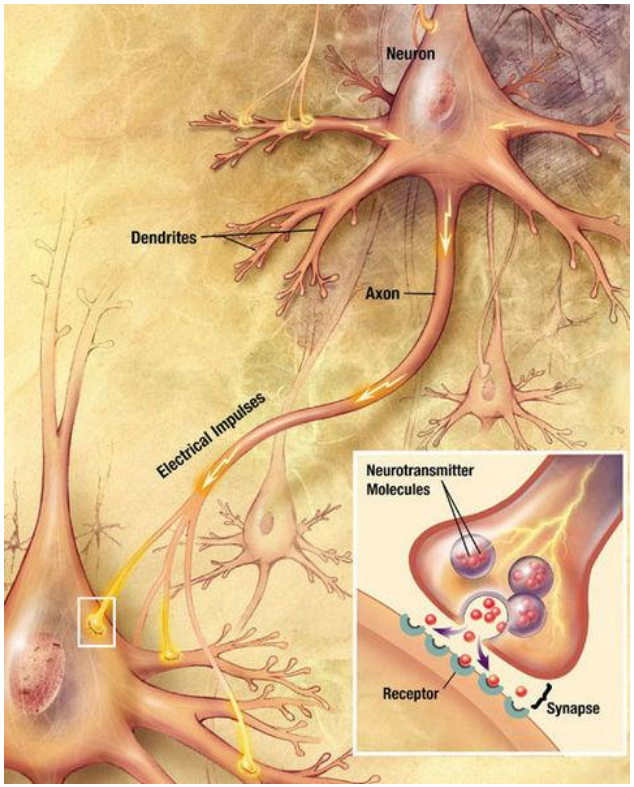
Chemical Synapse

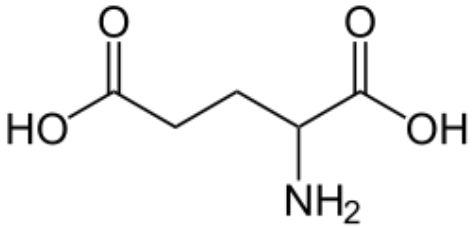
How one nerve talks to a nerve, an organ (muscle, pancreas…)



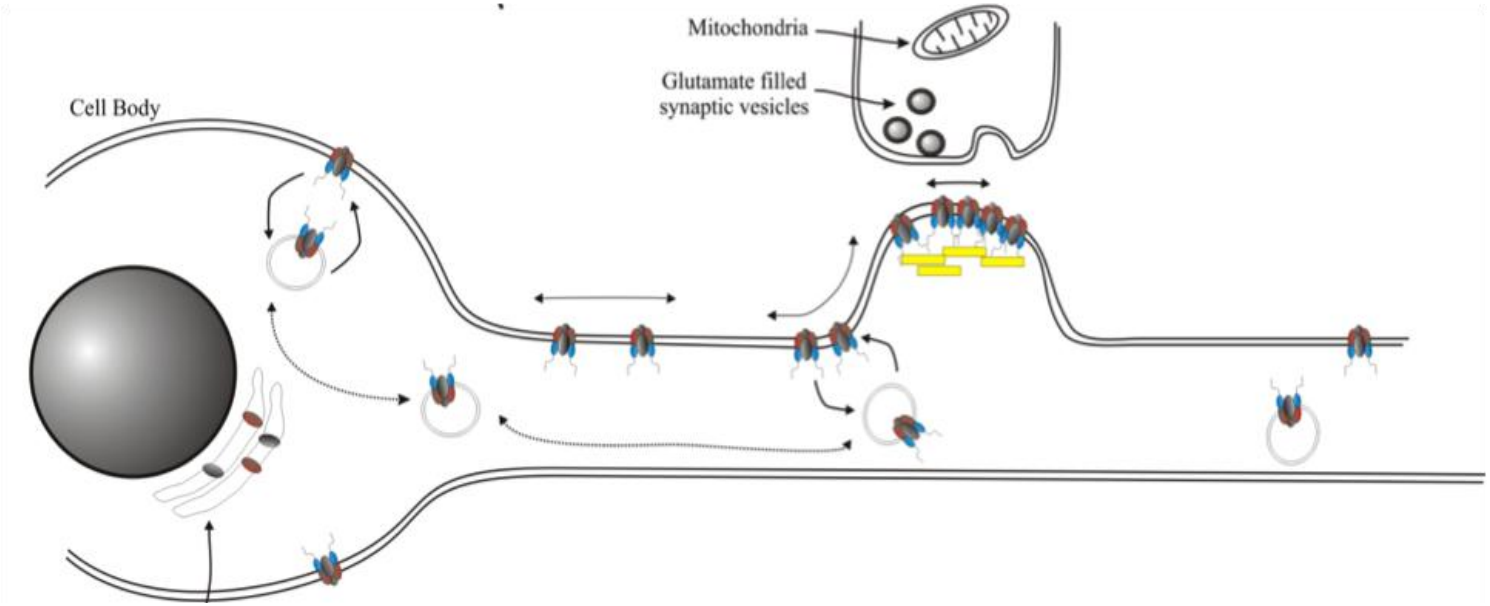
Neurons create action potential—electrical inpulse
Flow of sodium (and later potassium).
This causes a signal at end of neuron (at axon).
To transfer info, must cause a chemical change across synapse.
How to do it:
Depolarization causes Glutamate to diffuse
Interacts with AMPAR
Repetitive firing leads to short-term and long-term learning and memory.

Vision: photons (next lecture) → nerve impulse. Initiate chemical signal using a metatropic

Glutamate: an amino acid



AMPA Receptor Trafficking



- Why study AMPAR trafficking?
  - Alters synaptic strength
  - Molecular basis of learning and memory
  - More AMAPR → memory; less AMPAR → forgetting
- Open questions:
  - How AMPAR trafficking into synapse?
  - Diffusion behavior in synapse?

AMPARs trafficking is important for learning and memory.

Neurons & Synapses

AMPAR and NMDAR: ion channels in synapse, lead to action potentials.
short-term memory & long-term memory:
More AMPAR in synapse of hippocampus– stronger response, more STM.
Sleep (& other processes) leads to long-term memory.
Long-term Potentiation– best model for memories.

Neurons (Nerve cells) and Synapses

- Neuron:
  - Building blocks of nervous systems.
- Soma
  - Cell body
- Dendrites
  - Collect signals
- Axon
  - Sends signals
- Synapse
  - Dendrite-axon junctions

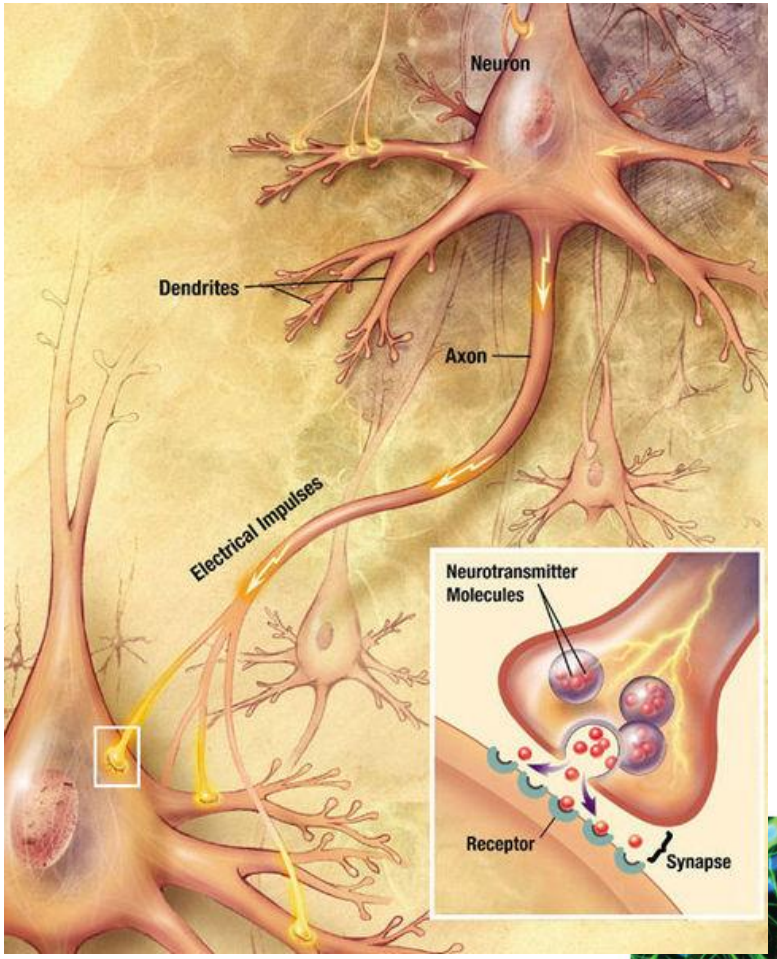
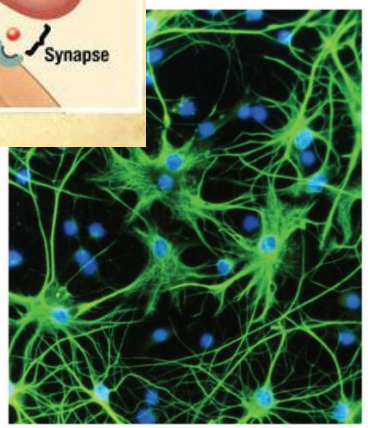


Image from wikipedia



Neurons transmit signals via synapses.

The Synapse

- Synapse
  - Presynapse (Axon)
  - Postsynapse (dendrite)
  - Synaptic cleft (~30 nm)
- Active zone (PAZ)
  - Vesicle release
- Postsynaptic density (PSD)
  - Receptors
  - Scaffold proteins
- PSD size is 250 -500 nm

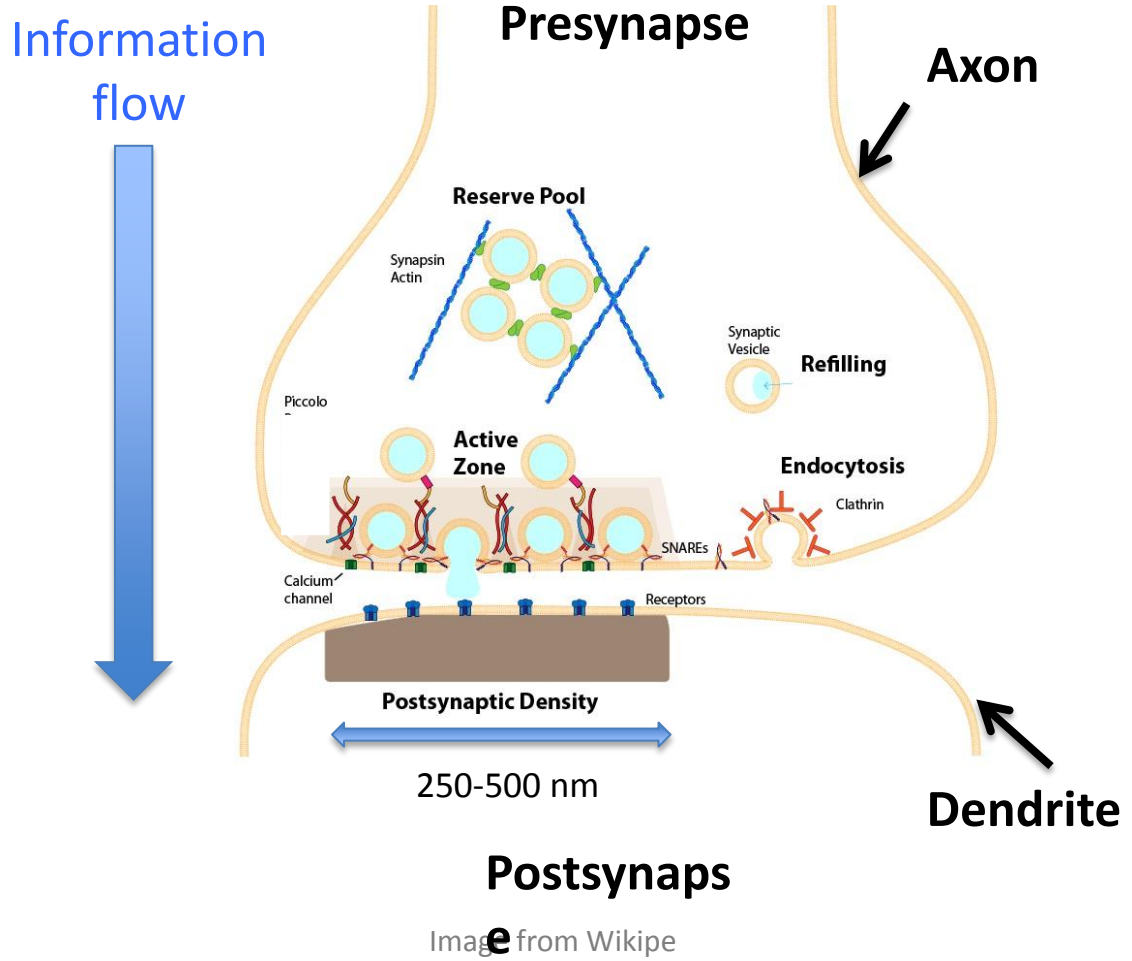
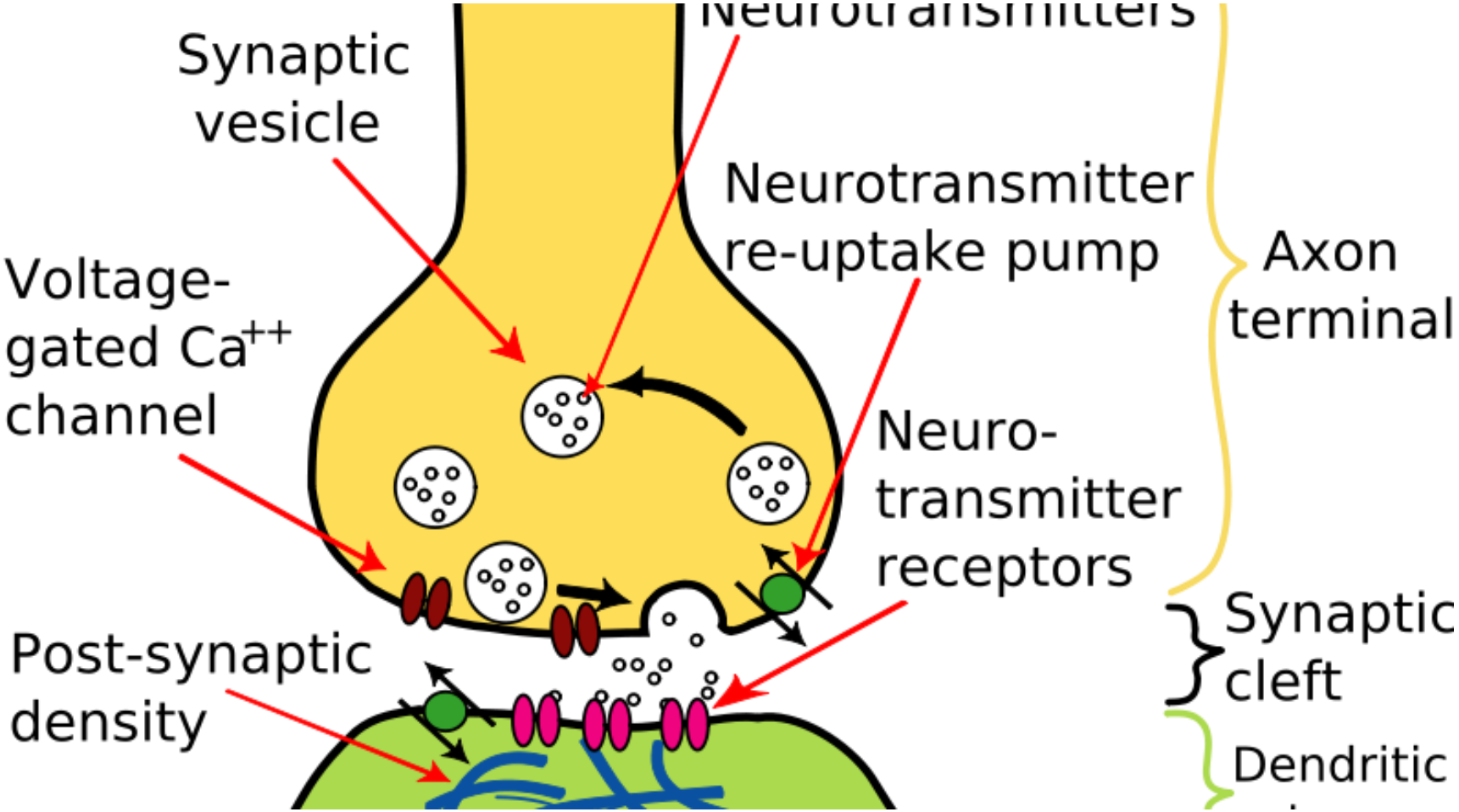


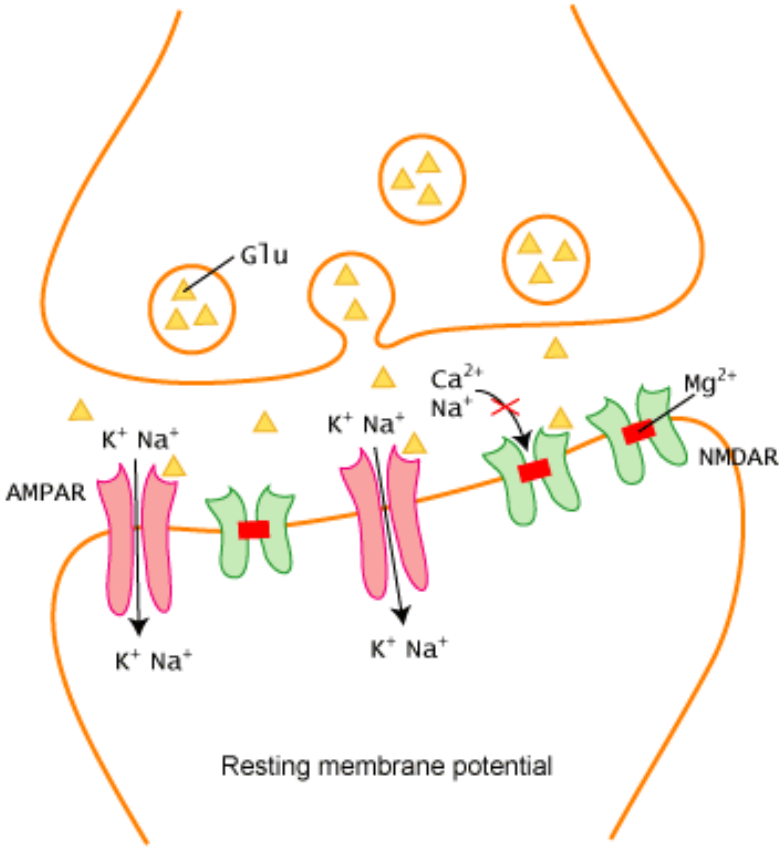
Image from Wikipe

The PSD is small, comparable to the light diffraction limit.
Super-resolution techniques are required for imaging the PSD.

A first view of the Synaptic cleft



What are the proteins which are sensitive to glutamate? AMPAR and NMDAR



http://en.wikipedia.org/wiki/File:Synapse_with_NMDAR_and_AMPAR.png

AMPA receptor because it is particularly sensitive to α-***a***mino-3-hydroxy-5-***m***ethyl-4-isoxazole-***p***ropionic ***a***cid.

NMDA receptor because it is particularly sensitive to the glutamate agonist ***N-m***ethyl-***D-a***spartate.

AMPAR are directly responsive to Glutamate (letting in K^{+}, Na^{+}).

NMDAR are responsive to glutamate (& glycine) & voltage-dependent blockage due to Mg^{2+}.

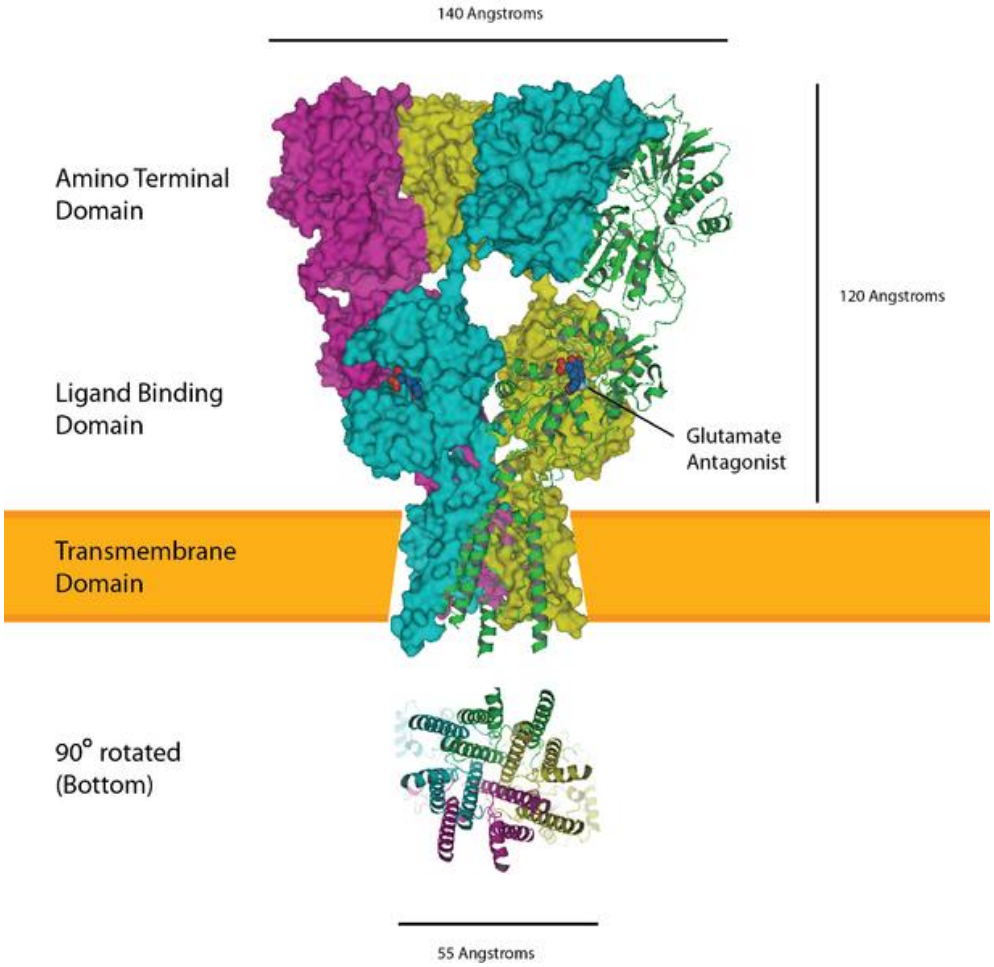
NMDAR controls the amount of AMPAR.

AMPAR can be in the post-synaptic membrane and in recycling endosomes.

The more AMPAR in the post-synaptic membrane, the stronger is the result.

AMPA Receptors

- What is AMPAR?
  - α-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid receptor: an inhibitor of AMPAR.
  - Transmembrane ion channel
  - Glutamate gated
  - Mediate Fast synaptic transmission
- AMPAR trafficking
  - Alters the synaptic strength

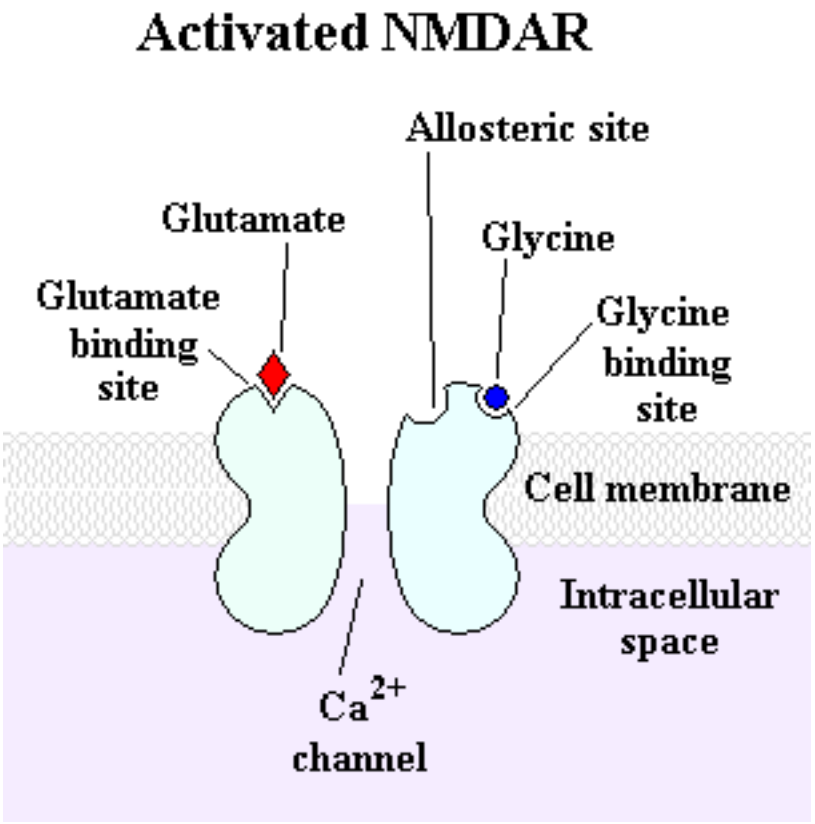


We want to understand how AMPAR trafficking at the synapse.

NMDAR

believed to be structurally similar to AMPAR

The NMDA receptor forms a heterotetramer between two NR1 and two NR2 subunits.

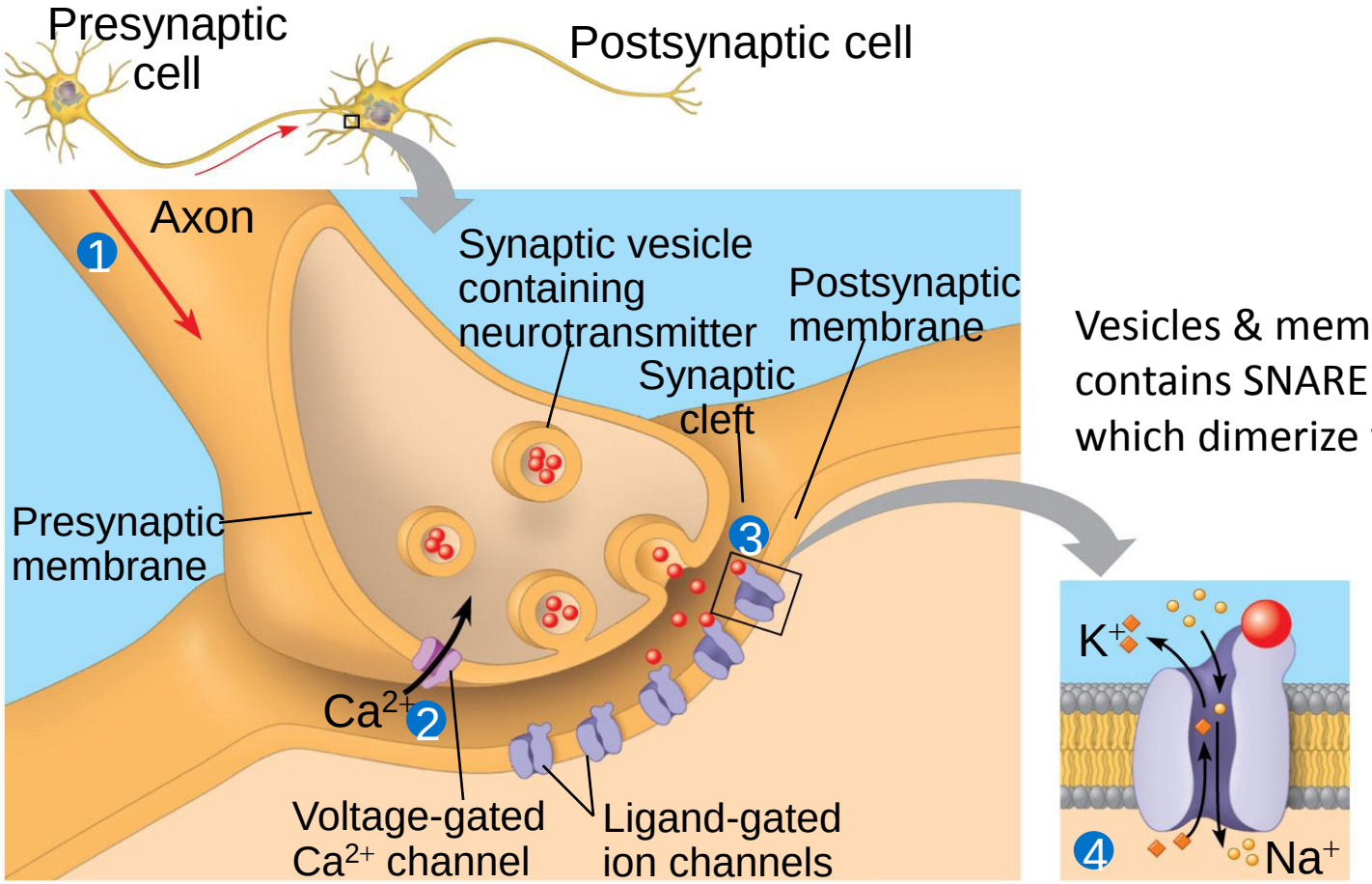


Glutamate-binding,
Glycine-binding
High-calcium permeability
Voltage-dependent magnesium block.

How does nerve impulse traveling down the axon lead to vesicle fusion and glutamate release?

The action potential travels down the axon to the terminal. Arrival at the terminal causes membrane depolarization, which opens voltage-dependent Ca^{2+} channels situated in the active zone where the neurotransmitter vesicles are docked. Ca^{2+} binds to proteins, mainly synaptotagmin (a presynaptic protein—see next pg), which cause vesicle fusion mainly through an interaction of synaptotagmin with the SNARE proteins.

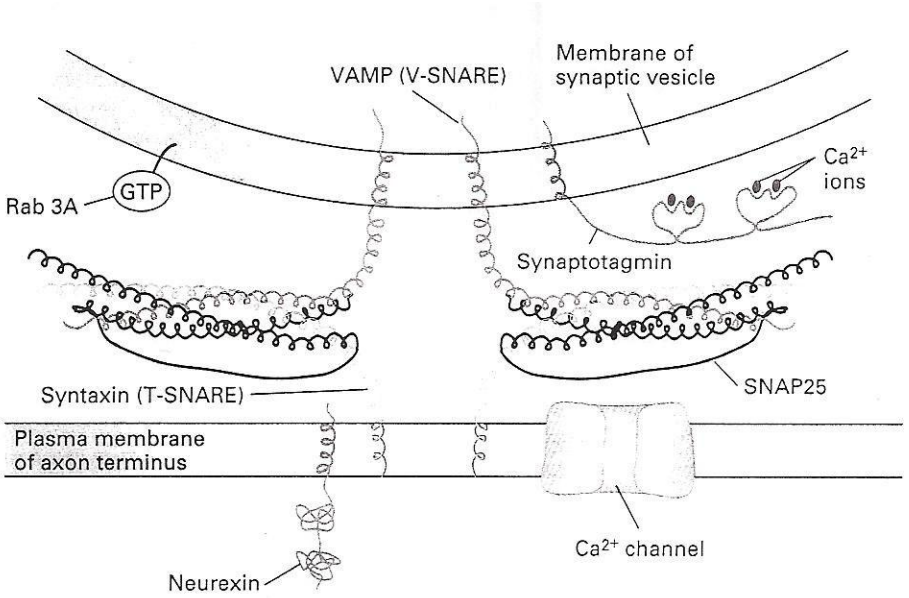
Figure 48.15

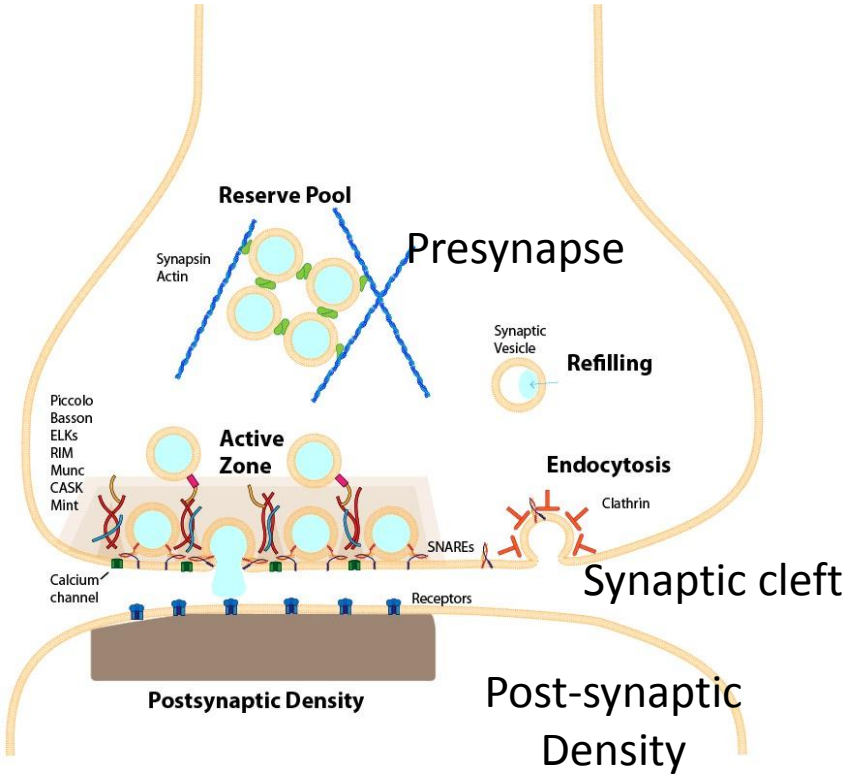


Vesicles & membrane contains SNARE proteins which dimerize w Ca^{2+}

How does synaptic vesicle attach to membrane?

SNARE proteins on vesicle and membrane are Ca^{2+}-dependent



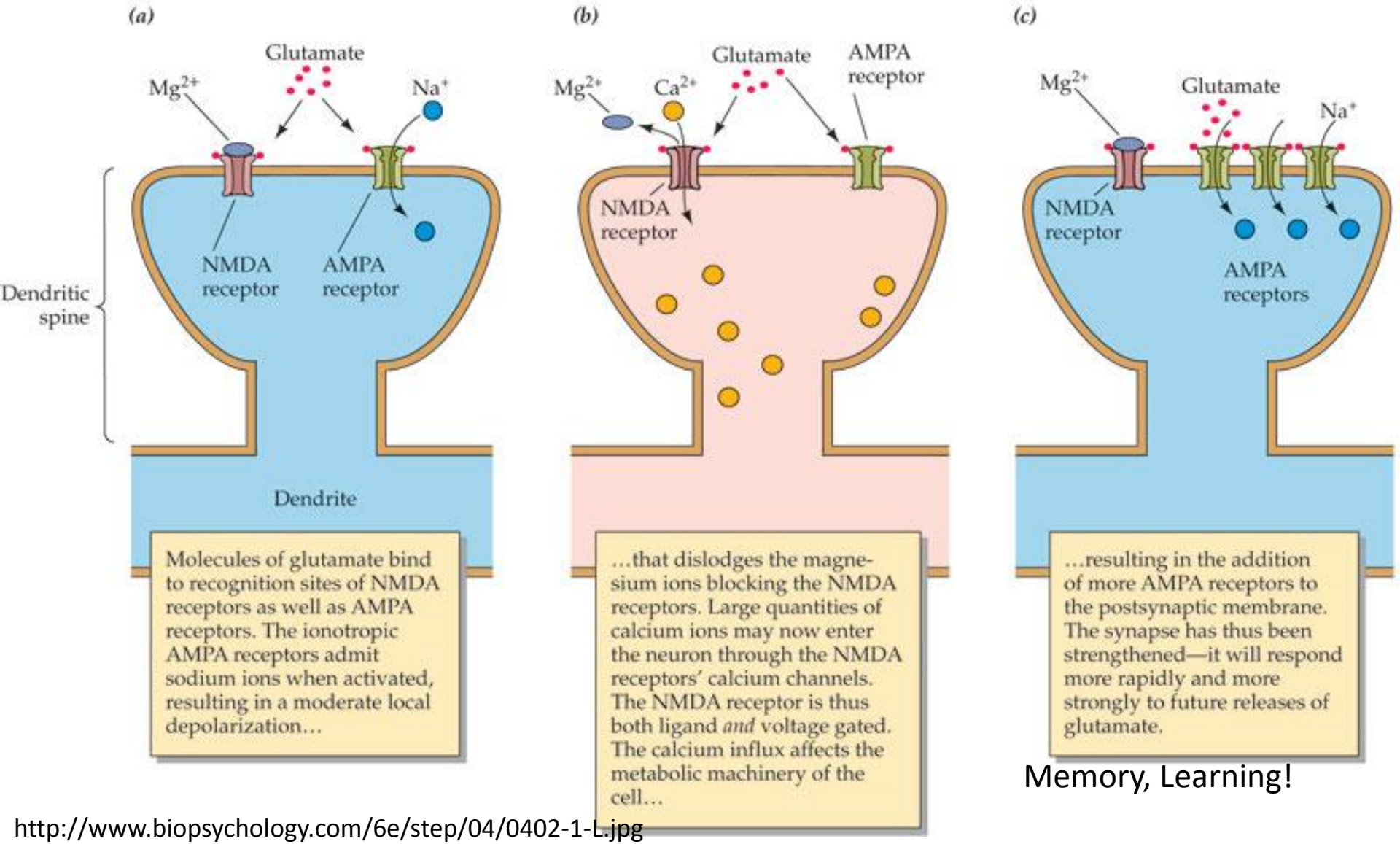


Long-term Potentiation

Long-term potentiation (LTP), a phenomenon in which brief repetitive activity causes a long lasting (many weeks) enhancement in the strength of synaptic transmission, is generally accepted to be a key cellular substrate for learning and memory.

AMPAR and NMDAR

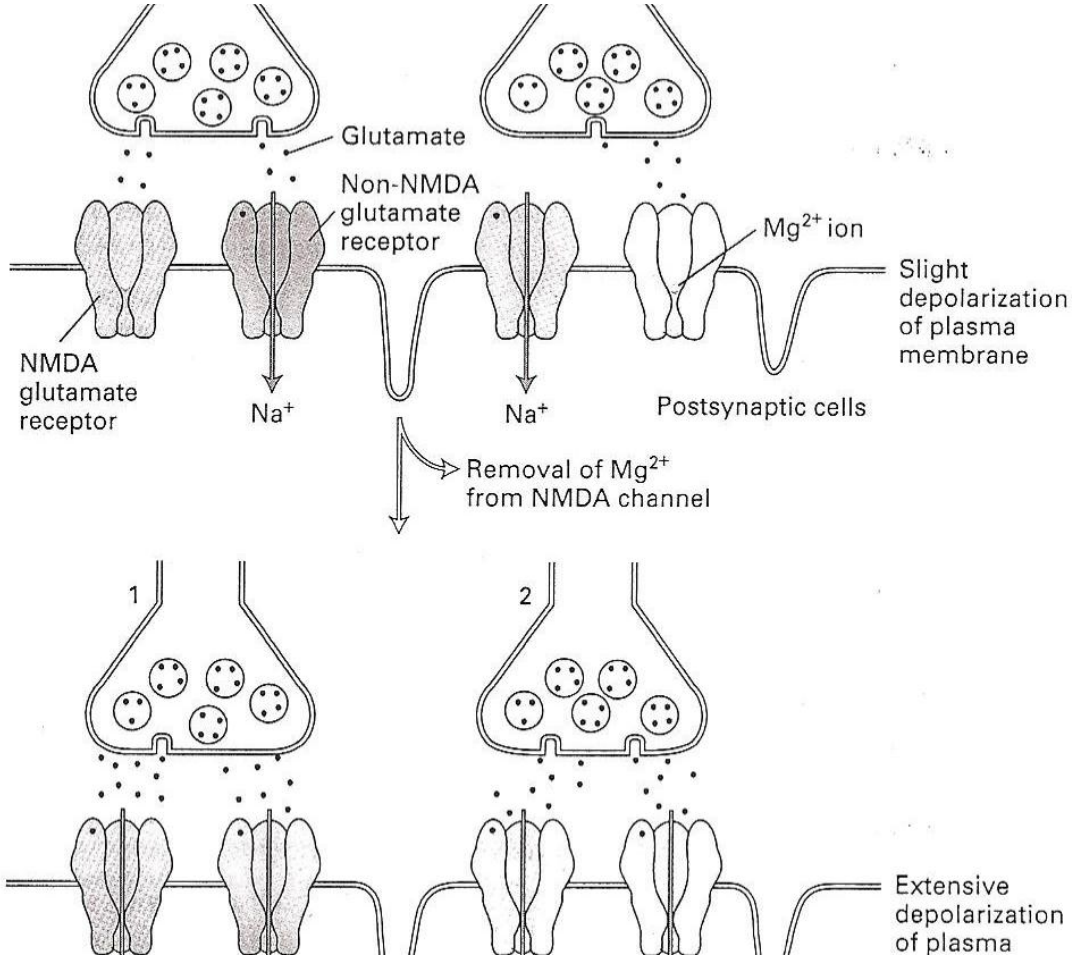
Increase in # of AMPAR via NMDAR, leads to learning & Memory



Memory, Learning!

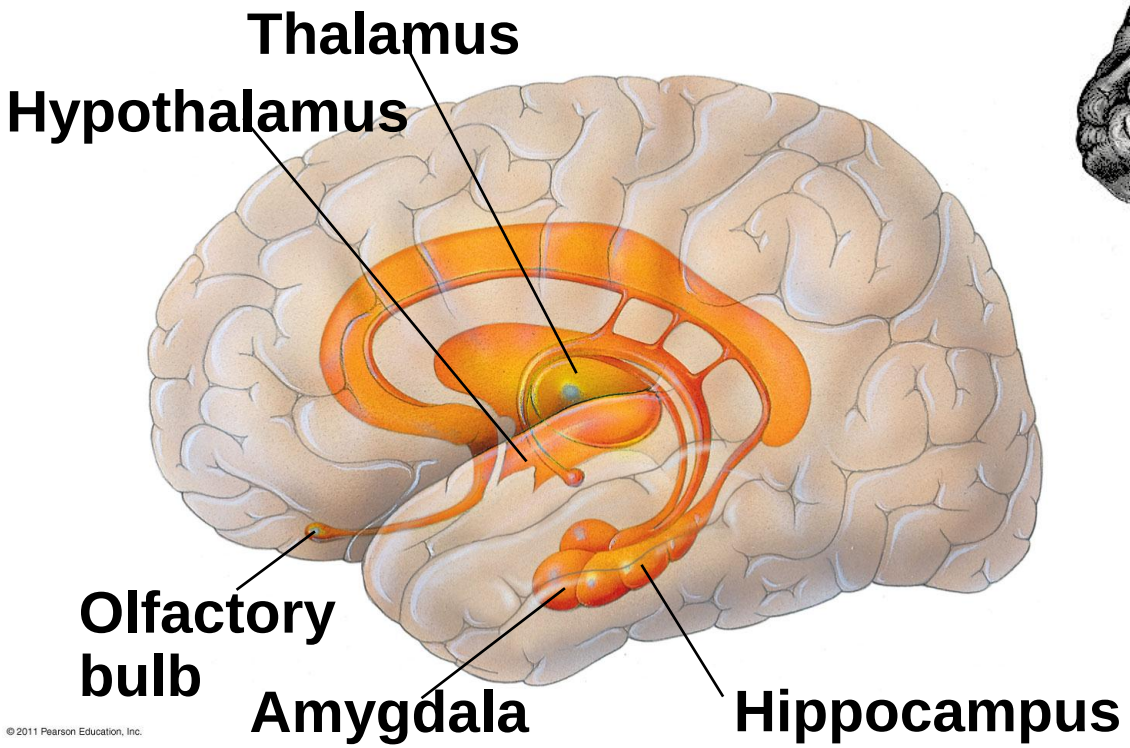
http://www.biopsychology.com/6e/step/04/0402-1-L.jpg

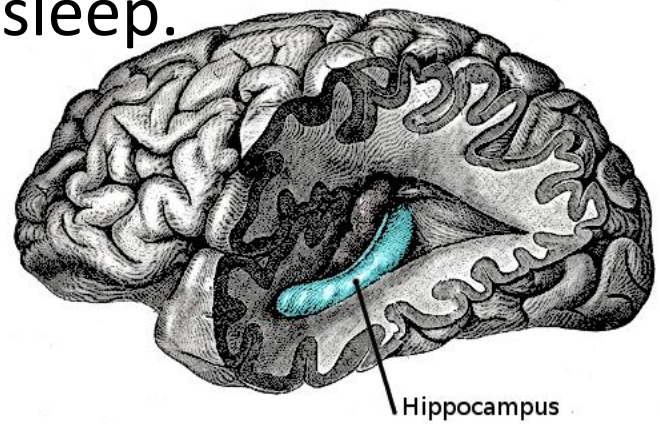
Need more than one action potential for nerve to fire, LTP.

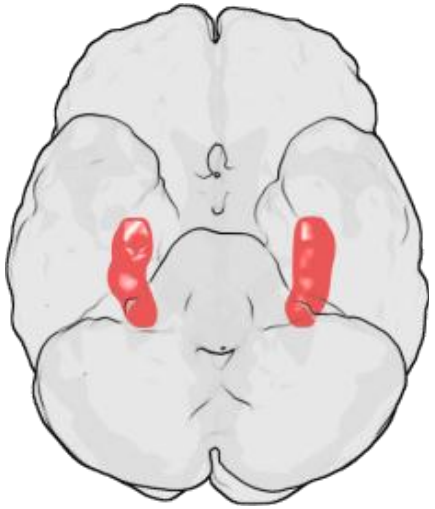


Short-term Memory: Info. Stored in temporary links in Hippocampus

Long-term Memory: : links transferred to cerebral cortex, possibly during sleep.







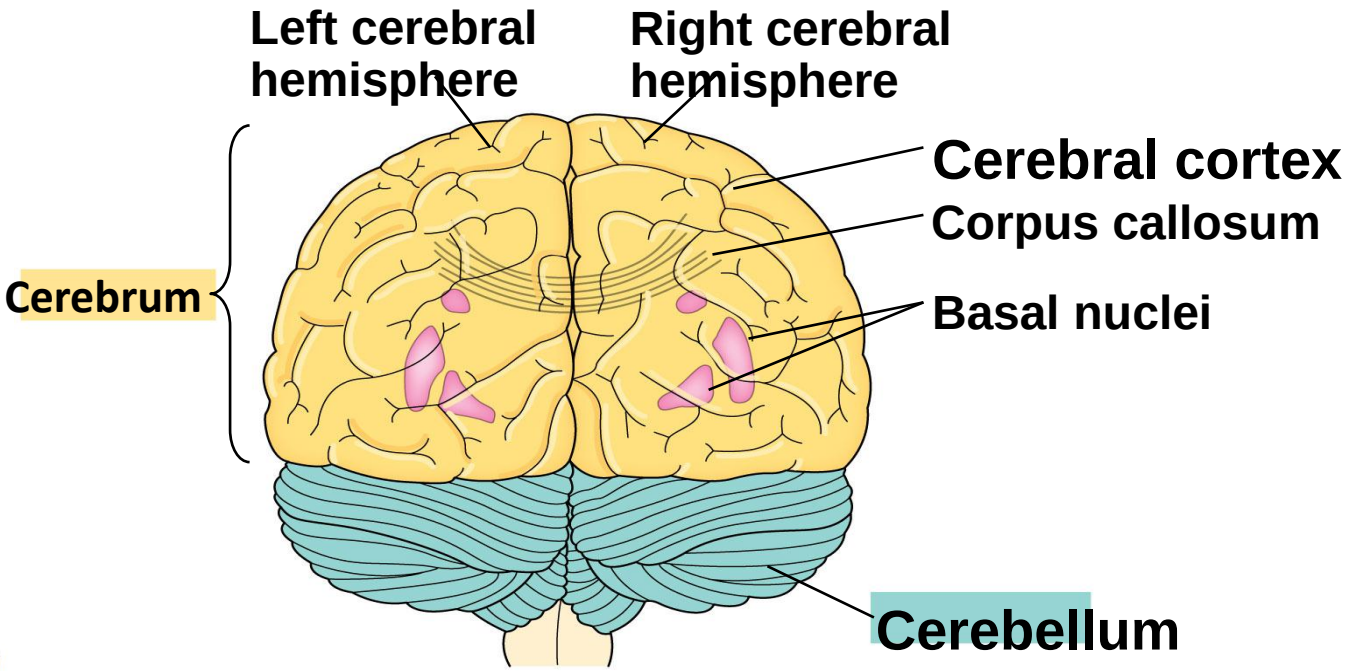
Hippocampus: Essential for acquiring new long-term memory. Injury to hippocampus: cannot form any new lasting memories but can recall events from before their injury.

Memory & Learning

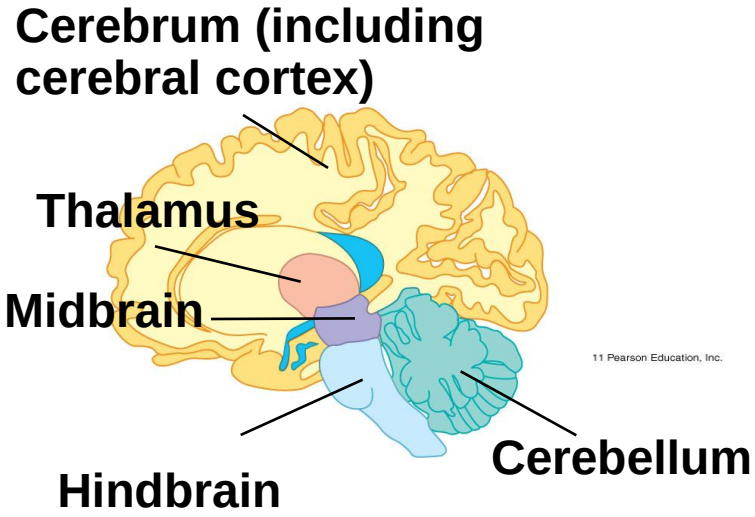
Example of Neural Plasticity (synaptic plasticity)

Long-term and Short-term Memories

LTM stored in
Cerebral cortex



Adult brain viewed from the rear



Long-Term Potentiation (LTP)

In neuroscience, **long-term potentiation** (**LTP**) is a long-lasting enhancement in signal transmission between two neurons that results from stimulating them synchronously. It is one of several phenomena underlying synaptic plasticity, the ability of chemical synapses to change their strength. As memories are thought to be encoded by modification of synaptic strength, LTP is widely considered one of the major cellular mechanisms that underlies learning and memory.

LTP shares many features with long-term memory, making it an attractive candidate for a cellular mechanism of learning. For example, LTP and long-term memory are triggered rapidly, each depends upon the synthesis of new proteins, each has properties of associativity, and each can last for many months. LTP may account for many types of learning, from the relatively simple classical conditioning present in all animals, to the more complex, higher-level cognition observed in humans.

LTP & Relation to Memory

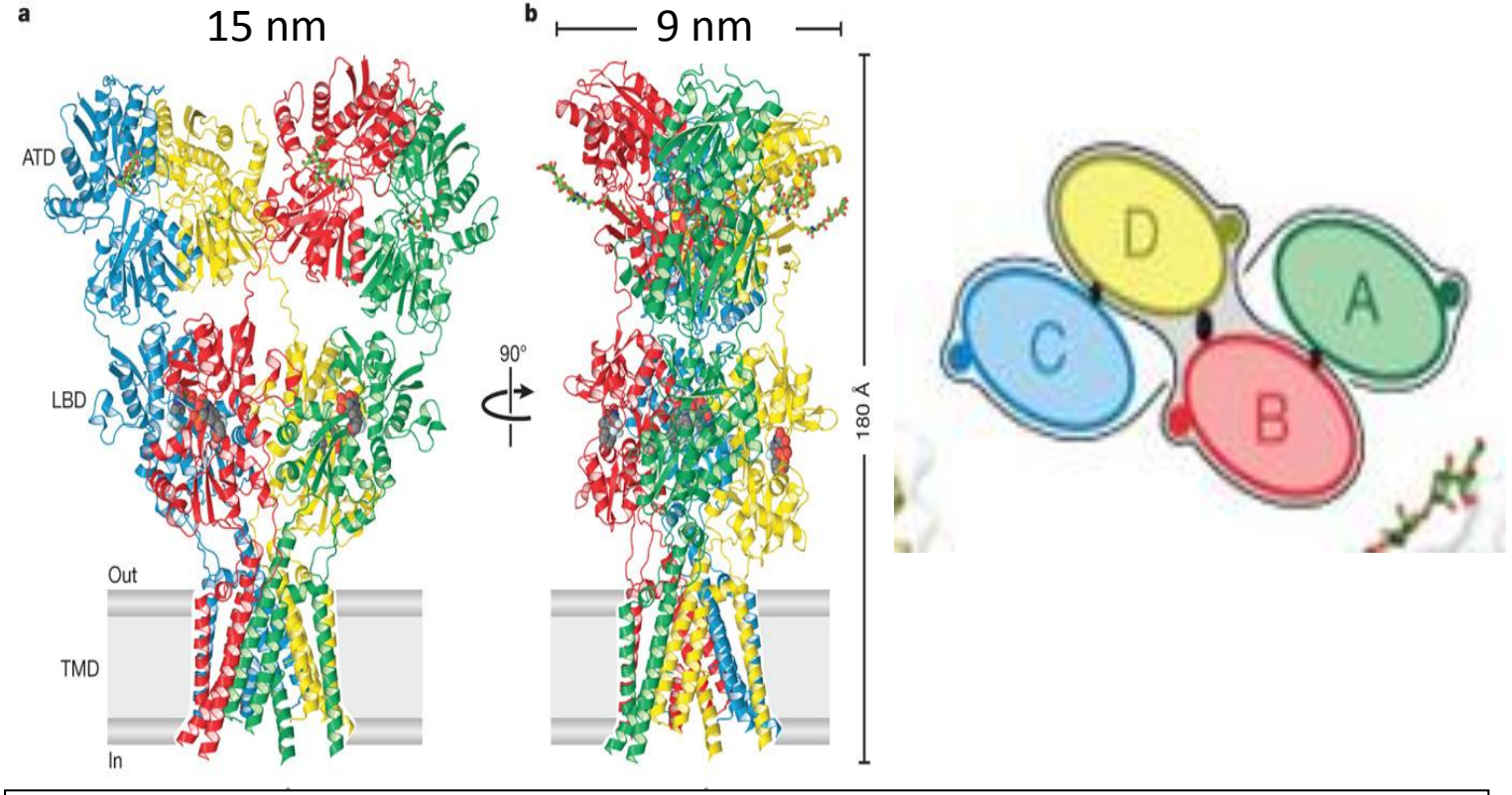
At a cellular level, LTP enhances synaptic transmission. It improves the ability of two neurons, one presynaptic and the other postsynaptic, to communicate with one another across a synapse. The precise molecular mechanisms for this enhancement of transmission have not been fully established, in part because LTP is governed by multiple mechanisms that vary by species and brain region. In the most well understood form of LTP, enhanced communication is predominantly carried out by improving the postsynaptic cell's sensitivity to signals received from the presynaptic cell. These signals, in the form of neurotransmitter molecules, are received by neurotransmitter receptors present on the surface of the postsynaptic cell. LTP improves the postsynaptic cell's sensitivity to neurotransmitter in large part by increasing the activity of existing receptors and by increasing the number of receptors on the postsynaptic cell surface.

Two classes of Receptors:
Ionotropic and Metabotropic Receptors

- See Chpt 7. Ionotropic. Opened or closed in response to the binding of a chemical messenger (i.e., a ligand), such as a neurotransmitter (response to: Glutamate, excitatory; GABA, glycine, inhibitory
- Metabotropic Glutamine– e.g. in Vision (next)
- metabotropic receptors do not form an ion channel pore; rather, they are indirectly linked with ion-channels on the plasma membrane of the cell through signal transduction mechanisms, often G proteins.

Recent (2009, Nature) results: **AMPA Receptors**

Rectangular geometry, maximize packing?



X-ray crystal structure of the $(GluA2)_4$ AMPAR, showing the two-fold crystal structure (left) and schematic (right). If the sub-units are labeled as shown by the solid dots (right) the expected distances will be 9 and 15 nm. (From Sobolevsky, 2009)