بسم الله الرحمن الرحيم

Physiology | Lecture 3

# Neurotransmitters and changes in membrane potential

Done by : Heba Salah

# Introduction to Neurophysiology 3

# Neurotransmitters and changes in membrane potential

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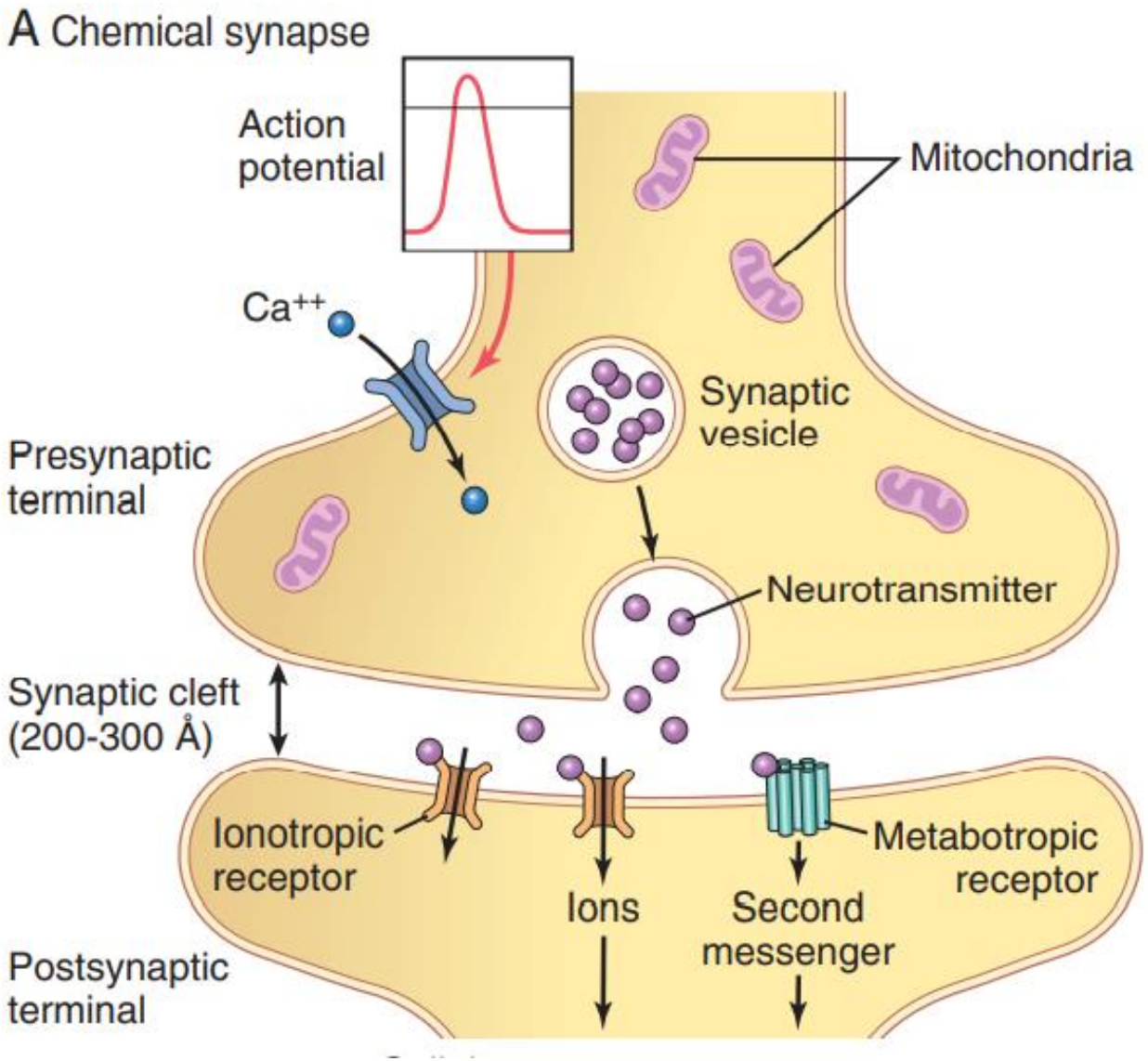



Neurotransmitters are chemicals. The word “neuro” means that these chemicals are secreted by neuronal cells, specifically from the presynaptic neuron. The word “transmit” refers to their role in transmitting signals from one neuron to another. Sometimes, they are also called neuromodulators.

**<u>Neuromodulators</u> are chemicals that adjust how neurons communicate, by changing the strength or duration of signals rather than directly causing a response.**

There are many ways to classify neurotransmitters, but in general, they are classified into small-molecule neurotransmitters and neuropeptides.

## Small-Molecule, Rapidly Acting Transmitters

are a type of neurotransmitters. They are also called neuromodulators, because rather than changing the permeability of the postsynaptic neuron, they may cause different metabolic effects, thus modulating the function of the postsynaptic neuron.

**This type is divided into subclasses:**

### Class I

Acetylcholine (a choline derivative)

### Class II: The Amines (amino derivatives. )

Norepinephrine
Epinephrine
Dopamine
Serotonin

→ These neurotransmitters can act as either inhibitory or excitatory, depending on the type of receptors they bind to on the postsynaptic neuron.

Melatonin
Histamine

### Class III: Amino Acids

Gamma-aminobutyric acid (GABA)
Glycine

→ Inhibitory neurotransmitters

Glutamate
Aspartate

→ Excitatory neurotransmitters

### Class IV → Different molecules

ATP
Arachidonic acid
Nitric oxide
Carbon monoxide

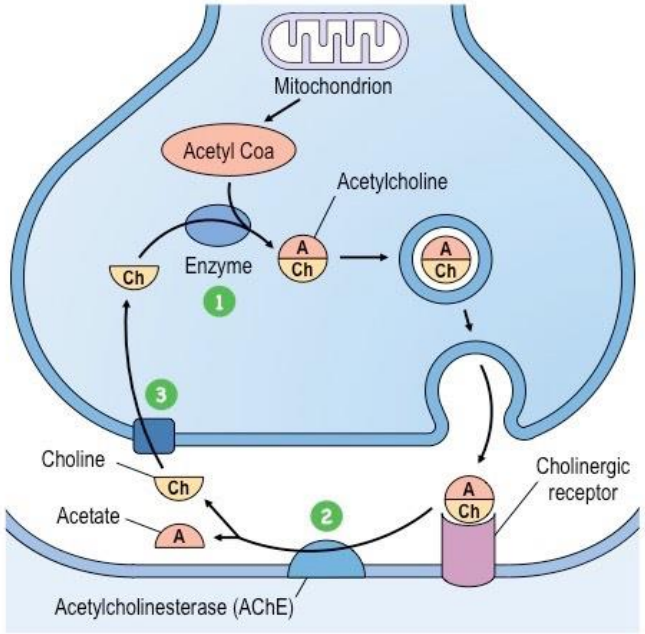
→ Gases

-The classes of small molecule transmitters can be classified based on their effect, whether they are excitatory or inhibitory. This means that when the molecule binds to a receptor on the postsynaptic neuron, it produces either an excitatory effect or an inhibitory effect. These transmitters are also subdivided into different classifications.

-The function depends on the complex ->the (neurotransmitter-receptor) complex which is formed when the neurotransmitter binds to its receptor. For example, dopamine with a D1 receptor will cause excitation, whereas dopamine with a D2 receptor may cause inhibition of the postsynaptic neuron.

The science of neurotransmitters is continuously evolving and is crucial when discussing health, disease, and their effects. Neurotransmitters have different functions, characteristics, and effects on our health, particularly on the health of the nervous system. For example, when we talk about acetylcholine, it comes to mind as the main neurotransmitter released at the neuromuscular junction, which is the synapse between a motor neuron and a muscle, specifically when discussing the motor neuron and skeletal muscles. On the other hand, epinephrine is released by the sympathetic nervous system, and we know that it triggers a sequence of effects resulting from the activation of this sympathetic nervous system.

A small molecule neurotransmitter has several characteristics. For example, acetylcholine can be synthesized locally within the presynaptic neuron at its terminal, because the machinery, the enzymes, and the energy substrates are all available within this presynaptic terminal. For example, choline combines with acetyl-CoA, and in the presence of the enzyme choline acetyltransferase, it will be converted into acetylcholine. Then, this acetylcholine will be packaged and stored within vesicles here in the terminal, so they can be ready until the signal comes, and calcium can influx through voltage-gated calcium channels. So, exocytosis can occur in this case, and acetylcholine will be released into the synaptic cleft. Then, acetylcholine will bind to a specific receptor on the postsynaptic neuron. This receptor is actually a cholinergic receptor. Now, this binding usually activates ionotropic receptors, which means changing the permeability of the postsynaptic membrane, resulting in a postsynaptic potential. But this binding shouldn't last forever. So, we should get rid of this binding between acetylcholine and the receptor. That occurs, particularly in the case of small molecules, through mechanisms that decrease the concentration of the neurotransmitter in the synaptic cleft. Some of these neurotransmitters will diffuse away from the cleft, some will be reuptaken into the presynaptic neuron, and others, like acetylcholine, will be degraded by a specific enzyme. In this case, it's acetylcholinesterase. It will degrade acetylcholine into choline and acetate, and now the choline will be reuptaken into the presynaptic neuron to be resynthesized again.




1. Acetylcholine (ACh) is made from choline and acetyl CoA
2. In the synapse, ACh is rapidly broken down by the enzyme **acetylcholinesterase (AChE)**
3. Choline is transported back into the axon terminal and used to make more ACh

# Types of synaptic transmitters

- The **small-molecule, rapidly acting transmitters:** cause most acute responses of the nervous system, such as transmission of sensory signals to the brain and of motor signals back to the muscles.

- The **neuropeptides,** in contrast, usually cause more prolonged actions, such as long-term changes in numbers of neuronal receptors, long-term opening or closure of certain ion channels, and possibly long-term changes in numbers of synapses or sizes of synapses.

# Small-molecule, rapidly acting transmitter

- In most cases, they are synthesized in the cytosol of the presynaptic terminal and are absorbed by means of active transport into the transmitter vesicles in the terminal.

- Each time an action potential reaches the presynaptic terminal, a few vesicles at a time release their transmitter into the synaptic cleft. This action usually occurs within a millisecond or less.

# Small-molecule, rapidly acting transmitter

- The subsequent action on the membrane receptors of the postsynaptic neuron usually also occurs within another millisecond or less.

- Most often the effect is to increase or decrease conductance through ion channels.

# Small-molecule, rapidly acting transmitter

- Vesicles that store and release small-molecule transmitters are continually recycled and used over and over again.

- After they fuse with the synaptic membrane and open to release their transmitter substance, the vesicle membrane at first simply becomes part of the synaptic membrane.

# Small-molecule, rapidly acting transmitter

- Within seconds to minutes, the vesicle portion of the membrane invaginates back to the inside of the presynaptic terminal and pinches off to form a new vesicle.

- The new vesicular membrane still contains appropriate enzyme proteins or transport proteins required for synthesizing and/or concentrating new transmitter substance inside the vesicle.

# Neurotransmitters

- Acetylcholine is secreted by motor neurons at neuromuscular junctions (NMJ).
- Glutamate is an excitatory neurotransmitter.
- Glycine and GABA are inhibitory transmitters.
- **Serotonin** is related to mood pathways, and pain inhibitory pathways.

GABA is the primary inhibitory neurotransmitter, along with glycine. However, certain infections can affect GABA function. For example, tetanus toxin prevents the release of GABA from specific neurons. As a result, the absence of inhibitory signaling leads to unopposed excitatory activity, which causes muscle spasms in affected patients.

is derived from tryptophan, that's why foods that contain the element tryptophan can help improve your mood when you eat these types of food. Also, it is important in patients with depression, as in patients with depression, we give them what we call Selective Serotonin Reuptake Inhibitors (SSRI). So from their name, you know that they prevent the reuptake of serotonin. Again, preventing the reuptake of neurotransmitters means that you increase the concentration of these neurotransmitters in the synaptic clefts. So, you increase their effect, and we say that serotonin is linked to improving the mood pathways, because when we give patients with depression an SSRI, this improves their mood.

# Dopamine

- Dopamine is secreted by neurons that originate in the substantia nigra to control movement of muscles.
- Dopamine is present in pleasure pathways.
- The effect of dopamine can be inhibitory or excitatory depends on the type of the receptor.

**Disorders in the dopaminergic neurons at the level of the substantia nigra, which is in the brainstem, affect the control of muscle movement, as this area is considered part of the basal nuclei. So, this impairment will affect our muscle movement, and this is most specifically related to a common disease that we know of, which is Parkinson's disease.**

**Also, dopamine is related to the pleasure sensation pathway. One example of the implication of that is cocaine. Cocaine actually works to prevent the reuptake of dopamine, and consequently, dopamine will accumulate in the synaptic cleft. So, it will continue binding to the postsynaptic neuron and act on these postsynaptic neurons. And as we said, it is part of the pleasure pathway, so that's why cocaine uptake will give this kind of pleasure sensation. But later on, that will cause addiction and the consequences of addiction.**

# Nitric Oxide

is a gas, and mostly it is kind of a neuromodulator, rather than just binding to ionotropic receptors and changing the permeability. It can do more structural changes within the postsynaptic neuron.

- It is not preformed and stored in vesicles in the presynaptic terminal as are other transmitters.

- Instead, it is synthesized almost instantly as needed and then diffuses out of the presynaptic terminals over a period of seconds rather than being released in vesicular packets.

- Next, it diffuses into postsynaptic neurons nearby.

# Nitric Oxide

- In the postsynaptic neuron, it usually does not greatly alter the membrane potential but instead changes intracellular metabolic functions that modify neuronal excitability for seconds, minutes, or longer.

# Neuropeptides( Large molecules)

| Hypothalamic-Releasing Hormones | Peptides that Act on Gut and Brain | From Other Tissues |
|---|---|---|
| Thyrotropin-releasing hormone | Leucine enkephalin | Angiotensin II |
| Luteinizing hormone–releasing hormone | Methionine enkephalin | Bradykinin |
| Somatostatin (growth hormone inhibitory factor) | Substance P | Carnosine |
| **Pituitary Peptides** | Gastrin | Sleep peptides |
| Adrenocorticotropic hormone | Cholecystokinin | Calcitonin |
| β-Endorphin | Vasoactive intestinal polypeptide | |
| α-Melanocyte-stimulating hormone | Nerve growth factor | |
| Prolactin | Brain-derived neurotropic factor | |
| Luteinizing hormone | Neurotensin | |
| Thyrotropin | Insulin | |
| Growth hormone | Glucagon | |
| Vasopressin | | |
| Oxytocin | | |

has many systemic effects, especially when we are talking about blood pressure and fluid regulation.

There are many types of neuropeptides, generally acting as hormones, such as hypothalamic releasing hormones and pituitary hormones. Some of these hormones are released at the level of the gut, but also act in the brain. For example cholecystokinin (sometimes confused with cholesterol) is released from the stomach to act on the gallbladder, causing it to contract and release bile, and also to act on the brain to give the feeling of satiety, or feeling full.

# Neuropeptides

- Actions are usually **slow** and in other ways quite different from those of the small-molecule transmitters.

- **Not synthesized in the cytosol of the presynaptic terminals but in the neuronal cell body**.

# Neuropeptides

- Because of this laborious method of forming the neuropeptides, much **smaller quantities** of neuropeptides than of the small-molecule transmitters are usually released.

- This difference is partly compensated for by the fact that the neuropeptides are generally a thousand or more times as **potent** as the small-molecule transmitters.

# Neuropeptides

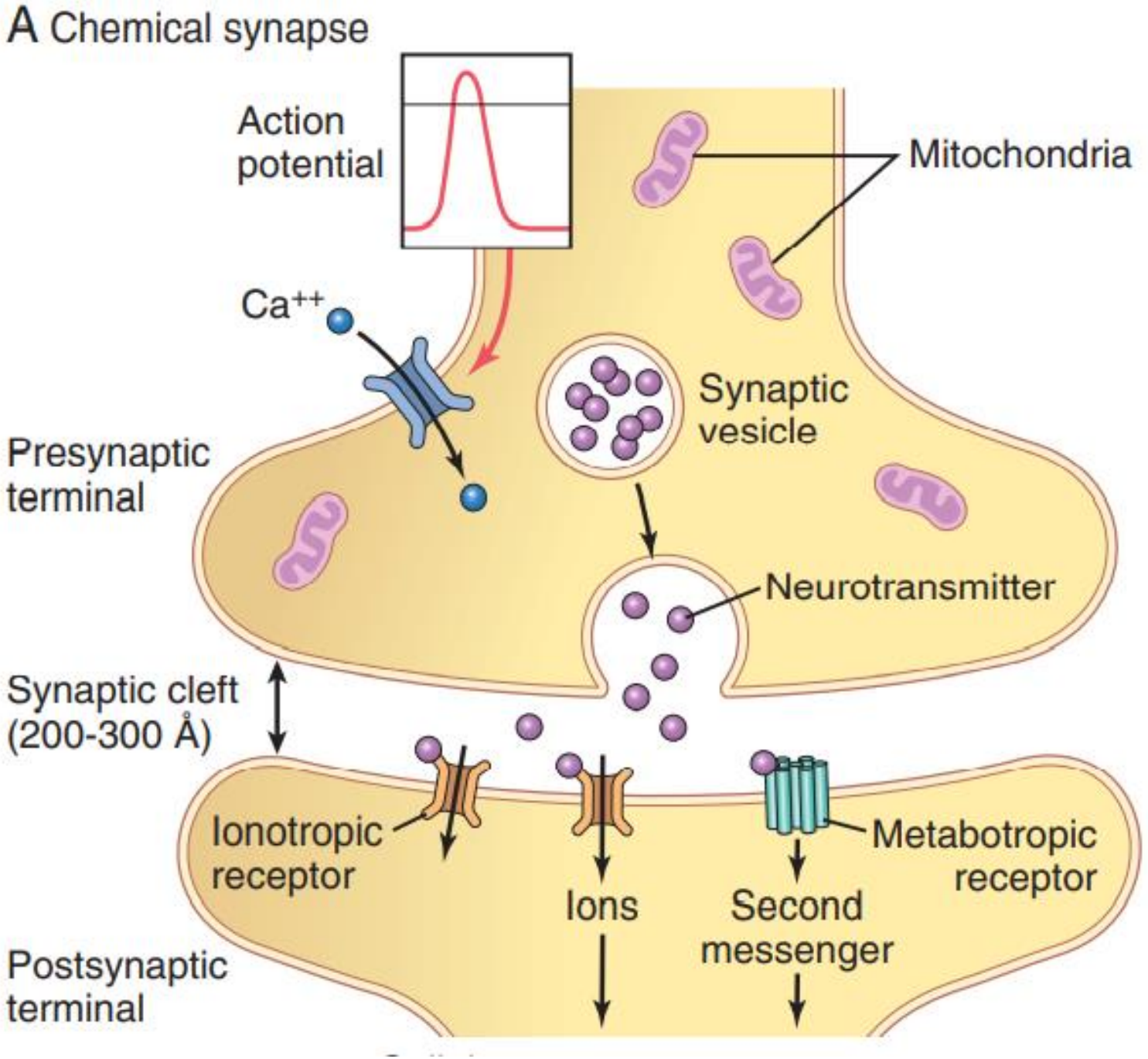
- The vesicles are transported by axonal streaming of the axon cytoplasm, **traveling at the slow rate** of only a few centimeters per day.
- Vesicle is autolyzed and is not reused.
- Small quantities are released, but more potent.

There is more delay in the effect, or more prolonged action, of the neuropeptides, because most of them will act on a metabotropic receptor rather than an ionotropic receptor. So this will change the metabolism within the neuronal cell, for example causing upregulation or downregulation in certain receptor. They may cause a change in synapse area. They may change the enzymatic activity within this postsynaptic neuron. So most of them actually are called neuromodulators rather than neurotransmitters, so they are not only binding to an ionotropic receptor that transmits the signal changing the permeability, but they can modulate the function of the postsynaptic neuron to have more prolonged effect compared to the small molecular neurotransmitters.

# Neuropeptides

- Another important characteristic of the neuropeptides is that they often cause much more **prolonged actions**.

- Some of these actions include prolonged closure of calcium channels, prolonged changes in the metabolic machinery of cells, prolonged changes in activation or deactivation of specific genes in the cell nucleus, and/or prolonged alterations in numbers of excitatory or inhibitory receptors. Some of these effects last for days, but others last perhaps for months or years.




When neurotransmitters bind to ionotropic receptors, the main effect is the alteration of the membrane potential by changing the permeability of specific ions.

# Basics of the membrane potential

The membrane potential is the result of a separation of charges between the intracellular (inside the muscle or neuron cell) and the extracellular space. At the resting membrane potential, specifically in a neuron, the potential is negative, meaning there are more negative charges inside the cell compared to the outside.

This separation is maintained by the lipid bilayer of the cell membrane, which is impermeable to ions. Therefore, ions cannot freely pass through the membrane; instead, they must move via specific ion channels.

The ions involved in generating and maintaining the membrane potential are both cations (positively charged) and anions (negatively charged). The most important ions are:

Sodium ($Na^+$) – a cation

Potassium ($K^+$) – a cation

Chloride ($Cl^-$) – an anion

These ions are distributed unequally between the intracellular and extracellular compartments:

The main extracellular cation is sodium ($Na^+$).

The main intracellular cation is potassium ($K^+$).

The main extracellular anion is chloride ($Cl^-$).

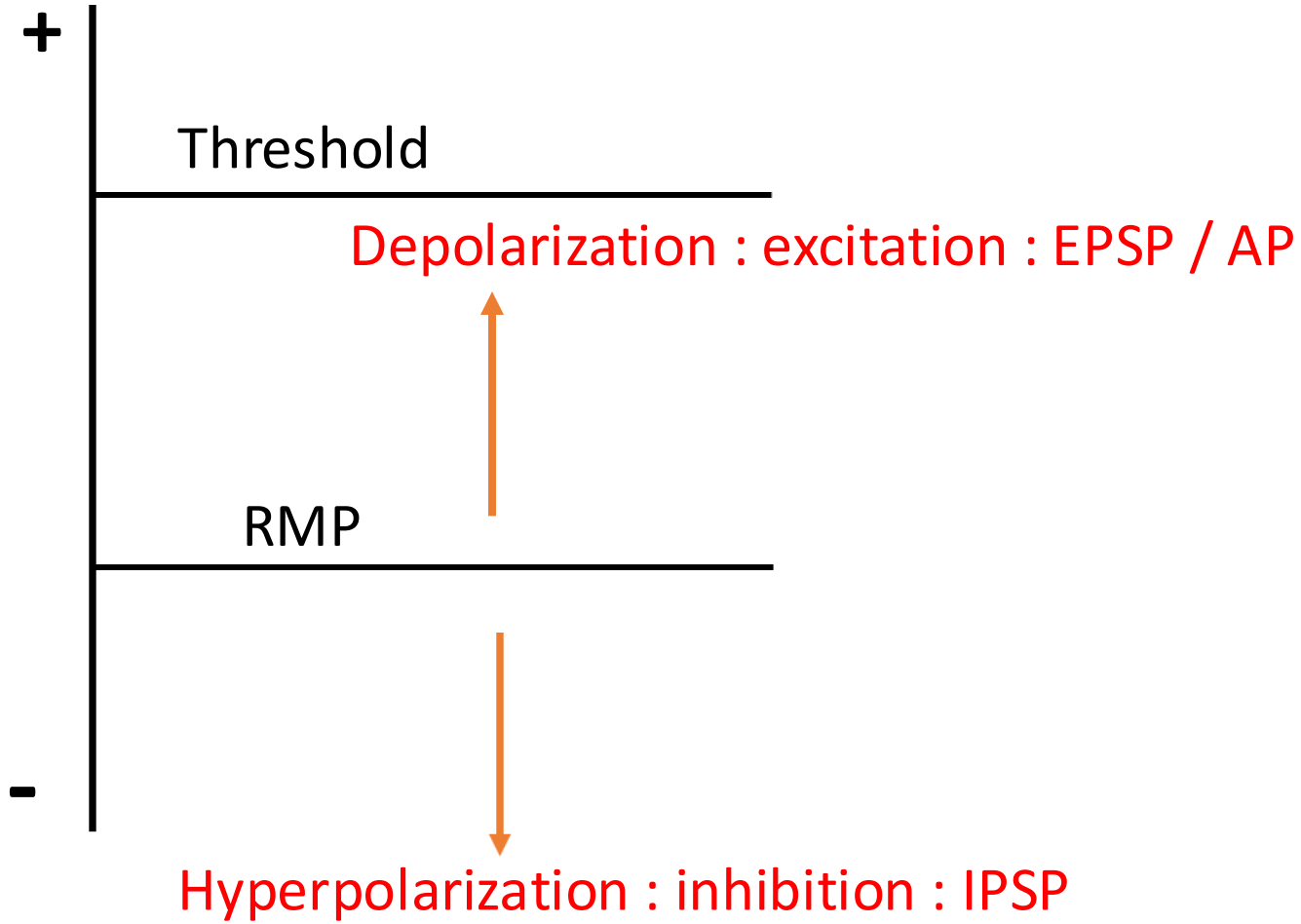
If these ions are allowed to move (if ion channels open), they follow their concentration gradients:

Sodium ($Na^+$) tends to move from the extracellular space to the intracellular space, bringing positive charges into the cell. This decreases the negativity of the membrane ( depolarization).

Chloride ($Cl^-$) moves from extracellular to intracellular, bringing more negative charge, which increases the negativity of the membrane potential — this is called hyperpolarization, and the membrane potential may become more negative ( –90 mV).

Potassium ($K^+$) tends to move from the intracellular to the extracellular space, taking positive charge out of the cell, which also increases the negativity inside the cell (also causing hyperpolarization).

# Basics of the membrane potential




**Hyperpolarization:**

**Polarization means the difference in charge between the intracellular and extracellular spaces. When the membrane potential reaches zero, it means there is no polarization. That's why any signal that decreases the negativity and moves the membrane potential toward the positive side is called depolarization. Hyperpolarization is caused by chloride influx and potassium efflux. Both of them increase the negativity inside the cell. This increases the distance from zero, which means it moves the membrane potential away from depolarization, increasing the polarity between the intracellular and extracellular spaces.**

**Depolarization happens when more positive ions, like sodium, enter the intracellular space. This decreases the negativity, and is mainly caused by sodium influx.**

**Depolarization leads to excitation of the neuron, while hyperpolarization causes inhibition of the neuron.**

Depolarization effect is called excitation of the neuron because the ultimate goal of the neuronal cell is to fire an action potential. To allow the signal to be transmitted over a longer distance, the action potential is required, as it is propagative and the only type of membrane potential change that can travel over long distances.

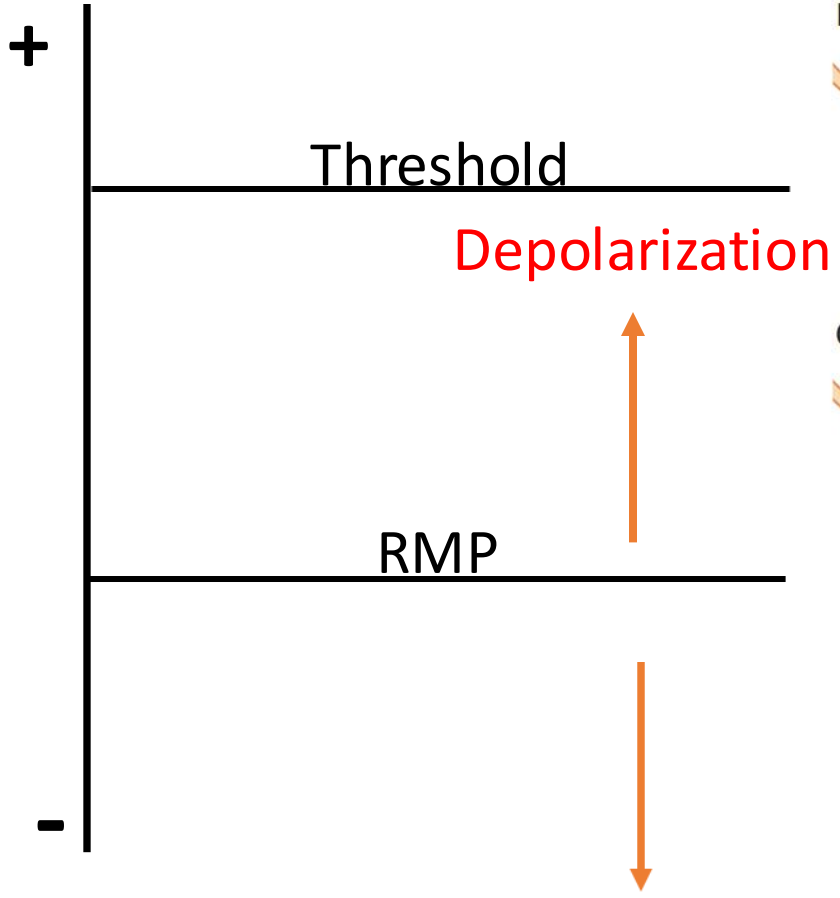
To make an action potential take place, there must be a threshold, which is a specific membrane potential in a specific neuronal cell. Once the membrane potential reaches this threshold, the action potential will fire. At that point, there will be activation of voltage-gated channels.

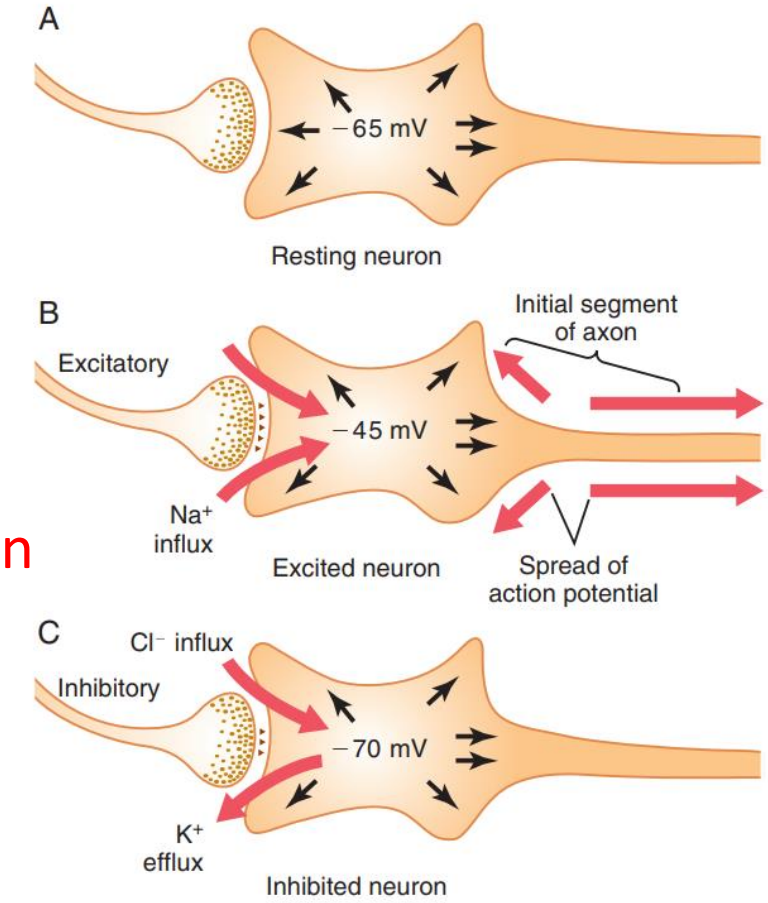
When a depolarization occurs — mainly by sodium ion influx — and brings the membrane potential closer to the threshold, this excites the neuron. If the membrane potential does not reach the threshold, it is called a sub-threshold stimulus.

This sub-threshold change still causes excitation in the post-synaptic neuron, producing a change in the membrane potential of the post-synaptic neuron. This change is called an excitatory post-synaptic potential (EPSP). If the membrane does reach the threshold, it results in an action potential, which occurs by depolarization of the membrane, mainly due to sodium influx.

On the other hand, if there is chloride influx or potassium efflux, this causes hyperpolarization, which moves the membrane away from the threshold, thus inhibiting the membrane. This results in an inhibitory post-synaptic potential (IPSP).

These concepts are very important to understand the function and changes within the nervous system.




This neuron, during the resting state, has a resting membrane potential of minus 65 millivolts. Assume there is a trigger that causes an influx of sodium ions. This leads to a change in the membrane potential toward depolarization, and the neuron becomes excited.

If this depolarization is strong enough to reach the threshold, then an action potential will fire. If not, the change will stay localized as an excitatory postsynaptic potential (EPSP), which is a type of graded potential.

If the trigger causes an influx of chloride ions or an efflux of potassium ions, this will change the membrane potential as well. In this case, it causes hyperpolarization, making the membrane potential more negative, and inhibiting the neuron.

# Resting membrane potential

- The basic cause of the change in membrane potential is a change in membrane permeability of the neuron, which allows ions to diffuse more or less readily through the membrane and thereby to change the membrane potential.

# Graded potential vs Action potential

**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. |

A graded potential can be called a receptor potential or an end-plate potential, depending on the site in the cell where the change in the electrical signal begins.
In contrast, an action potential is always called an action potential. You may specify it as a neural action potential or a muscular action potential, but it is still referred to as action potential.

because these are the sites where the incoming signals arrive.

AP starts at a specific site in the axon called the trigger zone or the axon hillock, and then propagates through the neuron.

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| **Types of channels** | Ligand-gated or mechanically-gated ion channels. | Voltage-gated channels for $Na^+$ and $K^+$. |

**Channels lead to changes in the membrane potential.**

**In the initial phase of the action potential, voltage-gated sodium channels are used first, followed by the activation of potassium channels.**

# Graded potential vs Action potential

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| **Conduction** | Decremental (not propagated); permit communication over short distances. | Propagate and thus permit communication over longer distances. |

**A graded potential can't travel over a long distance; it is localized, so it acts only over a short distance.**
**For example, if it occurs in the dendrites, it will act there and may reach the soma.**
**If it occurs in the soma, it will act locally within the soma, but it cannot transmit on its own into the axon or reach the terminal — unless it reaches the threshold and becomes an action potential.**

**An action potential is called a propagative type of electrical signal, because it can travel long distances.**
**In contrast, conduction in the graded potential is decremental, meaning it decreases and dies out over short distances, whereas the action potential maintains the same change in membrane potential throughout its propagation.**

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| **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. |

**the stronger the stimulus, the greater the amplitude of the change in the membrane potential.**

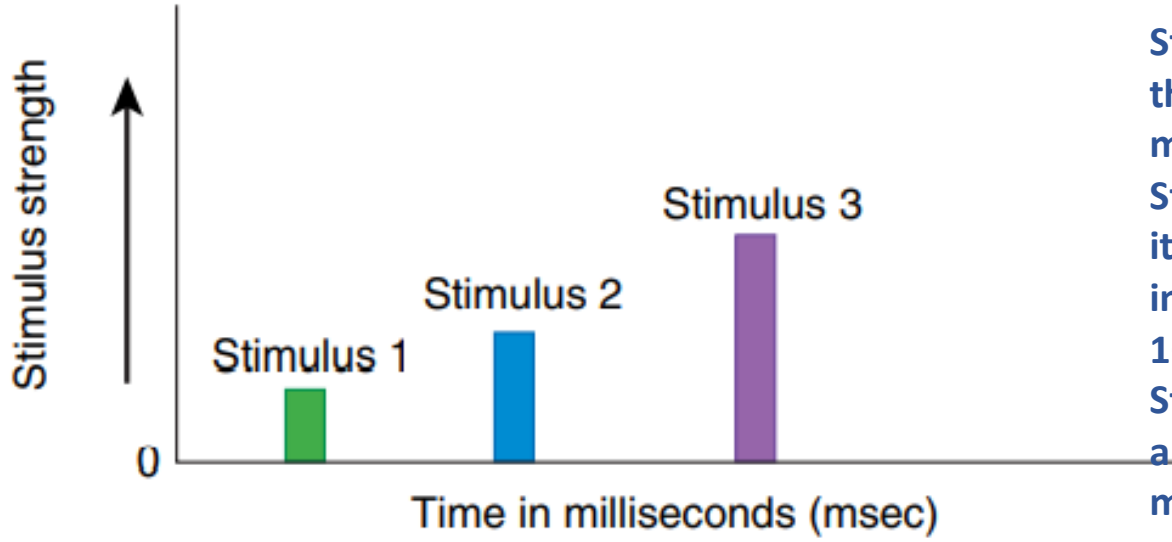
**no matter what the strength of the stimulus is, it follows the all-or-none principle, so it always has the same amplitude.**

The amplitude of a graded potential depends on the stimulus strength. The greater the stimulus strength, the larger the amplitude of the graded potential.

This figure shows the effect on the membrane potential of this neuron resulting from the stimuli.

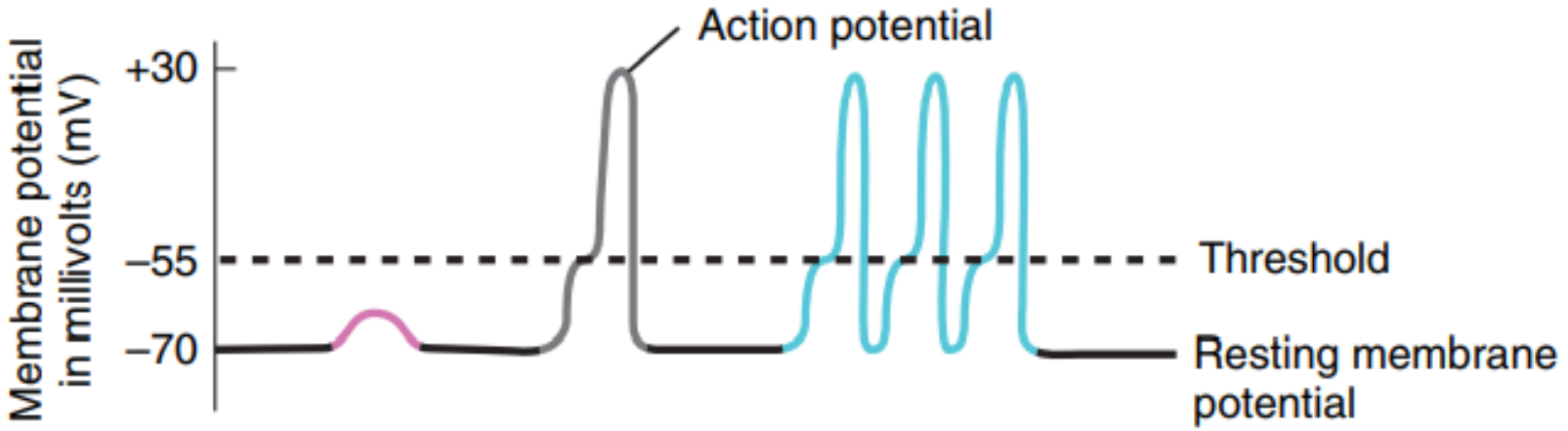

the stronger the stimulus, the greater the amplitude of the graded potential.

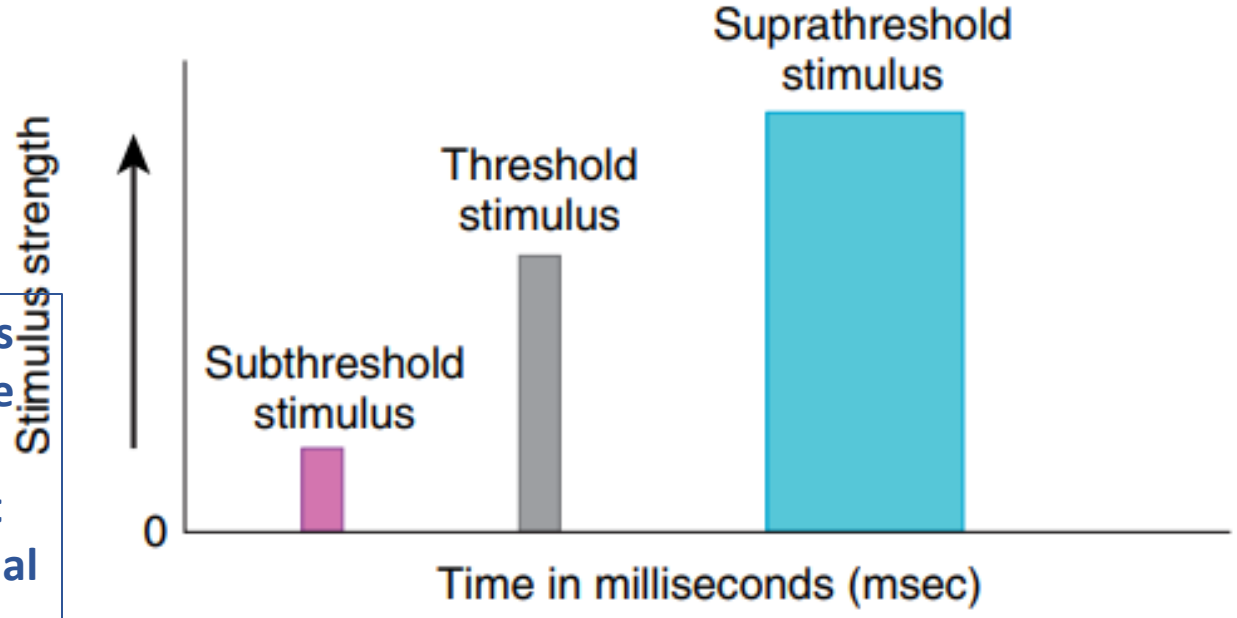
The figure shows three types of stimuli, each with a different strength.




Stimulus 1, the weakest stimulus, changes the membrane potential by, let's say, 5 millivolts.
Stimulus 2 is stronger than stimulus 1, so it increases the amplitude of the change in the membrane potential, let's say, by 10 millivolts.
Stimulus 3, the strongest stimulus, causes a larger change in magnitude, let's say 12 millivolts.

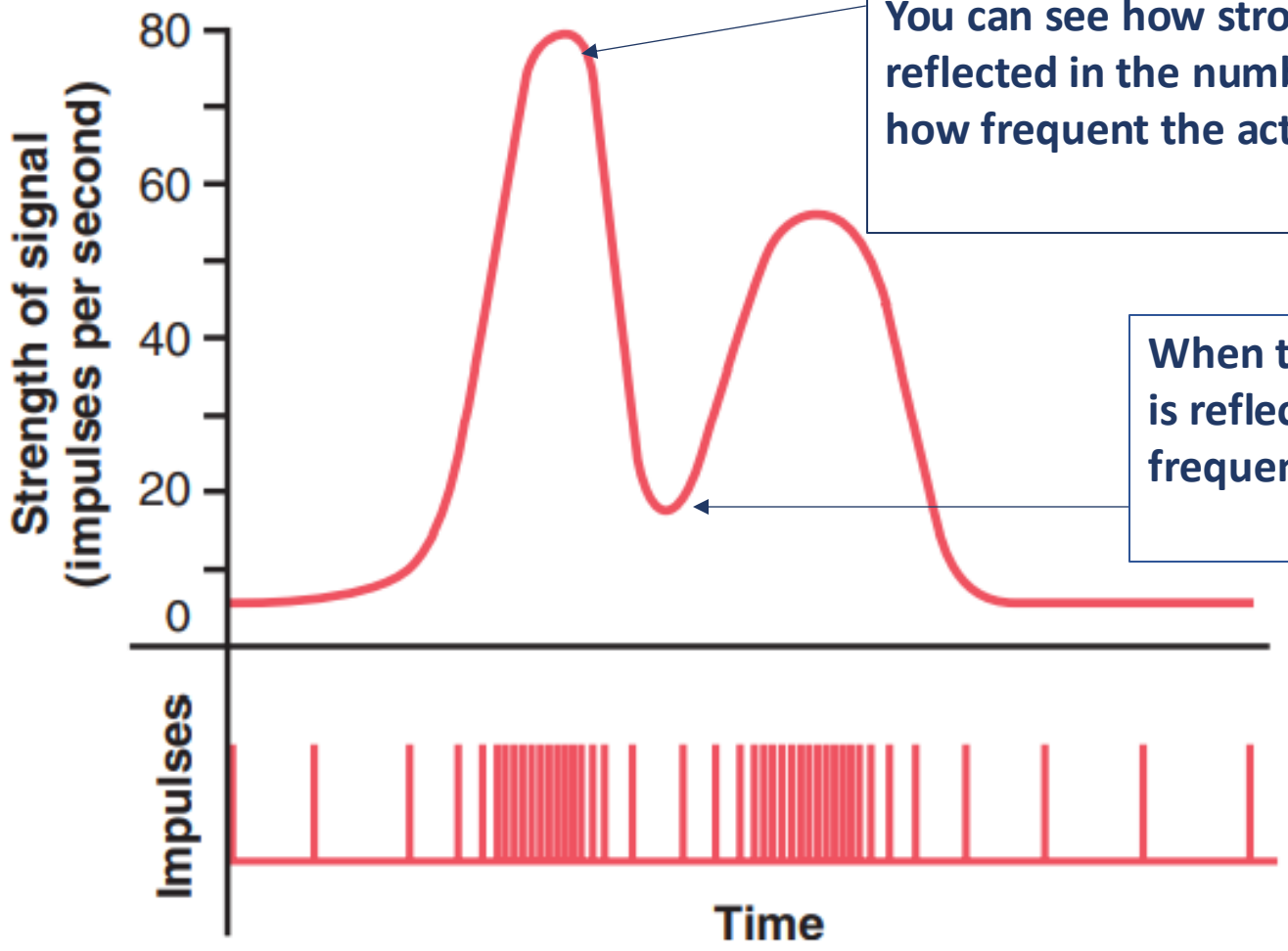
-This shows how the amplitude changes in graded potential versus action potential.




A sub-threshold stimulus is called like this because it does not reach the threshold, so it does not trigger an action potential

A supra-threshold stimulus does not increase the amplitude of the action potential, because the action potential follows the all-or-none principle —> it either occurs or it doesn't. However, as you can see, a stronger stimulus — a supra-threshold stimulus — may cause an increase in the frequency of action potential firing, but not an increase in its amplitude.




You can see how strong the stimulus is, and this will be reflected in the number of action potentials — that is, how frequent the action potentials are firing.

When the stimulus decreases, this is reflected by a decrease in the frequency of action potential firing.

This concept( the relationship between the strength of the stimulus and the frequency of action potential firing )is important when we discuss the nervous system in more detail later on.

For example, the cerebral cortex in the central nervous system receives signals from the same sensory pathway, and if it receives less frequent stimulation, it will decode it as a weaker stimulus. If the stimulation is more frequent, the cortex will interpret it as a stronger stimulus.

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| **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. |

**AP is shorter because the voltage-gated channels act very fast.**
**You can see the spike-like shape, and then it returns back within about 0.5 millisecond, up to a maximum of 2 milliseconds.**

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| **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. |

**In a graded potential, the stimulus can cause either a depolarization effect or a hyperpolarization effect. This is important when we talk about the sensory nervous system, as certain sensory receptors produce hyperpolarizing potentials, while others produce depolarizing potentials.**
**In both cases, these signals are important for the central nervous system, and they will be decoded as different signals.**

# Graded potential vs Action potential

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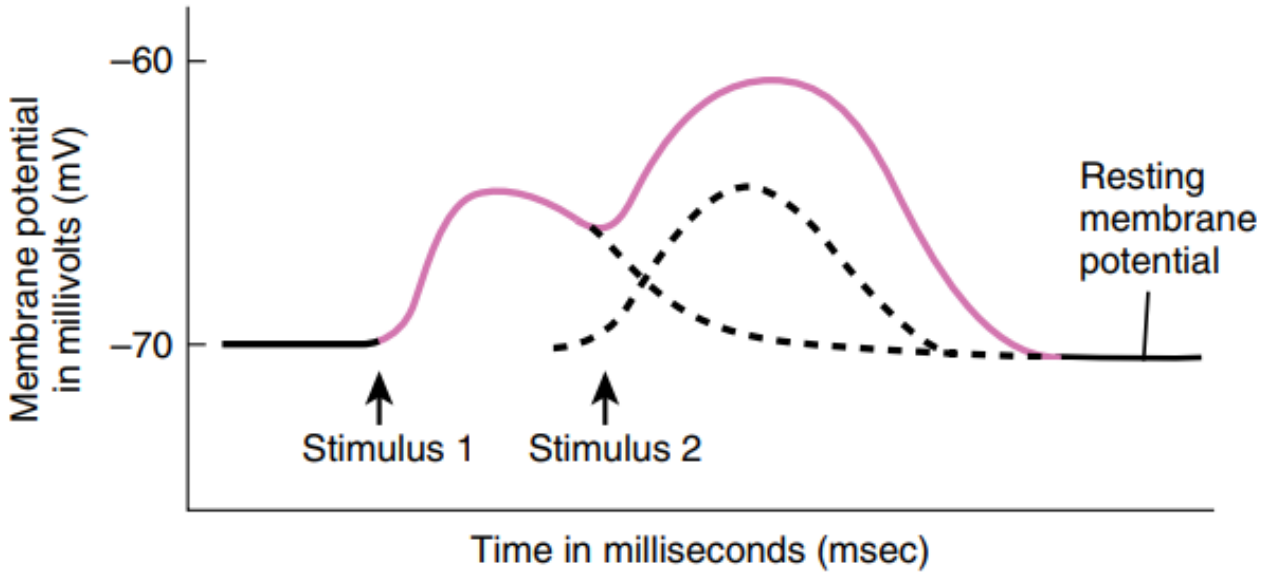
| **Refractory period** | Not present; summation can occur. | Present; summation cannot occur. |

**The more frequent the stimulus, the more summation can happen. This allows the signals to build up on each other, increasing the strength of the stimulus until it reaches the threshold.**

**there is a refractory period, during which no summation is allowed.**

# Summation in graded potential




Basically, what happens in summation: let's say you have stimulus 1, and it causes a change in the membrane potential, causing a depolarization —>let's say a graded potential.

As we said, it is of short duration, so it will die out and come back to the resting membrane potential.

As soon as there is another stimulus that comes to the same neuron, but before it comes back to the resting state , so again, while it is still within the change in the membrane potential, during the depolarization phase , another stimulus builds up on the first one.

So, we sum them together, we add them together, and this will cause a summation.

So you can see a stronger stimulus by combining both stimuli together.

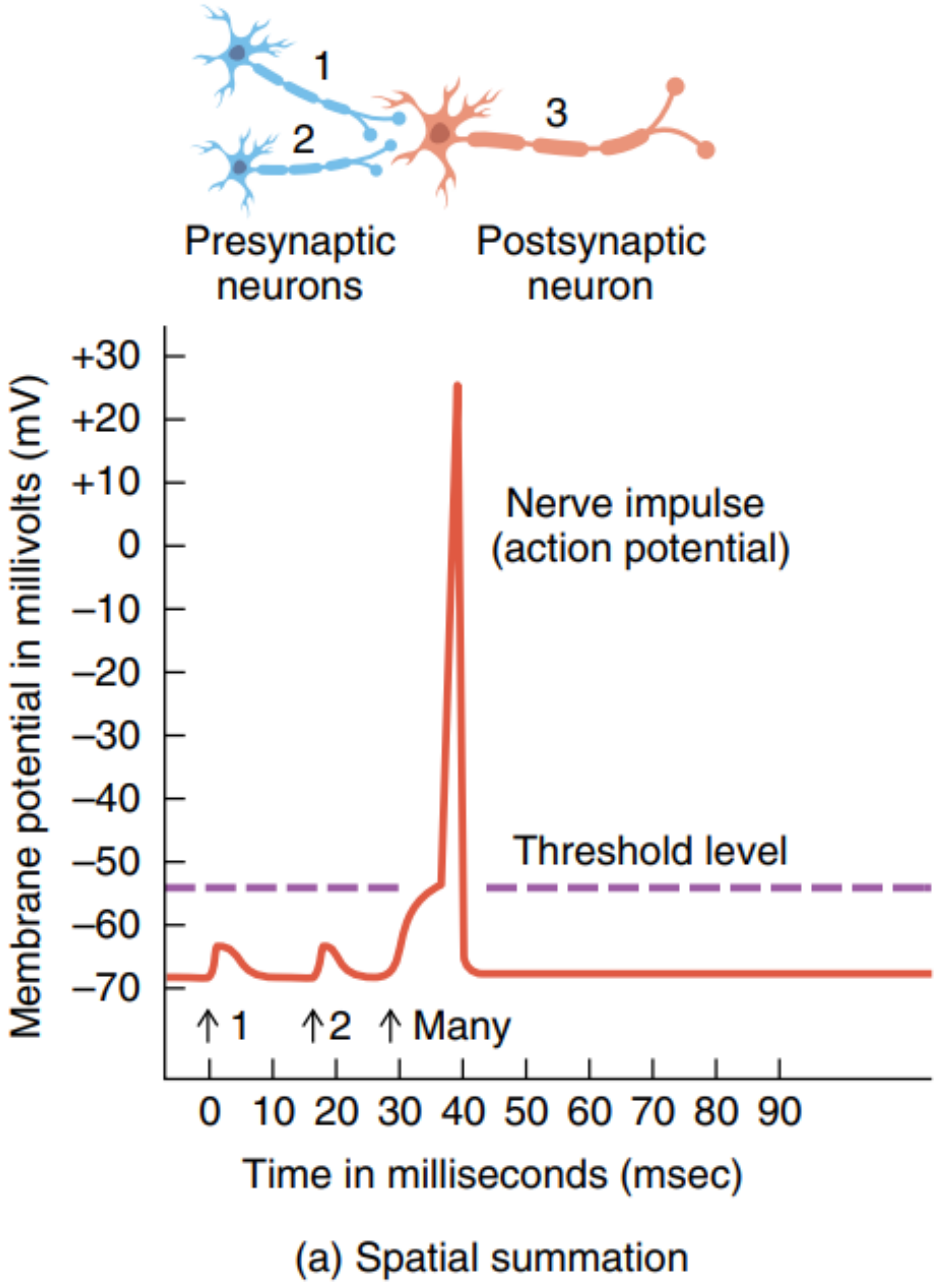
Remember that summation can occur — or does occur — in the case of a graded potential, and don't forget that graded potential can be depolarizing or can be hyperpolarizing.

So when you do the summation, always remember these signs, whether it is a positive sign or a negative sign.

# Spatial summation in neurons

two stimuli are different in spatial location, so they are located differently in space, but they come simultaneously to affect the same postsynaptic neuron.

- The effect of summing simultaneous postsynaptic potentials by activating multiple terminals on widely spaced areas of the neuronal membrane is called **spatial summation**.



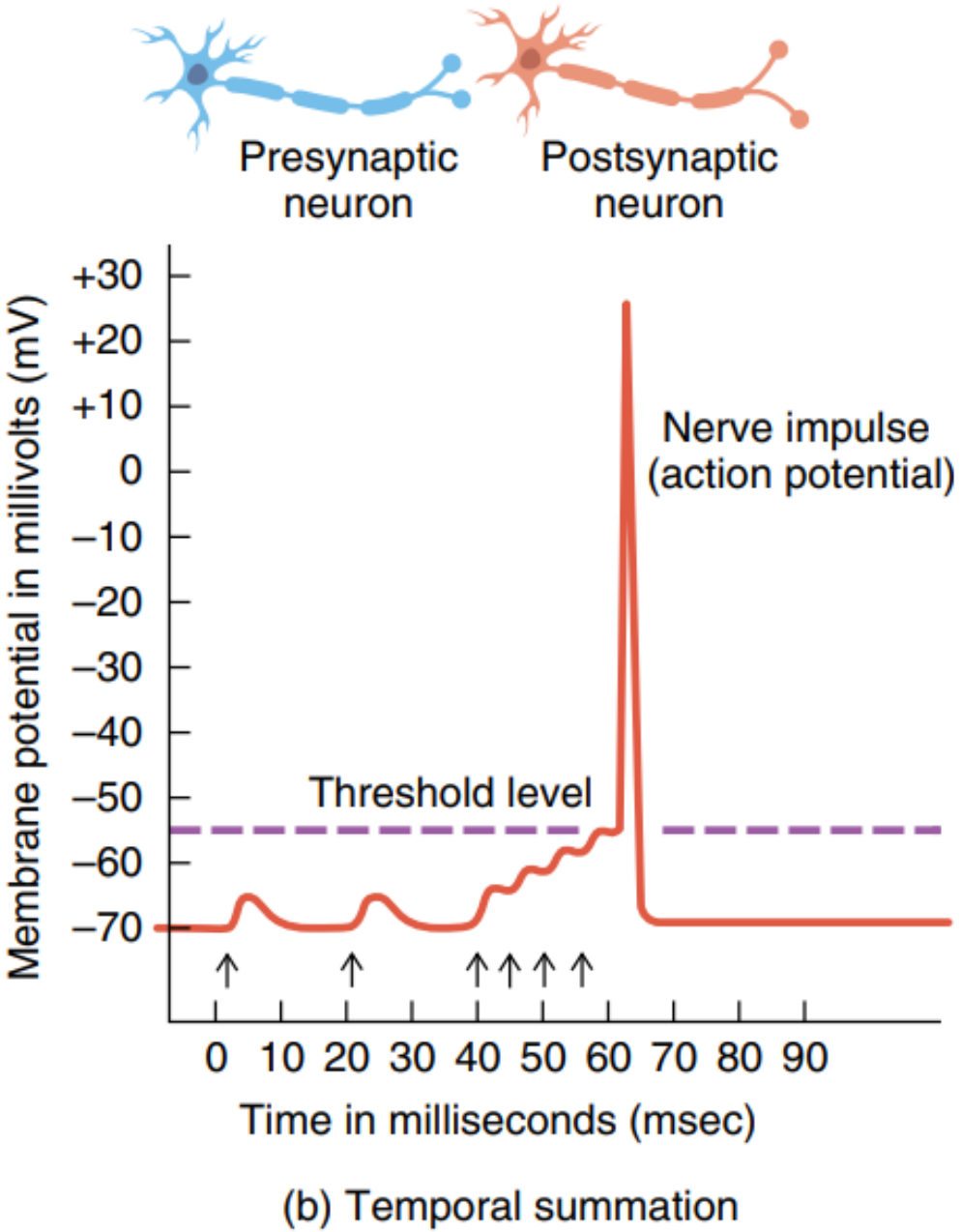

(a) Spatial summation

You can see here that Stimulus 1 from Neuron 1 caused depolarization, and Stimulus 2 from Neuron 2 also caused depolarization with a certain degree.
But at the same time, on Neuron 3, both of them are depolarizing.
Let's say this is +10, and this is another +10, you add them, it becomes +20.
So, action potential can take place because of the summation of these two stimuli that come from two separate neurons.
These stimuli are added together, and they facilitate or allow the firing of the action potential.
This is called spatial summation.

Temporal means time.

# Temporal summation in neurons

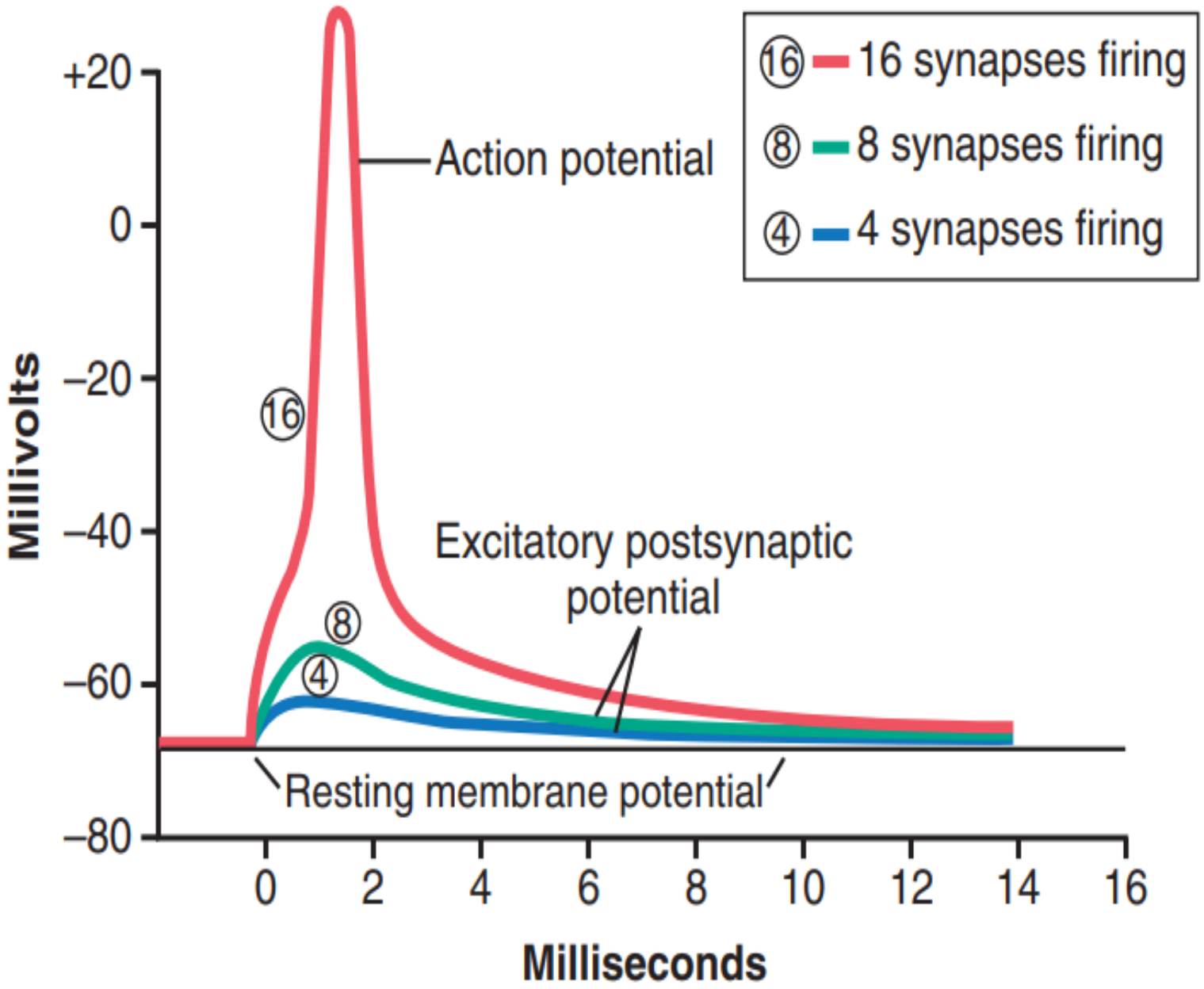
- Each time a presynaptic terminal fires, the released transmitter substance opens the membrane channels for at most a millisecond or so. However, the changed postsynaptic potential lasts up to 15 milliseconds after the synaptic membrane channels have already closed.
- Therefore, a second opening of the same channels can increase the postsynaptic potential to a still greater level, and the more rapid the rate of stimulation, the greater the postsynaptic potential becomes. Thus, successive discharges from a single presynaptic terminal, if they occur rapidly enough, can add to one another; that is, they can "summate." This type of summation is called temporal summation.




(b) Temporal summation

One pre-synaptic neuron synapses with a post-synaptic neuron, and this neuron fires a first signal, then in a short duration, another signal comes before the first one comes back to the resting state, and before the end of the absolute refractory period.
That's why they build up on each other. So the second one combines with the first one, because it comes before the first signal returns to resting, so they can add up to reach the threshold.

For example, sometimes with summation, we don't even reach the threshold, but most of the time, the aim of this summation, especially if they are both depolarizing, is to reach the action threshold, and then fire an action potential in the post-synaptic neuron.




This graph shows the change in the membrane potential.
See the blue line? It shows 4 excitatory synapses on the same postsynaptic neuron.
You can see the level of change in the membrane potential.
So, if you increase the number of excitatory synapses, you will increase the change in the membrane potential.
Here we have 8 synapses, and if you increase the excitatory synapses to 16, now it reaches the threshold and fires an action potential.
The more excitatory synapses, the more the summation, and the more the chance to reach an action potential.

# Time course of postsynaptic potentials

- When an excitatory synapse excites the anterior motor neuron, the neuronal membrane becomes highly permeable to sodium ions for 1 to 2 milliseconds.
- During this very short time, enough sodium ions diffuse rapidly to the interior of the postsynaptic motor neuron to increase its intraneuronal potential by a few millivolts, thus creating the EPSP.
- This potential then slowly declines over the next 15 milliseconds because this is the time required for the excess positive charges to leak out of the excited neuron and to re-establish the normal resting membrane potential.

# Time course of postsynaptic potentials

- The opposite effect occurs for an **IPSP**;
- The inhibitory synapse increases the permeability of the membrane to potassium or chloride ions, or both, for 1 to 2 milliseconds, and this action decreases the intraneuronal potential to a more negative value than normal, thereby creating the IPSP.
- This potential also dies away in about 15 milliseconds.

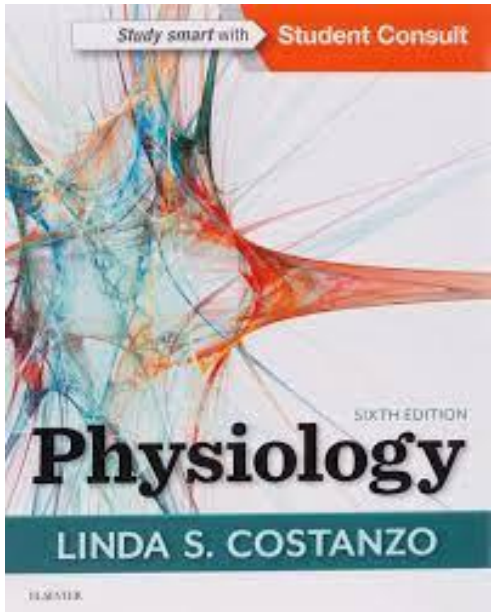
# Time course of postsynaptic potentials

- Other types of transmitter substances can excite or inhibit the postsynaptic neuron for much longer periods— for hundreds of milliseconds or even for seconds, minutes, or hours. This is especially true for some of the **neuropeptide transmitters**.

# Summation of IPSP and EPSP

- If an IPSP is tending to decrease the membrane potential to a more negative value while an EPSP is tending to increase the potential at the same time, these two effects can either completely or partially nullify each other.

# References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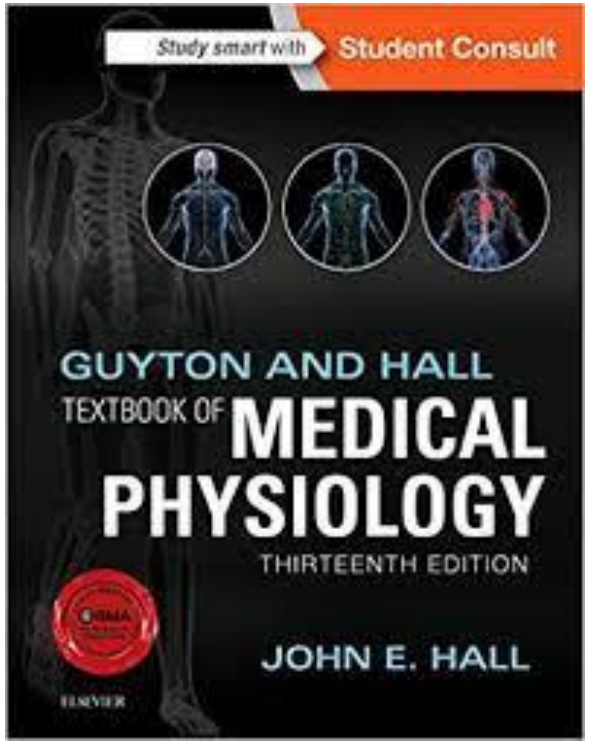
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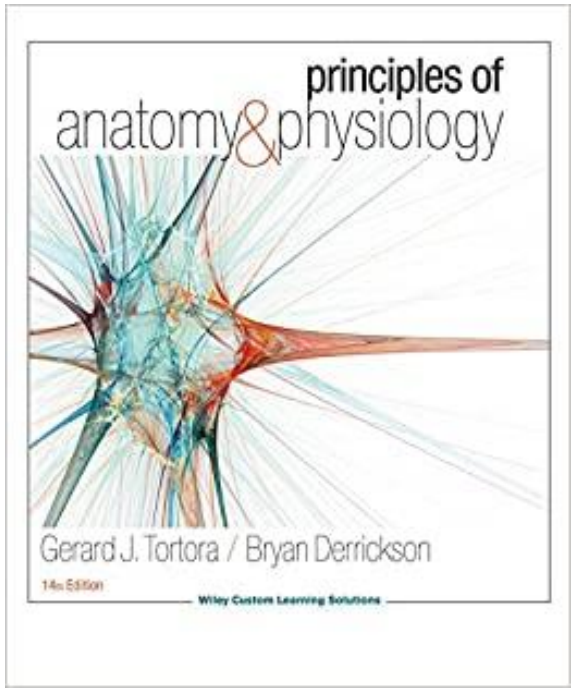
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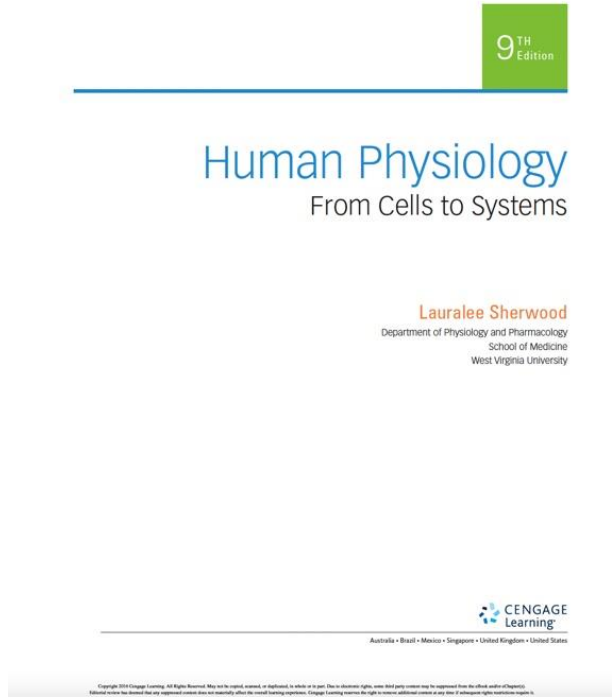
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Corrections from previous versions:

| Versions | Slide # and Place of Error | Before Correction | After Correction |
|---|---|---|---|
| V0 → V1 | Slide 16 | Neurotropic receptor | Ionotropic receptor |
| V1 → V2 | | | |

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