

Introduction to Neurophysiology 2

Synapses

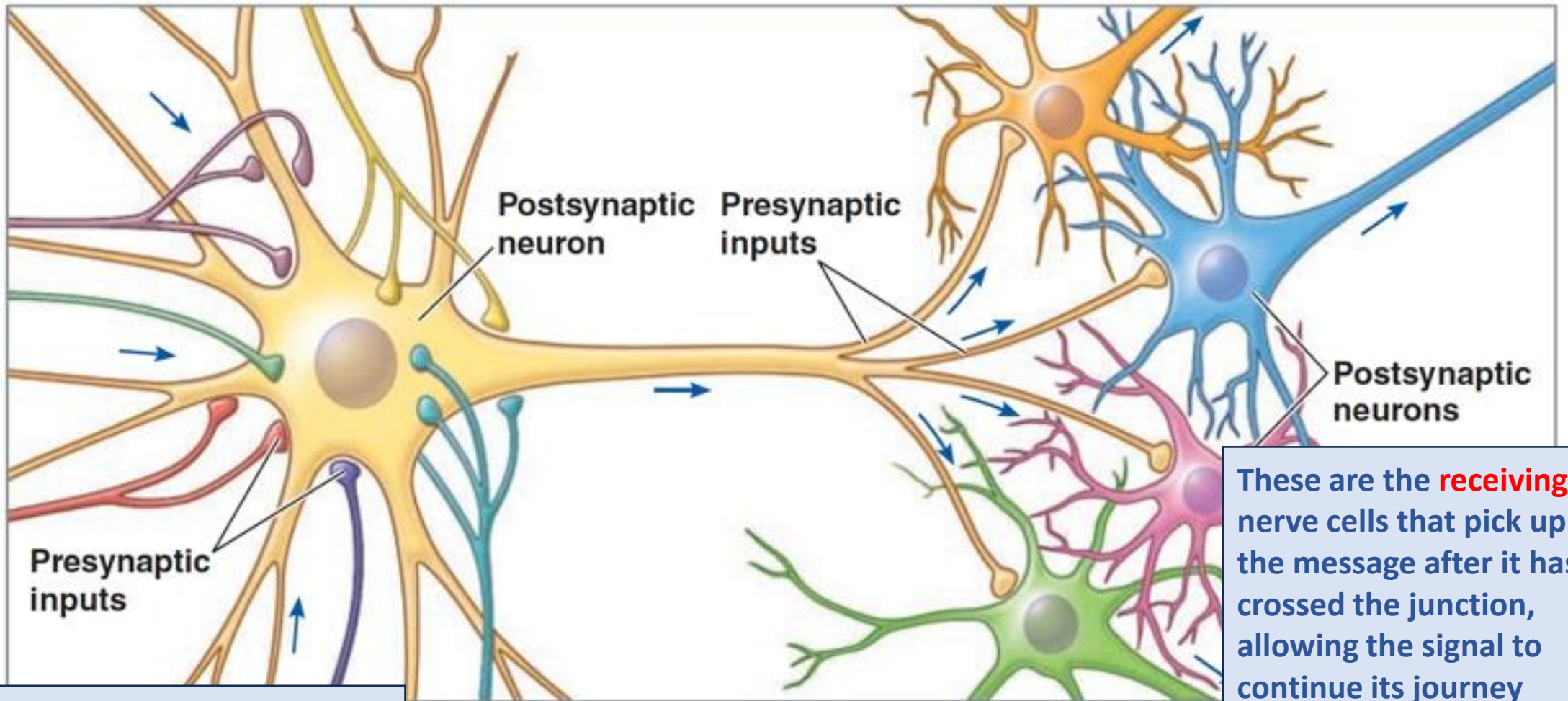
A synapse is the specific junction where **communication** occurs between two neurons, or between a neuron and an effector cell, such as a muscle or glandular cell.

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These are the **incoming** nerve endings from preceding cells that deliver signals (nerve impulses) into the communication junction

These are the **receiving** nerve cells that pick up the message after it has crossed the junction, allowing the signal to continue its journey

Synapses

- **The synapse is a region where communication occurs between two neurons or between a neuron and an effector cell (muscle cell or glandular cell).**

Question: Which of the following physiological interactions strictly represents communication across a synapse?

- **A)** Action potential propagation between Nodes of Ranvier on a single axon.
- **B)** A motor neuron stimulating a glandular cell to secrete.
- **C)** A circulating hormone activating a distant neuronal receptor.
- **D)** Ion exchange through gap junctions between two adjacent epithelial cells.
- **E)** Oxygen transfer from an erythrocyte to a skeletal muscle fiber.

By definition, a synapse must be a communication junction between either two neurons, or a neuron and an effector cell (specifically a muscle or glandular cell). Choice B directly applies this concept, while the other choices describe intracellular conduction (A), endocrine signaling (C), non-neural cellular junctions (D), or gas exchange (E).



Synaptic functions of neurons

Information is transmitted in the nervous system mainly in the form of nerve action potentials, called nerve impulses, through a succession of neurons, one after another.

However, this impulse may be blocked, changed into repetitive impulses, or integrated with other impulses.

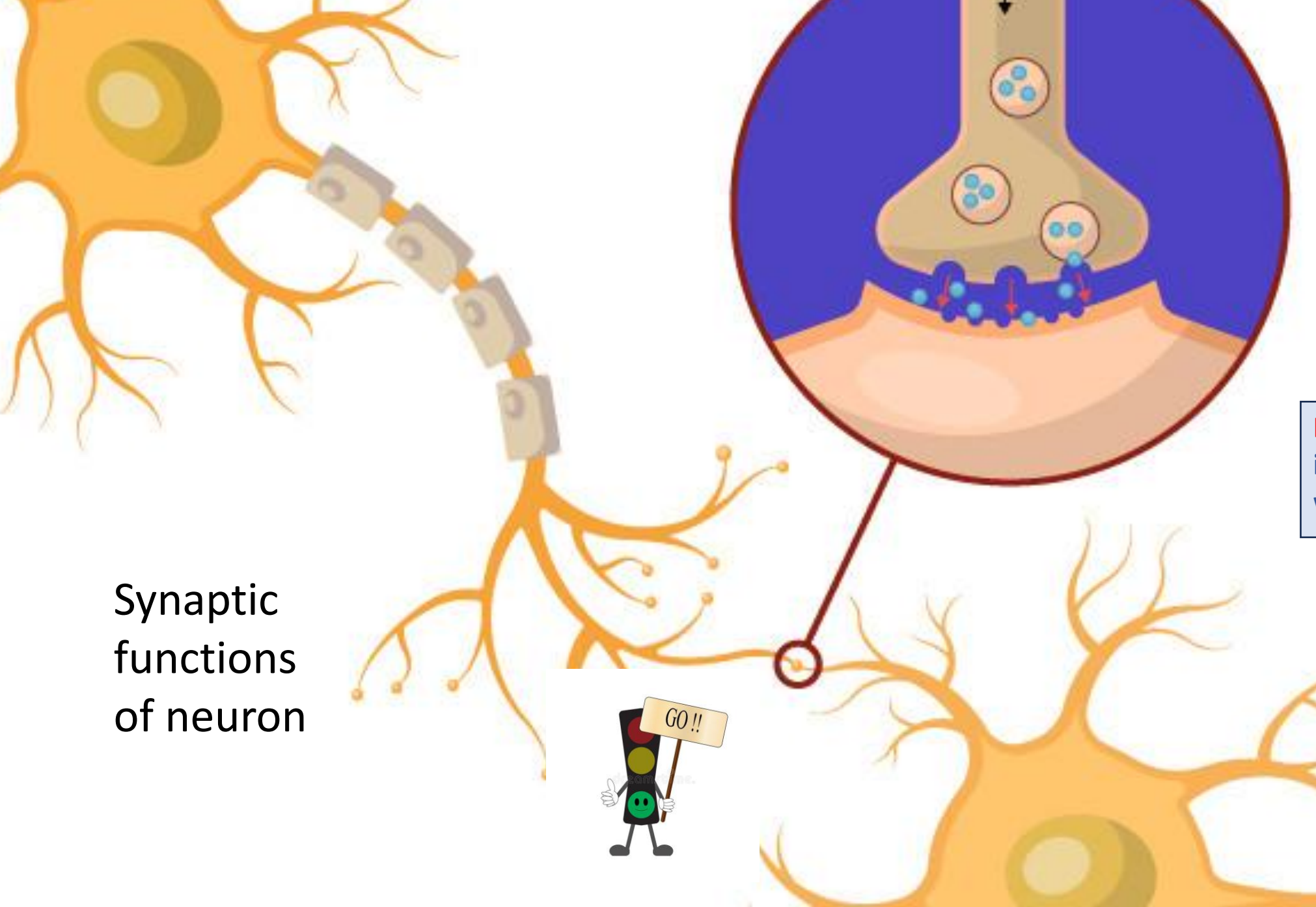
A synapse doesn't just blindly pass the message along; it acts like a **processing gate**. At this gate, the incoming signal can be:

Blocked: The message is stopped entirely

Changed: A single message is multiplied into a rapid-fire series of signals

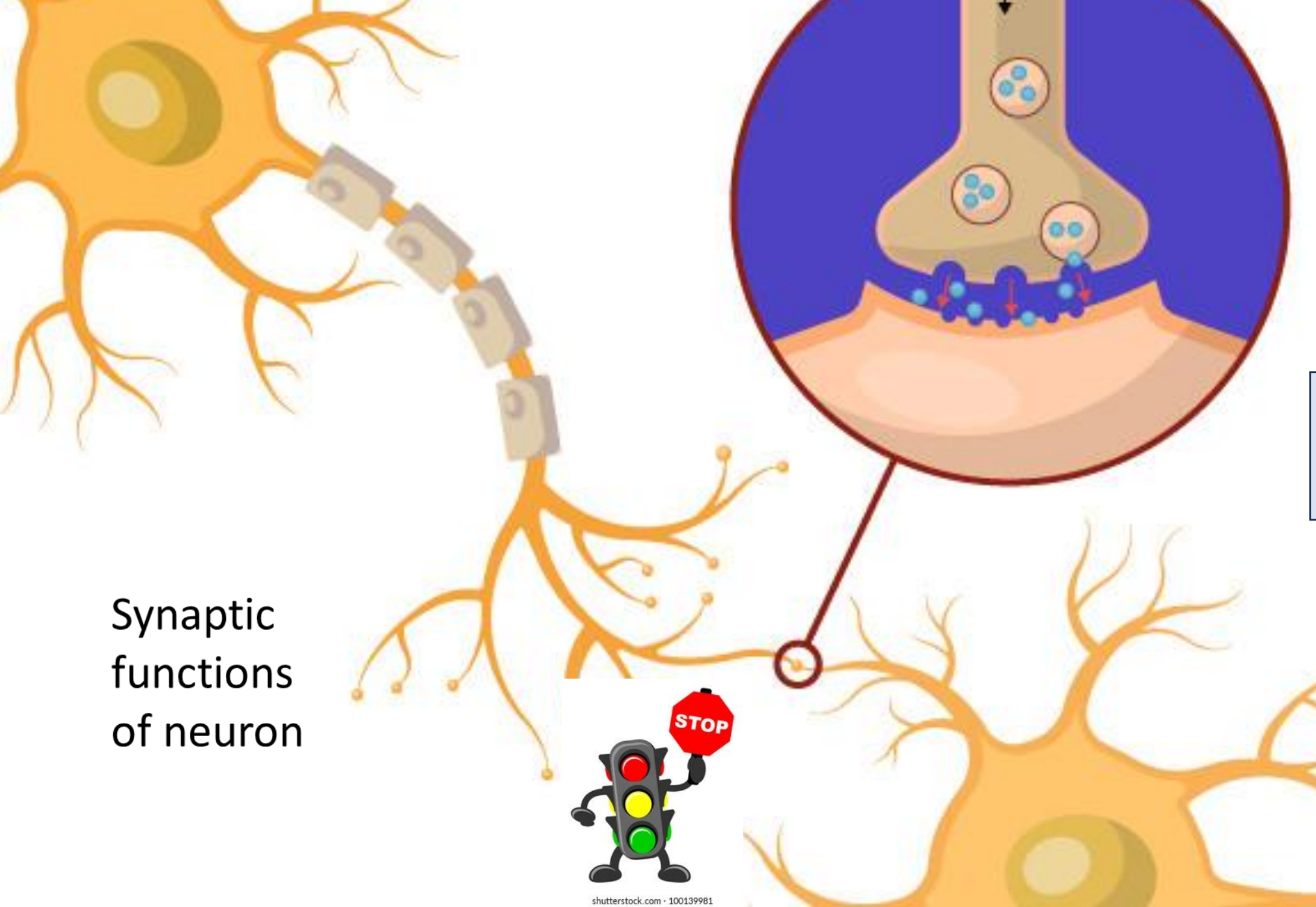
Integrated: The message is combined or merged with other incoming signals from different neurons

These functions are called **synaptic functions of neurons**.



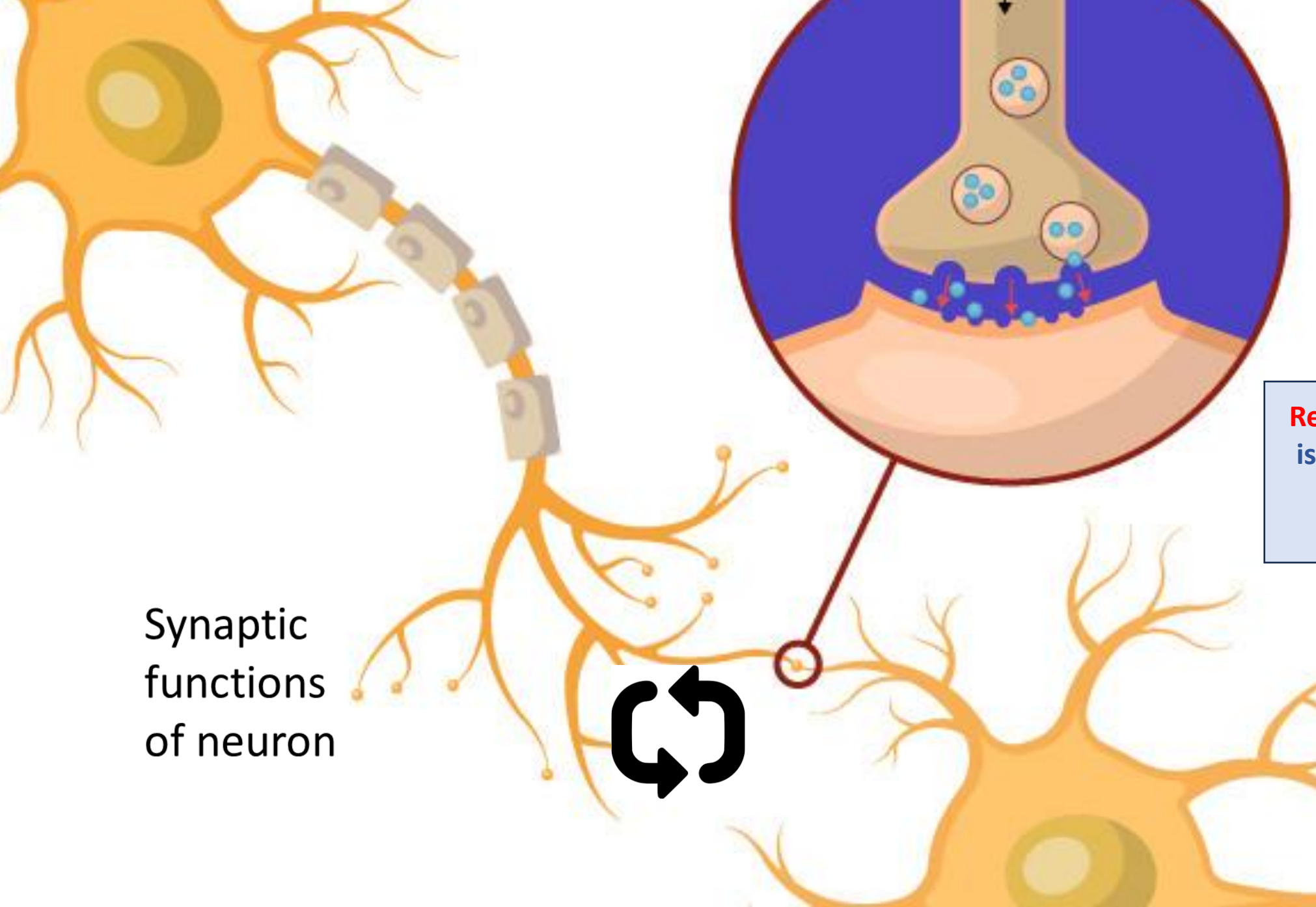
Synaptic
functions
of neuron

Integrated: The
impulse is combined
with other impulses



Synaptic
functions
of neuron

Blocked: The impulse
is stopped from
continuing further



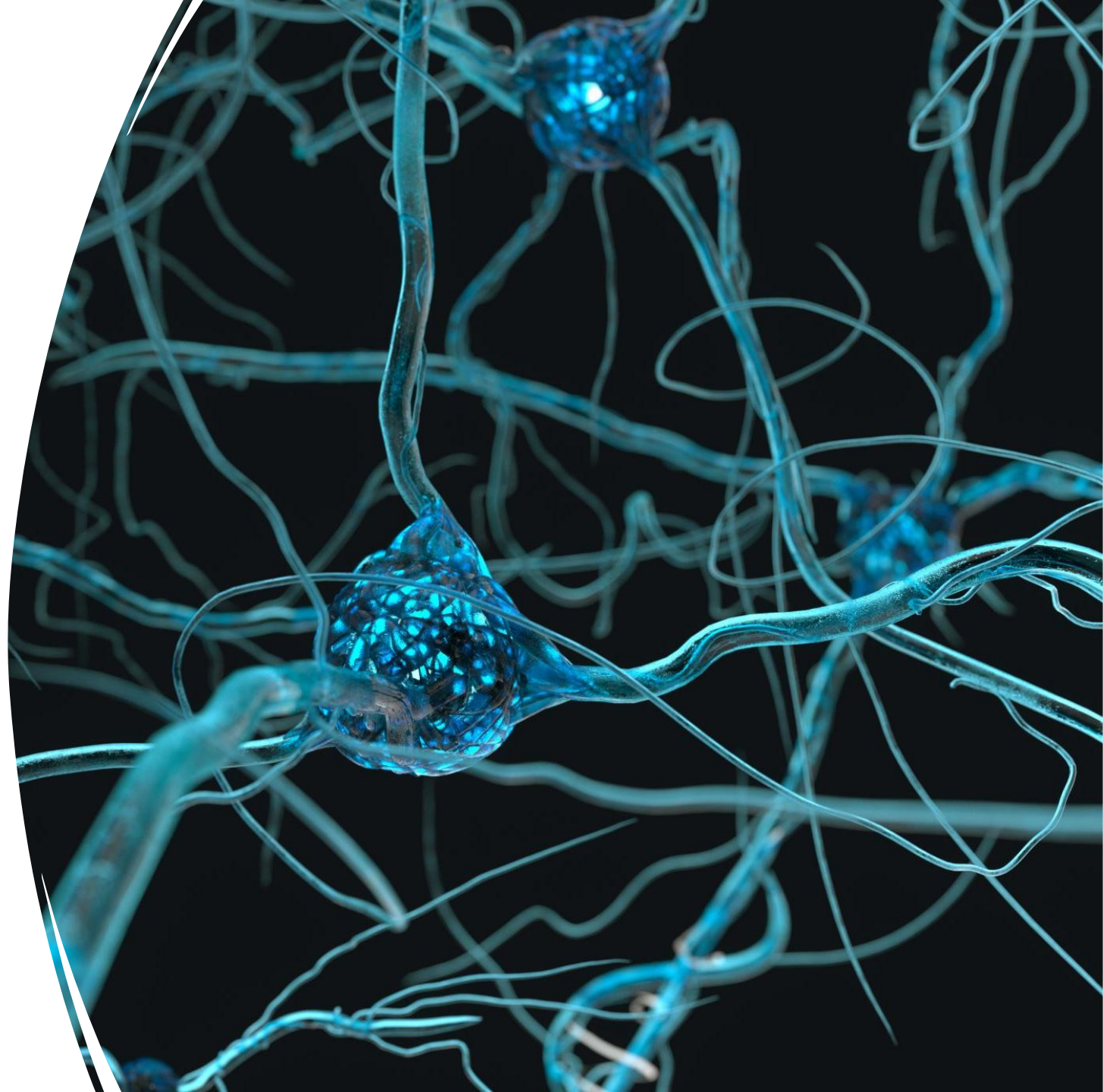
Synaptic
functions
of neuron



Repetitive: The impulse
is changed into a rapid
series of repetitive
impulses

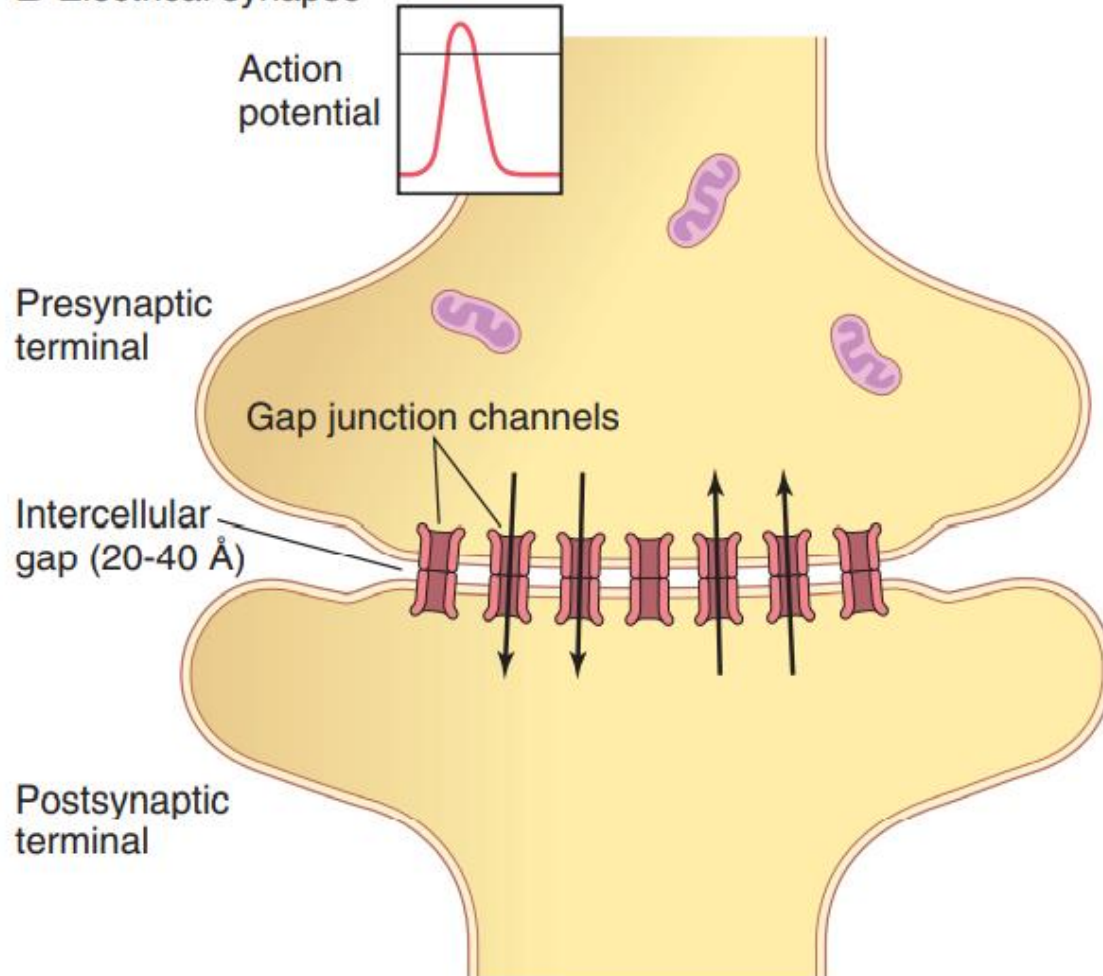
Types of Synapses

- **Chemical synapses.**
- **Electrical synapses.**



The incoming electrical nerve impulse arriving at the presynaptic terminal. It **depolarizes** the membrane, forcing the Calcium (Ca^{++}) channels to open so neurotransmitters can be released

B Electrical synapse



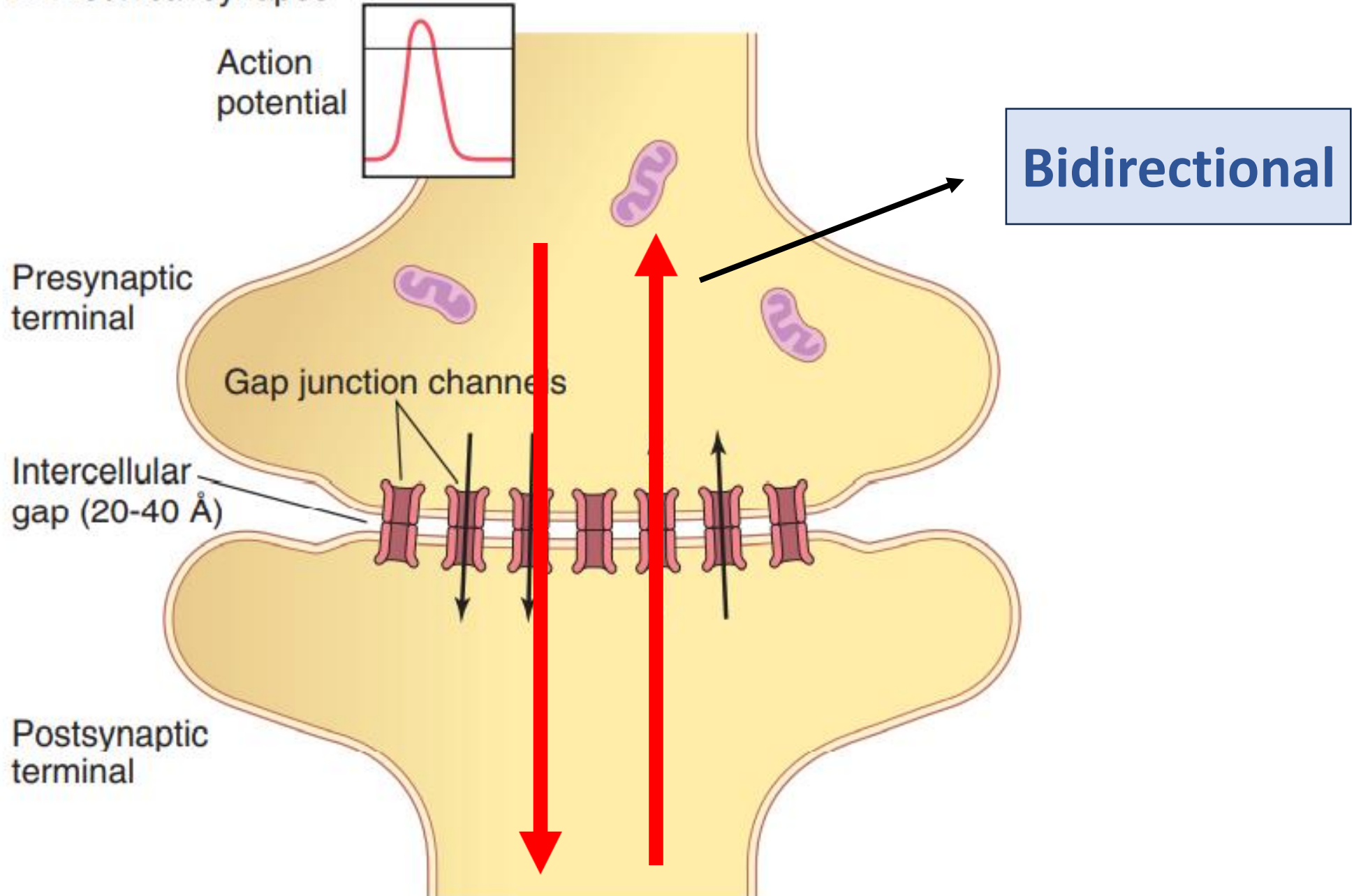
Cells are physically joined by "**gap junctions**" which act like open doors allowing ions to flow **directly** from one cell to the next

Signals can travel in both directions (**bidirectional**), unlike chemical synapses

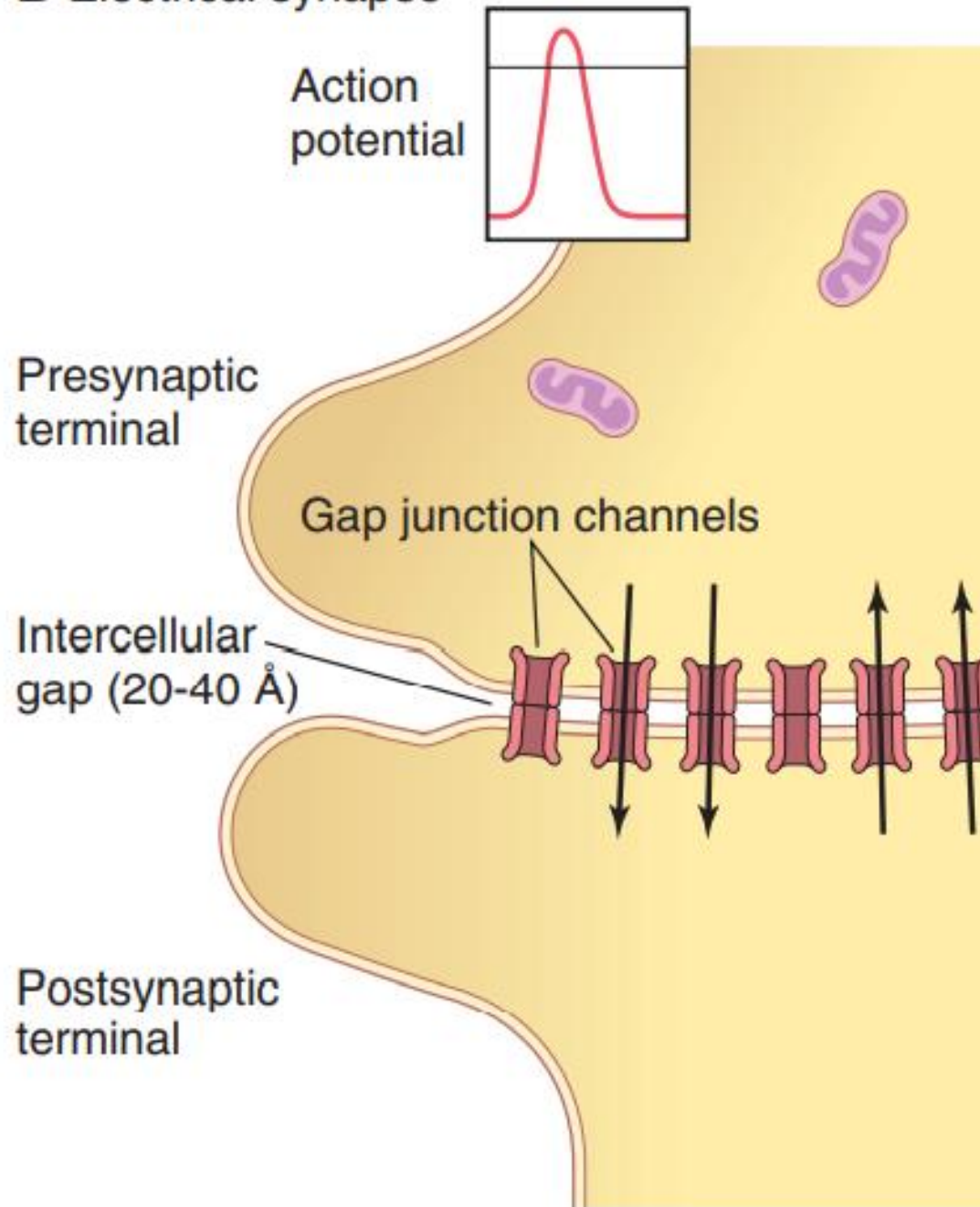
Because ions pass directly without waiting for chemicals to be released, this communication is **much faster**

Cytoplasm are directly connected by gap junctions

B Electrical synapse



B Electrical synapse



- **FAST**

Communication is much faster than chemical synapses because the electrical signals (action potentials) pass directly through gap junctions from one cell to another

- **Synchronization**

This direct connection allows a group of connected neurons or muscle fibers to coordinate their activity and fire at the exact same time

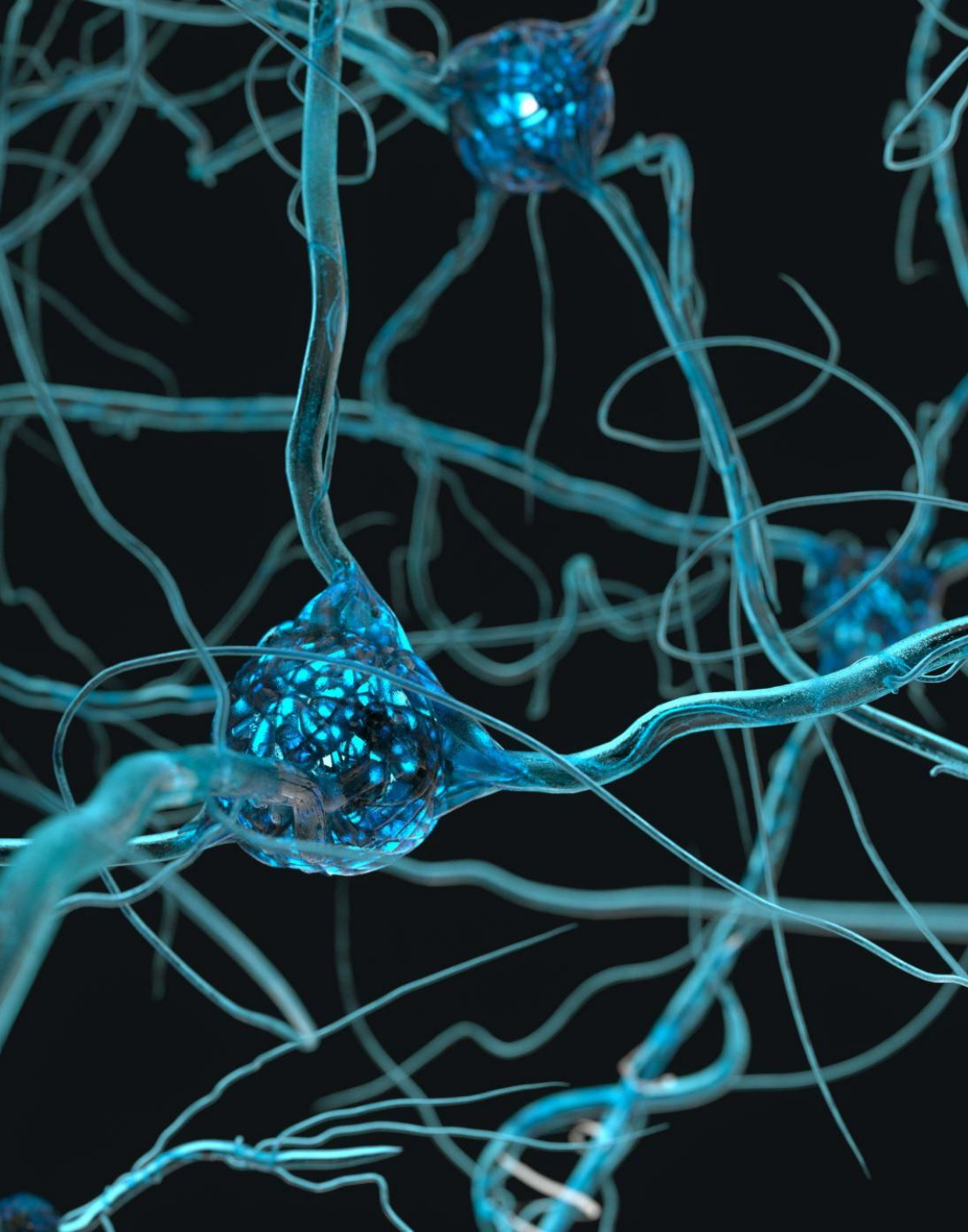
Electrical Synapses



The **cytoplasms of adjacent cells are directly connected by gap junctions** that allow free movement of ions between cells.



Similar to the ones in smooth muscles and cardiac muscles.

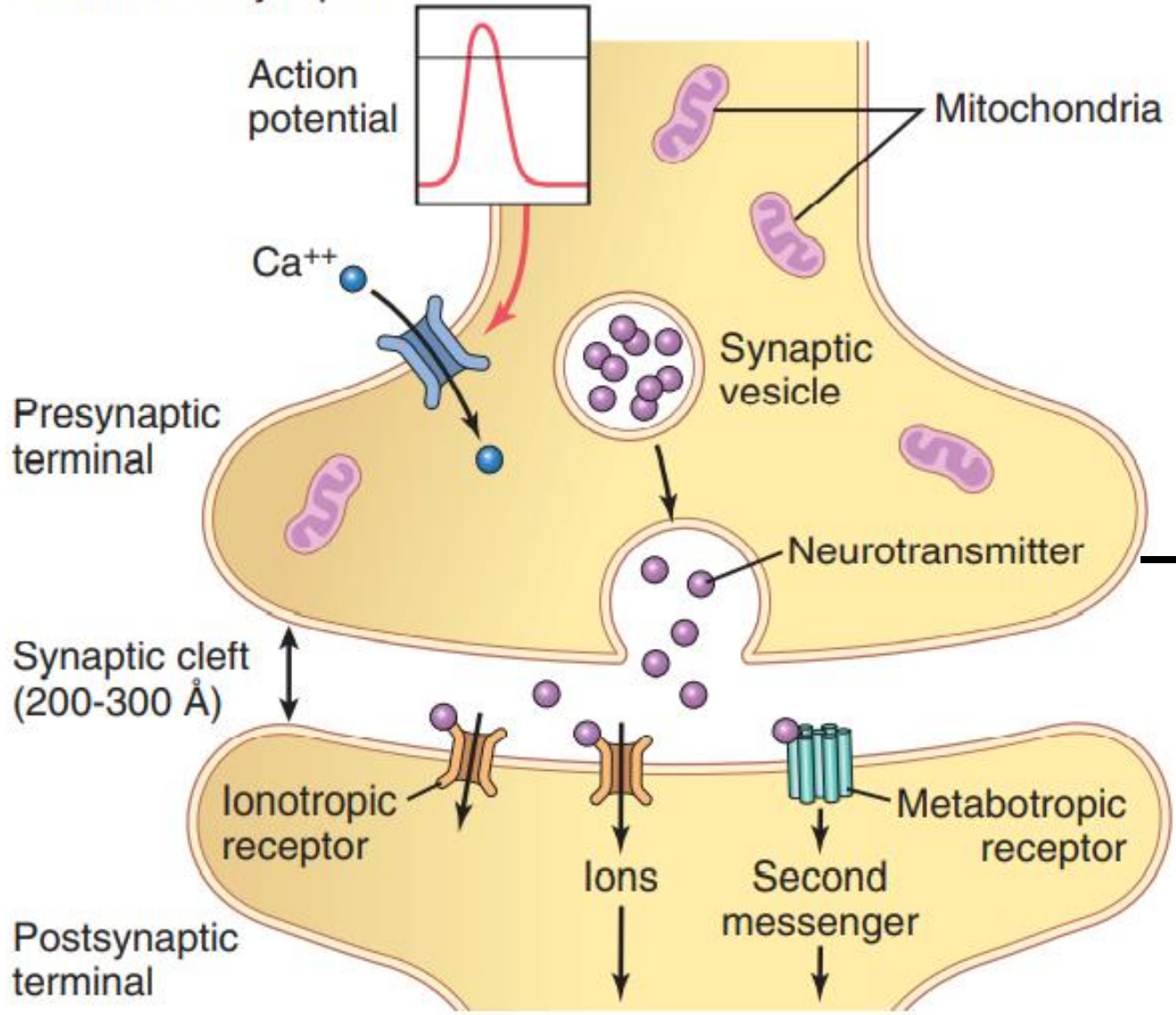


Bidirectional transmission of electrical synapses

Two main advantages:

- **1. Faster communication.** Because action potentials conduct directly through gap junctions, electrical synapses are faster than chemical synapses.
- **2. Synchronization.** Electrical synapses can synchronize (coordinate) the activity of a group of neurons or muscle fibers. As well as increasing neuronal sensitivity of connected neurons.

A Chemical synapse



**More
common**

They are the primary and most common type of synapse in the Central Nervous System (CNS)

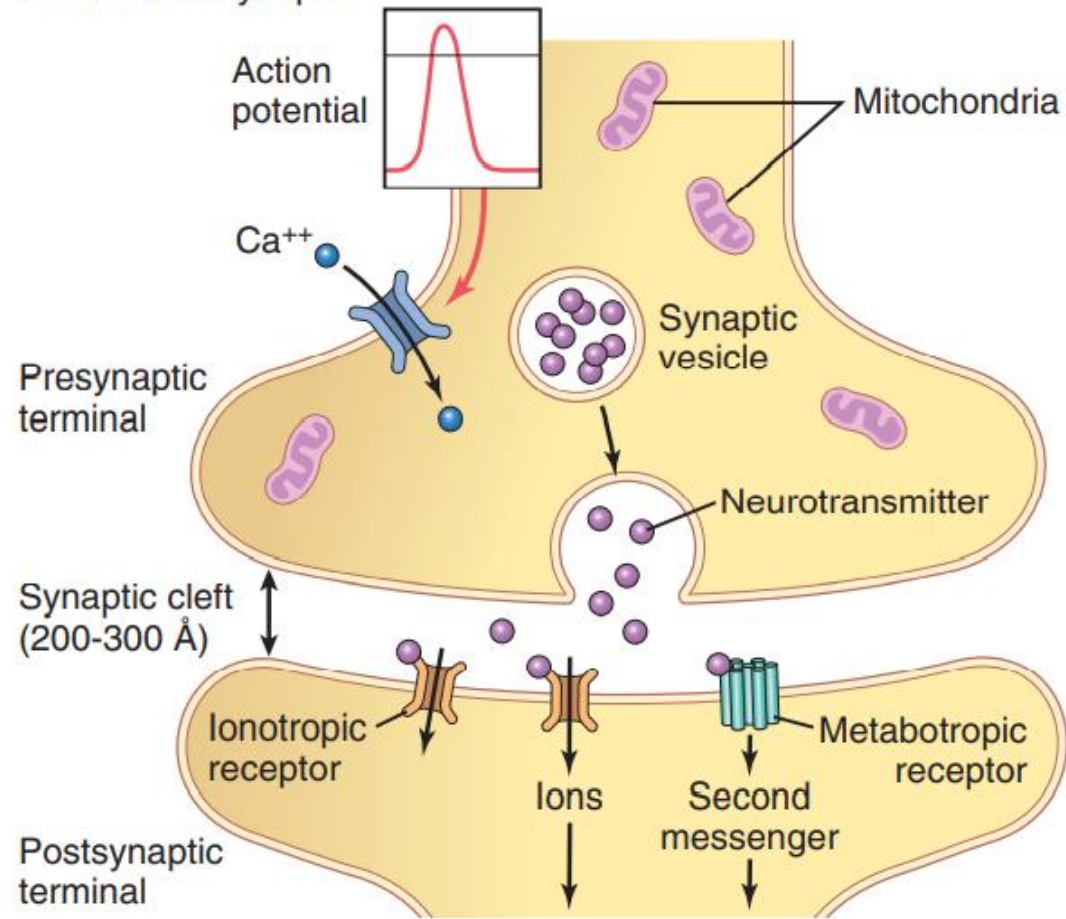
The sending neuron releases a chemical messenger known as a **"neurotransmitter"**

This chemical binds to receptors on the receiving neuron to either turn it on (excite), turn it off (inhibit), or change its sensitivity

Chemical synapses

- **Most** of the synapses in the CNS are chemical synapses.
- The first neuron secretes at its nerve ending synapse a chemical substance called a **neurotransmitter**.
- Neurotransmitter acts on receptor proteins in the membrane of the next neuron to **excite** the neuron, **inhibit** it, or **modify** its sensitivity in some other way.

A Chemical synapse

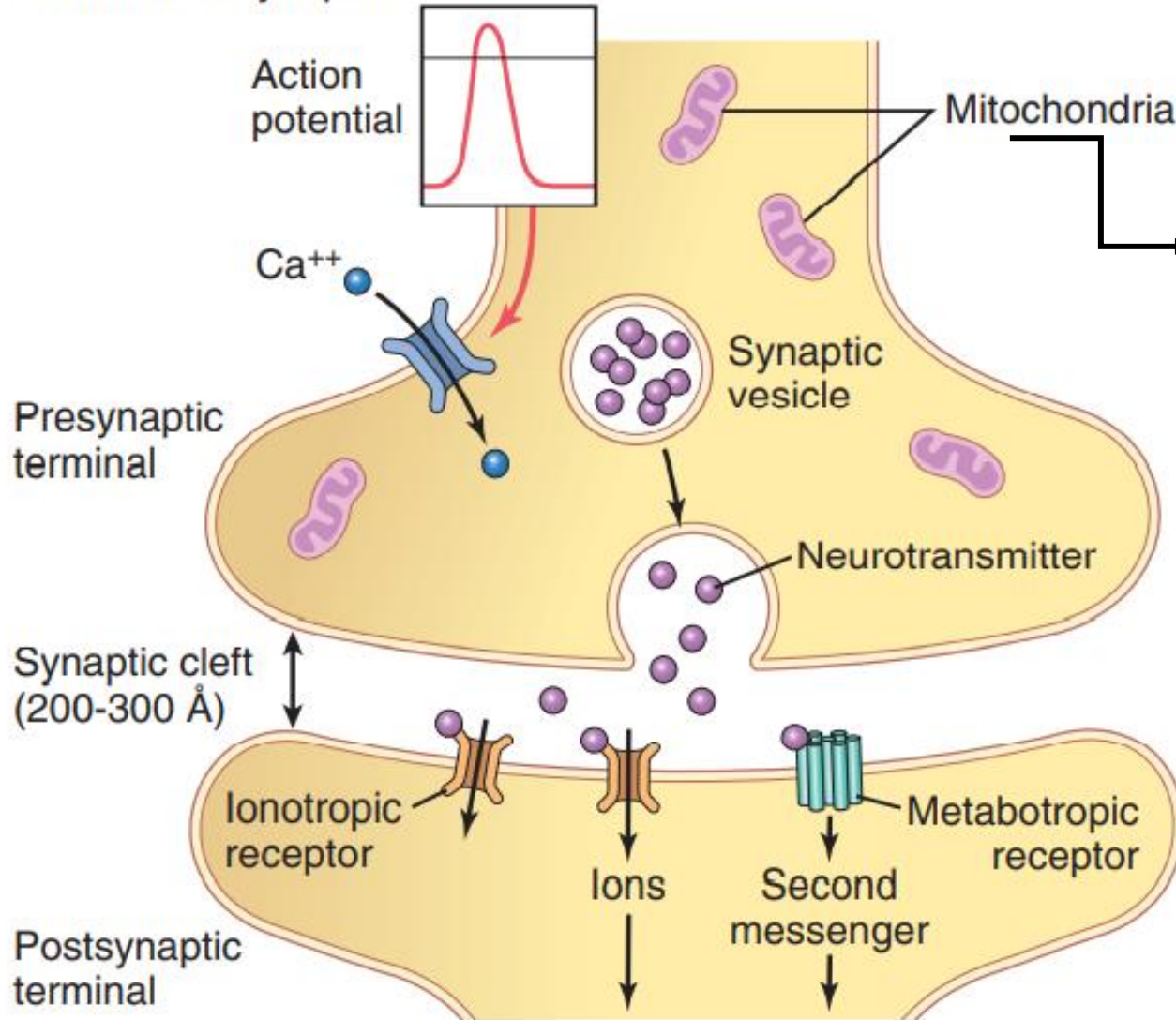


Inhibition:

Turning it off: The chemical messenger (neurotransmitter) acts to stop or "turn off" the receiving neuron

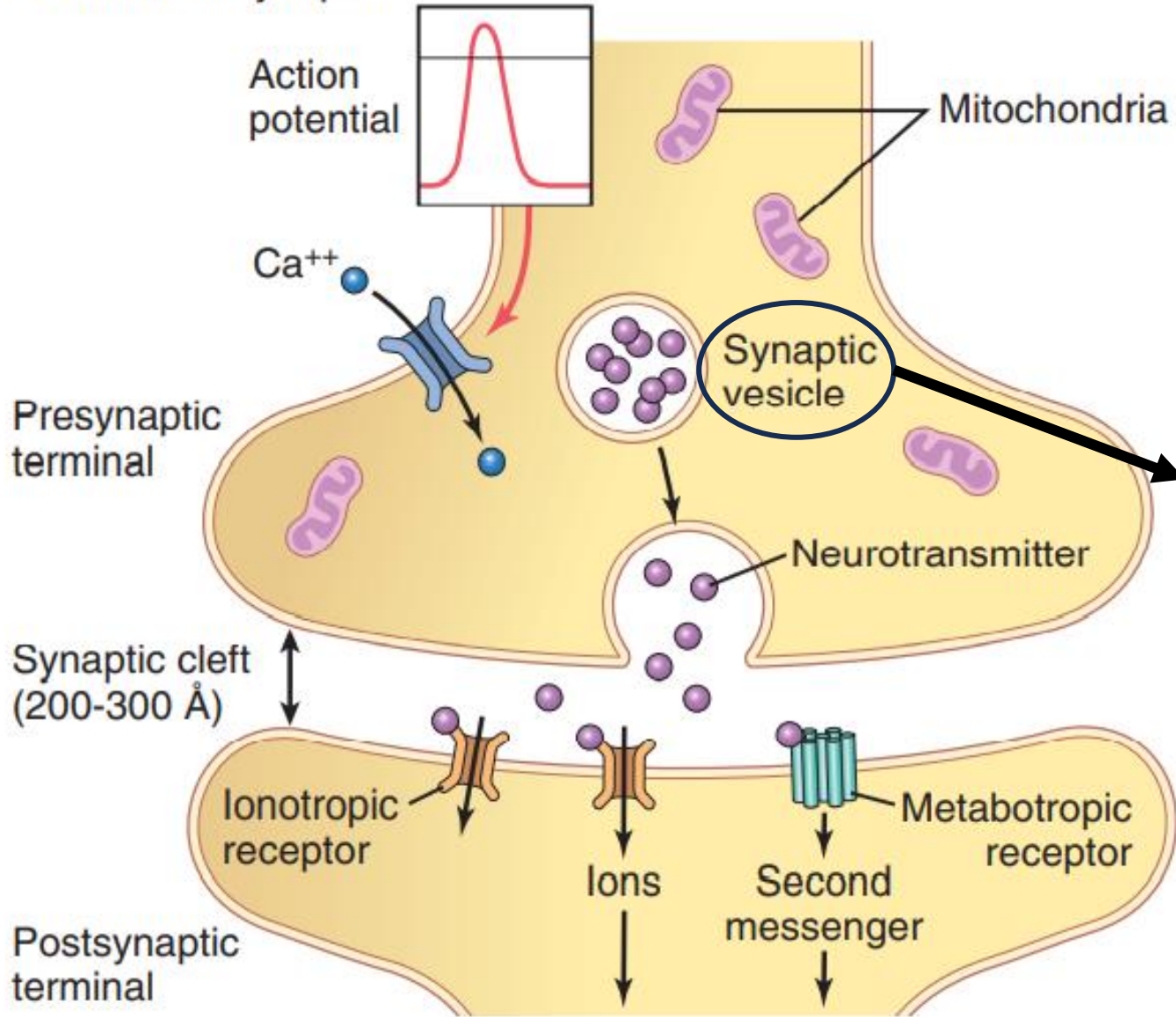
Preventing the signal: It blocks the next cell from firing, just like unplugging a cord stops the flow of electricity

A Chemical synapse



They provide **ATP (energy)** for the cell.
Main Function: They supply the energy needed to **manufacture new neurotransmitters** (chemical messengers).

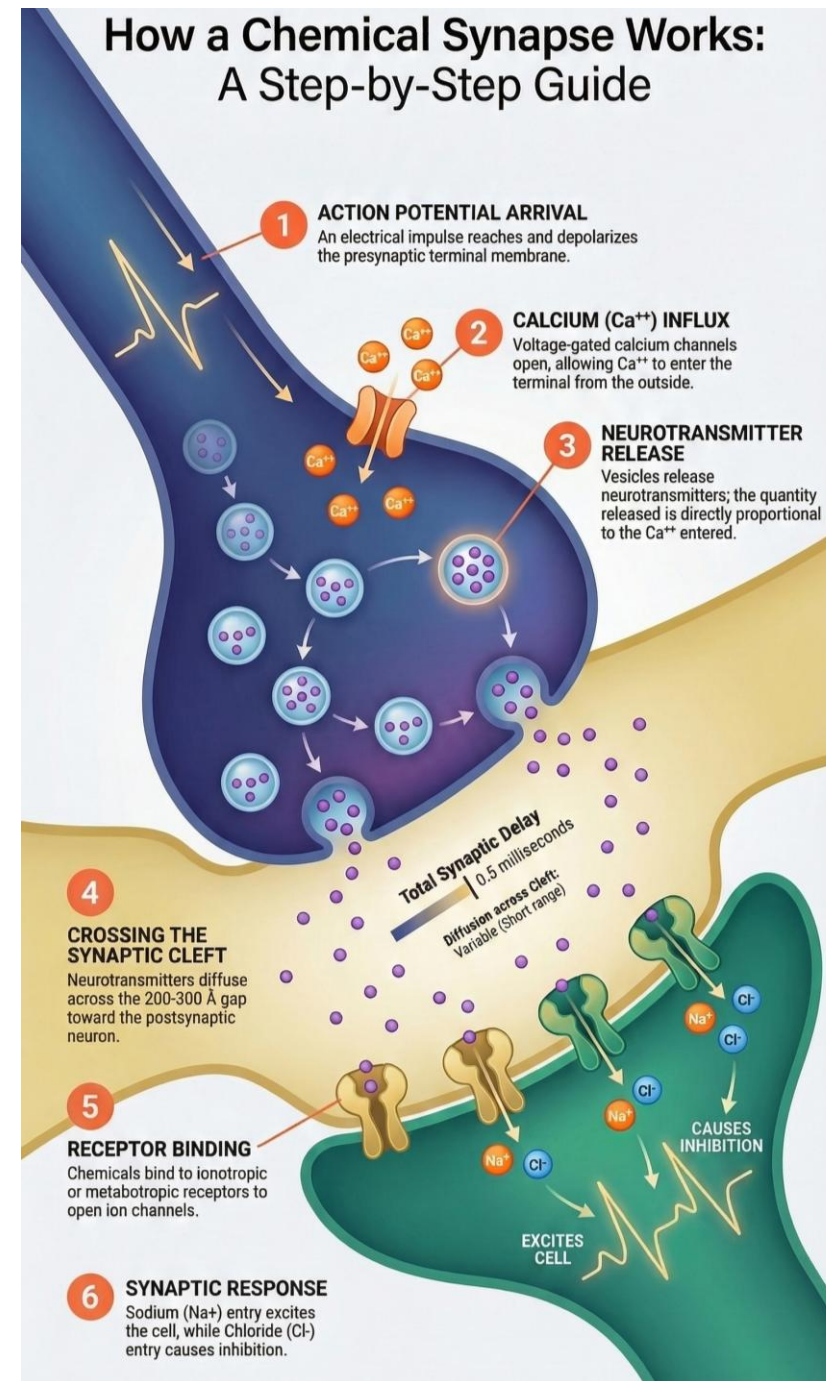
A Chemical synapse

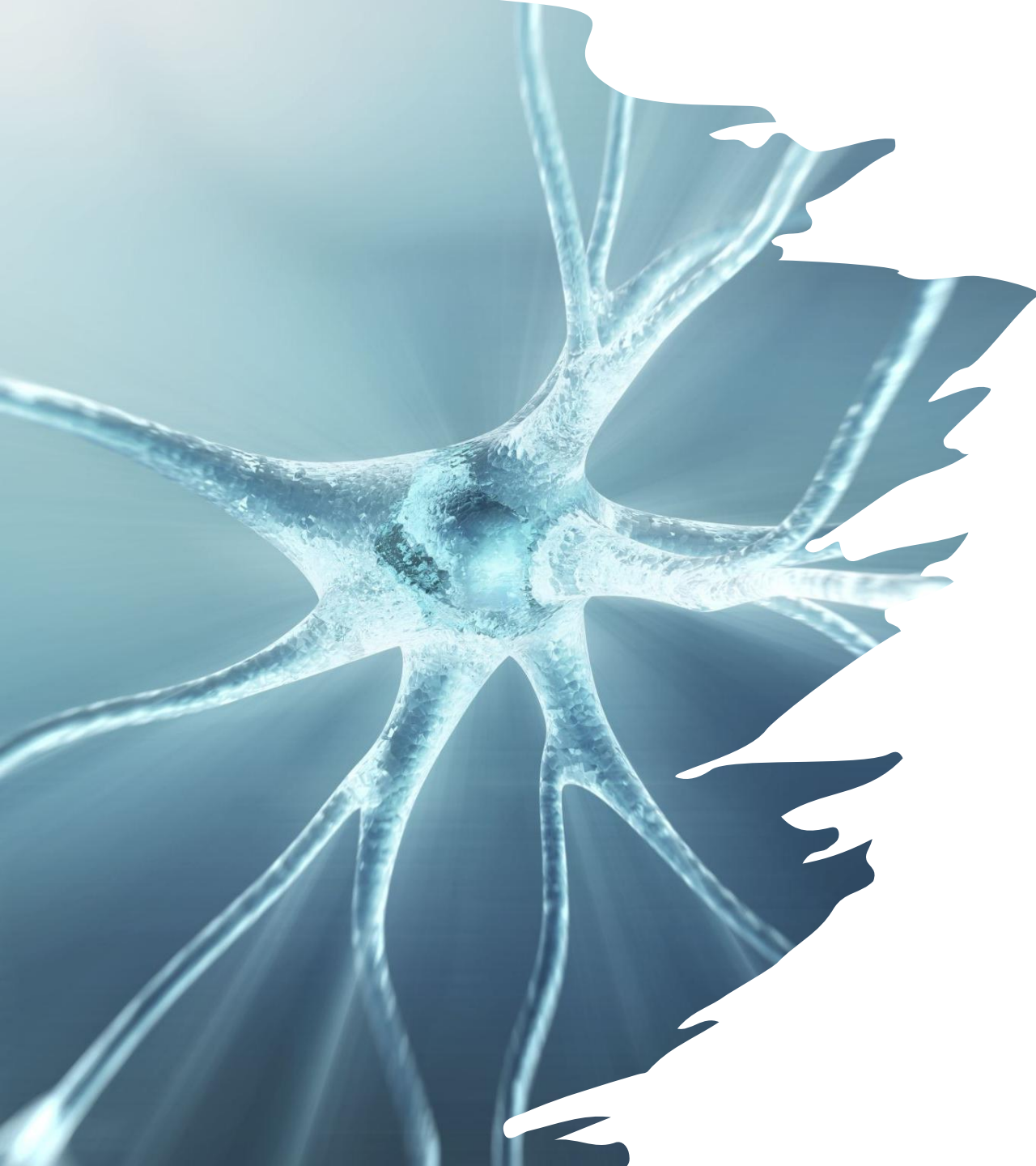


They are **small sacs** inside the terminal that contain and **store** the chemical messengers (**neurotransmitters**)

Release: They release these chemicals into the gap (**synaptic cleft**) to either **excite** or **inhibit** the next cell

More Ca^{++}
More NT





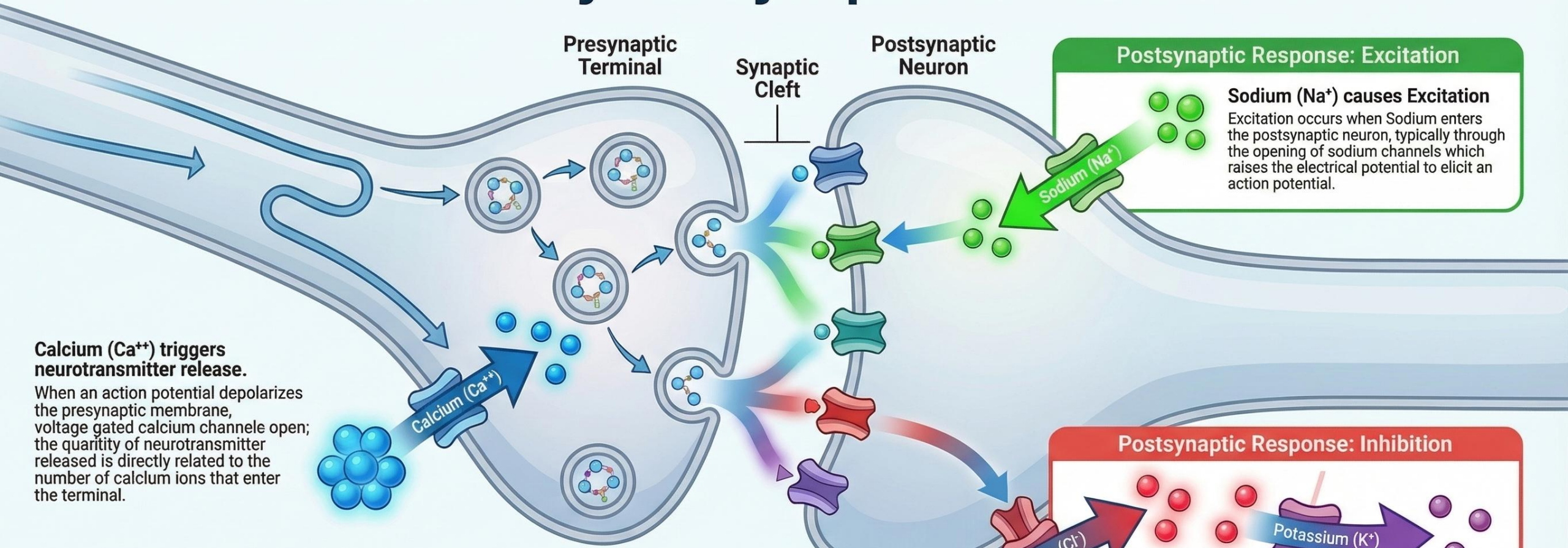
Presynaptic terminals

- The terminal has **two** important internal structures:
- The **transmitter vesicles** contain the **neurotransmitter** that, when released into the **synaptic cleft**, either excites or inhibits the postsynaptic neuron.
- The **mitochondria** provide adenosine triphosphate (**ATP**), which in turn supplies the energy for **synthesizing** new transmitter substance.

Presynaptic terminals

- The presynaptic membrane contains large numbers of **voltage-gated calcium channels**.
- When an action potential **depolarizes** the presynaptic membrane, these calcium channels **open**.
- The quantity of **neurotransmitter** that is released is **directly** related to the number of **calcium** ions that enter.

The Ionic Keys of Synaptic Transmission



Calcium (Ca^{++}) triggers neurotransmitter release.
 When an action potential depolarizes the presynaptic membrane, voltage gated calcium channels open; the quantity of neurotransmitter released is directly related to the number of calcium ions that enter the terminal.

Postsynaptic Response: Excitation

Sodium (Na^+) causes Excitation
 Excitation occurs when Sodium enters the postsynaptic neuron, typically through the opening of sodium channels which raises the electrical potential to elicit an action potential.

Postsynaptic Response: Inhibition

Chloride (Cl^-) causes Inhibition
 Inhibition of the postsynaptic neuron is achieved by the opening of chloride ion channels, allowing Chloride to enter the cell.

Potassium (K^+) causes Inhibition
 Inhibition is also caused by an increase in conductance that allows Potassium to flow out of the postsynaptic neuron.

ION	LOCATION	MOVEMENT	EFFECT
Calcium (Ca^{++})	Presynaptic Terminal	Enters the neuron	Triggers neurotransmitter release
Sodium (Na^+)	Postsynaptic Neuron	Enters the neuron	Excitation
Chloride (Cl^-)	Postsynaptic Neuron	Enters the neuron	Inhibition
Potassium (K^+)	Postsynaptic Neuron	Flows out of the neuron	Inhibition

Prolonged action e.g. memory



The Problem: Normal ion channels are too fast; they close within milliseconds and cannot store long-term information



The Solution: The neuron uses a "Second-Messenger System" (Metabotropic receptors) instead

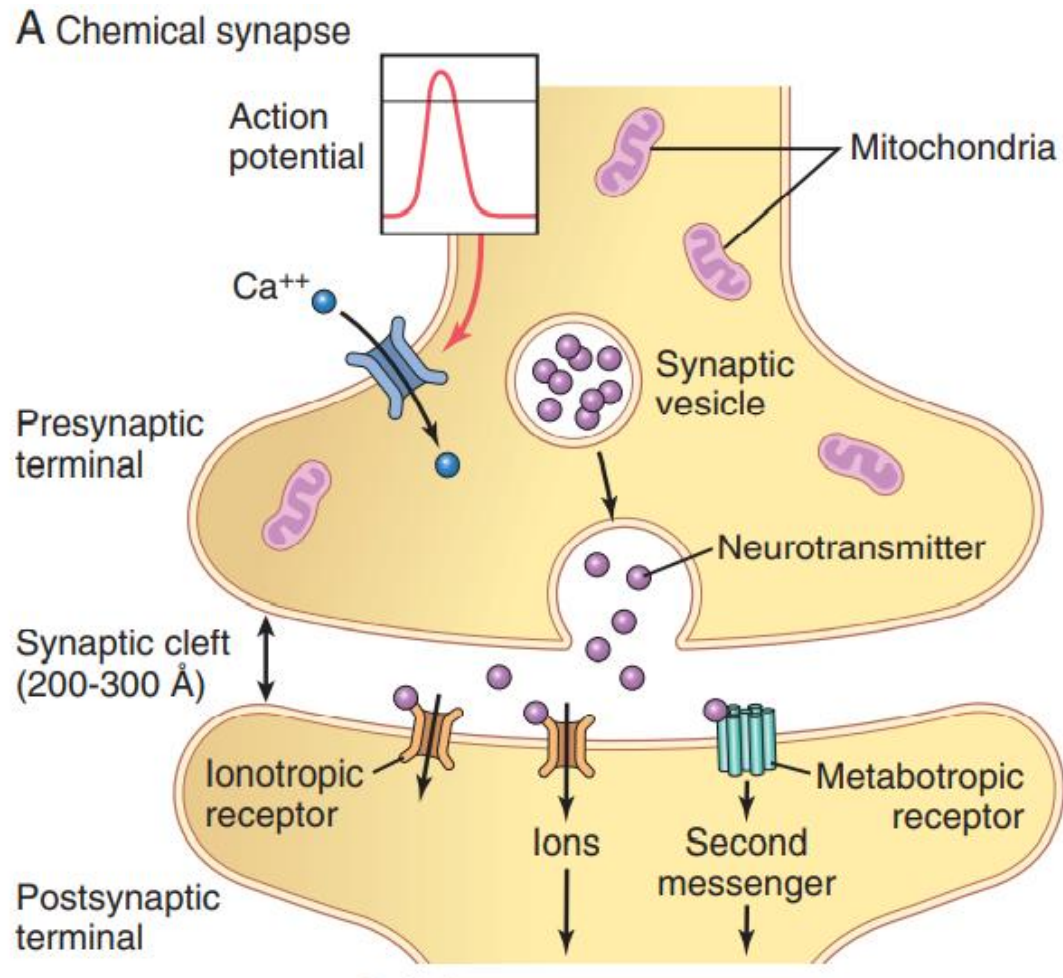


How it Works: The neurotransmitter activates a special chemical inside the receiving cell



The Result: This internal "second messenger" creates long-lasting changes (from seconds to months) that are required for processes like memory

Principle of one-way conduction at chemical synapse



Signals always travel in a single, forward direction—from the **sending neuron** (presynaptic) to the **receiving neuron** (postsynaptic)

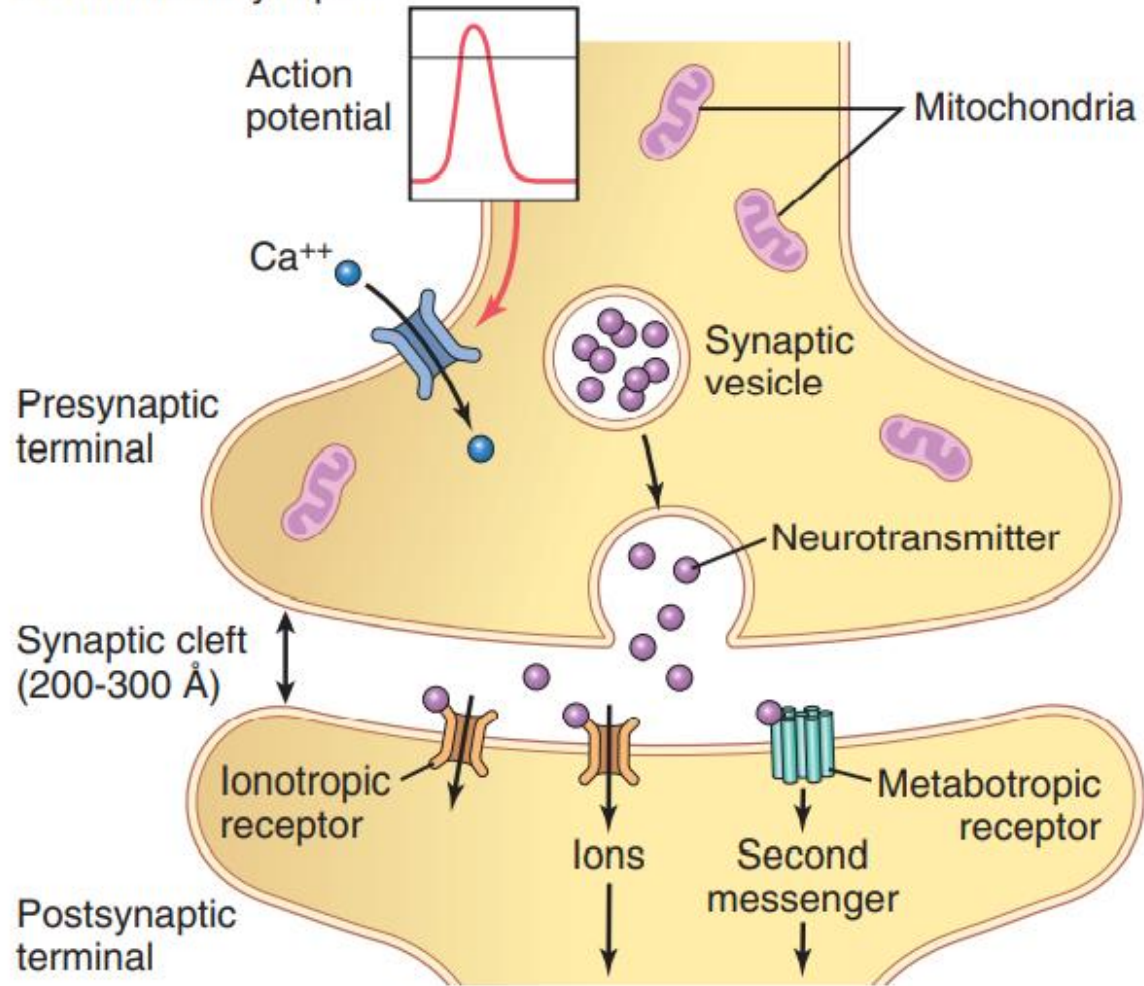
This strict one-way traffic ensures that electrical signals are accurately directed toward specific targets to perform precise tasks, without going backwards or getting mixed up

Principle of one-way conduction at chemical synapses

Always transmit the signals in one direction: from the presynaptic neuron to the postsynaptic neuron.

Allows signals to be directed toward **specific goals** and **perform specific nervous functions**.

A Chemical synapse



DELAYED

The Pause: It takes a tiny amount of time (about 0.5 milliseconds) for a signal to cross from one neuron to the next

The Reason: This delay happens because the physical process takes time: **releasing** the chemical, **crossing** the gap, **binding** to the receptor, and **starting** a new signal

Synaptic delay

- During transmission of a neuronal signal from a presynaptic neuron to a postsynaptic neuron, a certain amount of time (**0.5 msec**) is consumed in the process of
- (1) **discharge** of the transmitter substance by the presynaptic terminal
- (2) **diffusion** of the transmitter to the postsynaptic neuronal membrane

Synaptic delay

- (3) **action** of the transmitter on the membrane receptor
- (4) action of the **receptor** to increase the membrane permeability
- (5) inward diffusion of sodium to raise the EPSP to a high enough level to elicit an action potential

EPSP (Excitatory Postsynaptic Potential):

What is it? It is the build-up of **positive electrical charge** inside the receiving neuron.

How it happens: The inward flow of Sodium (Na^+) **raises** the EPSP

The Goal: If the EPSP reaches a high enough level, it successfully elicits a new action potential (**excites** the cell)

Postsynaptic neurons

- Receptor activation controls the opening of ion channels in the postsynaptic cell in one of two ways:

(1) by **gating ion channels** directly (Ionotropic receptors).

(2) by **activating a second messenger** (metabotropic receptors).

Excitation of postsynaptic neuron

- Opening of sodium channels.
- Changes in the internal metabolism of the postsynaptic neuron to excite cell activity or to increase the number of excitatory membrane receptors or decrease the number of inhibitory membrane receptors.

Inhibition of postsynaptic neuron

- Opening of chloride ion channels through the postsynaptic neuronal membrane.
- Increase in conductance of potassium ions out of the neuron.
- **Activation of receptor enzymes that inhibit cellular metabolic functions or that increase the number of inhibitory synaptic receptors or decrease the number of excitatory receptors.**

Second-messenger system

Many functions of the nervous system—for instance, the process of memory—require **prolonged changes** in neurons for seconds to months after the initial transmitter substance is gone.

The ion channels are not suitable for causing prolonged postsynaptic neuronal changes because these channels close within milliseconds after the transmitter substance is no longer present.

Second-messenger system

The "second messenger" system typically uses a **G-protein** to create prolonged changes inside the neuron.

- However, in many instances, **prolonged** postsynaptic neuronal excitation or inhibition is achieved by activating a "**second messenger**" chemical system inside the postsynaptic neuronal cell itself, and then it is the second messenger that causes the prolonged effect.