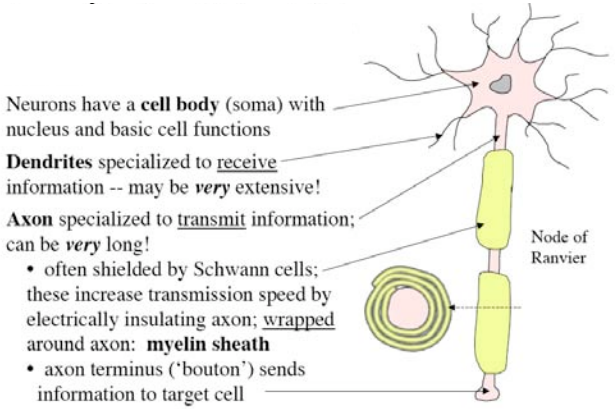
The two fundamental control systems in animals:

Hormones: slow, long-lasting, specificity based on target cells with correct receptors

Nervous system: fast, very short duration, specificity based on delivering message precisely to the target cell only

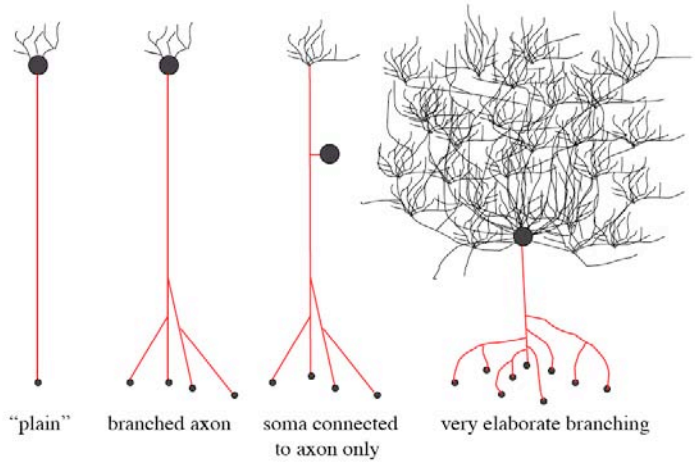
# Neurons and synapses

Nervous systems are based on a characteristic cell type highly specialized for sending and receiving messages: **neurons**.




# Neurons and synapses

Variations on basic neuron structure:




# Neurons and synapses

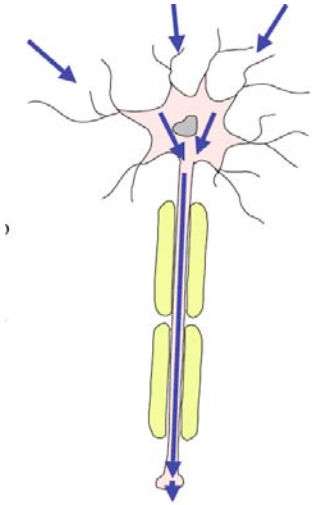
Information flow in a neuron is usually in one direction only :

• information enters cell in **dendrites**

• information passes through cell body to **base of axon**

• information moves **along axon** to axon terminus

• information moves to **target cell** from axon terminus



# Message transmission in neurons

Neurons send information by ***combined electrical and chemical*** means:

• *passive* transmission through dendrites and soma

• *active* transmission in axons: they generate self-propagating electrical impulses moving from axon base to axon terminal

This depends on the *distribution of charged molecules* across the nerve cell membrane, and the neuron's ability to *rapidly change* that distribution

# Message transmission in neurons

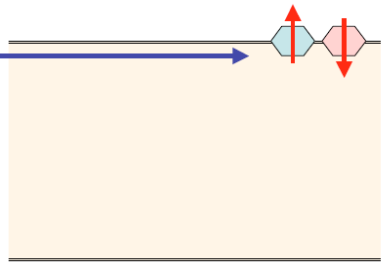
Neurons send information by ***combined electrical and chemical*** means. Some important electrical principles:

• *Voltage* (or **potential**): a measure of the driving force of electrical charges. Always measures as a difference between areas – i.e., between the inside and the outside of a neuron. Somewhat analogous to *water pressure* in a pipe.
• *Ions*: molecules or atoms carrying an electrical charge (they have 'missing' or 'extra' electrons, as in $K^+$, $Na^+$, $Ca^{2+}$, or $Cl^-$).
• *Current*: the amount of electrical charge moving. In a neuron this means the number of ions moving. Analogous to the *amount of water* flowing in a pipe.
• ***Like*** electrical charges repel, while ***unlike*** charges (+ and -) attract.

# Message transmission in neurons

Neurons have ***semipermeable membranes*** (some things cross easily, others do not)

Membranes have ***active transport*** systems for some ions



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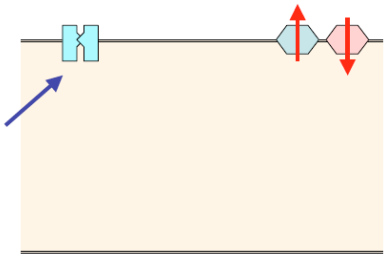
Also have ***ion 'gates,'*** or 'pores': membrane proteins that open or close to change permeability to a particular ion



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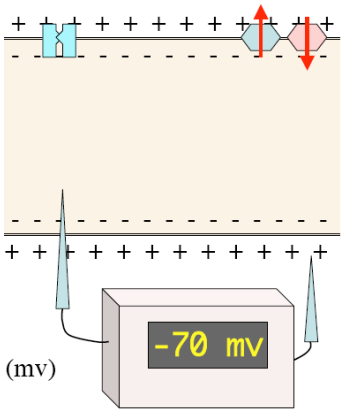


A resting neuron has a **slight excess of negative charge** ***inside:*** this ***resting potential*** is usually about -70 millivolts (mv)

# Message transmission in neurons

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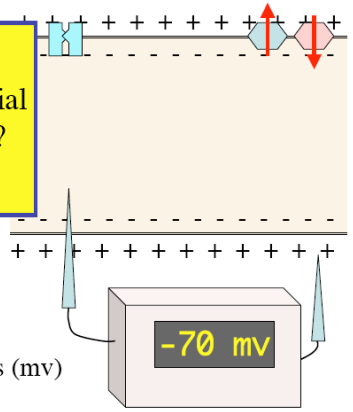
How is the resting potential created and maintained?

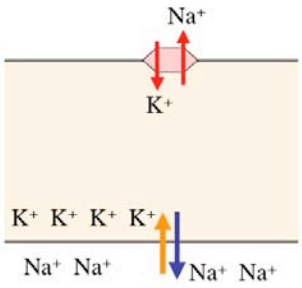



A resting neuron has a **slight excess of negative charge** ***inside:*** this ***resting potential*** is usually about -70 millivolts (mv)

# Message transmission in neurons

How is the resting potential created and maintained?

- system ***as a whole*** has equal numbers of positive and negative ions (mainly $K^+$, $Na^+$, $Cl^-$, various charged proteins, amino acids)
- ***sodium-potassium cotransporter*** pumps $K^+$ **in** and $Na^+$ **out** (3:2)
- about 10 X more $Na^+$ out than in; about 20-30X more $K^+$ in than out: ***concentration gradient*** drives diffusion



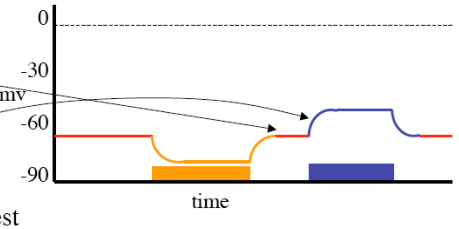

- membrane permeable to $K^+$ but ***not*** to $Na^+$
- ***more*** $K^+$ diffuses *out* than $Na^+$ diffuses *in*, making inside of neuron ***negative;*** net flux stops when ***electrical gradient*** exactly balances ***concentration gradient:*** ⇨ ***about -70 mv***

# Message transmission in neurons

***Polarization*** of membrane potential to ~ -70 mv (inside) is maintained indefinitely in a resting neuron.

But that resting potential can change if external events affect charge distribution: ***generator potentials***

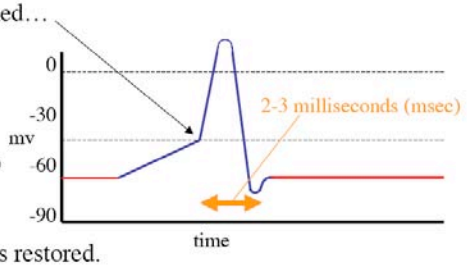
- a ***hyperpolarization*** makes potential more ***negative*** (normal rest potential is restored after event is over)
- a small ***depolarization*** makes potential more ***positive*** (again, normal rest potential is restored after event is over)



# Message transmission in neurons

Something ***very different*** happens if a depolarization makes the membrane potential more positive than a certain ***threshold:***

- slowly raise membrane potential….
- until threshold is reached…
- sudden ***rapid*** voltage increase…
- followed by rapid drop in voltage…
- until resting potential is restored.



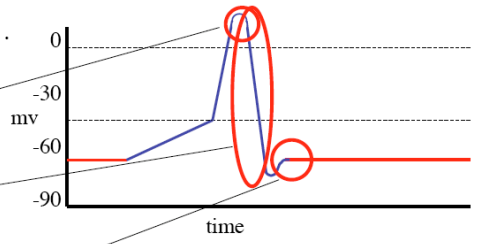

this is the ***action potential,*** or 'spike'

# Message transmission in neurons

What causes the action potential to appear and disappear?

- at threshold (~ -40 mv), voltage-sensitive sodium channels open…
- sodium rapidly moves inward, ***raising*** voltage…
- sodium gates close; $K^+$ gates open…
- $Na^+$ pumped out; $K^+$ rapidly leaves neuron…
- resting potential is restored (often after slight 'undershoot').

Note that although ion currents change very rapidly, the amounts of $Na^+$ and $K^+$ that cross the membrane are ***very small*** compared to the total quantities of these ions in the system.

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$K^+$ gates open…
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The action potential is ***self-propagating:***

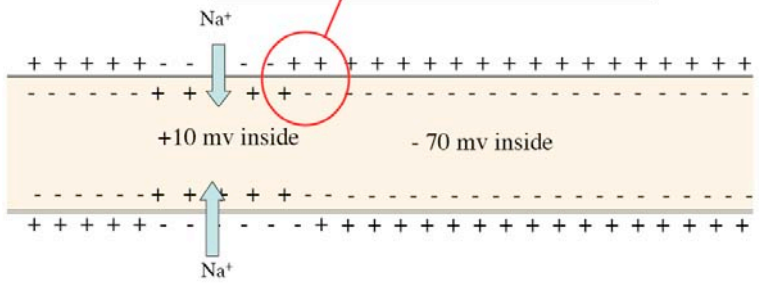
- once threshold is exceeded, AP is triggered and moves rapidly down the axon.
- APs usually move in one direction: from soma to axon terminus
- all action potentials in a given axon are alike (in duration, magnitude)

# Message transmission in neurons

Why is the action potential ***self propagating?***

- it's 'autocatalytic': an action potential in one piece of axon causes current flow that depolarizes adjacent membrane:

This region is depolarized above threshold by inward sodium current



# Message transmission in neurons

Why doesn't action potential run ***backwards?***

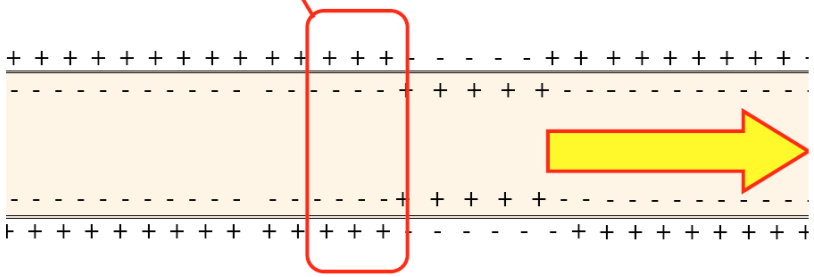
-- for a few milliseconds after an AP, the membrane is not responsive to depolarization, so no AP is possible.

***f propagating?***

ential in one piece of axon

s adjacent membrane

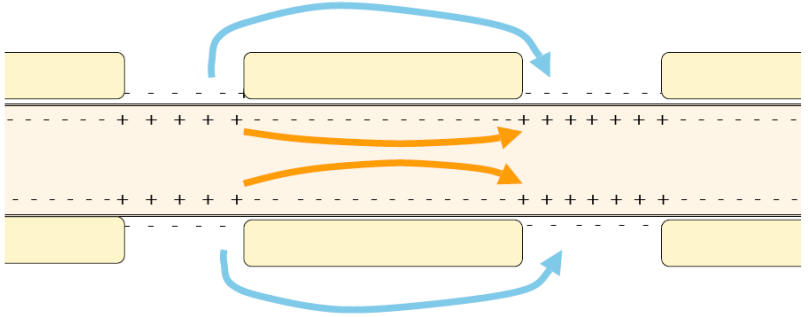
ng the membrane, each piece



# Message transmission in neurons

Schwann cells and ***saltatory conduction***

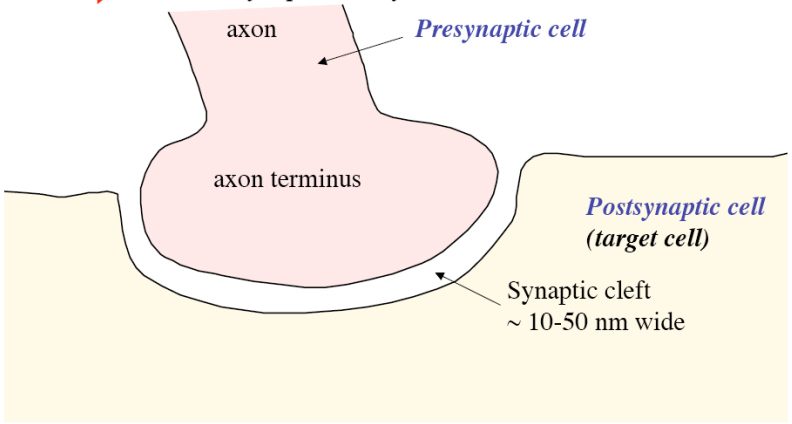
- in small unmyelinated neurons, conduction speed is 1-5 m/s -- ***slow!***
- in myelinated axons, depolarization 'jumps' between nodes of Ranvier -- ***very fast*** (>100 m/s)



# Message transmission in neurons

- junction between neuron and target cell is a **synapse.** Two kinds: ***electrical*** and ***chemical.***

⇨ ***Chemical synapses*** are by far the most common.

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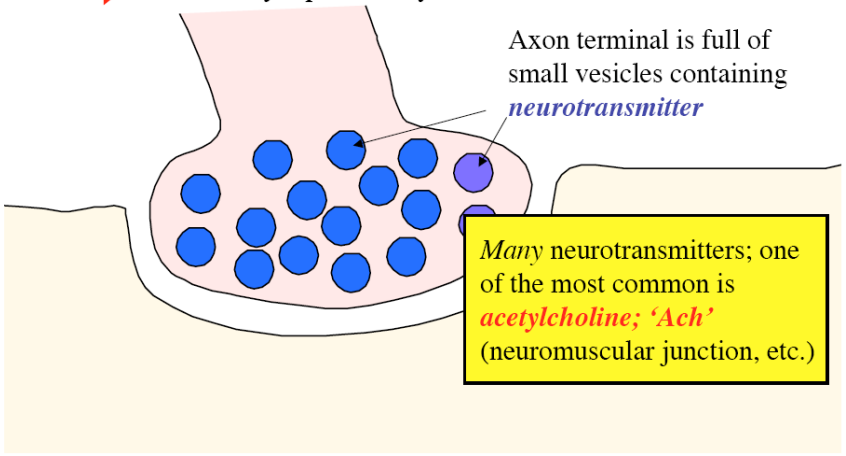

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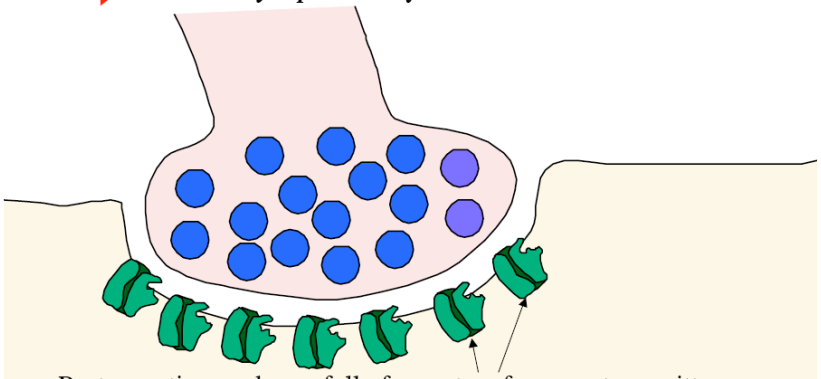

Postsynaptic membrane full of receptors for neurotransmitter; these are controllable ***ion channels*** (normally closed)

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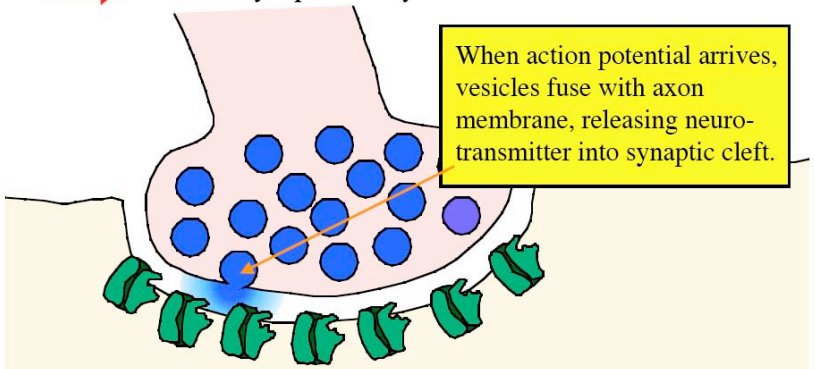


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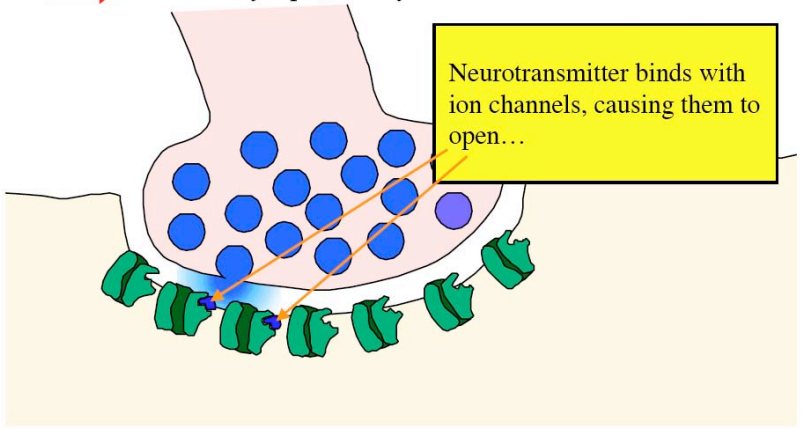


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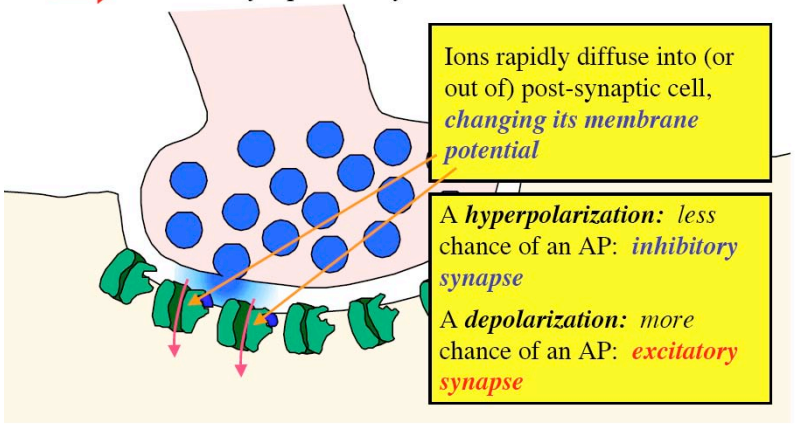

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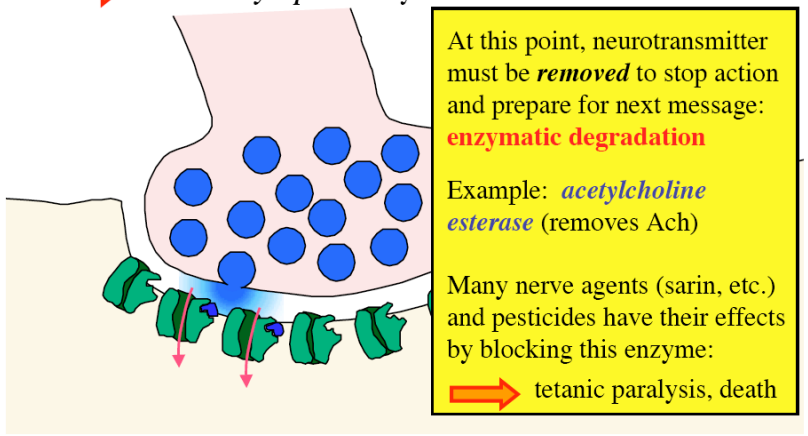


At this point, neurotransmitter must be ***removed*** to stop action and prepare for next message: **enzymatic degradation**

Example: *acetylcholine esterase* (removes Ach)

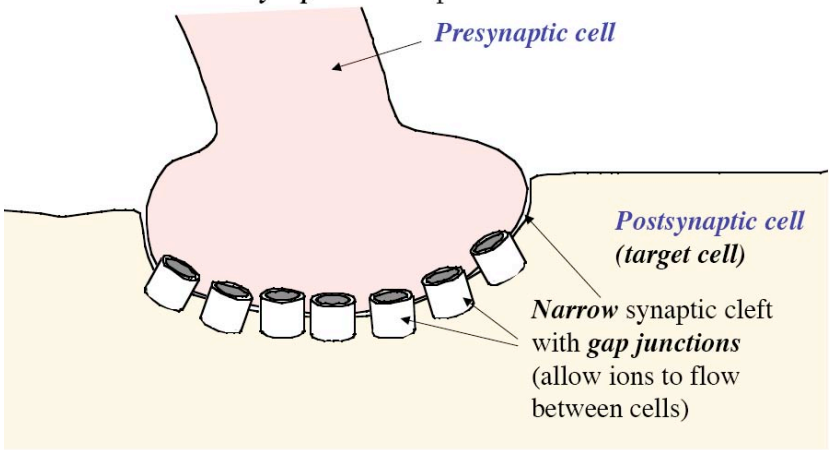
Many nerve agents (sarin, etc.) and pesticides have their effects by blocking this enzyme:

⇨ tetanic paralysis, death

# Message transmission in neurons

- junction between neuron and target cell is a **synapse.** Two kinds: ***electrical*** and ***chemical.***

***Electrical synapses*** are simpler and faster:

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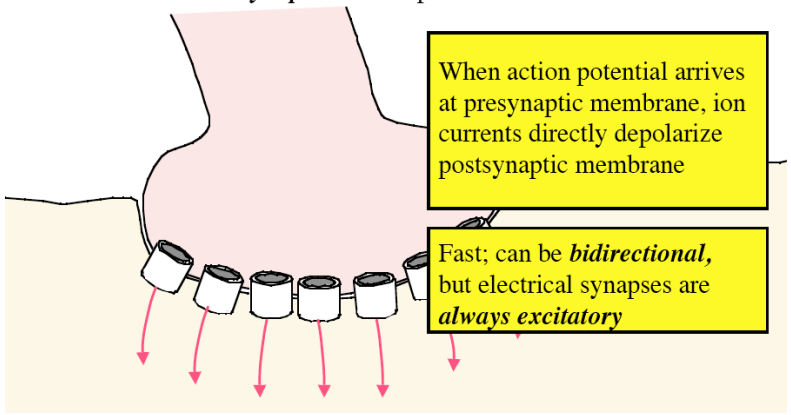

When action potential arrives at presynaptic membrane, ion currents directly depolarize postsynaptic membrane

Fast; can be ***bidirectional,*** but electrical synapses are ***always excitatory***