

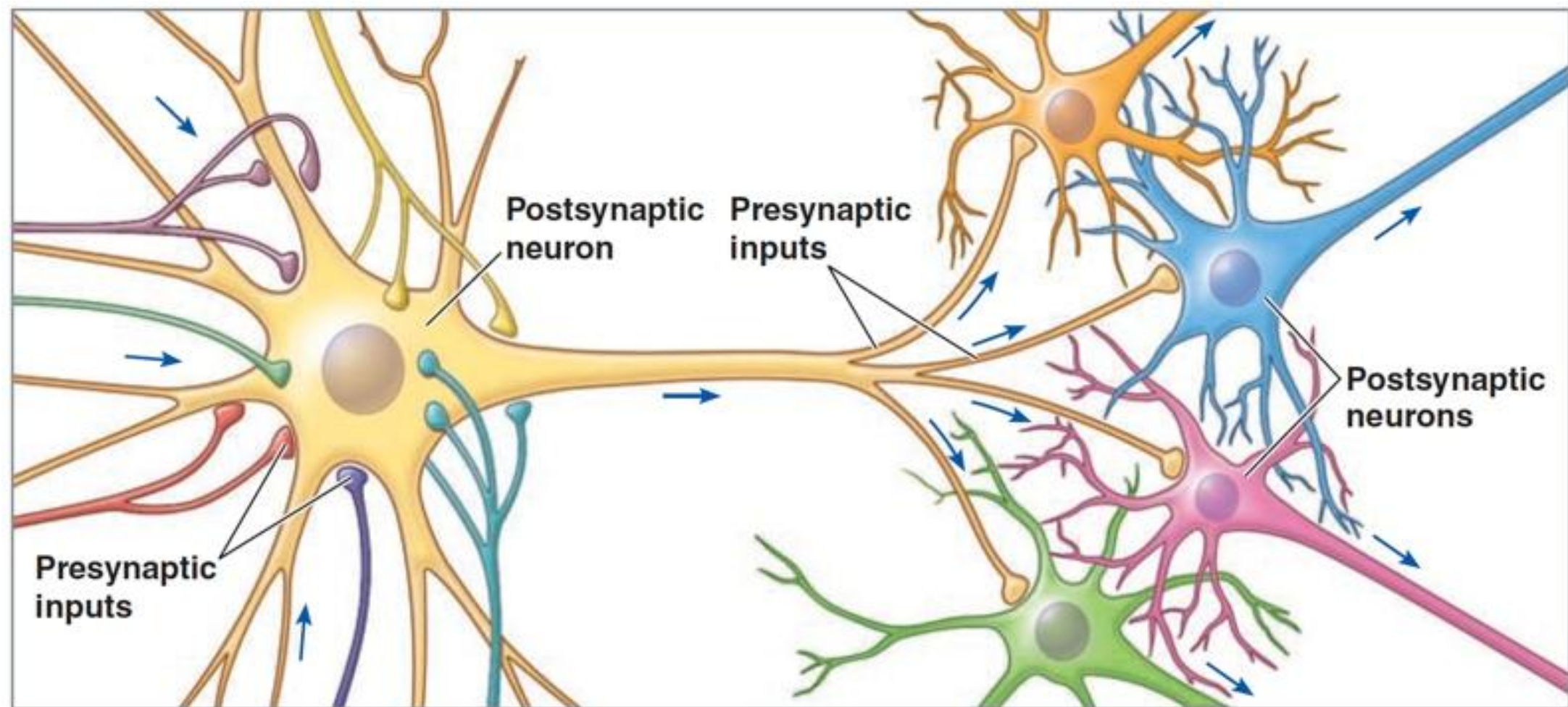
Introduction to Neurophysiology 2

Synapses

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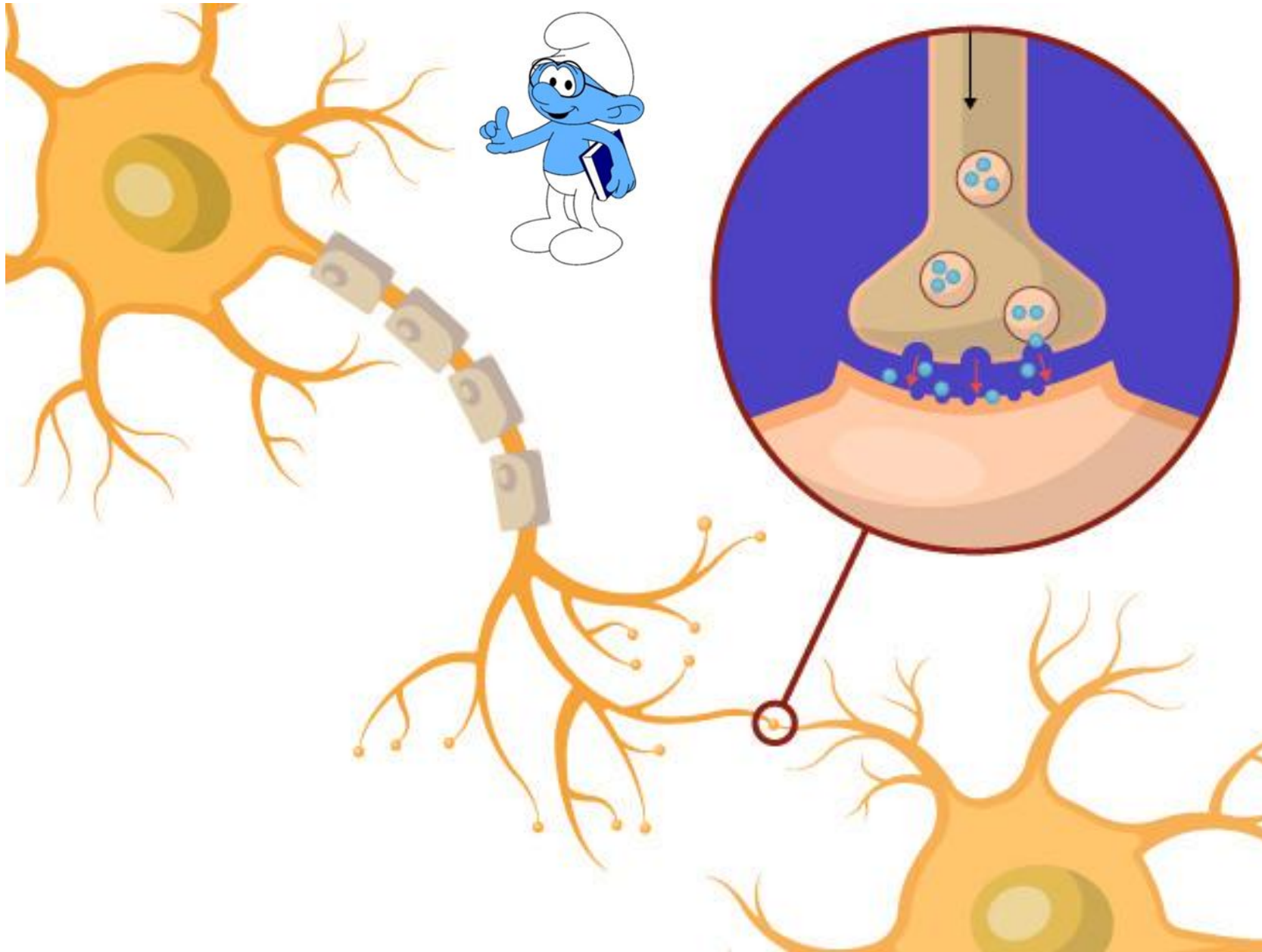


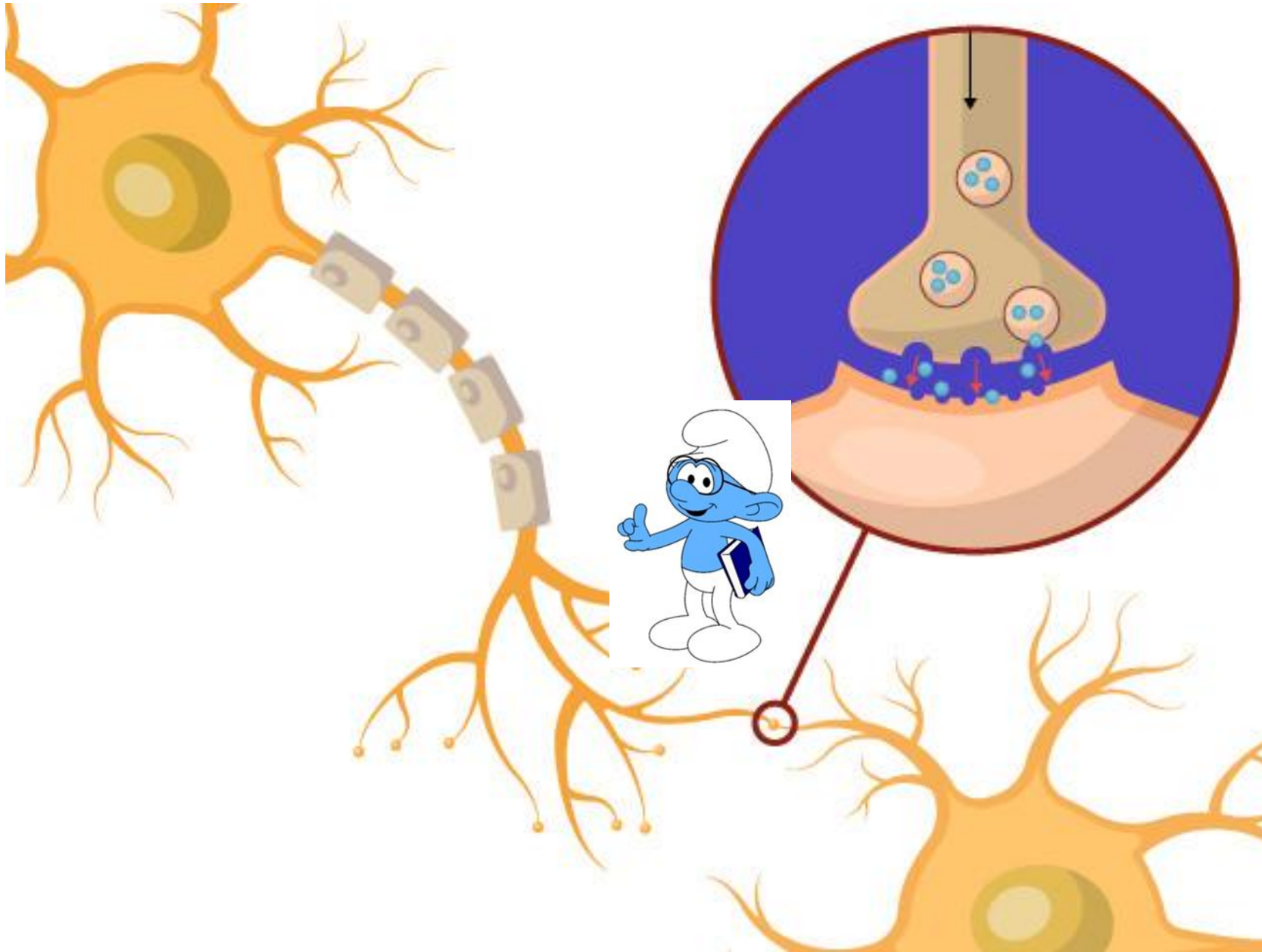
Synapses

- A synapse is the region where communication occurs between two neurons, or between a neuron and an effector cell (muscle or glandular cell). Synapses are the "communication areas" of the nervous system.

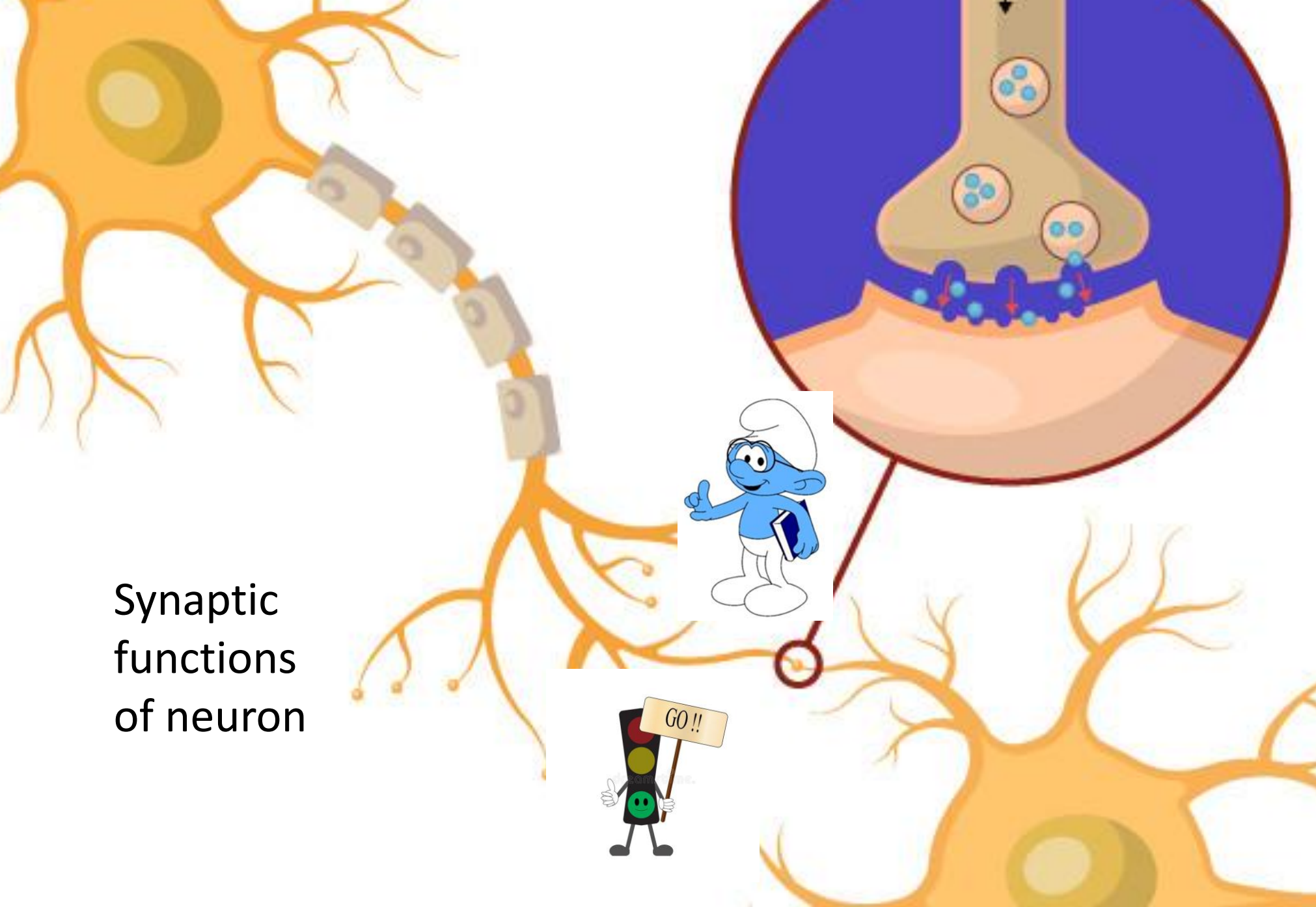
Synaptic functions of neurons

- In the central nervous system (CNS), information is transmitted mainly through action potentials (nerve impulses) along a series of neurons. However, this transmission:
- May be **blocked**
- May become **repetitive**
- May be **integrated** with other signals
- These represent the key **synaptic functions** of neurons.
- When a strong enough signal reaches the **presynaptic neuron**, it generates an action potential that travels to the **axon terminal**, where it is transmitted to the **postsynaptic neuron**. This transmission, however, is **not linear**—multiple processes can occur at the synapse:
- **Signal integration** with other impulses
- **Inhibition/blocking** of signal transmission
- **Repetition** of the signal to prolong its duration

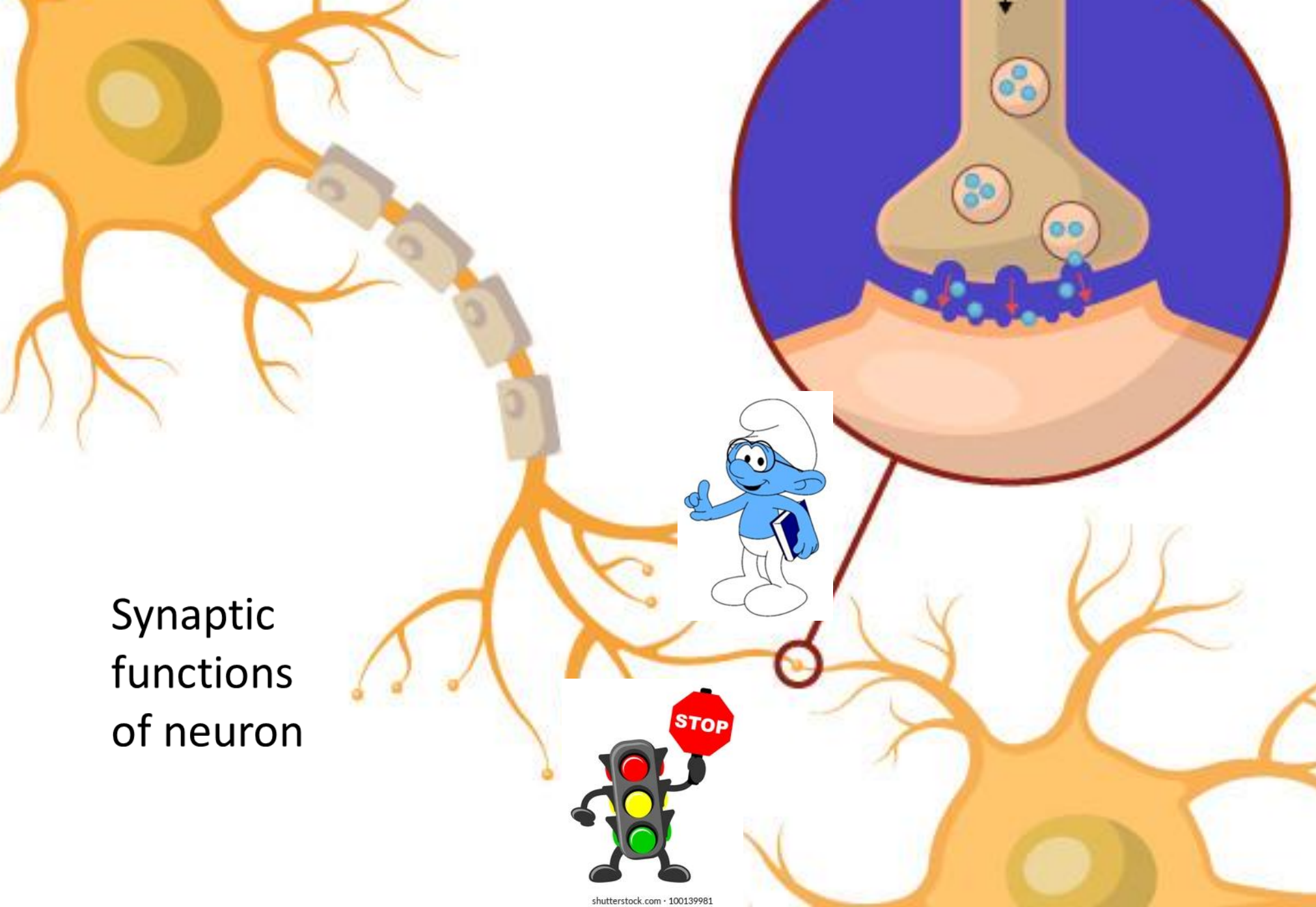




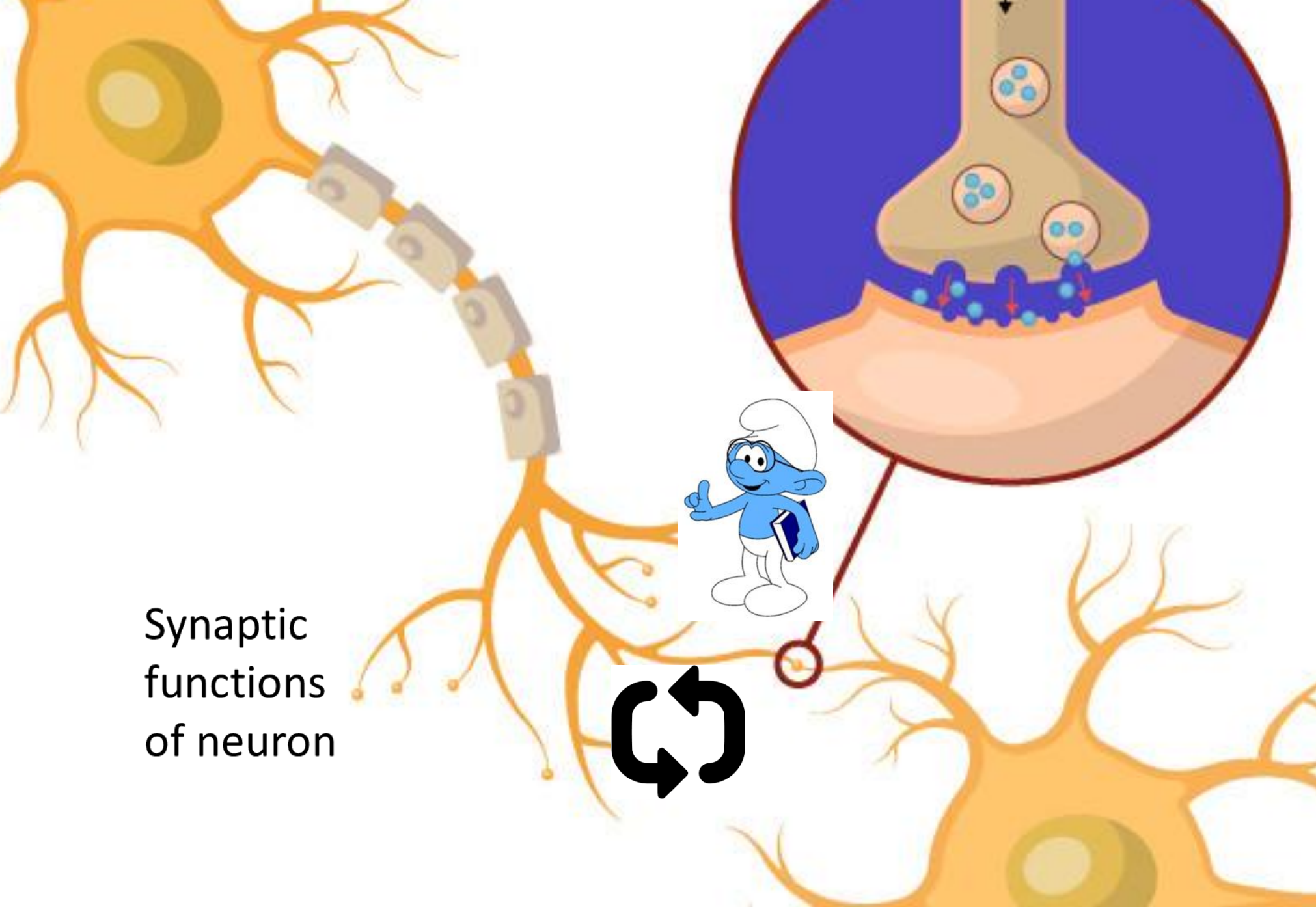
Synaptic functions of neuron



Synaptic functions of neuron



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Synaptic
functions
of neuron

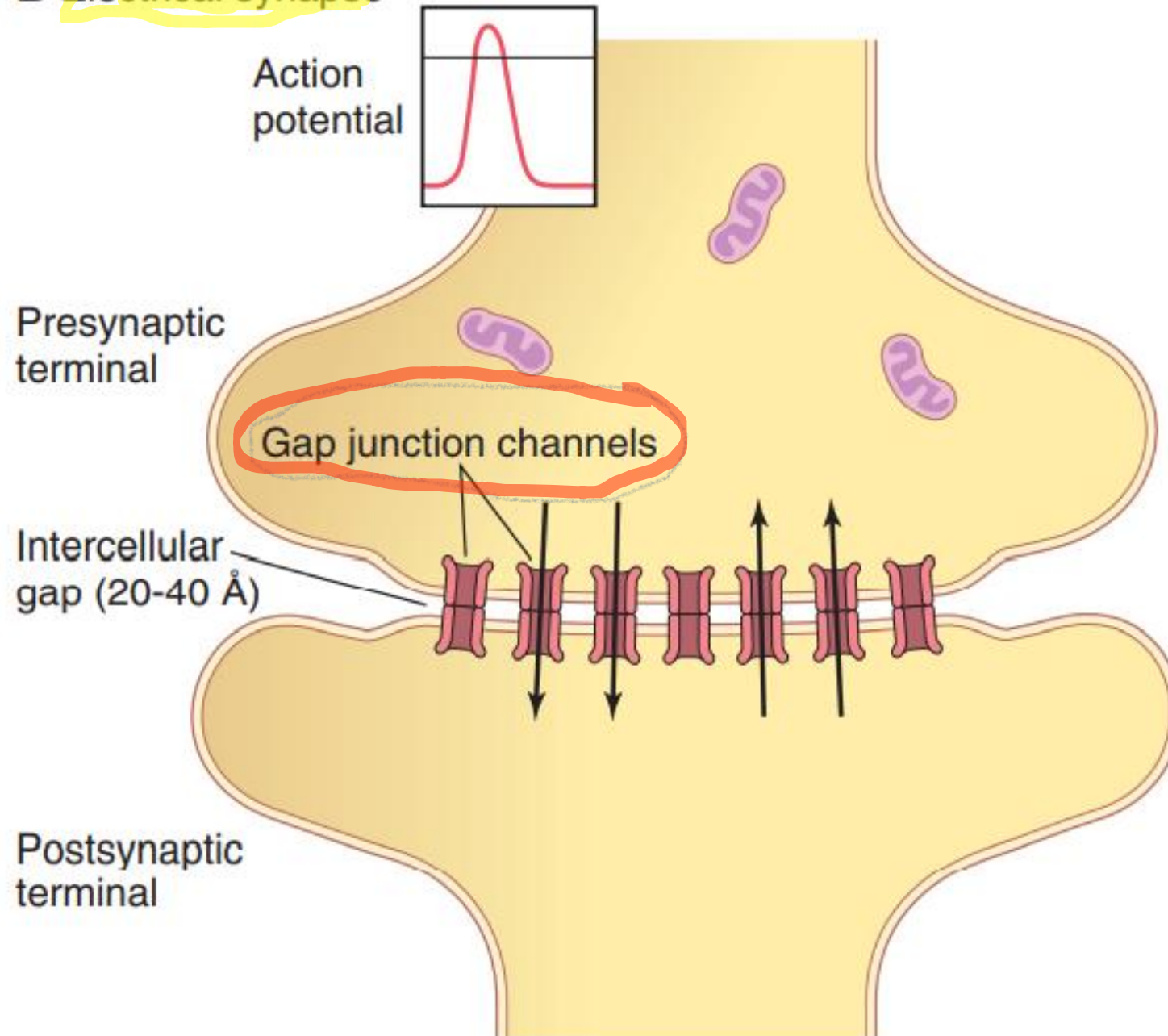
Types of Synapses

- Chemical synapses.

- Electrical synapses.



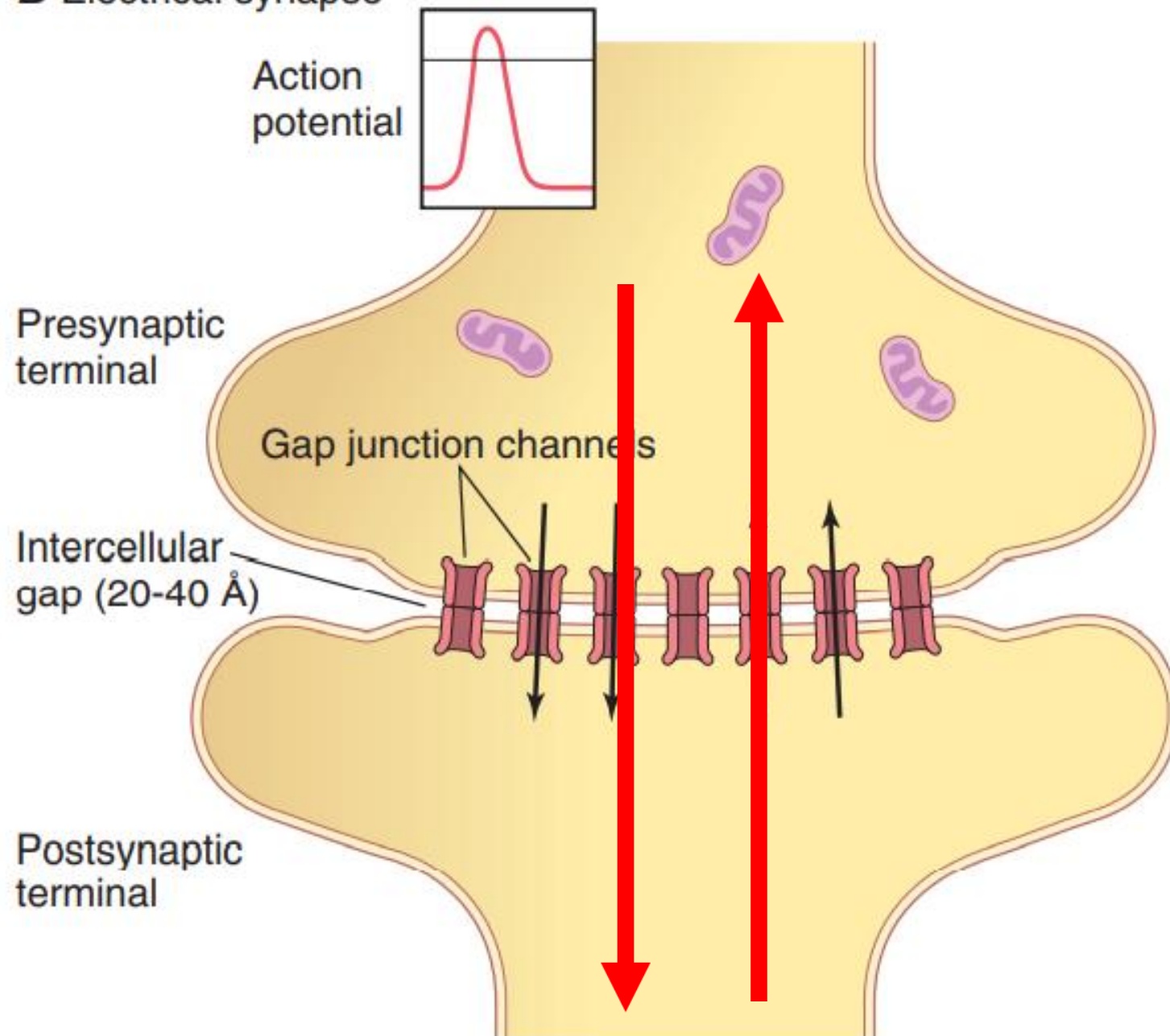
B Electrical synapse



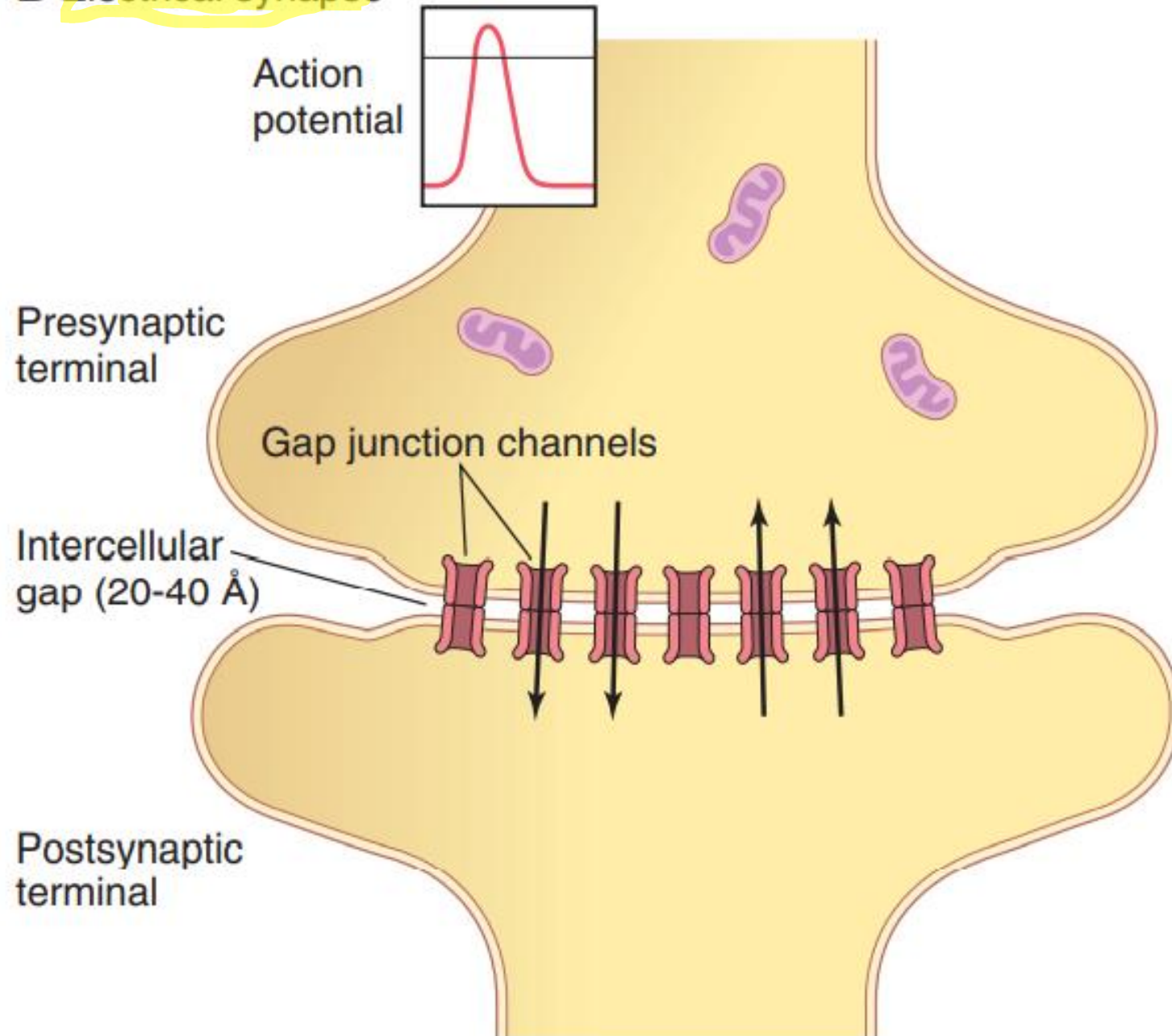
Cytoplasms are directly connected by gap junctions



B Electrical synapse



B Electrical synapse



FAST

Synchronization



Electrical Synapses

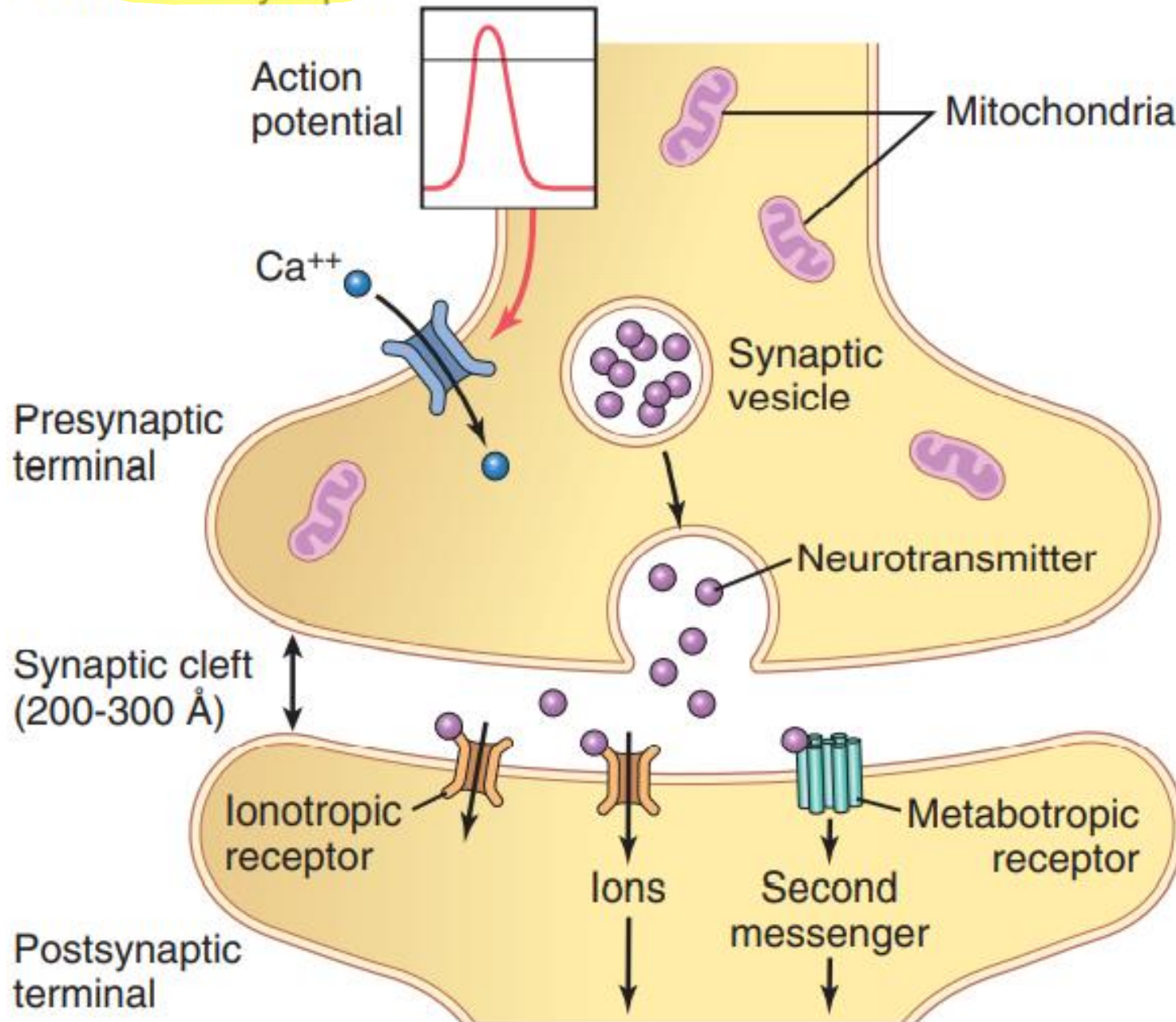
- Involve direct **ion flow** across cell membranes via **gap junctions**
- Found in **cardiac and smooth muscle**
- Cytoplasm is directly connected by **specialized channels**
- **Advantages:**
 - 1.Speed:** Signals travel almost instantaneously.
 - 2.Coordination:** Useful in tissues requiring synchronized activity (e.g., cardiac muscle).

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



Chemical synapses

- No direct ion flow; **no gap junctions**
- Signals are converted from **electrical to chemical**, then back to **electrical**
- A neurotransmitter is released from the presynaptic neuron into the **synaptic cleft**
- **Key Features:**
- **Most common type** in the CNS
- **Unidirectional transmission** (presynaptic → postsynaptic)
- Requires **mitochondria** for:
 - Neurotransmitter synthesis
 - **Exocytosis** (energy-dependent release of neurotransmitter)

Chemical synapses

- **Presynaptic Terminal Structures:**

- 1. **Transmitter vesicles** – Contain neurotransmitters

- 2. **Mitochondria** – Supply ATP for neurotransmitter synthesis and release

- **Voltage-Gated Calcium Channels:**

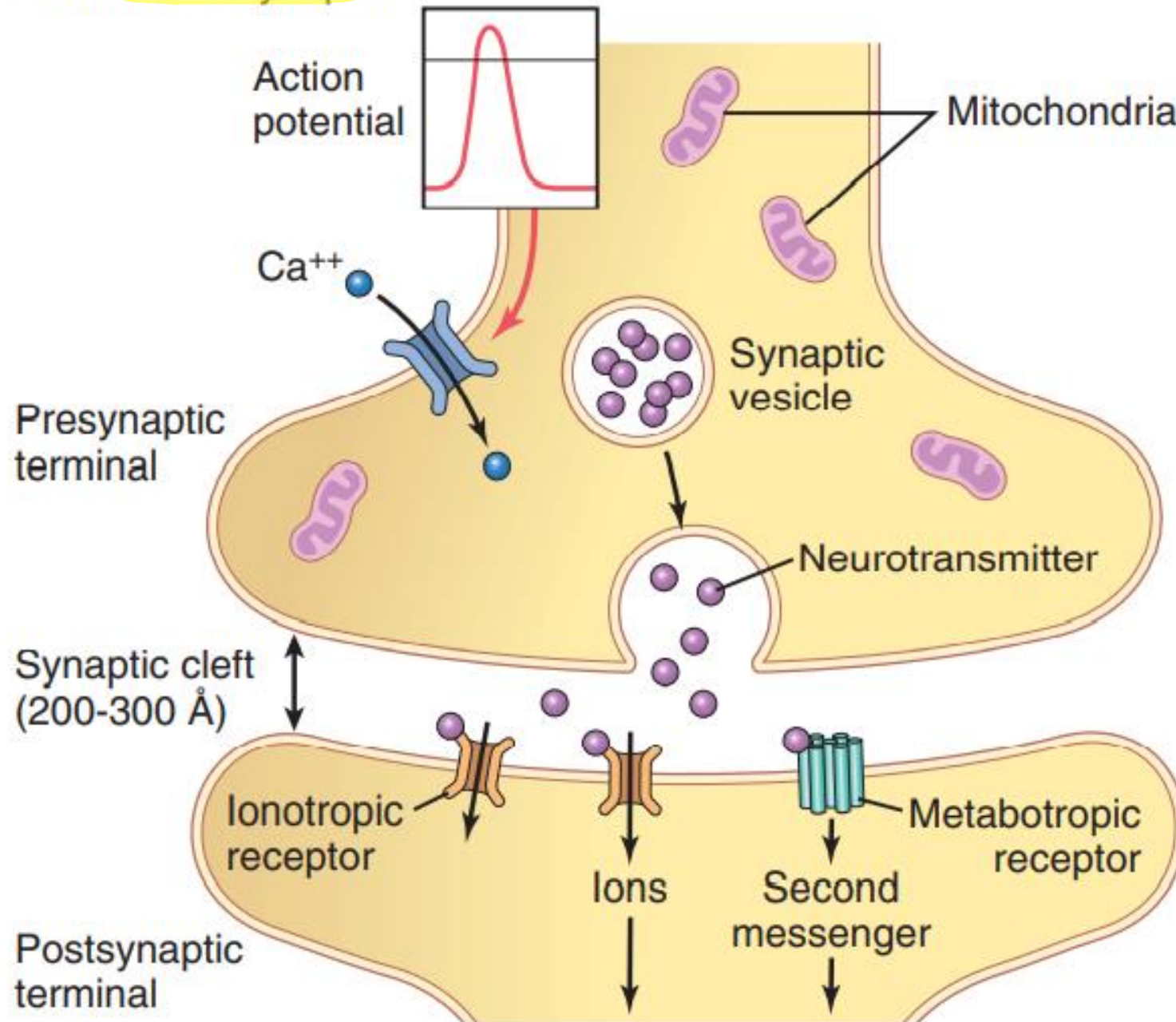
- Located on the presynaptic membrane

- Depolarization opens these channels

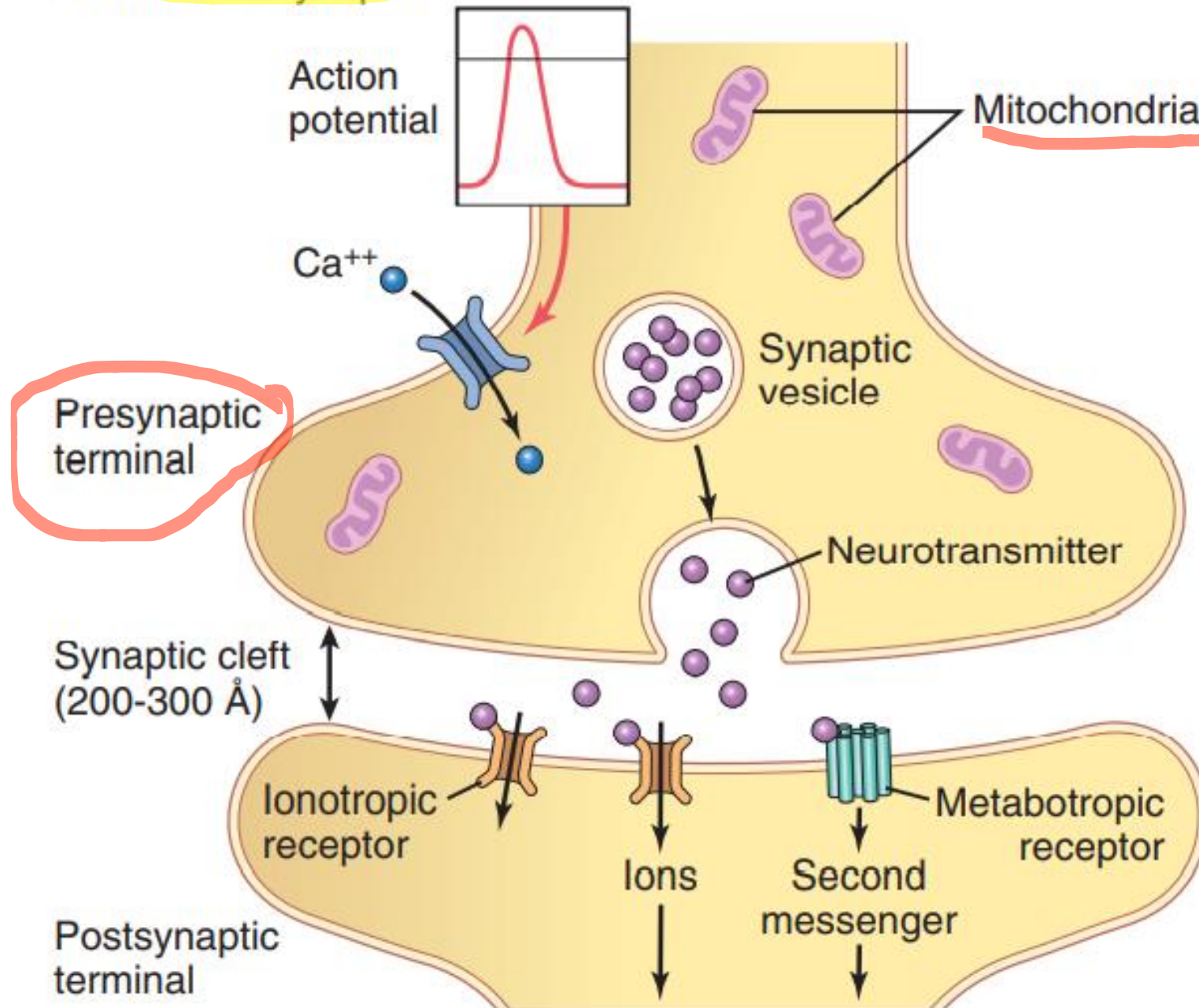
- **Calcium influx** triggers **exocytosis** of neurotransmitter vesicles

- Amount of neurotransmitter released is proportional to calcium entry

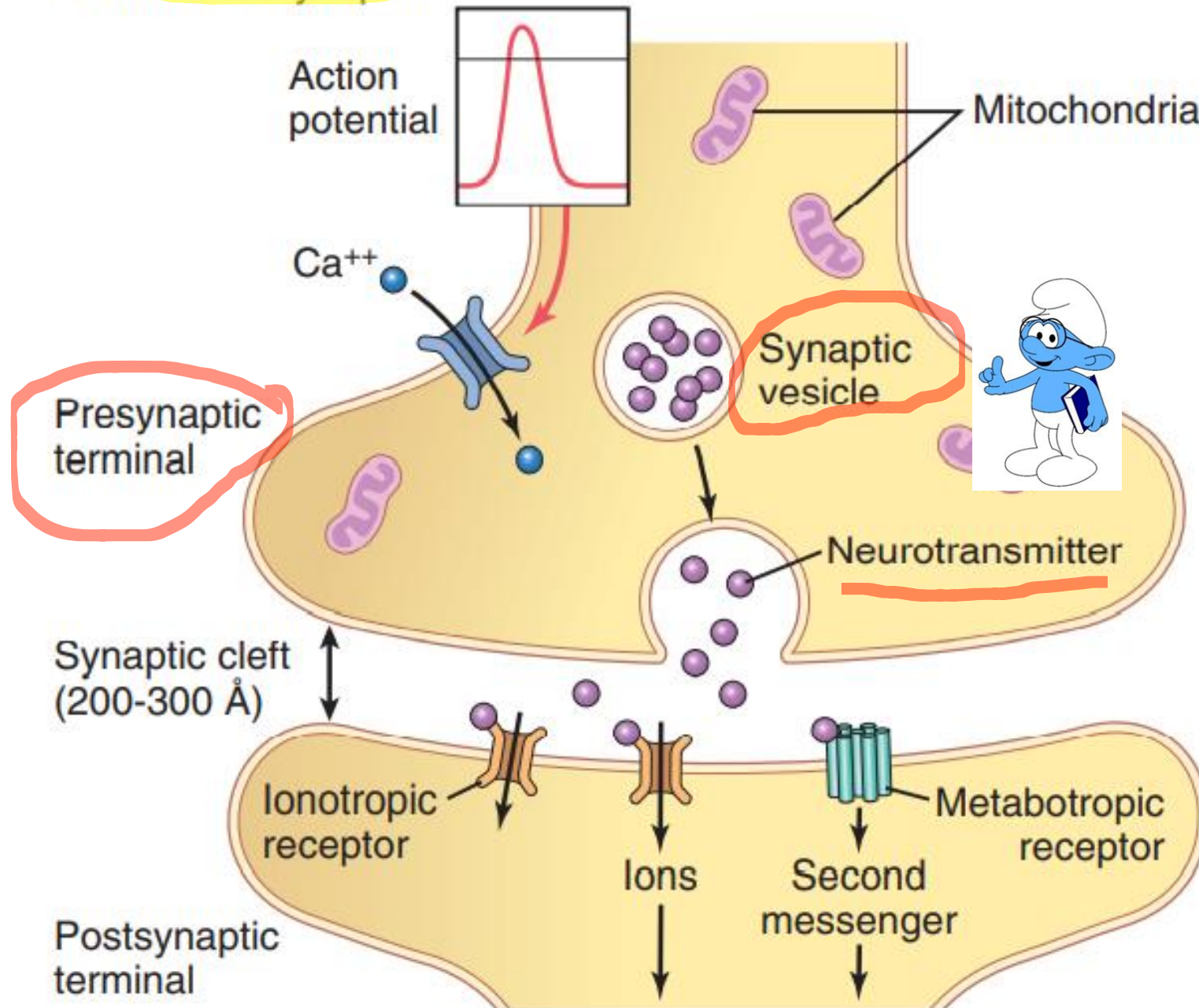
A Chemical synapse



A Chemical synapse

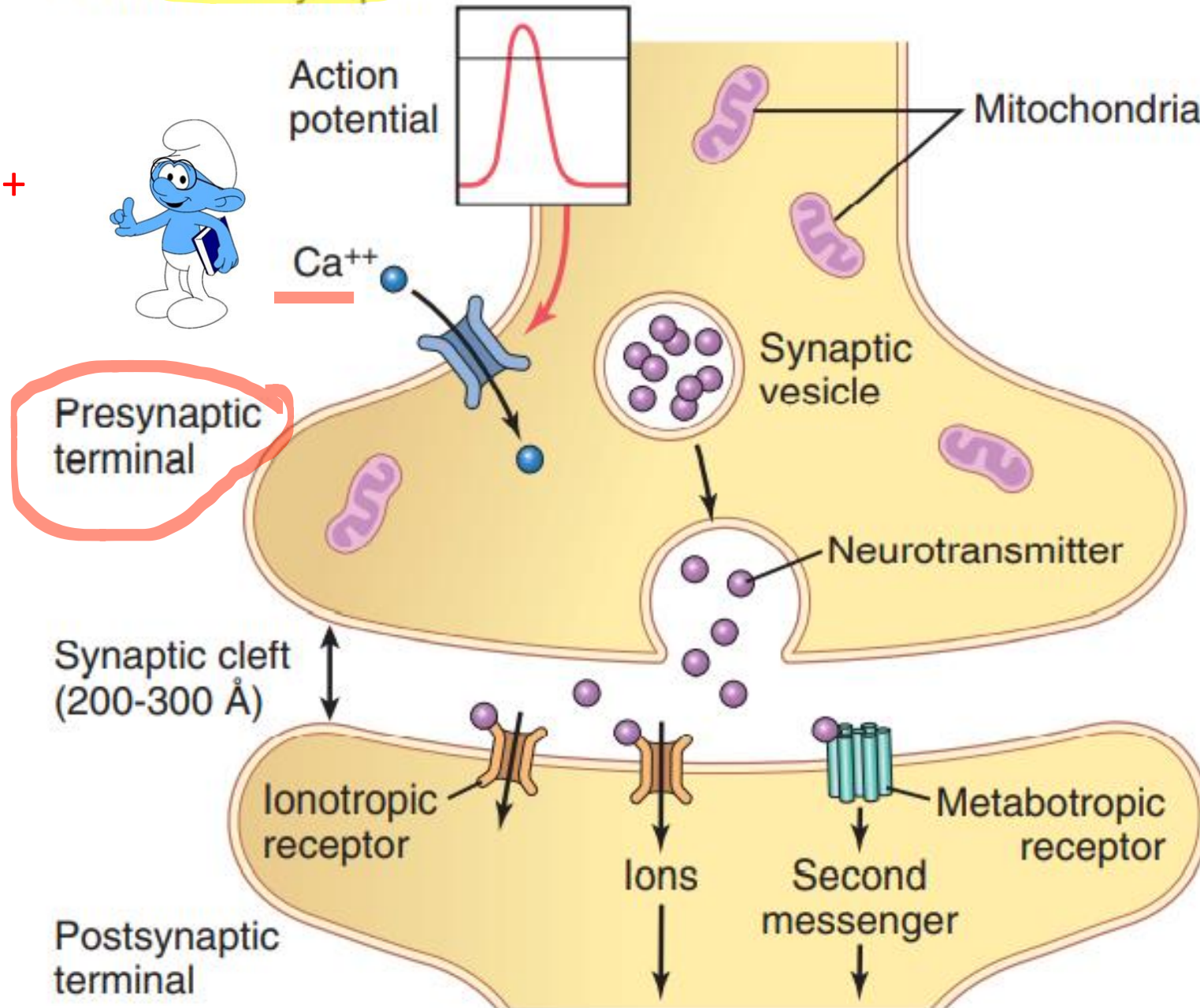


A Chemical synapse



A Chemical synapse

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.

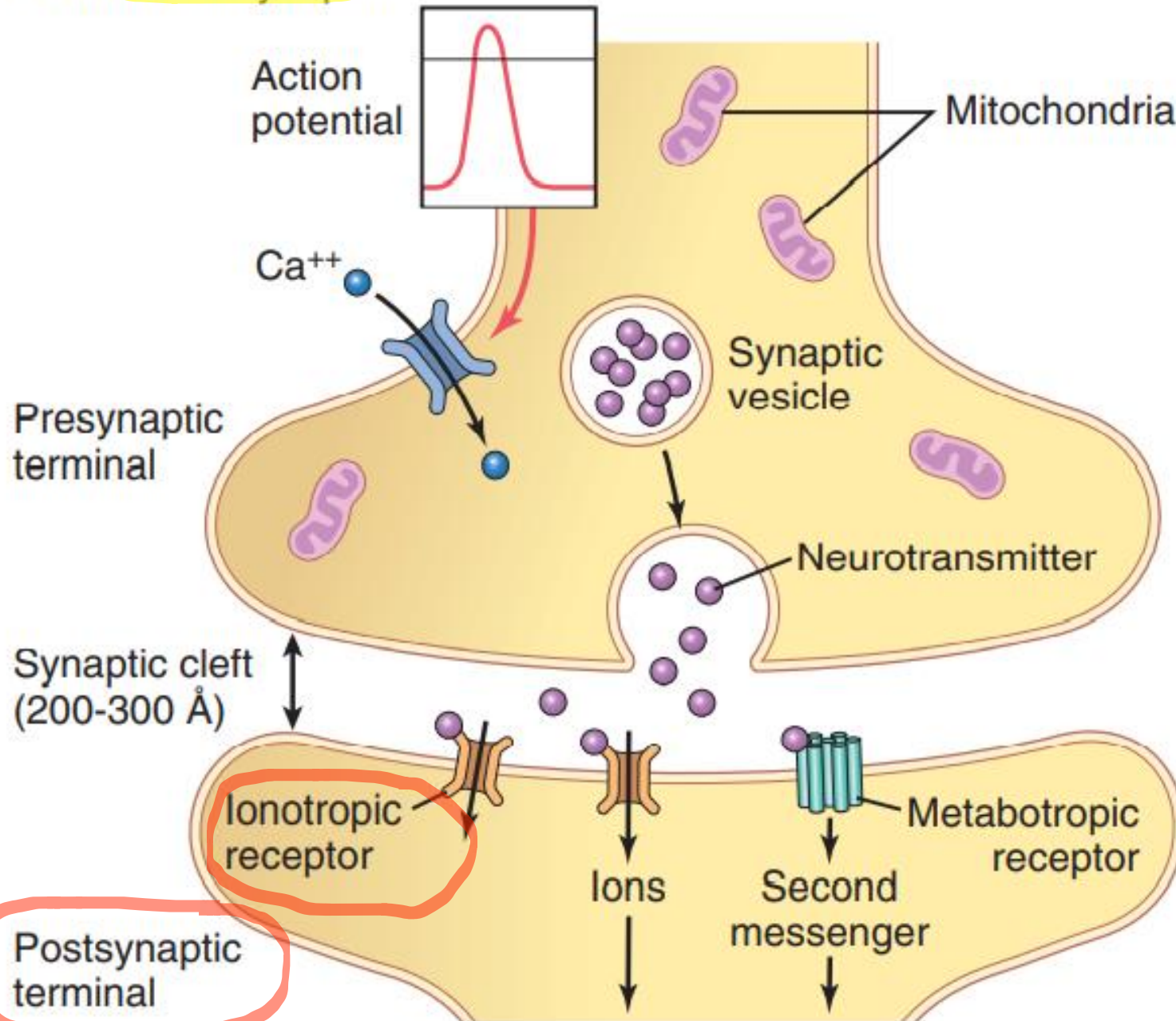
Presynaptic terminals

- 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.

Neurotransmitter Receptors

- **1. Ionotropic Receptors**
- **Ligand-gated ion channels**
- Activated directly by neurotransmitter binding
- Cause **rapid** membrane potential changes (fast-acting, short duration)
- Allow ion flow such as:
 - $\text{Na}^+ \rightarrow$ Excitation
 - $\text{Cl}^- \rightarrow$ Inhibition
- **2. Metabotropic Receptors**
- **G-protein coupled receptors (GPCRs)**
- Activate **second messengers**
- Slower onset, **longer duration** (e.g., long-term memory)
- Can cause structural and metabolic changes

A Chemical synapse

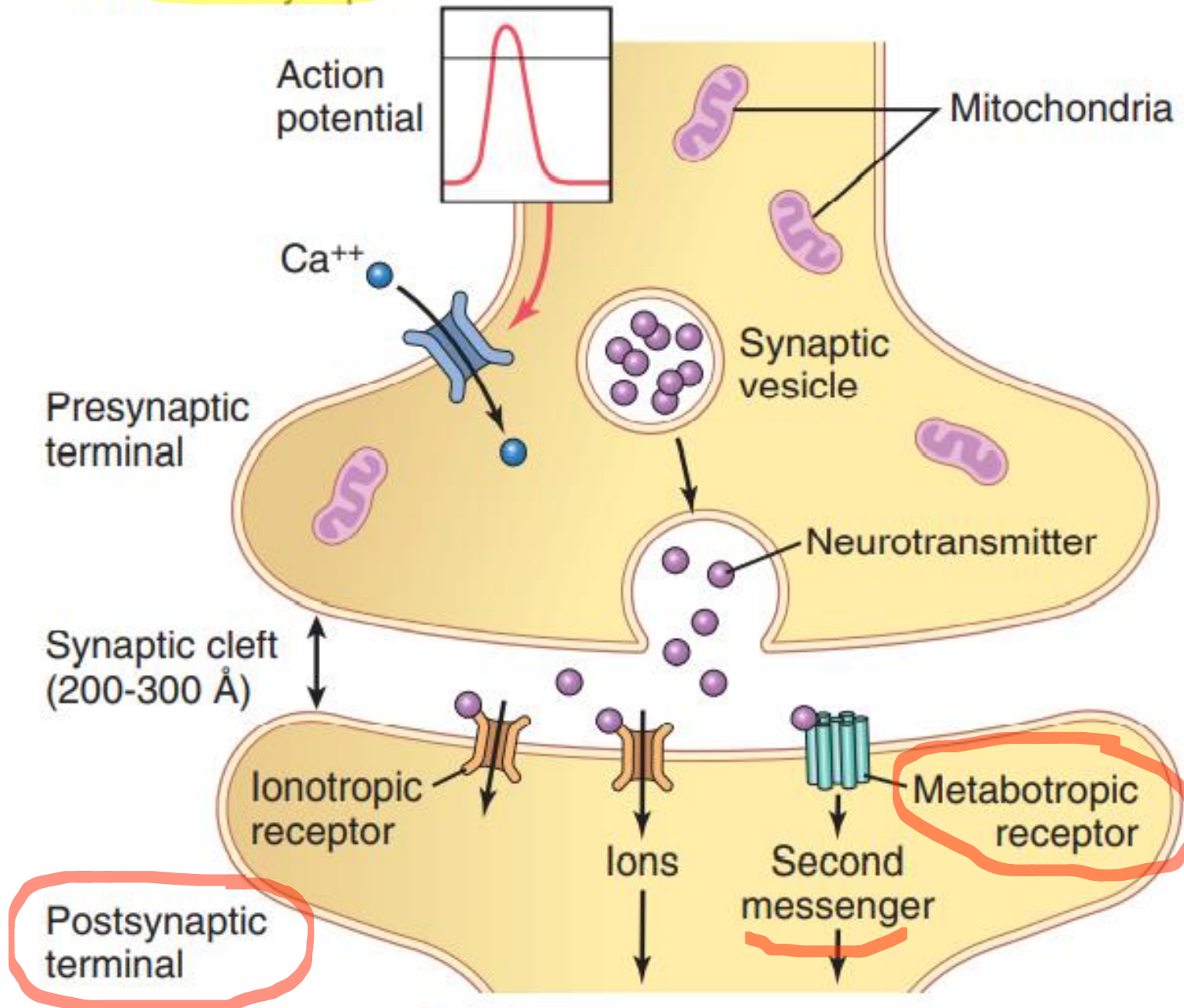


Cation and anion channels

Excitation (Na⁺) or inhibition (Cl⁻)



A Chemical synapse



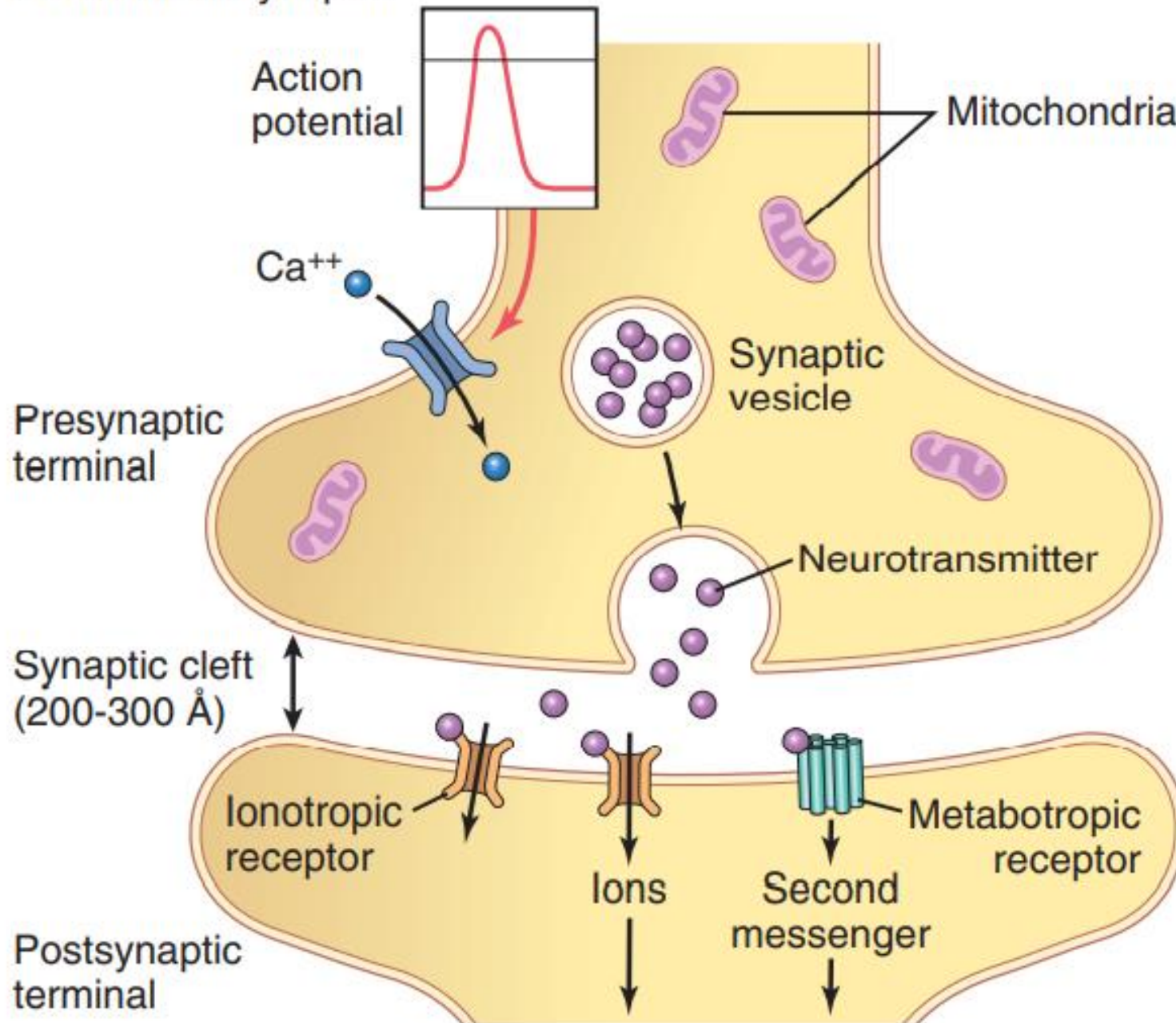
Prolonged
action
e.g.
memory



Fate of Neurotransmitters

- After binding:
- Broken down by **enzymes**
- **Diffuse away** from the synaptic cleft
- **Reuptaken** and possibly **resynthesized** in presynaptic terminal

A Chemical synapse



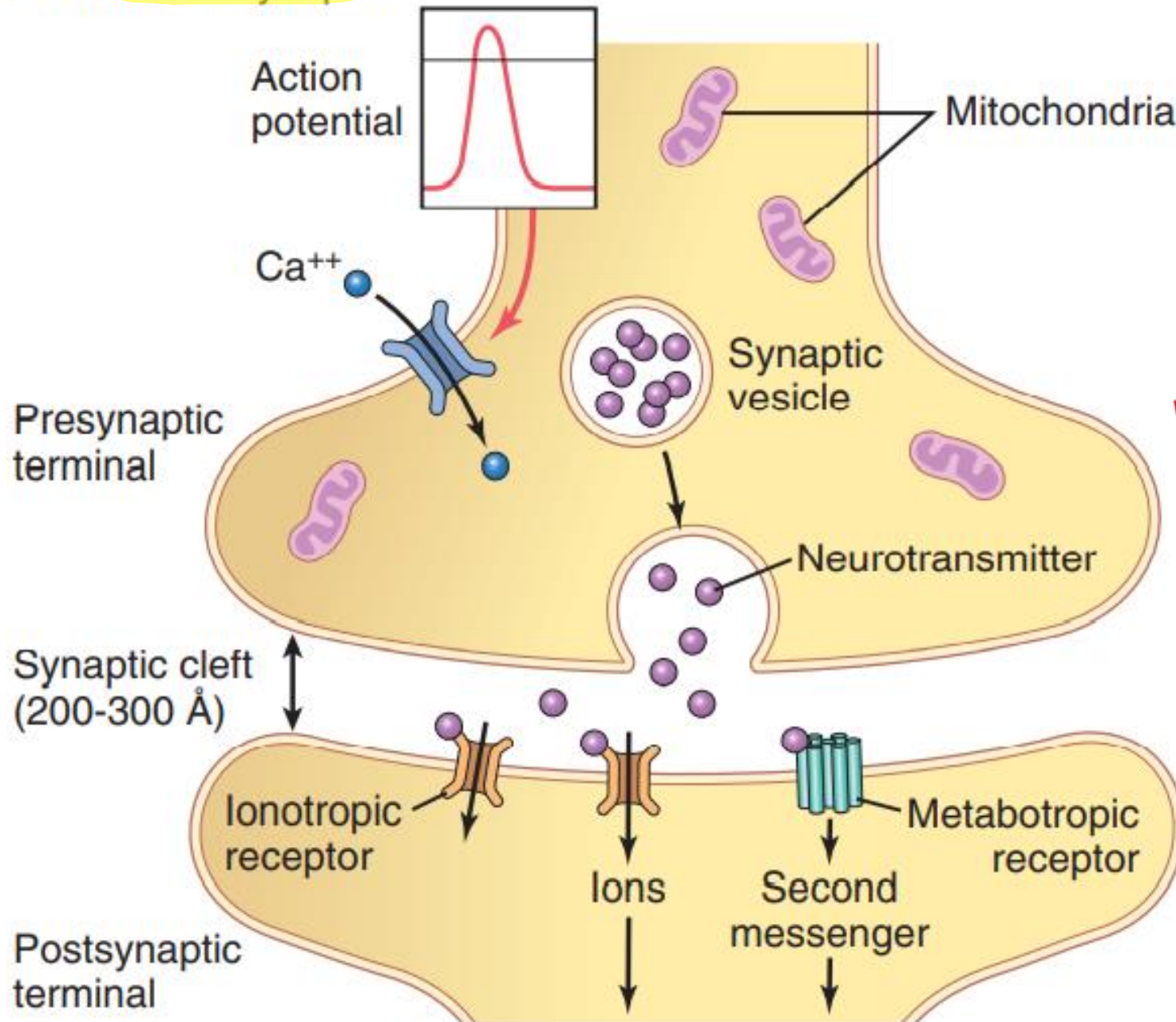
Principle of one-way conduction at chemical synapse



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



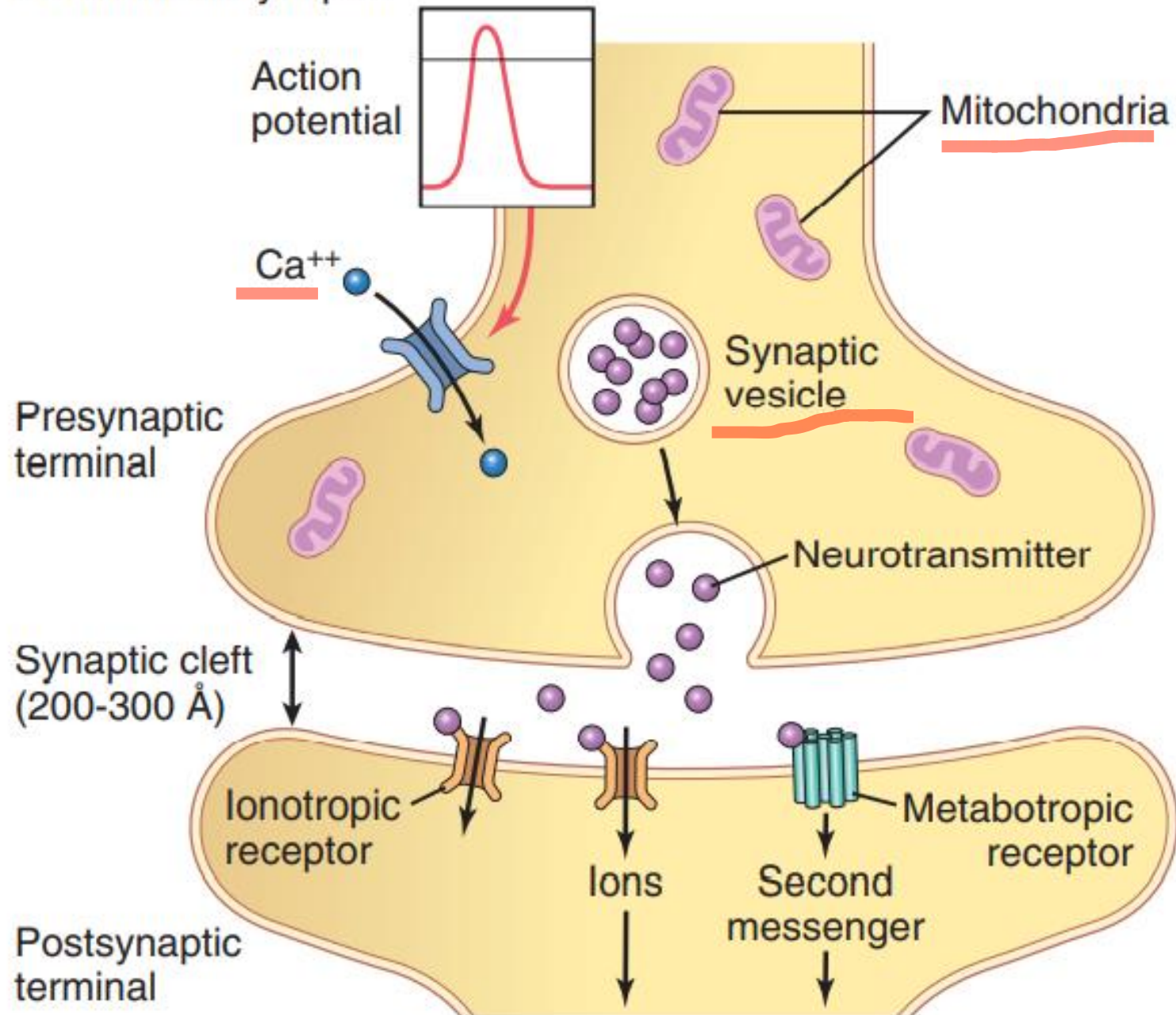
Synaptic delay

- 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.

A Chemical synapse



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

- 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.