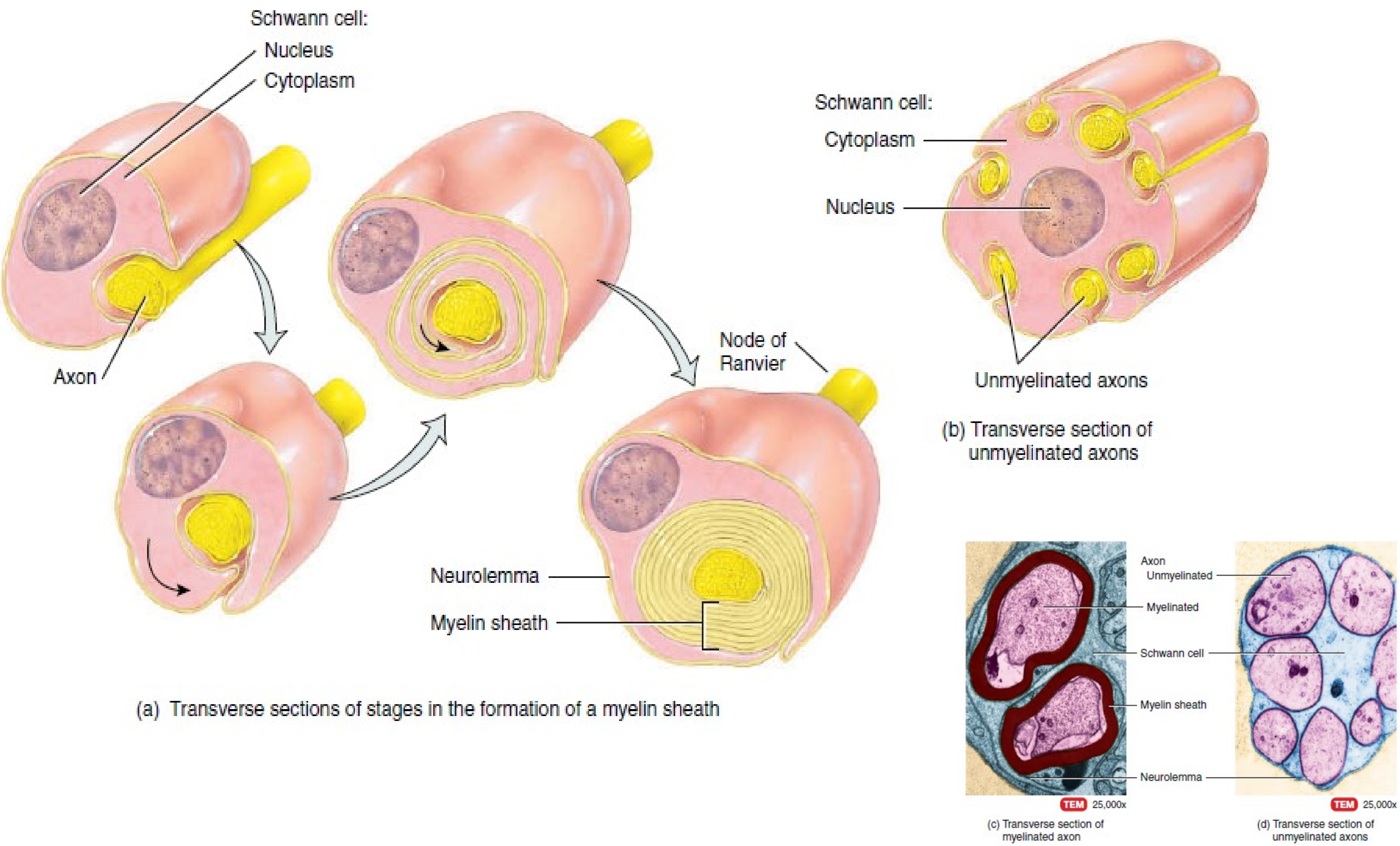


Figure 12.8 Myelinated and unmyelinated axons. Notice that one layer of Schwann cell plasma membrane surrounds unmyelinated axons.

→ Axons surrounded by a myelin sheath produced either by Schwann cells in the PNS or by oligodendrocytes in the CNS are said to be myelinated.



(a) Transverse sections of stages in the formation of a myelin sheath

(b) Transverse section of unmyelinated axons

(c) Transverse section of myelinated axon

(d) Transverse section of unmyelinated axons

Myelination

- Two types of neuroglia produce myelin sheaths: Schwann cells (in the PNS) and oligodendrocytes in the CNS).

- Axons surrounded by a multilayered lipid and protein covering, called the **myelin sheath**, are said to be **myelinated** (Figure 12.8a).

  → The sheath electrically insulates the axon of a neuron and increases the speed of nerve impulse conduction.

- Axons without such a covering are said to be **unmyelinated** (Figure 12.8b).

- GAPS in the myelin sheath, called **nodes of Ranvier** (RON-ve»-a¯), appear at intervals along the axon (Figure 12.8; see also Figure 12.2).

- The amount of myelin increases from birth to maturity, and its presence greatly increases the speed of nerve impulse conduction.

Collections of Nervous Tissue → *Gray and White Matter*

The components of nervous tissue are **grouped** together in a variety of ways.

Neuronal cell bodies are often grouped together in clusters:

→ A **ganglion** (plural is *ganglia*) refers to a cluster of neuronal cell bodies located in the *PNS*

→A **nucleus** is a cluster of neuronal cell bodies located in the *CNS.*

The axons of neurons are usually grouped together in bundles:

→ A **nerve** is a bundle of axons that is located in the *PNS (*connect CNS to periphery*)*

→ A **tract** is a bundle of axons that is located in the *CNS* (interconnect neurons in the CNS)

Collections of Nervous Tissue → *Gray and White Matter* (continued)

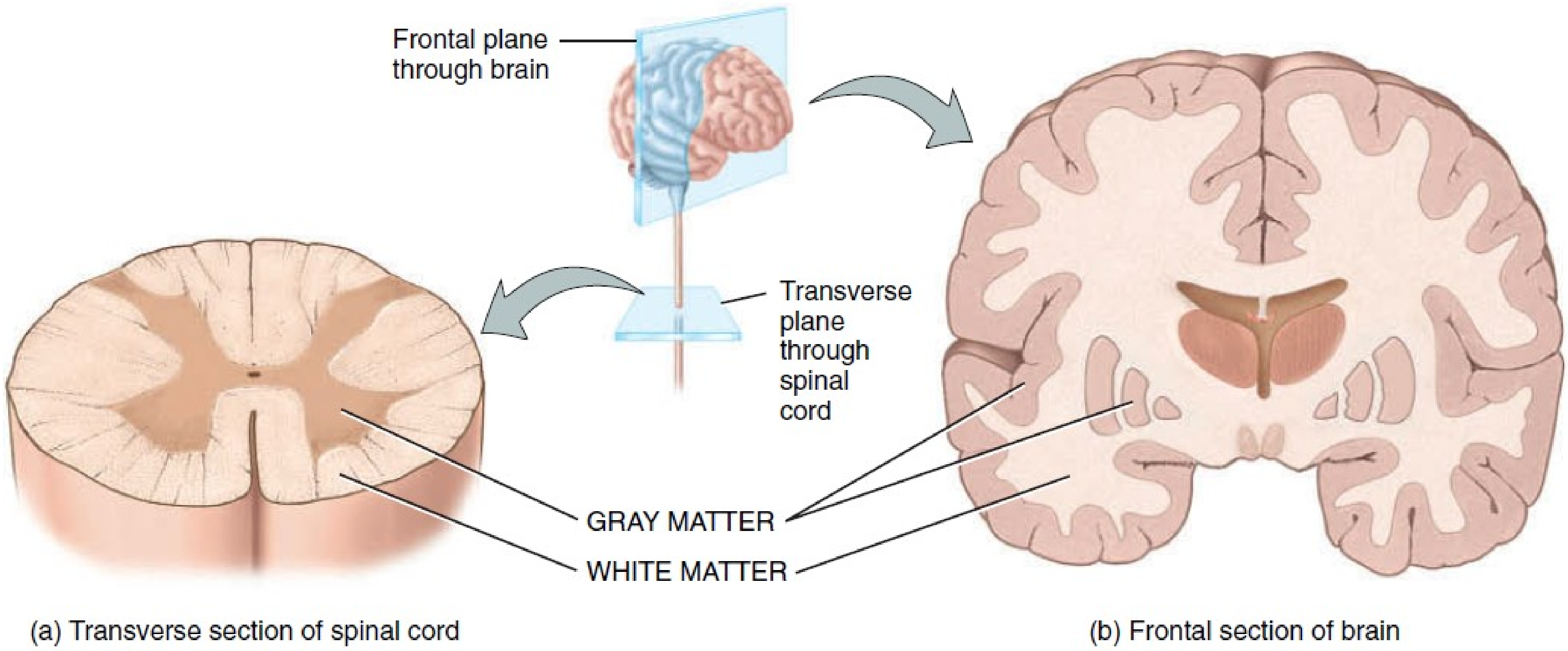
Widespread regions of nervous tissue are grouped together as either gray matter or white matter:

→**White matter** is composed primarily of myelinated axons. The whitish color of myelin gives white matter its name.

→ **Gray matter** of the nervous system contains neuronal cell bodies, dendrites, unmyelinated axons, axon terminals, and neuroglia.

- In the spinal cord, the white matter surrounds an inner core of gray matter
- In the brain, a thin shell of gray matter covers the surface of the largest portions of the brain, the cerebrum and cerebellum (Figure 12.9).

Figure 12.9 Distribution of gray matter and white matter in the spinal cord and brain.
White matter consists primarily of myelinated axons of many neurons. Gray matter consists of neuron cell bodies, dendrites, unmyelinated axons, axon terminals, and neuroglia.



Electrical Signals In Neurons

Neurons are electrically excitable. They communicate with one another using two types of electrical signals:

(1) Graded potentials are used for short- distance communication only.

(2) Action potentials allow communication over long distances within the body.

The production of graded potentials and action potentials depends on two basic features of the plasma membrane of excitable cells:

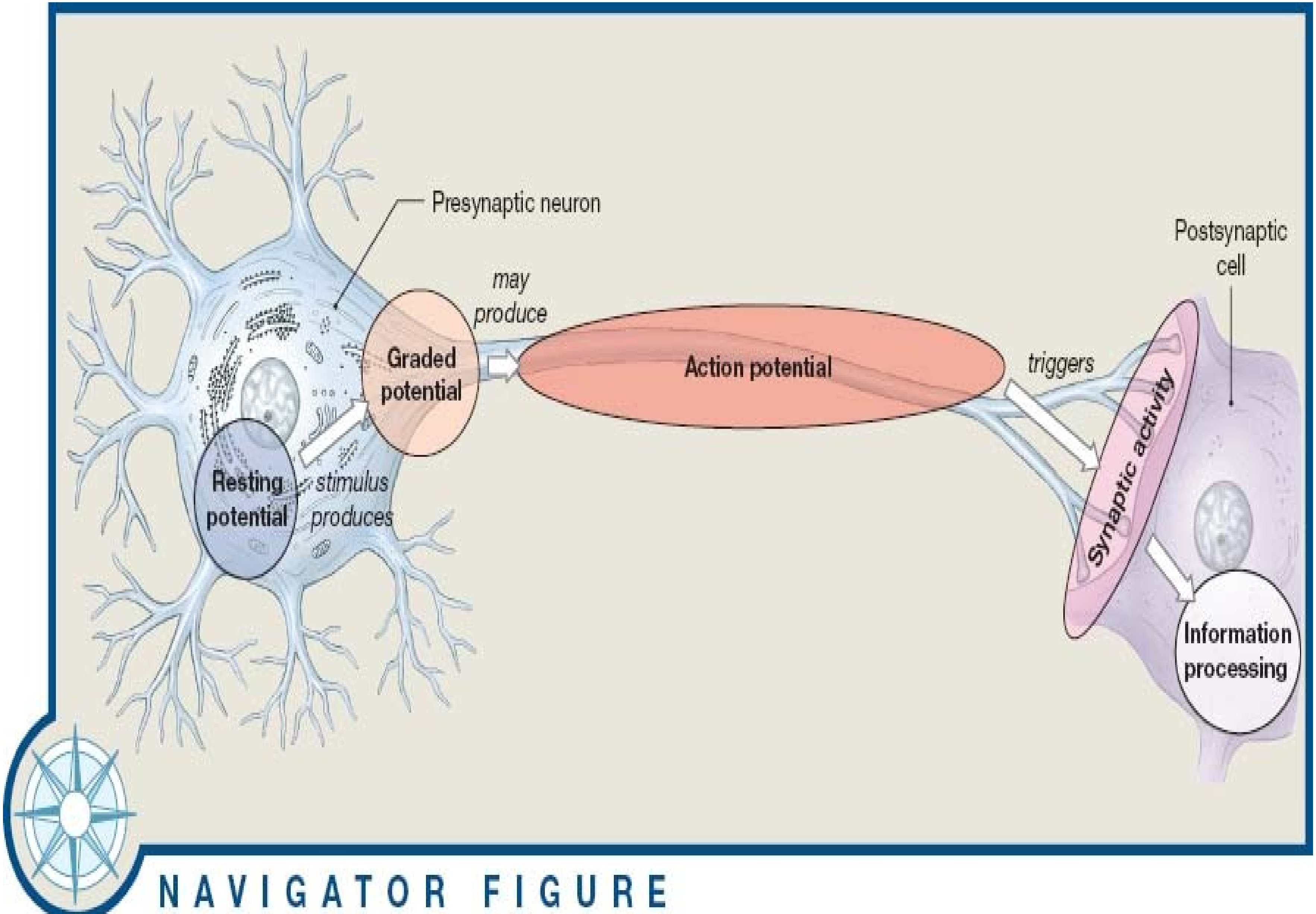
1- the existence of a resting membrane potential

2- the presence of specific types of ion channels.

Like most other cells in the body, the plasma membrane of excitable cells exhibits a **membrane potential,** an electrical potential difference (voltage) across the membrane. In excitable cells, this voltage is termed the **resting membrane potential.**

Graded potentials and action potentials occur because the membranes of neurons contain many different kinds of ion channels that open or close in response to specific stimuli. Because the lipid bilayer of the plasma membrane is a good electrical insulator, the main paths for current to flow across the membrane are through the ion channels.

Overview of neural activities



Ion Channels in Neurons

TYPE OF ION CHANNEL	DESCRIPTION	LOCATION
Leak channels	Gated channels that randomly open and close.	Found in nearly all cells, including dendrites, cell bodies, and axons of all types of neurons.
Ligand-gated channels	Gated channels that open in response to binding of ligand (chemical) stimulus.	Dendrites of some sensory neurons such as pain receptors and dendrites and cell bodies of interneurons and motor neurons.
Mechanically-gated channels	Gated channels that open in response to mechanical stimulus (such as touch, pressure, vibration, or tissue stretching).	Dendrites of some sensory neurons such as touch receptors, pressure receptors, and some pain receptors.
Voltage-gated channels	Gated channels that open in response to voltage stimulus (change in membrane potential).	Axons of all types of neurons.

Resting Membrane Potential

- The resting membrane potential exists because of a small buildup of negative ions in the cytosol along the inside of the membrane, and an **equal** buildup of positive ions in the extracellular fluid (ECF) along the outside surface of the membrane (Figure 12.12a).

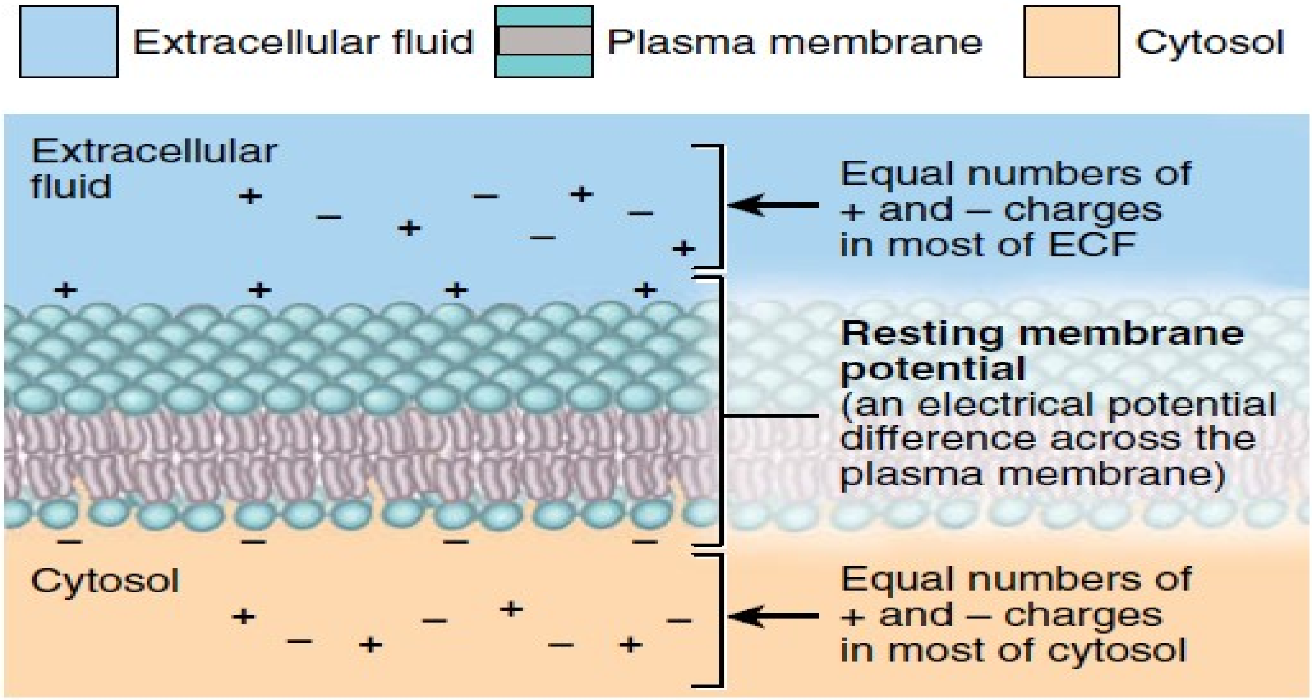
- Such a separation of positive and negative electrical charges is a form of potential energy, which is measured in volts or millivolts (1 mV 0.001 V). The greater the difference in charge across the membrane, the larger the membrane potential (voltage).

- Notice in Figure 12.12a that the buildup of charge occurs only very close to the membrane. The cytosol or extracellular fluid elsewhere in the cell contains equal numbers of positive and negative charges and is electrically neutral.

- In neurons, the resting membrane potential ranges from -40 to -90 mV. A typical value is -70 mV. The minus sign indicates that the inside of the cell is negative relative to the outside. A cell that exhibits a membrane potential is said to be **polarized.** Most body cells are polarized; the membrane potential varies from +5 mV to -100 mV in different types of cells.

Resting membrane potential. To measure resting membrane potential, the tip of the recording microelectrode is inserted inside the neuron, and the reference electrode is placed in the extracellular fluid. The electrodes are connected to a voltmeter that measures the difference in charge across the plasma membrane (in this case -70 mV, indicating that the inside of the cell is negative relative to the outside).

The resting membrane potential is an electrical potential difference (voltage) that exists across the plasma membrane of an excitable cell under resting conditions.



(a) Distribution of charges that produce the resting membrane potential of a neuron

Resting Membrane Potential (continued)

<u>The resting membrane potential is determined by three major factors:</u>

1. Unequal distribution of ions in the ECF and cytosol

→ *Because the plasma membrane has more K^+ leak channels (blue) than Na^+ leak channels (rust), the number of K^+ ions that leave the cell is greater than the number of Na^+ ions that enter the cell. As more and more K^+ ions leave the cell, the inside of the membrane becomes increasingly negative and the outside of the membrane becomes increasingly positive.*

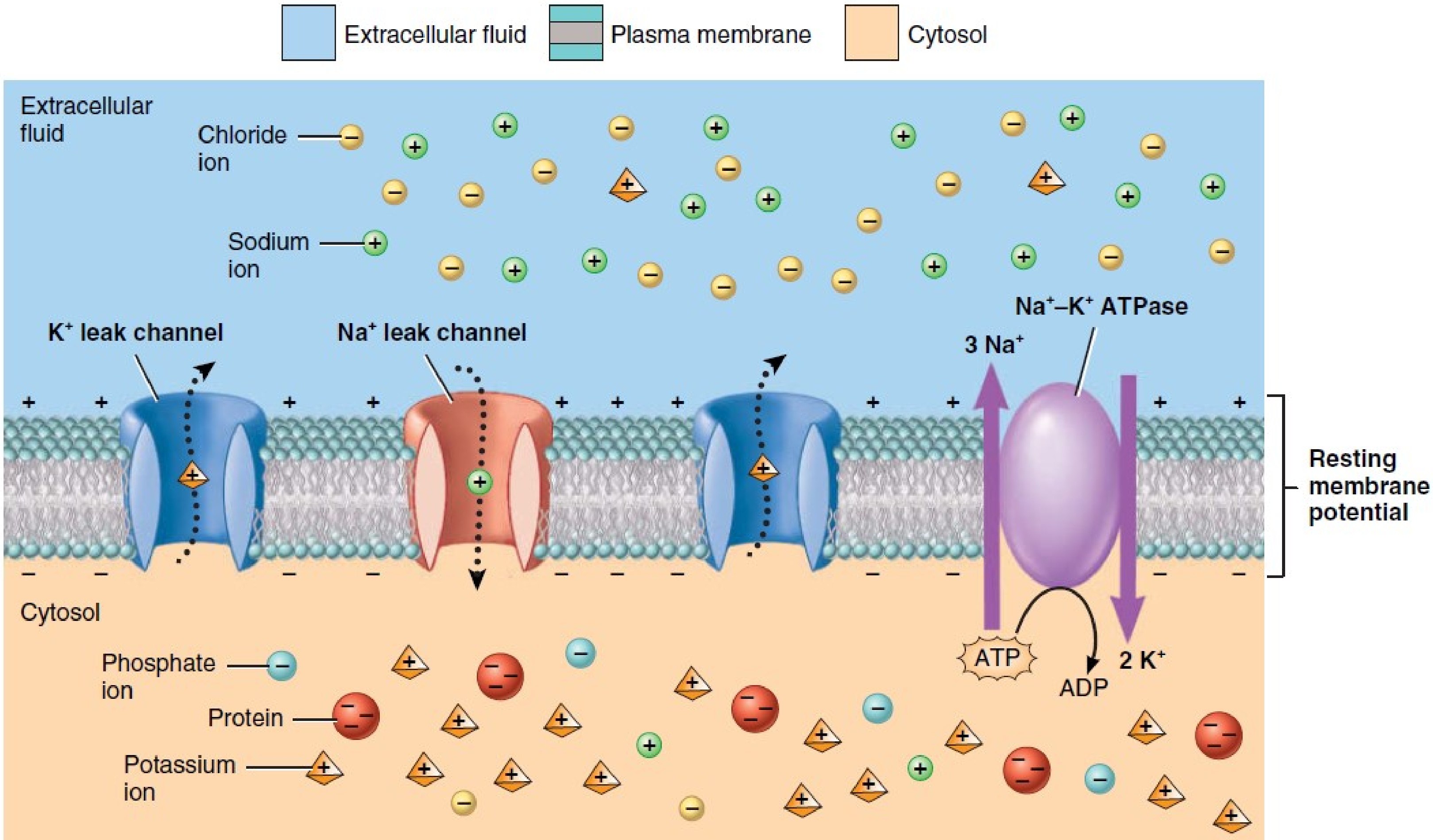
2. Inability of most anions to leave the cell

→ *Trapped anions (turquoise and red) cannot follow K^+ out of the cell because they are attached to nondiffusible molecules such as ATP and large proteins.*

3. The electrogenic nature of the Na–K ATPases.

→ *The electrogenic Na^+–K^+ ATPase (purple) expels 3 Na^+ ions for every 2 K^+ ion imported.*

Figure 12.13 Three factors that contribute to the resting membrane potential.



Graded Potentials

Generation of graded potentials in response to the opening of mechanically-gated channels or ligand-gated channels.

- ✓Typically, mechanically-gated channels and ligand-gated channels can be present in the ***dendrites*** of sensory neurons, and ligand-gated channels are numerous in the ***dendrites and cell bodies*** of interneurons and motor neurons. **Hence, graded potentials occur mainly in the dendrites and cell body of a neuron.**
- ✓To say that these electrical signals are *graded* means that they vary in amplitude (size), depending on the strength of the stimulus.
  - →They are larger or smaller depending on how many ligand-gated or mechanically-gated channels have opened (or closed) and how long each remains open.
- ✓The opening or closing of these ion channels alters the flow of specific ions across the membrane, producing a flow of current that is *localized,* which means that it spreads to adjacent regions along the plasma membrane in either direction from the stimulus source for a short distance and then gradually dies out as the charges are lost across the membrane through leak channels.

Generation of Action Potentials

An **action potential (AP)** or **impulse** is a sequence of rapidly occurring events that **decrease and reverse** the membrane potential and then eventually restore it to the resting state.

An action potential has two main phases: (Figure 12.18)

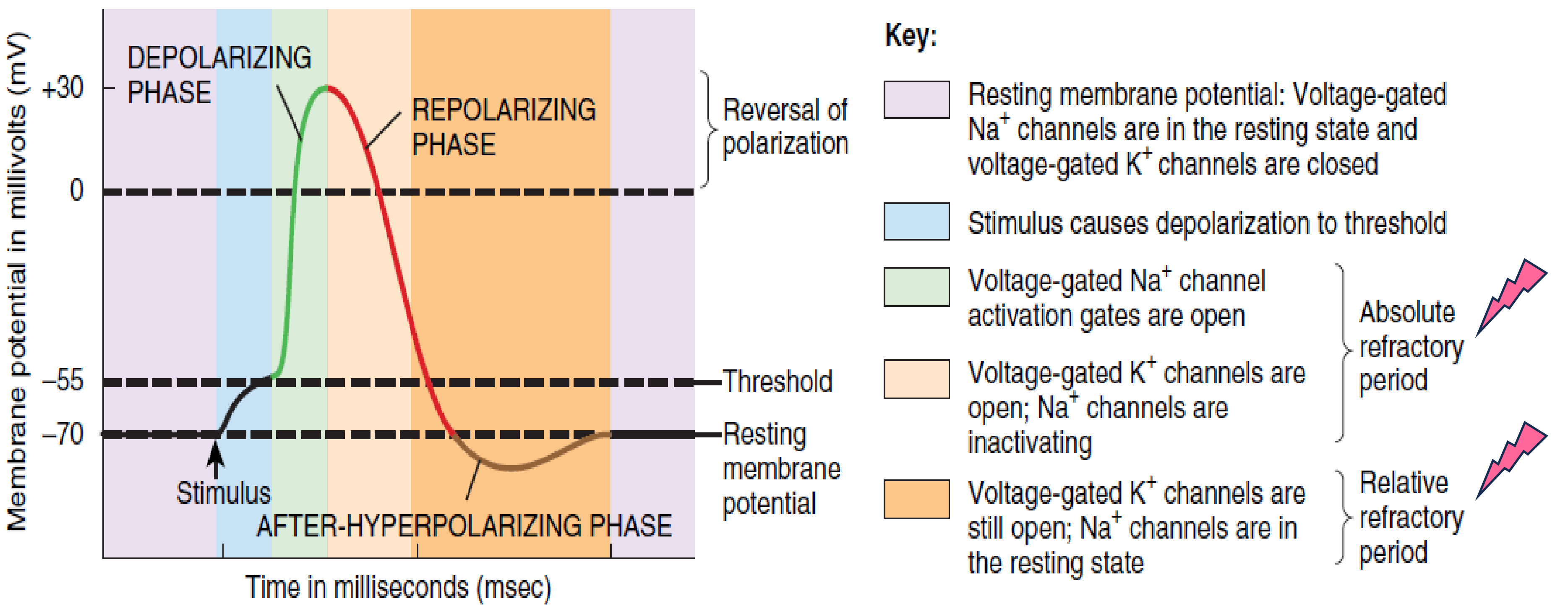
1- Depolarizing phase: During this phase the negative membrane potential becomes less negative, reaches zero, and then becomes positive.

2- **Repolarizing phase,** During this phase the membrane potential is restored to the resting state of -70 mV.

→ Following the repolarizing phase there **May** be an **after-hyperpolarizing phase,** during which the membrane potential temporarily becomes more negative than the resting level.

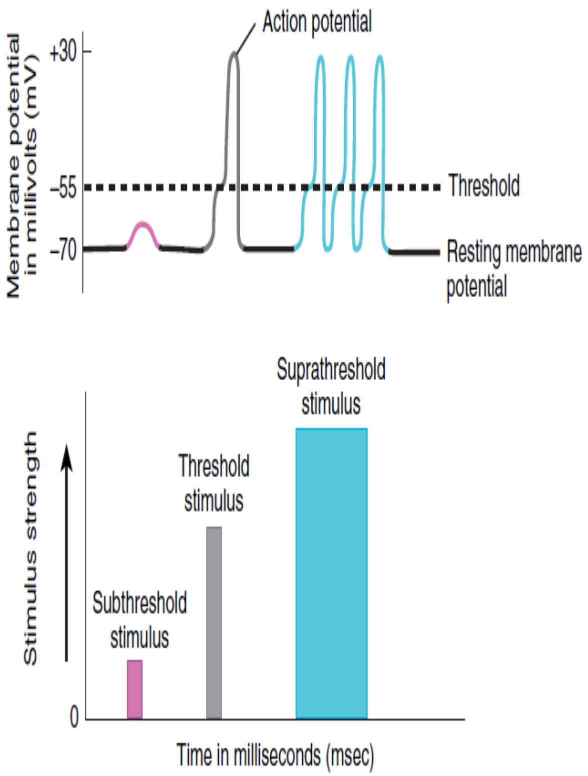
Figure 12.18 Action potential (AP) or impulse. The action potential arises at the trigger zone (at the junction of the axon hillock and the initial segment) and then propagates along the axon to the axon terminals. The **green-colored** regions of the neuron indicate parts that typically have voltage-gated Na+ and K+ channels (axon plasma membrane and axon terminals).

→ An action potential consists of a depolarizing phase and a repolarizing phase, which may be followed by an after hyperpolarizing phase.



Stimulus strength and action potential generation

- A subthreshold stimulus does not cause an action potential.
- **An action potential does occur in response to a threshold stimulus, which is just strong enough to depolarize the membrane to threshold.**
- Several action potentials form in response to a suprathreshold stimulus. Each of the action potentials caused by the suprathreshold stimulus has the same amplitude (size) as the action potential caused by the threshold stimulus.



Refractory Period → Figure 12.18

- The period of time after an action potential begins during which an excitable cell cannot generate another action potential in response to a *normal* threshold stimulus.

- **Absolute refractory period,** even a very strong stimulus cannot initiate a second action potential. This period coincides with the period of Na channel activation and inactivation Inactivated Na^+ channels cannot reopen; they first must return to the resting state. In contrast to action potentials, graded potentials do not exhibit a refractory period.

- **Relative refractory period** is the period of time during which a second action potential can be initiated, but only by a larger than normal stimulus. It coincides with the period when the voltage-gated K^+ channels are still open after inactivated Na^+ channels have returned to their resting state

Propagation of Action Potentials

- To communicate information from one part of the body to another, action potentials in a neuron must travel from where they arise at the trigger zone of the axon to the axon terminals.
- In contrast to the graded potential, an action potential is not decremental (it does not die out). Instead, an action potential keeps its strength as it spreads along the membrane. This mode of conduction is called **propagation**
- The action potential **regenerates** over and over at adjacent regions of membrane from the trigger zone to the axon terminals.
- In a neuron, an action potential can propagate in one direction only—it cannot propagate back toward the cell body because any region of membrane that has just undergone an action potential is temporarily in the absolute refractory period and cannot generate another action potential.
- Because they can travel along a membrane without dying out, action potentials function in communication over long distances.

Figure 12.21 Propagation of an action potential in a neuron after it arises at the trigger zone.

→ ***Unmyelinated axons exhibit continuous conduction; myelinated axons exhibit saltatory conduction.***

- *Dotted lines indicate ionic current flow. The insets show the path of current flow.*

(a) In continuous conduction along an **unmyelinated** axon, ionic currents flow across each adjacent segment of the **membrane**.

(b) In saltatory conduction along a **myelinated** axon, the action potential (nerve impulse) at the first node generates ionic currents in the **cytosol and interstitial fluid** that open voltage-gated Na^+ channels at the second node, and so on at each subsequent node.

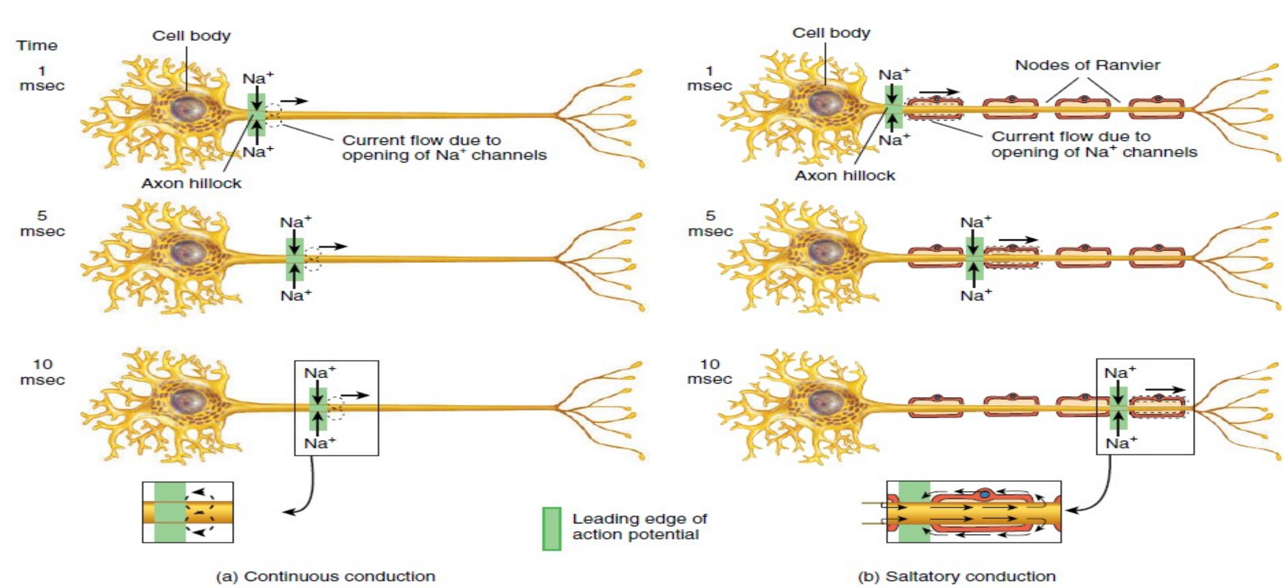


TABLE 12.2

Comparison of Graded Potentials and Action Potentials in Neurons

CHARACTERISTIC	GRADED POTENTIALS	ACTION POTENTIALS
Origin	Arise mainly in dendrites and cell body.	Arise at trigger zones and propagate along axon.
Types of channels	Ligand-gated or mechanically-gated ion channels.	Voltage-gated channels for Na^+ and K^+.
Conduction	Decremental (not propagated); permit communication over short distances.	Propagate and thus permit communication over longer distances.
Amplitude (size)	Depending on strength of stimulus, varies from less than 1 mV to more than 50 mV.	All or none; typically about 100 mV.
Duration	Typically longer, ranging from several milliseconds to several minutes.	Shorter, ranging from 0.5 to 2 msec.
Polarity	May be hyperpolarizing (inhibitory to generation of action potential) or depolarizing (excitatory to generation of action potential).	Always consist of depolarizing phase followed by repolarizing phase and return to resting membrane potential.
Refractory period	Not present; summation can occur.	Present; summation cannot occur.

The All-or-None Principle

- ✓**Conduction of a nerve impulse is an all-or-nothing event.**
- ✓**None:** when Depolarization, is below the threshold (gates are closed).
- ✓**All:** when Depolarization, reaches the threshold, gates open and nerve impulse is produced.
- ✓***Stronger stimuli*** produce action potentials with greater frequency (more are produced per second).
- ✓***Intensity of signal*** is determined by how many impulses are generated within a given time span.
- ✓The amplitude (size) of action potential is always the **same** in all axons at all time (from -70 to +30)

Factors That Affect the Speed of Propagation

1. ***Amount of myelination.*** As you have just learned, action potentials propagate more rapidly along myelinated axons than along unmyelinated axons.

2. ***Axon diameter.*** Larger diameter axons propagate action potentials faster than smaller ones due to their larger surface areas.

3. ***Temperature.*** Axons propagate action potentials at lower speeds when cooled.

Classification of Nerve Fibers

Axons are classified into three groups according to the relationships among the diameter, myelination, and propagation speed

1. **Type A fibers** are the largest axons, with diameters ranging from 4 to 20 µm. These fibers are myelinated axons that carry action potentials at speeds of up to 120 meters per second.
2. **Type B fibers** are smaller myelinated axons, with diameters of 2–4 µm. Their propagation speeds average around 18 meters per second.
3. **Type C fibers** are unmyelinated and less than 2 µm in diameter. These axons propagate action potentials at a speed of 1 meter per second.

Signal Transmission at Synapses

- **A Synapse** is a region where communication occurs between two neurons or between a neuron (in CNS) and an effector cell (muscle cell or glandular cell, in PNS)

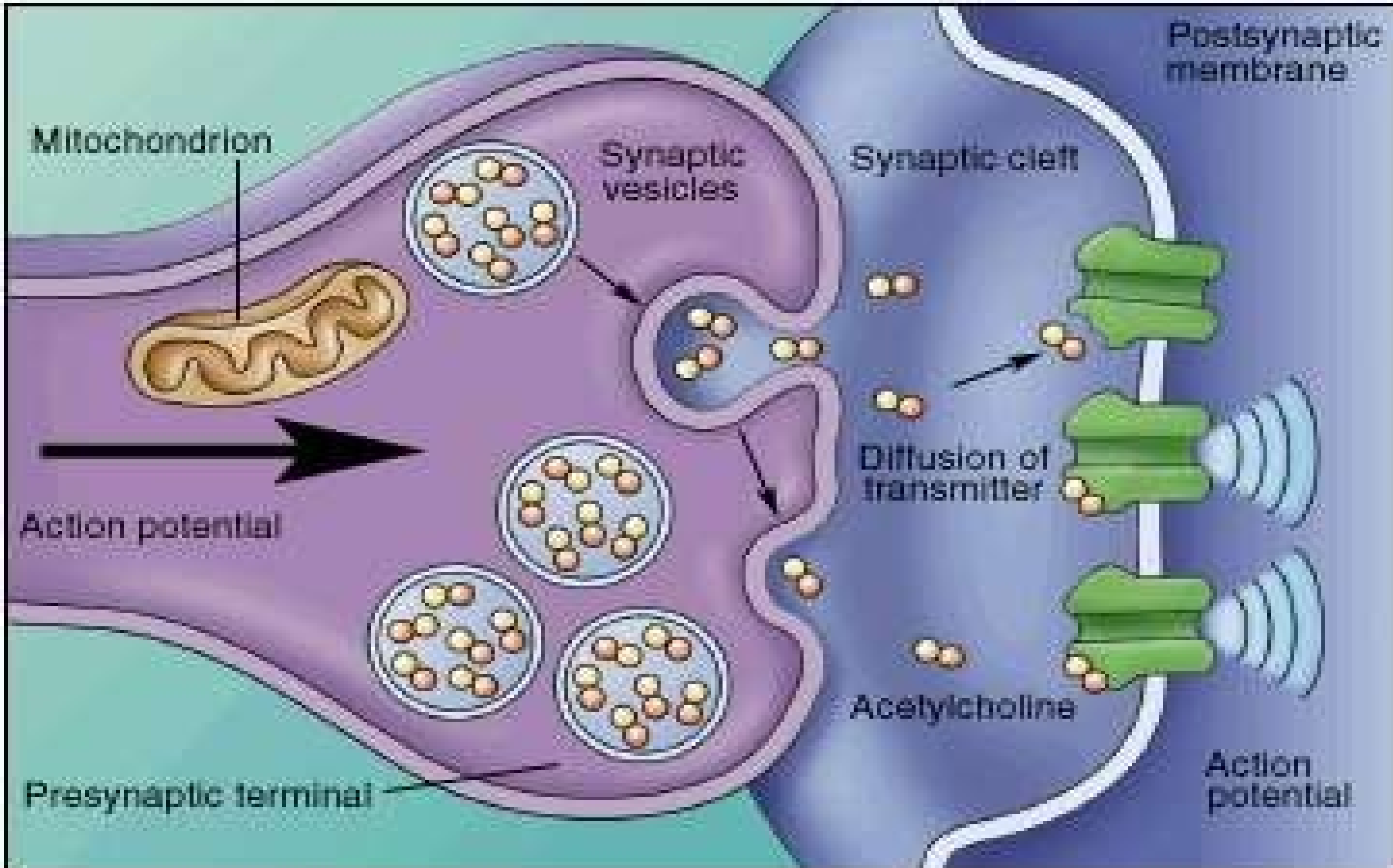
- The term **presynaptic neuron** (*pre-* before) refers to a nerve cell that carries a nerve impulse toward a synapse. It is the cell that sends a signal.
- A **postsynaptic cell** is the cell that receives a signal.

  → *It may be a nerve cell called a **postsynaptic neuron** (post- after) that carries a nerve impulse away from a synapse or an **effector cell** that responds to the impulse at the synapse.*

- Most synapses between neurons are **axodendritic** (from axon to dendrite), while others are **axosomatic** (from axon to cell body) or **axoaxonic (**from axon to axon) (Figure 12.22).

- Synapses may be **electrical or chemical** and they differ both structurally and functionally.

The Synapse

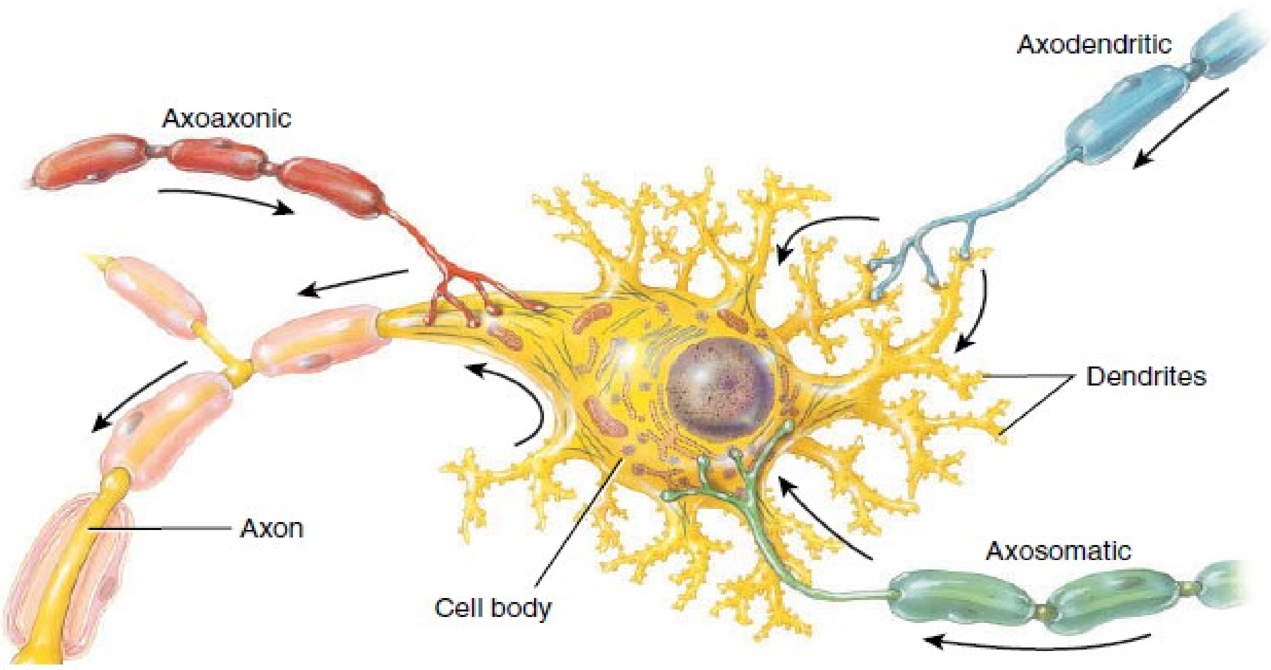


Synaptic Transmission

The end of the axon, the presynaptic terminal, is separated by a space, the synaptic cleft, from the postsynaptic membrane. The neurotransmitter acetylcholine diffuses from the presynaptic terminal across the synaptic cleft to the receptors specific for acetylcholine in the postsynaptic membrane.

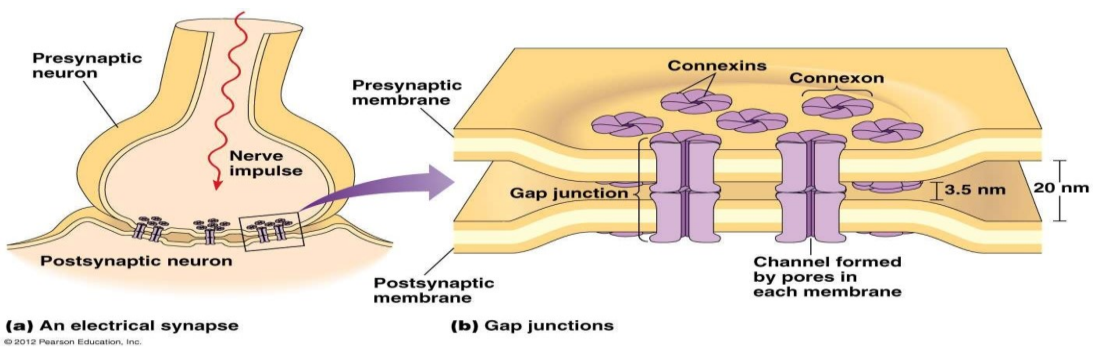
Figure 12.22 Examples of synapses between neurons. Arrows indicate the direction of information flow: presynaptic neuron n postsynaptic neuron. Presynaptic neurons usually synapse on the axon (axoaxonic: red), a dendrite (axodendritic; blue), or the cell body (axosomatic; green).

Neurons communicate with other neurons at synapses, which are junctions between one neuron and a second neuron or an effector cell.



1. Electrical Synapses

- At electrical synapses the presynaptic and postsynaptic membranes are electrically coupled through gap junctions
- Impulses are regenerated from one cell to the next.
- Ions flow directly from one neuron to the next.
- An electrical synapse propagates action potentials quickly and efficiently from one cell to the next.
- Electrical synapses are located in both the CNS and PNS



2-Chemical synapses

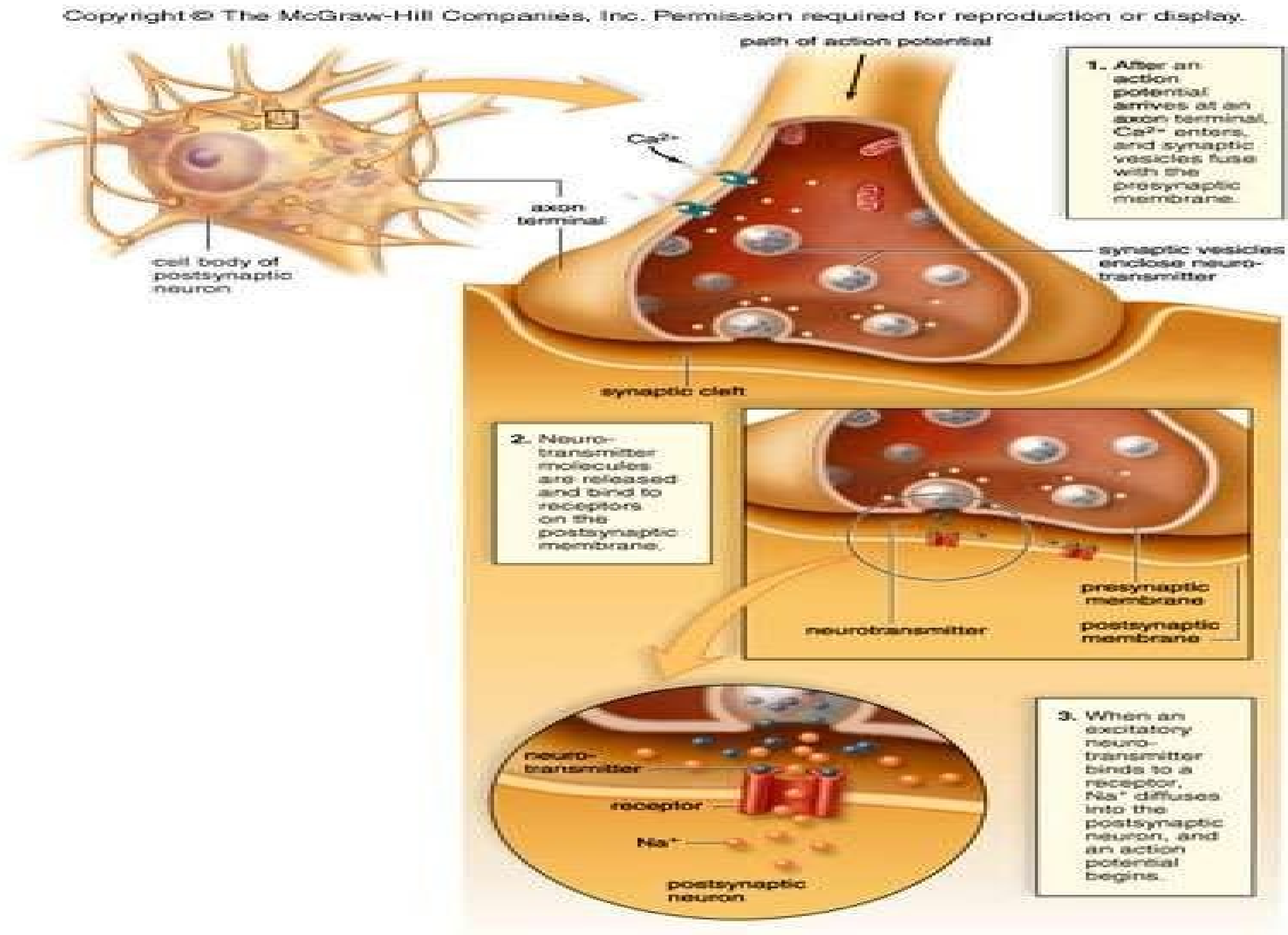
- Transmission across a synapse is carried out by neurotransmitters
  ----
- Sudden rise in calcium at end of one neuron stimulates synaptic vesicles to merge with the presynaptic membrane

----

- Neurotransmitter molecules are released into the synaptic cleft
- Presynaptic neuron releases NT that binds postsynaptic neuron receptors.
- Excitatory neurotransmitters cause depolarization and promote the generation of action potentials.
- Inhibitory neurotransmitters cause hyperpolarization and suppress the generation of action potentials.

- Neurotransmitter is removed from the synaptic cleft ***in three ways:*** diffusion, enzymatic degradation, and uptake by cells (neurons and neuroglia).

Chemical synapses



Neurotransmitters

- Both excitatory and inhibitory neurotransmitters are present in the CNS and the PNS. ***A given neurotransmitter may be excitatory in some locations and inhibitory in others.***

- Neurotransmitters can be divided into two classes based on size:

(1) **Small-molecule neurotransmitters** (acetylcholine, amino acids, biogenic amines, ATP and other purines, nitric oxide, and carbon monoxide),

(2) **Neuropeptides,** which are composed of 3 to 40 amino acids.

- Chemical synaptic transmission **may be modified** by affecting synthesis, release, or removal of a neurotransmitter or by blocking or stimulating neurotransmitter receptors.

EXAMPLES OF NEUROTRANSMITTERS

1. **Norepinephrine:** Norepinephrine typically has an excitatory effects.
2. **Dopamine** a CNS neurotransmitter released in many areas of the brain, may have either inhibitory or excitatory effects.
3. **Serotonin** is another important CNS neurotransmitter. Inadequate serotonin production can have widespread effects on a person's attention and emotional states.
4. **Gamma-aminobutyric acid**, or **GABA**, generally has an inhibitory effect.