Biological Basis of Behaviour

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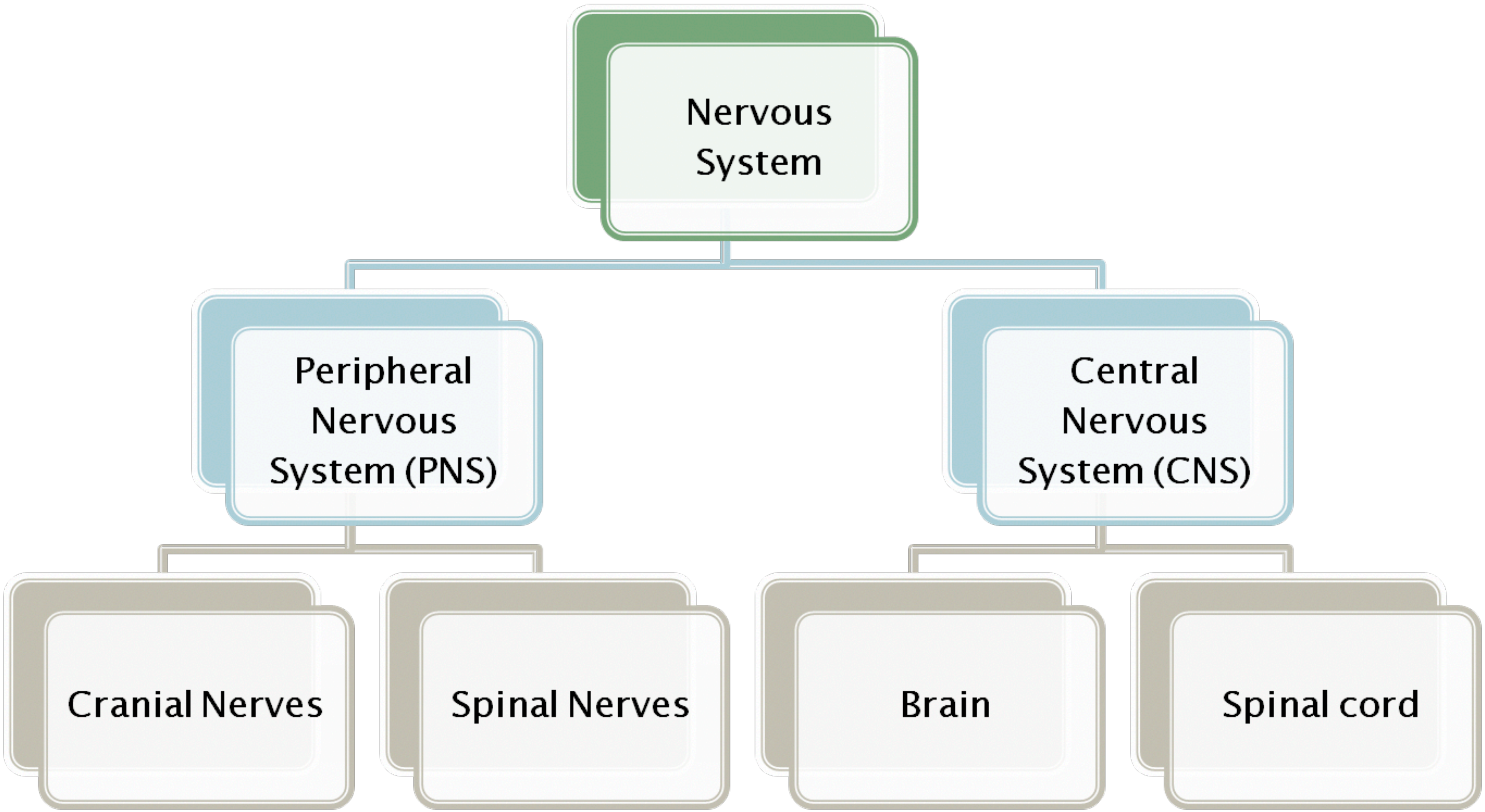
The human nervous system consists of :



The human nervous system consists of the **central nervous system (CNS)** and the **peripheral nervous system (PNS)**.

A. The **CNS** contains the brain and spinal cord.

1. The **cerebral cortex** can be divided

a. Anatomically into at least four sets of lobes: Frontal, temporal, parietal, and occipital, as well as the limbic lobes (which contain medial parts of the frontal, temporal, and parietal lobes and include the hippocampus, amygdala, fornix, septum, parts of the thalamus, and cingulate gyrus and related structures).

b. By arrangement of neuron layers or cytoarchitecture.

c. Functionally into motor, sensory, and association areas.

2. The cerebral hemispheres

a. The hemispheres are connected by the corpus callosum, anterior commissure, hippocampal commissure, and habenular commissure.

b. The functions of the hemispheres are lateralized.

(1) The right, or nondominant, hemisphere is associated primarily with perception; it is also associated with spatial relations, body image, and musical and artistic ability.

(2) The left, or dominant, hemisphere is associated with language function in about almost all right-handed people and most left-handed people.

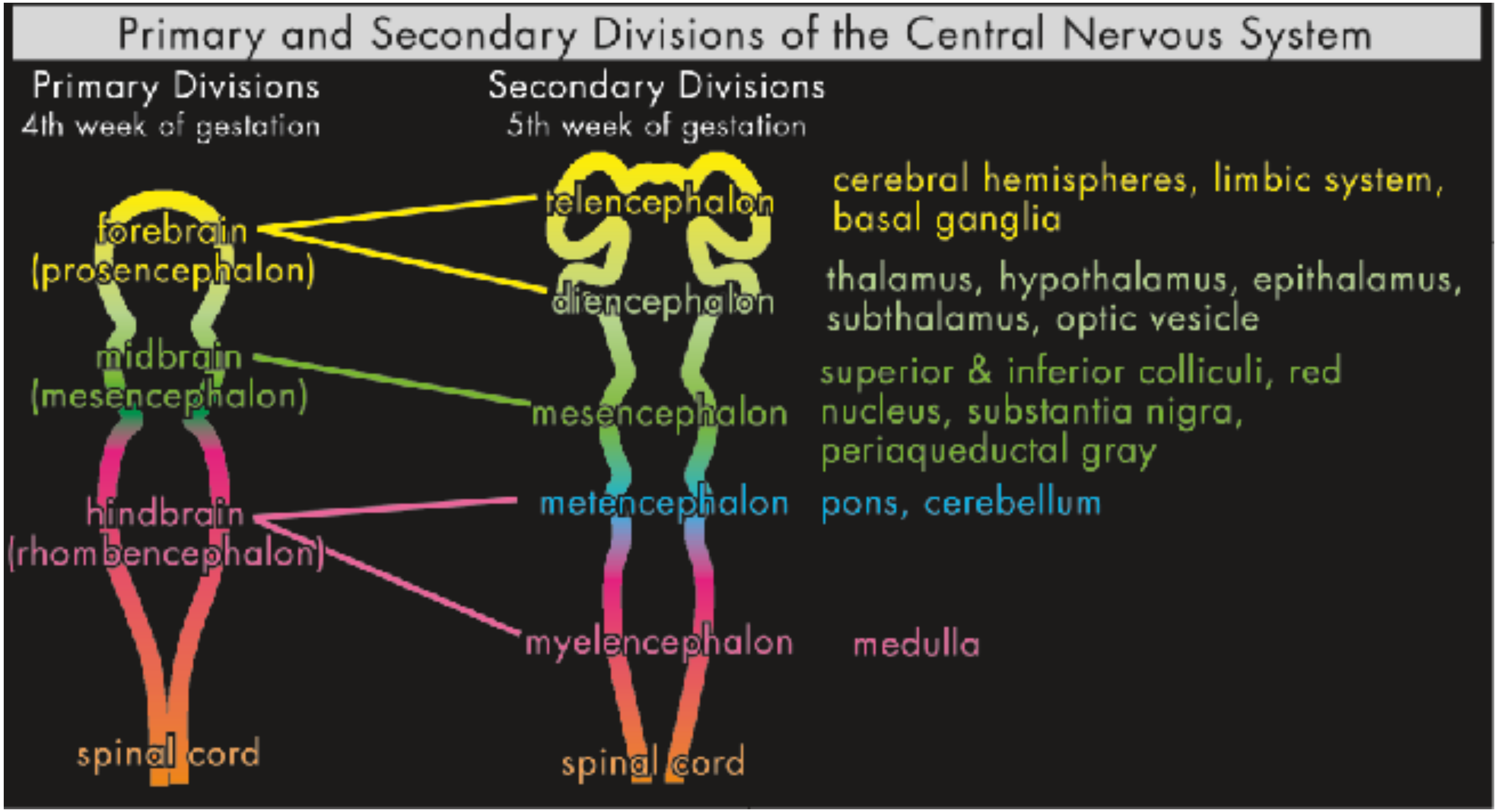
c. Sex differences in cerebral lateralization. Women may have a larger corpus callosum and anterior commissure and appear to have better interhemispheric communication than men. Men may have better-developed right hemispheres and appear to be more adept at spatial tasks than women.

B. The **PNS** contains all **sensory, motor**, and **autonomic** fibers outside of the CNS, including the **spinal nerves, cranial nerves**, and **peripheral ganglia**.

1. ThePNS carries **sensory** information to the CNS and **motor** information away from the CNS.

2. **The autonomic nervous system, which consists of sympathetic and parasympathetic divisions, innervates the internal organs.**

3. **The autonomic nervous system coordinates emotions with visceral responses such as heart rate, blood pressure, and peptic acid secretion.**



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The Forebrain
Telencephalon

1. Cerebrum, covered by the cerebral cortex

2. Limbic system

3. Basal ganglia

The Cerebrum & the Cerebral cortex

Two cerebral hemispheres

The outer 2 - 5 mm of the cerebral hemispheres is called the cerebral cortex. This is the famous “grey matter”

>> Glia, cell bodies, dendrite, and interconnecting axons of neurons

>> The cerebral hemisphere can be divided into four areas

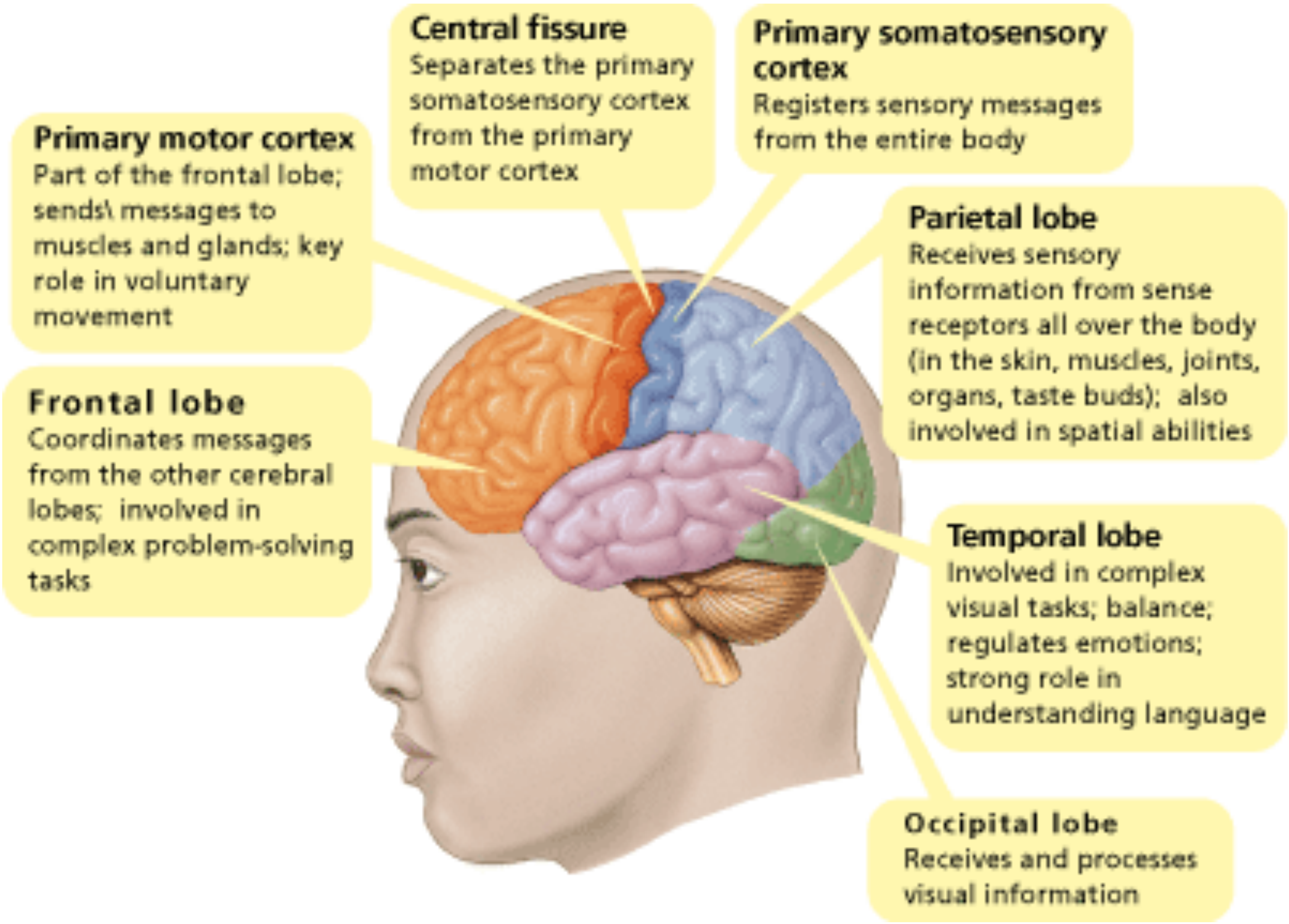
Cerebral cortex

Frontal Lobe Primary motor cortex, Motor association cortex

Parietal Lobe Primary somatosensory cortex, somatosensory association cortex

Occipital Lobe Primary visual cortex, Visual association cortex

Temporal Lobe Primary auditory cortex, Auditory association cortex



Central fissure
Separates the primary somatosensory cortex from the primary motor cortex
Primary somatosensory cortex
Registers sensory messages from the entire body
Primary motor cortex
Part of the frontal lobe; sends\ messages to muscles and glands; key role in voluntary movement
Parietal lobe
Receives sensory information from sense receptors all over the body (in the skin, muscles, joints, organs, taste buds); also involved in spatial abilities
Frontal lobe
Coordinates messages from the other cerebral lobes; involved in complex problem-solving tasks
Temporal lobe
Involved in complex visual tasks; balance; regulates emotions; strong role in understanding language
Occipital lobe
Receives and processes visual information

Frontal Lobe

On the lateral surface of the human brain, the central sulcus separates the frontal lobe from the parietal lobe. The lateral sulcus separates the frontal lobe from the temporal lobe.

Functions :

- The frontal lobe plays a large role in voluntary movement. It houses the primary motor cortex which regulates activities like walking.
- The function of the frontal lobe involves the ability to project future consequences resulting from current actions, the choice between good and bad actions << Judgement
- Speech and language production
- Forming memories
- Understanding and reacting to the feelings of others: The frontal lobe is vital for empathy.
- Forming personality
- Reward-seeking behavior and motivation
- Managing attention, including selective attention
- Executive functioning

Neuropsychiatric Effects of Frontal lobe Lesions on Behavior

Mood changes (e.g., depression with dominant lesions, mood elevation with nondominant lesions) Difficulties with motivation, concentration, attention, orientation, and problem solving (dorsolateral convexity lesions)

Difficulties with judgment, inhibitions, emotions, personality changes (orbitofrontal cortex lesions) Inability to speak fluently (i.e., Broca aphasia [dominant lesions])

parietal lobe

The parietal lobe is defined by three anatomical boundaries: The central sulcus separates the parietal lobe from the frontal lobe; the parieto-occipital sulcus separates the parietal and occipital lobes; the lateral sulcus (sylvian fissure) is the most lateral boundary, separating it from the temporal lobe .The parietal lobe's two hemispheres are divided by the medial longitudinal fissure.

Functions:

- The parietal lobe is vital for sensory perception and integration, including the management of taste, hearing, sight, touch, and smell.
- Integrating sensory information from most regions of the body.
- Visuospatial navigation and reasoning
- Assessing numerical relationships, including the number of objects you see.

Neuropsychiatric Effects of parietal lobe Lesions on Behavior

Impaired processing of visual–spatial information (e.g., cannot copy a simple line drawing or neglects the numbers on the left side when drawing a clock face [right-sided lesions])

Impaired processing of verbal information (e.g., cannot tell left from right, do simple math, name fingers, or write [Gerstmann's syndrome; dominant lesions])

Gerstmann's syndrome includes agraphia, calculation difficulties (acalculia), right-left disorientation, and finger agnosia.It has been attributed to lesions of the dominant parietal lobe.

Temporal Lobe

The temporal lobe is involved in processing sensory input into derived meanings for the appropriate retention of visual memory, language comprehension, and emotion association.

The temporal lobe holds the primary auditory cortex, which is important for the processing of semantics in both speech and vision in humans. Wernicke's area, which spans the region between temporal and parietal lobes, plays a key role (in tandem with Broca's area in the frontal lobe) in speech comprehension.
The temporal lobe is involved in primary auditory perception, such as hearing

The temporal lobe communicates with the hippocampus and plays a key role in the formation of explicit long-term memory modulated by the amygdala.

Neuropsychiatric Effects of temporal lobe Lesions on Behavior

Impaired memory
Psychomotor seizures
Inability to understand language (i.e., Wernicke aphasia [dominant lesions])

Occipital Lobe

The two occipital lobes are the smallest of four paired lobes in the human cerebral cortex. Located in the rearmost portion of the skull.
The primary function of the occipital lobe is controlling vision and visual processing.
Damage to the primary visual areas of the occipital lobe can leave a person with partial or complete blindness

Neuropsychiatric Effects of occipital lobe Lesions on Behavior

Visual hallucinations and illusions

Color perception may be ablated

Antons syndrome is a failure to acknowledge blindness, seen with bilateral occipital lobe lesion

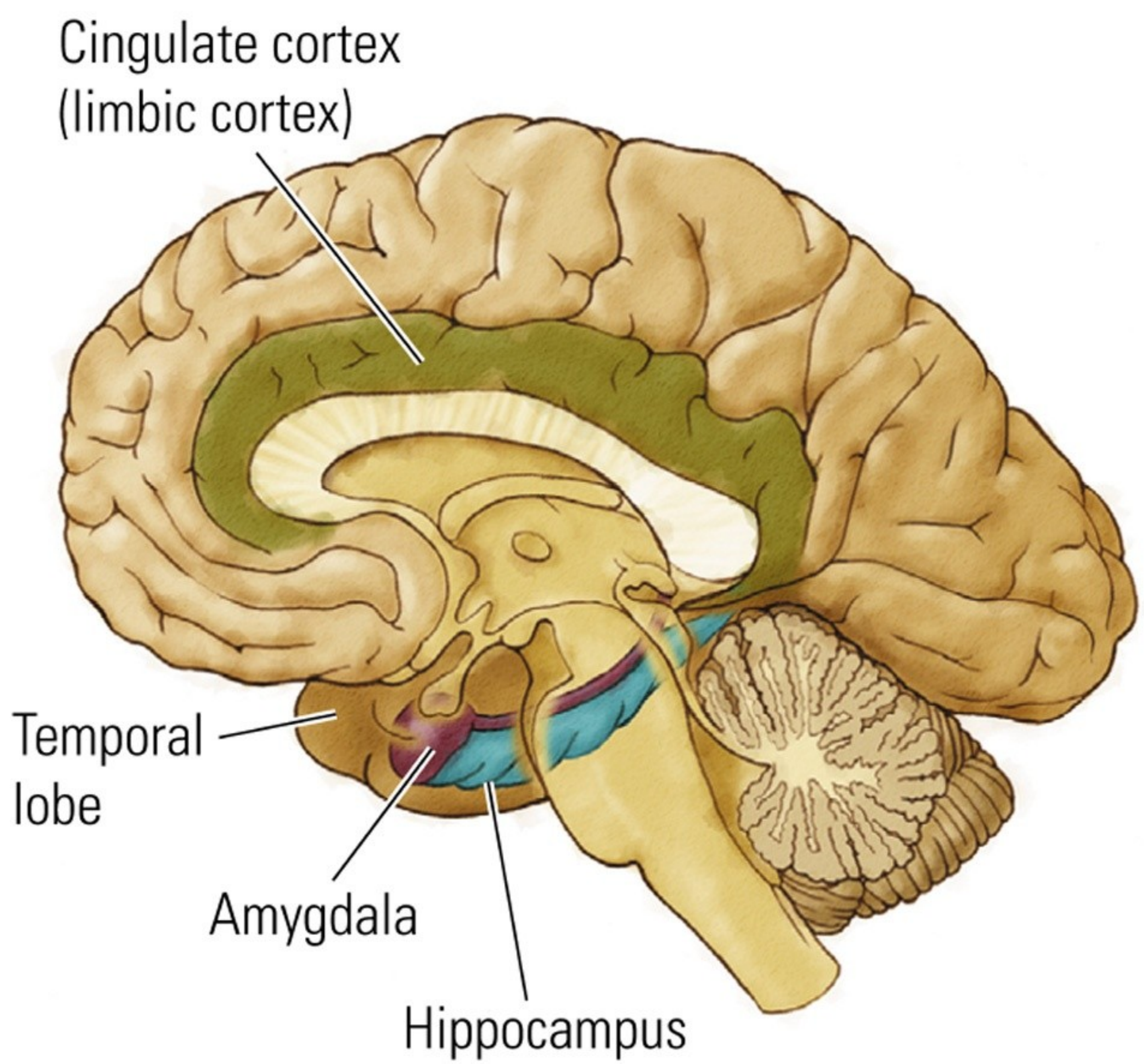
Blindness

The Forebrain
Telencephalon

1. Cerebrum, covered by the cerebral cortex

2. Limbic system

3. Basal ganglia


Cingulate cortex
(limbic cortex)
Temporal
lobe
Amygdala
Hippocampus

The Forebrain
Telencephalon

1. Cerebrum, covered by the cerebral cortex

2. Limbic system

3. Basal ganglia

Basal Ganglia

The basal ganglia is predominantly composed of cell bodies (grey matter)deep within the forebrain .

The basal ganglia, a subcortical group of gray matter nuclei, appear to mediate postural tone. The four functionally distinct ganglia are the striatum, the pallidum, the substantia nigra, and the subthalamic nucleus. Collectively known as the corpus striatum , the caudate and putamen harbor components of both motor and association systems. **The caudate nucleus** plays an important role in the modulation of motor acts. Anatomical and functional neuroimaging studies have correlated decreased activation of the caudate with obsessive-compulsive behavior.

The caudate, in particular, shrinks dramatically in Huntington's disease. This disorder is characterized by rigidity, on which is gradually superimposed choreiform, or"dancing; 'movements. Psychosis may be a prominent feature of Huntington's disease, and suicide is not uncommon.

Basal Ganglia

The **globus pallidus** may be severely damaged in Wilson's disease and in carbon monoxide poisoning, which are characterized by dystonic posturing and flapping movements of the arms and legs.

Finally, lesions in the **subthalamic nucleus** yield ballistic movements, sudden limb jerks of such velocity that they are compared to projectile movement.

The **substantia nigra** degenerates in Parkinson's disease

Diencephalon

The Thalamus:

is the large mass of gray matter in the dorsal part of the diencephalon of the brain with several functions such as relaying of sensory signals, including motor signals, to the cerebral cortex, and the regulation of consciousness, sleep, and alertness.

Has two lobes

Most neural input to the cerebral cortex is received from the thalamus via projection axons

The Hypothalamus:

Is located below the thalamus and is part of limbic system.

The primary link between the endocrine and nervous systems

The hypothalamus is responsible for the regulation of certain metabolic processes and other activities of the autonomic nervous system. It synthesizes and secretes certain neurohormones, and these in turn stimulate or inhibit the secretion of pituitary hormones The hypothalamus controls body temperature, hunger, important aspects of parenting and attachment behaviours, thirst, fatigue, sleep, and circadian rhythms.

Midbrain
Mesencephalon

The midbrain comprises the tectum, tegmentum, the cerebral aqueduct, and the cerebral peduncles, as well as several nuclei and fasciculi

The mesencephalon is considered part of the brainstem. Its substantia nigra is closely associated with motor system pathways of the basal ganglia.
Dopamine produced in the substantia nigra and ventral tegmental area plays a role in excitation, motivation and habituation of species from humans to the most elementary animals such as insects

Tectum:
Inferior colliculi - part of the auditory system

Superior colliculi - part of the visual system; involved in visual reflexes and reaction to moving objects

Tegmentum: Structures included in the midbrain tegmentum include the red nucleus, reticular formation, Periaqueductal gray matter and substantia nigra

Reticular formation - plays role in sleep and arousal, attention, muscle tonus, movement and various vital reflexes

Periaqueductal gray matter - contains neural circuits that control sequences of movements such as fighting and mating. primary control center for descending pain modulation. It has enkephalin-producing cells that suppress pain.

****The degeneration of neuron in the substantia nigra is responsible for Parkinson’s disease ****

Hindbrain
Metencephalon

Cerebellum : The "little brain"

>> Attached to the dorsal surface of the pons by bundles of axons

>> Facilitates standing, walking or performance of coordinated movement, such as playing a musical instrument

>> Receives and integrates visual, auditory, vestibular and somatosensory information about individual muscle movements and modifies the motor outflow by exerting a coordinating and smoothing effect on the movements.

Pons :Contains portion of the reticular formation - important in sleep and arousal

>> Also contains a large nucleus that relays information from the cerebral cortex to the cerebellum

Hindbrain
Myelencephalon

Medulla oblongata

<<Contains portion of the reticular formation - Contains part of the reticular formation

<<As well as nuclei that controls vital function such as regulation of cardiovascular system, respiration, and skeletal muscle tonus

Neurons

The brain is composed of 25 billion nerve cells (neurons) and each is connected to around 1000 others. Thus, at any time, there is an incomprehensible number of electrical impulses (or messages) flashing around a vast array of brain circuits.

- Neuron: A **neuron**, also known as a **nerve cell**, is an electrically excitable cell that receives, processes, and transmits information through electrical and chemical signals. These signals between neurons occur via specialized connections called synapses.

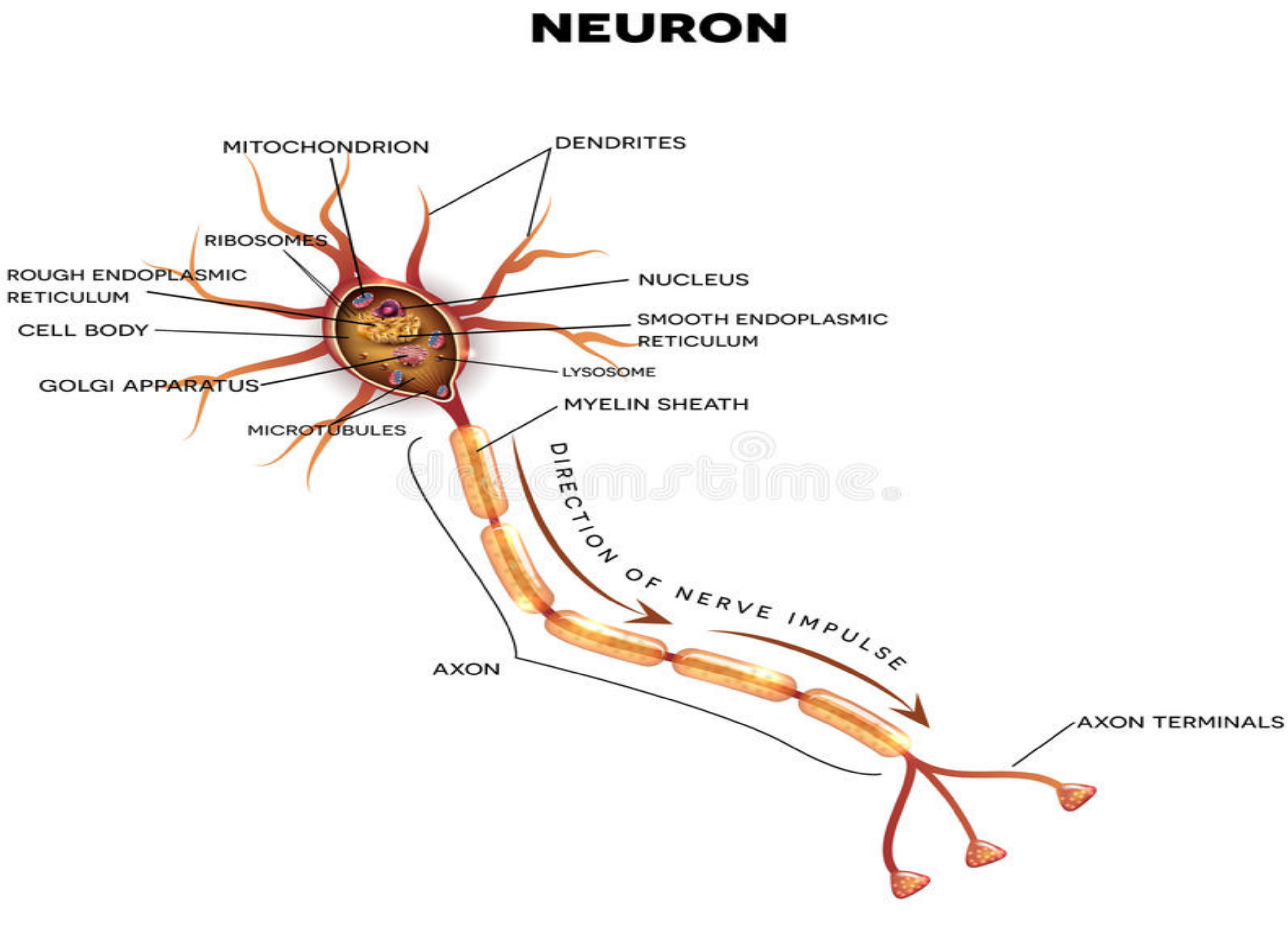
The most common type of neuron is composed of three parts: 1) the cell body, 2) numerous short projections from the cell body called dendrites, and 3) the long thin spaghetti - like projection from the cell body called the axon.

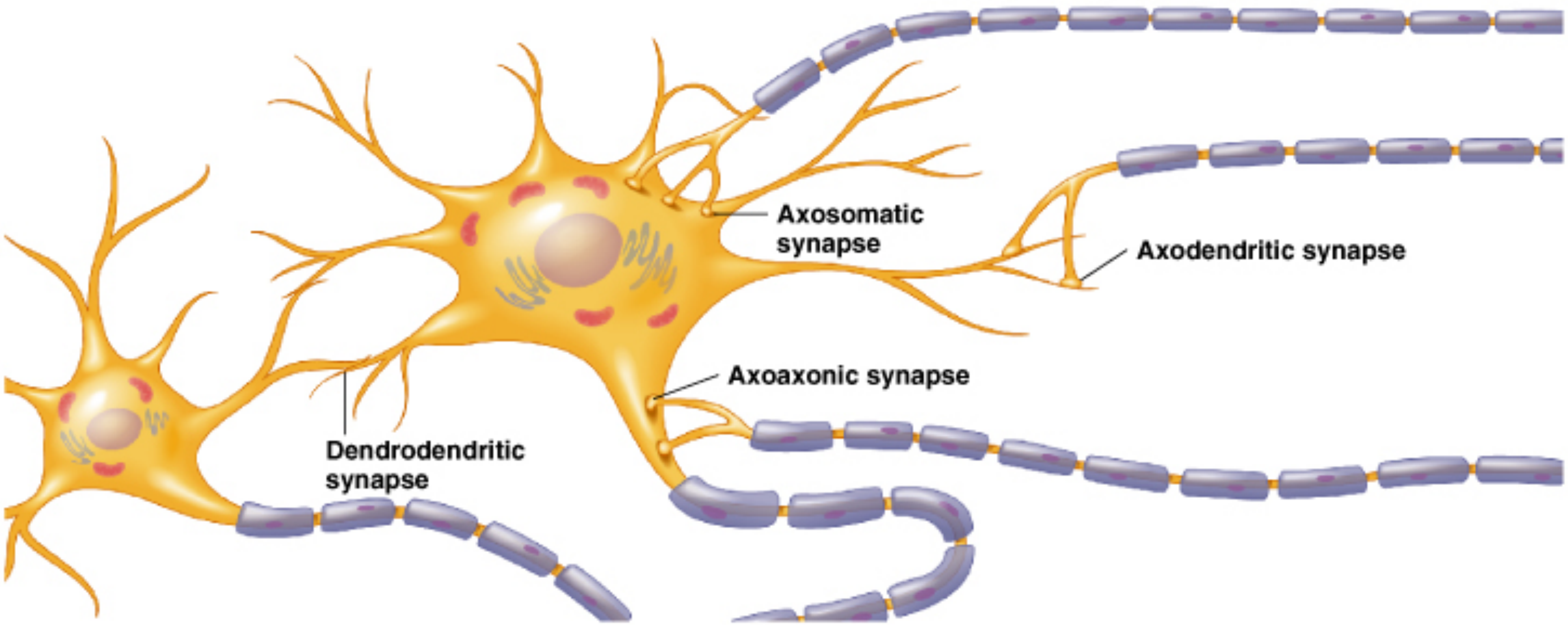
Neurons

The cell body contains the nucleus (which contains the genes) and other essential structures. Most of the materials needed by the neuron are synthesized in the cell body, and transported to distant parts , including the far distant end of the axon.

The dendrites receive nerve impulses and conduct them to the cell body. The axon conducts impulses away from the cell body, toward connections (usually on dendrites) with other neurons. The axon divides into thousands of tiny branches, called synaptic terminals, which form junctions, called synapses, with the dendrites or cell bodies of other neurons

ANATOMY OF NERVE:





(b) Locations of neuron-to-neuron synapses

Transmission of impulses is possible because of the wonderful properties of the membrane enclosing the neuron. In the resting (not actively transmitting) neuron, the material inside the membrane (the cytoplasm) is negatively charged in relation to the material outside the membrane (extracellular fluid). This is the result of the special positioning of charged chemicals (ions). There is a slight excess of negative ions inside the membrane and a slight excess of positive ions outside the membrane.

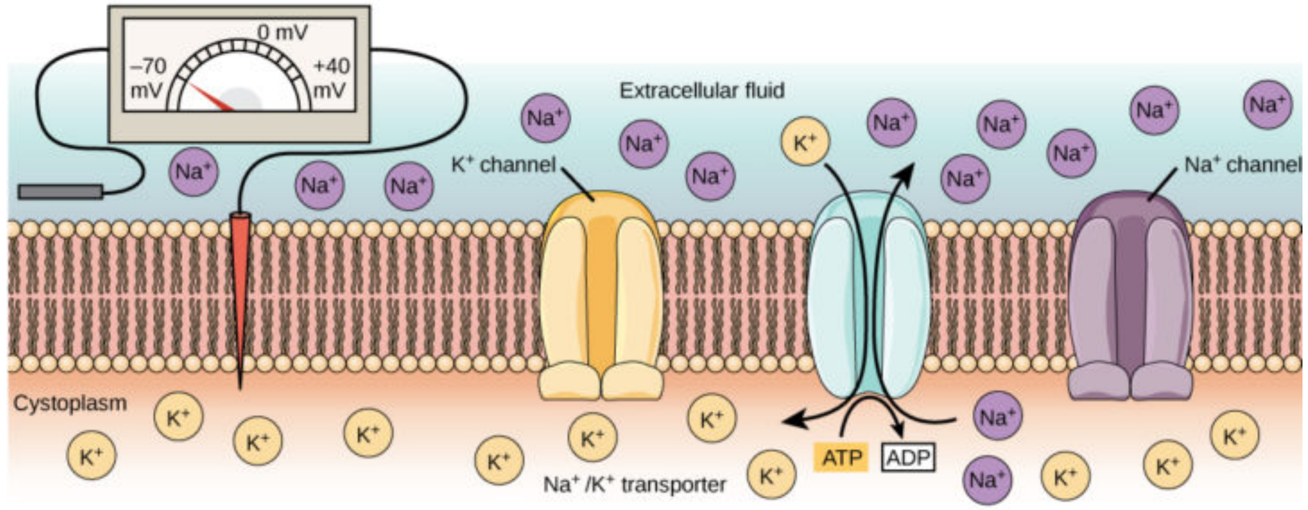
The imbalance of ions is maintained by several factors which work together. Most important are tiny sodium pumps in the cell membrane, which pump sodium ions (positively charged) out of the cell.

When the stimulus applied to the cell membrane is sufficiently strong, the potential difference between the inside and outside of the cell is reduced below a threshold level. This causes local ion channels to open, sodium ions flow into the cell, and there is complete, temporary, loss of charge imbalance across the membrane. These changes cause similar changes in adjacent areas (chain reaction) , and by this mechanism, an electrical impulse progresses along the axon.

If these signals exceed a minimum intensity, called the threshold, they trigger an impulse. The impulse, called the action potential, is a brief electrical charge that travels down to the axon.

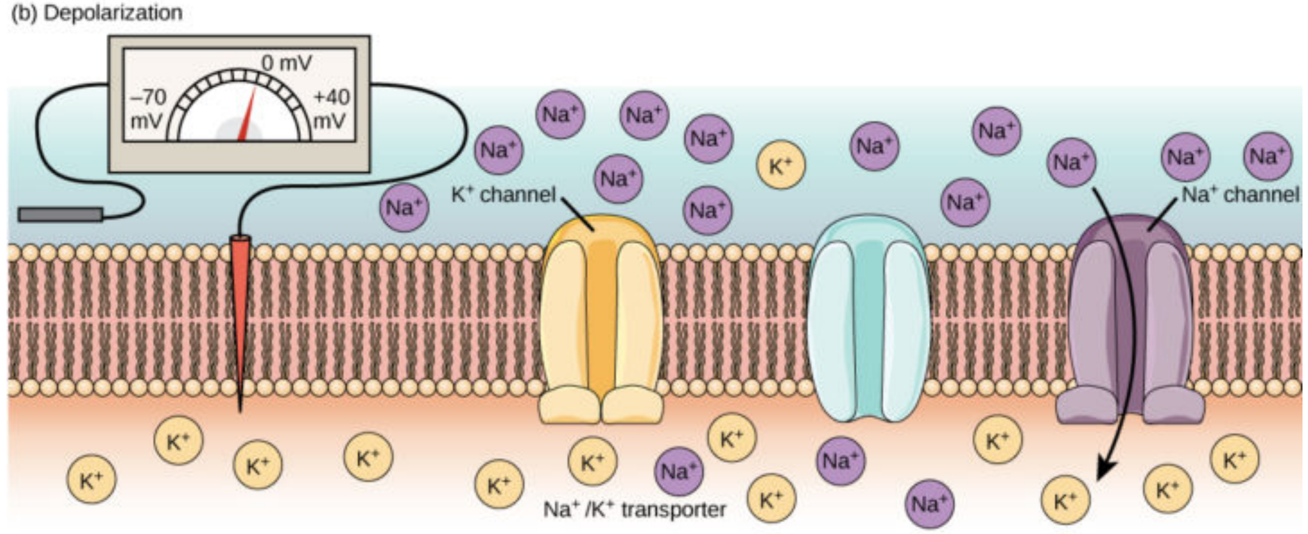
A neuron fires an impulse when it receives signals from sense receptors that are stimulated by pressure, heat or light, or when it is simulated by chemical messages from adjacent neurons

(a) Resting potential



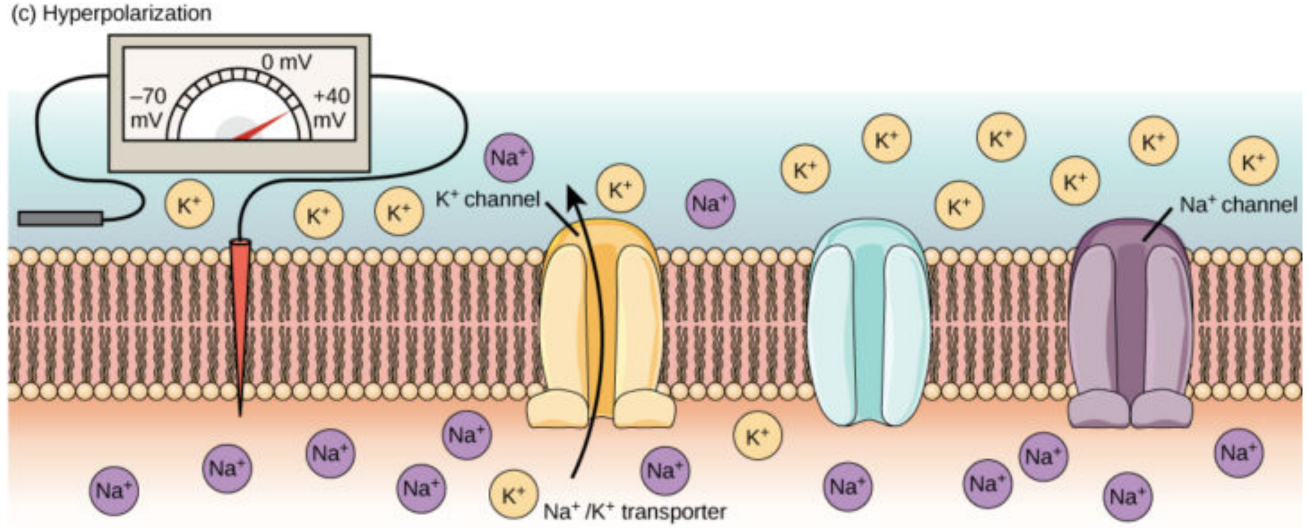
At the resting potential, all voltage-gated Na^+ channels and most voltage-gated K^+ channels are closed. The Na^+/K^+ transporter pumps K^+ ions into the cell and Na^+ ions out.

(b) Depolarization



In response to a depolarization, some Na^+ channels open, allowing Na^+ ions to enter the cell. The membrane starts to depolarize (the charge across the membrane lessens). If the threshold of excitation is reached, all the Na^+ channels open.

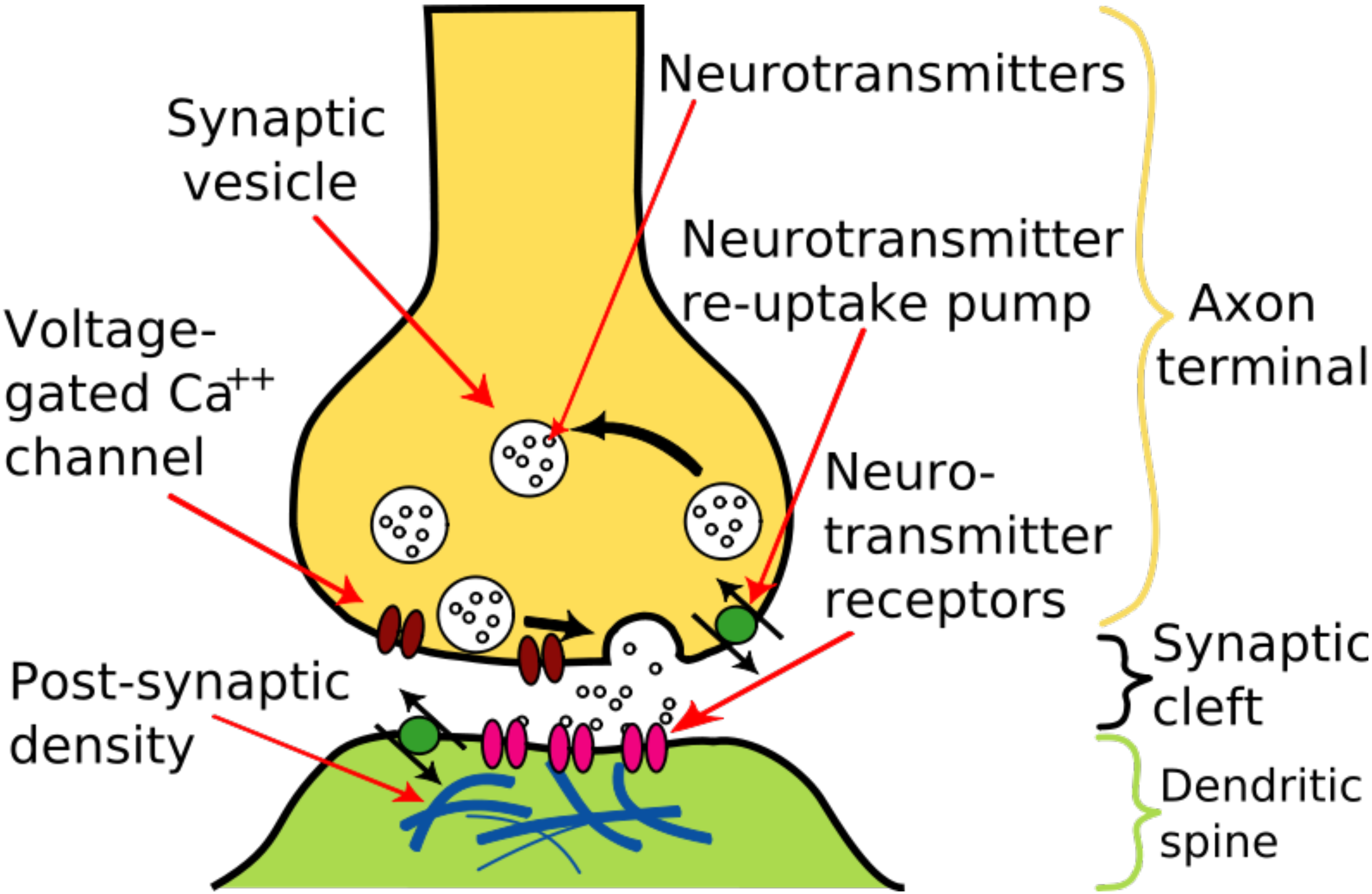
(c) Hyperpolarization



At the peak action potential, Na^+ channels close while K^+ channels open. K^+ leaves the cell, and the membrane eventually becomes hyperpolarized.

The synapse is a critical component of the nervous system, and is the focus of most current drug treatments of mental disorders . This connection is usually between a projection from the end of an axon to the body or dendrites of another cell .

At the synapse there is a tiny gap (called the synaptic gap or cleft) between the end of the transmitting (presynaptic) axon and the dendrite or body of the receiving (postsynaptic) neuron. The electrical pulse stops when it reaches the synaptic gap. For the message to pass across the gap a special chemical (neurotransmitter) is released by the presynaptic neuron (triggered by the arrival of the electrical impulse) , which passes across the gap and fits into a special receptor (like a docking space ship) on the post synaptic neuron. This docking process triggers an electrical impulse, which then travels along the axon of the post synaptic neuron.


Neurotransmitters
Synaptic vesicle
Neurotransmitter re-uptake pump
Axon terminal
Voltage-gated Ca++ channel
Neuro-transmitter receptors
Synaptic cleft
Post-synaptic density
Dendritic spine

Neurotransmitters

There are at least 200 different neurotransmitters in the brain. Those believed to be most important in mental disorders are listed below. Neurons predominantly release a single type neurotransmitters, but recent research indicates that a neuron can release more than one type.

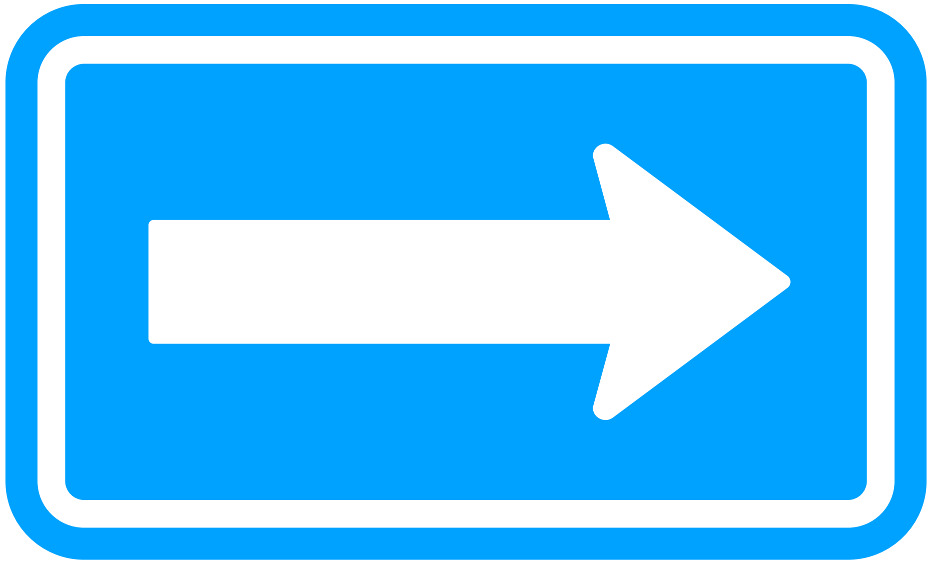
Monoamines: Dopamine, Serotonin, Norepinephrine, Histamine

Amino Acids: Gamma amino butyric acid (GABA), Glutamate

Others: Acetylcholine, Nitric oxide, Adenosine

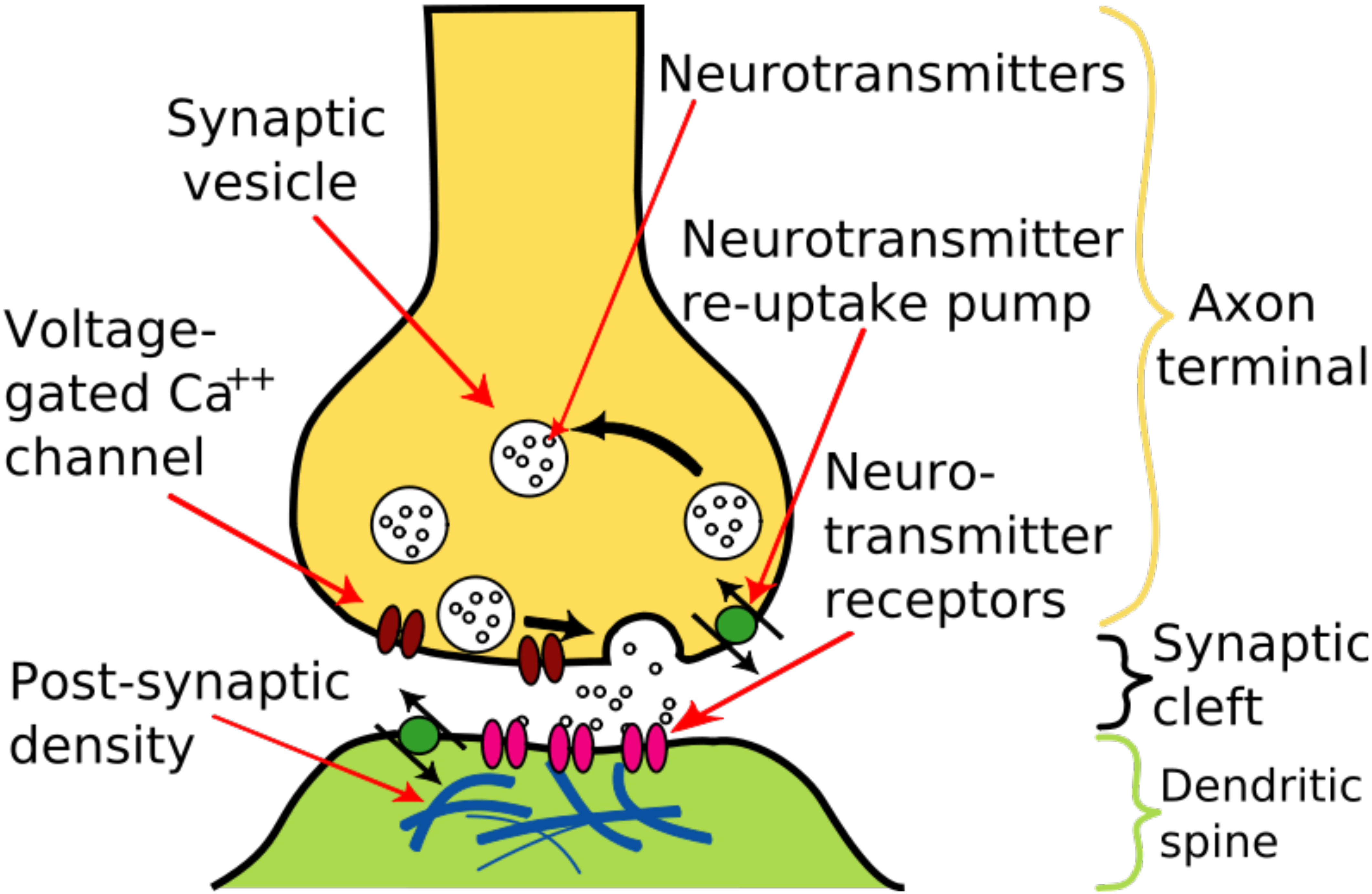
Neurotransmitters may be synthesized in the cell bodies of neurons and transported down the axon to the nerve (axon) terminal, or they may be synthesized locally at the terminal. In either case, they are stored at the terminals in special containers (vesicles).

At the arrival of the electrical impulse a vesicle fuses with the presynaptic membrane , opens and empties neurotransmitter into the synaptic gap. Various events may then transpire .

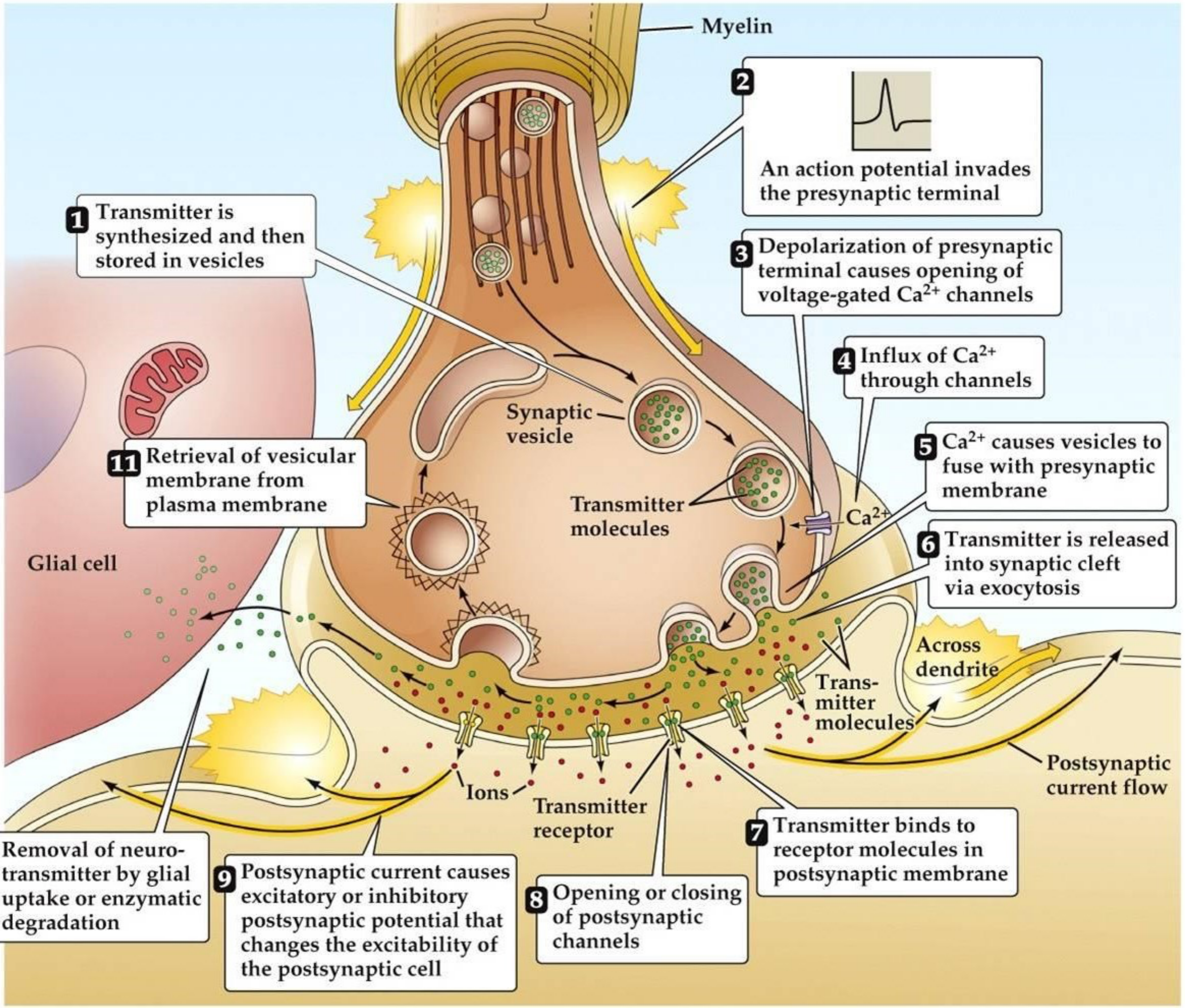


- The neurotransmitter may pass across the gap and fit into a receptor on the postsynaptic membrane and initiate an electrical impulse.
- Second, the neurotransmitter may move through the gap and fit into a receptor on the presynaptic membrane, that is, fit into a receptor on the neuron from which it was released. These receptors are called autoreceptors. When an autoreceptor is activated, it turns off the release of further neurotransmitters. Thus, autoreceptors may act as a break or regulator. This can only happen, of course, when sufficient neurotransmitter is available for some to reach the autoreceptors to press on the brake .
- Third, the neurotransmitter may be destroyed by naturally occurring chemicals (oxidases) which are located in the gap. This is another mode of regulation, which prevents excessive stimulation of the second neuron.
- Fourth, the neurotransmitter may return back into the presynaptic neuron by special reuptake mechanisms and be restored in a vesicle.

There is no order to these events.


Synaptic vesicle
Neurotransmitters
Neurotransmitter re-uptake pump
Voltage-gated Ca++ channel
Neuro-transmitter receptors
Post-synaptic density
Axon terminal
Synaptic cleft
Dendritic spine

In a general sense, current thinking is that most mental disorders have to do with insufficient or excessive release of one or more specific neurotransmitters. Accordingly, medications are developed to perform particular actions. They act on one specific, or sometimes more than one neurotransmitter or receptors. The actions of medications include increasing the release of neurotransmitters, activating postsynaptic (that is, to act like neurotransmitters), blocking postsynaptic (that is, preventing natural neurotransmitters doing their job), and inactivating the reuptake mechanism or inactivating the destructive oxidases (so that more neurotransmitter remains available in the synaptic gap).


Myelin
2 An action potential invades the presynaptic terminal
1 Transmitter is synthesized and then stored in vesicles
3 Depolarization of presynaptic terminal causes opening of voltage-gated Ca^{2+} channels
4 Influx of Ca^{2+} through channels
Synaptic vesicle
5 Ca^{2+} causes vesicles to fuse with presynaptic membrane
11 Retrieval of vesicular membrane from plasma membrane
Transmitter molecules
Ca^{2+}
6 Transmitter is released into synaptic cleft via exocytosis
Glial cell
Across dendrite
Trans-mitter molecules
Postsynaptic current flow
Ions
Transmitter receptor
7 Transmitter binds to receptor molecules in postsynaptic membrane
10 Removal of neuro-transmitter by glial uptake or enzymatic degradation
9 Postsynaptic current causes excitatory or inhibitory postsynaptic potential that changes the excitability of the postsynaptic cell
8 Opening or closing of postsynaptic channels

- Excitatory Neurotransmitters:
- It is the chemical substance which is responsible for the conduction of impulses from presynaptic neurons to post synaptic neurons.

- Inhibitory Neurotransmitters:
- It is the chemical substance which inhibits the conduction of impulses from the presynaptic neuron to the postsynaptic neuron.
- When it is released from the presynaptic axon terminal due to the arrival of action potential, it causes opening of potassium channels in the postsynaptic membrane and efflux of potassium ions.
- This leads to hyperpolarization which is called inhibitory postsynaptic potentials (IPSP).
- When IPSP is developed, the action potential is not generated in the postsynaptic neuron.
- The common inhibitory neurotransmitters is gamma amino butyric acid (GABA)

Amino acid Neurotransmitters

The GABAergic system

Gamma aminobutyric acid (GABA) is the most abundant inhibitory neurotransmitter in the brain. GABA is widely distributed and has a role in modulating dopaminergic, serotonergic and noradrenergic neurons.

GABA is generated in the presynaptic neuron – from glutamate – through the action of glutamic acid decarboxylase (GAD), which need vitamin B6 (pyridoxine) as a cofactor.

Benzodiazepines modify the GABA A receptor, such that inhibition by GABA is more effective. Because the GABAergic system modulates the actions of other neurotransmitters, it will probably become more important in mental disorder management , as our understanding grows and new pharmacological agents become available.

Amino acid Neurotransmitters

The Glutamatergic system

Glutamate is the most abundant excitatory neurotransmitter in the brain. The glutamatergic system contributes to the pathophysiology of neurodegenerative illnesses such as Alzheimer disease and schizophrenia. The mechanism of this association involves the activation of the glutamate receptor **N-Methyl-d-Aspartate(NMDA)**. Such activation results in calcium ions entering the neurons leading to nerve cell degeneration and death through exocytosis.

Memantine, an NMDA receptor antagonist, blocks this influx of calcium and is Indicated for patients with moderate to severe Alzheimer diseases.

Monoamine Neurotransmitters

Dopamine

- **Dopamine:** involved in the pathophysiology of schizophrenia , mood and other psychotic disorders , Parkinson's disease and the rewarding nature of drugs of abuse.

Synthesized from the amino acid tyrosine by the enzyme Tyrosine Hydroxylase

Receptor subtypes: D1-D5

D_2receptor is the most important

Dopamine

Three pathways of known psychiatric importance:

a. **Nigrostriatal pathway** : involved in regulation of muscle tone and movement

This tract degenerates in Parkinson disease.

Blockade(ex. By Antipsychotic drugs) leads to tremors, muscle rigidity, bradykinesia

b. **Mesolimbic-mesocortical pathway** : associated with psychotic symptoms and expression of emotion

hyperactivity of the mesolimbic tracts is associated with the psychotic symptoms of schizophrenia

Hypoactivity of the mesocortical tract is associated with the negative symptoms of schizophrenia

c. **Tuberoinfundibular pathway:**

- Blockade leads to increases in prolactin(leading to breast enlargement ,galactorrhea, amenorrhea , and sexual dysfunction

Serotonin

Serotonin:

The transmitter of a discrete group of neurons that have cell bodies located in the raphe nuclei of the brain stem .

The amino acid Tryptophan is converted to serotonin by the enzyme tryptophan hydroxylase

Changes in the activity of serotonin neurons are related to the actions of psychedelic drugs.

Involved in the therapeutic mechanism of action of antidepressant treatments (most are 5-HT re-uptake inhibitors; a few new ones are 5-HT agonists)

Has inhibitory influence; linked to impulse control

Low5-HT=low impulse control , depression and poor sleep

Very high levels are associated with psychotic symptoms

Has role in regulation of mood, sleep, sexual activity, aggression, anxiety, motor activity, cognitive function, appetite, circadian rhythms, neuroendocrine function, and body temperature.

Norepinephrine

- **Norepinephrine:** Transmitter of the sympathetic nerves of the autonomic nervous system, which mediate emergency response

a. Acceleration of the heart

b. Dilatation of the bronchi

c. Elevation of blood pressure

- Implicated in altering attention, perception, and mood

- Key pathway:locus ceruleus in upper pons

Norepinephrine

Implicated in monoamine hypothesis of affective disorders:

a. Depletion of NE leads to depression

b. Excess of NE (and serotonin) leads to mania

c. Based on two observations:

1. Reserpine depletes NE and causes depression.
2. Antidepressant drugs block NE re-uptake, thus increasing the amount of NE available postsynaptically.

Receptors:

a. Alpha- I: sympathetic (vasoconstriction) antagonism

- Sedation
- Orthostatic hypotension
- Priapism

b. Alpha-2: on cell bodies of presynaptic neurons, inhibit NE release , Presynaptic receptors provide negative feedback on the release of serotonin and norepinephrine

- Agonists – decreases serotonin and norepinephrine release
  - Clonidine – sympatholytic action; helpful in opiate withdrawal
- Antagonists – increases serotonin and norepinephrine release

c. Beta-1:excitatory for heart, lungs, brain

d. Beta-2: excitatory for vasodilatation and bronchodilatation

Acetylcholine

Acetylcholine (ACh):

Neurotransmitter at nerve-muscle connections for all voluntary muscles of the body.

Also many of the involuntary (autonomic) nervous system synapses .

Synthesized from choline and acetyl coenzyme A using the enzyme choline acetyltransferase.

The **nucleus basalis of Meynert** is a brain area involved in the production of Ach

Acetylcholinesterase(AchE) breaks Ach to choline and acetate.

Blocking the AchE with drugs such as Donepezil, Rivastigmine and galantine may delay the progression of Alzheimer disease but cannot reverse the function already lost.

Cholinergic neurons concentrated in the RAS and basal forerbrain .

Significant role in Alzheimer disease ; dementia in general associated with decreased ACh concentrations in amygdala, hippocampus, and temporal neocortex .

<<< Muscarinic and nicotinic receptors

Blockade of the muscarinic receptors results in the antichoinergic adverse effects.

Histamine

- Histamine : Blockade of histamine H_1 receptor by drugs such as antipsychotics or tricyclic antidepressants leads to sedation, allergy relief, hypotension, and weight gain

Psychiatric Conditions and Associated Neurotransmitter Activity

Depression	Norepinephrine (↓), serotonin (↓), dopamine (↓)
Mania	Dopamine (↑), serotonin (↑), g-aminobutyric acid (GABA) (↓)
Schizophrenia	Dopamine (↑), serotonin (↑), glutamate (↑or ↓)
Anxiety	GABA (↓), serotonin (↓), norepinephrine (↑)
Alzheimer disease	Acetylcholine (↓), glutamate (↑)

Amino Acids

Group	Name	Site of secrition	Action
Amino Acid	GABA	Cerebral cortex, cerebellum, basal ganglia, spinal cord and retina	Inhibitory
Amino Acid	Glycine	Forebrain, brainstem, spinal cord and retina	Inhibitory
Amino Acid	Glutamate	Cerebral cortex, brainstem and cerebellum	Excitatory
Amino Acid	Aspartate	Cerebellum, spinal cord and retina	Excitatory

Brain Function: Behavioral State

TABLE 9-3 The Diffuse Modulatory Systems

SYSTEM (NEUROMODULATOR)	SITE WHERE NEURONS ORIGINATE	STRUCTURES THAT NEURONS INNERVATE	FUNCTIONS MODULATED BY THE SYSTEM
Noradrenergic (norepinephrine)	Locus coeruleus of the pons	Cerebral cortex, thalamus, hypothalamus, olfactory bulb, cerebellum, midbrain, spinal cord	Attention, arousal, sleep-wake cycles, learning, memory, anxiety, pain, and mood
Serotonergic (serotonin)	Raphe nuclei along brain stem midline	Lower nuclei project to spinal cord	Pain, locomotion
		Upper nuclei project to most of brain	Sleep-wake cycle; mood and emotional behaviors, such as aggression and depression
Dopaminergic (dopamine)	Substantia nigra in midbrain	Cortex	Motor control
	Ventral tegumentum in midbrain	Cortex and parts of limbic system	"Reward" centers linked to addictive behaviors
Cholinergic (acetylcholine)	Base of cerebrum; pons and midbrain	Cerebrum, hippocampus, thalamus	Sleep-wake cycles, arousal, learning, memory, sensory information passing through thalamus

Thank You