Action potential

Action potential phases

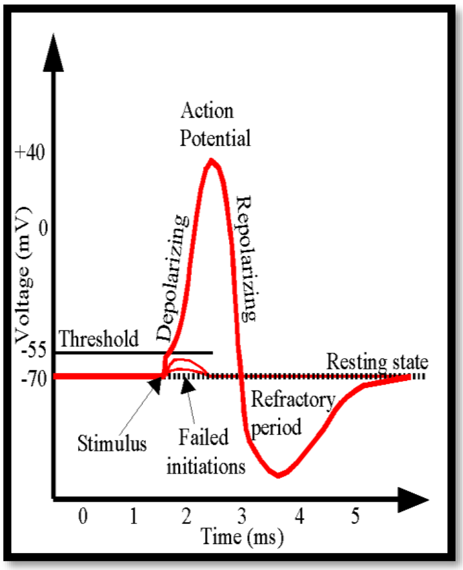
The changes in membrane conductance of Na^+ and K^+ that occur during the action potentials are shown in the next figure

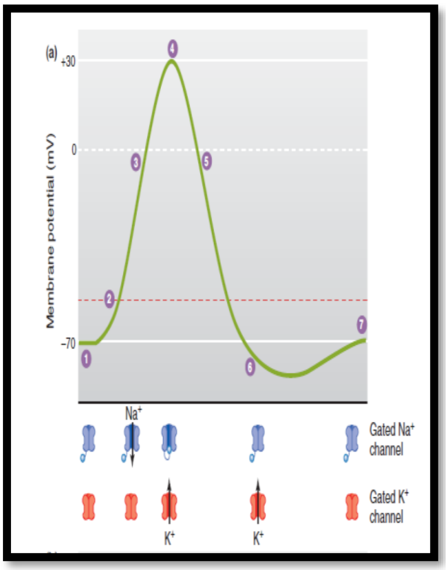
1- Depolariztion: Depolarizing stimulus lead the voltage-gated Na^+ channels overwhelm the K^+ and other channels and an action potential results when a threshold potential reached . The membran potential move toward the equlibrium potential of Na+ mV but dosenot reach it because the increase in Na^+ conductance is short-lived.

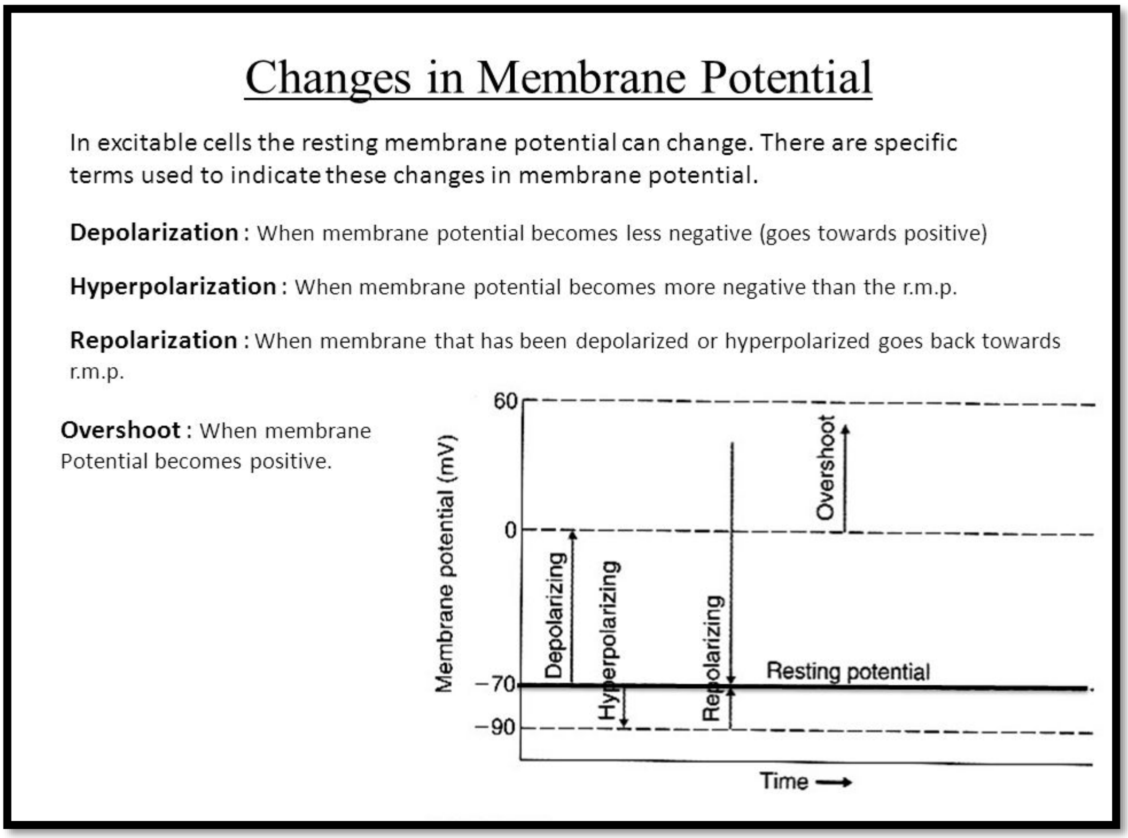
2- Inactivated state: in this phase the Na+ channels rapidly inter a closed state (the in activated state) and remain in this state for a few milliseconds before returning to the resting state when they again can be activated .

3- Repolarization: In this phase the opening of voltage-gated K^+ channels occurs. This opening is slower and more prolonged than the opening of the Na^+ channels,. The net movement of positive charge out of the cell due to K^+ efflux (outward) at this time helps complete the process of repolarization.

4- After-hyperpolarization: The slow return of the K^+ channels to the closed state followed by a return to the resting membrane potential. Thus, voltage-gated K^+ channels bring the action potential to an end and cause closure of their gates through a negative feedback process.







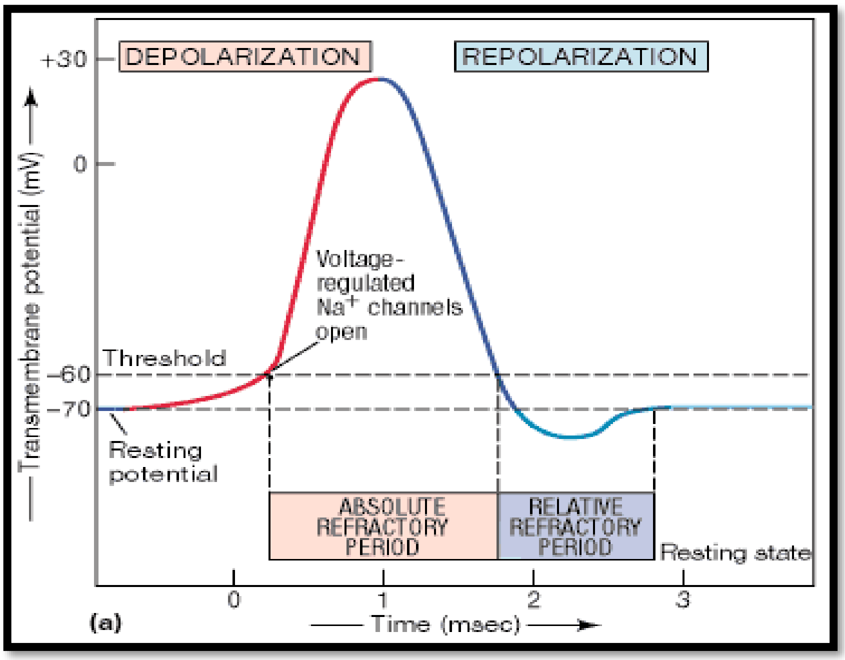
Changes in membrane potential

1- “ALL-OR-NONE” LAW

- **The action potential “all or none” in character and is said to obey the all-or-none law, in that :**
- **The action potential fails to occur if the stimulus is sub-threshold in magnitude.**
- **Once threshold intensity is reached, a full-fledged action potential is produced, and it occurs with constant amplitude and form regardless of the strength of the stimulus if the stimulus is at or above threshold intensity, i.e further increases in the intensity of a stimulus produce no increment or other change in the action potential as long**

2- Changes in Excitability during the Action Potential

- **During the action potential , the throshold of the neuron to stimulation changes.**
- **Hyperpolarization responses elevate the threshold, and depolarizing potential lower it .**
- **Thus during the rising and much of the falling phases of the spike potential, the neuron is refractory to stimulation.This refractory period is divided into :**
- **<u>Absolute Refractory Period</u>, corresponding to the period from the time the firing level is reached until repolarization is about one-third complete. During this period , no stimulus , no matterhow strong , willexite thenerve.**
- **<u>Relative Refractory Period</u>, lasting from this point to the start of after-depolarization. During this period , stronger than normal stimulus can cause exitation .**



Saltatory Conduction

- **Conduction in myelinated axons is faster than that in unmyelinated axons because the depolarization in myelinated axons involves jumping from one node of Ranvier to the next.**
- **This jumping of depolarization from node to node is called saltatory conduction.**
- **It is a rapid process that allows myelinated axons to conduct up to 50 times faster than the unmyelinated fibers.**

Nerve Fiber Types & Function

- **Erlanger and Gasser divided mammalian nerve fibers into A, B, and C groups, further subdividing the A group into (α , β , Ƴ , and б) fibers.**
- **In general, the greater the diameter of a given nerve fiber, the greater its speed of conduction.**
- **The large axons are concerned primarily with proprioceptive sensation, somatic motor function, conscious touch, and pressure.**
- **The smaller axons subserve pain and temperature sensations and autonomic function.**

Synapses & Synaptic Potential

- **Synapse :** is the site at which the impulse is transmitted from one cell to the next.
- **A neuron may terminate on a muscle cell, glandular cell, or another neuron.**
- **Neuron-to-Neuron Transmission: At these types of synapses, the presynaptic neuron transmits the impulse toward the synapse and the postsynaptic neuron transmits the impulse away from the synapse.**
- **Specifically, it is the axon terminal of the presynaptic neuron that comes into contact with the cell body or the dendrites or axons of the postsynaptic neuron.**

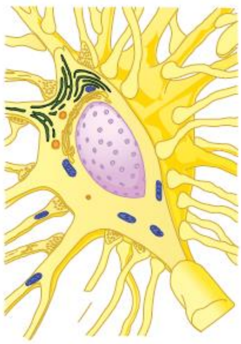
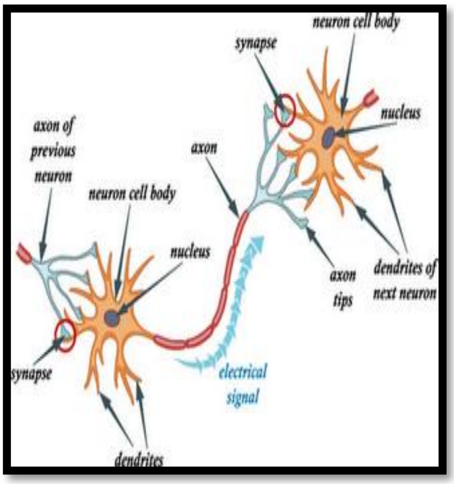
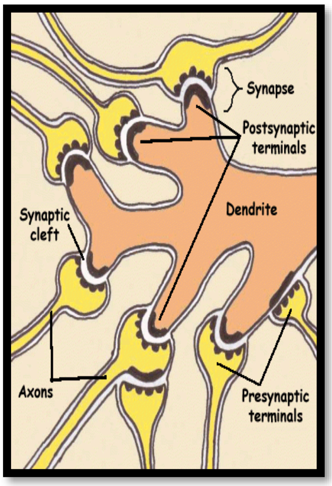


FIGURE 6–1 **Synapses on a typical motor neuron.** The neuron has dendrites (1), an axon (2), and a prominent nucleus (3). Note that rough endoplasmic reticulum extends into the dendrites but not into the axon. Many different axons converge on the neuron, and their terminal boutons form axodendritic (4) and axosomatic (5) synapses. (6) Myelin sheath. (Reproduced with permission from Krstic RV: *Ultrastructure of the Mammalian Cell*. Springer, 1979.)





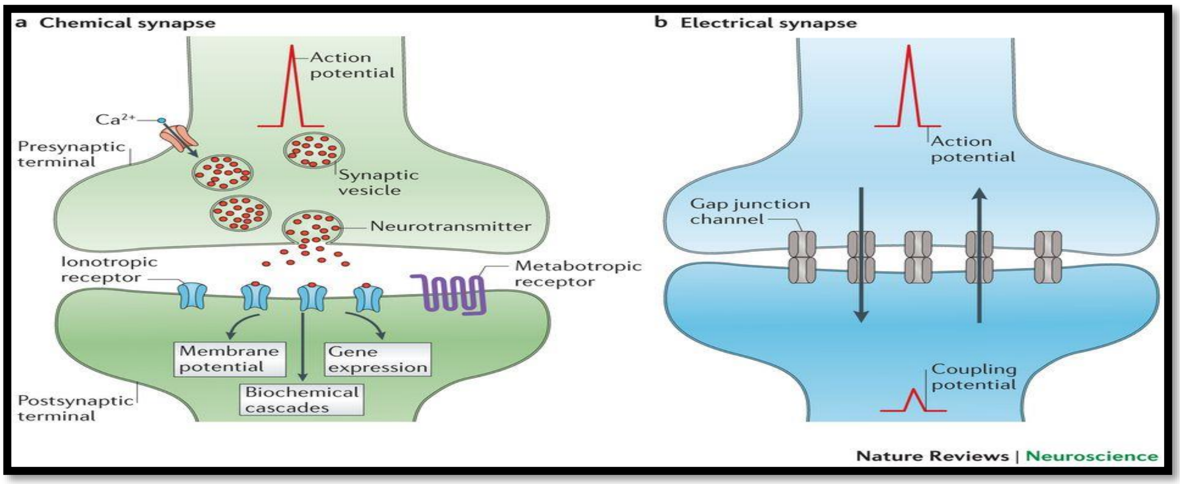
Types of Synapses

1. **Chemical Synapses :**

- **Most of the synapses in the nervous system are of this type , in which the presynaptic neuron and the postsynaptic neuron are not in direct contact but instead are separated by a narrow (0.01 to 0.02mm) space called the synaptic cleft .**
- **An impulse in the presynaptic axon causes secretion of a chemical that diffuses across the synaptic cleft and binds to receptors on the surface of the postsynaptic cell.**
- **This triggers events that open or close channels in the membrane of the postsynaptic cell.**
- **Thus the synaptic cleft space prevents the direct spread of the electrical impulse from one cell to the next. Instead, a chemical referred to as a neurotransmitter is released from the presynaptic neuron triggers the subsequent events .**

2. **Electrical Synapses :**

- **In this type of synapses the membranes of the presynaptic and postsynaptic neurons come close together, and gap junctions form between the cells.**
- **These junctions form low-resistance bridges through which ions can pass with relative ease.**



Synaptic transmission is a complex process

- Regardless of the type of synapse, transmission is not a simple jumping of an action potential from the presynaptic to the postsynaptic cell.
- The effects of discharge at individual synaptic endings can be excitatory or inhibitory, and when the postsynaptic cell is a neuron, the summation of all the excitatory and inhibitory effects determines whether an action potential is generated. Thus, synaptic transmission is a complex process that permits the grading and adjustment of neural activity necessary for normal function.
- Transmission from nerve to muscle resembles chemical synaptic transmission from one neuron to another.
- The neuromuscular junction, the specialized area where a motor nerve terminates on a skeletal muscle fiber, is the site of a stereotyped transmission process.
- The contacts between autonomic neurons and smooth and cardiac muscle are less specialized, and transmission in these locations is a more diffuse process.

The mechanism of action of a chemical synapse

The mechanism of action of a chemical synapse is as the following

1- The ends of the presynaptic fibers are generally enlarged to form terminal boutons (synaptic knobs), at which the nerve impulse (AP) arrived firstly . Within the synaptic knob are many mitochondria, synaptic vesicles that store the preformed neurotransmitter & voltage-gated Ca++ Channels that distributed within the membrane of the synaptic knob .

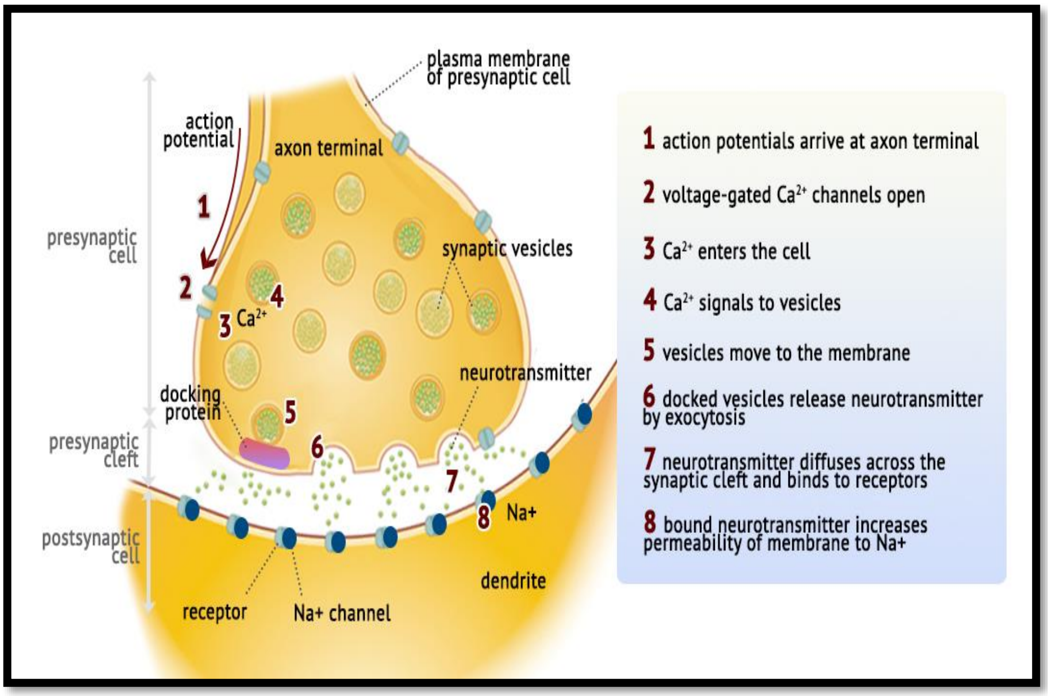
2- When the electrical impulse, or action potential, has been transmitted along the length of the axon and reaches the axon terminal, the accompanying change in voltage causes the voltage-gated Ca++ channels to open.

3- Because calcium has greater concentration in the ECF as compared to the ICF , Ca++ ions enter the cell down their concentration gradient.

4- The Ca++ ions then induce the release of the neurotransmitter from synaptic vesicles into the synaptic cleft by causing the vesicles to fuse with the presynaptic membrane, thereby facilitating the process of exocytosis.

5- Across the synaptic cleft are many neurotransmitter receptors in the postsynaptic membrane, and usually a postsynaptic thickening called the postsynaptic density. The postsynaptic density is an ordered complex of specific receptors, binding proteins, and enzymes induced by postsynaptic effects.

6- The neurotransmitter molecules diffuse across the cleft and bind to specific receptors on the membrane of the postsynaptic neuron. This binding of the neurotransmitter alters permeability of the postsynaptic neuron to one or more ions. As always, a change in ion permeability results in a change in the membrane potential of the cell. This change at the synapse is in the form of a graded potential only.



Types of synaptic vesicles

There are three kinds of synaptic vesicles:

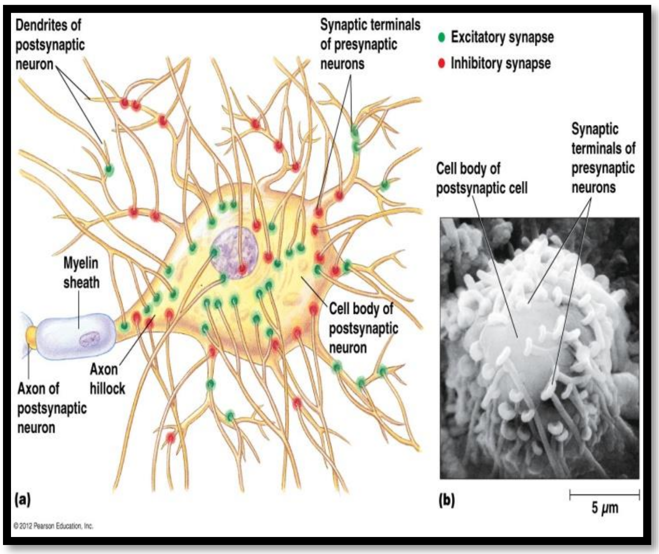
1. **Small, clear synaptic vesicles that contain acetylcholine, glycine, GABA,or glutamate.**
2. **Small vesicles with a dense core that contain catecholamines.**
3. **Large vesicles with a dense core that contain neuropeptides.**

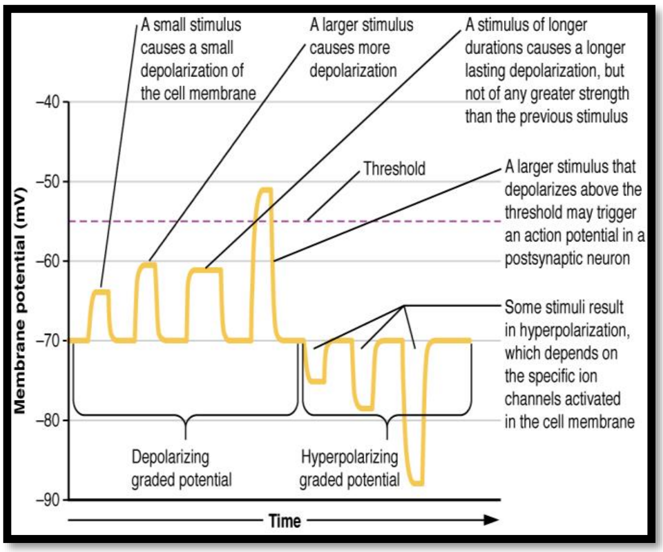
Graded Potentials

- **Graded potentials are changes in membrane potential that vary in size, as opposed to being all-or-none.**
- **They arise from the summation of the individual actions of ligand-gated ion channel proteins, and decrease over time and space.**
- **They do not typically involve voltage-gated sodium and potassium channels.**
- **These impulses are incremental and may be excitatory or inhibitory.**
- **They occur at the postsynaptic dendrite as a result of presynaptic neuron firing and release of neurotransmitter, or may occur in skeletal, smooth, or cardiac muscle in response to nerve input.**
- **The magnitude of a graded potential is determined by the strength of the stimulus.**

NOTE:

Almost invariably, a neuron is genetically programmed to synthesize and release only a single type of neurotransmitter. Therefore, a given synapse is either always excitatory or always inhibitory.





Excitatory & Inhibitory potentials

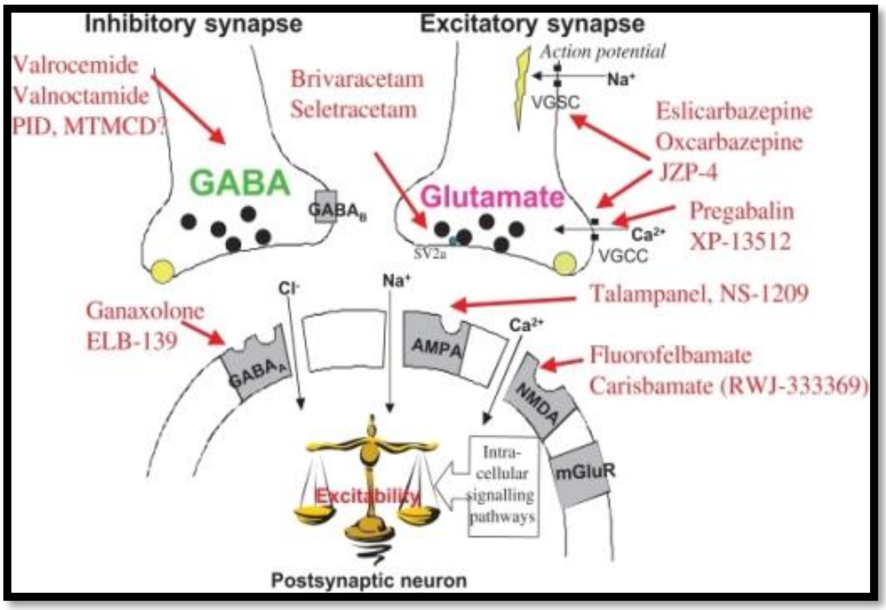
1- Excitatory Postsynaptic Potentials (EPSPs):

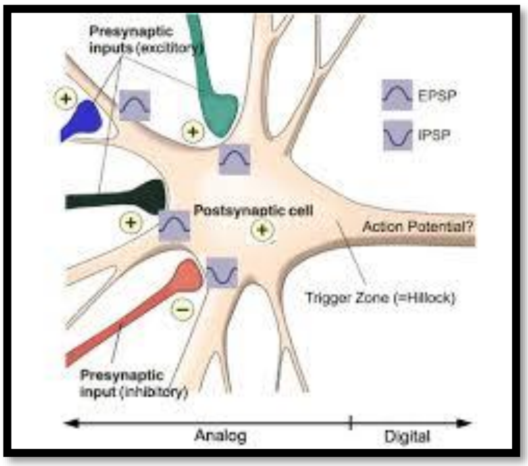
- **Graded potentials that make the membrane potential less negative or more positive, thus making the postsynaptic cell more likely to have an action potential.**
- **Depolarizing local potentials sum together, and if the voltage reaches the threshold potential, an action potential occurs in that cell.**
- **The EPSP is produced by depolarization of the postsynaptic cell membrane immediately under the presynaptic ending.**

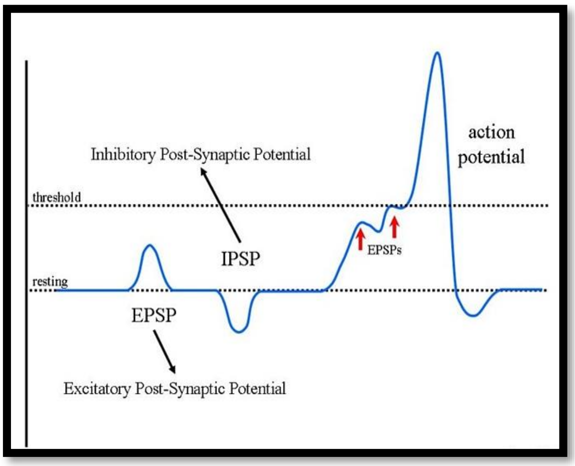
- The excitatory transmitter opens Na +or Ca ++ ion channels in the postsynaptic membrane, producing an inward current. The area of current flow thus created is so small that it does not drain off enough positive charge to depolarize the whole membrane. Instead, an EPSP is inscribed. The EPSP due to activity in one synaptic knob is small, but the depolarizations produced by each of the active knobs summate.

2- Inhibitory Post sSynaptic Potentials (IPSPs):

- Graded potentials that make the membrane potential more negative, and make the postsynaptic cell less likely to have an action potential.
- Hyperpolarization of membranes is caused by influx of Cl− or efflux of K+.
- As with EPSPs, the amplitude of the IPSP is directly proportional to the number of synaptic vesicles that were released.
- At an inhibitory synapse : binding of the neurotransmitter to its receptor increases permeability of the membrane to K+ ions or to Cl–ions through chemical messenger-gated channels. As a result, K+ ions may leave the cell down their concentration gradient carrying (+) charges outward or Cl – ions may enter the cell down their concentration gradient carrying (–) charges inward.
- In either case, the neuron becomes more negative inside relative to the outside and the membrane is now hyperpolarized.
- This small hyper polarization is referred to as an Inhibitory Post Synaptic Potential (IPSP).
- Because IPSPs are net hyperpolarizations, they can be produced by alterations in other ion channels in the neuron. For example, they can be produced by opening of K +channels, with movement of K +out of the postsynaptic cell, or by closure of Na +or Ca ++ channels.







TEMPORAL & SPATIAL SUMMATION

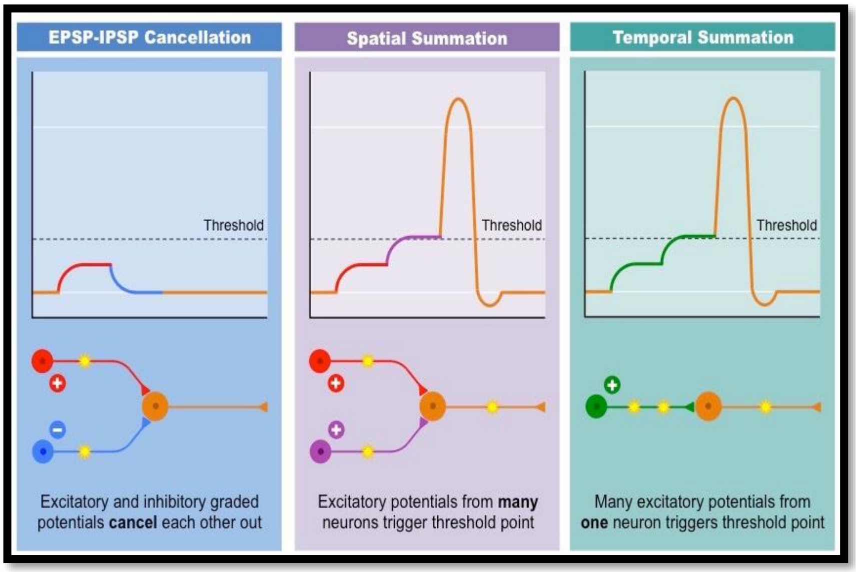
Central neurons integrate a variety of synaptic inputs through temporal and spatial summation:

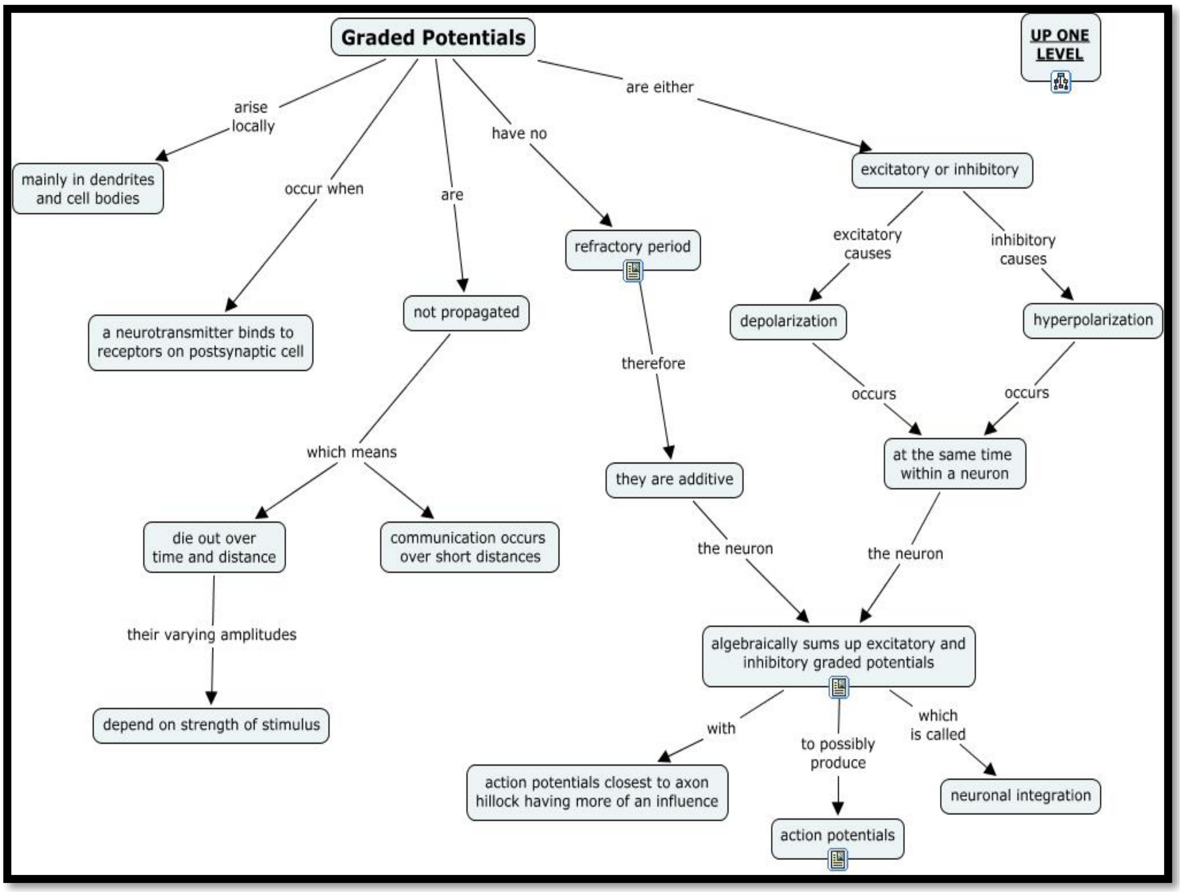
1- **Temporal Summation:**

- **occurs if repeated afferent stimuli cause new EPSPs before previous EPSPs have decayed.**
- **A longer time constant for the EPSP allows for a greater opportunity for summation, when activity is present in more than one synaptic knob at the same time.**

2- **Spatial Summation:**

- **occurs in that activity in one synaptic knob summates with activity in another to approach the firing level.**
- **The EPSP is therefore not an all or- none response but is proportionate in size to the strength of the afferent stimulus.**
- **Spatial summation of IPSPs also occurs, as shown by the increasing size of the response, as the strength of an inhibitory afferent volley is increased.**
- **Temporal summation of IPSPs also occurs.**




Graded Potentials
UP ONE LEVEL
arise locally
mainly in dendrites and cell bodies
occur when
a neurotransmitter binds to receptors on postsynaptic cell
are
not propagated
which means
die out over time and distance
communication occurs over short distances
their varying amplitudes
depend on strength of stimulus
have no
refractory period
therefore
they are additive
are either
excitatory or inhibitory
excitatory causes
depolarization
inhibitory causes
hyperpolarization
occurs
occurs
at the same time within a neuron
the neuron
the neuron
algebraically sums up excitatory and inhibitory graded potentials
with
action potentials closest to axon hillock having more of an influence
to possibly produce
action potentials
which is called
neuronal integration